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International SSL Alliance

Global Solid State Lighting Outlook 1

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International SSL Alliance (ISA)

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Preface

Solid State Lighting (SSL) is a recent technology with more than promising characteristics, in terms of energy saving, design creativity and usability of new lighting systems. While technical performance (energy efficiency, colorimetry, electronic control) are steadily improving, industrial and volume applications like street lighting are now taking off. Meanwhile the overall market is still in infancy: prices are far from being stabilized; new lighting standards are needed to enable researchers, manufacturers and end customers to agree on specifications, to cleverly design, efficiently produce, safely acquire and operate SSL systems.

New technology, new applications, new markets ... It means many new investments, uneasy to correctly seize and anticipate without a minimum knowledge on the ins and outs. This is why the document you have in hands, our Global SSL Outlook 1 (GSO1), aims at providing you with a panoramic overview on the various technical and economical aspects of SSL: strategic research developments, industry trends and status, market potential and forecast, applications hotspots and perspectives as well as leading countries policies and strategies toward SSL developments in the world.

Should you be knowing just a little, or only certain aspects of the global SSL industry and policy development, should you be in urgent need of a comprehensive understanding of the overall picture either for investment-driven or policy-making oriented endeavors, then I do hope that this GSO will satisfy part or all of your needs.

Many market and technological reports on SSL markets and related topics are available, but the most panoramic, objective, authoritative and reliable analysis of the current status and future trends for global SSL developments remains yet to be established, which is the rationale our GSO is based upon. I must add that there exist many authoritative and reliable marketing analysts, and ISA has absolutely no pretention to become another one ; GSO may only cite some conclusions from existing reports.

I believe the GSO is a long-term effort, with accumulative joint collaboration from multi-stakeholders of various countries and regions, contributions from diversified communities from policy-makers, NGOs, industry leaders, researchers, financial and market analysts and general public to eventually become the ultimate reference on global SSL developments. I welcome you're hopefully numerous future voluntary contributions for the next editions of this document!

Our special thanks to Energy Foundation for their kind support.

Wu ling
President of ISA

Contents

Chapter I:

Governmental policies and development plans

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1.1 Overview of governmental policies and development plans on SSL

SSL policy plays a key role in supporting the development of SSL industry as well as R&D. Despite the various differences of how policies are made and functioned in different areas around the world, it is obvious that many countries whose rapid and successful SSL industry development have been benefitted from strong and effective policy measures and development plans. It is important to keep in mind that policy is changing and needs changing all the time as the reality is changing all the time, it's also important to understand the trajectory of the policies and the results of the policies in a specific environment and situation.

1.1.1 China

Policy

China realized the importance of policy support for SSL industry a long time ago. Early in the year 2003, China's Ministry of Science and Technology (MOST) established National SSL projects coordination leading team with ministries including Ministry of Information Industry, Ministry of Construction, and Chinese Academy of Science and so on, and launched National SSL projects. In 2006 State Council issued "National Mid to Long Term Science and Technology development Plan", in which SSL products were listed as the first key areas and the first priorities.

In 2009, National Development and Reform Committee(NDRC), MOST, Ministry of Industry and Information Technology, Ministry of Finance(MOF), Ministry of Housing and Urban-Rural Development (MOURD) and General Administration of Quality Supervision, Inspection and Quarantine jointly issued the "Solid State Lighting Energy Conservation Industry Development Advice" , SSL was identified as another revolution of lighting source after Incandescent and fluorescent, the document illustrated the current situation and trends of SSL energy conservation industry, identified the major problems and proposed guiding ideas, basic principles, development targets and focal areas. The document also specified the Policy measures, including

1. Overall planning, promote healthy development of the SSL industry;
2. Continue to increase the support of SSL technologies innovation;
3. Steadily improve the development level of SSL industry development;
4. Actively promote the SSL standard development, products testing and energy conservation certification;
5. Actively implement the incentive policies for SSL industry development;
6. Broadly conduct SSL energy conservation introduction, education and training;
7. Enhance regional and international communication and cooperation.

The latest comprehensive policy on SSL is the “Specific Plan of 12th FYP for SSL Science and Technology Development” issued by China’s Ministry of Science and Technology (MOST). This Plan identifies the current situation and needs of SSL industry, summarizes guidelines and principals of development, proposes development targets, points out key tasks and specifies safeguarding measures.

This plans sets many binding targets, such as the white LED luminous industrial efficiency reach 150-200 lm/W, the domestic production rate of LED chip reach 80%, the domestic industry reach the scale of 500 billion yuan in the year 2015, and establish 20 national level industrial bases and 50 pilot cities.

This plan identifies key tasks including:
Basic research on Ultra-high-efficiency nitride LED chip;
New micro-and nano-structure SSL;
Basic research on short-distance optical communication with the lighting combined with the new LED devices;
Basic research on ultra-efficient OLED white light devices;
Research on substrate preparation technology for SSL;
Key technologies research for Epitaxial silicon chip industrialization;
Research on Packaging and system integration technology;
Key technologies research on lighting systems;
Key technologies research on OLED SSL;
Research on oriented class white SSL exploration;
High efficiency, low costs LED driver technology development;
LED outdoor lighting sources, luminaries and systems integration technology research;
LED indoor lighting sources, luminaries and systems integration technology research;
OLED indoor lighting luminaries and systems integration technology research;
Intelligent, networking LED lighting system development;
LED innovation application technology research;
SSL testing technology development.

Also NDRC is going to issue a specific and comprehensive 12th FYP for SSL industry, which means the attention on this industry has been great enough compared with other relatively mature industries which can be qualified to be granted a specific and comprehensive industry 12th FYP. This SSL 12th FYP is expected to be released on late October or early November of 2012.

Incentive measures

In 2007 NDRC issued “Policies on software industry and IC industry development promotion” featuring tax reductions for SSL industry with ministries including Ministry of Finance, Ministry of Commerce and so on.

In 2008, the Ministry of Finance and NDRC jointly issued” Interim Management Measures for High Efficiency Lighting Products Promotion Financial Subsidies”, targeting at promoting 150 million high efficiency lighting products, which can save 29 billion Kwh of electricity and reduce 29 million tons of CO_2 emission.

In 2010, NDRC, MOF, The People’s Bank of China and State Administration of Taxation jointly issued the Advice on accelerate the implementation of Energy Management Contract(EMC) and promotion the development of energy conservation industry, featured financial support and tax deductions for EMC companies.

On the Executive meeting of the State Council on May 16th, 2012, the policy measures for promoting energy conservation home appliances consumption was discussed, and it was decided to allocate 2.2 billion yuan to support the promotion of CFLs and LEDs.

MOF, NDRC and MOST launched the 2012/2013 SSL products Financial Subsidy Promotion Program, the program covered indoor lighting products - LED Downlight, reflective self-ballasted LED lamps, outdoor lighting products-LED street lights, LED tunnel lights. The results were released in August.

Roadmap

In 2007 the Ministry of Construction issued the "11th FYP of Urban Green Lighting Project Planning Framework", took the year 2005 as baseline, set the annual urban lighting electricity consumption reduction at 5% and the application rate of high efficiency energy saving luminaries reach 85% in urban lighting by 2010.

In 2009, NDRC, UNDP and GEF launched the China gradually phasing out incandescent light; accelerate the promotion of energy-saving lamps program, subcontracted various institutions and organizations on the subjects including China gradually phasing out incandescent lights roadmap, China gradually phasing out incandescent light, accelerate the promotion of energy-saving lamps macro economy impacts and solutions research and so on.

China gradually phasing out incandescent lights roadmap was released in 2011, five steps were proposed to gradually phase out incandescent lights:

Steps	Implementation period	Target Products	Rated Power	Scale and Measures	Notes
1	October 1st ,2011 to September 30th, 2012	Transition period: one year			Issue notices and roadmap
2	Start from October 1st ,2012	ordinary illumination incandescent lights	≥100 W	Ban import and domestic sale	---
3	Start from October 1st ,2014	ordinary illumination incandescent lights	≥60 W	Ban import and domestic sale	Issue Tungsten halogen lamps energy efficiency standards, ban production, import and sales of those who do not meet the standards.
4	October 1st ,2015 to September 30th, 2016	Conduct Mid-term assessment, adjust subsequent policy			
5	Start from October 1st ,2016	ordinary illumination incandescent lights	≥15 W	Ban import and domestic sale	The final time and products of banning, and whether to ban production will depend on the mid-term assessment of 2015.

Table 1.1 Five steps to phase out incandescent lights

Governmental procurement

In 2007, the Office of State Council issued "Notice on establishing the compulsory governmental procurement mechanisms for energy conservation products", required that the energy conservation products should be a priority in consideration of government procurement, and for those whose energy conservation effects and quality meets requirements should be compulsory procurement.

In 2008, China launched the "Energy Conservation Regulations for Public Agencies", which requires all level of government agencies should include the energy conservation products and equipments into the government procurement list. Meantime the "Civil Construction Energy Conservation Regulation" was also released, which requires construction companies to choose suitable renewable energy for heating, cooling, lighting and hot water. These two regulations provided legal sources for local government to include LED products into the procurement list.

Major SSL showcases

1.“10k Lamps ,10 Cities”

In early 2009, China’s MOST launched the “10k lamps, 10 cities” SSL application pilot city plans, the plan covered 21 developed Chinese cities like Tianjin, Shanghai, Shenzhen, and Chengdu etc. in phase one, and will add another 50 cities in phase two. The plan is about to be carried out in three phases:

Phase one (pilot phase): by 2009, install 1 million LED municipal lighting luminaries in 21 pilot cities, the domestic production rate of LED parts reach 60%, estimated annual electricity saved 2200 million Kwh. The support focuses on the demonstration and application of road lighting, tunnel lighting, subway coach and platform, underground parking lot and gas station lighting, indoor lighting.

Phase two (demonstration phase): by 2010, complete the 50 SSL application pilot city nationwide, install 2 million LED municipal lighting luminaries, the domestic production rate of LED parts reach 70%, add to the “Green Lighting Project” of Ministry of Finance, estimated annual electricity saved 1 billion Kwh.

Phase three(Promotion phase): by 2015, SSL take up 30% of universal lighting market, estimated annual electricity saved 140 billion Kwh, SSL industry scale reach 500 billion yuan, export reach 30 billion US Dollars, create 1 million jobs, and become one of the three strongest of the world SSL industry.

2. The Great Hall of the People and the surrounding rooms LED lighting retrofit project

The Great Hall of the People was built in 1959. As one of ten big structures in Beijing in 1950s，it is where National People’s Congress Standing Committee is located，also is the place where Chinese state leaders and citizens hold political, diplomatic, cultural activities.

The retrofit project is conducted on the basis of completely keeping original lighting effect and control characteristics, and improves a lot in the aspects of horizontal luminance, cylindrical luminance, CRI, CCT, etc. In total, the overall power of LED luminaries installed in the main auditorium is 193KW; the amount is more than 6000 sets. The overall efficiency of the lighting system has been increased by 7 times compared with the original one, and 85% of heat has been reduced.

1.1.2 U.S.A

Policy

The U.S. also has been making good use of policy tools and frameworks to promote the development of SSL industry and R&D. On federal governmental level, U.S. Department of Energy's Energy Efficiency & Renewable Energy Office is the implementing agency of National Solid State Lighting programs. DOE has set the long term national strategy of LED general illumination Science and Technology support and market guidance, including six parts: including LED into energy basic science, key technology R&D, new products development, commercialization support, standards promotion and SSL partnership establishment.

The DOE also has set forth the mission statement for the SSL R&D Portfolio as follows:

Guided by a Government-industry partnership, the mission is to create a new, U.S.-led market for high-efficiency, general illumination products through the advancement of semiconductor technologies, to save energy, reduce costs and enhance the quality of the lighted environment.

On federal legislation level, The Energy Policy Act of 2005 (EPACT 2005) directed the Department of Energy to carry out a “Next Generation Lighting Initiative” to include support of research and development of solid state lighting (SSL) with the objective of lighting that would be more efficient, longer lasting, and have less environmental impact than incumbent lighting technologies.

R&D Projects

The U.S. Department of Energy (DOE) plays a core role in supporting solid state lighting (SSL) research and development (R&D) to accelerate market introduction of high-efficiency, high-performance SSL products. DOE leadership and support are producing the results of driving the lighting industry to higher levels of efficiency and quality than they might achieve otherwise.

DOE and its SSL partners have developed a multi-year R&D plan to ensure that the appropriate R&D topics being funded by DOE can successfully move SSL technologies from the lab to the market. The R&D roadmap is updated every year with feedbacks from industry partners and SSL workshop attendees, and this provides guiding for the development of annual SSL R&D solicitations.

DOE's plan for SSL R&D has two concurrent, interactive ways. Core technology research is conducted mainly by academia, national laboratories, and research institutions. This research aims to overcome technical barrier by filling technology gaps, and is subject to the Exceptional Circumstances Determination regarding intellectual property. Product development is conducted primarily by industry, and involves the utilization of research achievements to develop or improve commercially viable materials, devices, or systems.

DOE five year solidstate lighting commercialization support plan

This plan spans a five-year period from FY'08 to FY'12 and it applies only to general illumination solidstate lighting luminaries. It does not apply to lighting products that are intended for indications for example, traffic lights or any kind of signage. It is meant for products that provide general illumination. And there are three all related purposes: The first purpose is the activities covered by the plan try to affect the types of products that are already accepted by the market. The second purpose is that it addresses the efforts to accelerate the commercial adoption of those products and then the third purpose; it provides supports for applications that maximize energy savings.

The goals that are established for the last year in the plan, fiscal year 2012 and the goals are broken into three major categories: the products brought to market, market adoption, and energy savings.

This plan provided a basic framework for the commercial activities of the products, described how the product aligned with the general lighting market, including domestic, commercial, industrial and outdoor lighting.

Technical Information Network for Solid State Lighting (TINSSL)

DOE's Technical Information Network for Solid State Lighting (TINSSL) aims to raise awareness of SSL technology, performance, and appropriate applications. TINSSL members include representatives from regional energy efficiency organizations and program sponsors, utilities, state and local energy offices, lighting trade groups, and other stakeholders.

TINSSL members receive regular updates on technical progress of SSL technologies, upcoming meetings and events that address market issues related to SSL, and outreach materials developed for target audiences.

CALiPER Program

The DOE Commercially Available LED Product Evaluation and Reporting (CALiPER) program supports testing of a wide array of SSL products available for general illumination. For the consideration that SSL technologies today are changing and improving rapidly, and products arriving on the market exhibit a wide range of performance. There is a huge need for reliable, unbiased product performance information to foster the developing market for high-performance SSL products.

DOE allows its test results to be distributed in the public interest for non-commercial, educational purposes only.

Incentive measures

The ENERGY STAR Summary of Lighting Programs

The ENERGY STAR Summary of Lighting Programs presents information submitted by 138 energy efficiency program sponsors from across the United States. They have provided information about 423 individual incentive and promotion programs for ENERGY STAR lighting products including spiral and specialty compact fluorescent light (CFL) bulbs ; fluorescent light fixtures; light emitting diode (LED) light bulbs and fixtures; decorative light strings; and ceiling fans and components sold separately, such as light kits. The key highlights include:

Promotions by Region – The Midwest has the greatest number of lighting promotions with 147, followed by the West and Northeast regions with 113 and 73 respectively. The Mid-Atlantic, Southeast, and Southwest programs submitted about 30 promotions each.

Promotions by Product – While the majority of product promotions are for spiral CFLs (34%) and specialty CFLs (17%) or fluorescent fixtures (13%), a significant number of LED light bulb and fixture promotions have been added to programs in the past year. Together, these LED lighting promotions make up about 19 percent of total submitted promotions.

Promotions by Type –Nearly 40 percent of lighting promotions are provided through buy-down programs (manufacturer and/or retailer), which result in instant in-store discounts for customers. mail-in (30%) and instant rebates (14%) also frequently featured. Incentives range from $0.50 for spiral CFLs to $300 for one of the new construction programs, with the average and most frequent incentives between $2.00 and $12.00.

Encourage companies or company alliances to become the innovators

U.S. government provides funding to enterprises, universities or other departments in the form of research contracts, research funding and collaborative research, which greatly stimulates the enthusiasm for technological innovation. One successful case is semiconductor manufacturing technology strategic alliance Sematech.

Interaction between Science and technology policy and financial and tax policy

The Economic Recovery Tax Act, the enterprise can receive a 25% tax deduction if the R&D costs exceed the increase amount of three year average level.

Roadmap

In September 2009, U.S. DOE issued “SolidState Lighting Research and Development: Manufacturing Roadmap”. This SSL Manufacturing Roadmap is an extension of the 2009 MYPP. It focuses on the R&D needs for achieving cost effective, high quality manufacturing capabilities for solid state lighting products, be they packaged devices, replacement lamps, or complete luminaries.

On the manufacturing side, there are one roadmap for each year, start from the year 2010, namely the Solid State Lighting Manufacturing Roadmap – 2010/2011/2012. A workshop was held and all stakeholders and players were engaged and their feedbacks will be added to the roadmaps.

The main content of the roadmap covers the following areas: first introduced the key findings and general recommendations for the year and overall projections/contributions to cost reduction. And then illustrated the specific roadmaps for LED and OLED, and also discussed the manufacturing research priorities and standards.

Governmental procurement

Building on the directives issued in the Energy Policy Act of 2005 (EPACT 2005), Pub. L. 109-58, the FY2009 Omnibus Appropriations Act, H.R.1105, enacted on March 11, 2009, which authorizes $25 million to the DOE for solid state lighting research and development and directs DOE to implement an Energy Star program for solid state lighting.

On December 19, 2007, President Bush signed the Energy Independence and Security Act (EISA), Pub. L 110-140 which again builds on EPACT 2005. EISA instituted the "Bright Tomorrow Lighting Prizes." The "Bright Tomorrow Lighting Prizes" establishes prizes for a solidstate lighting product with an efficacy of 90 lm/W to replace an incandescent 60W lamp, a solidstate lighting product with an efficacy of 123 lm/W to replace halogen PAR 38 lamps, and a solidstate lighting product with an efficacy of 150 lm/W. After the prizes are awarded, the Federal Government may purchase the lamps for its own facilities.

Major SSL showcases

The Next Generation Luminaires™ (NGL) Solid State Lighting (SSL) Design Competition

The Next Generation Luminaires™ (NGL) SolidState Lighting (SSL) Design Competition was created to recognize and promote excellence in the design of energy-efficient LED commercial lighting luminaires. The competition seeks to encourage technical innovation and recognize and promote excellence in the design of energy-efficient LED luminaires for commercial, industrial and institutional applications.

The competition also encourages manufacturers to develop innovative luminaires that are energy-efficient and provide high lighting quality and consistency, glare control, lumen maintenance, and luminaire appearance needed to meet specification lighting requirements.

In its first year of 2008, the competition selected 22 products from among a total of 68 entries. In 2009, as the number of commercial LED lighting products on the market increased, the number of NGL entries nearly doubled – to 126, coming from 60 different lighting companies. Among these entries, 43 were chosen as "recognized" winners and four of were chosen as "best in class." In 2010, forty-two products were recognized out of a field of 138 judged entries with four of these products again receiving "best in class" designations.

The L Prize

The L Prize competition aims to substantially accelerate America's shift from inefficient, dated lighting products to innovative, high-performance products., the L Prize will drive innovation and market adoption again just as Thomas Edison transformed illumination over a hundred years ago .

The prize is sponsored by the U.S. Department of Energy, and is the first government-sponsored technology competition designed to spur lighting manufacturers to develop high-quality, high-efficiency solidstate lighting products to replace the common light bulb.

DOE GATEWAY demonstrations

DOE GATEWAY demonstrations serve as a showcase of high-performance LED products for general illumination in a variety of commercial and residential applications.

Demonstration results provide real-world experience and data on state-of-the-art SSL product performance and cost effectiveness. These results connect DOE technology procurement efforts with large-volume purchasers and provide buyers with reliable data on product performance.

DOE shares the results of completed GATEWAY demonstration projects, publishes detailed reports and briefs on completed projects. The reports also include analysis of data collected, projected energy savings, payback analysis, and user feedback.

The DOE Municipal Solid State Street Lighting Consortium

The DOE Municipal Solid State Street Lighting Consortium aims to share technical information and experiences related to LED street and area lighting demonstrations and serves as an objective resource for evaluating new products on the market which are designed for street and area lighting applications. Cities, power providers, and investors in street and area lighting are invited to join the Consortium and share their experiences. The goal of the Consortium is to build a repository of valuable field experience and data that can significantly accelerate the learning curve for buying and implementing high-quality, energy-efficient LED street and area lighting. The members of the Consortium are also part of an international knowledge base and peer group, they can receive updates on Consortium tools and resources, the Consortium E-Newsletter, and are able to join a Consortium committee.

1.1.3 EU

Policy

The EU is committed to reduce its overall carbon emissions to at least 20% below 1990 levels by 2020, and at least 20% of EU energy consumption is supposed to come from renewable sources by 2020. To achieve these goals, EU has already set up a range of policy and legislative measures that support renewable energy and energy efficiency, which provides a good policy framework for SSL R&D and industry as well.

There have been many both voluntary and mandatory policy measures already exist that are relevant to SSL and will help to support its further development through the requirements like minimum performance and safety requirements for SSL products. Main instruments include: Eco-design, Energy labeling, Eco-label, the Low-Voltage Directive or the General Product Safety Directive, the Directives on the Restriction of Hazardous Substances (RoHS) and on Waste Electrical and Electronic Equipment (WEEE), Green Public Procurement (GPP) and the New Legislative Framework. These measures are reviewed at regular intervals along with the new progress of technologies and possibly new EU policy in the fields. In particular:

–EU is currently revising or developing measures implementing the Eco-design and Energy Labeling directives and the Eco-label Regulation for light sources. EU intends to adopt a new Eco-design regulation that will cover directional light sources (reflector lamps). It is going to introduce compulsory EU legislation on directional lamps with minimum functionality requirements for all LEDs (non-directional LEDs already have to comply with minimum energy efficiency requirements under an existing Eco-design regulation). In the revised Energy labeling regulation, EU also intends to include LEDs and all kinds of directional and professional lamps.

–The Low-Voltage Directive will be aligned with the New Legislative Framework.

–Revised Eco-label criteria for light sources in order to include specifically LEDs are under consideration for development in 2012.

On incandescent phase out side, according to the European Commission Regulation (EC) 244/2009, the phase-out will be completed by September 1^{st}， 2012. About 8 billion bulbs in the homes of European citizens are expected to be replaced in the next few years.

Incentive measures

The seventh Framework Programme(FP7) contributes more than 90 million euro to support research in SSL across the EU. Activities cover research in LEDs and OLEDs and in their manufacturing processes. The NMP Theme supports materials research for more efficient light sources. The ICT Theme supports research aiming at significantly improving the functionality, quality and performance of SSL-based lighting applications. The ENIAC Joint Undertaking funds R&D addressing the development of affordable SSL solutions across the entire value chain. Further R&D opportunities for SSL are provided in the respective work-programmes of these themes for 2011-12.

The Competitiveness and Innovation Framework Programme (CIP) supports i.e. lighting-related innovation activities and provides better access to finance. The CIP Intelligent Energy Europe (IEE) Programme finances several support measures related to SSL for raising consumer awareness, supporting Member States in market surveillance activities or helping them implement intelligent lighting solutions. In 2012, the CIP ICT Policy Support

Programme will support several SSL pilot actions with about seven million euro with the aim of demonstrating the latest SSL technologies and to widely disseminate the results in Europe.

Through the Cohesion policy, Structural Funds are used by several European regions to enhance their capacity to change and innovate in SSL. Their investment focuses on R&D and innovation activities, pilot manufacturing lines and human capital development e.g. in the emerging OLED area.

The EUREKA program aims to raise the productivity and competitiveness of European business through technology, boost national economies on the international market, and strengthening the basis for sustainable prosperity and employment. EUREKA has been supporting many R&D projects on LED lighting technologies.

Roadmap

In 2011, the European Commission released the Green Paper: Lighting the Future Accelerating the deployment of innovative lighting technologies. The Green Paper set out the key issues to be addressed in a European strategy aiming to accelerate the deployment of high-quality SSL for general lighting. It is designed to help Europe achieve its key energy efficiency, industrial and innovation policy objectives of Europe 2020 Strategy for smart, sustainable and inclusive growth.

The Green Paper proposes to launch a number of new policy initiatives and a public debate in Europe with all interested parties for accelerating the pace of SSL deployment. It has the ambition to pro-actively define a coherent set of strategic objectives in the Union addressing both the demand and the supply side, as well as to lay down the generic conditions for achieving these objectives as a basis for future action for all involved players.

The research and business stakeholders, governments, civil society communities and citizens are called upon to engage in this debate.

Since the Digital Agenda for Europe is a cross-cutting initiative, this Green Paper has important links to several other flagship initiatives of Europe 2020. For example, it is proposing to apply several of the general policy goals the Union has defined in its new Innovation and Industrial policy in the field of SSL. It also proposes a framework of actions related to some more specific initiatives of the Union such as the Energy Efficiency 2011 Plan the upcoming new framework for research and innovation, 'Horizon 2020', the Thematic Strategy on Prevention and Recycling of Waste, the Key Enabling Technologies initiative and the Regional Policy Funds.

Governmental procurement

Commission of The European Communities released the Public procurement for a better environment in 2008. By the end of 2011 the new EU Green Public Procurement (GPP) criteria for "indoor lighting" will be adopted and the existing criteria for "street lighting & traffic signals" will be updated.

Within the EU, the potential of GPP was first highlighted in the 2003 Commission Communication on Integrated Product Policy where Member States were recommended to adopt national action plans for GPP by the end of 2006. The new European legal framework for public procurement has clarified how public purchasers can include environmental considerations in their procurement processes and procedures. In June 2006, the renewed EU Sustainable Development Strategy set the policy objective for 2010 of bringing the average level of EU green public procurement up to the standard achieved by the best performing Member States in 2006.

This Communication is part of the Action Plan on Sustainable Consumption and Production and Sustainable Industrial Policy (SCP/SIP), which establishes a framework for the integrated implementation of a mix of instruments aimed at improving the energy and environmental performances of products.

Major SSL showcases

Rainbow project brings color to LEDs

The Rainbow project ended in 2000, but it marked the beginning of EU wide projects especially addressing LED related technologies. It was funded by the European Union, brought together a multidisciplinary consortium from industry and academia to develop nitride-based devices and related manufacturing infrastructure.

Upon its completion, four major technological milestones were all successfully reached:

- Development of a multilayer metal-organic chemical vapor deposition (MOCVD) reactor for the growth of group III nitride materials;
- Identification and development of optimum group III and nitrogen precursors;
- Optimization of the LP-MOCVD growth process for group III nitrides;
- Definition of basic technology for the fabrication of group III nitride-based devices.

EU has also been making a lot of efforts on OLEDs and initialized many projects, including The OLLA consortium, The Fast2Light project, The AEVIOM Project, CombOLED Project and OLED100.EU.

OLLA project

The objective of the OLLA project is to demonstrate high brightness and efficient OLED technology for use in real lighting and ICT applications. The project's major challenge was to advance the combination of size, lifetime and efficiency of OLEDs, without compromising on the white color experience.

The related OLED materials and other technical issues were discussed at OLLA wide workshops, which were organized every half year. In the second year, OLLA released a white paper on luminous efficacy measurement. This was developed to set a minimal laboratory evaluation standard. In the final year of the project, most effort was put into the development and delivery of the OLLA lighting demonstrators.

During the whole 45 months period, the project got very much attention from the outside world. The OLLA consortium concluded its cooperation with a large public demonstration event on June 12th 2008, in Eindhoven, the Netherlands. The final demonstrators (Final milestone demonstrator and ICT demonstrators) were exhibited in a mini symposium on OLED lighting.

Fast2Light project

The Fast2Light project is also focusing on OLED. The overall objective of the project is to develop novel, cost-effective, high-throughput, roll-to-roll, large area deposition processes for fabricating light-emitting polymer-OLED foils for intelligent lighting applications.

The scope of the project includes all the layers that are part of an OLED lighting foil. It will start with the substrate choice, and introduce high-throughput deposition and patterning methods for all of the materials necessary to fabricate the final lighting foil. In doing so, it will become clear what device architectures and designs are best suited to integrate these new deposition and patterning methods. The interplay between the choice of device architecture and processing methods will be unraveled and a set of design rules for a producible product will be determined, together with a final process flow. Results will be measurable in the form of demonstrators that prove the performance of the technologies and the design rules.

The AEVIOM Project

The ICT-STREP project AEVIOM (Advanced Experimentally Validated OLED model) is cooperation between leading academic and industrial groups in Europe. The project aims to enable a breakthrough in white OLED efficiency and lifetime by the development and application of an integrated "second-generation" OLED model.

The model will serve as the basis for efficient numerical methods that properly include the entire chain of electrical and optical effects inside the disordered organic semiconductor material, as well as the optical outcoupling.

CombOLED Project

The CombOLED project is a European funded research and development project, it aims to combine new device structures, advantageous manufacturing approaches and less complex materials with the aim to achieve cost effective OLED lighting solutions. The cost reduction, together with transparency as a device feature, will enable a huge penetration of the organic light-emitting device (OLED) technology into the lighting market. The project is lead by OSRAM Opto-Semiconductors.

OLED100.EU

The Organic LED lighting in European dimensions (OLED100.EU) is funded under 7th FWP (Seventh Framework Programme) started at 2008 ended at 2011 with a total project funding of 12.5 million euro.

The overall goal of OLED100.eu is to develop all the necessary technologies forming the basis for efficient OLED applications for the general lighting industry in Europe. There are five main objectives:

-High power efficacy (100 lm/W)
-Long lifetime (100.000 h)
-Large area (100x100 cm2)
-Low-cost (100 Euro/m2)
-System integration / standardization / application

1.1.4 Japan

Policy

Japan's Ministry of Economy, Trade and Industry (METI) is responsible for the making and implementation of industrial polices. In the strategic energy plan of Japan made by METI, specific measures to achieve targets were listed, and inside the realizing a low carbon energy demand structure, it was clearly stated that one measure is replacing 100% of lights with highly-efficient lights (including LED and organic EL lighting) on a flow basis by 2020 and on a stock basis by 2030.

Incentive measures

The Tokyo Metropolitan Government (TMG) Bureau of Environment announced on March 30, 2012, that it would be adding LED (light-emitting diode) lighting to the list of devices eligible under the Energy Saving Tax Incentives for Small and Medium-Sized Enterprises as of July 1. The purpose of this program is to provide tax breaks to small and medium-sized enterprises that purchase energy-saving equipment as a measure against global warming.

Basically, small and medium-sized enterprises that submit a Report on Measures Against Global Warming get a reduction in corporate and individual enterprise taxes if they purchase energy-saving devices specified by the TMG for business premises that are not subject to mandatory reductions in total emissions of greenhouse gases. This tax incentive has been in effect since April 2009.

The following equipment has been specified by the TMG for installation to be eligible for the tax incentive: air-conditioning equipment, light fixtures, compact boilers, and renewable energy equipment. The LED lighting device category was added to the list of recommended equipment for installation in December 2011, after energy-saving performance standards were established for them under Japanese Industrial Standards (JIS).

Under the Eco-point Program, in April 2009, then Prime Minister Taro Aso of Japan announced a large economic-stimulus package that included the $10.9 billion Eco-point Program to stimulate consumer purchases of energy-efficient air conditioners, refrigerators, and televisions. In addition to stimulating the economy, the program sought to reduce greenhouse-gas emissions and hasten digital broadcasting across Japan.

After purchasing an energy-efficient appliance, a consumer will receive eco-points worth 5-10% of the value of the purchase from the government– with each eco-point worth ¥1. The consumer then redeemed these points for a variety of 271 so-called green goods and services listed in a catalog sponsored by the government.

In December 2009, the government added LED lamps to the list of redeemable products. From April 2010 onward, consumers were allowed to exchange their eco-points for LED lamps at twice their value. For example, only 2,000 eco-points (instead of 4,000 previously) were needed to redeem an LED lamp priced at ¥4,000 (around $50).

The Japanese government is under huge pressure to draft comprehensive energy-saving measures to address the energy crisis after the earthquake and tsunami in Fukushima. On design level, eco-points can also target purchases that may actually increase residential energy consumption like the flat-screen TVs. However, the LED products' involvement of the program demonstrated that significant energy savings and rapid market transformation could be achieved with significantly lowering the initial cost of products in a way that appealed to the public's concerns.

Generally speaking, Japan's Eco-point Program quickly built market share for LED lamps in a short period, while stimulating the economy and boosting Japan's LED manufacturing sector. Despite its cultural biases, the Eco-point Program could serve as a model for other national governments seeking to rapidly transform their domestic retail markets for LED lighting.

Roadmap

After the earthquake and tsunami of March 2011, the power shortages have spurred both the public and private sector to seek ways of reducing energy consumption in Japan. To this end, Japan has set a target of achieving a 50% LED lighting penetration rate by 2015; and research shows that the country can easily meet the 2015 goal according to the current rate and development trend.

Governmental procurement

Japan's Green Purchasing Law lays a good foundation to the governmental procurement on SSL products, it was enacted in May 2000 in order to establish a society which can enjoy sustainable development with a lower environmental impact by encouraging the State and other entities in the public sector to procure eco-friendly goods and services that will contribute to the reduction of environmental impact and through various other activities.

Green purchasing means selectively choosing products with less environmental impact when purchasing goods, etc. It is expected to innovate and improve all economic activities, not only by making the activities of purchasers eco-friendly, as they consume goods and services in their daily life, but also by encouraging suppliers to develop eco-friendly products.

The above law obliges green purchasing by the State and other public organizations and expects the same of local governments, businesses and citizens.

Major SSL showcases

Light for the 21st Century Project

It is,one of the first national programs was initiated in Japan. In 1998, the Japan Research and Development Center of Metals established the five-year national project "The Development of Compound Semiconductors for High Efficiency Optoelectronic Conversion", also known as the "Light for the 21st Century". The project brought together thirteen member companies and universities, and targeted an energy efficiency twice that of traditional fluorescent lamps through the use of long-life, thin, lightweight, GaN-based high-efficiency blue and ultraviolet LEDs.

The project concluded that the 21st Century is certainly the era of technology innovation with semiconductor lighting and this project is playing a leadership role. Differing from conventional visible light LEDs, white LEDs have strong needs as a general lighting source. Nonetheless, since such applications need a high volume of light (several tens to several thousand lm) in future new and innovative technologies by researchers and engineers of semiconductor technology, light emission element technology, and illumination engineering in collaboration with lighting and interior designers is critical to the realization of white LED lighting systems. It is hoped that further technology innovation in white LEDs for illumination will not only create a new lighting culture through LED applications, but will also build a safe societal foundation which produces less environmental waste.

Project to develop medical equipment and therapeutic techniques based on LEDs.

The Ministry of Education, Culture, Science and Technology (MEXT) has allocated ¥500 million (around $4.6 million) for the 2004 financial year to establish the Yamaguchi-Ube Medical Innovation Centre (YuMIC). Similar amounts are expected to be allocated in each of the subsequent four years.

Located in Yamaguchi Prefecture, YuMIC will develop next-generation non-invasive medical diagnostic and therapeutic equipment. The project will make use of InGaN-based white LED technology developed in part by Professor Tsunemasa Taguchi of Yamaguchi University, who is the research director for the YuMIC project.

The program planned to develop endoscopes and other invasive optical equipment that utilize the benefits of high-brightness LEDs, these include long lifetime, low power consumption, small size, high color fidelity and lack of heat production from infrared radiation. A surgical navigation system is also planned, which will use bicolor fluorescence spectroscopy.

1.1.5 Republic of Korea

Policy

The Korean government announced the “Low Carbon, Green growth” strategy in 2009 and SSL forms a major part of the plan. Korea plans to invest 540.1 billion KRW (€ 355 Million) in the next five years, to accelerate ecofriendly segments such as SSL. The government also allocated 4.5 Billion KRW (€ 3.0 Million) for retrofitting existing lamps to LED lamps (second half of 2009).

Korean government is proposing policies to distribute LED lighting of various aspects such as lighting power savings for expanded distribution of LED lighting products, achieving 30% LED replacement in public facilities for LED industry development, and replacement support of traditional market lighting and small-business advertising signs. Korea LED Lighting Distribution Expansion Policy includes:

1) Spread LED lighting distribution to large market such as Industry Park, school, etc.
2) Set annual goals for distribution from 2013 on public buildings
3) Mandatory installation on new public buildings
4) Nationwide promotion on LED lighting saving effect
5) Supplement appropriate to item-specific, sector-specific situation on LED Lighting 2060 Plan

According to the national policy, related agencies are improving LED lighting product performance standard and policy for stable growth of the market and to provide high-quality LED lighting products to consumers, and policy will be continued to be revised in accordance with market situation and technology development.

As an example, the performance criteria of existing high-efficiency certified LED lighting products has been raised, and LED certification process has been simplified; makers can save administrative cost due to simplification of certification procedures and consumers can use high-quality products at the same price, being helpful to both sides.

Incentive measures

In order to drive the ‘LED Light 15/30 Distribution Project’ forward, an estimated 350 billion KRW is to be funded by the government with effects of 4.6 times the investment. Expected energy savings are estimated to be around 4 million TOEs worth 1.6 trillion KRW. (Estimations by Korea Energy Management Corporation <KEMCO>)

List of Items to be Funded (Proposal)

1. Traffic Lights
2. Exit Lights / Lane Lights
3. Exchange of Halogen Lamps
4. Exchange of Incandescent Lamps
5. Channel Signs
6. Exchange of Fluorescent Lamps
7. Street Lights

Funding of traffic lights, exit lights/lane lights, and exchange of halogen lamps began already in 2007.

Distribution will be divided into 3 phases:

1. Early Phase
   a. Certification of Highly Efficient Energy Materials
   b. Test Distribution Business
2. Growth Phase
   a. Funding Policy
   b. Loans & Tax Credits
3. Mature Phase

The Korean Government also introduced a green credit card scheme in July 2011, to encourage consumers to adopt more sustainable lifestyles.

Roadmap

As the capital of ROK, Seoul City plans all the municipal government office to use LED lighting in 2018, and to establish an intelligent lighting grid contains 1.32 million energy-saving road lamps in 2014.

LED lighting 15/30 universal project

The government set a target for 30% of LED lighting penetration in public sector by 2015 and 100% by 2020.

LED Lighting 2060 Plan (long-term road map for universal LED)

Korea's Ministry of Knowledge Economy released the proposed lighting plan for the realization of social green lights "LED 2060". It set the target LED takes up 60% penetration of country's total by the year 2020, and100% in public institutions. The plan aims to greatly expand government installations funding of the public sector by promoting the creation of market-leading, promote the use of high-efficiency lighting and LED private buildings housing, and also propose various programs using ESCO and carbon capitals etc.

Additionally, the Korean Government is providing low-interest loans and tax exemptions for the installation of energy-efficient lighting in private buildings as part of its LED Lighting 2060 Plan.

Governmental procurement

In February 2012, Korea significantly expanded public sector LED lighting distribution budget from KRW 8.2B to KRW 31.9B through the inspection of green growth policy implementation.

Major SSL showcases

Program of verifying LED lighting and developing infrastructure for knowledge information on converging photonics and information technology

The Ministry of Knowledge Economy held on June 5 the completion ceremony of LED Lighting Verification Center installed in the Korea Photonics Technology Institute. The Center is established as part of the 'Program of verifying LED lighting and developing infrastructure for knowledge information on converging photonics and information technology' to establish test bed for a variety of LED lighting products.

The Center is equipped with systematic system that can verify reliability and qualitative performance of lighting products in real-life environment, the first of its kind in Korea, by installing test beds and testing equipment by purposes.

Particularly, the street light testing equipment is the world's first assessment facility that can test photonic performance of streetlamps and security lights in compliance with street conditions and environments where lighting apparatuses are installed.

The Photonics Industry Project

This project was to build an information center for Photonics industry; it started in December 200 and expected to finish in August 2004. The objective of the project is to bring the optical industry together under the one network to improve the overall competitiveness of the industry and to help its transition to a knowledge industry.

This Project was sponsored by Ministry of Commerce, Industry and Energy (MOCIE), Gwangju City, organized by Korea Association for Photonics Industry Development, commissioned by Korea Institute of Science and Technology Information and developers including LG CNS, P&I Sys.Co.Ltd, Management Research Institute Of Chonnam National University.

1.1.6 India

Policy

The SSL policy is still yet to be fully formed in India as well as the LED industry itself. But the government has already realized the importance of policy support on SSL development and there were a number of measures and actions.

India's Ministry of Power released the Economic Case for Multi-State DSM Programme (MSDP) to Stimulate LED Lighting in India in 2010, which is India's first specific policy framework on SSL. In which the major barriers that need to be overcome to accelerate the penetration of LEDs were identified and recommendations on roadmap are proposed.

The major barriers include:

1. Limited availability of LED technology in India;
2. High initial cost of LEDs that makes the payback period very long;
3. Absence of National standards for LEDs;
4. Lack of testing protocols, facilities and accredited laboratories at the national level;
5. No incentive either to set up manufacturing facilities in India as is the case with China.

The Ministry of Commerce issued notification to Delhi Government to ensure all showrooms or show windows using Incandescent Lamp or halogen lamps to immediately replace with LED down lighters. More States to follow. The Ministry of Commerce issued advisory to Ministry of Urban Development to ensure all medium and small municipalities change to LED Street Lighting and small municipalities change to LED Street Lighting. The Bureau of Energy Efficiency started Pilot programs to encourage use of LED streetlights for Municipalities and Local Bodies for secondary roads, parks and parking areas etc., about180 bodies being funded

Incentive measures

The India Government has been subsidizing the establishment of LED test facilities at existing Test Lab (About Rs 25 Crores). It is expected at least 3 more Test Labs supported by Government will be established and a total of 12 Test Labs by 2013.

Roadmap

In the Stimulate LED Lighting in India white paper, the roadmaps are proposed:

1. A Central Institutional Mechanism (CIM) may be constituted under the Chairmanship of Secretary, Ministry of Power with representatives from MoUD, DIT, MNRE, DIPP, FOR, BIS and BEE;
2. Aggregation of future LED demand under regulatory oversight is the appropriate way to significantly enhance volumes and therefore attract leading manufacturers to India and have the co-benefit of reduced cost;

3. Mandating phased domestic manufacturing for such demands must be integrated in the policy framework;
4. Appropriate fiscal incentives need to be structured by the government to promote LEDs in India;
5. To overcome the twin barriers of lack of standard monitoring and verification and lack of LED technical standards;
6. The scheme announced by Ministry of Power of providing electricity to all villages within a 5 km radius of all central power generating stations to provide at one LED lamp to each household.
7. Central and state procurement agencies including CPWD could be motivated/convinced to take part in this programme.
8. Setting up of a neutral, trusted, testing facility in the government sector needs to be initiated in this current financial year itself;
9. Other measures need to be carried out in parallel to meet the afore-referred goals.

Governmental procurement

Government bulk procurement includes three parts:

1. Preparing bulk requirement of Railways, Airport authority, Urban Housing, Highways and other large development projects to create a large demand to encourage industry to establish;
2. LED Self Ballasted Lamp for “Bachat Lamp Yojna”;
3. All Households within 5 KM of Power Generating Plants to be given one LED bulb free.

Major SSL showcases

There are no major SSL showcases yet in India, but the industry is under development and plans are being made.

There are many Exhibition and Workshops serving as the awareness programs that have been conducted and will be conducted, such as May 2010 at Delhi, April 2011 at Hyderabad, January 2012 at Mumbai, MEGA LED Seminar in New Delhi in October 2012, and more workshops are to be organized in Kolkata, Bangalore, Chandigarh and Ahmedabad during 2012-2013.

1.1.7 South Africa

Policy

The policy specifically on SSL is yet to be formed in South Africa; they have decided to phase out incandescent lights and pays attention to the efficient lighting areas.

The Department of Energy of South Africa issued the Policy to support the Energy Efficiency and Demand Side Management Program for the Electricity Sector through the Standard Offer Incentive Scheme, in which the efficient lighting was identified as one of the key areas.

Roadmap

On COP17 of UNFCCC, the South African Minister of Energy Dipuo Peters announced that it would prohibit the production and sales of incandescent lamps within five years. South Africa became the first African countries to phase out incandescent lighting products. South Africa will phase out and ban incandescent products in 2016.

1.1.8 Indonesia

Policy

The overall policy for SSL in Indonesia is also under development and not formed yet. However, there have been a set of laws and policies on energy conservation, which lays a good foundation for energy efficiency lighting technologies and products, including:

The Energy Law(Law No. 30/2007) outlines the economy's philosophy on the management of energy resources, the environment and energy, energy conservation, energy pricing, international cooperation, institutional aspects with regard to formulation of energy policy, business in energy, and rights and responsibilities.

National Energy Policy (Presidential Regulation No.5/2006) stated the focus of assurance of availability of domestic energy supply and realization of energy conservation;

Indonesia has some minimum energy performance standards (MEPS) for electrical appliances based on the Standar Nasional Indonesia (SNI) and other technical standards on energy performance testing standards (EPTS) for electrical appliances.

The Ministry of Energy and Mineral Resources issued the Applying Energy Saving Label for Self-Ballasted Lamp;

Incentive measures

An annual government budget is allocated for energy conservation programs and R&D. The government budget for the Energy Conservation Partnership Program—energy audit was 400,000 US Dollars in FY2009.

In accordance with the action plan (Governmental Regulation No. 70/2009), the government is expected to introduce government incentives that include tax exemption and fiscal incentives on imports of energy saving equipment and appliances, and special low interest rates on investments in energy conservation in the near future.

Roadmap

There are no roadmaps on SSL yet in Indonesia yet, but there are many energy conservation policies and targets.

The National Energy Conservation Master Plan (2005)—RIKEN (Rencana Induk Konservasi Energi Nasional) states that Indonesia's goal is to decrease energy intensity by around 1% per year on average until 2025.

The National Energy Management Blueprint—PEN (2006) explains that the goal of RIKEN is to realize Indonesia's energy saving potential through energy efficiency and conservation (EE&C) measures.

The National Energy Policy (2006) stated that Indonesia's goal was to achieve energy elasticity of less than 1 in 2025.

Governmental procurement

According to the Presidential Decree No. 2/2008 on Energy and Water Efficiency, there are mandatory energy conservation for government office buildings: Government departments and agencies and regional governments are mandated to implement best-practice energy saving measures as explained in the government's guidelines and directives on energy saving in government buildings, and are mandated to report their monthly energy use in buildings to the National Team on Energy and Water Efficiency every six-months.

Major SSL showcases

Although there are no major SSL showcases, there have been some energy efficient lighting programs in the residential sector: The lighting program in the residential sector is primarily demand-side management (DSM), in addition to energy savings.

There are two lighting programs:

(1) The Caring Program (Program Perduli)—a program of the state owned electricity company—PLN and
(2) Brightness Program (Program Terang)—a government program. The programs provide subsidized, and in certain cases, free CFLs to eligible households.

1.1.9 Brazil

Policy

The specific policy for SSL in Brazil is also under development and yet to be formed. However, there have been a set of laws and policies on energy efficiency, which lays a good foundation for LED lighting technologies and products, including:

Law No. 9991 – Energy Efficiency Programs of Distribution Utilities, which require electricity Distribution Utilities must apply at least 0.25% of their revenue in energy efficiency programs, the project types including: commerce and services, low-income consumers, industries, public sector, residential, water heating etc.

Law No.10295 – Energy Efficiency Law, which set out minimum energy performance standards for equipment and buildings. The regulated equipment including: three-phase electric motors and CFL.

PBE – Brazilian Labeling Program, which focus on energy conservation through informative labels about energy efficiency of equipment sold in the country, it has become mandatory for a number of products in 2006. The labeled products including electric motors, CFL, refrigerators, air-conditioners, stoves, solar water heaters, gas water heaters etc. and next products including water pumps, washing machines, photovoltaic and wind generators, design and installation of solar water heaters, stand-by power etc.

Governmental procurement

In Brazil, although the Attorney-General's office determined that the National Procurement Law (8666/93) did not prohibit the consideration of sustainability criteria in public purchases, it was still deemed desirable to amend the law to state explicitly that public purchases should take those criteria into consideration whenever possible (7709/2007).

Some Brazilian states have started to promote SPP (Sustainable public procurement). Criteria for socially and environmentally responsible public procurement have been defined for a large number of products and services and are being incorporated in the electronic bidding system.

Roadmap

National Energy Plan 2030 (PNE 2030)

For the first time in its history, Brazil has a document that allows the demand and supply of energy to be estimated for a 25 year horizon. Based on data from the National Energy Plan 2030 (PNE 2030, acronym in Portuguese), it is possible to devise strategies and develop policies that ensure the security and quality of energy supply for decades to come.

The PNE 2030 takes into account market variables, social & environmental issues and potential technological advances in its forecasts. All types of energy were considered by the PNE. The plan is considered a milestone for the energy sector planning in the country.

Along with another document, namely the National Energy Matrix 2030, the PNE 2030 is the primary tool available to the public and private sector for long-term planning. Organs such as the Ministry of Mines and Energy (MME), the Energy Research Company (EPE) - responsible for studies and research for the realization of the energy sector planning - and the National Energy Policy Council (CNPE) refer to the 2030 PNE on a daily basis.

The document was released by the MME in 2007, as a result of the studies and networking undertaken by the Energy Research Company (EPE), which is subordinate to the MME. The PNE 2030 consists of 12 volumes and more than one hundred technical notes - studies that analyze and present suggestions for a variety of sector issues.

The Secretary of Energy Planning and Development of the MME was responsible for coordinating the work on the EPE. The Center for Energy Research (Cepel), linked to Eletrobras, also collaborated in the production of the PNE 2030.

Major SSL showcases

Brazilian Energy Efficient Lighting Program

The inter-ministerial act No. 1007, published on December 31, 2010, regulates incandescent light bulbs in terms of a minimum energy efficiency level, according to the Energy Efficiency Law No. 10295/2001.

The program begins on June 30, 2012, starting with 150 watt (or higher) light bulbs and finishes four years later with 25 watt (or less) sources. The manufacturers and importers will have six months from these deadlines to deplete their stock and wholesalers and retailers will have one year to do the same.

Brazil has two predominant voltage levels – 127 and 220 volts. Thus, it needs two energy efficiency minimum levels for incandescent light bulbs, as described below:

Power (W)	220 VOLTS - EE minimum level (lm/W) *				
	30/06/2012	30/06/2013	30/06/2014	30/06/2015	30/06/2016
150+	18,0	22,0			
101 to 150	17,0	21,0			
76 to 100		14,0	20,0		
61 to 75		14,0	19,0		
41 to 60			13,0	18,0	
26 to 40				11,0	16,0
Below 26				10,0	15,0

Power (W)	127 VOLTS - EE minimum level (lm/W) *				
	30/06/2012	30/06/2013	30/06/2014	30/06/2015	30/06/2016
150+	20,0	24,0			
101 to 150	19,0	23,0			
76 to 100		17,0	22,0		
61 to 75		16,0	21,0		
41 to 60			15,5	20,0	
26 to 40				14,0	19,0
Below 26				11,0	15,0

The implementers stated that essentially, energy efficiency was the motivating factor to initiate such a program, to increase the Compact Fluorescent Lamp (CFL) market and encourage LED and OLED manufacturers to invest in Brazil.

The Guarulhos LED retro-fit project

The Brazilian city of Guarulhos retro-fitted 5,370 incandescent lamps in 1252 vehicular and 807 pedestrian traffic signals with custom light bulbs illuminated by high-power LUXEON® I LEDs.

Spearheaded and funded by electric power distributor Bandeirante Energia S.A with approval from the Brazilian federal government, the project has slashed signal-related energy usage in Guarulhos by nearly 90%. The savings of 1340 megawatt hours per year is enough to power about 558 Brazilian households. It has also chopped approximately USD$240,000 (R$434,200) per year off the city's electricity expenditures, freeing funds to add over 300 new traffic lights to improve safety and traffic management.

The initiative cost approximately USD$750,000 (R$1.35 million) and paid for itself in 12 months through a combination of energy savings and maintenance reductions made possible by long LED life.

A proposal to the Agência Nacional de Energia Elétrica (Electric Energy National Agency, or ANEEL)—part of the Mines and Energy Ministry of Brazil, and the government agency that enforces the energy conservation law—to replace all existing green, yellow and red traffic lights, arrows and pedestrian signals in Guarulhos with the new LED bulbs. The plan got the approval in November 2005.

1.1.10 Chinese Taiwan region

Policy

The energy policy of Chinese Taiwan region is mainly based upon its development and sustainable growth, reaching a balance among the three aspects: energy (stable energy supply), environment (low-carbon emission for the reduction of greenhouse gas) and economy (maintenance of affordable energy prices). And the LED industry plays a key role to realize that balance.

The Dawning Green Energy Industry Program: Reducing CO2 emissions to the 2000 level in 2025. (Including LED Traffic Light subsidy Policy)

In 2009, the "*Executive Yuan*" approved the third wave of its emerging industries development plan-the Dawning Green Energy Industry Program. The program calls for the investment of NT$45 billion over five years to boost the overall production of the green energy industry from 1.2% of overall manufacturing value in 2008 to 6.6% in 2015, and to create 110,000 jobs. Two industries for priority development: solar photovoltaic energy (in the renewable-energy field) and LED lighting (in the energy-conservation field). The LED lighting industries have already grown to considerable economic scale in Taiwan. In 2011, "*Executive Yuan"* promulgated the vision of energy development to "ensure nuclear safety, gradually reduce reliance on nuclear power, and create a green power and low-carbon environment to gradually become a nuclear-free country".

Five policies guidance of LED are;

1. Technology Breakthrough
Establish IP think tank and foundation to solve international IP issue.
2. Critical Investment
Develop technology and the company which has economic scale.
Establish international lighting enterprise
3. Conducive Environment
Lighting standard and criterion evaluation Internationalized.
Set up the standard of national measurement of LED lighting
4. Export Market Expansion
Support LED industry to approach international market.
5. Domestic Market Growth
Develop the LED lighting domestic application market.

Incentive measures

LED Bulbs Subsidy Policy

In the year 2012, the "*Ministry of Economic Affairs"* is studying the feasibility of subsidizing households which replace fluorescent lighting and incandescent lights with energy-efficient and higher-priced LED light bulbs, vice "*Ministry of Economic Affairs"* Francis Liang made the remark on the sidelines of an investment forum in Taipei. The ministry is planning to spend about NT$1 billion (US$34 million) on a new green energy subsidy program, citing "*Ministry of Economic Affairs"* Shih Yen-shiang. The ministry is planning the subsidy program in a bid to encourage consumers to buy LED bulbs and expected to release details about the subsidy program within on October in 2012, including subsidizing consumers by offering half the cost of each LED bulb purchase. In retail stores, LED bulbs cost around NT$400 to NT$500 each, much more than other energy-saving light bulbs. With the ministry’s subsidy, consumers would pay half as much for LED bulbs. The subsidy program should accelerate the growth of LED lighting in the residential market, which has a low single-digit penetration rate now.

Roadmap

Incandescent light phase out plan

The "*Ministry of Economic Affairs"* announced in 2008 that the incandescent lights would be phased out within 5 years and at the end the year 2008 the manufacture, import and sales of incandescent light would be fully banned, and the public agencies would ban the use of incandescent light starting from 2009.

In order to promote the use of LED lights, the "*Bureau of Energy (BOE)"* is said to allocate NT 130 million and more than 4000 LED lights for the local government for application. Also the BOE would cooperate with major incandescent light consumers like hotels, restaurants, hospitals and agriculture departments and encourage them to sign voluntary energy conservation agreements. And for household consumers, the energy saving lights promotion initiatives will help them to choose energy saving lights instead.

Governmental procurement

In light of Europe Debt crisis and internal industrial structure transformation, the "*Executive Yuan"* issued the Economic Climate Response Program in January 2012. Among its 7 strategies and 10 focuses, LED Street lights all over Taiwan is the first of 10 focuses.

Starting in 2012, the government will expand the conduct of the “LED Street Lighting Demonstration Plan” to the 5 special municipalities and 14 counties and cities. It is expected that, in 2012, 326,000 street lights will be replaced with LED lighting, including 53,000 in Keelung, Hsinchu and Chiayi Cities under the “LED Street Lighting Demonstration City Plan”, 23,000 in the 5 special municipalities and 14 counties and cities under the “LED Street Lighting Energy-Saving Demonstration Plan”, and 25,000 in the 5 special municipalities and 14 counties and cities under the “Special Plan for the Expanded Installation of Energy-Saving LED Street Lighting”.

These three plans will be subsidized by a budget of approximately NT$2.424 billion in 2012. The replacement of some 300,000 street lights will result in annual saving of 131 million kilowatt-hours (kWh) of electricity and reduction of 80,400 tons of CO2 emission, equivalent to the carbon absorption capacity of 206 Da’an Forest Parks, and will induce industrial output worth NT$3.9 billion.

The "*Bureau of Energy (BOE)"* was in the process of switching 700,000 traditional traffic signals to LED and will be the second country in Asia, after Singapore, to have all-LED signals. "*Ministry of Economic Affairs (MOEA)"* estimate that after the new semiconductor light source is adopted, annual electricity consumption is expected to be slashed by 85 percent, saving 247 million kilowatt-hours and reducing carbon emissions by 151,200 metric tons.

Major SSL showcases

"Three-cities, 10,000 lights” project

Advanced technology, patents and production capability have fueled the LED illumination market, listed by the government as a high-growth industry. The “three-cities, 10,000 lights” project starting in 2012 aims to speed up industry development, with the goal of helping operators generate production value of US$9 billion by that year, a growth of 30% year-on-year.

Next Generation lighting project

Chinese Taiwan is investing in solid-state lighting at the island level. The "Next Generation Lighting project" involves a consortium of 11 companies. Between 2003 and 2005, approximately NT$ 383 million would be invested in the technology. The goal is to achieve 50 lm/W output products and 100 lm/W in the laboratory.

1.1.11 NGOs

1. The LightSavers program

At Rio+20 the Climate Group launched the report: Lighting the Clean Revolution: The rise of LEDs and what it means for cities. The results of the report came from the LightSavers program, which is a global program established by the Climate Group with the support of the HSBC Climate Partnership to accelerate market adoption of outdoor LED lighting and smart lighting controls.

This report illustrates the global market status and potential for LED and smart control technologies, and provides guidance for policy makers and lighting managers who want to scale up and finance large-scale LED retrofits. The report also shows that LEDs are ready to be brought to scale in outdoor applications. The independent and verifiable results from the LightSavers trials and accompanying public surveys give compelling evidence that many commercially-available, outdoor LED products offer high quality light, durability, and significant electricity savings in the range of 50-70%.

The LED program is systematically evaluating the best pilot examples available globally, partners including:

Adelaide, Australia

Pedestrian pathway LED retrofit in the northern parklands of Adelaide.

Guiyang, China

The municipal government is testing two Chinese-made LED street light luminaires, one on a riverside pedestrian pathway and another on a local street.

Haldia, India

Haldia in West Bengal, India, is receiving LED installations on a major highway in the heart of the city.

Hong Kong, China

Two municipal universities and the Hong Kong International Airport are testing and comparing Taiwanese, Chinese, and American-made LED pathway luminaries on their respective pilot sites.

Kolkata, India

The Kolkata Municipal Corporation is testing over a 100 Indian made LED street light luminaries in several locales.

London, United Kingdom

Transport for London is testing high powered LED roadway lights in demanding applications on their Red Routes.

Mumbai, India

The Thane Municipal Corporation will install a trial of LED streetlights in the Greater Mumbai Region with support from the national government's Bureau of Energy Efficiency.

New York City, United States

The New York Department of Transportation is testing nine LED products in Central Park and on FDR East Side Drive.

Sydney, Australia

The City of Sydney is testing LED lighting with smart controls on George Street, a road in the centre of Sydney's business district.

Tianjin, China

Local government agencies are testing two Chinese-made LED street lights products in a new ecocity development and on a university campus.

Toronto, Canada

Four City of Toronto agencies are testing parking lot, parking garage, and pedestrian pathway LED lighting products, some with smart controls.

2. The en.lighten initiative

The en.lighten initiative addresses the challenge of accelerating global market transformation to environmentally sustainable lighting technologies by developing a coordinated global strategy and providing technical support for the phase-out of inefficient lighting. This will reduce global GHGs from the lighting sector and mercury released from coal combustion. The en.lighten initiative was created in 2009 as a partnership between the United Nations Environment Programme (UNEP), OSRAM AG and Philips Lighting with the support of the Global Environment Facility (GEF). The National Lighting Test Centre (NLTC) became a partner in 2011.

The en.lighten initiative has been established to accelerate global market transformation to environmentally sustainable lighting technologies by developing a coordinated global strategy and providing technical support for the phase-out of inefficient lighting.

en.lighten assists countries in accelerating market transformation with environmentally sustainable, efficient lighting technologies by:

• Promoting high performance, efficient technologies in developing countries.
• Developing a global policy strategy to phase-out inefficient and obsolete lighting products.
• Substituting traditional fuel-based lighting with modern, efficient alternatives.
The major deliverables of en.lighten including:
• Roadmap for global lighting market transformation to provide guidance on the phase-out of obsolete technologies and the introduction of new energy efficient replacements. This will include key policy and technical recommendations to assist countries with their progress.
• Set of global harmonized guidelines for quality, performance-based standards, and certification procedures for energy-efficient lighting products.
• Comprehensive tool kit to promote market transformation on a national level based on examples of countries' best practices and experiences.
• Guidance and training materials for governments, the private sector and civil society for various lighting related topics including: standards development, certification, verification, communication programs, consumer and environmental protection, recycling, etc.
• Country Lighting Assessments developed for each country to provide key information including; technology options, economic savings and GHG reductions potential that would result from the implementation of an efficient lighting program.
• Support for national and regional strategies and policies.
• Model end-of-life treatment strategy and guidance for efficient lighting products, addressing various health and environmental considerations.

3. Lighting Africa program

Lighting Africa is a joint World Bank-IFC program, which was launched in September 2007 aimed to improve access to clean, affordable lighting in Africa. About 600 million people in Africa (60% of the population) have no access to electricity. This number is expected to rise faster than new grid connections to about 700 million by 2030. Most of those people are in rural areas; rely on increasingly expensive, hazardous and polluting fuel-based sources of energy for lighting and cooking. Fuel-based lighting is generally of low quality impeding learning and economic productivity.

The Lighting Africa program was working to catalyze and accelerate the development of sustainable markets for affordable, modern off-grid lighting solutions for low-income households and small enterprises.

Lighting Africa had deployed this market development approach in Ethiopia, Ghana, Kenya, Nigeria, Senegal and Tanzania Specifically, the program aimed to increase access to efficient lighting technologies such as light-emitting diodes (LEDs) for households and small businesses.

The Goals

Lighting Africa's goal was to facilitate the transition from fuel-based lighting to clean, modern lighting through:

- Initially mobilizing and supporting the commercial sector to supply high quality, affordable, and clean lighting to 2.5 million people by 2012.
- Ultimately eliminating market barriers so that the private sector can supply high quality, modern, off-grid lighting products to the 250 million people in Africa without electricity by 2030.

Lighting Africa is part of the global Solar and LED Energy Access program, an initiative of the Clean Energy Ministerial, which is a global forum encouraging transition to a clean energy global economy.

The Approach

The overall approach of the program was to accelerate the development of off-grid lighting markets by:

- Demonstrating the viability of the market to companies and investors by providing market intelligence on market size, consumer preferences and behavior, and on the 'base of the pyramid' business models and distribution channels.
- Improving the enabling environment for the sector by developing quality assurance market infrastructure, and facilitating business to business interactions through conferences, workshops and a dedicated web-platform. We also work with governments to address policy barriers.
- Supporting the scale up and replication of successful businesses by providing targeted business development services and facilitating access to finance for manufacturers, local distributors and other stakeholders.

1.2 Comparative analysis of SSL policies

1.2.1 The features and highlights of government policy support

China SSL policy measures and support features

Comprehensive and specific policy measures for SSL. After years of development, China has been able to establish comprehensive and specific policy measures especially for SSL industry, and cover all the links of the whole industry. China also takes the advantages of the Five Year Planning and set up a specific plan for SSL. This will provide solid policy foundations for the development of SSL and create new and flexible policy measures.

Strong financial support for the early stage. China has been allocating strong financial support for the early stage development of SSL industry, including direct and indirect incentives, governmental procurement, and some SSL showcases. This can help incubate the market and help the SSL companies to gain necessary demand to get started and being able to make innovation and expand the market share.

Decision making efficiency. The SSL policy makers in China also take the good advantages of policy making efficiency on SSL policy measures. This can help the industry receive sufficient policy support in time and save time to avoid long time fruitless debate. And this does not mean that the stakeholders' opinions are not listened and considered, there are some mechanisms that will make sure the good communication between policy makers and other stakeholders of the industry can be established and in good operation. In this case, civil SSL organizations like China SSL Alliance and International SSL Alliance plays a key role.

U.S.SSL policy measures and support features

Specific, there are roadmaps for R&D, and roadmaps for manufacturing separately and specifically. The SSL policy in U.S. always features in being specific instead of macro level only, this helps greatly in serving the nature of the government policy: to direct the healthy development of the target industry. The real constructive way of policy is always the specific way, as the industry needs specific advice and guidance on how to solve specific problems in their process of development. There will not be enough effective support if the policy is too general.

Realistic, focusing on cost reduction and market adoption, the key of keeping the industry alive and developing. Policy makers need to be realistic so that the policy made can solve the problems come up, for the development of an emerging industry, including SSL industry and others, the first priority is always the cost reduction and market adoption, subsidized cost and stimulated market can work in the very beginning, but it is not a winning strategy in the long run. The industry has to be able to reduce the cost significantly and gain market adoption by itself before it becomes a real mature industry.

Focus on stimulating and inspiring innovation. Inside U.S. SSL policies, one feature is that there are many prizes and competitions and programs to stimulate and inspire innovations, innovation is the key to technology breakthroughs, and technology breakthroughs are the key for cost reduction and customer acceptance which are the key factors for an industry to survive. Innovators can be vulnerable and lack of confidence and resources to develop their innovative ideas into reality. Thus it is very important to set up an effective mechanism and a series of stimulating and inspiring programs to help them and encourage more innovations.

Focus on application and market realization, not only in the lab but also the market. The SSL industry has to focus on application and market realization or it can never develop well and better. It is good to develop an idea to the lab level, but that's not good enough, the policy makers need to understand the great leap forward is happening when the technology reached the market and household level from the lab, and that is the focal point of policy support. Specific measures and financial resources should be utilized to this direction to make sure the purposes can be realized as planned.

Different agencies coordination and maximize the results. As an new industry covering multiple sectors, the SSL industry needs different agencies' best coordination to maximize the effective results, the working areas distribution and communication mechanisms are the key factors to make this happen. Multiple agencies involvement is a delicate situation as there might be problems if the coordination is ineffective and the disagreements among relating agencies can substantially offset each agency's efforts thus the policy tools may not working or not working effectively. In the US case, the DOE takes a very good lead, and other related agencies plays the roles properly, the successfully working areas distribution and coordination contribute greatly to the success of U.S. SSL policy.

Stakeholders and players feedbacks considered and listened. One of the core factors that makes the policy effective is the stakeholders and players involvement, in the U.S. case, the stakeholders and major players are always involved in the roadmap making process as well as other policy making process. The stakeholders and players always have access to the main resources and constantly reviewing the opportunities and challenges of the business and industry, this makes them the major and ideal source demand providers, which are the key factors for the effectiveness of the policy. As the successful policies always find out what the demands are first and then offer feasible solutions.

EU SSL policy measures and support features

Focus on standards. Influenced by other industry and its own tradition, EU has been focused on standards of SSL. It is ambitious yet very challenging in the case of SSL. Standards are obviously very important for the SSL, but the timing and form are also important if taking into the consideration of the overall development plan of the industry itself. Besides, different member states still have their own different standards that may related to SSL technologies and products, this may not so helpful the for development of the industry and also for the application of the products.

Focus on safety and environment, eco-design. Focusing on the impacts on environment and eco-design is also one of the good traditions of EU. It can make sure the newly emerged technologies and products prove to be environmentally friendly as they promised, it is the ultimate target of all policies that ensure the safety and environment of the products so that they won't do major harm to the people using them and the environment.

Focus on OLED. From the policy summarize above we can find out the EU has been setting up many projects on OLEDs. Maybe the reason for this is that facing the situation that U.S. and Asia have already taken the lead in the LED technologies, and they are just trying to focus on this new field and make some breakthroughs. It is good to have a particular area of focus so that resources can be more effectively used. But this also poses the risks that no major share of technologies in the field of LED and also the risk of limited progress in the field of OLED itself.

1.2.2 The stages and roles of SSL policy

For different stages of SSL industry development, there should be different stages and roles of SSL policies, after all, the policy is supposed to serve the healthy and sustainable development of SSL industry. Thus it is highly recommended to policy makers to first and foremost clearly understand this current situation of their own country's situation and then choose to learn from the most appropriate examples.

From the listing and summarization of policies from major economies of the world above, we can see that mainly the stages of SSL policy can be summarized as the following stages:

Initial stage: the country or area has almost no SSL industry and the R&D is still at the early stage. This is the starting stage of SSL industry, the policy focus features in specific measures like phasing out incandescent lights, general policy on energy efficiency and renewable energy, energy conservation in the electricity sector and so on. The important issues for the countries and areas which are still at this stage are: policy determinations; overall plan with specific roadmap; industry preparation and R&D stimulation.

First the policy makers have to make the policy determination to develop the SSL industry and transform to the more efficient and economical lighting sources. This is the basis for all the afterwards development of policy as well as the industry itself. Then it is recommended to make an overall plan with specific roadmaps on SSL development. Plan making will help increase the effectiveness of policies and roadmaps can help the policy implementation more efficiently. And also the policy makers can add the specific situation and conditions of their own country and areas into the consideration. The industry preparation and R&D stimulation should be conducted simultaneously to make sure the R&D achievements can be realized in industry level and the industry development has adequate knowledge support.

Starting stage: In the starting stage, countries and areas are initializing relatively larger scale of phasing out incandescent lights, and replacing them with more efficient LEDs, the SSL industry start to grow, market is forming and R&D is expanding. SSL or LEDs are mentioned explicitly. The important issues for the countries and areas which reach this stage are: effective and specific stimulating policies, development plan and specific roadmap; industry support and strong R&D stimulation.

At this stage the policies need to focus on effectiveness and specific on stimulating. The SSL industry is often week when first started, and will face many different obstacles according to the different situations in different countries and areas. So the policies for this stage must be effective and specific enough to make sure the stimulation works. And then the industry level development plan and specific roadmap needs to be made, mainly address how the industry develop in the coming years and the mechanisms to tackle problems come up, and also how to deal with basic challenges like cost reductions and market adoption. Policy and financial support plans need to be in place and working to ensure the industry can grow at the beginning, and also the R&D should be effective supported to be able to help the industry solve technical and cost challenges.

Consolidating stage: If the countries and areas managed to complete the initial stage and starting stage, they may be able to make it to the consolidating stage. In this stage, there are comprehensive policy measures and even some legislation especially addressing SSL industry. Also there are more and more companies doing SSL business, the industry is eager to expand domestically and internationally. Massive propaganda has been in place and more and more people are realizing the benefits of SSL industry and its products and applications, there are multiple subsidies and incentives going to both the industry and R&D. And R&D has been well developed with significant achievements and the coordination with industry has been stable. Furthermore, the standard issue has been under discussion and proposals are being made but not yet able to form some universal standards on SSL technology and products. At present, the countries and areas with the best developed SSL industry and policy has already reached this stage. The important issues for these countries and areas are: appropriate directing policy and proper government role, sustainable development plan and roadmap, industry independence measures and R&D coordination and support.

The SSL industry in this stage has been quite differently from the first two stages, the policy makers need to understand the new and specific demands of the industry in this stage, and also the government's role in the industry development needs to be redefined to make sure the industry can and will continue to development without the strong stimulation to generate market adoption by governmental force. The industry development plan should transform to the focus of sustainable development of the industry itself and make the roadmap to realize that target accordingly. The measures of industry independence needs to be taken into consideration and the R&D focus needs to be shifted to better coordinated with the industry based on the experiences from the two stages before. The issue of standards establishment should be taken into consideration and preparation.

Mature stage: When the consolidating stage is completed, the SSL industry should be in a rational and steady development manner. The policy can reduce its stimulation measures and major financial support, and shift the major focus on the supervision and monitoring role, not one of the leading promoters. Subsidies and incentives will be reduced or minimized. The industry has already with solid and stable industry basis and proper layout. Worldwide trade barrier and market issue has arisen and under discussion. A large scale of customers have accepted the idea of SSL and started to buy the products on their own without too much propaganda. The coordination between R&D and industry has been mature and effective. The solutions to intellectual property rights issue has been proposed and under discussion. The universal standards on the major aspects of SSL technology has been proposed and starts the trial stage. However, No one has reached this stage yet but it's a direction where many efforts are going to. It is also the desired developing direction of the SSL industry.

The policy focus of this stage will shift as well, to mainly look into the supervision role of the government, the reduction of subsidies and financial incentives, the market for the industry should be mature as well so the policy makers will not have to worry about the market capacity itself but only the supervision issue that to fix the possible malfunction of the market or irrational expanding or overheated bubbles. And also the policy makers will need to consider the rational overall industry layout, make sure the completion is rational and healthy. Other important issues are the worldwide trade agreement and IPR protection issues, the leading countries need to make worldwide trade agreement and IPR protection protocols to avoid trade conflicts and IPR disputes. And also the universal standards on the major aspects of SSL industry need to be made to ensure the quality of the industry and its products.

Sustainable stage: After the former four stages of development, the industry is expected to reach the self sustainable stage; this is the ultimate goal and an ideal state of development. In this stage, there should be minimal policy interventions and basically focus on the necessary supervision and prevent new problems from happening. No subsidies and incentives needed because the industry itself can develop in a self sustainable way. The industry has been self sustainable in all aspect and industrial chains. R&D and industry are in great harmony and cooperation. There are mature and effective mechanisms to deal with IPR and trade issues. The standards have been well developed and comprehensive.

ChapterII:

Strategic Research Agenda

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Executive Summary

The Strategic Research Agenda chapter of Global SSL Outlook is a summary of the “ISA Strategic Research Agenda” published in 2011 and 2012, which were prepared by the ISA working group for “Strategic Research Agenda (SRA) and Industrial Roadmap”, on behalf of the ISA council of management. It is revised and enriched every other year, with interim updates issued when needed.

The SRA is the concerted action of global experts from industry and academia. It aims at preparing the future of SSL, by serving the global SSL value chain; connecting and strengthening global high-quality competencies to enable critical knowledge; identifying disruptive technologies to solve blocking points; enhancing cooperation between industry and academia and to develop strong R&D eco-system; focusing on research leading to innovations. Notice that SRA is not Industrial Roadmap, which will be based on collective inputs from industry, to provide quantified prognosis for the development of specific technology and process.

SSL is a global opportunity, has global challenge, and needs global effort. We hope that the SRA can be helpful for the global SSL R&D community, and we warmly welcome world-wide leading experts and professional organizations to join us for SRA activities.

Driven mainly by some grand societal needs and challenges, fast development of LED and semiconductors technologies, lighting is going through a radical transformation. This transformation is characterized by continuous and aggressive efficacy increase and cost reduction to replace traditional lighting sources by LED lamps; revolution of forms and fixtures; seamless integration with semiconductors to create digitalized and smart lighting systems and solutions; enabling to create “more than Illumination” functions and applications by using LED for healthcare and wellbeing, horticulture and food, and communication, etc. The success of this lighting transformation depends on not only the SSL industry and market development, but also on the creation of new fundamental knowledge and applied sciences. For the simultaneous development of new technology and new applications, new knowledge is vital.

To ensure a fast and sustainable development of SSL, a symphony is necessary among the many subjects, since a breakthrough probably needs synchronized progress in several domains. The Strategic Research Agenda (SRA) is a concerted action of experts from academia, industry and public authorities across the world. It requires an understanding of global value chain and a forward-looking of technical goals and market. The SRA tries to guide global SSL technology and application developments and provide a 2020 vision to academia, industry and policy makers.

Unlike conventional light source, SSL technologies and applications requires a thorough collaboration across many subjects such as physics, material, semiconductor, mechanical engineering, optical engineering, packaging, power electronics, computer engineering, communication, biology etc. The advances of all these technologies enable developments of SSL products in multiple levels, shown in . Level 0 is the Bare die. Level 1 is the packaged die or dies. Level 2 is the Assembly. Level 3 is the Module, which packs the LED assembly together with the power electronics, controllers, etc. Level 4 is the Luminaire, which is the combination of the SSL module and mechanical support, thermal solution, and electrical supply. Level 5 is the MonoSystem, which includes multiple luminaires, control, sensors, power supply, etc. in one application scenario (e.g., home, office, shop, street). Level 6 is the Complex System, which includes a large number of luminaires and other components of different types. It is normally an integration of multiple MonoSystems in a large space such as a building, a campus, or a city.

Figure2.0 SSL Product Levels

The rest of this chapter introduces the rationales and priorities of research subjects along three dimensions. One is the product levels, which include packaging, driver and complex systems. Another is along the technologies used in all the product levels, which include reliability, testing, recycling, human perception and SSL safety. The last one is the novel applications of SSL beyond lighting, which are called “More than Illumination” applications. These parts include SSL for protected horticulture and poultry.

2.1 Packaging and Compact Integration

The cost is one of the biggest challenge at the moment. Packaging including the materials like sub-mount, housing and filling is five times the cost of the LED chip itself. Therefore more efficient and easier packaging processes must be established to be competitive.

Besides cost, future LED luminaries will be based on new LED packages and modules. Beside the thermal aspect, those packages have to compensate the different thermal expansion coefficients between the semiconductor and standard board materials, have to output the generated light with nearly no loss and must withstand a wide range of environmental conditions, from moderate indoor lighting, medical applications and street illumination up to harsh industrial lighting with corrosive atmospheres.

Finally, the interface to the next level connection done by the customer must be standardized and simple, to get sufficient market acceptance. This multi-disciplinary responsibility of LED packaging makes it an ideal location for multi-function integration, including electrical, optical, mechanical and thermal functions. The compact integration of the LED packaging will contribute to high added values components. These components contribute to high value luminaire, and indirectly to the cost reduction at luminaire level.

The research challenges in packaging and compact integration are listed in the followings.

2.1.1 Interconnection Technologies

For operation, LEDs must be connected to an external circuit. Besides the driver, other components are required like sensors and control circuits, which are electrically connected to form a lighting engine. In addition to the electrical interconnect functionality, the thermal interconnection is another challenge. Thermal heat is dissipated and a good thermal path is needed to limit the increase of the temperature during operation.

For the electrical and thermal interconnections, different substrate technologies and lead-frames are available today, which are used for direct chip attach or for board level integration. The substrates must provide low thermal resistivity but high electrical isolation. Metal based substrates are excellent thermal conductors, but for electrical isolation dielectric layers (e.g. metal core substrates) have to be placed on the substrates, which are the bottleneck in the thermal path. AIN ceramic substrates have a high thermal conductivity, but are quite expensive. Silicon is also used as a substrate and MEMS can be implemented with additional processing functions.

Assembly and interconnection processes are significantly contributing to the cost of LEDs. Today the main assembly processes are: thermosonic flip chip bonding using gold stud bumps, die bond soldering, adhesive bonding and wire bonding.

2.1.2 Light conversion

Solid state lighting is the direct conversion of electricity to visible white light using semiconductor materials with or without light conversion materials (e.g., phosphors). There are mainly three ways to produce high color quality white light with LEDS:

[1] Mixing multiple wavelengths (red, green, blue) of different LED chips,
[2] Usage of blue LED source with yellow converter,
[3] Usage of UV-LED source with RGB converter.

The separate generation of red, green, and blue light is the most efficient method because no energy is lost during conversion. But this option has several disadvantages. As the luminance of each color depends differently on chip temperature, a separate active regulation must be implemented to ensure a stable color temperature.

The easiest way to generate white light with LEDs is to use blue light and convert about 50% to yellow light. Due to the physiology of the human eye, this combination looks white, even if the color rendering index is poor (about 65-75). A clear disadvantage of the blue/yellow combination is the impact of thickness variations and different path length of light through the converter layer, because the amount of source color is also part of the final color mixing and therefore significant changes in the correlated color temperature occur.

The conversion from UV-light to red, green, and blue is the best way to get a stable white light with a high color rendering index. Due to the invisibility of the UV-light the thickness of the converting layer has no influence on the color of the emitted light. Only intensity goes down either if the layer is too thin and not all UV light is converted or the layer is too thick and the reabsorbance of the converted light is too high. Unfortunately, UV-LEDs are expensive and less efficient, and also the Stoke shift will lower efficiency and produce additional heat. Exploring new materials and approaches for photon conversion is a major research challenge.

The successful realization of solid-state lighting will be accelerated by advances in our understanding of the fundamental properties of light-emitting materials, and of the physical processes that take place during the conversion of electricity to light, rational design of SSL lighting structures, and controlling losses in the light emission process.

2.1.3 Optical encapsulation

Cavity encapsulation is a common method of covering the LED die to provide protection and optical functionality. Silicone or epoxy materials are used with and without light-converting phosphors. The assembled LED chips at cavity bottom can be potted using optical shaped molds or are jetted or dispensed to fill the cavity. The most important challenges are optical stability regarding temperature and UV light and heat dissipation aspects. The refractive index of the material and the refractive curvature cause the far field radiance angle and dispersion properties of the packaged LED.

For many applications a multi-material approach can be applied: the light-emitting semiconductor die is encapsulated with more compounds, including a hard outer shell, an interior gel or resilient layer, or both. The material has to be stable over temperature and humidity ranges, and over exposure to ambient UV radiation. In addition, optical uniformity is crucial especially when LED is applied to indoor lighting. Conformal coating can usually achieve up to plus and minus 200 Kelvins deviation.

LEDs need protection from moisture and other harsh environmental hazards, and from optical beam shaping. This optical protection is normally provided on two levels, micro and macro. The encapsulation materials can be used to improve the light output and overall optical efficiency of the device.

Features of encapsulants are: UV resistance, non-yellowing, high refractive index 1.4...1.6, low impurity content, low modulus, high CTE, high and low temperature resistance -55 to +260ºC, optical clarity, optical uniformity especially when nano-sized particles are added.

2.1.4 3D Waferlevel Technologies

3D waferlevel packaging is nowadays mainly used to transfer the epitaxial grown optical layer to the chip substrate. But the advantage may also be useful for packaging to increase the throughput significantly. Not only the assembly time itself will be reduced, also wafer probing level will have an impact to save production costs.

The following subjects should be emphasized in research in 3D wafer level technologies: 3D structuring of Si-wafer, TSVs, hybrid WLP solutions and hermetic packaging.

2.1.5 Long Term Reliability and Color Consistency

LED efficiency, color consistency and life time are a function of operating temperature and current density, which therefore defines the main task in LED development and is substantially different to solutions in classic lightning.

The task of LED packaging is to achieve maximum cooling to ensure the functional goals efficiency, color consistency and life time. But in order to make the functionality feasible and affordable, the goal of maximum cooling is limited. Therefore a compromise has to be found with respect to price, cooling efficiency and functional performance. Today the solution is found in an engineering process, which is based on experience gathered during a trial and error. In some cases, simulation tools are being used to predict and optimize the thermal behavior of LED packages. But also reliability needs to be evaluated in a “Design for Reliability”, which is a main challenge for today: making reliability predictable and identifying cost efficient technologies.

2.1.6 Compact integration

SSL system integration is a creative, meaningful innovation that improves people’s health and well-being with tremendous business potentials. System integration plays an essential role as the key enabler governing the multi-functional performance, size, weight, and reliability of the final products. In addition, it accounts for most of the manufacturing cost of a product (more than 70% on average). It will not only bring various components together into one module but also provide an interface to the application environment. SSL system integration also provides the freedom for new lighting designs to lighting designers, energy efficient architecture to system managers and new intelligent functions to end-users.

Compact integration is mainly focused on the integration among level 1 to level 4, in order to create more added value and less costly SSL products. As SSL is digital in nature, it has inherently excellent advantages to combine lighting function with other functions to create advanced, smart, miniaturized and multi-function system. Compact system integration proposes generic, low-cost and highly-flexible smart SSL system integration technologies, processes and platform.

High product prices are one of the major challenges for SSL general illumination applications. Compact system integration will induce a significant cost-reduction by less space, less material, more function and fast manufacturing, towards SSL products. To enable the various compact system integration potentials, research subjects and priorities are: functional enrichment of the LED packaging towards LED sub-module, design and optimization methodology for compact system, interconnection and carrier bonding in 3D integration, alignment, testability and reliability development for compact integration.

2.1.7 Environmental sustainability and shortage of resources

LEDs depend on critical materials, which are not only steeply increasing in price but may encounter serious shortages when different emerging technologies depend on similar element groups. For LEDs, the use of gallium, as well as indium and rare earth metals, are currently the top concerns. The main drivers for the growing use of gallium are emerging technologies: thin layer photovoltaics, integrated circuits (IC) and white LEDs. The forecasted growth of the LED market is estimated to drive the demand for gallium from 9 t in 2006 to 143 tons annually in 2030 for white high-brightness LEDs alone. In comparison current world annual mining of gallium is estimated at around 106 tons.

For indium and rare earth metals, also required in LEDs, the demand and supply situation is similar. The current consumption pattern hence may result in serious shortages and the loss of ecologically and economically valuable resources.

The EU Commission has classified gallium and indium as critical raw materials at EU level. The US National Research Council considers indium as a critical material and gallium as a potentially critical one. Therefore, while the current expansion of LED technologies is most welcome and necessary from energy efficiency point of view, the resource situation raises new environmental, social and political problems that need to be addressed.

2.2 Driver

In LED lighting systems, drivers have been frequently referred to as the “weakest link”. LEDs as solid-state current devices require proper current/voltage/power to generate appropriate light output with a long lifetime. The End of Life (EOL) of a driver plays a critical role in the whole LED lighting system. The quality and performance of light are directly impacted by the driver performance, which includes efficiency, current regulation, and dimming control. The LED driver often operates in harsh and hazardous environments and at a high operating ambient temperature. High power efficiency leads to less power consumption, which could result in durability, reliability, and long lifetime. The cavity of the bulb has limited space for the LED driver. The current trend for system integration is to include the LED driver and the control module.

LED drivers can enable dimming and color-changing or sequencing of LEDs. LEDs are easily integrated with circuits to control dimming and color-changing so that these functions can respond to preset commands, or occupant presence or commands. The advantages of SSL include not only energy savings, but also the “more than illumination” concept by way of more SSL applications in the fields of medical/health, lifestyle, and horticulture/food.The use of SSL brings opportunities and challenges to the light control system. The smart LED lighting control system is becoming increasingly popular. To make the LED technology fully accepted by the market, we need to overcome some barriers, such as cost, color quality, luminous efficacy, life-time, testing methods, codes and standards, and lumen output.

Research subjects in driver include the following items.

2.2.1 Low cost High-quality LED Driver

The driver currently accounts for 30% of the total cost of a SSL luminaire. First of all, minimizations is an important topic. In the retro-fit market, the smallest space for an LED driver is the E27 socket cavity. Physical size is limited by the power consumption, which is related to the power efficiency of the LED driver, the component count, the mechanical structure and the thermal management. Secondly, SSL driver has to increase its efficiency. Next to them, driver topology, cost and thermal management are vital in producing low cost and high quality LED drivers. Finally, a common dimmer is required.

2.2.2 Standardizations and Integrations

The LED lighting system is a complex system. It can be classified into the following sub-system: LED emitter, Optics system, Electrical driver, and Heat-sink.The ideal situation is that each sub-system is standardized. Products from different manufacturers are interchangeable. To realize a standardized SSL driver module, we have to 1) identify the right power categories 2) standardize the physical dimension, following the categories in the above 3) develop the standard testing and manufacturing process flow.

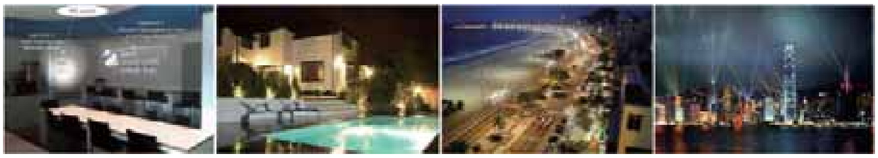
To improve system reliability and manufacturability, system integration is the trend. By reducing the number of components, and simplifying the manufacturing process, the controller, power switch, and magnetics can be integrated into a single package or module. To achieve it, we have to 1) develop a standardized ultra-miniaturized integrated module; the module technology package includes standardized controller and its surrounding components, power stage, output stage, LED lighting unit, and the manufacture process 2) improve Package and Thermal management 3) develop robust manufacturing process.

2.2.3 Components

Compared with the conventional power supply design, the driver for SSL lamps operates in a harsh and hazardous environment, including high ambient temperature, low air flow and limited physical size. So, in the selection of components for LEDs, issues such as the thermal stress, voltage stress, and current stress are critical. The most critical components are: electrolytic capacitor, power Semiconductor and magnetics.

2.3 Complex System

Complex system integration happens at/between Level 5 Mono System and Level 6 Complex System. Moreover, it takes care of interfacing with other systems such as smart-grid, weather, traffic, surveillance, etc. Complex system integration deals with more than one kind of luminaire and more than one function like lighting, sensing, processing, or communication. The objectives at this level are to ensure the complex system is sustainable, manageable, operable, maintainable, and upgradable. A simple system of even thousands of similar lamps controlled with switches is not in the scope of complex system integration.



Examples of complex systems

Complex system integration is a creative, meaningful innovation that improves people's health and well-being with tremendous business potentials. Complex system integration gives freedom for new lighting designs to lighting designers, energy efficient architecture to system managers, and new intelligent functions to end-users. Its development is mainly driven by the following three factors.

The need for new functions drives the development of SSL applications beyond retrofit. On one hand, users need context-aware, personalized, adaptive or even anticipatory lighting color, pattern or intensity depending on their age, behavior, and ambience for the sake of well-being and energy saving. On the other hand, along with rising energy and labor costs, lighting systems at a campus or city require automated operation, maintenance, and upgrading. For example, the lighting system should be controlled remotely and be responsive to weather, traffic, or other events. Its status should be monitored continuously and reported in case of failure.

The need for new business models and growth also drives complex system integration, and will especially once SSL is largely adopted. Traditional lighting business relies on selling products. However, due to SSL's long lifetime, this business model is hardly sustainable. The industry has to focus on new solutions and services, for example, an integrated lighting management system in a city or an intelligent lighting system in a retail environment. The development of both the solutions and services requires support from complex system integration technologies.

Development of complex systems requires mastering of both hardware and software design and implementation. Due to the diverse needs in applications, it is hard to develop one system and sell many pieces of it. Moreover, fierce competition in the business domain also demands fast development of new systems. Thus the need for mastering complex system integration also drives its research activities.

By definition, a system is a set of interacting or interdependent components forming an integrated whole. A complex system is a system composed of interconnected parts which, as a whole, exhibit one or more properties not obviously derived from the properties of the individual parts. In a complex system, these interconnected parts are normally luminaires, sensors, controllers, memory, communication devices, actuators, user interface, etc. Together they show integral properties such as higher reliability, more functions, intelligence, and autonomy.

A complex system starts from system integration but does not end there. It is self-sustainable, upgradable, and highly reliable. It is frequently deployed in a public space and is often a part of it. The design, installation, upgrading and maintenance of the complex lighting system should meet the illumination needs of the public architecture, which is continuously changing. The lifetime of the system should be equal to the public space's lifetime, such as a street light system, building lighting system. During this long lifetime, the components or subsystem can be updated or replaced due to their limited lifetime or technology evolution, which should not interrupt the continuous operation of the system. To fulfill the requirement of system cost, time-to-market, reliability, interoperability, updatability and robustness, optimizations and decision-making are done at every step within system life-cycle, consisting in system integration/upgrade, system operation, and system maintenance, as shown in **Figure2.3.1 .**

Figure2.3.1 Complex system life-cycle

2.3.1 System Integration

System integration is the beginning and key to a complex system life cycle. By definition, system integration is the grouping the components and subsystems into one system and ensuring that the subsystems function together as a system. However, it is more than “gluing” components together. System integration is about adding value to the system, which is the capability enabled by the interactions between components/ subsystems. Research topics include

- System architecture
- Interaction and interface between different disciplines
- Cost down in system development
- System modeling and simulation
- Accurate and low cost user and ambience sensing
- Low power, scalable and secured communication
- Actuation
- Context generation
- Hardware and software platforms
- Fast time to market
- Complex system testing
- Standardization

2.3.2 System operation

System operation happens in the period after the system being integrated/deployed and before upgrading. The complex system, in this period, has to be self-commissioning, adaptive to different operation conditions and environments, reliably functioning in a specific lifetime, controlled, and monitored. Research topics include

- Commissioning
- Reliability in operation
- Management system

2.3.3 System maintenance

System maintenance is a set of actions to keep a system running up properly. It is a series of special events during system operation, in which (potential) problems or breakdowns of the system are forecasted, identified, self-healed, timely attended, or removed. Due to the complexity of the system, system maintenance gets extremely difficult to schedule based only on the lifetime of each individual component. The same difficulty also emerges in developing automatic diagnosis and control functions, because more sophisticated physical models are needed to precisely describe the complicated couplings and interactions among all the individual components.

- Failure forecast
- Maintenance scheduling
- System Diagnostics and self-healing
- Plug & play hardware

2.3.4 System upgrading

During the system lifetime, new function, new service, new technology, or new demand from customers may drive system upgrading. In system upgrading, parts of the system, including both hardware and software, are replaced to meet various new requirements.

- Software centric upgrading
- Open software architecture
- Replaceable components

2.4 Reliability and Thermal Management

Lifetime here refers to the period of time during which something is functional and is a derivate from the reliability performance of the product. As with any products, the consistency and reliability of SSL systems need be ensured before they can be adopted in any application. To add to the complexity, there is too a need to ensure that the cost of this technology is comparable or even lower than the current technology for them to be adopted in these applications. Although SSL systems with low reliability requirements have already been developed, they can only be used in applications that operate in modest environments or in non-critical applications. For demanding applications in terms of environmental conditions such as automotive application, or where strict consistency is needed, such as healthcare applications and horticulture applications, the conventional lighting sources are currently still preferred until the reliability of SSL is proven in these applications. Therefore, knowledge of reliability is crucial for the business success of SSL, but is also a very scientific challenge. In principle, all components (LEDs, optics, drive electronics, controls, and thermal design) as well as the integrated system must live equally long and be highly efficient in order to fully utilize the product lifetime, compete with conventional light sources and save energy. The link between thermal design and reliability is obvious: the higher the temperature on the components and/or (sub) system, the lower the lifetime expectance. Thermal management is one of the key features to control the reliability of an SSL system.

It is currently not possible to qualify the SSL lifetime (10 years and beyond) before these products are available in the commercial market. This is a rather new challenge since typical consumer electronics devices are expected to function for only 2-3 years. Predicting the reliability of traditional electronics devices is already very challenging due to their multi-disciplinary issues, as well as their strong dependence on materials, design, manufacturing and application. This will be even more challenging for SSL systems since they are comprised of several levels and length scales with different failure modes in each level. The tendency towards system integration, via advanced luminaries, System-in-Package approaches, and even heterogeneous chip on chip integrations poses an additional challenge on SSL reliability.

To add to the complexity, a functional SSL system is made of different functional subsystems working in closed collaboration. These subsystems included the optics, drive electronics, controls and thermal design. Hence, there is too a need to address the interaction between the different subsystems. Furthermore, an added challenge for system reliability is that accelerated testing condition for one subsystem is often too harsh for another subsystem. Alternatively, even the highest acceleration rate possible for one subsystem may be too low to be of any use for yet another subsystem. Hence, new techniques and methodologies are needed to accurately predict the system level reliability of SSL systems. This requires advanced reliability testing methods since todays available standards are mainly providing the probability at which LEDs may fail within a certain amount of time.

In engineering, reliability is the ability of a system or component to perform its required functions under stated conditions for a specified period of time. It is often reported in terms of a probability. It is very challenging to understand and predict the reliability of a macro-level system, because reliability is always a multi-disciplinary issue, and strongly associated with materials, design, manufacturing process, testing and application conditions. System reliability, herein, mainly addresses the reliability of all components of the system, is even more challenging. It needs not only new fundamental theory and methodology, but also different techniques, be it experimental and/or numerical, and engineering practices to deal with the new behavior and characteristics of the total system. Due to the relatively short period of time for technology and industrial development, system reliability is a young scientific playground with limited knowledge, but tremendous opportunities for creativity, innovation and new business development. The word system originates from the Latin systēma, in turn from Greek σύστημα systēma, and described as 'whole compounded of several parts or members, system', and literary means composition.

The commonly used description of a system is given as:

System: a set of interacting or interdependent system components forming an integrated whole.

A complex system: a system composed of interconnected parts that as a whole exhibit one or more properties (behavior among the possible properties) not obvious from the properties of the individual parts.

A system's complexity may be of one of two forms: disorganized complexity and organized complexity. In essence, disorganized complexity is a matter of a very large number of parts, and organized complexity is a matter of the subject system (quite possibly with only a limited number of parts) exhibiting emergent properties. Examples of complex systems include any colonies, human economies and social structures, climate, nervous systems, cells and living things, including human beings, as well as modern energy or telecommunication infrastructures.

New processes and materials will always introduce a series of new and unknown failure modes. In the particular case of SSL, the lighting industry does not have the installed reliability testing base that is needed to cover the promised lifetimes. Even more, there are no test standards available with appropriate pass/fail criteria for the (key) components and/or SSL products. Relationships with material and component supplier need to be tightened, as is the case in the automotive industry, in order to share the responsibility for the product quality and reliability. In other words: a huge mindset change is needed in reliability to make the marked introduction of SSL application a big success.

Within the SSL Reliability and Thermal Management domain, 4 strategic areas are identified:

2.4.1 Component Reliability

Component reliability refers to the performance over time of the individual key-components in a system. Each system can just last as long as it's lowest life component. Key-components in a SSL system are the LED package, the optics, drive electronics, controls, thermal design, connectors, sealants and other plastics. Research topics include:

- In-depth understanding of failure modes and mechanisms
- Advanced failure analysis methodologies
- Materials that can withstand temperature beyond 100°C for lifetimes beyond 25khrs
- Accelerated test methodologies for key-components, including acceleration models / factors
- Design rules for cost effective reliable drivers
- Simulation techniques that allow multi-function modeling of light, thermal and mechanical effects

• Color consistency over life
• Standardization

2.4.2 System Reliability

System reliability refers to the probability that a system, including all hardware, firmware, and software, will satisfactorily perform the task for which it was designed or intended, for a specified time and in a specified environment. Research topics include:

• Accelerated test methodologies for SSL systems
• Fast and reliable online testing techniques
• Customized methods for material degradation within SSL systems
• Design for reliability; pick-your-reliability
• Software reliability, in interaction with hardware
• Standardization
• Diagnostics and Self-Healing

2.4.3 Reliability Modelling and Prediction

Reliability modelling refers to the process of predicting or understanding the failure modes of a component or system prior to its implementation by using multi-physic techniques. Reliability prediction refers to forecasting the reliability performance of a component or system by using statistical techniques.Research topics include:

• Integrated thermal, thermo-mechanical, optical and multi-physical modeling techniques
• Advanced dynamic reliability prediction techniques
• Component and system level reliability prediction models
• Warranty, service and commissioning strategy

2.4.4 Thermal Management

Thermal management refers the use of various temperatures monitoring devices and cooling methods, such as heat sinks and/or forced air flow, within a system, to control the overall temperature of components.Research topics include:

• Advanced LED package thermal management methodologies
• Novel thermal architectures for SSL systems
• System level compact thermal modeling techniques
• Design for thermal management tools
• Standardization

2.5 Testing

Because of numerous benefits like energy efficiency, environmental friendliness, a long lifetime, range of color, and small size, SSL has become a rapid growth technology in recent years and is considered as the technology for future lighting. However, when compared to conventional lighting systems, an SSL system is complicated, consisting not only in a light source, but also in drivers, lenses, a housing, and electronics for controlling. Due to their unique physical attributes, existing testing solutions are not sufficient anymore.

First of all, although SSL has many unique characteristics compared to conventional light source, specialized testing methods for SSL are missing. For example current testing method is unable to measure parameters related to color qualities. Secondly, although a variety of existing industrial standards such as thermo-mechanical fatigue tests can also be used to describe the degradation of a SSL system, these standards were initially designed for the electronic industry and may not be fully compatible with SSL. For example, standard approaches with a high testing temperature may introduce new failure mechanisms to SSL. Thirdly, current testing methods require a long testing duration and sometimes are expensive, which increase product cost and time-to-market. For example, luminaries makers often sent their product to the time consuming and expensive LM-79 or energy star qualification without any prior knowledge or confidence in their products passing these tests. This often resulted in the products failing these quantifications. Last but no least, since the lighting market serves such a diverse array of applications and mission profiles, each application will require different set of criteria to quantify their quality and reliability. However, the current method failed to address this limitation.

2.5.1 Photometric Testing

Research topics in photometric testing include testing method for AC driven products, photometry for curved light systems, color Rendering Index (CRI), mesopic parameters, photo biological safety, lumen maintenance and lifetime and calibration.

2.5.2 Power, Electronic, Thermal and Environment

Research topics in photometric testing include harmonic distortion and power factor, thermal testing, environmental behavior, test and diagnosis for electronics yield enhancement.

2.5.3 New Testing Methods

Research topics in this category include accelerated testing, adaptive testing, system testing and inline testing.

2.6 Green Sustainability and Recycling

Sustainability refers to the long-term maintenance of the well being of humans and our environment. The notion of sustainability for electronics in general and solid state lighting specifically is at present mostly driven by energy efficiency during the use phase, which from a the perspective of life cycle analysis indeed is the dominant factor in the environmental impact of lighting products. However, limiting the use of hazardous substances, depletion of resources and environmental damage are rapidly growing in importance. This is not only based on the need for long-term environmental sustainability, but also due to shorter term issues like the supply risks and the availability of sufficient resources to enable the transition to less energy consuming technologies. In this chapter the focus will be on resource efficiency.

Electronics by their nature use small amounts of material per device. However, the total volume of the electronics and associated components leads to the dissipative use of many scarce and valuable metals as well as to extreme dilution of these metals in waste streams.

This results in the loss of raw materials that are vital to the economy.

Focusing on solid state lighting, properly dealing with waste is in this respect crucial. However, unlike product manufacturing, dealing with waste in an optimal way involves many players at various stages of the value chain. From a technological perspective, the composition and design of products and assemblies should be such that materials can be separated, identified and recovered. From a business perspective the incentive should be distributed fairly among the various players. This will also involve governmental regulations and cooperation of users.

It is inevitable that for a successful sustainable transition, political, societal and technological efforts are required, reducing the vulnerability for supply disruption and in parallel create new relevant business opportunities.

This document will first provide information on the present status with respect to sustainability related topics and approaches toward improvement. Research should focus on the following topics:

- Environmental impact of SSL products, based on life cycle assessment
- Materials used specifically in SSL
- Legislation and regulation in different parts of the world
- Design concepts
- Manufacturing concepts
- Business analysis

2.7 Human Interactions with LED Lighting

Further SSL researches are needed to expand our fundamental understanding of the effects of lighting conditions on performance, comfort and safety. It is equally important to explore the new application possibilities for LED light sources and LED luminaires to demonstrate new approaches for challenging conventional lighting application concepts. As users are able to control the color and color sequence, intensity, duration, etc. with LED based products, it is desired to have an appearance model of lighting to define the viewing field, to understand various visual phenomena, to predict various appearance attributes. It is also possible to create almost any desired light effect in a space at will by adjusting a number of lighting parameters independently, i.e. chromaticity, intensity, and beam shape. The advantage is that in principle every light ambience can be created and adapted to suit the end user's needs at any time. The lighting ambience is able to influence the emotional state of people and through it their mood, behavior and well-being. In addition to visual effects, light has biological, non-visual effects which affect the other biological rhythms, most notably the circadian system, which generates and regulates a number of rhythms that run with a period close to 24 hours. The research agenda should take into consideration the similarities and differences of these two effects in the way of developing new lighting technologies that deliver light for the circadian system and other biological rhythms.

2.7.1Visual performance, comfort and safety

LEDs have a number of properties that make them more flexible than other light sources. LEDs can be combined so as to allow variations in the amount, distribution and spectrum of the light emitted. It is the potential of this flexibility to enhance human performance, comfort and safety that needs be studied. Such studies can take two forms, studies that expand our basic understanding of the effects of lighting conditions on performance, comfort and safety, and studies that explore the potential for LEDs to provide new approaches for specific applications. Studies of both types need to be strategic. This can be done by generating testable hypotheses and creating models of the effects of interest that can be widely applied. Such studies are different from those that simply seek to demonstrate the use of LEDs as a substitute for other light sources, which usually generate little by way of understanding.

2.7.2 Appearance Model of Lighting

With the advance of the SSL-based products, users are able to control the colour, intensity, duration and colour sequence, etc. It is desired to have an appearance model of lighting to define the viewing field, to understand various visual phenomena, to predict various appearance attributes. The approach is very similar to the CIECAM02 colour appearance model developed for the colour imaging and the surface industries.

The goal of the research is to provide guidelines toward developing model(s),

1) To predict the appearance of lighting including brightness, colourfulness and hue, and each will have two viewing modes:
   a) Aperture mode (unrelated colours: see in isolation such as perceived as filling a hole in a screen),
   b) Complex field (related colours: practical viewing condition such as illuminated wall, road lighting condition),

And

2) To provide guidelines to accumulate experimental data to develop a model.

2.7.3 Light appearance and atmosphere creation with LED lighting

With SSL-based products it is possible to create almost any desired light effect in a space at will by independently adjusting a number of light parameters. Examples of such parameters are chromaticity, intensity, and beam shape. Moreover, due to the small form factor and the very short response time of LEDs, the light settings can be varied at high spatial and temporal resolution. The advantage of this huge amount of freedom is that in principle every light ambience can be created and adapted to suit the end user's needs at any time. Additionally, the lighting ambience is able to influence the emotional state of people and through it their mood, behavior and well-being. Examples of possible applications are:

- Consumers can adjust the atmosphere at home according to their mood and activity;
- In shops one can create the atmosphere that enables brand recognition or that fits the latest trends and/or the season;
- In hotels one can create atmospheres that make people feel welcome and 'at ease', or create a unique ambience to support brand recognition;
- In offices and schools one can influence the well-being and productivity of employees and students.

2.7.4 Non-visual effect of LED light

Biological, non-visual effects of lighting constitute a new field within lighting research and education. In addition to visual effects, light is known to affect the other biological rhythms, most notably the circadian system, which generates and regulates a number of rhythms that run with a period close to 24 hours. Light-dark pattern incident on the retina is the major synchronizer of circadian rhythms to the 24-hour solar day. Lighting characteristics (quantity, spectrum, timing, duration and distribution) affecting the visual and circadian systems differ. Symptoms of circadian sleep disorders, such as Seasonal Affective Disease, Jet lag, and Delayed Sleep Phase Disorder can be mitigated by timed light exposure.

The neural machinery in the mammalian retina provides light information to both the visual and circadian systems, but the two systems process light differently [30]. Rods, cones and a newly discovered photoreceptor, the instrinsically photosensitive retinal ganglion cells (ipRGCs) participate in circadian phototransduction (how the retina converts light signals into neural signals for the biological clock). The quantity of polychromatic "white" light necessary to activate the circadian system is at least two orders of magnitude greater than the amount that activates the visual system. The circadian system is maximally sensitive to short-wavelength ("blue") light, with a peak spectral sensitivity at around 460 nm, while the visual system is most sensitive to the middle-wavelength portion of the visible spectrum at around 555 nm. Operation of the visual system does not depend significantly on the timing of light exposure, and thus responds well to a light stimulus at any time of the day or night. On the other hand, the circadian system is dependent on the timing of light exposure. In addition, while the visual system responds to a light stimulus very quickly (less than one second), the duration of light exposure needed to affect the circadian system can take minutes. For the visual system, spatial light distribution is critical (e.g., when reading black letters on white paper), while the circadian system does not respond to spatial patterns. Additionally, light reaching the lower retina is more effective in suppressing melatonin than light reaching the upper retina, but it is not yet well-established how light incidents on different portions of the retina affect the circadian system. It is also important to note that the short-term history of light exposure affects the sensitivity of the circadian system to light; the higher the exposure to light during the day, the lower the sensitivity of the circadian system to light, as measured by nocturnal melatonin suppression and phase shifting.

Therefore, the research agenda should take into consideration the similarities and differences of these two systems, and determine how light emitting diodes (LEDs) can aid in the development of new lighting technologies that will effectively deliver light for the circadian system and other biological rhythms that are impacted by light.

2.8 SSL applications in protected horticulture

Light is a vital environmental factor that affects plant growth and development by acting on plants not only as the sole energy source of photosynthesis, but also as the external signal of morphogenesis after being intercepted and absorbed by photosynthetic tissue. Normally visible light spectrum can manipulate plant photosynthesis via acting on chlorophyll, controlling photomorphogenesis, cryptochrome, phototropin and the other photoreceptors. Three dimensions of light each influence plant growth and development. Light quantity or intensity refers to the instantaneous or cumulative amount of photosynthetic light received in a period of time (usually s or d) in a defined area (usually m^2) and is expressed in μmol or mol of photons. Light quantity primarily influences photosynthesis and thus root and shoot growth of plant. Light quality refers to the spectral distribution of light, for example, the ratio of red (R, 600 to 700 nm) to far red (FR, 700 to 800 nm) photons. Light quality can influence flowering and plant morphogenesis, such as stem extension, branching, leaf area and leaf thickness, color of flowers and leaves. Lastly, light duration refers to photoperiod, or the duration of light each day. Many ornamental crops are sensitive to photoperiod with respect to flowering and thus, photoperiod is commonly truncated or increased to inhibit or promote flowering, whichever is desired.

Many experiments with LED have been conducted as an artificial light in greenhouse for a supplement light and in plant factories as sole light source for plant growth. LEDs can be used in plant tissue culture, seedling production, vegetable & flower cultivation in closed chamber or plant factory and greenhouse as artificial light. However, the optimal light environmental parameters, i.e. photobiology of horticultural plants, is far from being fully understood, which limits the further practical use. Based on current literatures, light requirements of horticultural plants are different due to species, cultivar, growth and developmental stages, and environmental conditions etc. Therefore, detailed studies on light quality requirements, i.e. light formula, based on biological and physiological requirements are urgently needed to investigate for getting high yield and good quality. With the development of SSL sources, more detailed researches on plant photobiology of monochromatic light are extensively conducted globally.

To develop SSL for protected horticulture, we have to focus on the following research topics.

2.8.1 Cost down of LED system

Price of one product is one of the limiting factors of its market competition. A major challenge for the use of artificial light is the reduction of energy use and costs. It is reported that the price of LEDs is around 5 and 7 times higher than those of HPS and FL, respectively, at equal power. Reduction of costs are possible by increasing the light utilization efficiency of the crop, optimizing light duration and intensity, interplanting, change plant densities, changing the shape of the growing system.

2.8.2 SSL system designed for protected horticulture

Previous studies showed us a promising picture of potential SSL application in protected horticulture. However, we are still seeking for many solutions to the challenges such as suitable wavelength combination for a specific horticulture plant; management of light quality, light intensity and photoperiod integrally and synergic; lighting environment management strategy for various protected facilities. All of these is such a complex, challenging and intractable research field, and continuously require us to explore.

2.9 LED for poultry

Although the growth of broilers have been extremely accelerated with the development of breeding techniques, deficiencies of rearing environments have a negative effect on it and may lead to some metabolic diseases. When breeding techniques of fowl could not be improved, the rearing environments will become the key factor of the development of poultry breeding industry.

The study of effects of feeds on broiler's growth involves nutriology and toxicology. Actually, these studies need a long period to complete while the results cannot be guaranteed. For example, there is a feed additive which could accelerate broiler's growth, may have toxic effects on poultry, human or environment. Besides, a plenty of funds, sources and labors are indispensable. So, the study on poultry feed made little progress. As to the ambient temperature, it's hard and costly to control in rearing house. Thus, the convenient, inexpensive and efficient approach to study the effects of lighting environment on broiler's growth.

Poultry have a broader spectral range (380□760 nm) and it can discriminate colors. It is important to adopt favorable lighting source and reasonable lighting program (color, intensity and photoperiod) to promote the growth performance of poultry. Since incandescent was invented, it has been widely used to light broiler's house. However, the disadvantages of short life, high energy consumption and costly maintenance have become more prominent in cultivation. Besides, the spectrum of incandescent cannot meet the physiological preference of poultry. Over the last three decades, different types of lighting were invented. Currently, few studies of low pressure mercury and high-pressure sodium vapor on boiler's growth can be found. Besides, these lighting source may bring unpredictable pollutions (heavy metal pollution especially mercury pollution) on poultry and environment though they may have positive effects on poultry. The invisible harms cannot be ignored when compared to the benefits.

LED has advantages in terms of efficiency, long life and narrow spectrum. However, for poultry's production, enormous potential benefits of those traits are usually ignored. First, LED, as a representative semiconductor light source, can decrease the electricity in a large degree (electricity accounts for most part of costs in breeding farm) because of its high efficiency. Second, long life (50,000 hrs) of LED help producer to save the fees of lights change. Because of short life (1000 hrs), old or damaged incandescent have to be changed often and this work may stimulate poultry then affect their growth and health. Thirdly, LED can deliver monochromatic light which is worth for poultry's growth and reproduction. The characteristic of poultry's eye leads to different performances with different light colors.

Our prophase research showed that red light can accelerate laying rate while yellow light can bring more drink, better body weight gain and lower feed conversion. Thus, appropriate monochromatic light is capable of increasing production. Besides, chickens reared in kinds of monochromatic may selectively uptake nutrients.

Popularizing LED is of great significance in alleviating global environmental protection. Firstly, the replacement may relieve energy shortage. Secondly, with reasonable lighting program, it may also relieve resource shortage. Thirdly, as to the air quality of chicken house, implementing a suitable lighting may decrease the emission of acid gas (NO_x, NH_3 and H_2S). Bringing LED lighting into the light environment of poultry production, not only makes a breakthrough of original lighting function and expands the application of LED in agriculture to realize energy saving, growth promotion and emission reduction, but also is significant in alleviating global environmental problems.

LED in poultry has the following research challenges.

2.9.1 Establishing an evaluation system of poultry preference of LED

Observing their self-selective preferences under different lighting conditions (colors, intensities, photoperiods) can be meaningful to promote poultry welfare and growth performance. Knowing the preference of broiler on different light colors may increase the feed intake. Considering animal welfare, poultry reared in preferable light colors, can reduce their stresses and improve meat quality as well as health. As to light intensity, high intensity may increase feed intake, but excess intensity cause metabolic diseases; low intensity can calm chicks down (main energy intake converted into fat deposition), but even lower may decrease feed intake.

2.9.2 Lighting control system

As previously mentioned, the incandescent bulbs predominate in poultry breeding industry. However, spectral property of LED significantly differs from incandescent bulb. At the same intensity level, spectrum energy of incandescent spans in the entire wave band of visible light, while LED distributes in nanometer range. So, existing light program of incandescent in breeding house cannot be ported to LED lamps. Moreover, the existing light programs of photoperiod are vague and coarse, which lack of colors and intensities. Obviously, the reform of light program in poultry breeding industry is imminent.

2.9.3 Quantitative relation between LED and performance indexes of poultry

Fawwad Ahmad revealed that light intensities have non significant effects on feed conversion and body weight gain of broiler chickens. However, Rehovot, Israel (the Hebrew University of Jerusalem) had a preliminary test which concluded that light intensities have significant effects on growth performance of broiler chickens. We are facing challenges to figure out the quantitative relationships between intensities and light regimes of LED and performance indexes of poultry.

2.9.4 Genetic changing in application of LED lamps

Lighting affects reproduction and organs development of broiler. According to Darwin's Theory of Evolution, creatures have to adapt to environment so as to genetic changing. If generations are reared in the same lighting condition, it may stimulate the genetic changing so that the elite genotype of poultry express. We can make the elite performance stably inherited by selfing, backcrossing and crossing. The challenges are to improve heredity performance by lighting stimulating.

2.9.5 Intelligent LED control system

Different light sensitivities differ by genotypes. The significant difference of light sensitivity shows between broilers and layers. In spite of a certain strain of chick, different growth phase has different needs of lighting. Thus we need an intelligent LED control system to adapt the proper lighting for poultry based on genotype by using theories of computer and control science.

2.9.6 Animal welfare and environment

Welfares of poultry differ sharply on different light sources. There are researches indicating that fluorescent lamps can reduce the leg disorder of chicks compared with incandescent lamps. Relationships between animal welfare (live weight, lameness, feature condition etc.) and lighting conditions are still unclear. Chicks reared in different light conditions perform differently on feed intake and metabolism result in diverse components of chicken manure. The scientific evaluation of LED lighting on poultry welfare and environment can be a big challenge.

Chapter III:
SSL industry development

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3.1 SSL Materials and Equipment

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Here we talk about the key materials and equipment used in the LED (Light Emitting Diode) solid state lighting industry. The most important LED materials include the substrate and epitaxial semiconductor material, which will be further discussed in the chapter of epitaxy. We here give a brief introduction of the solid state lighting materials, and mainly focus on the LED equipment, and more specifically MOCVD.

3.1.1 Solid State Lighting Materials

The key materials for the LED industry include series of nitride materials and arsenide materials. Nitride materials are the essential ones of violet, blue, green and white LEDs, while arsenide materials correspond to red LEDs of relatively longer wavelength. Nitride-based material system, which includes GaN, InN, AlN and their ternary and quaternary alloys, is regarded as the most crucial material to cover the whole visible light spectrum. Generally, epitaxial growth is used as the major production method to obtain nitride based material. Sapphire and Si are employed as substrates for heteroepitaxy due to the lack of homogeneous substrate material. 2, 4 and 6 inches sapphire substrates are the most commonly used candidates. However, the epitaxy of nitride based LEDs suffer from serious problems because of the large lattice and thermal mismatch between substrates and epilayers. Although several manufacturers attempt to develop GaN homogeneous substrates, there are still severe hindrances such as imperfect technical solution and high cost (>1000$/pcs). As a consequence, sapphire and Si will remain as the most conventional substrates for the epitaxy of nitride based LEDs in the near future.

3.1.2 Solid State Lighting Equipment – MOCVD

The semiconductor equipment is essential in epitaxy, chip processes and packaging of LEDs. The MOCVD (Metal Organic Chemical Vapor Deposition) system is the most significant key equipment for the epitaxy process, acting as the critical and topmost component of the industrial chain. The properties of LEDs wafer and chips are determined by the performance of corresponding MOCVD system to a certain extent. As a result, we will focus below on the development and trend of MOCVD system.

3.1.2.1 Brief History of MOCVD

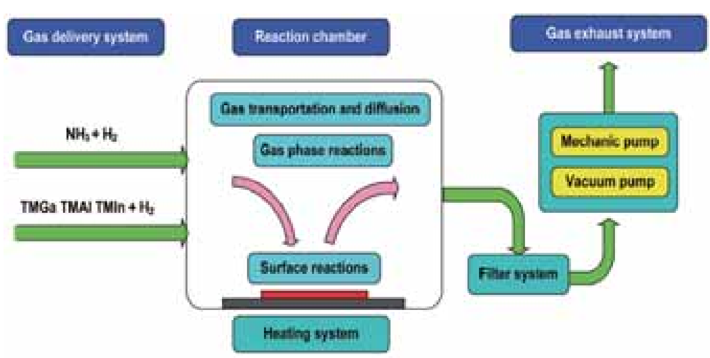
The MOCVD system is the gas phase epitaxial equipment which takes metal organic compound and a non metallic hydride as sources to grow epitaxial compound semiconductor via pyrolysis synthesis reaction. The original research on MOCVD technology was initiated in 1960s by Harold M. Manasevit et al from Rockwell Inc. MOCVD system has the advantages of flexibility and uniformity due to the gas flow and chamber temperature affecting epilayer growth. Meanwhile, the pyrolysis, combination and deposition of precursors are insensitive to the temperature, leading to the high repetitiveness of epitaxy growth. Furthermore, industrialized mass production could be realized by MOCVD system due to the capacity of multi- and large wafer epitaxy. After nearly thirty years of development, MOCVD has become a core and widely used growth technology for epitaxial growth of GaAs and InP in 1990s. The first p-n junction GaN LED was developed using MOCVD by Japanese scientists Isamu Akasaki and Hiroshi Amano in 1989. In 1994, high brightness blue LEDs were achieved by Japanese scientist Shuji Nakamura using self-developed MOCVD system, which is considered as an epochal advance. The epitaxial growth of GaAs-based red LEDs and GaN-based blue LEDs have been performed by MOCVD system in industrial production so far.

3.1.2.2 Fundamentals of MOCVD

MOCVD system is large and sophisticated, generally including gas delivery, reaction chamber, gas exhaust system, monitoring control, etc. The reaction chamber, in which the reaction between MO precursor in carrier gas and hydride takes place above the high temperature substrate, is the key component of MOCVD system. Take the GaN LEDs growth for example: TMG, TEGa, TMAl, and TMIn are the commonly used MO sources and NH3 is the hydride source. Cp2Mg and SiH4 are the p- and n-type dopants, respectively. H2 or N2 is the carrier gas. The reaction is as follows:

$(1-x-y)(CH3)\ 3Ga + x(CH3)\ 3In + y(CH3)\ 3Al + NH3 \rightarrow Ga1-x-yInxAlyN + CH4$

In fact, the actual reactions in chamber are far more complicated than the global reaction described above, including the output of complexes and byproducts. They will be carried by the gas flow into the gas exhaust treatment system.



Schematic diagram of the MOCVD system

According to different chamber designs, MOCVD system can be divided into different types, that is, horizontal and vertical chamber in respect of flow direction, low pressure and atmosphere pressure MOCVD in respect of chamber pressure. Low pressure MOCVD is commonly employed in the present industrial production.

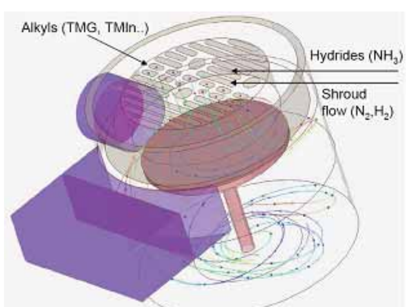
3.1.2.3 Introduction to Commercial MOCVD Products.

Recently, the demand for MOCVD equipment largely increased with the installation of over 1,000 systems required by the significant development of semiconductor lighting industry. The installed base of MOCVD in China exceeded 700 in 2010 and 650 in 2011. The price of the productive MOCVD equipment is up to 2 million dollars or even more, suggesting the massive market size of MOCVD equipment. However, the amount of companies able to deliver commercial MOCVD equipment is limited. Statistical data shows that more than 90% of global market share is occupied by Aixtron (Germany) and Veeco (U.S.A).

Industrial MOCVD equipment of Aixtron includes planetary type and close coupled showerhead type. The typical models of planetary MOCVD are G4 and G5. The volume of G4 and G5 is 42×2” wafers and 56×2” wafers. The largest size of substrate is 6 inches for G4 and 8 inches for G5. The susceptor of planetary chamber revolves slowly in combination with the rotation of air cushion supported plate, enabling rise of the radial flow of gas flux from center to edge. CRIUS and CRIUS II are typical close coupled showerhead MOCVD models, which technique originated from Thomas Swan taken over by Aixtron. The MO sources and gases are delivered into the chamber by massive close coupled showerheads. The epitaxial uniformity depends on the distribution of showerheads and the rotation of susceptor. The volume of CRIUS II is 69×2” wafers, and the largest size of substrate is up to 8 inches.

Aixtron’s planetary chamber (left) and close coupled showerhead chamber (right).

The typical models of Veeco TurboDisc series industrial MOCVD system are K465 and K465i, which volume is 54×2” wafers, and the largest size of substrate is 8 inches. The up-to-date model of MaxBright has multi-chambers with the total volume even up to 216×2” wafers. The technical feature of TurboDisc series lies in the patented unique high speed rotation technology. The rotation rate of the susceptor can exceed 1000 rpm. The uniform rate, temperature and concentration boundary layer above the susceptor can be tuned by adjusting rotation rate and chamber pressure.



Gas flow model in TurboDisc chamber

Besides Aixtron and Veeco, Nippon Sanso and Nissin Electric from Japan are important MOCVD equipment providers too, whose main market is in Japan. In recent years, there are more and more international equipment giants, such as Applied Materials, demonstrating increased interest in MOCVD equipment research and development.

As for the development trends of the MOCVD equipment, further increasing single furnace's epitaxy volume, which is beneficial to costs cutting, is still a promising development direction. Meanwhile, multi-chamber equipment is very likely to be one of the most crucial directions for raising production of the MOCVD in the future. For instance, Veeco's MaxBright employs a four chambers design. Another significant development trend is largest size epitaxy, which means to increase the size of the epitaxy wafer. The size of the wafer has been increased from the current main trend of 2 inches to 4, 6 and even to 8 inches. However, with the increasing size of the wafer, stress and warpage are becoming very serious problems for wafer yield. For that reason, in-situ monitoring ability of the epitaxy equipment is still improving.

3.2 Epitaxial growth of LEDs wafer

Section Contributor: Maosheng Hao

Epitaxy is the growth of a monocrystalline layer on a monocrystalline substrate or on a monocrystalline underlayer with different composition or different dopant. The term epitaxy comes from the Greek: epi "above" and taxis "in ordered manner", it describes a kind of interface between a thin film and an underlayer. Because the underlayer acts as a seed crystal, the deposited film takes on a lattice structure and orientation identical to or similar to those of the underlayer. This is different from other thin-film deposition methods which deposit polycrystalline or amorphous films, even on single-crystal substrates.

A simple light emitting diode (LEDs) could just be a pn junction with two electrodes, which could be fabricated by using liquid phase epitaxy (LPE), an old epitaxial growth technique. However, such a simple structure could not provide higher internal quantum efficiency (IQE) for modern applications such as LCD backlighting and general lighting. In order to improve the IQE of LEDs, a sophisticated multiple quantum wells (MQW) active layer sandwiched between the n type and p type layers, is inevitable. There are several other functional layers or superlattices in the modern LEDs layer structure, for example, a layer under active layer helps to spread the injection current; a layer under active layer helps to control the stress in the active layer and at the same time acts as the electron reservoir; a layer over the active layer helps to stop the electron overflow. These layers might be a binary compound, a ternary compound or a quaternary compound of very high purity. The thickness of some layers must be controlled with dimensions of the order of ten to several hundred angstroms. The interface between the neighboring layers must be very sharp, implying that the composition transition region must be controlled within a few angstroms. Therefore, a high brightness LEDs structure cannot be made without the modern epitaxial growth technology.

Several epitaxial growth techniques are available for the growth of semiconductor optoelectronic devices. Both molecular-beam epitaxy (MBE) and metal-organic chemical vapor deposition (MOCVD) can meet the requirements for the most advanced semiconductor structures. The LEDs manufacturers ubiquitously choose MOCVD rather than MBE. It is because MOCVD is more flexible and more scalable than MBE. Red, Orange and yellow LEDs are consist of AlGaInP system. Blue and green LEDs are consisting of AlGaInN system. It is difficult to grow alloy containing P by using MBE, it is even more difficult to grow more volatile AlGaInN by using MBE.

Another important issue for the epitaxy is the choice of the substrate. The substrate is the base, on which the epitaxial layers are built. At In molar composition of 50%, AlGaInP is lattice matched to GaAs. GaAs substrate is the best choice for AlGaInP-based red LEDs.

The growth of AlGaInP-based red LEDs on the GaAs substrate does not suffer from lattice mismatch. It is not difficult to get AlGaInP-based red LEDs structure with very high crystalline quality. The IQE of the red LEDs is already very high. There is not much room for the further improvement. On the other hand, the band gap of GaAs occurs at 870 nm so that red light (~620 nm) emitted downward from active layer is absorbed by GaAs substrate. The extraction efficiency of this type red LEDs is quite low. In order to improve the extraction efficiency of AlGaInP-based red LEDs, a distributed Bragg reflector (DBR) is included between the substrate and the LEDs structure. However, the DBRs could only partially solve the problem due to the fact that the excellent reflection of DBRs is limited to vertical incident light. These drawbacks are avoided by pyramidal micro reflectors and thin-film (TF) structures, which utilize metal to metal wafer bonding techniques followed by substrate removal. OSRAM Opto Semiconductors R&D lab has set a new record with an electro-optical efficiency of 61% for red high-power LED. The 1 mm chip housed on a laboratory package emits at a wavelength of 609 nm and has achieved a record value of 201 lm/W at an operating current of 40 mA. At a typical operating current of 350 mA, its luminous efficacy is still an impressive 168 lm/W.

For the GaN-based blue and green LEDs, the choice of the substrate is not that easy. Due to a very high volatility, it is very difficult to get GaN bulk crystal. So, the foreign substrate has to be selected for GaN-based LEDs. It is easier for GaN to be grown along (0001) direction. The atomic structure of GaN (0001) surface has hexangular symmetry. For epitaxial growth, the atomic structure of substrate must be similar to that of the epilayer. Therefore, Si (111), sapphire (0001) and SiC (0001) with hexangular symmetry have been extensively explored as the substrates for GaN-based LEDs. It is also because these substrates are quite stable at GaN growth condition (above 1000 ℃ and in NH3 atmosphere).

Growth of GaN on Si substrate is much more difficult than that on SiC or sapphire substrate. Due to big mismatch between GaN and Si substrate, tensile stress accumulates within the GaN epilayer during growth and also during cooling down from the growth temperature, which easily causes the epilayer crack. A lot of efforts have been made to overcome this problem because Si substrate is cheaper and available with big size. Lattice Power, a Chinese company spun out from Lanchang university, has announced the production of high power LEDs chips by using Si substrate with efficiency of 120 lm/W. This efficiency is very close to that of LED chips made on sapphire substrate with a lateral structure. It is said that if the LED wafers could be grown on 8 inch Si substrate and processed in 8 inch process line already available in most existing wafer fabs, it would be very competitive.

Compared with sapphire, SiC has less lattice mismatch to GaN. GaN-based LEDs structure grown on SiC substrate could have a smaller dislocation density and a higher IQE. SiC also has a higher thermal conductivity than sapphire. It is another benefit for GaN-based LEDs grown on SiC substrate. But, only Cree produces industrial LEDs by using SiC substrate in the world because SiC substrate is much more expensive than sapphire substrate. Cree manufactures SiC substrate itself. And as the only player for so long time, it might be very difficult for others to break Cree's patent barrier. Cree has published a lot of champion data for the emission efficiency of GaN-based LEDs. The most recent one is 128 lm/W at 350 mA, 85°C or 143 lm/W at 350mA, 25°C in cool white (6000K).

Sapphire is the most popular substrate used both in research and in industry. Most major breakthroughs in epitaxial growth of GaN were made by using sapphire substrate. Except Cree, almost all major players are using sapphire substrate to make their GaN-based LED production. In 1986, high-quality GaN with a mirror surface was grown by MOCVD for the first time using a low-temperature buffer layer on sapphire. In 1989, it was found that p-type GaN can be obtained by using Mg doping and followed by an activation process. Since then, the industry has witnessed a steady growth on GaN-based LEDs business. In 1993, Nichia produced the first GaN-based blue LED with brightness of candela level in the world, and shortly after, Toyoda-Gosei, another Japanese company, also started mass-production of GaN-based LEDs. These two Japanese companies are still leading the research and development in epitaxial growth techniques of GaN on sapphire. It is worth to mention that these two Japanese companies are using custom-designed MOCVD reactors for their production, which can be operated at atmospheric pressure. The rest of LEDs manufactures are using commercial low-pressure MOCVD reactors from Aixtron or Veeco. It is said that the higher growth pressure, the better crystalline quality of GaN epilayer.

Anyway, The GaN-based LEDs structures grown on foreign substrates are far away from perfect. The dislocation density in current commercially available GaN-based LEDs is in the order of 108cm-2. It is very fortunate that emission efficiency of InGaN is not as sensitive to the dislocation as that of AlGaInP. Therefore, we could make bright GaN-based LEDs on the foreign substrates. On the other hand, it is meant that there is still room for IQE improvement of GaN-based LEDs. A big performance jump on GaN-based LEDs will be achieved when low-price GaN substrate will be commercially available. The GaN substrate grown by hydride vapor phase epitaxy (HVPE) is already available. Due to its high price and low productivity, it is only used to produce GaN-based lasers. The growth of bulk GaN by using ammonothermal method is now under development. This method requires a relative low growth temperature and low growth pressure. And its scalability is good. Therefore, high performance GaN-based LEDs will be manufactured with GaN substrates in the near future.

Most LEDs manufactures are involved in epitaxial growth as well as in chip process. There are very few LEDs wafer producers willing to sell LEDs wafers to others. It is difficult to get the accurate data for LEDs wafer capacity worldwide. The data in table 3.2.1 is from IMS Research's Q2'12 Quaterly GaN LED Supply and Demand Report. These data are estimated according to the numbers of MOCVD tools installed by the region. As pointed out by IMS Research, China is currently dominating the MOCVD market, peaking at 92% of shipment for Q4’11. China is projected to take the lead in Q3’12 for LEDs wafer capacity.

In order to improve the die yield and increase the productivity of chip process lines, the wafer size is becoming bigger and bigger. The data in table 3.2.2 comes also from IMS Research. From this table, we cannot see the increasing of percentage for bigger size wafer during 2011. It is because, as pointed out above, most of MOCVD equipment shipped during 2011 were installed in China. And there are only a few Chinese LEDs plants, which just started switching from 2" to 4" at the beginning of 2012.

As for a summary, it is worth pointing out that currently LEDs wafer capacity already exceeds the demand due to China’s MOCVD stimulus program. Within last few years, MOCVD plants have put a lot of effort on increasing of the capacity of MOCVD for single run. With the debut of CRIUS II-L, Aixtron says it is the world's largest MOCVD reactor available with a 16x4 inch or 69x2 inch capacity, now it is time for both MOCVD manufactures and LED chip manufactures to put more efforts on die yield increase, and more important, on the increase of binned die rate, through the improvement of epitaxial growth uniformity.

	Total piece	China	Europe	Japan	USA	Korea	Chinese Taiwan
Q1'11	7,237,000	6%	3%	13%	6%	37%	35%
Q2'11	8,507,000	12%	3%	12%	6%	32%	35%
Q3'11	9,113,000	15%	3%	12%	5%	31%	34%
Q4'11	10,330,000	22%	3%	11%	4%	29%	31%

Table3.2.1 Quarterly 2" equivalent wafer capacity in 2011 by Region

	Q1'11	Q2'11	Q3'11	Q4'11
2"	80%	81%	82%	83%
3"	4%	4%	3%	2%
4"	15%	14%	14%	14%
6"	1%	1.1%	1.1%	1.2%

Table 3.2.2 Quarterly percentage of wafer capacity for different wafer size in 2011

3.3 The development of LED module and Chip

Section Contributor: Guowei Xiao

3.3.1 LED Module

Generally, LED module refers to an assembly of LED packages (components), or dies on a printed circuit board (PCB) or substrate, possibly with optical elements and additional thermal, mechanical, and electrical interfaces that are intended to connect to the load side of a LED driver. Power source is not incorporated into the device. When LED driver circuit is integrated with the LED module, it will be referred as light engine. LED packages assembled on PCB are called DOB (Device On Board) and LED chips on PCB are called COB (Chip On Board). In comparison with the DOB, the COB has advantages in smaller thermal resistance, lower in BOM (Bill Of Materials) cost. Using COB as single-core light source, the optical design for luminaries is also relatively easier and more efficient.

The U.S. Department of Energy released the roadmap of SSL (Solid State Lighting), in which both efficacy (in lm/W) and price (in $/klm) targets were released. The efficacy and price target for both LED packages and LED luminaries are shown in table 3.3.1.

Year	2011	2013	2015	2020
LED package lm/W	97	126	150	189
LED package $/Klm	12	5.1	2.3	0.7
LED luminaries lm/W	61	85	112	170
LED luminaries $/Klm	50	30	10	5

Table 3.3.1: efficacy and price targets for LED packages and LED luminaries

The lm/W gap between LED package and LED luminaries becomes smaller over years, meaning the light efficiency of luminaries increase by optimization of design. The smaller gap also requires the LED package matches the luminaries design for higher light extraction. Single core light source like the LED module is relatively better choice for optical designer than multi- light source on board.

This table also shows the price target of LED package, prices decrease dramatically after 2015, the year was predicted to be the take-off year for LED in general lighting. This decrease of price will be achieved by lumen up, and price down. The efficacy could not be tripled, then price down will be the bigger cause for the dramatic cost reduction of package. New architecture of LED package is necessary to realize higher lumen output and lower BOM cost.

Figure3.3.1 shows typical PLCC (Plastic Leadless Chip Carrier) LED package cost structure, including chip, leadframe (LF) and other packaging materials. To realize lower cost package, COB is a good direction; if LED chips or dies are directly bonded on board, it will spare the cost of leadframe, and also gain some flexibility of COB module design to match the dimensions and drive specification requirements. The current issues for COB are the no standards, and automatic equipments are not available to handle various COB. In comparison with DOB, the COB module also has cost advantages, by saving surface mount process of discrete devices. The cost factor is very important to trigger the take off of LED penetration in general lighting.

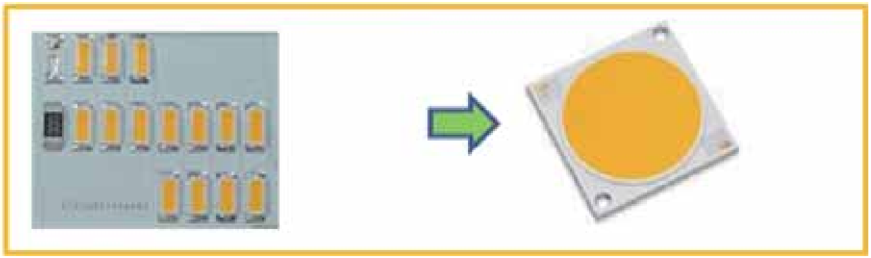


Figure3.3.1: Typical PLCC LED package cost structure

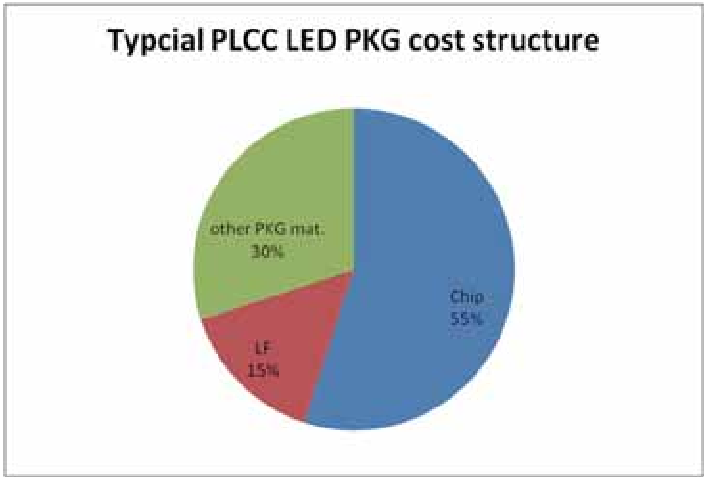


Figure 3.3.2: discrete devices on board versus COB

Figure 3.3.2 shows the DOB versus COB, currently more LED packagers are involved in COB manufacturing, to match simple assembly line of traditional luminaries factory.

COB products could be classified by substrates, one kind of substrate is PCB, generally metal-core PCB (MC-PCB) used, and the other main substrates are ceramic. MC-PCB is widely used in various products, because of lower substrate cost and easy handling during assembly process. Ceramic substrate shows significant advantages in reliability and much higher breakdown voltage performance. Citizen and Bridgelux in Japan are two leading companies in MCPCB-based COB products; Sharp provides COB products mainly based on ceramic substrates. Considering chip solutions, currently lower-middle power chips are mainstream, while high power chips solution is also used to realize very high lumen output on very limited light emitting surface; Luminus Devices provides this kind of high-power LED solutions.

Vertical integration of SSL industry chain is happening and will strengthen, chip makers will do more on chip level processing to easily release chip level package. Based on the novel chip level package, cost will be decreased and more function could be included on the package level, even on die level.

LED module is a clear direction for easier assembly for luminaire makers and high volume manufacturing requirements in the near future. The various dimensions of COB are until now the problem, and will be solved and standardized by luminaires requirements in the future.

3.3.2 LED Chip

In the LED industry chain, the epitaxial growth and chip fabrication are the components which not only mostly represent the technological level of enterprises and industry level of a country, but also involve the highest technical content and the fiercest patent competition. Meanwhile, the epitaxial growth and chip fabrication are also capital-intensive. In the entire terminal application products of LEDs, the share of the cost of LED chip is only about 10%, but LED chip is the core device, which emits light directly. Therefore, the performance and features of LED chip have direct impacts on light color and reliability of application products.

3.3.2.1Structure and Technological Process of LED Chips

On one hand, the manufacturing process and the structure option of LED chip determine the process parameters of LED epitaxial growth, on the other hand they influence the selection of packaging process and the performance of packaging devices. Therefore, the chip technology, which links epitaxy and packaging process, is an important component of the three links (extension - chip - package) in the manufacturing of LED devices. Currently, there are three common chip structures: conventional structure, flip-chip structure and vertical structure. Different chip structures will lead to different light-emitting efficiency and reliability of chip products and different choices of the packaging process. The technological process is relative with the chip structure. The appropriate process should be designed based on different chip structure. The introduction of advanced technology could effectively improve LED chips performance and reduce cost.

The technological process of LED chips has something to do with the design of the chips structure, as shown in Figure 1. The conventional structure: first, use dry etching to etch away certain areas of the P-GaN, active layer, and partial N-GaN, making the N-GaN bared. Second, produce P-electrode and N-electrodes in the P-GaN and the N-GaN regions respectively. Preparing a transparent conductive layer ITO on the surface of P-GaN is the technical feature that distinguishes conventional structure from flip-chip structure and vertical structure. Flip-chip LEDs also use dry etching to expose some regions of the N-GaN, and make the P-electrode and the N-electrode region in the P-GaN and N-GaN respectively. Unlike conventional LEDs, the flip-chip LEDs set a metal reflecting layer on the surface of the P-GaN, instead of transparent conductive layer ITO. And flip-chip LEDs generally need connect the flip-chips to the base through the metal bump. The vertical structure LED: first, produce the metal electrode on the surface of P-GaN; second, connect to the base of conductive transfer through bonding; third, remove the epitaxial substrate connecting to the N-GaN by methods such as laser lift off; fourth, N-electrode is produced on the surface of N-GaN.

In general, the chip electrodes can be achieved by metal sputtering or metal

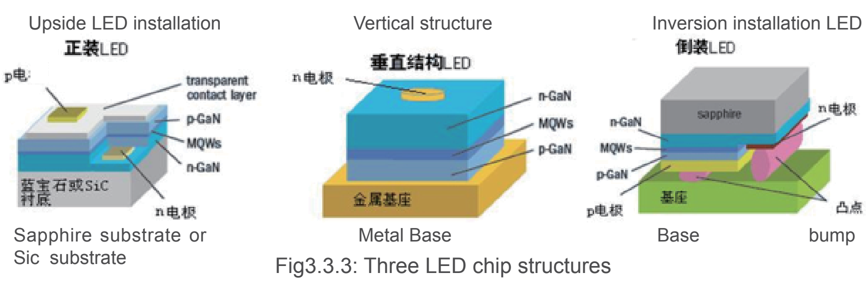


Fig3.3.3: Three LED chip structures

vapor deposition process, and the chip layout and electrode pattern can be realized by combining photolithography process to etching or lift-off process. However, the above is only the introduction of simple chip structure and general processes. The actual design of the LED chip structure and process is a quite complex project, involving the design of the electroluminescent structure for the purpose of improving injection efficiency and optical efficiency, the design of the structure for light extraction, and electrode design targeting higher optical output efficiency.

3.3.2.2Current Development of LED Chips

At present, the global LED chip market is divided into the following three camps:

The first camp are big LED manufacturers in Europe, the United States and Japan, including Philips Lumileds, Osram, Cree, Nichia and Toyoda Gosei — the top Five global LED players — plus Sharp, Toshiba and Panasonic. Three manufacturers in Europe and United States mainly produce high-power chips for lighting with mass production up to 140-150lm/W. But their products are expensive. For example, Philips Lumileds of Netherlands has always insisted on manufacturing high-power flip-chips. Osram of Germany and Cree in the United States mainly manufacture vertical structure high-power chips. LED manufacturers in Japan take into account both the backlight market and consumer electronics market. Their chip products contain small- and medium-power series and high-power chips. The strength of Japanese manufacturers represented by Nichia in the lighting field cannot be underestimated.

The big LED manufacturers in the first camp have strong R&D, production and sales capacity. In particular, they own the huge number of the upper patents related to the core technology and authorize each other to form a patent pool barriers, firmly occupying the leading position of LED industry and guiding the development trend of LED lighting technology.

The second camp includes the LED manufacturers in South Korea and China Taiwan with Samsung LED, with LG Innotek and Epistar as key representatives. The manufacturers of this camp have a complete industrial chain of consumer electronics. Their chip products are for backlight and consumer products, mainly small and medium power dress chips. Their high power chip technologies have a slight gap compared with big European and American manufacturers. However, with the rapid development of the general lighting market, the high-power chip technologies of the second camp manufacturers have greatly improved. For example, the world's largest LED chip manufacturer Epistar currently has its 130-135lm/W high-power chips in mass production, and its quality and performance enjoy equally excellent reputation with its small and medium-power chips.

The third camp brings together the chip manufacturers in mainland China. Mainland China is late in LED chip technology, and its technological capacity and R&D capabilities lags behind big international players. Mainland China mainly manufactures mature, low-cost and low-power conventional chips. The chip technology has made great progress in mainland China's under strong support of the Chinese government and joint efforts of technical elites. For example, the high-power LED chip independently developed by APT Electronics reaches the internationally advanced level with mass production level over 130lm/W. Xiamen Sanan's low-power conventional chips are comparable to Epistar chips. However, the price of mainland China's chips is lower than that of Taiwan and international manufacturers.

In fact, with vertical integration of manufacturers in the LED industry chain, major plants' chips are mainly used for their own packaged devices or lighting products, and their external sales gradually reduce after the golden period of LED high power chip in 2009 and 2010.

According to the data of Chinese Industry Research Network (http://www.chinairn.com), up to the end of 2011, the global total of MOCVD reactors is 2547. Estimated by the production of 2'' high brightness blue LED epitaxial wafers, it is expected that about 127.35 million chips will be manufactured each year, which is equivalent to about 200 billion 40mil high-power LED chips. According to the statistics of New Century LED Network (www.ledth.com) and The First LED Network (www.d1led.com), the output value of global LED devices will reach $17.5-18.3 billion in 2012 and the LED chip output value of mainland China will reach $8.7 billion.

There was a global investment boom in the LED industry in 2009 and 2010, especially in mainland China. Under the support of the Chinese government, the investment in LED upstream epitaxy and chip manufacturing in the mainland China became crazy and lasted until the first six months of 2011. Mr. Ross Young, senior Vice President of IMS Research said that LED chip production capacity in 2011 already meets the demand of 2014 and excessive capacity of LED chips occurred in the second half of 2011.

Under the double impacts of LED chip overcapacity due to irrational investment and too high expectations of LED backlight market, the price of LED chip encountered a sharp decline. According to the statistics of New Century LED Network's (www.ledth.com) in Table 1, the price had 13.3% reduction for high-end 0.06W low-power chips, 48.6% reduction for low-end chips and 18.2% reduction for high-end 1W chips and 48.7% reduction of low-end 1W chips in the whole year in mainland China.

The performance-price ratio of LED chips is under continuous improvement with the reduction of LED chip price, improvement of technology and production capacity of LED chip and the decline of the price of raw materials. Coupled with advanced packaging technology, the record of the highest luminous efficiency of white LED is constantly updated and with rising lm/$ value. At present, the R&D records of highest light efficiency is 263 lm/W released by CREE in 2012, while the Q4 performance-price ratio of SMD5630 mid-power conventional chip products exceeds 700lm/$ in 2012. It is expected that the originally expected 1000lm/$ target in 2015 will be achieved in 2013 according to this development trend.

Power	Category	Brightness profile	Average price ($ / K)				Year decline
			2011Q1	2011Q2	2011Q3	2011Q4	
Small power	Low-end	2.5-4.5 lm	38.1	28.9	22.6	19.6	48.6%
	Mid-end	4.5-6 lm	62.3	52.5	43.3	36.8	40.9%
	High-end	6-8 lm	107.5	104.1	95.2	92.7	13.3%
High-power	Low-end	70-90 lm	1101.2	819.1	641.5	564.8	48.7%
	Mid-end	90-110 lm	1685.2	1455.4	1185.5	973.6	42.2%
	High-end	110-130 lm	2156.2	2005.4	1860.2	1762.8	18.2%

Table3.3.2 Statistics of the reduction of chip price in 2011 (data from www.ledth.com)

3.3.2.3 Prediction and Prospects of the Development Trend

The future development of LED chip will show the following characteristics:

First, vertical integration of the industry chain is accelerating, and the profit of chips is keeping declining. Major LED manufacturers are carrying vertical integration at different degrees, ranging from the substrate material, epitaxy, chip, package to the application products, and the integration speed will be quicker in the future. The performance-price ratio will become an important indicator for application products. It is expected that, under the pressure of decreasing cost, the profit margins of LED chips will go down and enterprises simply depending on manufacturing and sales of LED chips will encounter difficulties to survive. Thus, it will accelerate the pace of vertical integration.

Second, conventional structure will still dominate low-power chips. The simple conventional structure will continue to be the main form of low-power chips driven by lower lm/$. To reduce the thermal resistance of the conventional structure LED products and improve its reliability, optimizing the solid crystal glue materials and the technology will become a hot research topic.

Third, flip-chip structure will become the trend for mid-power and high-power chips. In addition to Philips Lumileds and Jingke (APT Electronics) who have been promoting the flipchip LED, other manufacturers including Cree are developing the flipchip technology and launching related products. This is mainly because the flip-LED products exhibit good thermal capacity and high reliability, and a single chip can be used under a higher power.

Fourth, chip brightness will continuously rise. According to the prediction of U.S. Department of Energy, the efficiency of cool white LED products will rise from 135 lm/W in 2011 to164 lm/W in 2013 and 190 lm/W in 2015.

Fifth, the chip manufacturing costs will decrease with the increase of dimension size. With the dimension size increasing from 2" to 4" or even 6", it is expected that there will be some adjustment of relevant manufacturing processes and equipment, and that the manufacturing cost of single chip will go down.

3.4 Global LED Package Manufacture Business Strategy

Section Contributor: Chunpeng Hsu

With 2012 ending, the revenue of global LED package manufacturers can be estimated and reflect the market of this year. Many consider 2012 as “The first year of LED lighting year”. As the LED backlight market is close to maturity, LED chip and package companies have plans to develop the LED lighting market. The policy of phasing out incandescent lamps launched by China, Korea, Japan and other Western countries, and the rising environmental awareness encourage the development of LED lighting market. Although promising to become a very huge potential market, the corresponding revenues will increase very slowly. According to Strategy Unlimited estimation, the global LED revenue CAGR is about 10% from 2011 to 2016. The LED lighting has many different business models depending on their own technologies and characteristics, and regionalization and localization are also key factors. We will discuss the different strategies in a next session.

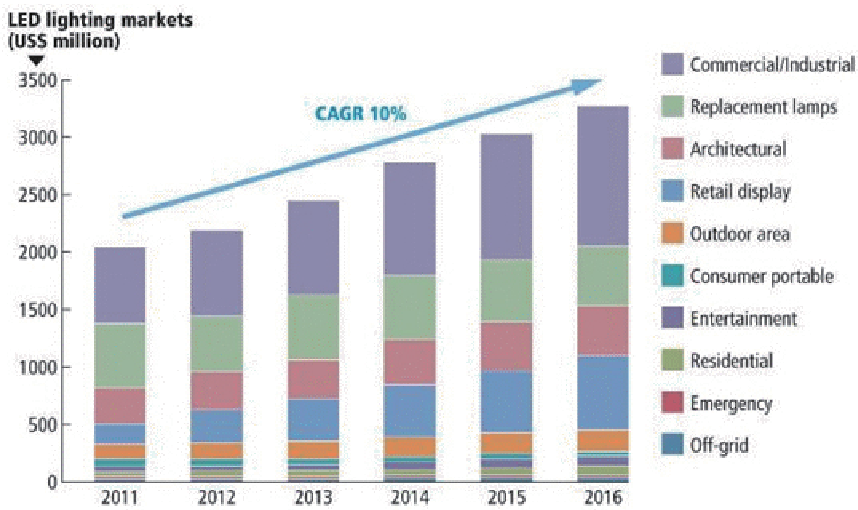


Figure 3.4.1: Strategy Unlimited LED revenue CAGR

According to the Strategy Unlimited HB-LED report, the global top 10 LED package companies in terms of revenue are : 1.) Nichia, 2.) Samsung LED, 3.) Osram Opto Semiconductors, 4.) LG Innotek, 5.) Seoul Semiconductor, 6.) Cree and Philips Lumileds (same rank), 7.) Sharp, 8.) TG, 9.)Everlight. We can distinguish three main business strategies from those top 10 LED package companies. First class: the company focuses on improving LED performance and patent strategy, such like Nichia, TG, and Cree. Although they have their own LED lighting products or merge the down-stream lighting fixture company, they have no branding plan to prevent conflicts with their customers. Although Nichia set up sales centers in Hongkong, Shenzhen, Shanghai and Beijing and production base in Songjiang of Shanghai with total investment up to RMB800 million in China, they still focus on LED package. Toyoda Gosei and Showa Denko Electronics (SDK), have announced plans to form a joint venture in Japan to manufacture and market GaN-based LED chips and they also focus on chip development. Second class: based on the TFT-LCD backlight business, there is vertical integration within mother company like Samsung LED, LG Innotek and Sharp. In the past, these companies paid attention to LCD backlight, but developed the LED lighting brand, taking advantage on parent companies reputation. Third class: the lighting company and LED chip or package companies merge or create a joint venture like Philips Lumileds, Cree and Ruud.

Beside the three business models, more regions and local LED package makers or lighting players have more flexible and smart strategy because they do not have enough resource to create joint ventures, so they coordinate the LENS, driver IC, lighting fixture assemble, even the LED chip company to make a low-cost lighting solution. The advantage is that every component or assembly company was already engaged in their own field for many years, so they develop the best production methods and the lowest costs; local LED package makers do not need purchase new machine and equipment, not bearing supplemental depreciation and amortization costs because the component and assemble factories have their own equipments, it is also unnecessary to set-up the assembly line and go through a learning curve. Different from the vertical integrated business, it is a horizontal supply chain. Sometimes chip vendor leads the business and sometimes does driver IC supplier, depending on their technology. Even the assembly factory could purchase the LED chip by itself to match their lighting product because they have their own R&D team and customer. Many well-known lighting companies also follow this business model to reduce cost. Thus, some LED package manufacturer are back to develop lighting engine and promote single lighting source to face complicated business model to avoid cost increase. The big problem of the horizontal supply chain is the quality issue; every government should enforce the after-market mechanism.

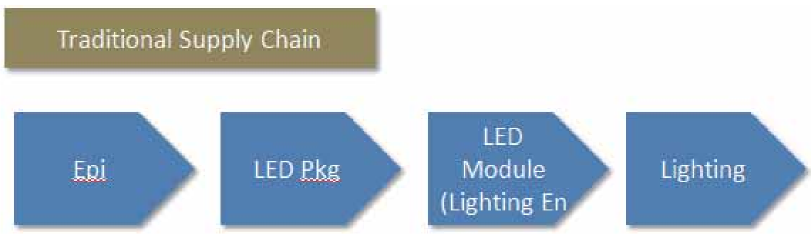


Figure 3.4.2 : Traditional Supply Chain

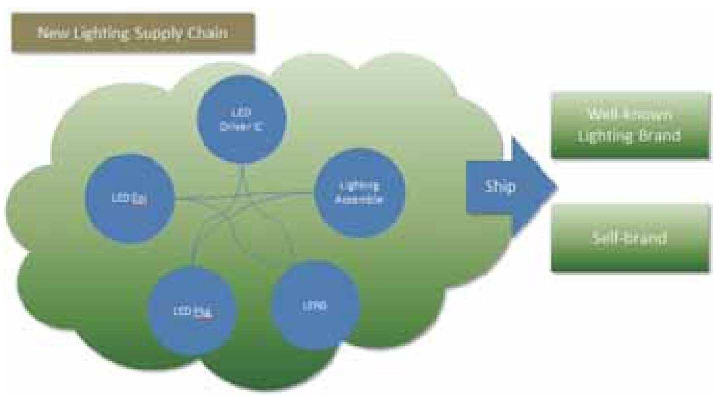


Figure 3.4.3: New Lighting Supply Chain

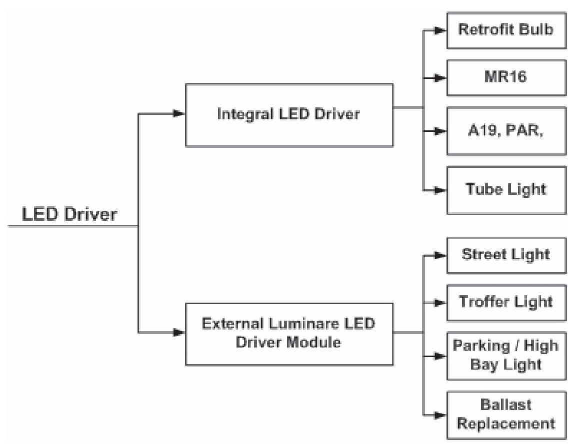
Since people know that LEDs have energy-saving effect to reduce the carbon footprint, LED lighting becomes a large potential market, and prices are becoming affordable. With LEDs exhibiting long-lifetime and prices going down, LED package manufacturers should devise what is the next generation lighting solution and provide the best quality product for this world.

3.5 Global SSL Outlook on LED Driver

Section Contributor: Jerry Zheng

By its physical nature, LED is a low voltage semiconductor device converting electrical energy into light. The brightness increases with the increasing current through LED. LED driver is an essential part of LED lamp. It provides a regulated DC current to the LED or LEDs from an AC or DC power source. The LED driver plays a critical role in delivering the best cost-performance of LED lamp in the SSL market. It has been often referred to the “weakest link” in the LED lighting system. The life-time, quality of light and the lumens performance are directly impacted by the characteristics of LED driver.

LED drivers can be classified into two categories: Integral LED driver and external luminaries LED driver module. The “external luminaries LED driver module” means that the LED driver can be easily separated from the LED emitter module, such as street light LED driver. Normally, the external LED modules are the high power modules from 25 up to 400W. The integral LED driver is built in with LED emitter, and it cannot be easily separated, such as A19 retrofit lamp. Normally, the required power is less than 25W.



Up to now worldwide, the external LED driver module is more reliable, and well established with high quality manufacturing system and high reliability. The price is also slowly decreasing while volume increases. Now, retrofit LED bulbs are emerging as a high volume market, expected to grow as devices prices decline sharply. More and more LED lighting suppliers have been more focused on the retrofit market. So, this section of LED driver outlook mainly focuses on the integral LED driver and the driver ICs. The purpose is to give a brief outlook of LEDs driving technologies and IC controllers employed in residential and commercial lighting.

3.5.1 Overview

Solid State Lighting (SSL) based on Light Emitting Diodes (LED) approaches its maturity as technology. With constant LEDs performance improvement - increasing efficacy, getting better quality of light and reducing the cost - power management went through its evolutionary cycle and now reaches a maturity stage when literally dozens and dozens of semiconductor companies deliver quality IC controllers and reference designs to support massive market penetration of SSL.

LED efficacy and Driver Power Requirement

The required power from LED driver keeps decreasing as LEDs' lumens per watt keep increasing. More efficient LEDs allow looser space restrictions for retrofit LED bulb. This creates better form factors. Meanwhile, the number of LEDs per LED driver ICs will decrease too. The targeting equivalent LED driver power by 2015 is expected to be reduced to:

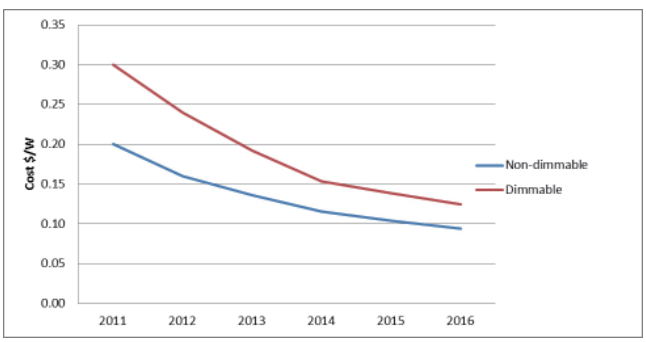
- 45W incandescent, target equivalent LED driver power (< 5W)
- 60W incandescent, target equivalent LED driver power (< 7W)
- 100W incandescent, target equivalent LED driver power (<10W)
- 50W incandescent, target equivalent LED driver power (<15W)
- MR16 incandescent, target equivalent LED driver power (< 5W)

Conversion efficiency is an important characteristic of LED drivers as it directly influences the energy consumption, thermal management needs and reliability. The current efficiency expectation is shown in the table below.

Power Level	Expect Power Consumption
>15W	90%, or < 2W power consumption
>10W	85%, or < 1.5W Power consumption
>5W	80%, or < 1W Power consumption
< 5W	< 0.5W Power consumption

Cost

Cost reduction is one of the major drivers for wide adoption of SSL. Cost-effectiveness is always the final successful factor. In the past years, the price of LED lamp significantly dropped. The LED driver keeps on reducing over 20% from 2010 to 2011. Especially for the non-dimmable LED driver, the ODM price has been reduced over 20%. With the volume increasing, the LED driver price is expected to drop down to 0.1 USD per watt, making it close to CFL driver price. Currently, the cost of dimmable LED driver is much higher than non-dimmable LED driver. The current cost of LED driver is about $0.4/W for dimmable LED driver, and is expected to be reduced to $0.1/W by 2015.



Quality of Light and Driver

Quality of light is the hottest subject in 2012. The quality of light provides a first impression to the user. So, when we design the LED driver, user experience and quality of light should be our top priorities. The quality of light and the performance of lumens are directly impacted by the driver performance, including driver efficiency, current regulation, and dimming control. Solutions to produce high efficiency drivers depend on less heat generation and longer lifetime of the drivers. The market for integral SSL lamp is competing with that of CFL lamp at cost level. The latest LED driver can resolve the issue of small size and cost, but the quality of light and user experience is not improved. In the long run, this impacts the LED lighting's application on the market.

The qualities of LED drive are measured by LED current ripple peak to peak ratio to average. LED ripple current is not just another technical parameter. Frequency and amplitude of LED ripple current, more known as flicker, is a factor concerning human health. Making LED light flickerless requires more sophisticated architecture of drivers (two stages instead of one) and more filtering. It should be paid attention to the products which claim to have no electrolytic capacitors. That would mean high flickers almost universally. Today we do not have any standard for acceptable flickers, though an IEEE committee is working on it. That situation benefits manufacturers who have higher flickers at lower driver cost.

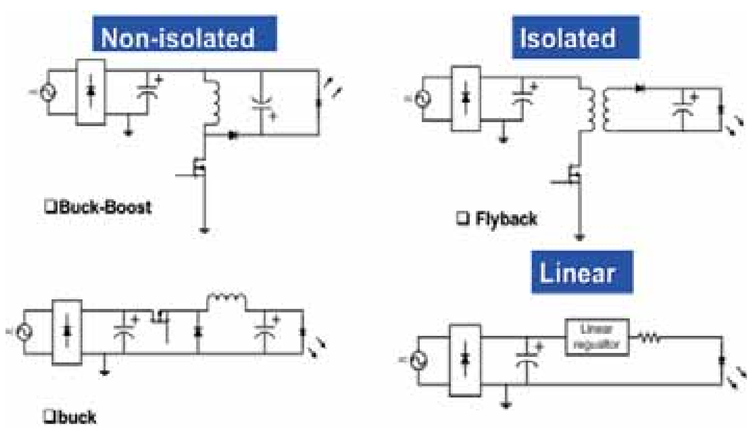
Overall, it is expected to have new topology and architecture to achieve the best cost performance, and to be "Simple, Reliable and Flexible".

- High switching frequency to allow small size of magnetic components
- Elimination of the electrolytic capacitor
- High efficiency > 90%
- Meeting the harmonic requirement (Refer to IEC61000-3-2 Class C).
- Small enough in size to fill in the cavity of E27 socket.
- Lower EMI noise
- Lower ripple current of LED (< 30% under any LED current regulation frequency)

3.5.2 Power Conversion Topologies

AC-direct LED driver is the most simple topology. AC-direct LED driver is used when the power source is directly supplied to LEDs without converting the voltage and current. It provides the lowest cost and simplest solution to the LED driver. The challenges for AC-direct LED lamps consist in the quality of light, efficacy, and tolerance of LEDs. A simple constant-current LED controller is required to regulate the LED current. There are opportunities for improvement in the quality of light and overall efficacy. Other popular topologies and architecture include:

- Low-power LED driver circuit
  Isolated solutions: Single-stage flyback, Forward, 2-stage boost + flyback;
  Non-isolated solutions: buck, boost, buck-boost and SEPIC, etc.
- For the high-power LED driver, the resonant controller has been widely used since it can achieve high-efficiency. But the components count and size present a challenge.

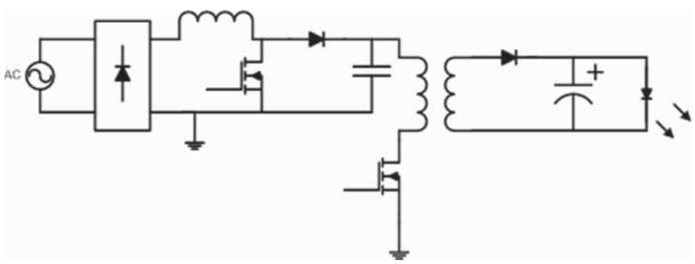


Currently, two dominant topologies for these converters are used almost by every manufacturer: buck for non-isolated and flyback for isolated. In flyback topology, the LEDs are connected to the secondary side of the transformer while IC controller is predominantly connected to the primary side, and that requires the implementation of a regulator having a feedback signal traveling across the isolation barrier. The off line isolated or non-isolated LED driver will always have an AC/DC rectifier and is followed by a DC/DC current source.

The driver is called one stage if this DC/DC is a one stage converter, or two stages driver if DC/DC converter has two stages.

The single-stage LED driver is simpler and normally has lower cost than 2-stage LED driver. It is widely used in the application such as TRIAC dimmable LED lighting designs; residential Retrofit LED lighting drivers for such as A19 (E27/26, E14), PAR30/38, GU10, MR16, BR; down and architectural wall LED lighting drivers; sconces, pathway and overhead lighting drivers. The main concern regarding the single-stage LED driver is the output current ripple. Practically, the output current ripple cannot be reduced below 5%. This imposes severe limitations in many applications that require the so-called “zero-ripple” LED drivers. These drivers are usually used for task lamps, office lamps, and places that are close to human activities and need to illuminate for a long time. The single-stage LED driver is also weak in terms of rejecting AC line transient and distortions, which may cause undesirable light flicker or interruption if AC voltage fluctuates.

Two stage LED drivers addresses the issues of single-stage LED driver by adding a boost front-end converter. The front-end circuit handles the input fluctuations and disturbances. It then delivers a stable power to the flyback converter. Because its output voltage is stable, it allows the flyback converter to control the output ripple current to the extent it can be reduced to close to zero. Since the flyback converter does not directly interface with the AC input, the output regulation is more stable under AC voltage fluctuation conditions. The figure below shows a representative circuit with a 2-stage controller iW3616 designed by iWatt. Similar topology of two-stage driver can also be found by Cirrus Logic.



3.5.3 Lighting Control

One of the basic requirements for SSL lighting is to provide dimming. It can be done in many ways, including a wireless intelligent control of the LED driver. The capability of achieving high quality dimming control enables better LED lighting performance than the CFL lighting. The complete dimming control system includes

1) The operator interface for the user to perform the dimming
2) The transmission of dimming control signal to the LED current control module
3) The receiver in the LED current control module receives and decodes the signaling
4) he lighting control unit that converts the dimming control command to the actual light output
5) The feedback to the commander to perform the transmission of status reporting and monitoring information

In reality, most dimming control systems or modules implement a subset of the control functions described above. These dimming control systems are used in different environments and show many limitations and challenges. Therefore, it is more realistic to differentiate these dimming control methods and form separate research areas. Typical dimming control areas can include:

- Retro-fit TRIAC dimming
- Analog control, like 0-10V dimming
- Digital control (it can be further divided into sub-categories based on the form of message links: wired; wireless (or RF); power line communication)

TRIAC Dimming Control

Currently, the dominant legacy remains dimming using existing infrastructure with wall TRIAC dimmers. These dimmers were designed for incandescent bulbs for a total 300W, 600W or

1000W power. Needless to say that, if a retrofit LED bulb is used instead of incandescent and no other bulbs are turned on, the wall dimmer will work out of specifications, producing unwanted turns on and off of the TRIAC during the cycle (flickers). To make SSL lighting compatible with legacy wall dimmers (in every possible implementation) LED drivers are delivered as dimmable; though non-dimmable exist too to reduce the cost. The challenges imposed on the TRIAC dimming method are both on the dimmer impedance matching and stable light output control.

The TRIAC dimmers are built to work with resistive load that is within certain range of resistance of incandescent bulbs. The LED driver has to control its dimmer interface to be not only resistive, but also within certain range of resistance. If the impedance is too high, the dimmer cannot maintain its conduction and the driver can lose the input dimming phase-cut information. Then the light output control loses its ground. Further requirement of input impedance is the consistence. Unstable resistive interface can also create unstable matching between the driver and the dimmer. Even small amount of mismatch can generate lighting control command change. Because of the fast response of LED light output, these changes are eventually visible to the users.

The light output control is also challenged by large input ratio, THD requirements, and output current stability at low dimming level. It has been widely accepted that this generation of LED driver has difficulty in stabilizing the light output below 5% dimming, especially facing hundreds or even thousands of different dimmers. Some dimmer can be very unstable at lower power ranges, which cannot generate the output as low as 10-20V, or be asymmetrical between the positive and the negative AC polarities. This imposes a limitation on the current control driver design due to the trade-off between efficiency, size and compatibility.

3.5.4 System Integration on “LED driver in Package”

To improve reliability and manufacturability, system integration is the trend. The Controller, Power Switch, and Magnetics can be integrated into a single package or module. Several LED driver suppliers propose the solution of “LED driver in Package”.

Monolithic integration has enabled unprecedented levels of miniaturization, cost reduction, and reliability in microelectronics. Like the majority of other power converters, LED drivers are traditionally built largely in discrete component technology. Controllers and power semiconductors integrated in one package are state-of-the-art, but power passive components are by and large discrete. The conventional power passive components are bulky, have different form factors and therefore are still suited for high density packaging. By introducing passive components as standard building blocks with the same form factor, more compact LED driver assemblies can be built in. Integrating several components into one is expected to increase reliability of the system. Small passive components can be integrated into the printed circuit board of the driver, further reducing the number of components.

3.5.5 Summary

Over years, the LED driver for integral retrofit bulb will be more simple, reliable and flexible. It enables to drive the high-voltage LED and low-voltage effectively. The quality of LED driver still has the potential to improve. The new architectures and topologies are to be upgraded in order to simplify the LED driver design and to boost the SSL lamp market.

Chapter IV:

Market acceptance and forecast

Chapter Contributor: Jed Dorsheimer
Other Contributor：Yuan Fu

Executive Summary

Today's global economy is at a crossroads. To drive growth, we must expand and exploit the emerging markets while creating greater wealth in the inhabited regions of the world as well. The fuel for this growth is energy, but it begets the political firestorm of reducing energy dependence in many countries. In short, energy has become today's modern currency.

As nations strive for energy independence to bolster their trade balances and promote growth, we see the move towards energy efficiency in motors, networking, and lighting in particular playing an increasingly important role. As we seek at mitigating electricity generation and consumption, lighting stands out as easy to pick hanging fruit, given the low electrical to optical conversion rates of most lighting technologies. We calculate that 17% of the world's purchased electricity is consumed by lighting and the overwhelming majority is considered inefficient. Further, as incumbent lighting technologies seem unable to increase luminous flux light quality, they are becoming more and more unnatural compared to sunlight. We believe the trends towards solid state lighting (SSL) will be key to easing these burdens.

While we remain convinced of the inevitable trend of solid state lights to replace inefficient incumbent technologies, it is clear that the industry is experiencing its second major cyclical downturn. If we take a step back, we believe this is perhaps the best thing that could happen. Why? For all the pundits that were hoodwinked into believing there would be a perfect transition between backlighting (i.e., Second Cycle) and general lighting (i.e., Third Cycle), they forgot about a major variable: cost. We need a downturn to allow costs to naturally move downward. The rate and the slope are largely determined by the overbuild, and such an overbuild is presently experienced. The downturn depth and duration will hinge upon adoption of SSL, which we believe will continue to grow but begin hitting key inflection points in 2014, driven by policy and price points.

Analysis

4.1 Lighting

Our original study, The Third Cycle, was an industry first: the first bottom up worldwide lighting analysis. However, we don't discount the value of a top-down approach similar to what Navigant and the DOE published in 2004. We understand the limitations of both approaches and believe the true figures lie somewhere in between. This version is our attempt to bridge this gap.

	New Sockets (M)	Previous Sockets (M)
Residential	15,062.1	18,475.8
Commercial	6,465.1	8,481.9
Industrial	1,171.0	2,810.6
Outdoor	1,366.5	6,855.8
Total	24,064.8	36,624.2

Figure 4.1: Lighting market Source: Canaccord Genuity

Our fundamental elasticity model is unchanged as are our pricing, efficacy and other assumptions, as those still appear relevant from our May update. As such, overall

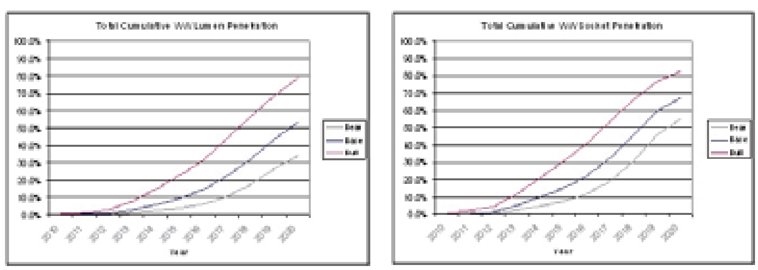


Figure4. 2: Lighting penetration

penetration does not change much. We conclude that LED lighting will penetrate between 54.8% and 82.5% of total sockets and produce between 33.7% and 78.7% of the world's lighting output, measured in lumens, by 2020.

These lighting adoption curves create cumulative LED demand of 73.1B and 167.0B square millimeters of yielded, packaged epi. We believe the greatest single yearly figure should occur around 2018/2019, and could be between 19.5B and 24.4B mm2, a 20x increase from 2011 lighting demand, which we estimate will be only 1B mm2.

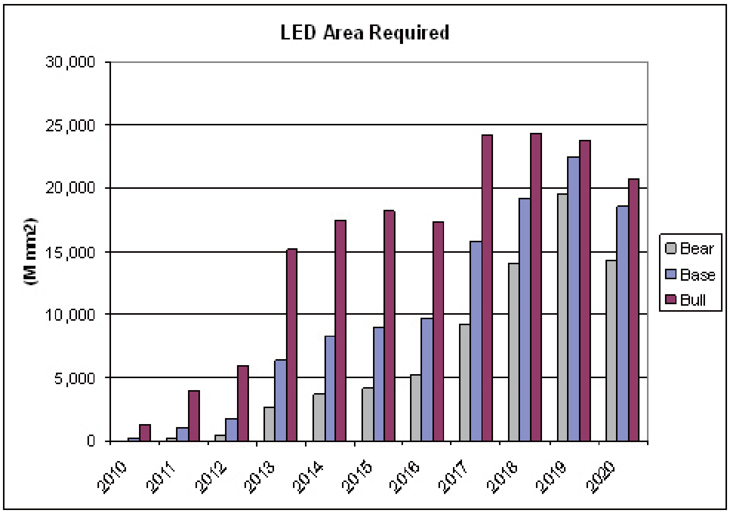


Figure 4.3: LED demand - lighting Source: Canaccord Genuity

4.2 Backlighting

Given the yearlong slowdown in large-area display sales and revised forecasts from third-party market research firms, we are reducing our estimates for the next decade's worth of LCD sales fairly significantly. In addition to the 21% reduction in TV sales, we also reduced the LED content per TV given the myriad changing specifications for fewer, brighter LEDs per set. Our handset and tablet figures have been synchronized to the most current Canaccord Genuity global estimates, but are more or less unchanged from our previous model. We have modified our OLED penetration assumptions as well but those, too, are more tweaks rather than major adjustments. What has not changed is that we still expect the OLED opportunity to significantly cannibalize handset and tablet LED backlighting opportunity towards the back half of the next decade.

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
TV										
Current	206	225	232	239	246	253	261	269	277	285
Previous	200	219	241	265	291	321	353	388	427	469

Figure 4.4: Changes in TV shipment estimates Source: Canaccord Genuity

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Monitors (M)	181	186	192	198	204	210	216	223	229	236
OLED penetration			1%	3%	5%	7%	9%	11%	13%	15%
TVs (M)	206	225	232	239	246	253	261	269	277	285
OLED penetration			0%	1%	2%	4%	8%	12%	16%	20%
Notebooks (M)	176.3	199.9	205.9	212.0	218.4	224.9	231.7	238.6	245.8	253.2
OLED percentage	1%	5%	7%	10%	20%	30%	40%	50%	60%	70%
Tablets (M)	65.3	100.0	110.0	130.7	143.7	158.1	173.9	191.3	210.5	231.5
OLED percentage	0%	1%	4%	15%	23%	25%	30%	35%	40%	50%
Smartphones (M)	468	650	680	717	752	790	830	871	915	960
OLED Penetration	15%	18%	32%	35%	37%	41%	43%	46%	50%	55%

Figure 4.5: OLED penetration rates Source: Canaccord Genuity

4.3 Total LED demand

Even though we believe lighting area generally grows y/y over the next 10 years, total LED area demand is flattish because of the coincident decline in TV backlighting from OLED cannibalization plus increases in efficacy and/or reduction in chip size. We expect total cumulative LED area demand to range from 258.8B mm2 to 385.0B mm2, with an annual peak in the range of 36.9B mm2 to 51.1B mm2 – 2-3x the estimated 15B mm2 for 2011.

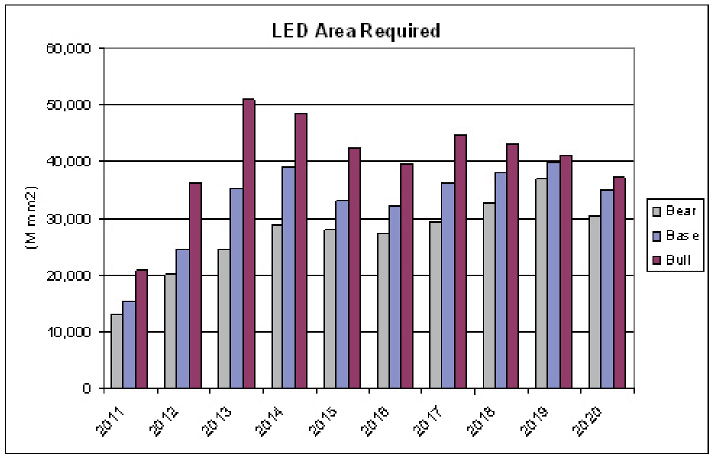


Figure 4.6: Total LED demand   Source: Canaccord Genuity

As we explained above, we expect the decline in TV demand to just about offset the growth in lighting, a phenomenon shown very clearly in the chart below. This is a serious difference from most market expectations. Analysts focus on LED lighting growth, which as we indicated above is an expected factor of 20x, but ignore the maturing of the LCD TV industry. "Other, which includes automotive, display, signage, signals, etc., is expected to remain rather flat over much of the same time period and less material to the overall analysis.

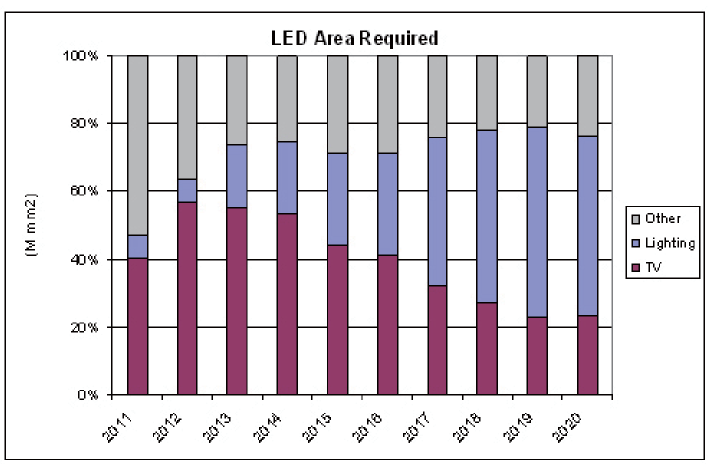


Figure 4.7: LED demand by application   Source: Canaccord Genuity estimates

We have chosen to convert our estimates to area to normalize the differences in chip size, which simplifies the assumptions needed for different package designs such as multi-chip arrays or larger power chips, for example. We will continue to use area going forward but, for comparison sake to our Third Cycle Update 2.1 (May 2011), we present the physical LED numbers as well as figures for weighted average die size per application below in Figure 4.8.

We are expecting a 25% reduction in TV backlighting chip sizes, no change in “other,” and a 60%+ reduction in the average lighting die size. The change in lighting is not a structural shift in die size over time (as is the case with TV), but more a function of the increased weighting of smaller die likely to be used in the commercial and industrial fluorescent replacement market. We still see the 40x40mil power chip as a dominant geometry in most of the HB lighting applications going forward.

Avg die area (mm2)	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
TV	0.421	[illegible]	[illegible]	0.455	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Other	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196
Lighting	1.105	0.614	0.504	0.573	0.510	0.449	[illegible]	[illegible]	0.474	[illegible]

Figure 4.8: LED changes Source: Canaccord Genuity estimates

	2012	2013	2014	2015	2016	2017	2018	2019	2020
CURRENT									
TV demand									
Bear Demand (M)	21,397.500	25,930.044	34,736.370	45,143.795	40,806.872	36,291.209	32,144.318	28,443.338	25,111.404
Base Demand (M)	26,746.875	38,895.066	46,315.160	45,143.795	40,806.872	36,291.209	32,144.318	28,443.338	25,111.404
Bull Demand (M)	40,120.313	51,860.088	46,315.160	45,143.795	40,806.872	36,291.209	32,144.318	28,443.338	25,111.404
Non-TV, Non-Lighting demand									
Bear Demand (M)	67,137.489	70,209.840	74,172.326	74,300.463	71,426.116	68,285.562	65,327.133	65,101.080	64,541.747
Base Demand (M)	70,409.679	73,928.876	78,151.187	75,270.582	72,397.754	69,013.627	66,057.585	65,855.839	65,313.024
Bull Demand (M)	73,918.637	78,187.769	79,558.541	76,694.978	73,596.935	70,223.635	67,284.437	67,121.892	66,610.934
Lighting Demand									
Bear Demand (M)	727.537	5,234.902	5,977.598	6,648.475	9,912.586	18,419.941	24,133.781	29,400.726	27,900.022
Base Demand (M)	2,831.375	12,692.789	14,369.999	17,570.707	21,673.606	41,058.374	44,529.224	47,305.828	46,132.528
Bull Demand (M)	10,893.648	32,485.881	35,661.800	44,011.834	46,132.147	75,801.114	71,753.541	68,594.889	64,814.547
Total Demand (LEDs)									
Bear (M)	89,262.525	101,374.786	114,886.294	126,092.733	122,145.575	122,996.712	121,605.232	122,945.144	117,553.172
Base (M)	99,987.929	125,516.730	138,836.345	137,985.084	134,878.231	146,363.211	142,731.127	141,605.006	136,556.957
Bull (M)	124,932.598	162,533.738	161,535.500	165,850.607	160,535.954	182,315.958	171,182.297	164,160.120	156,536.886
PREVIOUS									
TV demand									
Bear Demand (M)	52,264.350	66,474.910	87,255.928	95,523.557	94,092.798	92,653.590	91,173.234	89,613.356	87,929.090
Base Demand (M)	59,232.930	78,205.776	87,255.928	95,523.557	94,092.798	92,653.590	91,173.234	89,613.356	87,929.090
Bull Demand (M)	69,685.800	78,205.776	87,255.928	95,523.557	94,092.798	92,653.590	91,173.234	89,613.356	87,929.090
Non-TV, Non-Lighting demand									
Bear Demand (M)	64,732.134	69,231.681	75,389.714	77,640.058	76,377.500	74,193.306	71,993.673	71,300.526	70,217.291
Base Demand (M)	68,038.410	73,334.788	80,179.999	78,611.673	77,352.724	74,925.295	72,728.648	72,062.321	70,998.357
Bull Demand (M)	71,596.371	78,078.121	81,587.343	80,037.565	78,555.492	76,139.228	73,960.023	73,335.409	72,306.055
Lighting Demand									
Bear Demand (M)	1,513.881	8,314.445	9,291.415	10,130.305	13,353.614	24,524.187	30,648.320	35,259.981	40,206.424
Base Demand (M)	4,962.553	18,504.721	20,391.971	26,315.329	31,477.282	63,265.776	67,784.467	69,817.270	85,908.888
Bull Demand (M)	18,323.263	46,543.144	51,722.248	70,130.335	75,165.241	130,797.222	128,615.449	124,457.356	137,704.517
Total Demand									
Bear Demand (M)	118,510.365	144,021.036	171,937.057	183,293.920	183,823.911	191,371.082	193,815.227	196,173.863	198,352.805
Base Demand (M)	132,233.894	170,045.286	187,827.899	200,450.559	202,922.803	230,844.662	231,686.348	231,492.946	244,836.335
Bull Demand (M)	159,605.433	202,827.042	220,565.520	245,691.457	247,813.530	299,590.040	293,748.706	287,406.121	297,939.663

Figure4. 9: Weighted average die size Source: Canaccord Genuity estimates

4.4 MOCVD

We now expect third-party MOCVD reactor shipments of around 2,900 to 4,800 from the years 2010 through 2020, which includes the Second Cycle, down from our previous figures of 3,600 to 6,000. Following our recent tour of the LED fabs in China, we now expect fewer additional tools to be delivered overall given the low utilization rates, expiration of subsidies, lack of engineers, facility readiness and a growing stock of shipped-but-not-installed equipment, potentially still in crates. Our base case of 671 tools is now essentially where our Bear case number was previously. We still expect China shipments to make up between 60% and 70% of 2011 volumes, up from about 25% in 2010.

Perhaps the most surprising change is our 2012 number. We have cut this figure dramatically to 130-326 reactors, from 330-906 on account of significantly less Chinese demand due to customers exiting the market or choosing not to expand for the same reasons mentioned above.

With Korean and Taiwanese utilization rates painfully low (sub-50% in some cases), we do not see these drivers of the 2009/2010 boom coming back into the marketplace in the near-term either. While Street numbers have come down recently, we feel that expectations are still around a modestly down to flat year and not a 66% cut as our numbers indicate.

		2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2010-2020 Total	avg.
Bear	New	263	827	425	0	0	-	-	-	-	0	0	-	1,252	
	Repl.	-	-	126	130	149	129	192	188	188	179	171	161	1,614	
	Sum	263	827	551	130	149	129	192	188	188	179	171	161	2,866	261
Base	New	263	827	545	94	0	105	119	0	0	0	-	-	1,690	
	Repl.	-	-	126	135	168	136	220	250	250	239	228	217	1,969	
	Sum	263	827	671	229	168	241	339	250	250	239	228	217	3,659	333
Bull	New	263	827	623	189	172	204	249	0	-	-	0	-	2,264	
	Repl.	-	-	126	138	185	165	282	349	348	333	317	302	2,546	
	Sum	263	827	749	326	357	369	531	349	348	333	317	302	4,808	437

Figure 4.10: MOCVD projections Source: Canaccord Genuity estimates

Graphically, it is easy to see that we still do not expect the Third Cycle to ever rival the Second Cycle's exuberance. From a tool perspective we have experienced a historical peak. LED demand grows nicely, but not enough to justify another significant capacity cycle. In fact, most of the additional shipments in our forecasts are maintenance/upgrades driven by our unchanged, if not somewhat aggressive assumption that the replacement cycle for equipment goes from seven-plus years today to three years on the back of higher-yielding/higher throughput tool introductions from the equipment manufacturers. We continue to believe most of the future CAPEX and R&D in the LED supply chain will go to increasing yields from a blended 60% range to the traditional semiconductor range of 80%, perhaps 90%+ using more advanced back-end processing, metrology tools, automation, etc.

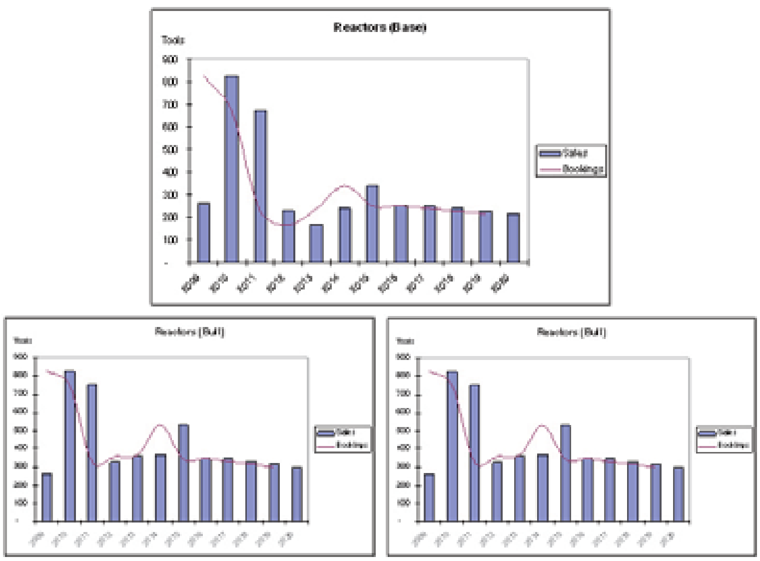


Figure 4.11: MOCVD shipment estimates 2009-2020 Source: Canaccord Genuity estimates

We see a clear oversupply in the market as a result of the massive Second Cycle. If we include the nameplate capacity of China, we find it unlikely that the market will tighten again. If we discount the Tier-3 capacity, there are some scenarios in which the market tightens in the 2015 timeframe, but it could quickly correct if the tightness spurs a familiar degree of overinvestment.

We see the extended supply-demand imbalance as a clear cause for LED commoditization. Note that our analysis does include a certain level of consolidation and market attrition. If these exits turn out to be more severe than our assumptions, which range from 10%-30% annually depending on industry-wide utilization rates, the S-D imbalance may improve beyond our current forecasts.

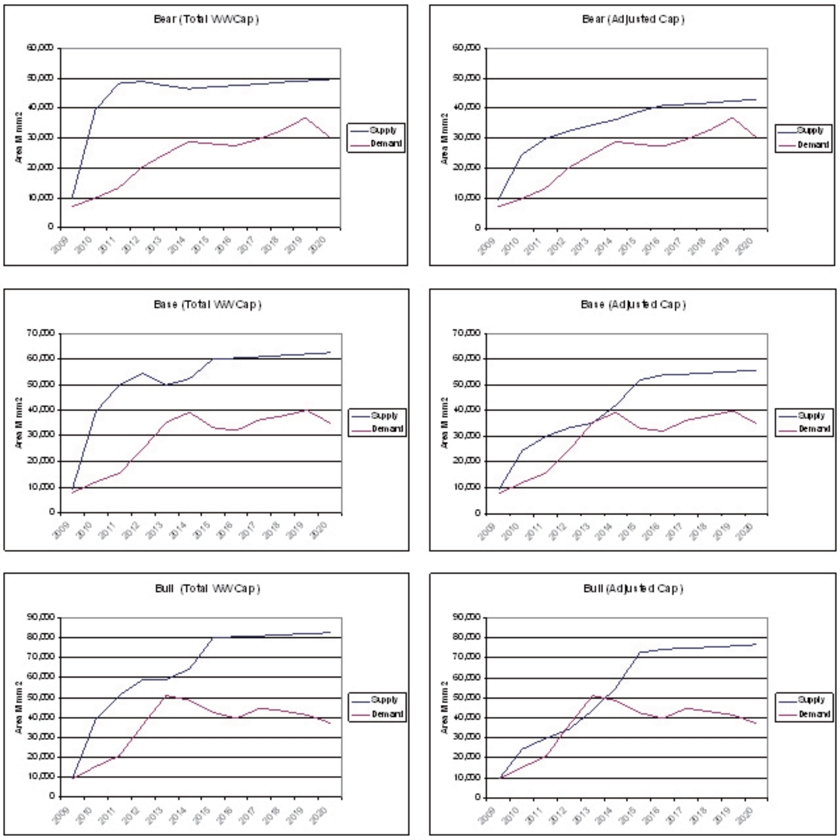


Figure4. 12: LED supply-demand (total and adjusted)   Source: Canaccord Genuity estimates

4.5 Sapphire

We are cutting our assumptions for sapphire pricing (already reflected in our Rubicon model) given the growing supply-demand imbalance. Below are our estimates for this imbalance, based on announced capacity plans and our proprietary demand figures. The industry was undersupplied in 2009 and was just slightly above equilibrium in 2010, forcing up prices and spurring a wave of additional capacity and new entrants. If all of the subsequently announced capacity materializes, the dire situation we have seen already in 2011 will quickly exacerbate to well over 2x demand. Naturally, the poor economics during this imbalance should ultimately result in push-outs, cancellations, exits, etc. However, we still see a rapid decline in sapphire prices going forward.

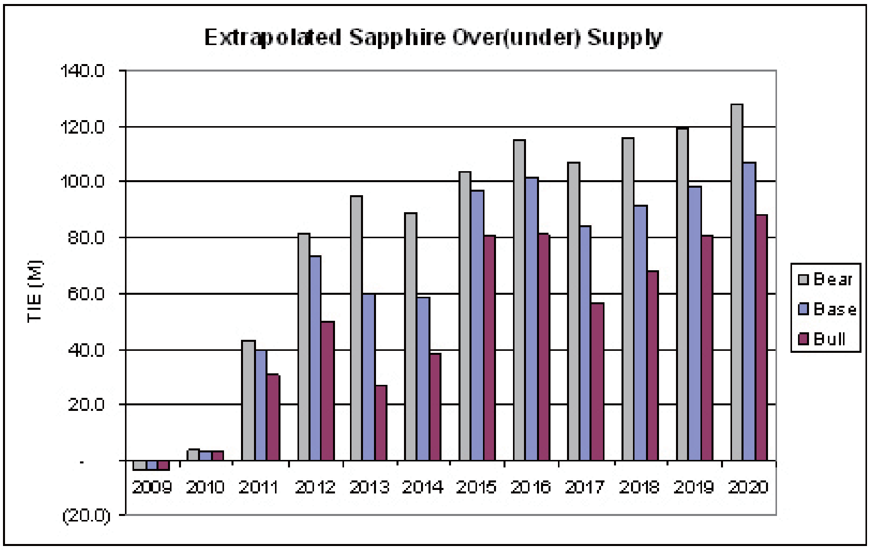


Figure 4.13: Sapphire imbalance Source: Canaccord Genuity estimates

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
2" Price	$10	$20	$15	$10	$9	$9	$8	$8	$8	$7	$7	$6
3" Price	$30	$45	$34	$22	$21	$20	$19	$18	$17	$16	$15	$15
4" Price	$80	$104	$78	$59	$47	$44	$42	$40	$38	$36	$34	$33
6" Price	$540	$540	$432	$281	$225	$180	$144	$137	$130	$123	$117	$111

Figure 4.14: Sapphire wafer pricing assumptions Source: Canaccord Genuity estimates

Since we have converted LED demand to area, it is relatively straight forward to calculate approximate sapphire demand – we just need an estimate for the industry's blended yield and the area of a 2" wafer. Doing so results in the sapphire demand model below. While a good starting point, we believe that looking toward actual MOCVD configurations provides a much more accurate picture given the differences in usable area and thickness per wafer as the industry migrates to 4" and then 6" substrates, and provides us with the ability to get more granular with yields, utilization, etc.

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Base Demand (M mm2)	15,520.9	24,702.1	35,277.9	39,165.0	33,059.9	32,066.4	36,193.9	37,945.5	39,921.8	34,970.0
Blended yield	50%	52%	54%	56%	58%	60%	62%	64%	66%	68%
2" surface area (mm2)	1576	1576	1576	1576	1576	1576	1576	1576	1576	1576
Sapphire Demand (M TIE)	19.7	30.1	41.4	44.4	36.2	33.9	37.0	37.6	38.4	32.6

Figure 4.15: Sapphire back of the envelope demand (base case) Source: Canaccord Genuity estimates

Our models that begin with MOCVD figures predict that demand for sapphire will 1) peak early given low yields and the weighting of small wafers, 2) fall as yields improve, then

3) rise again with the pickup in overall LED volumes toward the middle of the decade. Despite the cyclicality, it turns out that our models predict that demand sort of hovers around a core level of 80M TIE in the bearish case, 100M TIE in the base case; and 120M TIE in the bullish case.

Revenues, on the other hand, decline noticeably given our expectation for commoditization of the material through competitive market forces, continuous cost reduction and flattish demand. The flattish sapphire demand is a result of not only the flattening of the LED demand but also better utilization of overall reactor geometry as wafer size migrates to 4" and 6" (i.e., an 11x4" wafer carrier has approximately 5% more usable surface area than the equivalent 42x2" wafer carrier. For further detail, see our "A Light Read" report dated February 2010).

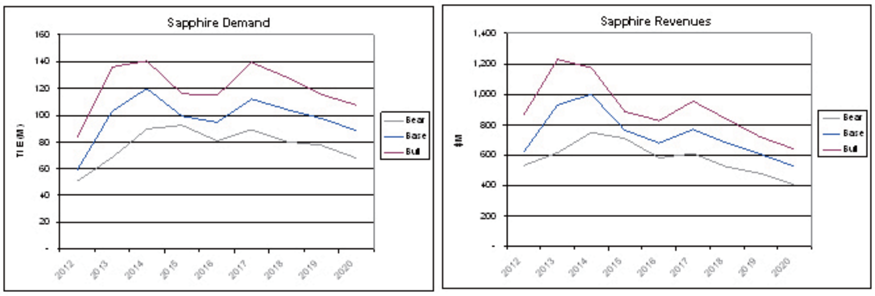


Figure 4.16: Sapphire forecasts Source: Canaccord Genuity

We see the majority of the sapphire CAPEX cycle occurring in the next four to five years. While the US merchant equipment manufacturers have been creating the most "buzz," we continue to believe the incumbents will invest proportionally to maintain their market share, plus it is important to note that we also have seen a surprising amount of investment in the Russian equipment from incumbents and start-ups alike.

In the following forecasts, we tried to capture a blend of the spectrum between incumbent suppliers' as well as new-comers' throughput/yields in addition to a 20% overbuild to demand. Changes in blended yields, throughput or the amount of overbuild would clearly affect our figures. Based on these factors we expect a total of between 1,200 and 2,000 additional furnaces worth between $730M to $1.3B, from all sources – proprietary and merchant – to be added to industry over the coming cycle.

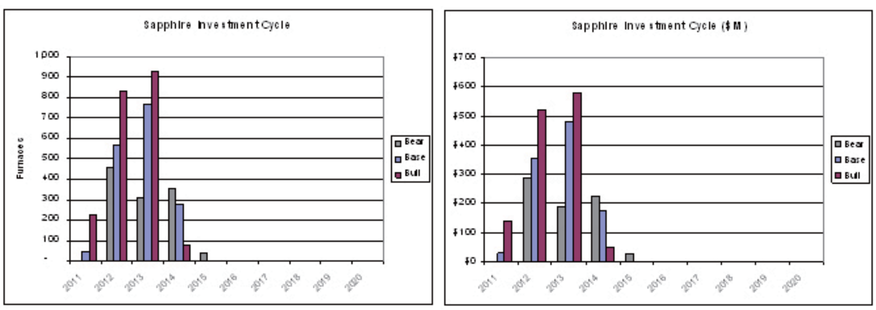


Figure 4.17: Sapphire investments Source: Canaccord Genuity estimates

Lastly, we expect momentary bottlenecks in wafering and polishing capacity, but we consistently hear that merchant wire saws from companies like Takatori and Meyer Burger and polishing tools from companies like Disco and Peter Wolters, not to mention likely "copycat" tools, should not create as significant a bottleneck as crystal growth did in 2009-2010. Similarly, we have heard from just about every sapphire company that high quality Alumina and densified feed stocks are readily available and not a major concern for them. We will continue to monitor these potential bottlenecks, however.

Chapter V

Overview of Solid State Lighting Standards

Chapter Contributor: Peng Jin

5.1 The standard making organizations and hierarchy

Without standards, we would live in an unpredictable world: incompatible products, unknown quality and unsure safety. A lack of standards in a fast growing industry such as solid state lighting has already resulted in absence of entry barriers for quality assurance and control, confusion in customers and frustration from suppliers. In recent years, various standard organizations across the globe have joined efforts to create SSL standards from component to system level. This report outlines the landscape of standard making organizations and status of the global SSL standards.

5.1.1 International Standards Organization

ISO, International Standards Organization - a nonprofit organization that develops and publishes standards of virtually every possible sort, ranging from standards for information technology to fluid dynamics and nuclear energy. Headquartered in Geneva, Switzerland, ISO is composed of 162 members, one single representative by country. As the largest developer and publisher of standards in the world, ISO fills the vital role of a medium for agreement between individual standards developers, spreading progress made by one country's local developers across the world to further the goal of standardization.

IEC, the International Electro-technical Commission - a nonprofit organization that develops and publishes standards concerning electrical technologies, of which a truly wide variety exists in today's modern world. Headquartered in Geneva, Switzerland, IEC standards spans over 150 countries. The world's leading standards organization in its field, IEC plays the crucial role of coordinating efforts carried out in different countries and unifying them, such as the development of various units of measurement and the standardization of the modern form of the metric system.

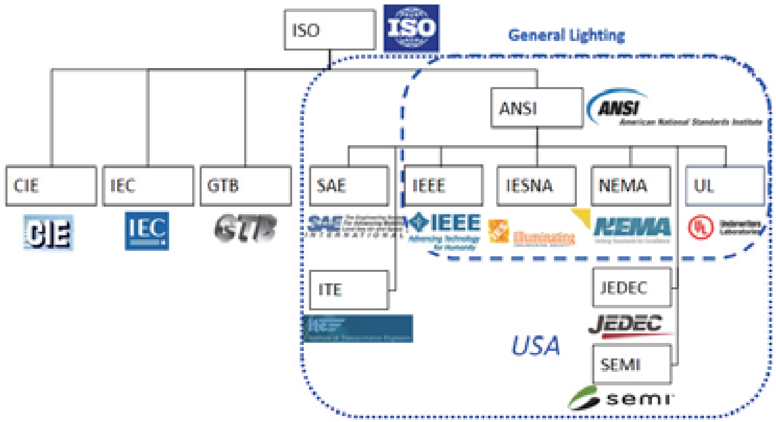


Figure 5.1. International Standards Organization Hierarchy

5.1.2. Industry bodies for LED Standardization in the US

Standard accreditation agency

- ANSI - American National Standards Institute. The Institute oversees the creation, promulgation and use of thousands of norms and guidelines that directly impact businesses in nearly every sector, including the key standards to SSL products.

Professional Associations

- IESNA - Illumination Engineering Society of North America, the recognized technical authority on illumination. It publishes a range of documents, including technical memorandums (TM), recommended practices (RP), application guides (G), and light measurement (LM) methods.
- IEEE - Institute of Electrical and Electronic Engineers, with collaborative thought leaders in more than 160 countries, IEEE is a leading consensus-building organization that enables the creation and expansion of international markets, and helps protect health and public safety.
- JEDEC, the Joint Electron Device Engineering Council. For over fifty years, JEDEC developed testing methods and product standards crucial to the electronics and semiconductor industry, also relating to LEDs.
- CIE - International Commission on Illumination. CIE is an international organization specializing in the advancement and standardization of lighting knowledge. Many national organizations consider information provided by the CIE in the development of standards and test methods.

Standards Developing Organizations (SDO)

- UL - Underwriters Laboratories, is a global independent safety science company offering expertise across five key strategic businesses: Product Safety, Environment, Life & Health, Knowledge Services and Verification Services.
- NEMA - National Electrical Manufacturers Association, it oversees the creation of a variety of industry norms and guidelines, including key documents of relevance to SSL products.
- NFPA, National Fire Protection Association, publishes National Electrical Code (NEC), for the safe installation of electrical wiring and equipment in the United States.

Government Agencies

- DOE - Department of Energy
- EPA - Environmental Protection Agency
- Energy Star Program. The designation is awarded to products that meet strict energy-efficiency guidelines set by DOE and EPA.

5.1.3 U.S. Standard Organization hierarchy

The United States is one of the leading countries for SSL standards development. The US Department of Energy has grouped representatives from the LED and traditional lighting industries and standard organizations, such as ANSI, IES, NEMA and UL, to develop basic LED standards for SSL industry and Energy star program, Figure5. 3. EPA now owns Energy Star program for SSL, and the essential standards in Energy Star are ANSIC78.377, IES LM79 and IES LM 80.

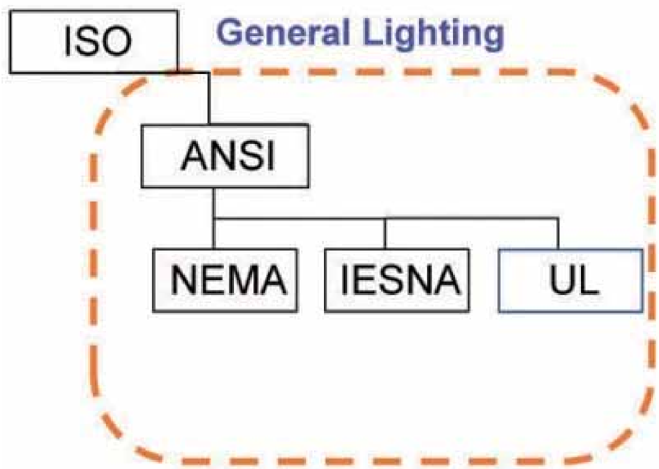


Figure5. 2 U.S. Standards Organization Hierarchy

Examples of ANSI-Accredited Standards Developers and U.S. TAGs		
ASTM International	**UL Inc.** Underwriters Laboratories	**NFPA** National Fire Protection Association
ADA American Dental Association	**API** American Petroleum Institute	**ICC** International Code Council
SAE Society of Automotive Engineers	**IEEE** Institute of Electrical and Electronics Engineers	**TIA** Toy Industry Association
U.S. Green Building Council	**AHAM** Association of Home Appliance Manufacturers	**Others**

Figure5. 3. ANSI accredited standards developers in US.

5.2 List of major standards related with SSL

5.2.1 Classification of standards

A logical way to classify SSL related standards is to sort them by functionality as listed below.

- Communication - the basic terms, symbols and other communication tools.
- Measurement - testing protocols to allow direct comparisons of product characteristics.
- Performance - methods for uniformly determining product performance and for rating products.
- Safety - electrical, mechanical, thermal, optical radiation, or other safety considerations.
- Electromagnetic Compatibility - determination of unintentional generation, propagation and reception of electromagnetic energy.
- Technology Development - best practices and standards needs for advancement of SSL technology.
- Design standards - dimensions, tolerances or other physical characteristics of products.

5.2.2 SSL standards map

In Cree's perspective, it classified the SSL standards by both applications and above mentioned functionalities, see shown in Table5.1.

Solid State Lighting – General Illumination – Standards Roadmap and Development Activities

	Drivers	LED	LED Package, LED Array, LED Module, LED Light Engine	LED Lamp, Integrated	LED Lamp, non-Integrated	LED Luminaire (AKA SSL)	Manufacturing
Communication	ANSI/IESNA RP-16 IEC/TS 62504	ANSI/IESNA RP-16 ANSI C78.XX (Standard LED data sheet) IEC/TS 62504 IEC 60050-845 IEC 62707 NEMA SSL-3	ANSI/IESNA RP-16 IEC/TS 62504 IEC 60050-845	ANSI/IESNA RP-16 ANSI C78.30 ANSI LCD ANSI C78.XXX Designation IEC 61231 IEC/TS 62504 NEMA/ALA LSD-51 IEC 60050-845	ANSI/IESNA RP-16 IEC 61231 IEC/TS 62504 NEMA/ALA LSD-51 IEC 60050-845	ANSI/IESNA RP-16 IEC/TS 62504 NEMA/ALA LSD-51 IEC 60050-845	ANSI/IESNA RP-16 IEC 61231 IEC/TS 62504
Measurement	ANSI C82.XX (LED Driver Testing Method)	CIE 127 CIE TC 2-63 IES TM-21 IES LM-80 IESNA LM-xx IESNA LM-xx2 IES proposal (OLED) IEC PAS – Lumen Maint.	CIE TC 2-50 IESNA LM-xx (HP DC LED) IESNA LM-xx2 (HP AC LED) IES LM-82	CIE 13.3 CIE TC 1-69 IEC/TR 61341 IES LM-79 IES LMXX	CIE 13.3 CIE TC 1-69 IEC/TR 61341	CIE 13.3 CIE TC 1-69 IEC/TR 6134 IES LM-79 IES proposal (LM-80 luminaire level)	CIE TC 2-64
Performance	IEC 62384 ANSI C82-SSL1-200X	Energy Star	IEC/PAS 62717	ANSI_C78.377 (color) PAS ANSI C78-377 IEC 62612 IEC 62663-2 Energy Star	ANSI_C78.377	ANSI_C78.377 PAS ANSI C78-377 IEC 62XX (Performance standard for LED-Luminaires) IEC 62xxx Energy Star	
Safety	ANSI/UL 1012 ANSI/UL 1310 IEEE Project P1789 IEC 61347-2-13 UL 8750 IEC NP – OLED Safety	CIE TC 2-58 CIE TC 6-55 UL 8750	IEC 62031 (module safety) UL 8750	ANSI/IESNA RP-27.1, 27.2, 27.3 IEC 62471/CIE S 009 IEC 62560 Ed1 IEEE Project P1789 UL 8750, UL1993 UL OOI 1598C IEC 62663-1	ANSI/IESNA RP-27.1 ANSI/IESNA RP-27.2 ANSI/IESNA RP-27.3 IEC 62471/CIE S 009 UL 8750 UL OOI 1598C	ANSI/IESNA RP-27.1 ANSI/IESNA RP-27.2 ANSI/IESNA RP-27.3 IEC 62471/CIE S 009 IEEE Project P1789 UL 8750 UL OOI 1598C	IEC TR 62471-2
Electromagnetic Compatibility	ANSI C82-SSL1-200X ANSI C82.77 CISPR 15 IEC 61547 IEC 61000-3-2 (EMC)			ANSI C82.77 CISPR 15 IEC 61547 IEC 61000-3-2 (EMC)		ANSI C82.77 CISPR 15 IEC 61547 IEC 61000-3-2 (EMC)	
Technology Development	IEC 62386-207 NEMA LSD-49 NEMA SSL-1	ANSI C78.XX (Standard LED data sheet) ANSI SR (Thermal Characterization of SSL Interconnects) ANSI C78.XX (ANSI Standard LED Footprint)	IEC 60838-2-2 (connectors) NEMA SSL-4 (form factors) NEMA LSD44 (interconnects) NEMA LSD45 (interconnects) Zhaga	NEMA LSD-49 (dimming) NEMA SSL-6 (dimming)		NEMA LSD 44 NEMA LSD 45 IEC 62386-207	

Table5. 1 SSL standards roadmap

5.2.3 SSL standards by organizations

Each organization publishes the standards independently or jointly according to its expertise and authority. And the efforts to set standards for SSL began several years ago. For example, the ANSI Working Group C78-09 was formed in December 2005, and the IESNA Testing Procedures Committee (TPC) solid-state lighting subcommittee was formed in April 2006. Each standards development organization (SDO) has a detailed process for creating and administrating standards. However, the LED standards process is proceeding quite rapidly. Here are the current standards organized according to publishing organizations.

ANSI:

C78.377: Specifications for the Chromaticity of SSL Products

C82.SSL1: Specify operational characteristics and electrical safety of SSL power supplies and drivers

C82.77-2002: Harmonic Emission Limits - Related Power Quality Requirements for Lighting

CIE:

CIE 13.3-1995, "Method of Measuring and Specifying Colour Rendering Properties of Light Sources,"

- Official document defining the CRI metric. (Referenced by ANSI C78.377)
  CIE 15:2004, "Colorimetry, 3rd Edition."
- Official document defining various CIE chromaticity and CCT metrics. (Referenced by ANSI C78.377)
  CIE 127:2007, "Measurements of LEDs," addresses LED luminous intensity measurement;
- Applies only to individual LEDs, not to arrays or luminaires.
  CIE S 009/E:2002, "Photobiological Safety of Lamps and Lamp Systems,"
- Specifies measurement techniques to evaluate optical radiation hazards and eye safety risks of LEDs and LED clusters.

IESNA:

G-2, "Guideline for the Application of General Illumination (White) Light-Emitting Diode (LED) Technologies,"

6) Provides lighting and design professionals with a general understanding of LED technology as it pertains to interior and exterior illumination, as well as useful design and application guidance for effective use of LEDs.

LM-79-2008, "Approved Method for the Electrical and Photometric Testing of Solid-State Lighting Devices,"

7) Specifies a standard test method for measuring the photometric properties of SSL devices, allowing calculation of luminaire efficacy.

LM-80-2008, "Approved Method for Measuring Lumen Depreciation of LED Light Sources,"

8) Specifies a standard method for measuring the lumen depreciation of LEDs, allowing calculation of LED lifetime.

LM-82-12 , "Approved Method for the Characterization of LED Light Engines and LED Lamps for Electrical and Photometric Properties as a Function of Temperature",

9) This approved laboratory method defines the procedures to quantify the performance of LED light engines and integrated LED lamps as a function of temperature.

RP-16 Addenda A and B, "Nomenclature and Definitions for Illuminating Engineering,"

10) Provides industry-standard definitions for terminology related to SSL.

TM-16-05, "Technical Memorandum on Light Emitting Diode Sources and Systems,"

11) Provides a general description of LED devices and systems and answers common questions about the use of LEDs.

UL

UL8750 Outline of Investigation for LED Light Sources for Use in Lighting Products

- Specify the minimum safety requirements for SSL components, including LEDs and LED arrays, power supplies, and control circuitry.

UL 1598 Luminaires

- Specifies the minimum safety requirements for luminaires. It may be referenced in other documents such as UL 8750 or separately used as part of the requirements for SSL products.

UL 1012 Power Units Other Than Class 2

- Specifies the minimum safety requirements for Class 2 power supplies (as defined in NFPA 70-2005).

UL 1310 Class 2 Power Units

- Specifies the minimum safety requirements for power supplies other than Class 2(as defined in NFPA 70-2005).

UL 1574 Track Lighting Systems

- Specifies the minimum safety requirements for track lighting systems.

UL 2108 Low Voltage Lighting Systems

- Species the minimum safety requirements for low-voltage lighting systems.

UL 60950-1 Information Technology Equipment – Safety – Part 1: General Requirements

- Species the minimum safety requirements for electronic hardware.

UL 153, "Portable Electric Luminaires,"

- Specifies the minimum safety requirements for corded portable luminaires.

UL OOI 1598C, " Light-Emitting Diode (LED) Retrofit Luminaire Conversion Kits."

- Primarily for Fluorescent lamp replacements

NFPA

NFPA 70-2005, "National Electrical Code,"

- Requires most SSL products to be installed in accordance with the National Electrical Code.

NEMA

NEMA.SSL-1, "Electric Drivers for LED Devices, Arrays, or Systems,"

- Specifies operational characteristics and electrical safety of SSL power supplies and drivers.

NEMA SSL 3-2010, "High-Power White LED Binning for General Illumination,"

- Provides a consistent format for categorizing, or binning, color varieties of LEDs during their production and integration into lighting products.

NEMA SSL-6, "Solid State Lighting for Incandescent Replacement — Dimming,"

- Specifies recommendations for the dimming and design of screw-based incandescent replacement SSL products.

Federal Communications Commission (FCC)

FCC 47 CFR Part 15, "Radio Frequency Devices,"

- Specifies FCC requirements for maximum allowable unintended radio-frequency emissions from electronic components, including SSL power supplies and electronic drivers.

IEC

IEC 61000-3-2: Electromagnetic compatibility (EMC) - Part 3-2: Limits

- Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)

IEC 61547-1995: Equipment for General Lighting Purposes

- EMC Immunity Requirements

IEC 61347-2-13:2006: Lamp control gear - Part 2-13

- Particular requirements for d.c. or a.c. supplied electronic control gear for LED modules.

IEC 62663-1, Ed. 1: Non-ballasted single capped LED lamps for general lighting –

- Part 1: Safety requirements.

IEC 62031: LED modules for general lighting –

• safety requirements

IEC 62471 Ed. 1.0 b:2006/CIE S 009 (CIE S 009:2002):
- Photobiological safety of lamps and lamp systems (under revision)

IEC/TR 62471-2 Ed. 1.0: Photobiological safety of lamps and lamp systems –
- Part 2: Guidance on manufacturing requirements relating to non-laser optical radiation safety

IEC 62560 Ed1: Self-ballasted LED-lamps for general lighting services > 50 V
- Safety specifications.

5.3 Product standardization

Migrating from the business of semiconductor and electronics, the majority of LED luminaire manufacturers has been experimenting on fixture designs and various supplies, and offers no interchangeability with other LED luminaire vendors. The lack of interchangeability and standardization has confused the customer on what to buy, how to repair and what to replace. To simplify the LED applications for general lighting, Zhaga Consortium was formed with members from LED module makers, material and lighting component suppliers. To date, seven books have been published aiming at creating specifications that enable interchangeability of LED light sources made by different manufacturers. The books have covered Common definitions and generic interfaces, socketable LED light engine, light engine for spot light and street light applications, etc. Zhaga specifies only the mechanical, photometrical, thermal and electrical interface of the target products to enable interchangeability, while leaving the freedom of design inside. Zhaga standards comply with the government regulations as shown in Figure5. 4.

Figure5. 4. Scope of Zhaga's interchangeability specifications

ISA TCS

International SSL Alliance (ISA) was established with active participation from regional associations, research institutions and leading companies in the SSL field. It aims to enhance public-private partnership and intensify global cooperation to accelerate and foster the sustainable development of SSL. ISA Technical Committee of Standardization (TCS) was established on Nov. 2011. The TCS, according to its First Meeting at June 2012, will focus its work on "white spots" of the current specification, testing and standards.

CSA

Interfaces inconsistency resulted in late scale manufacturing and high maintenance and repair costs. Led by China Solid State Lighting Alliance (CSA), a group of industry experts are currently working on the standardization of interface for various lighting products such as LED Street light, LED tunnel light, LED down light and spot light. Those interface standards are geared towards lowering the luminaire cost and improving interchangeability. Also, the reliability and the rapid evaluation of LED products are experimentally confirmed to promote applications. Guang Dong province, the "epicenter" of the booming China LED industries, has also standardized and benchmarked the LED luminaires in government procurements.

5.4 Global SSL related testing standards and entry requirements

The rest of the world is largely following the U.S. in basic & component standards, but making modifications according to their local markets. The lack of standards is no longer an impediment to SSL adoption. Table 2 lists the entry requirements in the world major SSL markets.

	North America	Europe	Japan	China
Environmental	California 65, RoHS	RoHS, Halogen Free		China RoHS
Performance	IESNA, ANSI, NEMA	CIE	JIS	Regional & National
Efficiency	DOE/lighting facts, California Title 24	EUP		Regional & National
Safety	UL, NRTL,NFPA,NEC	IEC, EN,CE,GS	PSE	CCC,CQC
EMC	FCC	EMC	VCCI	CCC,CQC
Reliability	Energy star, LM80, LM79, etc.	--	--	--
Material Analysis	ASTM	--	--	--

Table5. 2 Global SSL related testing standards and entry requirements

5.5 The perspectives

Like traditional lighting equipment, solid-state lighting (SSL) products sold in different regions are subject to industry standards governing safety and performance. Above standards lists, the key guidelines are performance and safety standards that are applicable to SSL products, including those utilizing LEDs. The use of international standards and test methods improves consistency of performance and facilitates product comparisons, thereby increasing consumer confidence and satisfaction. As the technology matures, standards and guidelines are created or revised as needed. While lighting, as a whole, already has many standards for mechanical shapes and fittings, electrical connections and measurement, LED lighting exhibit many different characteristics from lighting predecessors, making it different and requiring new standards development, considering human factors, environmental impacts and unique dimming capability of LED. In the wonderful world of solid state lighting, the impediment of high cost and lack of standard are still hanging over us, however, in the far horizon, the rays of morning lighting are beaming.

Chapter VI:
SSL application in new areas

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6.1Report on development of VLC (Visible Light Communication)

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Abstract-The recent industrial availability of color and white power LEDs (Light Emitting Diodes) has made LED lighting a reality for public and home lighting and various applications asking for powerful lighting. Besides their primary usage - delivering a lot of visible light for human eyes - these systems can take advantages of their electrical and optical properties to emit various information and data to dedicated receivers by modulated light. This report describes the state of the art of these new optical communication systems using visible light, which is called VLC (visible light communication). VLC demonstrated the brilliant prospects of power LEDs in communication systems.

6.1.1 Principle of visible light communication

Optical source of visible light communication system have evolved from sunlight to LED. Everything that emits light, like traffic lights, lightings for museum exhibitions and advertisements, become communication devices now. The modulated signal is transmitted by the switching of the LED.

Visible light waves are the only electromagnetic waves our eyes can see, but there is no uniform definition of wavelengths of the visible spectrum. Most people will respond to wavelengths of 400 to 700nm while some people are able to sense wavelengths of about 380 to 780nm. Generally, the wavelength of the visible spectrum covers a range from 350 to 770nm.

The basic idea of visible light communication is based on the fact that florescent lamp or light-emitting diodes (LEDs) are capable of transmitting information through fast switching, that flicker cannot be detected by human eyes. We can modulate and encode the visible light with information that we want to transmit, and a photoelectric converting device before the receiver will detect the light and convert optical information to electrical information. Once given an appropriate electric power, the fast switching of visible light can be used to transmit information.

The basic idea of visible light communication is illustrated in Fig6.1.1, which introduces the transmission of text information. At the transmitter end, the visible light can be modulated with binary codes carrying text information. The light is on the status of on or off corresponding to'1'or '0'. The photo-detector at the receiver end is used to detect light signal from the transmitter and demodulate the signal into an electrical signal according to the intensity of the light. The optical signal is decoded into '1'when receiving strong light and'0'when receiving weak light. The original text information can be recovered in this way. In order to keep the stability of the light to make it comfortable for human eyes, the communication rate should be high enough and there shouldn't be a continuous series of '0' or '1' in the transmitting binary code. In addition, the binary code '0' and '1' can also be represented by the variety of frequency, phase, and even the polarization state of the light to realize visible light communication. Ways like space division multiplexing, code division multiplexing, wave division multiplexing, frequency division multiplexing etc can be used to enlarge the transmission capacity in this communication system.

Fig6.1.1 Principle of text transmission by visible lighting communication

With the development of semiconductor technology, LED lighting techniques have been used in practice. LED is now considered as a strong candidate for the future lighting technology. Compared with conventional lighting methods, LED has smaller size, lower power consumption and longer lifetime, and is more environmentally friendly. It may replace the incandescent and fluorescent lamps currently in use as the fourth generation lighting. LED is sensitive to the injecting current and has a very short response time. It can realize fast switching which makes it possible to be modulated while illuminating rooms. As a consequence, LED is appropriate for the visible light communication system. The application and popularization of LED lighting technology in recent years has pushed the development of visible light communication. We can build a hybrid communication network with the visible light communication technology, the power line carrier communication technology, the radio frequency wireless communication technology, the infrared communication technology and so on. The combination of all kinds of communication technologies will be able to meet the need of customers in different application environment.

6.1.2 Technical difficulties and challenges

There are a lot of technical difficulties in visible light communication system since it is a new technique. They are come from materials, devices and systems. Although the LEDs can be applied in both visible light communication system and semiconductor illuminating system, the requirements of the two systems are different. The optical source of an optical wireless communication system should have a short response time, a fast intensity change and a good linearity. While the lighting device of an illuminating system emphasized stable intensity. Consequently, the LED should be designed specially to adapt to both of the two systems. At the same time, there are many noise signals affecting the visible light communication system. It includes the sunlight and the direct light or bounce light of all kinds of illuminating source except for the diffuse reflectance light of the LED light source itself. Therefore, it has increased the analysis complexity of visible light communication channel. To improve the performance of visible light communication system, there are some technical problems to be resolved.

1. The precise modeling of the information channel

Compared with the radio frequency wireless communication signal, the visible light possesses shorter wavelengths, weaker ability of diffraction. It is easier to have communication signal blind zone, and the reflection of the objects around the light source also can make the visible light communication channel to be a complex multipath channel under multiple diffusion conditions. It is obvious, that multipath interference and link vulnerability of visible light communication channel is serious than radio frequency wireless signal channel. The light extraction efficiency and temperature of LED affect each other. So, the photoelectric conversion efficiency of LED is nonlinear, and this should be taken into consideration when we do the modeling analysis of visible light communication channel. In conclusion, we need to generate a complicated nonlinear model of visible light communication channel that can be applied to both illumination and communication systems, and the precision of the model is difficult to ensure.

2. Collaborative optimization of communications and illumination

The optical source of the free-space optical communication system should be able to meet the need of high speed communication rate. So, LED device should have small parasitic resistance, small capacitance, stable output wavelengths, high lighting efficiency, highly-speed response, linear photoelectric response and controllable output light direction. It is possible to realize the multiplexing of LED's illumination and communication by improving the optical power efficiency of a unit square, shortening the recombination lifetime of the carrier radiation, improving the performance of ohmic contact, enhancing the light output efficiency, designing and making special LED device which can control the light transmission modes.

The LED device used for illumination can work under the condition of high current density, the illumination efficiency and frequency spectrum of the device will change when modulated by certain bias current. The traditional physics of semiconductor devices is suitable for the study of LED illumination under the condition of small injection current, while the study under the condition of large injection current it is not well enough. The physical mechanism of LED modulation frequency is not clear. The design of LED device should consider all kinds of transient process during the process of high speed modulate, like the recombination mechanism and modulation of the sub-wavelength micro-nano structure, the photon radiation, transmitting behavior and controlling in the sub-wavelength micro-nano structure and so on. Those are things should be deeply studied. To study the working characters of the LED device under the condition of both illumination and communication is very important, but studies of these problems are far from enough.

3. The high speed modulation technology

When it refers to the multiplexing of the information channel, the orthogonal frequency division multiplexing (OFDM) is regarded as one of the highest speed communication in optical communication and radio frequency communication, since it allows overlap of the sub-carriers which has largely improved the frequency efficiency of the communication system. Another character of OFDM is that it can use the approach of digital signal processing to make up for the loss of the information channel. However, OFDM requires synchronism of the sub-carrier data, and that raises a strict requirement for the LED's dynamic range. Meanwhile, we can enlarge the system transmitting capacity by using high order modulation, but it is stricter to the system nonlinear, phase noise and so on. Therefore we should study the compensation algorithm of the system nonlinear and phase noise. The digital signal processing equalization technology can enlarge the modulation bandwidth, improve the nonlinearity and enlarge the dynamic adjustment region. That is to say, we can efficiently enlarge the LED's frequency cover region to make the LED frequency response to be a constant during a long frequency region through equalization technology, to enlarge the LED's modulation bandwidth. The approaches referred to above can enlarge the system's transmitting capacitance. There are many research teams doing this in the visible light communication field, and the communication rate are increasing all the time.

4. The detector and optical receiver

Compared with the optical fiber communications based on the laser, the LED visible light communication has much smaller optical power density, and more complicated noise signal resource, so the signal-noise ratio of the system is lower. Usually, we only require the bit error rate of the former part to be lower than 2×10-3bps, and can lower the bit error rate through the forward error correction of the latter part. In order to acquire ideal signal-noise ratio, we can improve the lighting efficiency and illumination stability through small lightweight optical system at the transmitting end, and enhance the optical signal at the receiving end by a large field high gain non-imaging optical Antenna.

The PIN photo detector and the APD photo detector are detectors that may be used in visible light communication system. The APD photo detector has avalanche effect and high sensitivity, which can extend the transmitting distance, but it requires high working voltage and complicated and expensive temperature compensation circuit. No matter which one you choose for the visible light communication system, the photo-electric conversion speed is expected to be fast, and that requires small equivalent capacitance. However, the photocurrent will be lower and affect the detector's sensitivity. To eliminate the conflict between them, innovation is expected when designing the photo detector.

Since a low power small size receiver is welcomed to visible light communication system in practice. The design of the monolithic optoelectronic integrated receiver circuit may contribute to cutting down the cost and commercialize the visible light communication system due to the advantages of this system.

6.1.3 Development Evolution

VLC (visible light communication) is not a new word, warning light, signal lamp even sunlight were taken as optical source of VLC. The meanings of VLC are different in different times.

On June 3, 1880, Alexander Graham Bell transmitted the first wireless telephone message on his newly invented photophone from the top of the Franklin School in Washington, D.C. The photophone functioned similarly to the telephone, except this equipment used sunlight as a means of carrying the information, while the telephone relied on electricity.

In 1999, Prof. Grantham Pang of The University of Hong Kong developed an audio signal broadcasting system based on the traffic lights. The LED traffic light can broadcast local traffic information, vehicle location, road and navigation information, and at the same time perform its normal function of being a traffic signaling device.

The popularization and application of solid state lighting take an active part in the development of visible light communication. The most popular LED bulbs available in the market are blue light-emitting diode (LED)/yellow phosphor devices. In order to show the function reuse of visible light communication and solid state lighting, blue chip white LEDs are considered by most visible light communication (VLC) researchers for it is a low cost choice.

In 2000, Ph.D. Yuichi Tanaka of Keio University, Prof. Masao Nakagawa of Keio University, who heads the Visible Light Communications Consortium,and Shinichirou Haruyama of Sony Computer Science Laboratories proposed a optical wireless home links with white colored LED.

In October 2003, Japan established Visible Light Communications Consortium, VLCC. Those participating in VLCC include Tokyo Electric Power Co., NEC Corp., Matsushita Electric Industrial Co., Samsung Electronics Co., Agilent Technologies Japan Ltd., Sony Corp., Nippon Telegraph and Telephone Corp., NTTDoCoMo Inc. and Kyocera Corp. In May 2005, VLCC protocol standard for Visible Light Communication（VLCC-STD-001） and VLCC protocol standard for a low speed communication with Visible Light ID（VLCC-STD-003）were established. These standards define the physical layer and application layer interface for short-range optical wireless communications using visible light in optically transparent media, including the free space interface with light emitting element and light receiving element.

In 2006, Professor Harald Haas of International University Bremen exploited the high crest factor of Orthogonal Frequency Division Multiplexing (OFDM) to light emitting diode LED. The prototype system has managed a distance close to one meter with a bit error rate of 10−3 under the moderate ambient light conditions found indoors. This distance has been achieved with a single LED and without any kind of channel or source coding.

In 2006, Prof. Haas' group proposed a COFDM (coded OFDM) system with QPSK (Quadrature Phase Shift Keying) modulation and a single LED, an entire new and pioneering framework for cooperative. A BER of 2×10−5 is achieved for a distance of 90cm between the transmitter and the receiver.

In 2009, Prof. Haas' group proposed a LED reading lamp, with faster data converters and analog frontends supporting 20MHz signal bandwidth, has a throughput of greater than 80Mbit/s (using 2/3 coded 64-QAM) is feasible and would be sufficient for high quality audio and video broadcasting.

In 2010, Prof. Haas' group developed MIMO (Multiple-Input Multiple-Output) technique for optical wireless communication to avoid interference at the receiver by adopting the SM (spatial modulation) approach. This new OSM (optical spatial modulation) technique achieves twice and four times the data rate as compared to OOK (on-off keying) and PPM (pulse-position modulation), respectively.

In 2008, the Smart Lighting Project was supported by American government. The Smart Lighting Engineering Research Center (ERC) founded in 2008 by the National Science Foundation (NSF) is a partnership of Rensselaer Polytechnic Institute (lead institution), Boston University and the University of New Mexico. Outreach partners are Howard University, Morgan State University, and Rose-Hulman Institute of Technology. Almost $40 million is expected over 10 years from NSF. The do research on how to communicate using light to send information and enable lighting information processing.

In 2008, Professor Dominic O'Brien of University of Oxford developed a multiple-resonant-driving equalization technique to considerably increase the modulation BW (Band Width) of white LED-based VLC systems. An experimental demonstration using 16 LEDs achieved 25-MHz BW and low error-rate data transmission at 40 Mb/s.

In 2009, Professor Dominic O'Brien' group used a postequalized white LED to increase the bandwidth with 50 MHz and a 100 Mb/s NRZ transmission was achieved with low BER.

White LED lighting communication system with an imaging diversity receiver, combined with MIMO processing techniques allows 'alignment free' was modeled by Prof. Dominic O'Brien' group in 2009. Simulations showed such systems can operate up to G bit/s in many circumstances.

In 2009, Professor Dominic O'Brien' group developed a 220Mbit/s indoor optical wireless MIMO-OFDM system that uses an imaging receiver. A BER of 10-3 is achieved over a range of 1m with a 2x1 array of white LEDs and a 3x3 photodetector array.

IEEE802.15.7 is a standard for short-range wireless optical communication using visible light submitted by IEEE 802.15 WPAN Visual Light Communication Interest Group (IGvlc). This standard defines a PHY and MAC layer for short-range optical wireless communications using visible light in optically transparent media. The visible light spectrum extends from 380 to 780 nm in wavelength. The VLC MAC support 3 modes based on applications, such as Information Broadcast (IB) mode, VLC Local Area Network (VLAN) mode and P2P (Peer-to-peer) mode.

At the opinion of communication, RGB white-light LED is better than phosphorescent LED at modulation rate for no phosphors persistence. On the other hand, RGB white-light LED can offer the possibility for Wavelength Division Multiplexing (WDM) in VLC links and poses the potentiality of transmission capacity.

Natasha Shrestha from Asian Institute of Technology (Thailand) developed a visible light communication system with a small 4 x 10 RGB LED in 2010. The demo system can support transmission rates of 19.2kbps.

Se-Hoon Yang from Yonsei University considered that hexagonal cell structure based on RGB LED is suitable for minimizing interference, when adjacent cells transmit different signals and wavelengths. In 2011, Performance of RGB LED communication system had been numerically verified for the data rate range from 10Mbps to 300Mbps and optical filter was used to improve SNR.

Takuto Komiyama from Hosei University described a new RGB based visible light communication system on SICE annual conference 2011 in Tokyo. The prototype system used convolutional encoding and multilevel modulation by the variation in color and change in intensity of each RGB LED.

Jelena vucic from Heinrich-Hertz Institute developed a wireless visible light link based on WDM and DMT modulation of a single RGB white-light LED in 2011. The aggregate rate was over 803 Mb/s. and bit error ratios in all three WDM channels were below 2•10-3, i.e., within the FEC (Forward Error Correction) limit.

In general, development of visible light communication technology will benefit from the development of the light source. The optical source of visible light communication is not only the LED lighting lamp. The LED traffic light (see Fig6.1.2), backlight LED of TV and backlight LED of digital signage board (see Fig6.1.3) are candidates. Applications of visible light communication relate to high speed data communication, target location, identification, games, entertainment etc.

Fig6.1.2 Information broadcast system using LED traffic lights

(Application of visible light communication to Intelligent Transport System. The Nippon Signal Co., Ltd. And VLCC, at Japan Shop 2006)

Fig6.1.3 Message download system using digital signage board backlight LEDs

(Prototype made by VLCC(Visible Light Communications Consortium) in Tokyo,September 2009)

6.1.4 Status of Research

The main advantage of the visible light wireless communication is as follows. First, it is optical communication without electromagnetic pollution, so it is beneficial to human's health. Second, it can also used for illumination, so we don't have to build a specialized network. That's cheap and intensive. Third, it doesn't have a frequency permit. The visible light communication technology is appropriate to be used on airplane and in hospital because there is no electromagnetic radiation and it is immune to electromagnetic signals. However, it is not urgent to use the optical wireless communication system on airplane and in hospital, and it is difficult to get access to the communication industry either, so the spread of this technology won't be easy. Due to the second advantage, the technology should also be appropriate for home and meeting rooms but the high cost of the LED lights and the high possibility of failure slow down adoption of LED lighting and visible light communication. It may be easier to spread this technology in meeting rooms and other public places but the communication industry has not yet designed a promising commercial application system. What has been realized are demonstration systems like audio broadcast systems, optical networks and playing games through optical communication shown in figure 4, and optical positioning shown in Figure6.1.5. And the technology is just another one among many, so the research is not intensive. Most of the research works are now using the mature technology of radio frequency wireless communication and optical fiber communications to increase the communication rate, and there are few modulation technology specially designed for visible light communication, even the light source and the detector. Until now, the main research work of visible light communication in academia includes studying the character of the light source, the model of noise, and the model of the information channel; developing a new kind of LED and the blue light filter; studying some complicated modulation technology (just as the discrete multi-tone modulation techniques), new coding technology, forward equalization, space modulation, MIMO technology and other communication technology to increase the system's transmitting capacity.

Fig6.1.4. Application of visible light communication to amusement, By Sony and

Agilent at CEATEC 2004, Japan

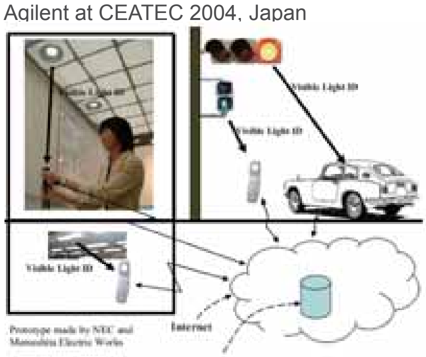

Fig6.1.5. Global location service that uses visible light ID system

When it refers to the establishment of standards about visible light communication, there is an IEEE draft standard for short-range wireless optical communication using visible light called IEEE802.15.7 raised by the institute of electrical and electronics engineers on Dec 10, 2008. And the modified standard about visible light communication IEEE802.15.7 was issued on Mar 31, 2011.

6.1.5 Application Cases

In the year of 2009, the Institute of Semiconductors, Chinese Academy of Sciences had built an optical wireless intelligent houseware experience zone in a demonstration hall inside the institute, as shown in figure6.1.6. We can use the light to control the household appliances, security equipments, electrical curtains and electrical toys. Later on the world exposition Shanghai 2010, they demonstrate the indoor visible light communication system including the optical wireless intelligent houseware system and the optical wireless network system that is shown in figure6.1.7.

Fig6.1.6. the optical wireless intelligent houseware system

Fig6.1.7. the optical wireless internet access system on the world exposition Shanghai 2010

Panasonic in Japan has declared to commercialize the visible light communication since July 11, 2012, providing ten LED lighting equipments and 20 signal receivers for the popular comics Pokemon in Nagashima amusement park. The terminal with a signal receiver can judge if the answer of the riddle is right or wrong after receiving the visible light from the ceiling.

On the advanced technology exhibition in Tokyo, 2012, several companies demonstrated the information transmitting technology using visible light, take Casio for example. The technology is applied in the popular products like intelligent mobile phone and Pad. Casio has exhibit the optical data exchanging technology using the camera of intelligent mobile phone.

Besides, on the advanced technology exhibition in Tokyo, 2012, Outstanding Technology of Japan had shown a communication light positioning system based on visible light communication technology. The intelligent mobile phones and pads can download information through visible light instead of radio wave by equipping a light receiver. The sensor of the light receiver uses the LED light above it to transmit data, so that it can catch the location and do precise positioning. Due to the small size of the mobile equipments, the receiver is designed to support USB port and headphone jack of 3.5mm.

At the final OMEGA open event in February 2011, the visible-light-communication (VLC) demonstrator consists in essence of 16 high-power LED lamps that are mounted into the ceiling of the Orange-Labs show room as shown in figure 8. Four HD videos are continuously broadcasted by all the lamps. The line rate of the packet transmission is about 100 Mb/s, while the net data rate at the transport layer is about 80 Mb/s. Partners contributing to this technical work on wire-less optics included, in alphabetical order, Apside, France Telecom, the Heinrich-Hertz Institute, Siemens AG, the University of Athens, the University of Illmenau, and the University of Oxford.

Fig6.1.8. the HD audio broadcasting system based on LED

6.1.6 Prospects

The bandwidth of the wireless communication is limited, but the need for information is increasing. The visible light communication system has developed new frequency resource and it has become more and more important because of the shortage of wireless communication frequency resource. New application of visible light communication can be developed except the LED wireless broadcasting system, the LED wireless online system, the LED under-the-water communication system and the LED optical wireless ID system. One character of visible light communication is that it has no electromagnetic radiation and is immune to electromagnetic signals, so it does no harm to human even we use larger power. With the illumination networks everywhere, we can build an information network covering many places. We used to use the light for illumination but we may use it for communication later. We are considering how to add the communication technology to the illumination technology now, but we may consider how to add the illumination technology to the communication technology in the future. When the flash light, car light, light box, television, signal light, illumination light and the street light all become the resource of visible light communication, we will see environmental optical wireless communication everywhere and there will be some new commercial applications.

6.2 Application of LED in protected horticulture

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Light is a vital environmental factor that affects plant growth and development by acting on plants not only as the sole energy source of photosynthesis, but also as the external signal of morphogenesis after being intercepted and absorbed by photosynthetic tissue. Normally visible light spectrum can manipulate plant photosynthesis via acting on chlorophyll, controlling photomorphogenesis through cryptochrome, phototropin and the other photoreceptors. Three dimensions of light each influence plant growth and development. Light quantity primarily influences photosynthesis and thus root and shoot growth of plant. Light quality refers to the spectral distribution of light, for example, the ratio of red (R, 600 to 700 nm) to far red (FR, 700 to 800 nm) photons. Light quality can influence flowering and plant morphogenesis, such as stem extension, branching, leaf area and leaf thickness, color of flowers and leaves. Lastly, light duration refers to photoperiod, or the duration of light each day. Many ornamental crops are sensitive to photoperiod with respect to flowering and thus, photoperiod is commonly truncated or increased to inhibit or promote flowering, whichever is desired.

6.2.1 Necessity of artificial lighting in protected horticulture

In the past two decades，protected cultivation has developed rapidly worldwide to meet the increasing demand of fresh vegetable, flower and other horticultural products. In China, the protected cultivation area has increased greatly and reached around 3.5 million hectares by 2012, which is 86% of total protected cultivation area in the world， ranking first in the world. The protected facilities mainly include multi-span greenhouses, Chinese solar greenhouses, plastic tunnels and plant factory for off-season horticultural cultivation. In horticultural cultivation, photosynthetically active radiation (PAR) (400-700nm) and ultraviolet light (UV-A, 280-400nm) are important spectral components for vegetable production. However, nature light levels often limit crop production during several periods due to insufficient sun light, sub-optimal growing systems, and/or the low light transmission of protected facility structures and covering materials (glass or plastic films) or it can be too high. For an optimum plant production and product quality light intensity, light spectrum and photoperiod have to be adapted to the needs of the plants at every moment. Therefore, the artificial light should be considered to optimize light, as well light intensity, daily light integral, light spectrum and the desired photoperiod to overcome the irregular sharply diurnal light intensity changes of nature light for horticulture products production under cover. More importantly, some protected horticultural systems, e.g. the plant factory and plant tissue culture, are dominated with artificial light. Thus, light parameters of artificial light source are particularly important for growth and development of horticultural plants.

6.2.2 Application principle of LED in protected horticulture

6.2.2.1 The application advantages of light-emitting lighting (LED) in protected horticulture

The traditional way of using artificial light in protected horticulture is the use of Fluorescent lamps (FL), High Pressure Sodium lamps (HPSL), Metal Halide lamps (MHL) and Incandescent lamps (IL). The disadvantages of commonly used artificial light were showed in Figure 1.The common disadvantage of the above lamps is that theirs energy consumption is high. With the development of SSL technology, light-emitting lighting (LED) as a new artificial light has been used for crop production these years. Advantages of LED over other artificial light for crop production includes: (1) high light efficiency and low heat generation, (2) small mass and volume, (3) easy manipulation, (4) wavelength specific, emitting single color light for plant growth, (5) long lifetime, and (6) energy saving. LEDs can almost emit all kinds of biologically active light qualities, including visible light, ultraviolet light and far-red light. LEDs also can tailor illumination spectra according to plant requirements through specific spectral combination. Therefore, LEDs can be used as artificial light source for supplemental lighting or sole light source for plant cultivation in protected horticulture. The most prominent benefits for the SSL are energy-saving, enhancement of plant productivity and promotion of food quality.

6.2.2.2 Application principle of LED in protected horticulture

It was well known that horticultural plants absorb PAR selectively with relative high absorbance value in red light and blue light zones. LED can emit all wavelength visible monochromatic lights, so it can irradiate horticultural plants including peak wavelength light for enhancement of photosynthesis, and subsequently the growth and development rates. In addition, LED also can give horticultural plants light environment as desired to regulate photosynthate metabolisms to obtain high nutritional substances. To sum up, as artificial light source, LED can entirely provide light environment according to plant requirements and human demand to increase plant productivity and healthy value of horticultural produce.

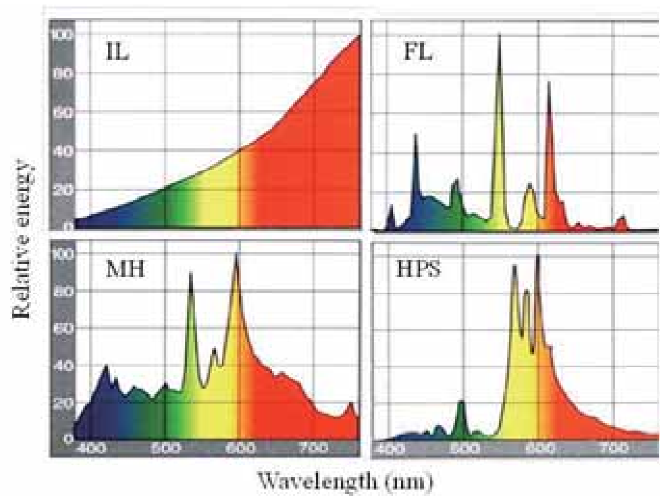


Figure6.2.1 Spectrum and defects of commonly used artificial light. Incandescent lamp (IL): much heat generation and lack of blue light; Fluorescent lamp (FL): lack of red light; Metal halide lamp (MH): much heat generation and much yellow and green light; High pressure sodium (HPS): lack of blue, green, red and orange light.

6.2.3 Key technologies for application of LED in the protected horticulture

6.2.3.1 Light formula should be established

Photobiology and photobiochemistry of horticultural plants have not been fully understood, and light formula of various horticultural plants should be studied further and established. LF, in essence, is an optimized and integrated assembly of spectral component emitted from light sources that is suitable for plant productivity and nutritional quality formation. LED is an ideal tool to study light quality requirements of every horticultural crop. Their small size, durability, long operating lifetime, wavelength specificity, relatively cool emitting surfaces, and linear photon output with electrical input current make these solid-state light sources ideal for use in plant lighting designs. Because the output waveband of LEDs is much narrower than that of traditional sources of electric lighting for plant growth, a challenge is to design an optimum light spectrum. LEDs have tremendous potential as supplemental or sole-source lighting systems for crop production. Several accepted advantages of LED can be classified. First, LED is energy-saving, small size and with high light efficiency; second, LED is cold light source with low thermal radiation, so it can illuminate plants closely; third, LED can emit multiple narrow-bandwidth monochromatic light with specific wavelengths, almost covering all biologically active light qualities. In addition, studies of light quality on biology and physiology have been gradually and extensively conducted worldwide by taking advantage of LED providing precise light spectrum and close illumination, providing abundant data to establish LF. Totally, LED is a best candidate as light source for regulating plant biology, productivity and nutritional quality. Up to date, a number of studies and their findings are useful for selection of LED types and positioning for a variety of purposes depending on crop type and desired responses. The ability to select specific wavelengths for a targeted plant response makes LEDs more suitable for plant-based usages than many other light sources. More importantly, compound or mixed light quality according to LF can be realized through combination with various LEDs. Thus, using LED as artificial light source, light quality can be controlled with great precision as desired.

6.2.3.2 Light environment management strategy (LEMS) for protected horticulture should be established

Establishment of LF will lay a foundation for establishing light environment management strategy (LEMS) for given protected plant species cultivated with artificial light source. Besides LF, light intensity and photoperiod are key contents of the light environment management. The LEMS refers to a comprehensive management method of light environment, including LF, light intensity and photoperiod for entire life of one special plant species, which should be established to facilitate high productivity and good nutritional quality with artificial LED light sources. By using LED lighting systems, it is possible to continually adjust fluence rate, wavelength combinations, and photoperiods to actively manipulate plant morphology and production, rather than using a stable light condition traditionally.

The application of LEMS will be used in the plant factory for the advantages of entire artificial light source, cultivation with nutrient solution and intelligent environmental control. Furthermore, vegetable production, particularly leafy vegetable cultivation, will benefit preferentially from the use of LEMS in plant factory. Corresponding LED lighting systems for plant factory should be designed and developed. Ideally, for an optimum plant production and product quality, light environment have to be adapted to the needs of the plants at every moment controlled by LEMS.

6.2.4 Developmental and application status of LED in protected horticulture

Many experiments have been conducted with LED as an artificial light in greenhouse for a supplement light, and in plant factories as sole light source for plant growth. LEDs can be used in plant tissue culture, seedling production, vegetable & flower cultivation in closed chamber or plant factory and greenhouse as artificial light (Figures 2 to 9). However, the optimal light environmental parameters of horticultural plants are far from being fully understood, which limits the further practical use. Based on current literatures, light requirements of horticultural plants are different due to species, cultivar, growth and developmental stages, environmental conditions, etc. Therefore, detailed studies on light quality requirements, i.e. light formula, based on biological and physiological requirement are urgently needed to investigate for getting high yield and good quality. More detailed researches on plant photobiology of monochromatic light by aid of LED are extensively conducted globally.

Fig 6.2.2 Flexible LED stripe for tissue culture

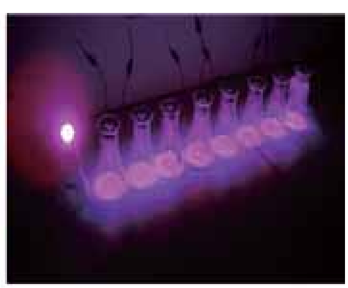


Fig 6.2.3 Tissue culture vessels with LED light source

Fig 6.2.4 LED tubes

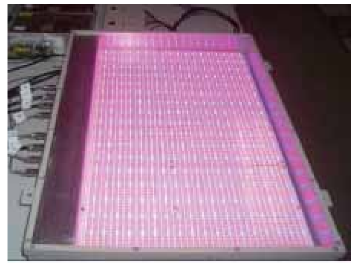


Fig6.2.5 LED light source plate

Fig6.2.6 LED for seedling cultivation

Fig6.2.7 LED cultivation leaf vegetable in plant

Fig6.2.8 Supplemental light with LED

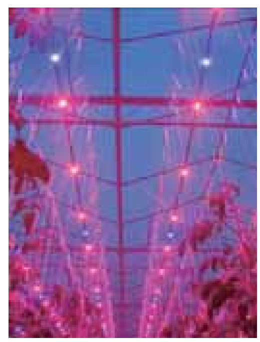


Fig6.2.9 Supplemental light with LED in glasshouse (G.P.A .Bot, 2010)

6.2.4.1 Light quality requirements of horticultural plants for high yield

Vegetable, flower and medicinal plants are major plant species for protected horticulture. Vegetables, as the basal source of essential substances for human health, suchas vitamins, cellulose, aminoacids and mineral elements, are important horticultural crops normally produced in the protected facilities. Yield of vegetables in protected cultivation are often affected, even cut by 20-30 percent due to insufficient light intensity, particularly non-uniform of spectral energy distribution under the cover environment. Acting mechanisms of light quality on yield formation of fruit and leafy vegetable should be examined species by species. Flower is another important horticultural crop, optimal light quality should be established to obtain high biomass and to be in flower on schedule or in advance. Apparently, high biomass is basal trait for better economic income of vegetable and flower in protected cultivation. LED lighting systems previously developed are mainly used on protected cultivation of vegetables and flower.

6.2.4.2 Light quality requirements of horticultural plants for high quality seedlings

Seedling production, e.g. vegetable and flower plantlets, by plant-tissue culture and seed germination is an important application aspect for LED lighting systems. Acting mechanisms of light quality on growth and development of plantlets and seedlings were fully investigated. Through studying the effects of monochromatic lights and combination lights of LEDs on the growth of seedlings, the suitable parameters of light spectrum and light intensity for high quality seedlings were obtained. The related study shows that high quality seedlings of vegetables and flowers with high survival rate can be produced with LEDs, and also can save energy by more than 60%.

6.2.4.3 Light quality requirements of horticultural plants with high nutritional value

For edible horticultural products, i.e. vegetables, their quality, especially nutritional value, was studied extensively. Nutritional value is generally evaluated by the contents of health-harmful substances and health-beneficial phytochemicals contained in edible parts of vegetables. In addition, for ornamental plants, i.e. flower plants, quality of plant size, flower shape and color, is closely linked to commercial value. Previous studies have showed some beneficial effects of LED light quality on quality of vegetables and flowers. Suitable light quality is the key to obtain high quality horticultural products. However, further investigations are needed.

6.2.4.3.1 Health-harmful substances

High-quality vegetables are vegetables with contaminated materials as little as possible. The contaminants/harmful substances are nitrate, oxalate, heavy metals and pesticides. Over-the-limit accumulation of the harmful substances in vegetables constitutes serious hazard to human health. In particular, off-season vegetables grown in protected systems with lower light intensity do tends to accumulate more nitrate in tissues due to excess N fertilization driven by farmers' desire for high yield. Beneficial effects of LED light quality on reducing harmful substances of vegetables are desired and explored extensively.

6.2.4.3.2 Health-beneficial substances

Health-beneficial substances in vegetables include conventional nutritional quality (i.e. contents of carbohydrate, protein, organic acid, mineral elements, etc.) and photophysiology biologically active substances (i.e. ascorbic acid, carotenoid, anthocyanin, flavonoid, etc.). Some of them are primary metabolites, and some of them are secondary metabolites. Recently, many studies have showed that LED light quality (such as blue and red light) could improve contents of carbohydrate and ascorbic acid in vegetable leaves or fruits. Also LED ultraviolet light can modify the contents of some secondary nutritional substances of vegetables. LEDs provide a tool facilitating the study of the light quality requirements of various vegetables according to specific nutritive index being manipulated. In addition, some medicinal plants cultured in protected systems under different light spectrums were investigated. Higher concentration of components of interests can be found thus leading to higher profit.

6.2.5 Prospects

LED has many attractive features for use in protected horticulture, which has been extensively recognized. The greatest advantage of using LED as light source for protected horticulture is that they enable precise control of the specific physiologies and growth of plants in a compact cultivating system. After establishment of LF and LEMS for horticultural plants, productivity of protected horticultural and nutritional value of horticultural produce will be promoted greatly. Moreover, with the reduction of price of LED, LED would be used in protected horticultural production extensively.

6.3 Prospects of the LED Light Source Application in Poultry Farming

Section contributors: Jinming Pan, Hong Zhou,Xuke Li

6.3.1 The Principle

Poultry are highly light-sensitive animals that have superior visual function. Poultry birds visible spectral range is even wider than that of human beings (380-760nm); in addition, they are able to distinguish between different colors. Therefore light environment is one of the critical environmental factors in poultry's growth and development process. Artificial light has been widely used in poultry farming to overcome restrictions on poultry's productive functions laid by seasonal change, to maximize domesticated birds genetic potential, so as to increase the economic benefits generated by poultry farming.

A lot of research and production practices show that the factors, such as color and wavelength, duration and intensity of the light, the combination of the light period and the darkness period and so on, have significant effects on poultry's production performance, physiological characteristics, behaviors and health. Although the working mechanism by which light affects poultry is not yet very clear, it is generally believed that light stimuli placed on chicken's retina and skull will trigger the transmission of nerve impulses to the hypothalamus which will then release related hormones to affect the metabolism of the chicken body; the effects on metabolism are observed from many aspects in relation to chicken's physical conditions and behaviors.

6.3.2The Technical Difficulties

Compared with traditional light sources, LED is blessed with many pronounced advantages, including inter alia long life expectancy, high color purity, low energy consumption, controllable light color, pollution-free after disposal, etc. Thus, it enables the development of a more effective and efficacious poultry light source system. In the past, American NCC and EU broiler welfare have made guidelines and rules for poultry lighting, which is based on traditional light sources. Such regulations are not suitable for LED light sources because of LED's distinctive spectral characteristics that are not shared by traditional light sources, so the above criteria do not apply to the LED light source. As a new type of light source, LED light source needs more academic inputs and experiments to facilitate its demonstration and dissemination.

6.3.2.1Establish poultry LED light test system with preferred light characteristics

The poultry house usually employs artificial light sources such as incandescent and energy-saving lamps, while they are full-spectrum, and immutable, without selective options for poultry. With its narrow spectrum light, LED has a controllable wavelength range which can be limited within 20nm, so there are more wavelength selections for poultry; response of the poultry varies on the degree of absorption of light of different colors and wavelengths, and the corresponding effects vary as well. In this case, prior to the large-scale application, there are requirements of test system on preference characteristics of poultry LED light, selection of the light color to match poultry species and genotypes, and targeted research on LED light intensity, and corresponding illumination regime; the research content needs to include poultry behavior, metabolism, feed consumption, growth, productivity and so on.

Some studies suggest that high light intensity may increase feather pecking behavior of laying hens and turkeys, but other findings get opposite result. The reason is that, though light intensity, light color and lighting program in the majority of studies are determined, due to the differences of spectral distributions, they produce more confusing results. With the development of LED and information technology, new technology has been put into use to study the light-induced poultry behavior, such as real-time image analysis by using of a video camera placed in the shed, static image analysis and image analysis software program to acquire and evaluate information, all of which contributing to the study of poultry's light preferences in order to select preferential spectrum for poultry.

6.3.2.2. Evaluate and improve the existing poultry lighting standard system

The response between avian and human in photoreceptor physiology wavelength is different. There are two types of cells in the retina of the human eye: rod cells and cone cells. The rod cells cannot distinguish the colors of the light, and feel low light illumination which is less than 0.4 Lx; while the cone cells feel all visible colors. Poultry have an extra kind of cone cells on their retina which are sensitive to light with wavelength of 425nm, and this physical structure enables poultry to see the light with wavelength between 320-400nm.

Due to the difference between the spectral sensitivity of human and chicken, for the same light, poultry feel brighter than man, and the degree of brightness differs with the different light sources (e.g. chickens feel that incandescent light source is 30% brighter than fluorescent light); because of this difference, the existing illumination units can not accurately deliver optimal poultry house lighting. A report named "light intensity, brightness and darkness gradually change the behavior of broiler chickens, laying hens, hens and turkeys and welfare impact" from Scientific Committee of the Norwegian Food Safety shows that applying existing illumination units to poultry is inappropriate, because eye spectral sensitivity of chicken and turkey is different from the human.

Light intensity has a significant impact on chickens' growth, behavior and physiological characteristics; at home and abroad, there are many mature light intensity control standards (such as the United States ASABE standards); the light intensity of the LED lights in existing research value is usually the same as incandescent, but the spectral energy distribution of incandescent lamp spans over the entire visible light wavelength range, while the LED-produced monochromatic energy is concentrated in a specific narrow band, and therefore both the light intensity represented by the energy and the stimulating effects on the chickens cannot be mentioned in the same manner, so we need evaluate for the existing poultry house lighting standards concentrating on the LED wavelength characteristics to provide a reference for poultry lighting.

6.3.2.3 Research and develop LED illumination system based on the poultry varieties and genotypes

There are a lot of research on effects of light intensity on poultry preferences, feather pecking, production, healthy legs, eye shape, and death rate. The study confirmed that the efficiency of different wavelengths of light through the optic nerve to the hypothalamus or through the skull and intracranial tissue are different; the penetration efficiency for the long-wavelength light (>650nm) to reach the hypothalamus is higher than short-wavelength light (400-450nm), and it differs from the different types of poultry, for instance, long wavelength light efficiency is 20 times higher than short wavelength light efficiency for chicken, 36 times for the duck, about 80-200 times for quail, even higher, for pigeons, about l00 to l000 times.

Therefore, the development of the poultry lighting solutions need further work to sort out the exact causality between light intensity, light environment of the system and the spectral composition of the light cycle. Therefore, in the development of lighting solutions, we need consider the types of poultry varieties genetics, nutrient density, feed intake and management program; based on the above consideration we develop the LED poultry illumination system which light color, lighting period, and light intensity can be flexibly controlled to achieve the smart poultry house lighting, and optimize the poultry house light environment.

6.2.3.4 Thoroughly assess the value of LED in the

improvement of poultry welfare

With the increasing intensification in the actual production of broiler, the problems of broiler health and welfare become more serious. More than 100 countries and regions have introduced the anti-animal cruelty bill, and some countries have established perfect animal welfare regulations, which have detailed provisions for animal rearing density, illumination time, barn greenhouse degrees, ammonia concentration. The Article 10 of the Welfare of Farmed Animals (England) 2007 has light requirements for commercialization indoor reared broiler. The requirement of light intensity for all construction must be at least 20lux, the strength only considers two factors of vision level of the chickens, as well as at least 80% of the available area is irradiated.

In the process of LED demonstration and promotion in the modern poultry industry, we need to study broiler production levels, health status, and product quality under different light conditions comparatively, analysis of poultry behavioral indicators, physiological indicators, productivity indicators, injury, death, carcass characteristics, then build scientific evaluation system to assess LED's impact on broiler welfare; study heat stress reaction of broilers at different welfare levels, and establish linkage between light environment, the welfare state and the meat quality, so as to improve the quality of poultry life and welfare of the poultry comprehensively.

6.3.2.5Take the most advantage of modern communication and information technology to create a superior light environment for poultry farming

As the requirement of poultry house intelligence is increasing and poultry housing is developing towards intensiveness and large scale, the inevitable development trend is sure to be the integration of production and management on the basis of remote communication. Usually the distribution of poultry house is relatively scattered and far away from the urban communities, therefore it is inconvenient to manage the poultry house. While we are pursuing the goal of managing the state of poultry farming environment around poultry house and the control information, and conducting monitoring the environment of poultry house scattered in various places, equipment automation and control, real-time online query and information services, integrated application of embedded technology and mobile communication technology, the process itself provides an opportunity for remote monitoring of poultry house environment and equipment.

The continuously advancing telecommunications technology, automation technology and computer technology make it possible to develop the intelligent, networked-LED birdhouse lighting system. Through combining with the new energy for implementing optimal regulation of the poultry house light environment and reducing the poultry optical stress response, it would be beneficial for improving the animal welfare and dramatically promoting the development state of the modern poultry industry. In conclusion, the poultry house environmental control technology is developing towards automation, intelligent, networked, real-time and integrated.

6.3.3 Development History and Status Quo

In the global context of advocating energy conservation and emission reduction, incandescent lamp is gradually withdrawing the market and progressively disappears from farms soon. A small number of farming enterprises still use the 28W energy-saving lamps for lighting, but its light color is white and it could just fulfill the function of lighting. Moreover because of the sight sensitivity, the poultry could be aware of the faint quiver of energy-saving lamps' light wave, which would weaken the light adaptability of poultry and increase the stress, thus the application of energy-saving lamps in poultry farming industry is limited. Owing to LED's specific features which enable LED to stand out and surpass conventional lighting products, the application of LED in the poultry farming industry is the trend of the times.

6.3.3.1 Effect of light color on the performances of

poultry growth and reproduction

Poultry would grow faster under blue and green light than under white light, and the growth rate under red light is almost the same with white light. Green light could promote the growth and development of 1 -- 20 days old chicks and it would promote the growth if the green light is replaced by other light color. Different monochromatic light is improving the chicken's body and muscle growth performance and the meat quality characteristics. Green light also allows earlier sexual maturity, strengthening the chicken breeding ability and accelerating the weight gain rate. And blue light could promote sexual maturity and rooster fecundity, improve the daily weight gain and reducing the feather pecking as well as elevate testosterone levels remarkably.

6.3.3.2 Effect of light intensity on the performances of poultry growth and reproduction

When the light intensity increases within 200lux, the ability of broiler to conduct daytime activity is strengthened. Although the leg disease and eye disease increase partially, it does not affect feed intake and weight gain per day. Light intensity (5lux and 101lux) does not affect the broiler's feed intake and the low lighting level would have little effect on the feed intake, growth rate, feed conversion ratio, survival ratio and leg healthy state, but it could improve the 51-day-old broiler's production performance. When the light intensity varies from 6 to 20lux, the hens would lay the largest quantity of eggs. When the light is uniform, 5.5lux light intensity could maintain the highest level of egg laying. Also a strong light intensity could reduce poultry hatching rate and make central nervous system develop asymmetrically.

6.3.3.3 Effect of light regime on the performances of poultry growth and reproduction

Different lighting program would decide the feed intake of birds. For each additional one-hour lighting time in the first 21 days of poultry life, their feed intake would increase 15g. And intermittent lighting could not only reduce the lighting time and feed intake, but also reduce activity levels and improve feed conversion rate. With the red and blue light LED and the lighting regime featured with first-decreased-then-increased order, the early growth rate of broiler might be reduced, but it could be achieved by compensatory growth that the indicators including slaughter weight and feed utilization are all superior to broilers which are farmed through traditional light regime (natural light and incandescent fill light). The broiler lighting time should increase from 1h in the second week to 23h in the 8th week at the increase rate of 4h per week and the broiler male hormone concentration would exceed that of broiler under the constant lighting conditions (24h every day).

6.3.4 Successful Cases

From 1997 the new series of monochromatic light lamps developed by Netherlands Gasolec Corporation have been applied successfully in more than 30 countries all over the world. Its red, light blue and green monochromatic light lamps could meet the farming requirement of different strains of poultry. According to Netherlands Gasolec Corporation research results, when the first-day-old meat chicks come into the coop they are under strong stress. If the green light lamp is used for 3-6 hours the chicks could calm down and actively take feed at the same time. When the chick coop is equipped with green light lamps, the death rate is very low for the first week, i.e. 0.8%. When the meat chicks are bred till the final days, their average weight could increase 80g. In terms of the feed-meat conversion ratio, it decreases from 1.5 to 1.4 in Netherlands, from 2.5 to 1.9 in Bulgaria, from 1.98 to 1.91 in Thailand. In Philippines the weight gain, feed-meat conversion rate and survival rate of meat chick all proved to increase by 10%.

In China, relying on the rapid development of the LED industry, there have been a growing number of enterprises and scientific research institutes involved in the application of LED in the field of poultry farming. For example, the Hangzhou HANHUI Technology Co., Ltd takes advantage of its expertise and technical strength to develop the energy-saving, yield-increasing LED poultry farming lights together with Zhejiang University. The products have been popularized and applied in Zhejiang, Anhui, Tianjin, Anhui, Shaanxi, and so on.

6.3.5 Prospects forecast

The conventional light sources for poultry farming are usually incandescent and fluorescent lamps. The former are high energy consuming and many countries including China are implementing Roadmap of Phase-out Incandescent Lamps; while the latters' light intensity isn't adjustable (only by changing number or power), and it is also easily stroboscopic (cause abnormal stress), intolerant to hot and humid harsh environment, short-life-timed, with limited light colors and contains mercury element which would be harmful for preventing pollution. In conclusion, it will have prominent future for dissemination and application of LED poultry farming lights in farming houses.

6.4 The Application Principle and Technology Research of LED in Microalgae Cells Culture Process

Section contributors: Zhiguo Fang
Hong Zhou,Xuedong Pan

The world today is facing two major problems: resource shortage and global warming.

Therefore, industrial biotechnology becomes a potential solution to effectively address resource, energy and environment crisis confronting human beings today. The industrial biotechnology is the technology of developing and utilizing the photoautotrophic microalgae which can directly transform solar energy and CO2 to produce medicine, bio-based chemicals (natural pigments, Isoprene, etc.) and bioenergy (ethanol, butanol, biodiesel etc.), all of which are necessary to sustain production and everyday life. Microalgae are a kind of photoautotrophic microorganisms which can transform CO2 and solar energy into organics through photosynthesis. Compared with the 0.5% solar energy conversion rate of higher plants, microalgae can convert 10-20% solar energy into organics. Therefore, when compared to higher plants, microalgae are the ideal choices to produce bio-fuels and bio-based chemicals, develop natural products, and fix CO2 to solve environmental problems, due to their advantages such as high photosynthetic efficiency and high growth rate. Moreover, microalgae do not occupy arable land and fresh water resources, are easily genetically manipulated, have metabolic diversity, etc. all of which adding to microalgae's advantages.

In the bioenergy and environment protection field, the microalgae-based research and development efforts mainly focus on the production of bio-fuels, such as biodiesel, hydrogen, ethanol, butanol, and on using microalgae to capture CO2 from industrial emissions and convert it into chemicals (Fig.6.4.1). Based on the above advantages and the fact that some microalgae could naturally accumulate grease equal to 60% of cell dry weight, therefore the microalgae-produced biodiesel has become a hot research point in the field of bioenergy. Now the microalgae biodiesel laboratory research is attempting to solve the problem that the grease accumulation level is inversely proportional to the growth rate of microalgae. On one hand, the researchers are selecting the microalgae that could not only accumulate large amount of grease but also have fast growth rate; on the other hand, by using the advanced technology of systems biology, researchers are able to genetically modify microalgae species. Regarding the process of microalgae development and industrialized production, how to solve the dilemma - lying in high cost and low yield rate of real producing process - has become the emphasis of research.

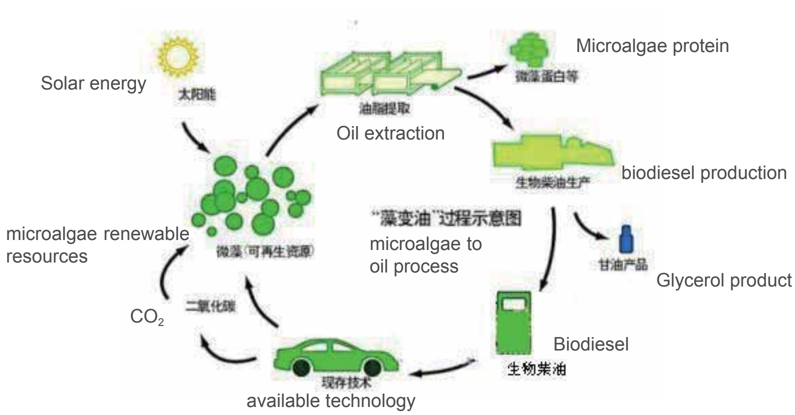


Fig6.4.1: An Illustration of "Turning Microalgae into Oil"

Illumination is one of the most important factors that affect the microalgae cell growth and the changes in biochemical composition; it has an important influence on microalgae growth, reproduction, color of the frond, cell morphology and metabolite content. As a complex ecological factor, illumination effect on microalgae cell growth mainly consists in light intensity, light quality and photoperiod, among which light quality is particularly important. Because of the difficulty in adjusting the quality of light source, there are two accessible means generally used to produce a specific wavelength of light quality needed by scientific research and agriculture production: one is getting the required light quality through shrouding filters or colored PVC films over the artificial light source; another is making the 40W long tube fluorescent lamps or the SSW H - type fluorescent lamps by blending different rare earth phosphors in certain proportions. However, the light quality acquired by these two means is not precise and its spectral range is hundred nanometers wide. This fact couldn't only ensure the accuracy of results but also lead to loss of light energy. Therefore the new wavelength-accurate energy-saving LED light sources can provide a basis for research on the light quality effect on microalgae growth and the law of secondary metabolites accumulation. Subsequently it will benefit mankind indirectly.

Both microalgae and higher plants are able to photosynthesize, while the pigments and corresponding composition in microalgae are far more complex than that of higher plants. The microalgae absorption spectrum of the visible band decides their competitiveness for the visible light, which also affects the succession between the algal populations. The types and the composition ratio of the pigment in algae decide the shape of their absorption spectrum, and the pigment concentrations and parcel effect mainly affect the value of absorption spectrum. For example cyanophyta pigments have no plastid, and its pigment composition comprises diverse pigments, including many kinds of pigments such as chloroplast a, β carotene, phycocyanin, xanthophyll and phycoerythrin prime. Chlorophyta chloroplasts and chloroplast may have many kinds of shapes, such as cup-like shape, links spiral ribbon shape, star-like shape and mesh-like shape.

Different kinds of microalgae in different growing stages require different light quality when they are photosynthesizing; therefore such performance facilitates the application of new LED light source in adjusting microalgae photosynthesis and seeking the best light use efficiency. At the same time, against the backdrop that environment is degrading and energy is running short, new LED light source application is able to promote effective energy saving and emission reduction technology, and development of new energy industry.

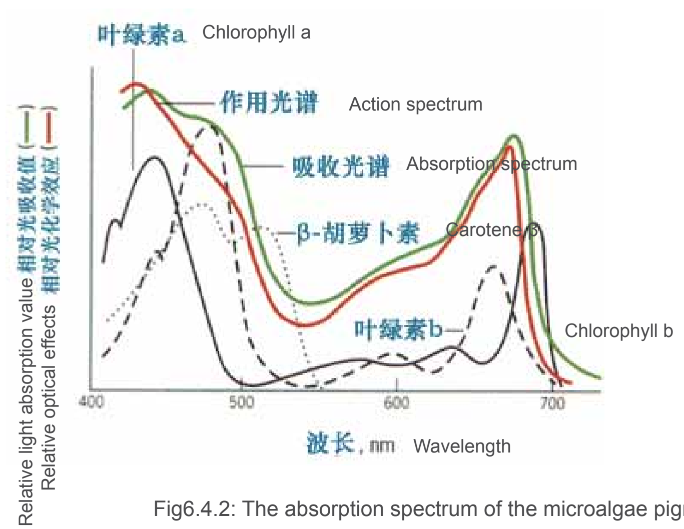


Fig6.4.2: The absorption spectrum of the microalgae pigments

LED has the characteristics of low cooling load, high electro-optical conversion efficiency, and allowance for setting a specific wavelength of light quality. So it is a perfect artificial light source for plant tissue and algal cell culture. Moreover the wavelength of LED light source could be accurate to 1nm, which means it has the unique advantage of mixing different light quality in arbitrary ratio; this is an incomparable advantage for the cultivation of light-needing creatures. However there are still four problems lying in the large-scale application of LED to microalgae cultivation.

The maturity of the LED light source technology needs to be improved. LED technology was successfully used in a number of areas of the displays, backlights, automobile lights and other LED applications, but it is still in the stage of laboratory tests in the field of microalgae culture. At present, research has proven the feasibility of the application of LED in the field of microalgae culture, but an accurate and reliable light source technology index system for microalgae farming is still missing.

The LED cost is still high. Currently, the price of the LED light source is plummeting at a rate of 20-30% per year, and the biological effectiveness is saving about 50% of power. But there is still a large price difference between the LED light source and conventional light sources, which largely limits the application and promotion of the LED light source.

The uniformity of the LED light quality needs to be improved. The wavelength of the LED light source can be accurate to 1 nm technically. But the LED light source generally fails to achieve this standard in the market. This requires to improving the uniformity of the light quality of LED light source, and the existing LED light sources in the market are all tainted with fast lumen depreciation (light loss).

The development of the LED photobioreactor technology needs to be improved. Large-scale microalgae farming must use the photobioreactor. Currently, the LED light bioreactor has been running in some laboratories, but we are still far from industrialization (Fig6.4.3). Therefore, it is very necessary to improve the development of the LED light bioreactor technology and fully and effectively use the LED light source for microalgae cultivation.

Fig6.4.3: LED microalgae culture photobioreactor schematic diagram.

The development of modern photovoltaic technology and birth of cold light source at nanometer-level accuracy, i.e. light-emitting diode (LED) light source, provides the light source for the research of the Efficient Culture of different microalgae and corresponding light quality. South Korean scientists' research results show that the LED light source can improve microalgae photosynthetic efficiency, thereby increasing cell density of microalgae; Taiwanese scholars' study results show that the LED's red light can improve the content of Spirulina biomass and chlorophyll; Tao You et al. studied the red and the blue lights on the the Porphyridium cruentum's growth, and found that a combination of the red and the blue lights' illumination accelerates its growth; Nathalie Korbee used five kinds of lights (red, yellow, green, blue and white), to irradiate the red algae Porphyra leucosticta, and found that the red and white lights can promote the photosynthetic rate and the growth rate, while the Blue-ray affecting worst; Xu Mingfang et al. from Jinan University, studied that the LED integrated lights affect the growth of Spirulina, and found that compared to the cool white fluorescent lamps, the radiation monochrome red LED integrated light board significantly improved the efficiency of Spirulina cultivation; through the use of eight kinds of monochromatic LED light to culture several marine economy microalgae, Mao Anjun and the research team in Ocean University of China discovered that the different spectral structures affected the growth rate of microalgae under the same light intensity condition and the continuous spectrum facilitated the highest growth rate; Fang Zhiguo et al. found that LED Blue-ray (Hangzhou HANHUI Optoelectronics Technology Co., Ltd – Fig6.4.4) played a significant role

Fig6.4.4: LED light source for microalgae cultivation.

of promoting the accumulation of metabolites with the growth of Chlorella pyrenoidosa, and compared with incandescent, the LED light played a positive role in the growth and the accumulation of grease of Brown grape algaethe (Fig6.4.5). The results of these studies have laid a good foundation for the practical application of the LED light source in the microalgae culture, and it has good prospects for development.

Compared with traditional light sources, LED is blessed with many pronounced advantages, including inter alia long life expectancy, high color purity, low energy consumption, controllable light color, pollution-free after abandoned, etc. These advantages make it promising to develop better LED microalgae incubator and LED microalgae photobioreactor, etc. However, as a new type of light source, the LED light source needs more research and testing on the demonstration application from a technical point of view, and needs more support from the policy level.

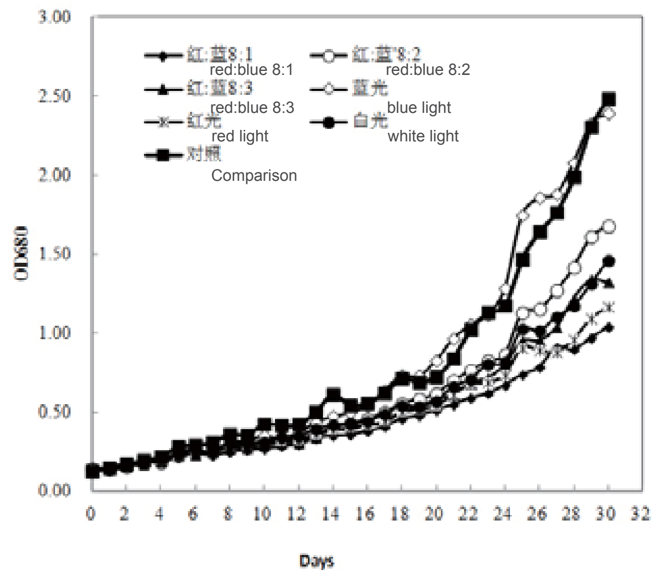


Fig6.4. 5: The influence of different light qualities of LED light source on the growth of Chlorella pyrenoidosa

First, develop highly-targeted microalgae cultivation LED light source systems.

In the process of long-term adaptation to their habitat, microalgae develop a complex pigment system to capture more light for autotrophic growth in order to enhance energy competitiveness. Therefore, the light source system for microalgae culture cannot simply copy LED light source system developed for plant growth, and it requires in-depth and detailed study of photobiology characteristics of the different varieties of microalgae. For example, Hangzhou HANHUI Optoelectronics Technology Co, in cooperation with Institute of Semiconductors, Zhejiang University and Zhejiang Industry and Commerce University, studies the microalgae of photosynthesis characteristics in-depth and successfully developed an intelligent LED light source. In addition, they hold a number of core and independent intellectual property rights of the microalgae LED light source spectral modulation, array design, and intelligent control.

Second, strengthen the study of the influence of the LED light on the different characteristics of microalgae farming and establish relative test systems.

At present, in laboratory, the artificial light source used in the microalgae culture studies is incandescent, while the open-air microalgae culture photobioreactor light source is sunlight currently. If the weather remained cloudy, it would be the negative impact on the large-scale cultivation of microalgae. And because these light sources are immutable full-spectrum light, there is a significant disadvantage using it for microalgae culture. As a narrow spectrum of light, LED has a controllable wavelength range which can be limited within 20 nm. Therefore, LED can provide more wavelength selections for different types of microalgae culture. The different types of microalgae and the different growth stages of the same microalgae have different light absorptions of different colors, and the microalgae growth is not the same. Thus, there is a need to select specific light colors to match different microalgae types and genotypes; and to conduct targeted research on corresponding light intensity and photoperiod. It is very necessary to strengthen research on LED light's impacts on different microalgae species' performance in cultivation; and establish corresponding test system.

Third, develop the LED microalgae incubators and LED microalgae photobioreactors based on the different types of microalgae and the genotypes.

The influence of Light quality, light intensity and photoperiod on microalgae growth and accumulation of metabolites has gained much emphasis in relevant research inputs and efforts. Zhang Aiqin et al used Spiruline platenesis as the test material, and found that Spiruline platenesis grew fastest in the red light. In the China Biddulphia experiments, Wang Wei found the daily proliferation rate is the fastest in the white light, followed by Blue-ray; Cai Minggang et al found that the red light can promote the growth of Haematococcus pluvialis. Wu Yin et al showed that Dunaliella in red or white light and Dicrateria inornata in blue or red light grew fast. As can be seen from the above results, the different types of microalgae need different optical quality, light intensity and light cycle. Therefore, in different microalgae cultivation process, it is necessary to further clarify the causal relationship between the characteristics of the microalgae growth and the accumulation of secondary metabolites and the light environment of light quality conditions, light intensity, photoperiod and spectral compositions. Especially, in the process of microalgae large-scale farming, according to the characteristics of different types of microalgae cultivation, the new practical and efficient LED microalgae incubators and LED microalgae photobioreactors need to be researched and developed.

Fourth, strengthen the cooperation of enterprises and research institutes and the integrated development of microalgae culture system.

Currently, the four key issues of the industrial production of microalgae biodiesel are the design technology of photobioreactors, the control systems of microalgae culture, equipment manufacturing and the control of production costs, involving multi-disciplinary and multi-field techniques. Enterprises need to strengthen energy efficiency and develop LED lamps which are suitable for microalgae culture. Research institutes need to strengthen systematic research of the LED microalgae culture technology, to explore supporting techniques of microalgae culture, and to tap and give full play to the advantages and potential of LED microalgae culture. For example, Taiwan Power Company released research program of that the TPRI solar LED lighting used in microalgae aquaculture in October 2010. Dalin power plant, which belongs to the company, cooperates with Chemistry and Environment Research Center of Taiwan Power Research Institute to carry out "seawater FGD, desalination and the reduction integration plan of microalgae fixed carbon dioxide". The preliminary assessment of the effectiveness of the microalgae fixed carbon is about four times higher than the tree-planting.

In addition, on the policy support level, government should combine the government guidance and support with market mechanisms, give proper incentives in tax and subsidies, and support scientific research and industrial innovation. Scientific research departments and enterprises need to undertake the projects together.

6.5 Current Situation and Prospect of LED Medical Lighting

Section Contributor: Guangzhou Lu

Abstract: This paper gives an introduction to medical lighting systems, analysis of the status quo of LED medical lighting, market demand, user acceptance and evaluation, as well as prediction of the prospects for the development of LED medical lighting industry.

Keywords: LED medical lighting, green lighting , shadowess lamp

6.5.1Introduction to LED medical lighting

6.5.1.1Overview of LED medical lighting development

LED lighting development began in 1970 with the first red LED, through white LED luminous 70lm/W flux in 2005, to Cree's white LEDs exhibiting luminous efficiency as high as 240lm/W in 2012. LED medical lighting develops rapidly due to the excellent characteristics of LED, support of state policies, improvement of standards, development of intellectual property as well as the huge market of medical lighting. The development of LED medical lighting in Europe and the United States started in 2005; China LED medical lighting started in 2007, and other countries entered the field of LED medical lighting over the past two years. LED medical lighting enterprise and technology have gradually matured after several years of development, and are gradually replacing traditional medical lighting.

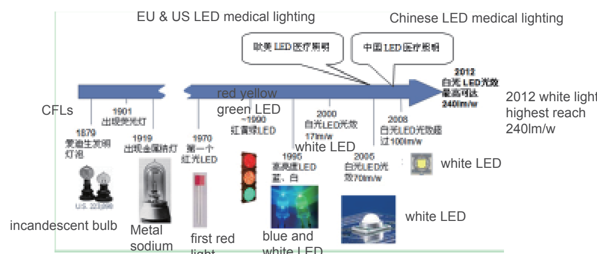
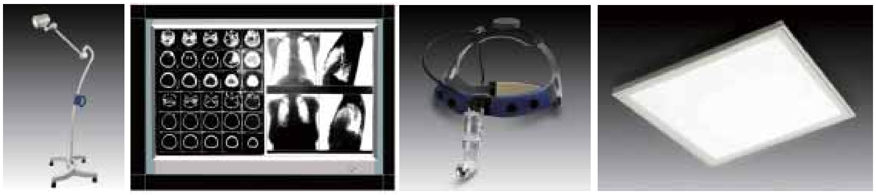


Figure 6.5.1 Development history of LED lighting

6.5.1.2 Classification of medical lighting

Medical lighting includes the following categories: special lighting equipment with special functional requirements used for examination, diagnosis and treatment process in clinical hospital, including surgical lighting, such as surgery shadowless lamp; localized lighting used for diagnosis and examination such as check lights, headlights, ear lights, oral lights, endoscopic lamp, nursing lamp, film viewer lamp; general lighting including the lights of the operating room, lights in the surgery preparation room, ward lights, such as flat-panel lamps, fluorescent lamps , down lights, etc.; special features lighting equipment, such as the light therapy equipment applied to the treatment of special parts or special diseases, special wavelength and intensity, such as photodynamic therapy instrument, infrared light virus inactivated instrument, etc.. Most medical lighting equipment is suitable for promotion of LED medical lighting.


LED surgical shadowless lamp



LED examination light | LED film light | LED headlamp | LED Panel Light

Figure 6.5.2 Equipment of LED medical lighting

6.5.1.3 Characteristics of LED medical lighting

There are different functional requirements of LED lighting in LED medical lighting, such as: a fixed-point, directional lighting, high-intensity lighting, pure light color (excellent color rendering property enabling doctors to clearly point organ and tissue structure, to better adjust color temperature to a certain extent to highlight a particular organ or tissue according to requirements) as well as uniform, shadowless lighting, low spectral damage, sealed disinfection structure, air permeable structure, dimming control, high reliability and other special needs. General lighting is able to meet the medical lighting standards or equivalent functional requirements. Special lighting, for example LED surgical shadowless lamp, has attractive characteristics such as high luminous efficiency, low power consumption, no AC strobe, low total radiant energy of the whole lamp, continuous adjustment of the color temperature, small size, high security, and additionaly solves drawbacks of traditional surgical shadowless lamp such as low luminous efficiency, high power consumption and high temperature rise. Secondly, when compared with traditional surgical shadowless lamp, performance of LED surgical shadowless lamp has been greatly improved, in terms of spot uniformity, improvement of shadowless effect, continuous adjustment of light color temperature, improvement of light beam depth, lower total irradiance. General lighting, for example LED panel light, has excellent features such as low power consumption, long lifetime, no AC strobe, good sealing, easy to clean and so on to create a comfortable lighting environment.

6.5.2 Current situation of LED medical lighting

6.5.2.1 Continuous improvement of global LED standardization

At the beginning of industry development, the standards and testing methods are very important to standardize the market and establish users' confidence. Due to the particularity of LED medical lighting, traditional lighting standards and testing methods cannot fully apply, and there is an urgent need for developing a new system of assessment. International Organization for Standardization such as the International Lighting Commission (CIE) and International Electrotechnical Commission (IEC) as well as countries like the United States, South Korea has initiated the study on the development of semiconductor lighting standards.

CIE paid attention to LED as early as in the 1990s. There are more than ten study reports from LED technical committee and products such as TC2-46: CIE / ISO standards on LED intensity measurement, TC2-50: Measurement of the optical properties of LED clusters and arrays, and so on.

IEC has released more than ten standards for LED electrical characteristics and safety such as IEC/PAS 62612:2009, Self-ballasted LED-lamps for general lighting services-performance requirements, IEC 62031:2008, LED modules for general lighting-safety specifications. Meanwhile, IEC is developing or revising a number of LED related standards and technical documents covering the classification of LED, OLED flat panel, LED module, LED lumen maintenance, LED bio-security, etc.

In the United States, the Illuminating Engineering Society of North America (IESNA), the American National Standards Organization (ANSI), National Electrical Manufacturer Association (NEMA), the U.S. Department of Energy (DOE) have taken part in LED standardization work. At present, IESNA has released two famous international technical specifications, IESNA LM-79-2008: Approved Method for the Electrical and Photometric Measurement of LED Light Sources, IESNA LM-80-2008: Approved Method for Measuring Lumen Maintenance of LED Light Sources. U.S. Department of Energy is revising a series of original technical requirements for lights and lamps in accordance with the characteristics of LED lamps. NEMA has released more than ten technical specifications for the semiconductor lighting. ANSI also has released two standards on division of semiconductor color temperature.

Japan released "Lighting white LED metering method General Principles" developed by the Illuminating Engineering Society of Japan, Japan's Commission on Illumination, Japanese lighting equipment industry, the Japan Global Industrial in 2004, and released several measurement standards in the last two years.

In 2007, South Korea announced that it would develop 15 national standards in three years. It has published nine standards mainly focusing on safety and performance.

China also attaches great importance to the semiconductor lighting standards and testing methods. The main organizations for the semiconductor standardization work include the National Semiconductor Lighting Project R&D and Industry Alliance (CSA), the National Standardization Technical Committee (SAC/TC224), National Rare Earth Standardization Technical Committee (SAC/TC229), Semiconductor Lighting Technology Standards Working Group of department of Industry and Information. The CSA established the Union of Standards Coordination and Promotion Working Group in 2007, which firstly has developed a number of technical specifications, including LB/T001-2009: Integral LED street light measurement method, LB/T002-2009: LED road lighting products technical specification, etc. National Technical Committee of Standardization (SAC/TC224) drafted a number of semiconductor lighting safety and performance standards in the past two years. National Rare Earth Standardization Technical Committee (SAC/TC229) has developed the standard for LED phosphor series. Semiconductor Lighting Technology Standards Working Group of the Ministry of Industry and Information has focused on the standardization of devices and materials.

The released standards of CIE, IEC, China and the United States, including the LED chip and phosphors, LED package, LED light, LED lamps, LED control device, LED connector, LED colorimeter ensure the performance, testing and security of medical lighting LED. Standard specifically for LED medical lighting such as LED surgical shadowless lamp is under drafting stage.

Figure 6.5.3. Situation of global LED standardization

6.5.2.2 LED medical lighting patents

Intellectual property (IP) plays an important role in the innovation and competition in LED industry. Among the 6714 U.S. patents related to LED technology issued in the past five years, United States holds a leading position with 2422 of them, followed by Japan with 1090, China Taiwan 972, Germany 279, 114 in mainland China, the Netherlands 65, Canada 61, France 51 and Britain 47. The scope of patents covers the entire LED industry chain, including the substrate, epitaxy, chip, package, application and others of such links. Among them, LED medical lighting belonging to a branch of LED lighting applications, has a shorter development period with less patents.

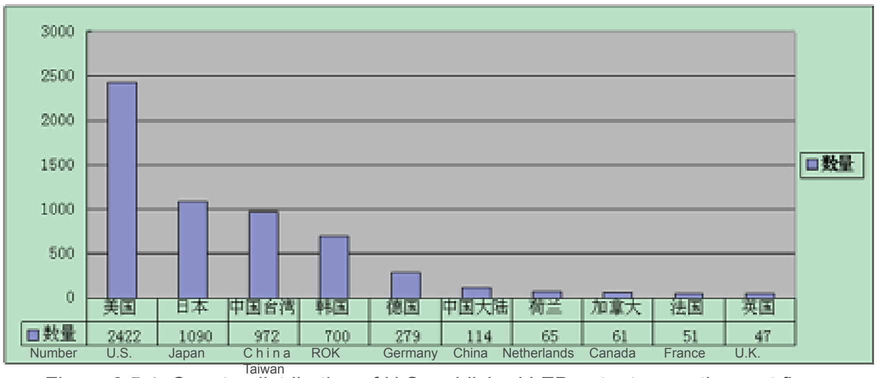


Figure 6.5.4. Country distribution of U.S. published LED patents over the past five years

6.5.2.3 Distribution of the LED medical lighting enterprises

Most LED medical lighting enterprises are concentrated in Europe, especially Germany and France, such as Dr. German Mark (DR MACH); German Kenswick (BERCHTOLD), the German Martin (Martin), Germany Heraeus (Heraeus), Germany MAQUET (MAQUET, Healforce), Germany the del (DRAGOR), Germany Lily (Berchtold), France ALM (ALM, HERUS, HANNUEX), France Sylvania (SYLVANIA), the French Ken Suowei (Kenswick) and so on.

LED medical lighting companies in the United States (AMOSCO) mainly include American medical lighting (NUVO), Burton (Burton), United States (MIDMARK), U.S. Si Tairui (Amsco) and others. In China Taiwan, there are LED medical lighting companies such as the Sampoong Group, Taiwan Mediland (MEDILAND), Taiwan Jaco virtues, etc.; in mainland China LED medical lighting companies include Shenzhen Mindray, Chongqing Bang Qiao, the Fifth factory of Shanghai, Shanghai Banking Corporation medical equipment, Shandong Minter. Japan, South Korea and other countries have fallen behind in the field of LED medical lighting.

Figure6.5. 5 Distribution of LED medical lighting enterprises

6.5.2.4 Developments of LED medical lighting

The competitive market environment

Firstly, due to the high barriers of the medical device industry, there are obstacles such as shortage of technical personnel, brand, sales channel, fund and market access which limits the access of a large number of enterprises. Secondly, medical device industry is less affected by the economic cycle but more subject to the influence of industrial policies. Finally, from the market perspective, the unique technical requirements and characteristics, with medical surgical shadowless lamp as an example, make medical lighting products extremely special among all the lighting products. They must comply with the regulations on medical equipment, pass strict clinical examination and acquire medical equipment product license. Therefore, relevant enterprises of special lighting products with high-tech, high-risk and strict access could avoid vicious competition confronting conventional lighting products.

LED lighting policy of different countries

European and American countries such as Germany, France and the United States have a long development history of medical lighting device which is very mature. However their LED appliance in medical lighting has rapidly developed only for the last few years.

China is now vigorously developing the LED industry. LED output value of China accounted for 4% of the global LED output value in 2009 and increased to 11% in 2010. Its semiconductor lighting industry keeps continuously rising in global LED industry chain with steady enhancement of its comprehensive competitiveness. At the same time, China developed a semiconductor lighting industrial base in many cities such as Xiamen, Nanchang, Shanghai, Dalian, Shenzhen, Yangzhou, Wuhan and carried out pilot and demonstration semiconductor lighting application projects, among which the "Ten City, ten thousand lamps" project. The development of LED medical applications in China is very fast. Chongqing State Bridge Technology Co., Ltd. launched the world's first color temperature adjustable LED surgical shadowless lights in 2008. Taiwan region of China ranks No.1 in production and No.2 in output value in the world in terms of optoelectronics industry and owns an optoelectronics industry supply chain and technology. It has addressed the problems of high requirements for LED specification, small number but diversified products, entered the LED medical lighting industry, raised the value-added of the LED light source and created a LED lighting industry. It is expected that Taiwan will have taken 5% to 20% market share of LED medical lighting industry by 2012.

South Korea is late in developing the LED industry when compared to Europe and U.S. Its industry features large-scale, self-reliance and vertical integration. With the help of Korea government and large enterprises, its LED industrial products are comparable with that of early LED manufacturing countries. But it has no internationally renowned brands in LED medical lighting field. Japan currently is the world's largest LED producer with complete industrial chain including raw materials, equipment, substrate, epitaxy, chip package and application. However it is still in its infancy in LED medical lighting field. Regarding other countries like Canada, Russia and Australia, their LED medical lighting field is still blank although they announced plans for phasing out incandescent bulbs.

6.5.3Market Demand

The market size

The global market for medical lighting in 2007 was $ 981.2 million, up by 5.1% compared with that of 2006. And in 2010 did it increase to $ 1111 million, which is a relatively big market.

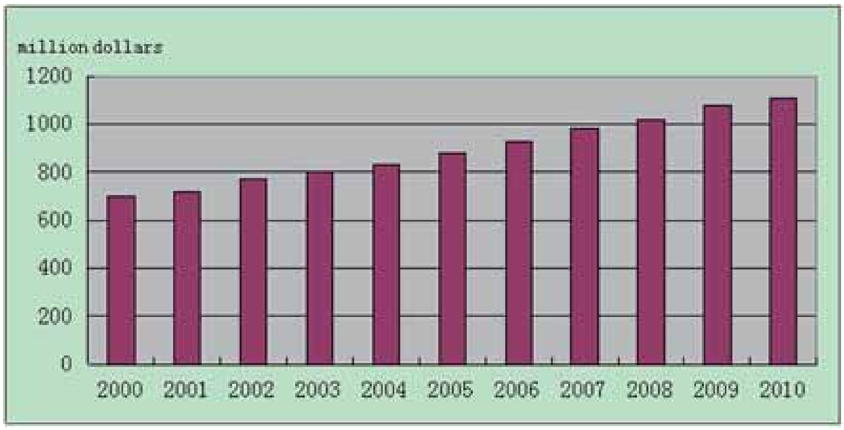


Figure 6.5.6 Global market of medical lighting

In recent years, there was a long-term steady increase of LED medical lighting market due to fast development of global health system, increasing new hospitals and medical institutions and more market demand for medical lighting. At present, the operational medical lighting equipment includes surgical shadowless lamp, various kinds of medical examination lights, headlights and watch-film lights, general lighting flat panel lamps and fluorescent lamps. With continuous phasing out of traditional medical lighting products and rising number of medical and health institutions, it is predicted by some research institutions that there will be a peak time for replacing conventional lighting lamps by LED medical lighting lamps in the next 3-5 years.

What's more, many countries in the world have made substantial efforts in energy saving and emission reduction to cope with shortage of resources. Medical institutions are big players in lighting and will save 50% energy at least if they replace the conventional lighting lamp with LED products. This will accelerate the lighting reform of all major hospitals.

6.5.4 User acceptance and evaluation

LED medical lighting equipment marches into the medical lighting field as a dark horse due to its excellent characteristics of energy-efficiency, high-performance and security. Therefore, it quickly gets the recognition and praise of health institutions at home and abroad. At present most international bidding projects on hospital lighting equipment especially require LED lighting equipment. This shows that LED medical lighting equipment has entered the international arena of medical lighting and obtained wide attention and recognition in the concerned industry, and is gradually replacing the traditional medical lamps.

Take the LED medical lighting holistic operating room built up by the Chongqing State Bridge Technology Co., Ltd as an example: the surgery lighting employs the consecutive color temperature adjustable LED shadowless lamp, achieving adjustable light source color temperature, high CRI, uniform and soft illumination and so on, which help doctors improve the quality of surgery and reduce risk. Inside the operating room, LED panel lamps offer appreciated characteristics such as high brightness, uniform illumination, soft light, no AC strobe, low noise and good color rendering. These characteristics satisfy the dual requirements for functionality and comfort of the operating room, improve the entire operating room lighting effects and receive unanimous recognition and praise from the medical institutions.

LED integrated operation room
Light environment: No ultraviolet and infrared ray, Uniform illumination
Low carbon: CO_2 emissions are about ¼ of that in traditional operation room
Energy-saving: about 50%
Life time of LED: No need to replace the LED in 5 years
Color rendering: >90

Figure 6.5.7 LED medical lighting holistic operating room

6.5.5 The outlook for LED medical lighting industry development

The great market potential of LED medical lighting product

LED industry is steadily developing with the progress of LED industrial chain, continuous improvement of global LED standards and the strong support of the government of all countries. The application of LED in medical lighting addresses many problems, such as high energy consumption, short service life and potential risks of conventional medical lighting equipment, which is recognized and positively commented by many clients. Currently the demand of international market for medical lighting mainly focuses on LED medical lighting equipment with great market potential and relative small competition pressure. Therefore, there is a huge market demand for the development of LED medical lighting equipment.

Trend for medical lighting system — green lighting

Green lighting saves energy, protects the environment and improves lighting quality. LED is the new generation of lighting source with characteristics such as high luminous efficiency, high brightness, index display, soft light, no infrared or ultraviolet light pollution, no AC strobe and low noise. The application of LED in medical lighting could satisfy both functional and comfortable requirements for medical lighting.

Modern hospital has a good lighting system, which could relieve the patient's negative feelings in such a bright and comfortable environment, make the patients peacefully wait for doctor and treatment, bring positive treatment effects, ensure that medical workers quickly and efficiently complete their work, ease the medical staff mental and physical fatigue in order to improve work efficiency. Therefore, the application of LED medical lighting is the inevitable trend for the achievement of green lighting in hospitals.

Chapter VII:

SSL products full life-cycle green manufacturing and recycling

Chapter Contributor: Sanders Gielen

In the ISA strategic research agenda for Green SSL and Sustainability (Gielen, 2011), we already outlined the background for this strategic outlook. The main points are reiterated here and some important additional information and references are given. This chapter ends with an outlook on R&D priorities to further green the SSL industry.

Figure 7.1 shows the industrial SSL value chain in which the LED systems are created, used, and disposed. It all starts with the materials that, with the aid of energy and equipment, are built into dies up to the LED system. After the life time the products are disposed. The disposal phase has opportunities to regain the materials or parts that may be reused or recycled.

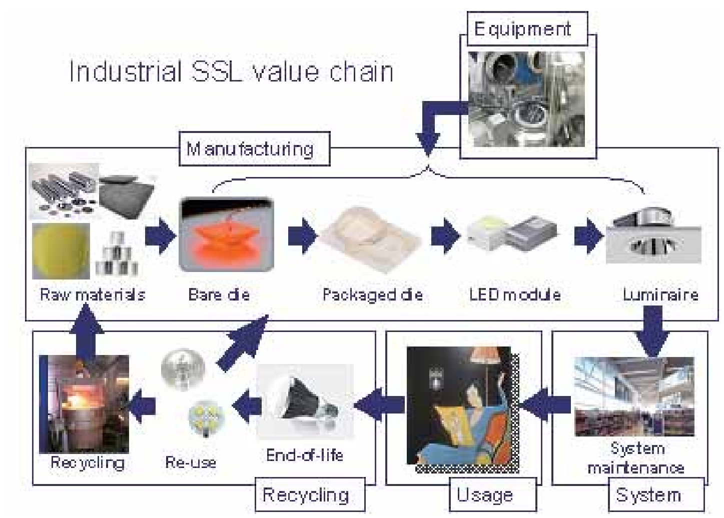


Figure 7.1: The industrial value chain for SSL products from creation to disposal.

Figure 7.2: Factors in the full SSL life cycle

The following sections will shortly discuss the main points of Figure 7.2.

7.1 Life cycle analysis with recycling

A life-cycle analysis (LCA, also known as life-cycle assessment, eco-balance, and cradle-to-grave analysis) is a technique to assess environmental impacts associated with all the stages of a product's life from-cradle-to-grave (i.e., from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling) (Wikipedia community, 2012). LCAs can help avoid a narrow outlook on environmental concerns by:

- Compiling an inventory of relevant energy and material inputs and environmental releases;
- Evaluating the potential impacts associated with identified inputs and releases;
- Interpreting the results to help make a more informed decision.

There is no single comprehensive LCA methodology and depending on the product and material streams under consideration, specific additions may be needed, for example to include recycling in more detail (Ligthart, et al., 2012). Still, a generic approach is shown in Figure7. 1. For example, a comprehensive overview of LCA for lighting, but excluding LED was presented by (Welz, et al., 2011). A LCA review for LED lighting, using a limited number of sources is given by (Solid State Lighting Program. US Dept. of Energy, 2012)

The general procedure for conducting a life-cycle analysis is defined by the International Organization for Standards (ISO) 14000 series. The main phases of an LCA according to ISO guidelines are goal, scope, and boundary definition; life-cycle inventory (LCI) analysis; life-cycle impact assessment; and interpretation.

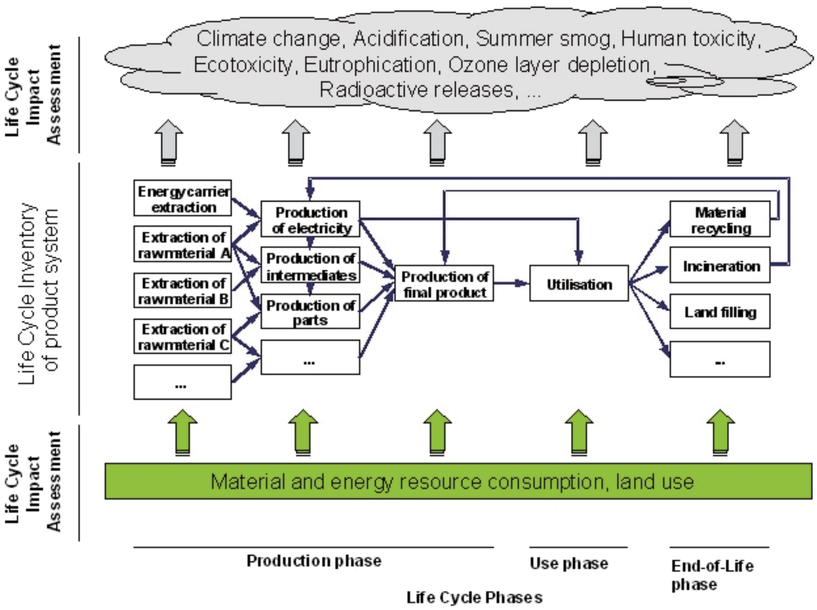


Figure7. 3: Scheme of a product system's life cycle with data collection of product and waste flows (blue lines) and resources (green) and emissions (grey arrows) followed by the impact assessment of the emissions and resource consumption (European Commission, 2012).

7.2 Materials in SSL

When building lighting systems the LED die is packaged. The LEDs are put into modules and built into luminaires (Figure7. 4). At the different levels materials are added in different quantities. When disposing the luminaire, these materials could be regained through appropriate “de-manufacturing” approaches .

Figure7.4: When building lighting systems, the packaged LED is built into the module, that in its turn is built into the luminaire.

The materials of interest at the different levels are given in the following tables.

Die Level	Package Level		Module Level	Luminaire Level
	Phosphors	Bonds, Solders, etc.		
Gallium	Yttrium	Gold	Copper	Iron
Indium	Cerium	Silver	Aluminum	Aluminum
Arsenic	Europium	Tin	Tin	Copper
Aluminum	Terbium	Copper	Silver	Plastics (housing)
Silicon	Erbium	Carbon	Indium	Clear Plastics (lenses)
Magnesium		Silicon		
Zinc				
Tungsten				
Germanium				

Table7.1: Materials of high interest in LED die, package (Gielen, 2011), module, and luminaire.

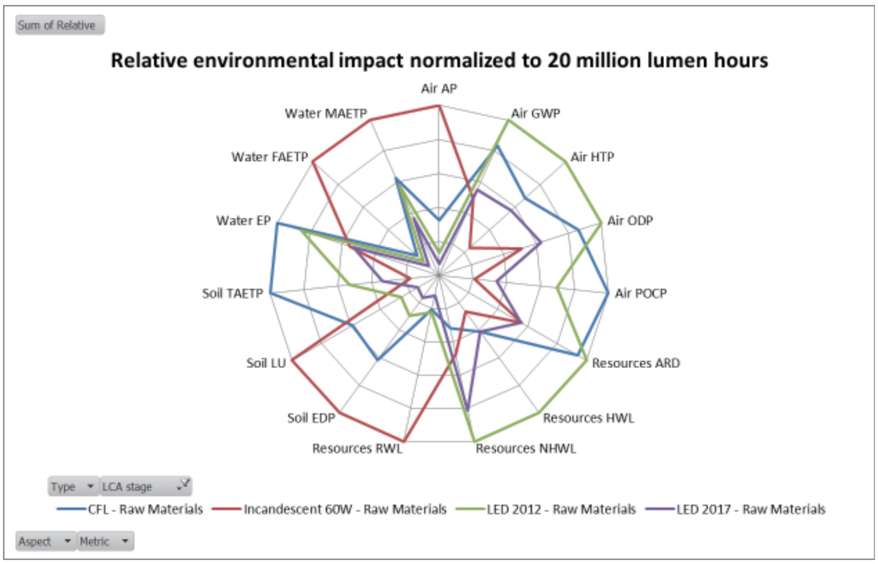


Figure7. 5: Relative environmental impact of different lighting products normalized to 20 million lumen hours and relative to the maximum impact value per category. All data used was obtained from (Scholand, et al., 2012) but reformatted to this figure. The abbreviations are explained in Table7. 2.

In Figure7. 5 the material use expressed in environmental impact indicators is shown. The use was calculated per 20 million lumen hours (see Table 7.3 the characteristics of the lamps under investigation are shown). It is clear that in certain material aspects the LED lamp is not yet the winner (green line) but is expected to improve in the coming years (purple line). A detailed analysis is given in (Scholand, et al., 2012).

	Abbreviation	Name	Indicator
Air / climate	GWP	Global warming potential	Greenhouse gas emissions
	AP	Acidification potential	Air pollution
	POCP	Photochemical ozone creation potential	Air pollution
	ODP	Ozone depleting potential	Air pollution
	HTP	Human toxicity potential	Toxicity
Water	FAETP	Freshwater aquatic ecotoxicity potential	Water pollution
	MAETP	Marine aquatic ecotoxicity potential	Water pollution
	EP	Eutrophication potential	Water pollution
Soil	LU	Land use	Land use
	EDP	Ecosystem damage potential	Biodiversity impacts
	TAETP	Terrestrial ecotoxicity potential	Soil degradation and contamination
Resources	ARD	Abiotic resource depletion	Resource depletion
	NHWL	Non-hazardous waste landfilled	Non-hazardous waste
	RWL	Radioactive waste landfilled	Hazardous waste
	HWL	Hazardous waste landfilled	Hazardous waste

One way of greening products is by reducing the materials in the product. In particular (potentially) toxic and scarce materials will be the prime target for reduction. However, the reduction of materials introduces other risks. These risks include:

- If material amounts in the product fall below a certain level, in particular levels defined in directives and legislation, the concentration might get too low for efficient recovery. Also, the product might be labeled "green", while recovery potential and even tracking of the materials may be lost.
- The processing needed to create small amounts of materials, in particular thin films, require additional energy as shown in Figure7. 9. Therefore, the material reduction needs to be in balance with the methods needed to reduce the materials.
- In some cases the material may become unhealthy or even toxic due to the size of the particles and fibers under the circumstances they are free moving (i.e., not particles or thin-film fixed to another material). It is known, for example, that very small glass fibers may induce inflammatory reactions for people.

Another helpful element is the expected efficiency increase of the LED, that increases the overall lumen output characteristics in combination with extended lifetime reducing the average environmental impact to about 60% of the current LED lamp value. Furthermore, the increased efficiency will also reduce the heat sink size, as less heat will be generated in future LED products.

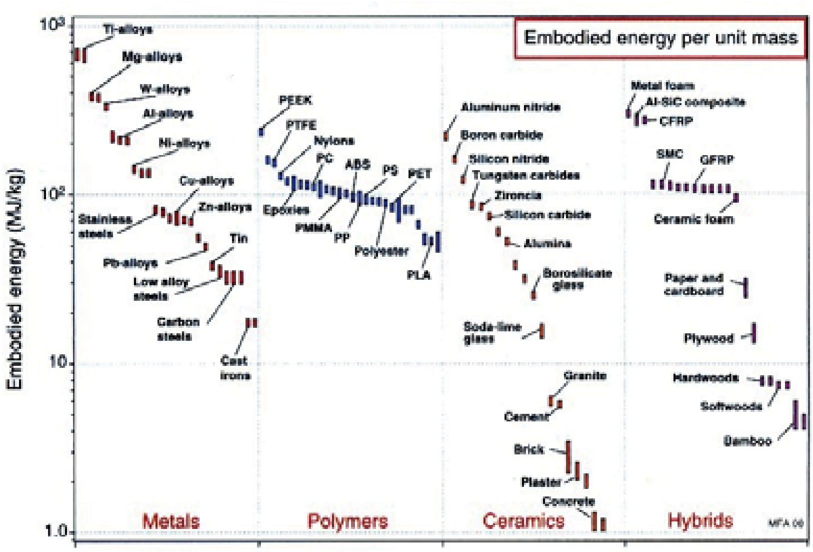


Figure7. 6: Energy embodied in bulk materials expressed per unit mass (Ashby, 2009)

In order to reduce the environmental footprint of the materials in LED products and supporting materials in the process represented in terms of energy embodied in the mass in Figure7. 4, one may want to choose more favorable materials. Furthermore, based on availability (scarcity), alternate materials that are readily available and that need less exotic refining processes may improve the green factor (Figure7. 5). Opportunities may be found in:

- Si wafers instead of sapphire wafers. The energy in a Si-wafer is less than in a sapphire wafer. This is also (partly) reflected in the price of the wafers. Furthermore, with the larger sizes of the Si-wafers, in particular the MOCVD processes can be more efficient from a deposition area point of view.
- Creating LED sources that are not based on GaN but are based on ZnO, MgSe, and other semiconductor materials. Possible LED material compositions are given in Figure 7.6. An example of a ZnO nano-wire LED is shown in Figure 7.7.
- Replacing the critical Au wire bonds with Cu wire bonds as the availability of Cu is better that Au.
- Light (wavelength) conversion materials

  o More effective inorganic phosphors
  o Quantum dot phosphors
  o Organic phosphors

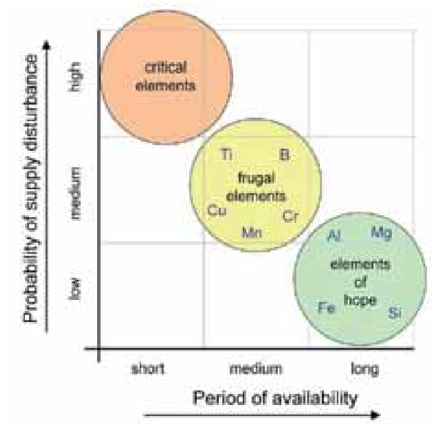


Figure7. 5: Three classes of elements from an availability and supply disruption point of view.

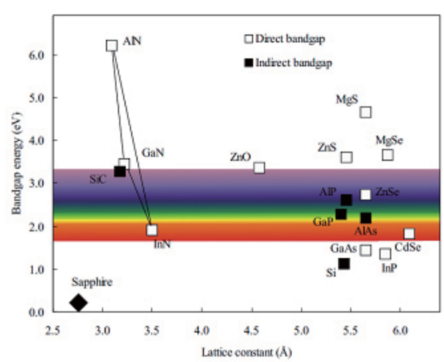


Figure 7.6: Band gap energy versus lattice constant for various semiconductor materials that may create LEDs.

Figure 7.7: ZnO nano-wire LED (Ecosparke)

7.3 Eco-design methodologies

Full life-cycle sustainability of products, requires that the design of products already starts with taking as much as possible the prerequisites into account, that favor “green” material choices, “green” manufacturing methods, and “green” disposal. The methodologies and tools that are developed all kind of satisfy or express the so called The Ten Golden Rules, as described by (Luttropp, et al., 2006). In short these rules are:

- ONE Do not use toxic substances and utilize closed loops for necessary but toxic ones.
- TWO Minimize energy and resource consumption in the production phase and transport through improved housekeeping.
- THREE Use structural features and high quality materials to minimize weight in products if such choices do not interfere with necessary flexibility, impact strength or other functional priorities.
- FOUR Minimize energy and resource consumption in the usage phase, especially for products with the most significant aspects in the usage phase.
- FIVE Promote repair and upgrading, especially for system-dependent products. (e.g. cell phones, computers, CD players, and possibly SSL products).
- SIX Promote long life, especially for products with significant environmental aspects outside of the usage phase.
- SEVEN Invest in better materials, surface treatments or structural arrangements to protect products from dirt, corrosion and wear, thereby ensuring reduced maintenance and longer product life.
- EIGHT Prearrange upgrading, repair and recycling through access ability, labelling, modules, breaking points and manuals.
- NINE Promote upgrading, repair and recycling by using few, simple, recycled, not blended materials and no alloys.
- TEN Use as few joining elements as possible and use screws, adhesives, welding, snap fits, geometric locking, etc. according to the life cycle scenario.

Naturally, these Ten Golden Rules must be made specific for solid-state-lighting products in relation to the production-use-disposal cycle.

7.4 Manufacturing

As shown in different studies (for example, (OSRAM, 2009), (Solid State Lighting Program. US Dept. of Energy, 2012) (Scholand, et al., 2012)), there is still room for improvement in the SSL manufacturing chain. LED lamps are already superior to CFL lamps (Figure7.8) and further environmental impact reduction is expected. Like for the materials, this is mainly due to the increase efficiency and lifetime.

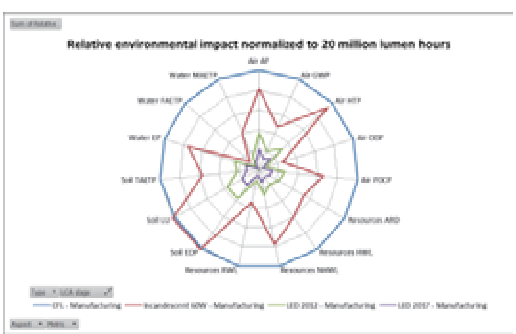


Figure7.8: Relative environmental impact of different lighting products normalized to 20 million lumen hours and relative to the maximum impact value per category. All data was used was obtained from (Scholand, et al., 2012) but reformatted to this figure.

An important method to reduce the material use (see previous section) is using thin films and coatings. An important drawback however, is that generating the small amount will require more energy (Figure7. 9).

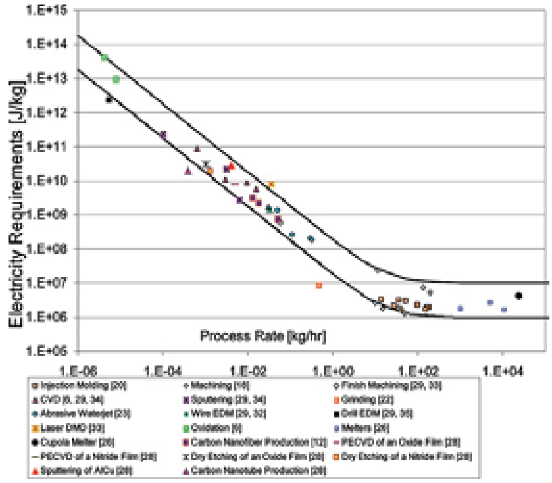


Figure7. 9: Electricity requirements for different production processes. The typical thin film processing technologies have low rate and high electricity requirements (Gutowski, et al., 2009)

A comprehensive overview on the interaction of manufacturing with LCA, R&D, and legislation is described in (Gutowski, et al., 2005). An extension of this survey with China, Korea, and India would be very useful. Furthermore, the investigation could be made more specific for the SSL industry.

7.5 Business models for maintenance and upgrade

As indicated earlier, a big progress in lighting products is expected in the coming year, in particular in efficacy and lifetime. This means that for light intensive place there can be useful to change the light sources to improved ones even before the lifetime of the current light source is consumed. Furthermore, lighting companies are busy making the lighting systems more intelligent, to further save energy and enhance the user experience. These kind of aspect give input to new maintenance and upgrade approaches, and thus new business opportunities.

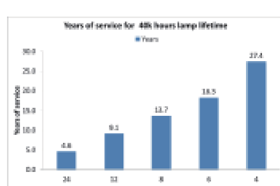


Figure7. 10: Service lifetime in years as a function of hours on per day for a 40k hours lifetime.

7.6 Energy use in lighting

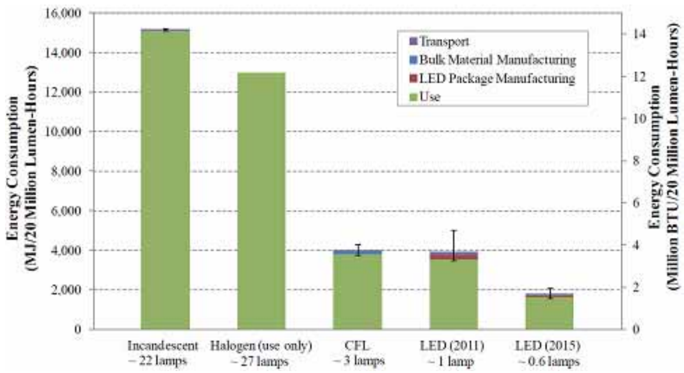


Figure7. 11: Energy consumption and energy needed for transport, material, and product manufacturing. (Solid State Lighting Program. US Dept. of Energy, 2012)

Solid-state-lighting, in particular LED lighting, already has a very "green" image because of the energy saving that is realized due to the higher efficiency of the light source compared to traditional light sources (Figure7. 11 and Table 7.3). The energy saving can be further enhance by making the SSL light sources intelligent, such that lights are switch off when there is sufficient daylight or no people are present, and other smart applications that tailor the light generation to the actual need (see for example (Pandharipande, et al., 2011)).

Characteristics	Incan-descent	CFL	LED lamp 2012	LED lamp 2017
Power (W)	60	15	12.5	6.1
Output (lm)	900	825	812	824
Efficacy (lm/W)	15	55	65	134
Lamp Lifetime (h)	1500	8000	25000	40000
Lifetime Light (M lm hr)	1.35	6.6	20.3	33.0
Impact scalar	15.04	3.08	1.00	0.61

Table 7.3: Performance Parameters for Lamps in the analysis of (Scholand, et al., 2012)

As LED light sources in general will exceed the lifetime of traditional light sources, the design of luminaires can be reconsidered: In traditional luminaire it is required that the light source can be replaced as the luminaire lifetime is multiple of the source lifetime. For LED the luminaire lifetime and source lifetime can be equal. This opens opportunities to design and produce in a different way. This different way should be greener as well and may reduce the relative high energy consumption of the materials and LED packaging for LED lights that can been seen in Figure7. 11.

In Figure7. 12 the environmental impact over lumen-lifetime of different lighting sources is shown.

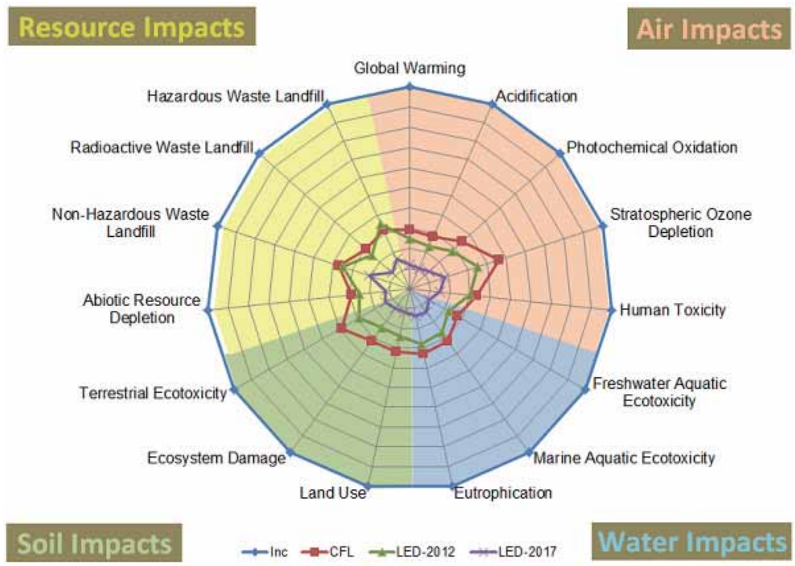


Figure7. 12: Comparison of environmental impact of different light sources normalized to the impact of the incandescent light sources (Scholand, et al., 2012)

7.7 Business models for disposal

As the recycling of products with valuable materials, and LED products belong to that category, there is value in the disposal of these products. In particular in the professional market, this can lead to new business opportunities. Companies may consider in combining the upgrade and maintenance services with targeted disposal and possibly re-use constructs. The attractiveness will depend on the developments in the field of disposal as well as the ease of disposal and recycling.

7.8 Disposal

In the disposal phase there are several aspects that need to be considered:

- How are products disposed of? For professional lighting this will happen in a different way than for consumer products. In professional lighting, in particular installation companies are also active in disposing old lighting systems. For consumer products, large differences will exist in the world, depending on the urbanization, and the level of organization of the collection of lamp waste.
- What are the options for recollection of the materials? This depends on the measures that have been taken in the design of the products (see section Ecodesign) as well as the options to "demanufacture" the LED lamps. An overview for electronic products is given by (Williams, 2006) and the effect of product recovery is described by (White, et al., 2003).
- What new methods will come available in the waste stream treatment to enrich the waste streams to value sources of materials. This requires separation systems (see (Wolf, et al., 2010).

The disposal must also be considered in conjunction with the recycling processes that are discussed in section 0.

7.9 Legislation and Regional Effects

In general it can be stated that governments worldwide strive to reduce the use of energy, reduce the use of toxic matter, and encourage recycling, as summarized in the ISA Strategic Research Agenda on Green and Sustainability (Gielen, 2011).

The main incentive of this worldwide effort is captured in the Kyoto Protocol (United Nations, 1998). In 1997, the signatories to the Climate Convention held a conference in Kyoto, Japan. The purpose of this conference was to come to an agreement that would commit the industrialized world to restrict the emission of greenhouse gases, the prime cause of global warming. The agreement, the Kyoto Protocol, came into force in 2005 and will remain valid until 2012.

The initial Protocol defines binding targets for the emission of greenhouse gases. By the end of 2009 a follow-up United Nations meeting was organized to define a follow-up for the Protocol. Unfortunately this meeting ended without a binding agreement on climate change. However a fund was established to support third world countries who are dealing with the consequences of climate change.

By the end of 2011 a decision on the Kyoto follow-up was made. The initial Kyoto Protocol will be extended to 2017 or even 2020, but participation will be voluntary. The European countries have promised to enforce Kyoto. The EU can be hold accountable for 15 percent of the global emissions. Unfortunately multiple polluting big countries have stated not to ratify the renewed Kyoto.

In the near future a roadmap will be build towards a new climate agreement. Negotiation on the matter will start in 2015 en should come into force for all UN member states by 2020.

Due to the Kyoto Protocol, local authorities have come up with different directives to pursue national climate protection targets. In general these directives contain regulation on energy efficiency, material restriction, eco design requirements and recycling.

As a result of the Kyoto Protocol most countries already have or are developing regulations to phase out incandescent lighting and favoring solid-state-lighting.

A more detailed overview of the multiple regulations concerning climate protection is given in the ISA Strategic Research Agenda on Green and Sustainability (Gielen, 2011).

In particular for the disposal phase of products large differences between regions can be found for the collection and processing of waste lighting products. For example, certain regions consider solid-state-lighting to be part of e-waste, while other regions have separate lighting waste-streams, yet other regions make no separation in the waste. The differences are mainly due to the degree of organization of the waste disposal in relation to the urbanization. See for example (Huisman, et al., 2012).

The local difference in regulation, result in a difference of attitudes to behavior in people. Social research has argued that two basic types of variables influence the environmental awareness behavior: incentives for the social behavior and facilitators and barriers for the social behavior (Hornik, et al., 1995).

For example they show that for recycling, rewarding only has a short-term effect. The reward is good for initiating the behavior, but once the reward is taken away, the recycling behavior stops. Besides monetary rewards, the feeling of being more self-sufficient and less wasteful has a strong positive influence on recycling. It is also shown that social influence, like friends and family, determines the recycling behavior. Often demographic variables such as education, income and age are associated with the social situation.

Next to personal feeling and education it is shown that the convenience and ease of recycling is an effective moderator (Nyamwange, 1996). Curbside recycling is a way to overcome inconvenience and facilitate recycling.

Finally is it important to know where, what and how to recycle, therefore it is important for governments to educate individuals and industry, and make them aware of reasons to recycle and the positive impact that recycling has.

7.10 Recycling

LED lighting is environmentally friendly during its lifespan and can be even more beneficial to the environment if recycled. Over 95% of an LED lamp is recyclable. Since LEDs do not contain significant amounts of any harmful components and they can therefore be disposed of and recycled in the same way as an ordinary light bulb.

Based on how and where the recycled material of the LED lamp is used again, the recycling process is called, closed loop, open loop or semi-closed loop recycling. The different recycling schemes are explained in Figure 7.13: Closed loop, semi-closed loop and open loop recycling (Ligthart, et al., 2012).

A recycling process is called closed loop recycling, when the materials of the discarded product are reused in the same product system. This in contrast to open loop recycling where the recycled materials is used in another system. Since this way of recycling often means a changing the material properties and therefore loss of quality, this type of recycling is also called down cycling. However if the recycled materials are used in another product system and there is no loss in quality of the material properties, on uses the term semi-closed loop recycling.

As LEDs do not contain significant amounts of any harmful components, they are classed as RoHS compliant. RoHS stands for the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment, which came into effect in the UK on 1stJuly 2006. These restrictions prevent the sale of equipment containing harmful levels of mercury, lead, cadmium, PBB, PBDE and hexavalent chromium. Due to this compliance, LEDs can be disposed of and recycled in the same way as an ordinary light bulb.

The recycling process generally involves the LED bulbs being crushed and separated, using a bar screen, into constituent components. From here, the glass is passed through a magnetic field that can remove any ferrous metal present. To remove the aluminum and lead that is present in LED lights, a non-ferrous metal separator blasts airs at the crushed glass to direct the metal down a separate chute. The glass can then be used in other products, as can the aluminum. As glass does not degrade during recycling, it can be recycled many times over.

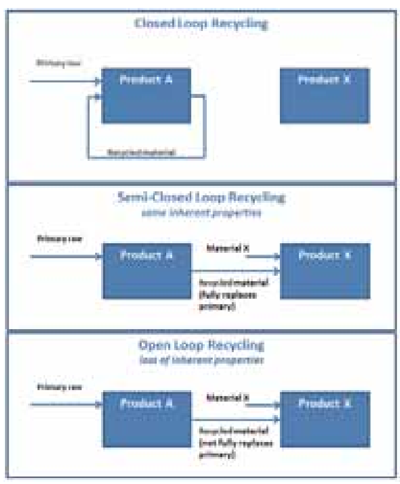


Figure 7.13: Closed loop, semi-closed loop and open loop recycling (Ligthart, et al., 2012).

In the recycling process for SSL, the LED lamps are crushed and shredded followed by separation and sorting of the different materials. Hereto common techniques like flotation and electrostatic separation are used. Reclaiming the metals used in SSL by means of recycling will lead to a small profit. However the recycling of plastics and glass still cost money, adding to this the transportation and process cost, and overall recycling of SSL will resolve in a negative money flow.

Unfortunately the additional costs of recycling have led to unregulated recycling of electronic waste, resulting in a negative environmental influence. Oftentimes this illegal trade dumps e-waste and toxic materials from the developed world in poorer countries in regions like Asia and Africa where exporting is easy, labor laws are flexible, and communities are poor.

To reduce the movements of hazardous waste between nations, The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal was designed in 1989 (United Nations, 1989). The Basel Convention, is an international treaty that was specifically designed to prevent transfer of hazardous waste from developed to less developed countries. In addition to the Basel Convention, the Bamako Convention on the ban on the Import into Africa and the Control of Transboundary Movement and Management of Hazardous Wastes within Africa negotiated a treaty among African nations prohibiting the import of any hazardous waste (African Union, 1991). The Bamako Convention similar to the Basel Convention, but is much stronger in prohibiting all imports of hazardous waste.

7.11 Strategic outlook

Figure 7.14: Summary of the actors and interaction within the SSL ecosystem (Gielen, et al., 2012)

This chapter gives a brief overview of the different actors and aspects in the SSL landscape that should work together to further green the SSL industry (Figure 7.14). Opportunities for SSL to further green the product itself, the production process, as well as after-life disposal are sketched. However, the research landscape for improving resource efficiency is complex. At the technological level recovery of materials is key. However, it should be realized that the materials are present in a single product in minute amounts. A prerequisite for efficient recovery is to concentrate recyclable materials during the disassembly and separation steps. This does not only put demands on the functional unit that contains the materials of interest, e.g. a LED. It also puts demand on the design of the product of which the functional unit is part, e.g. a retrofit lamp, a luminaire or a more advanced system in which solid state lighting sources are embedded. This implies that both with respect to overall composition as well as product design optimization should take place. An additional constraint is that this optimization aiming at resource efficiency should not deteriorate performance and preferably be at least cost neutral. Optimal choices can only be made when recycling is already taken into account in the specification, design and manufacturing stages. This asks in addition to the technological challenges for close cooperation between manufacturers and recyclers. Alignment along the value chain is required not only from a technological point of view, but the applications determine the business potential: all along the value chain there should be sufficient incentive for more sustainable production and products. Some research priorities resulting from this vision are briefly outlined below.

In an optimal recycling technology landscape, identification at different levels during recycling should be enabled. This will lead to a significant improvement in resource efficiency for materials used in solid state lighting by implementing identification methods for recycling into products and by using these methods during recycling. Sorting of lighting waste in well-defined streams should then be achieved in a kind of cascade process via subsequent identification steps.

Important aspects are then the choice of materials and components, design and manufacturing that allow a particular way of 'demanufacturing' (i.e. recycling controlled to a large extent) and optimization of recycling and recovery based on better defined waste streams. Here the merits of various scenarios should be explored: dedicated versus non-split collection, and controlled disassembly versus shredding.

As sufficiently large volumes in the end are key to profitable processes, options for standardization and regulations should be taken into account, to strive for a broad acceptance of the new technologies. This then links to development of suitable business models and policy arrangement. The first is essential to avoid that at once place in the value chain all cost are made, while at another part the revenues are generated, as this will limit the incentives for change. The second one should be aimed at regulators as well as consumers as they to a large extent can affect the demands on products and product treatment.

These topics can only be dealt with effectively by intimate collaboration and alignment between the various parts of the life cycle value chain.

Summarizing, the main challenge for creating value with green is the multi-disciplinary aspect: design, production, use, disposal, business models, political and industrial incentives, as well as logistics and regional situations interact. In all these areas alignment over different parts of the life cycle and the value chain should be taken into account. Specific research topics that should be addressed are the following:

- Materials and interfaces
- Substitution
- Production processes and equipment
- End-of-life management
- Recycling and re-use
- Design for Green
- Green business creation with new business models, including policies from governments to support and accelerate these new business models.

Research on green interfaces, materials, design methodologies, and more efficient and clean production process as such is valuable in its own right: more insight and alternative ideas in the different areas will enable to make the best choices for a complete green SSL industry. However, this should be done such that environmental advantages in one area will not lead to detrimental effects in other areas such that the overall gain is nullified or even worse. Due to the required multi- disciplinary approach it is very difficult to set concrete priorities for these different fields.

This should contribute to the key challenge in the green approach, which is optimization over the entire life cycle based on better understanding of the whole product cycle from creating, to use and disposal. As the abstraction level of such a task is very high, it is suggested to make the approach more tangible by building upon particular business or product cases: thus a strong starting point to create understanding and search for new opportunities and solutions is created. These solutions can then be generalized or translated to adjacent fields.

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