Solid-state lighting market poised for dramatic growth

Improvements in white LED performance and price will attract the attention of larger lighting companies, LED-based fixture designs will become more efficient, and solid-state lighting products will greatly increase their penetration of the mainstream general illumination market, predict **Robert Steele** and **Vrinda Bhandarkar** of Strategies Unlimited.

The use of high-brightness (HB) LEDs for lighting applications is receiving increased attention, particularly as the performance (lumen output, efficiency) of HB LEDs has progressed dramatically in the past year, enabling a wider variety of lighting applications to be addressed. In recent years, the phrase "solid-state lighting" has become a generally accepted description for the use of LEDs for lighting, and this is the definition that will be used here (rather than the broader definition which is sometimes used to encompass all HB LED applications).

In the late 1990s, LED technology began to penetrate limited lighting applications, including a few that required white light. In the period 2001–2006, a wider variety of niche lighting applications became accessible, in part due to the development of high-power LEDs that provide much higher lumen output than LEDs in standard (e.g. 5 mm, SMD) packages. In the coming years, much larger lighting market penetration, buoyed by the dramatic progress that has been made and continues to be made in LED technology, is envisioned. LEDs will begin to penetrate the general illumination market, including home and retail lighting, outdoor area lighting, and off-grid lighting.

LED lighting market overview

HB LEDs have penetrated a variety of niche lighting applications and are also beginning to be used in several white-light applications that could be considered to be part of the general illumination market. The market for HB LEDs in lighting amounted to $205 million in 2006, or approximately 5% of the overall HB LED market of $4.2 billion.

In spite of its small share of the overall HB LED market, lighting was the fastest growing segment in 2006, and is forecast to grow to approximately $1 billion in 2011, corresponding to an average annual growth rate of 37%. The largest application is architectural lighting, where the ability of LEDs to provide colors and color-changing effects is a major market driver.

The use of HB LEDs in lighting happened initially in architectural as well as other applications that use color, such as channel letters, exit signs and entertainment. With conventional lighting technologies the use of color is expensive and inefficient, and color-changing applications often use moving parts that need maintenance. With RGB LEDs, it is possible to produce a wide range of saturated colors, and with the use of appropriate control technologies, color changing has become readily available. However, the concept of using color and color changing is not ubiquitous; it is generally limited to high-end applications such as first-class hotels, restaurants, casinos and retail venues.

General illumination is closely associated with white light. The use of white LED lighting at present is mainly limited to applications where low lumen output is required, such as machine vision, path lighting, accent lighting, flashlights and small spot lights – and various other applications where lighting has to be reliable and have a long life to reduce the cost of maintenance. The total use of white LEDs in such applications has become a significant part of the solid-state lighting market. Thus, although the use of colored lighting was an early focus for LEDs, white light has grown to become a large percentage of the LED lighting market, as shown in figure 2.

The path to general illumination will depend on the improvements in efficiency and lumen output of white LEDs. Efficiency is important


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Fig. 1. Currently, the largest lighting application for HB LEDs is architectural lighting, where the ability of LEDs to provide colors and color-changing effects is a major market driver. The use of white LED lighting at present is mainly limited to applications where low lumen output is required, and where reliability and low maintenance are important. (Top) LEDs illuminate buildings along the Pearl River in China – see www.ledsmagazine.com/news/4/3/9. (Bottom) White LEDs in a pedestrian subway in Gateshead, UK – see www.ledsmagazine.com/news/4/3/30.

Table 1. Major LED lighting application categories

- **Channel Letter/Contour Lighting**
- **Architectural**: building exterior and interior lighting to create special effects (not general illumination), including color changing (e.g. hotel, restaurant, casino, fountain, landmarks); landscape lighting for gardens, parks, pools, and spas
  - Wall washers
  - Floodlights
  - Strip lights
  - Accent lights
  - Cove lighting
  - Festoon lights
  - Small spots
  - Path lights
  - In-ground and underwater lights
- **Retail Display**
  - Display case lighting
  - General merchandise lighting
  - Refrigerated display case lighting
- **Residential**
  - Recessed can lights
  - Reading lights
  - Under-cabinet
  - Pendants
  - Decorative
- **Consumer Portable (battery-powered)**
  - Flashlights
  - Headlights
  - Bicycle lights
- **Machine Vision**: light sources for cameras used in machine vision applications
- **Entertainment**: rock concerts, TV studios, theaters
  - Theater step lights
  - Stage lighting, including permanent and rental spot lights
  - Color-changing effects lighting in discos, bars, and clubs
- **Safety/Security**
  - Exit signs
  - Emergency lighting
- **Outdoor Area Lighting**
  - Parking lots
  - Street lights, highway lights, etc.
- **Off-Grid**: primarily remote villages and dwellings in developing countries; powered by solar, wind, micro-hydro, etc.

in consumer portable applications (e.g. flashlights) to reduce battery drain, and white LEDs long ago surpassed the efficiency of incandescent lamps. The best white LEDs available in the market in early 2007 are competitive with compact fluorescent lamps and lower wattage linear fluorescent lamps, i.e. in the 50–70 lm/W range.

However, fixture performance is paramount in lighting and by early 2007 there were no commercially available fixtures beyond 30–40 lm/W, with a number of fixtures offering measured performance of less than 20 lm/W – barely more than their incandescent counterparts. Thus, there is a strong need for fixture designs that optimize the performance of this new generation of high-efficiency LEDs.

LED lighting applications

A wide variety of applications, coming under the broad definition of lighting have already been addressed by LEDs, or will soon begin to be addressed. Some have already achieved significant market penetration (e.g. exit signs, channel letters, machine vision), while others, such as residential lighting, are still in the very early stages of market development. The most significant applications for LED lighting, currently or in the near future, are shown in table 1.

Each application listed in table 1 has associated with it a set of drivers that have caused LEDs to be adopted. Clearly, for LEDs to be adopted in lighting applications in preference to competing light sources, they must provide some advantages over those sources, especially because they are almost always more expensive on a first-cost basis. Some of the beneficial attributes of LEDs for lighting applications include:

- Long lifetime
- Design flexibility
- Saturated colors
- Directional light
- Energy efficiency
- Robustness
- Dynamic color control
- Dimmability without color shift
- Absence of regulated toxic substances (e.g. mercury)
- Absence of heat or UV in emitted light
- Low-voltage DC operation.

In most LED lighting applications developed to date, a combination of some of these attributes has been responsible for the adoption of LEDs. However, as LEDs – particularly white LEDs – begin to move into the mainstream of general illumination applications, high efficiency in combination with long lifetime will be the primary attributes that drive their adoption. In other aspects, such as the availability of warm-white colors, high color rendering index etc, they must at least be on par with other sources.

LED lighting market by color in 2006

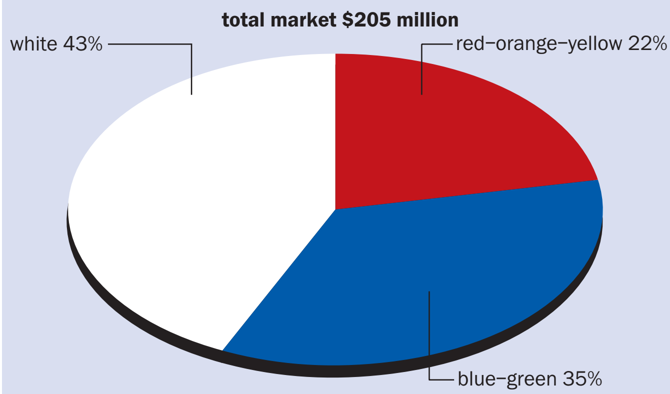

Fig. 2. White LEDs represented 43% of the $205 m market for LED lighting in 2006, but are forecast to become 61% of a $1 bn market by 2011.

As a new and unique lighting technology, LEDs compete in the lighting market with a variety of well-established and less-expensive incumbent light sources. The properties of these sources are well understood among the vast community of lighting end users, ranging from consumers to lighting designers and architects, whereas the properties of LEDs have only recently begun to be understood.

To date, LEDs have been adopted in lighting applications because of a combination of some of the attributes noted above. For example, lifetime considerations can be important in certain applications, such as architectural and accent lighting installations in which light sources are placed in hard-to-reach locations. The absence of heat in the light emitted by LEDs can be an important factor in some high-end retail applications. However, efficiency has generally not been a major consideration, except for a few select applications such as flashlights, where battery lifetime is a significant cost issue, and exit signs, which are subject to government certification for energy consumption.

While the long lifetimes of LEDs are well established (although often exaggerated with claims of 100 000 hours), the efficiencies of white LEDs are only now reaching levels at which they are becoming interesting relative to the highest efficiency conventional light sources available in the market. Efficiency is of interest not only because of its impact on lower operating costs, but also in terms of a variety of regulatory requirements that are being established regarding energy efficiency (e.g. Energy Star, Title 24 in California).

LED lighting market outlook

Over the next five years, LEDs will move beyond niche applications and into the general lighting market, including residential, retail display outdoor, and off-grid applications. Although niche applications will continue to be important, general lighting applications will provide much of the growth, and consequently white LEDs will become a more important part of the market. In 2011, white LEDs are forecast to be 61% of a $1 billion market, compared with 43% of a $205 million market in 2006.

As noted previously, most of the growth in general illumination will be driven by the high efficiency and long lifetimes of white LEDs, and their ability to compete head-to-head with conventional light sources on a life-cycle cost basis.

In order to grow the solid-state lighting market successfully, LEDs will have to penetrate the well-established design, manufacturing, marketing and sales infrastructure of the lighting industry. Displacing a well-established incumbent technology is always a challenge for any new technology and solid-state lighting is no exception. In particular, several hurdles will have to be overcome to make this market happen. Some of the major challenges include:

- Improved price/performance for HB LEDs
- Need for high-efficiency light engine/fixture design
- Other available alternatives for energy efficiency
- Consistency of color/binning issues
- Need to provide a complete lighting solution with ease of installation
- Adapt to standard electrical interfaces and controls
- Need realistic claims of performance
- Development of standards for solid-state lighting
- Need widespread base of lighting fixture designers and engineers who understand LEDs.

Fortunately, the first and most significant hurdle is being addressed aggressively by the LED industry. Recent improvements in white LED efficacy have been dramatic, with major achievements announced in the past year by Nichia, Cree, Philips Lumileds and Seoul Semiconductor, among others. From typical top-tier performance of 40–50 lm/W in 2005, efficacies have increased to 70 lm/W and above in 2006 and early 2007. While these performances refer to cool-white LEDs (CCT > 5000 K), warm-white LEDs (CCT < 4000 K) have shown similar improvement, although efficacies are still somewhat lower than for cool-white. Roadmaps for white LEDs indicate continuing improvement in the next five years. Prices can be expected to continue to decline through a combination of manufacturing efficiencies and competitive pressure. Moreover, when expressed as dollars per lumen, price declines will accelerate as the lumen output per packaged device continues to improve.

Lighting fixtures

A major challenge for the solid-state lighting industry is not at the device level but at the fixture level. As the US Department of Energy's LED fixture test program has indicated (see *LEDs Magazine* February 2007, p8), solid-state lighting products currently in the market are not translating the high performance of commercially available white

Table 2. Examples of fixture design using white LEDs

Efficient design	Inefficient design
Start with one-watt white LEDs at 70 lm/W	Start with one-watt white LEDs at 70 lm/W
(measured at 25 °C junction temperature)	(measured at 25 °C junction temperature)
Assume: 90% electrical efficiency	Assume: 80% electrical efficiency
90% optical efficiency	80% optical efficiency
Operate at 65 °C junction temperature.	Operate at 100 °C junction temperature.
Fixture efficacy = 70 × 0.9 × 0.9 × 0.85 = **48 lm/W**	Fixture efficacy = 70 × 0.8 × 0.8 × 0.75 = **34 lm/W**

LEDs into efficient fixtures. Careful attention needs to be paid to fundamental design processes to ensure that electrical conversion (120 or 240 V AC to DC, and DC to appropriate LED drive current and voltage) is efficient, that LED light emission is not lost due to poor optical design, and that good thermal management techniques are applied to maintain acceptable LED junction temperatures. Table 2 indicates the difference in light output from the same high-performance white LEDs using efficient and inefficient fixture designs.

Several of the other challenges on the list above are also being addressed by industry groups. In particular, regarding standards development, the Illuminating Engineering Society of North America (IESNA) is working with the American National Standards Institute (ANSI) to develop standards for solid-state lighting. Representatives from the LED industry and the lighting industry have formed committees to develop a broad set of standards which should be available later this year. Other participants include the DOE, Energy Star and the National Electrical Manufacturers Association (NEMA).

Conclusions

The solid-state lighting market is still at an early stage of development and the market is highly fragmented. Hundreds of companies are both offering and developing LED-based lighting fixtures, but volumes are low and so manufacturing costs are high. However, as white LED price/performance improves and the technology attracts the attention of the larger lighting companies, LED-based fixture designs will become more efficient, higher fixture manufacturing volumes and efficiencies will be achieved, and solid-state lighting products will greatly increase their penetration of the mainstream general illumination market. ●

About the authors

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