Where are LEDs leading us?

Jeanine Chrobak-Kando, Verbatim

Recently, LED lamps have begun to appear as general purpose light sources for domestic and commercial use. Most observers predict that LED lamps will replace compact fluorescent lamps (CFLs) in many applications in this market. This article looks at the fundamentals of LED technology and reviews the different lighting technologies against which LEDs compete in domestic and commercial applications. It then considers issues of quality and economics, the status of the LED lamp industry today and where it's going in the near future.

What is an LED?

An LED is an electronic semiconductor device of a particular material composition which, when current passes through it, gives off light. The first practical LED to produce light with a spectrum visible to the human eye, a red LED, was discovered in 1962. In later developments, orange, yellow, green, blue and violet LED chips were created. The main technology challenge has been to maximize the amount of light produced with respect to the energy supplied to the LED.

For general lighting in buildings, a key goal of LED lamp manufacturers is to replicate the spectrum of light that comes from the sun. Human eyesight is optimized for this so-called "white" light.

LEDs can be used to create white light in one of two ways. A lamp can consist of red, green and blue LED light sources, which are combined to produce white light. A more common method for general-purpose lighting is to use blue LED sources and coat them with chemicals known as phosphors that shift the light spectrum. By using several coatings, the light spectrum can be tailored towards that of sunlight. Of course, each phosphor layer reduces the light output so a key aspect of ongoing development is to create the best balance between the level and quality of light produced. Violet LED light sources, developed and patented by Mitsubishi Chemical Corporation under the Verbatim brand, promise a significant improvement in both characteristics.

How do LED lamps differ from others types?

A typical 100-Watt incandescent bulb, the most commonly used type, will produce 17 lumens of visible-spectrum light for each Watt of power consumed. This is referred to as its luminous "efficacy".

Halogen lamps are more efficient and at up to 30 lumens per Watt efficacy. Halogen lamps produce a wide spectrum of light, the wavelength of which is shifted towards the blue end of the spectrum. Such light is said to have a relatively high "colour temperature." Lamps with these spectral characteristics are often called "cool white" because we perceive blue as being a cold colour and red as a warm colour.

Fluorescent lamps are most familiar in offices and industrial premises. Compact fluorescent lamps (CFLs) have been widely promoted as energy-efficient alternatives to incandescent lamps, but with limited success. Luminous efficacy is typically in the range of 60 to 80 lumens per Watt. However, most are not dimmable, create a cold light that does not show colours naturally, and are slow to warm up. Also, they contain mercury, a poisonous metal. Some warm white, dimmable versions are available at higher cost but still suffer from the other disadvantages described.

The technical challenges in LED lamp development

The manufacturing challenge has been to produce such LED lamps at a price that consumers are willing to pay.

Materials development is at the heart of LED performance. Today's LED lamps for general lighting nearly all use blue LED chips with yellow phosphors to create an approximation to white light, although the green part of the spectrum tends to be rather subdued.

Of course, the LED lamp is more than just a chip. Each light emitting diode has to be driven by a direct current (DC) but the power supply in buildings is alternating current (AC) at a much higher voltage than that required by the LED chips. A power conversion and control circuit manages the transition. Most LED lamps for general lighting are designed to operate from 110V-115V AC or 220V-240V AC. However, some are designed to replace other 12V directional lamps and operate from 12V DC. The LED chips are built onto a module containing the electronics and a clear glass or plastic cover protects the assembly, distributes the light evenly and minimizes glare. With directional lighting, the cover includes a lens to focus the beam and reflectors behind the light source to direct it. There is a requirement to dissipate waste heat effectively, so some kind of heatsink needs to be built into the lamp. Finally, there must be a means of connecting the lamp to the electricity supply. This is via electrical contacts on its base. To meet the demands of the large retro-fit market, LED lamp makers use bases that fit industry-standard sockets.

Comparison based on 35,000 hours lamp use	Incandescent lamp classic A 40 W	LED lamp classic A 10 W
Average life of bulb	1,000 hrs	35,000 hrs
Power consumption	1,400 kWh	350 kWh
Cost of power consumption (0.17 €/kWh)[1]	238.00 €	59.50 €
Purchase cost[2]	70.00 € (2 €/piece)	30.00 €
Maintenance cost (2 €/piece)	70.00 €	2.00 €
CO_2 emissions[2]	700 kg	175 kg
Total cost (based on 35,000 hours lamp use)[4]	**378.00 €**	**91.50 €**

[1] European average electricity cost 0.17 € / kWh
[2] Purchase price based on current retail price and may vary according to country and market development
[3] CO_2 emissions (kg) @ 0.5 kg CO_2/kWh
[4] Calculation based on today's values

Table 1. Ecological and economic advantages of LED lamps over incandescent lamps.

The voltage conversion and control electronics, usually described as LED driver circuits, are the weakest link in most LED lamps. The design of the LED driver is also a critical factor in determining the overall efficiency of the lamp. Drivers themselves are typically between 80% and 90% efficient when operating at full load i.e. the LED is working at full brightness.

Why LED lamps are now growing in popularity

Consumers' experience of compact fluorescent lamps (CFLs) has often been poor, resulting in slow take-up of the technology. In the meantime, LED lamps have become brighter with up to 50 lumens per Watt efficacy. They deliver a more pleasing quality of light, are mechanically rugged and are now available in a variety of fittings, which makes it easy to substitute them for conventional incandescent lamps. Furthermore, the latest LED lamps are dimmable and lamps with tunable colour output, including the ability to vary the warmth of white light, are already available in Japan. Most important of all, the economic argument is now compelling. Although high quality LED lamps still cost significantly more than incandescent lamps, with a life expectancy of 30,000 hours or more and energy savings in the order of 75% to 80% due to their higher efficacy, they do pay back the initial investment within an acceptable period. However, the economic argument only holds true if the life expectancy is met. If you have to replace the lamp after 15,000 hours of operation, your lighting cost is increased significantly over a given period.

Figure 1. LED lamp construction: terminals, heatsink, housing, lens, control electronics, LED module

How to determine quality and reliability

As we've discussed, the major factors that determine LED lamp quality and reliability are not obvious when examining the exterior of the lamp. The quality of the diodes themselves, the design of the drivers and the quality of components used in these circuits, and the effectiveness of lamp housings in dissipating heat effectively are the main determinants of reliability. However, it is generally true that those products where attention to detail is apparent in their physical design are likely to have had similar attention to detail applied to their electronic design, so there is some value in careful visual inspection. If

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High-brightness LEDs: a rising tide lifts many boats

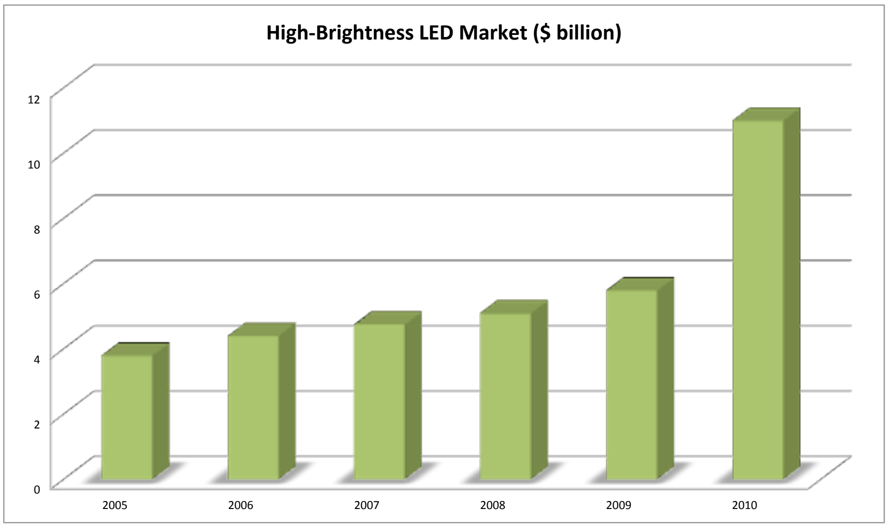
Lisa Bergson, Tiger Optics LLC

If you're engaged in any aspect of the high-brightness light-emitting diode (HB-LED) business, you could set the table for friends and family with your good fortune. Worldwide HB-LED revenues jumped to US$10.8 billion in 2010, up 93 percent from $5.6 billion in 2009, according to the latest report from Strategies Unlimited, the oft-cited California market research firm. The 2010 results exceeded, by 32 percent, the firm's year-earlier forecast of US$8.2 billion.

The rising tide of HB LEDs is lifting a *flotilla* of boats. Here's a story that could hearten anyone who was submerged in the Great Recession, yet it seems that the general public may be unaware of the ramifications of this surging LED industry. Knowing that I was a business journalist in an earlier career, a colleague has urged me to share my observations from the public record and as chief executive of a company that supplies the LED industry at multiple points.

Sales rose 177 percent last year at Tiger Optics LLC, the high-tech company I head in Warrington, Pennsylvania. We sell laser-based trace gas analyzers to HB-LED makers and tool manufacturers, as well as to the gas companies that supply ammonia, the favored source of nitrogen for the production of gallium nitride (GaN) compound semiconductor wafers, a key component of HB LEDs.

There is ample evidence that many companies—private and public—are prospering from their stakes in the HB-LED business. Albeo Technologies Inc., an LED-lighting products company in Boulder, Colorado, said (in August, 2010) that it has expanded twice in two years while averaging annual revenue growth of more than 110 percent for three years. California-based Bridgelux Inc., a pioneer in LED solid-state lighting, recorded US$30 million in 2010 revenues and expects to triple that amount in 2011, the *New York Times* recently reported.



At Veeco Instruments Inc., revenues from LED and solar process equipment in 2010 nearly quadrupled the $205 million reported in 2009. Veeco is a leading producer of the metal-organic chemical vapor deposition (MOCVD) systems used to manufacture HB LEDs.

Strategies Unlimited credits much of the industry's growth in 2010 to the escalating demand for HB LEDs to "backlight" the liquid crystal display (LCD) units of TV screens and computer monitors. Such demand will likely flatten out in 2013, with solid-state lighting becoming the "key market driver" in 2014 due to global demand for energy efficiency and the phase-out of incandescent bulbs, the market research firm predicted in a report presented at the Strategies In Light conference in Santa Clara, California, on February 23rd.

Meanwhile, a number of gas companies are prospering from the sale of ammonia for HB LED applications. At Tiger Optics, we also note some stellar performers among:

The MOCVD system suppliers

Two companies, **Aixtron SE** and **Veeco Instruments**, dominate the market for producing the MOCVD equipment used to create HB LEDs. An HB-LED fabrication plant typically allocates more than 50 percent of its capital expenditures to acquire MOCVD systems, according to Veeco. By the close of 2010, the global MOCVD market was expected to reach US$1.5 billion in sales, more than trebling the estimated 2009 market value of US$464 million, according to Aixtron, which cites market research by Gartner Dataquest. Aixtron notes that it also competes with a number of Asian manufacturers, including **Taiyo Nippon Sanso Corp**. Aixtron said it expects that equipment companies from "adjacent" industries will attempt to develop their own MOCVD tools and identified Applied Materials, Inc. as an aspiring competitor.

- Aixtron SE, based in Herzongenrath, Germany. reported revenues of EUR 783.8 million for the year ended December 31, 2010, up 159 percent from the same period in 2009. Aixtron said the increase was driven largely by its deposition equipment revenues, which rose 168 percent in 2010.

- Veeco Instruments Inc., headquartered in Plainview, New York, reported net sales of US$933 million for the year ended December 31, 2010, up 230 percent from the comparable period in 2009. (For its LED & Solar Process Equipment segment, Veeco's revenues rose 289 percent.)
- Taiyo Nippon Sanso Corp., the global industrial-gas company, serves 80-90 percent of the domestic Japanese market for MOCVD equipment. For the first six months of its fiscal 2011, the Tokyo-based company said operating income jumped nearly 101 percent in its electronics business, which includes MOCVD equipment.

The LED chip and component makers:

- Nichia Corp., headquartered in Anan-Shi, Japan, was the top-selling LED supplier in 2009 with revenues of US$2.2 billion, according to IMS Research of the United Kingdom. Nichia's shares are not publicly traded.
- Philips Lumileds Lighting Company LLC, a leading LED-component maker, also does not publish financial results, but it ranked fourth – in a tie with Seoul Semiconductor – in 2010 revenue, in the estimate of Strategies Unlimited.
- Epistar Corp., a leading LED chip producer based in Taiwan, reported net revenue of TWD 1.4 billion for the month of December 2010, representing a year-on-year increase of 55.6 percent.
- Cree Inc., based in Durham, N.C., said its net income rose almost 97 percent for the six months ended December 26, 2010, compared to a similar period the preceding year. Cree makes LED chip products and components.

Capturing the "frontier" spirit of the HB LED industry, Bridgelux Chief Executive Bill Watkins wrote in a Forbes.com commentary last August: "Light bulbs represent the world's last vacuum technology so digital lighting is where the semiconductor, software and disk-drive industries were 40 years ago—on the edge of steep and continuous growth."

Inevitably, the seas will grow choppy, but in the meantime . . . Hoist the sails!

Lisa Bergson, founder and chief executive of Tiger Optics LLC, pioneered the commercial development of the laser technology called Continuous Wave Cavity Ring-Down Spectroscopy that is presently used in more than 800 locations at chemical companies, semiconductor fabrication plants, laboratories, and gas productions and distribution facilities around the world.

Where are LEDs leading us?

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the product appearance is poor this probably reflects the approach to its design and manufacturing.

Comparing specifications carefully, particularly with respect to luminous efficacy and claimed operating life expectancy, will give you an indication of quality. If an unfamiliar brand claims to have performance and reliability figures well in excess of the norm, more research should be undertaken into the accuracy of the data.

LED lamp availability, economics and quality

The choice of LED lamps will grow over the next couple of years but most major vendors are producing products for the retrofit market, so are launching products with the most common fittings first. Luminous efficacy has reached the point where replacements for traditional 40W lamps are now available and replacements for incandescent bulbs rated at up to 100W should be on the market before the September 1st, 2012 deadline when all incandescent lamps will be banned by EU legislation.

Early LED lamps were not dimmable but recent products can now be dimmed

Figure 2. LED lamps are now available in a range of common fittings as low-energy retro-fit alternatives to traditional incandescent lamps

using standard dimmers designed for use with incandescent lamps.

The current life expectancy of a high quality LED lamp is typically between 15,000 and 45,000 hours. In general, LED lamps with smaller physical formats, such as candle lamps, will have lower life expectancy because they operate at higher temperatures. If a lamp is operated for 6 hours per day, 35,000 hours equates to 16 years. Few consumers are concerned about life expectancy beyond this time scale and even with such lamps costing 20 to 30 times the price of incandescent types, the economic argument in favour of LED lamps is compelling. Poor quality LED lamps, which might fail in a much shorter time, do not offer an attractive return on investment because replacement cost needs to be considered.

LED lamps are expected to replace most other forms of domestic and commercial lighting in the next few years. LED lamps not only reduce energy costs, they also cut maintenance requirements and offer new opportunities for creativity in lighting installations.

Jeanine Chrobak-Kando is Verbatim's business development manager for the LED lighting business in Europe, the Middle East and Africa. Based in Frankfurt, Jeanine previously spent 4 years at OSRAM GmbH as product manager for LED Luminaires. Jeanine began her career has a microstructure technology researcher. She has a Masters Degree in Electrical Engineering from the University of Karlsruhe, Germany.