ADVANCES IN SOLID STATE LIGHTING

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Abstract : Today, our nation is facing the urgent challenges of revitalizing our economy, strengthening our energy security and reducing greenhouse gas emissions. Solid-state lighting is an emerging technology with the potential to address all three of these challenges. Solid –state lighting (SSL) will mean greener homes and business that use substantially less electricity, making them less dependent on fossil fuels. In the coming decades, SSL will become a key to affordable high-performance buildings- buildings that consume less energy and produce a fewer greenhouse gas emissions than their counterparts. The Department of Energy (DOE) is committed to realizing the full potential of energy-efficient technologies such as solid - state lighting in meeting our nation's challenges. The standard incandescent light bulb, which still works mainly as Thomas Edison invented it, converts more than 90% of the consumed electricity into heat. Given the availability of newer lighting technologies that convert a greater percentage of electricity into useful light, there is potential to decrease the amount of energy used for lighting in both commercial and residential applications. Although technologies such as compact fluorescent lamps (CFLs) have emerged in the past few decades and will help achieve the goal of increased energy efficiency, solid-state lighting (SSL) stands to play a large role in dramatically decreasing U.S. energy consumption for lighting. Light emitting diodes, LEDs, provide point sources such as incandescent lamps while organic LEDs, OLEDs might replace area sources such as fluorescent lamps. Both LEDs and OLEDs are currently under development for niche markets in signalling and display applications. Last decade research led to LED based lighting to emerge as strong contender for the Mainstream Lighting (GLS, FTL and CFL) thanks to steep rise in efficiency (110Lumens/Watt) and steep fall in price (US Cent 0.7 per lumen).

***IndexTerms** - LEDs Past trends, the future, current issues, new players, future demand.*

I. INTRODUCTION

Over the past decade, advances in LEDs have enabled the potential for wide-scale replacement of traditional lighting with solid-state light sources. If LED performance targets are realized, solid-state lighting will provide significant energy savings, important environmental benefits, and dramatically new ways to utilize and control light. Solid-State lighting (SSL) based on LEDs is an emerging technology with potential to greatly exceed the efficiency of traditional lamp-based lighting systems. Whereas energy efficiency is the primary motivation behind SSL, LEDs are also anticipated to bring entirely new functionalities to lighting systems, greatly enhancing the ways in which we use light. LEDs have already replaced traditional lamps in a number of lighting systems, including traffic lights, signs, and displays. Many of these applications require monochrome light and the narrow-band emission properties of LEDs present a clear advantage over filtered-lamp approaches. However, the greatest impact of SSL will likely be in general illumination applications that demand a high-quality white-light source. Coupled with the need for high efficiency, the stringent colour requirements of white-light illumination place new challenges on LED technology, many of which have yet to be overcome.

Conservation of energy is as good as generation of energy: There are two important ways through which energy can be conserved using advance technologies. These are:

(i) Energy conservation through advanced light emitting diodes (LEDs)
(ii) Energy conservation through superconducting materials

Energy conservation through advanced light emitting diodes (LEDs):

Electric lighting burns up to 25% of the average home energy budget. Approximately 90% of the power consumed by an incandescent light bulb is emitted as heat, rather than as visible light. Light Emitting Diode(LED) and Compact Fluorescent Lights(CFL) bulbs have revolutionized energy efficient lighting than that of the incandescent bulbs. CFLs are simply miniature versions of full-sized fluorescents. Compared to general –service incandescent lamps giving the same amount of visible light, CFLs use one-fifth to one third the electric power, and last eight to fifteen times longer. LEDs are small, very efficient solid bulbs. New LED bulbs are groped in clusters with diffuser lenses which have broadened the applications for LED use in the home. LED technology is advancing rapidly. Initially more expensive than CFLs, LEDs bring more value since they last longer. Also, the price of LED bulbs is going down each year as the manufacturing technology continues to improve.

LEDs are long-lasting: last up to 10 times as long as compact fluorescents, and far longer than typical incandescents, durable, as they are solid, do not have a filament, cool as they do not heat up and avoid power waste, mercury free, more efficient and use only 2 to 17 watts of electricity ($1/3^{rd}$ to $1/30^{th}$ of incandescent or CFL), cost effective as their cost is reducing year by year and long lasting. They are very much suitable for remote areas with portable generators because of low power requirements.

Energy conservation through superconducting materials:

During power transmission and distribution, one needs step up and step down transformers to minimize the power loss. However, with the conventional transformers with best possible economical windings, the total power loss including the power loss as heat in conductors is as high as 30% Superconducting materials in their wire and tape forms can save these heavy losses. One can also use such materials in motors to save the heat losses in their windings.

Present Demand Scenario:

End demand for high brightness (HB) LEDs remained strong through 2008, with unit growth up 25%, to 48 billion while revenue grew to 11% to $5.1 billion (Strategies Unlimited). And presuming the general economy picks up again in 2010, advanced LEDs should resume their 19% annual growth rate, to reach some $12.4 billion by 2013, Lighting remains about a $450 million small slice of the total HB LED market, but that is expected to rapidly escalate $1.5 billion by 2012, and surge once cost targets are reached.

Role of Equipment and Process Technology:

SSL can reach cost and performance parity with current lighting technologies, dramatically reducing global energy usage. The semiconductor industry's experience in achieving remarkable cost and performance improvements is directly applicable to the solid state lighting (SSL) industry through support by industry standards, technology roadmaps and collaborative partnerships between equipment suppliers and Chip manufacturers.

Energy savings Potential of LEDs:

The LED Lighting estimates that by adopting energy efficiency lighting technologies, consumers and businesses will save approximately $18 billion annually on electricity bills by 2016 – while saving an amount of energy equivalent to the power generated by 30 nuclear power plants (at 1,000 megawatts) or up to 80 coal-burning power plants (at 500 MW).

Past Trends in Cost of Solid State Lighting:

During the past decade, the cost of LED devices has decreased by10x, primarily due to enhancements in LED device efficiency and increases in drive current. As devices become more efficient, the cost per lumen scales. In the past decade, LED efficiency has improved approximately 20-fold and this has led to the 10-fold decrease in cost per lumen (Haitz's law).

What will influence the future Cost of SSL:

The US DOE goal for 2020 requires an additional 10 to 20-fold decrease in costs while the theoretical maximum additional efficiency improvement is less than 2x.Additional cost saving must come from yield improvements, materials innovation, automation, and other manufacturing efficiencies.

The process issues:

The LED manufacturing process today is very similar to the semiconductor manufacturing processes in the mid-19670s. LED wafer sizes are 2-3 inch, process equipment tends to be custom made (internally modified by manufacturers), deposition processes are poorly controlled and line widths are only a few microns. LED throughput is typically less than 50 wafers per hour with low yields. Since 1975, the semiconductor industry has made enormous strides in cost reduction, mostly through scaling, but also through manufacturing efficiencies that can be directly applied to LED manufacturing. LED efficiencies are approaching their theoretical limits and will lead to a further reduction in manufacturing costs by about 2x, whereas driver current increases (while maintaining high efficiencies) probably will bring another factor of about 2x cost reductions, additional manufacturing cost reductions will need to come from a combination of larger wafers and more productive tools. The semiconductor supply chain helped deliver consistent and significant cost reductions, and how those same techniques have proven effective in the flat panel display and photovoltaic industries. These techniques include use of industry standards to reduce costs and spur innovation, and pre-competitive supply chain collaboration on technology roadmaps, technology targets and efficiency goals.

The process in Standardisation:

Following new standards have created preferred values and labelling, to help inner changeability and interoperability, allowing manufacturers to concentrate on economics of sale in there are of core competence without worry of forward and backward linkages.

- **Chromaticity: ANSI C78.377-2008**
  "Specifications for the Chromaticity of Solid State Lighting Products"
- **Luminous Flux: IESNA LM-79**
  "Electrical and Photometric Measurements of Solid-State Lighting Products"
- **Lumen Maintenance: IESNA LM-80**
  "Measuring Lumen Maintenance of LED Light Sources"

The Issues of current importance:

Reduce the cost of LED products to competitive levels, Ensure high product quality and consistent performance, Improvements in Organic LED products, Encourage and strengthen manufacturing of solid-state lighting products, Improve Economics of SSL manufacture, Materials and supply issues, Equipment needs, Light extraction Techniques.

Key to LED efficiency:

- The LEDs show fall in efficiency at high current density-referred to as "droop".
- The droop – has been attributed to mechanisms such as high plasma temperatures, a high density of threading dislocations or pockets of In GaN material with a high InN composition Philips Lumileds team's photoluminescence study of In GaN material identified the phenomenon of Auger recombination as causing IQE drop at high current densities.

Current status- The Gaps: Low efficiency of Green Emitters, Edge Emitting Lasers- Lack of affordable GaN substrates, GaN VCSEL, HIGH HFET Drain currents, Low production yield, High cost of SiC substrates.

LEDs – the future: George Craford, CTO Lumileds,"There's no longer any question that LEDs will take over", although it is only within the past 12 months that he has become convinced of this Evolutionary developments in LED design that increase the carrier recombination volume, such as thicker structures, could now lead to conventional 1 mm chip capable o emitting 500 1m opening up GLS application.

LED PHOSPHORS:

Early white LEDs, as introduced by Nichia, used existing phosphors such as Ce doped Yttrium Aluminium Garnet (YAG: Ce), a yellow phosphor, which when combined with the blue LED (460nm), produces white light (as the eye sees it). It has a low CRI, in the 60 to 70 range, but the benefits are a relatively low cost and its simplicity of use. Inclusion of a small amount of a red phosphor with the YAG: Ce improved the CRI to the acceptable range (a CRI of ≥ 80) and increased the high light conversion. Toshiba offers a Terbium activated Ce Co-activated Oxide. Cerium efficiently transfers energy to Terbium is mainly Green emission with long tail extending into green and Red. UV excitation gives white emission. Nichia claims patent rights to the use of this red phosphor and has created potential IP problems for other LED lamp manufacturers. Resulted in an industry wide drive to make a new range of phosphors stimulated by blue-violet radiation that are not IP hindered. Preferably, these should be more efficient emitters for these wavelengths and also more efficiently stimulated by 380 to 470 nm wavelength radiation.

LED PHOSPHORS- new players:

Intematix of California uses 'Combinational Discovery Engines' to develop a range of high efficiency phosphors under the Intellectual-property-free banner. The 'nano discovery engine',reduced the development time for the first two products to just over a year.

LED PHOSPHORS – future demand:

The phosphor industry is different from most industries. Fewer than ten companies supplying most of the world requirements. Many of these use their own closely held technology for the end product manufacture. The present LED market, few tones is of little interest to established industries.

Conclusion:

With the cooperation of the Next Generation Lighting Industry Alliance (NGLIA), and as directed by the Energy Policy Act of 23005, DOE is the lead federal agency for all research, development and market support efforts to systematically accelerate this ground breaking technology. Phosphor converted white LEDs are in competition with fluorescent lamps because of its huge energy saving. For the success of these lightings and display devices, development of phosphors with a required characteristic is essential. Solid-state lighting (SSL) has evolved to a point where the light-emitting diode (LED) is now the preferred light source for many lighting applications. The LED lighting system is a mostly mature technology, and LED market transformation is estimated to approach 50% by 2025. Organic light-emitting diodes (OLED) for lighting applications are also on the horizon. Research and development work is now moving toward exploring how SSL can be customized and how to use lighting to gather information that provides greater value to both producers and users. The Lighting Research Centre's Solid State Lighting Program is expanding its scope of research and educational programs to enhance this technology, overcome barriers, and shoe benefits beyond energy savings..

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