Dr Alan Mills reports from San Francisco

Since most of the silicon device markets are still in a depressed mode, the billion dollar plus, high brightness LED market, led by worldwide growth in most of its segments, continues to be the star performer of the semiconductor industry (see Figure 1). Such was the story presented to over 200 attendees at this year's Strategies in Light Conference, as a full recovery in LED growth from the 2001 stagnation appears to have occurred. This popular annual forum is provided by Strategies Unlimited, research unit of Pennwell Publishing and included exhibitors with many state of the art products.

Light Emitting Diodes — stars of the show

Healthy High-Brightness-LED market growth

In this bright compound semiconductor market, Bob Steele (from Strategies) reported a 2002 average market growth of 50% to $1.8bn, up from the stagnant 2001 value of $1.2bn. This 50% growth in value occurred in spite of declining unit prices and is an average of the highest growth rate of 114% for the largest segment (mobile appliances such as cell phones, personal digital assistants (PDAs), cameras) and a combined growth rate of 27% for the remaining market segments.

Over two thirds of the 2002 high brightness LED (HBLED) market value were based on gallium nitride technology, with about 25% on AlInGaP, the remainder on AlGaAs or multi-chip devices. This value distribution reflects the higher prices per chip (usually 3x and higher) obtained by gallium-nitride-based blue, green and white LEDs, although at this time, AlInGaP unit volumes are higher.

The rapid increase in the number of white LED manufacturers illustrate the high growth rates in the gallium nitride segment, which grew from two producers in 2001 to at least nine in 2002 and are listed in Table 1.

Key applications — mobile appliances

The number of blue and green HBLED manufacturers (nitride based) also grew rapidly in 2002, fuelled in particular by a rapid addition of Taiwanese III-nitride chip producer capacity

In 2002, mobile phones, with about 400m units being sold, provided most of the growth in the HBLED market segment as more LEDs were incorporated. The drivers for this HBLED growth were the installation of more full-colour LCD screens (for both mobile and large stationary displays using white LED backlighting), secondary screens (for clam shell models), and the increasing use of coloured screens (e.g. blue) and multi-coloured 'ringers' and in total they represent about 40% of the market on an application basis. The value of the lower quality (or off spec) HBLEDs used for the back lighting of mobile appliance keypads is not generally available and is so excluded from the HBLED market values.

— large screen displays

The other large market segment for HBLEDs, with about 25% market share in 2002, is the big screen or display market covering both indoor and outdoor uses and video and static displays. This segment is a complex market that is characterised by relatively low unit volumes of large area equipment. Competing display technologies include LED video and text, incandescent bulb matrix, LCD, electromechanical (destination signs), plasma, CRT and projection displays, although LEDs are making inroads into all the non-LED sub-segments.

The cost for these LED signs can be quite high on an area basis (see Table 2) where the average selling price per pixel for a range of pixel sizes and locations has been compared. However, the installed costs of these displays are declining because of a growing trend toward the use of

standardised assemblies such as one-foot or one-metre square modules and standardised power controls. As may be anticipated, indoor uses need lower sign brightness levels, typically 1000 to 2000 nits (and smaller pixel sizes) as opposed to outdoors where brightness requirements are in the range of 5000 to 6000 nits and pixel pitches of 7-30mm are used

Initially, many large outdoor video signs used miniature cathode ray tubes such as the Sony Jumbotron and the market was dominated by Japanese manufacturers.

However, the advent of the blue light emitting diode in the mid-nineties has allowed the use of balanced full colour, red green and blue LED pixels and enabled the technology to produce millions of colour hues.

Based on these improvements, the use of HBLED displays has increased over a wide range of applications. These include casinos, stadia, racetracks, indoor arenas and shows, mobile video screens and transportation uses (bus, rail, air) with the two most important market segments being indoor and outdoor text and video.

This change in display technology has enabled a regional market leadership change, where North America is the leading manufacturing region, led by such companies as Barco, Daktronics and Lighthouse. Other growing markets include automotive, illumination and signals.

Although there are still performance issues that can be improved, (matching colours across a screen, viewing angles, die colour uniformity, lifetime and system driver performance, Colour Rendition Index [CRI] issues, LED drivers and controls) the market continues to expand as quality continues to advance in all these fields, leading to even better displays in the future.

It should be noted that the CRI was really designed for incandescent lighting and that some RGB LED generated light (white) may be a long way from meeting a CR index requirement. However, LED based lighting can be tuned to provide almost any CRI requirement and to 'walk' the black body radiation curve, but many RGB LED blends with very low CRI indices (that utilise very efficient LED blends) can produce lighting that is very pleasing to the human eye, but not even close to a CRI value of >80, which is usually expected for a 'good' lighting source.

Thus, it is very probable that in the future a separate colour rendering system will be developed

Table 1: 2002 White LED Suppliers

Nichia
Matsushita
Toyoda Gosei
Stanley Electric
Citizen
Osram
Lumileds
Cree
Toshiba

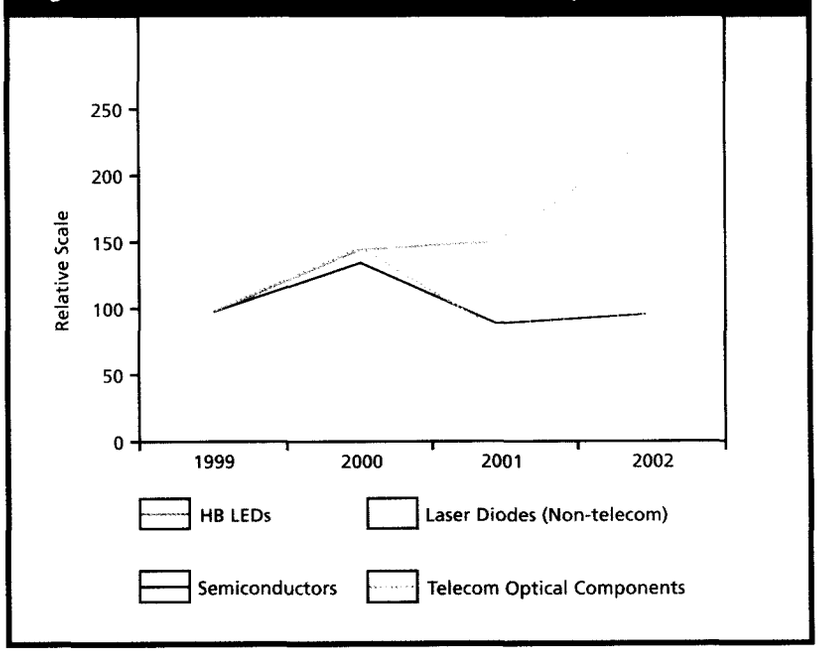
to evaluate light production from efficient LED sources. It is noteworthy that China is expected to significantly affect medium term display market growth, since the Chinese government plans to install large displays in many cities, in the 2008 Olympic Games Stadia and at more than 60 sight seeing locations.

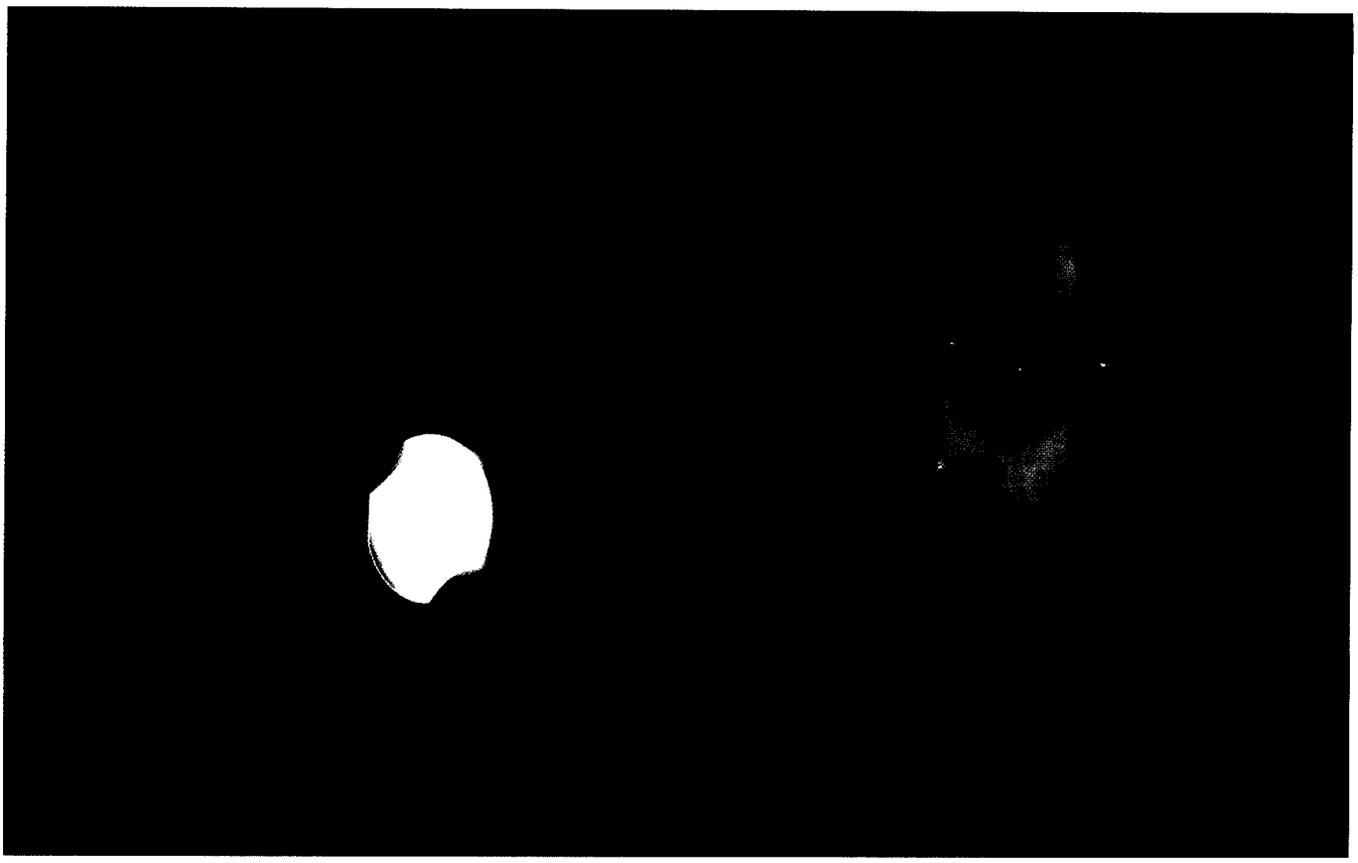
Some interesting market concepts that are the precursors for new HBLED markets include the use of blue light to correct the circadian rhythm of older people, the development of no spoilage lighting for meats and other food products, and internet protocol lighting control for each LED in large lighting systems or for complete buildings.

Trends

Although all of the above data shows the existence of very large LED markets, the reality is that in spite of today's widespread use of LED and other electrical signage, paper signs and billboards still command a larger market value!

Figure 1: Relative Growth of Semiconductor Component Markets





Sandia Laboratories' researcher, Art Fischer, holds a sapphire substrate with indium gallium nitride layers. This is one base material for LEDs that emit green, blue, and near-ultraviolet light. (Photo by Randy Montoya)

There are many trends in the various supporting technologies that will contribute to the future growth of LED based lighting and two of the more basic are the increasing exposure of LED lighting markets to the consumer and increases in the funding for market research.

Another development that should allow increasing world LED market growth is the recent increase in the cross-licensing of intellectual property, which until recently had been either jealously guarded or ignored by the industry.

Other market enhancing trends embraced by many manufacturers are the addition of sales personnel, the addition of higher wafer capacity reactors with better carrier gas and metal-organic precursor use (>50%), the production of a wider range of LED wavelengths (colours), a reduction in the dollar cost of light output, and improved heat removal.

Improved system performance and lower system costs will result from trends in the increased use of standard building block modules including standard voltage power supplies (e.g for 12 or 24V LED system modules).There is also an overall industry trend toward the production of larger LED die to provide increased light output per chip that will open up new applications for this class of emitters.

As far as chip capacity is concerned, most existing companies and some new ones are adding increased production volumes worldwide, but some of Taiwan's growth rate trends have far exceeded those of the rest of the world starting with the AlInGaP LEDs.

An other example of the latest Taiwanese investment focus on state of the art LED technology and driven by the rapid acquisition of MOCVD reactor capacity, is the rapid increase in Taiwan's market share of the gallium nitride based LED market.This has gone from zero percent of the world die output in 2000 to about 25% in 2002 (out of an estimated world production in the range of 3bn good nitride LED die) and more multi-wafer reactor capacity (about 20 reactors)

Table 2: Pricing for pixel pitch

Pixel pitch (mm)		Average Selling Price
Indoor	Outdoor	Per Square meter
<=5		$60 000+
6 - 10		$25 000 - $45 000
11 - 15	7 - 10	$20 000 - $25 000
16 - 20	11 - 15	$15 000 - $20 000
21 - 25	16 - 20	$10 000 - $15 000
>=34	21 - 25	$7 000 - $10 000
	>=34	$3 000 - $7 000

is in the process of being added. Additionally, Schiu Sche of Optotech Corporation recently reported that Taiwanese companies already have an 80% share of the world market in CD write and CD read/write emitters (pumped LEDs).

Technology trends

Technical trends that will advance the performance and market growth of LEDs are many and include the use of larger area substrates, the design of larger and more efficient die, the use of thinner substrates or substrate removal, chip shaping and chip reversal.

From an improved or more efficient light generation point of view, multi-quantum well chips are being designed, improved RGB phosphors that are more compatible with blue, violet or ultraviolet LEDs are being evaluated and new red phosphors are being added to the blue light/yellow phosphor based white LEDs to improve the CRI of these widely used chips.

In LED packaging, trends include the development of higher pixel density modules; of flexible light panels and laser cut lighting tapes that are 'peel-off' adhesively-backed; of ultra-small ultra-thin (0.3mm) modules (for low profile installations); of an expanded selection of light fixtures (clusters, light tapes; the increased use of surface mounting methods; of lead frames for better thermal management and of all-polycarbonate molded modules for ceiling panels or lighting fixtures.

At many companies there exist overall plans to expand LED's new lighting concepts to re-fixture a light rather than just re-lamp with LEDs. Extensions of these developments and digital control will make the individual address of each RGB LED lighting node and the development of three-dimensional intelligent lighting a near term probability and an individual RGB colour temperature selection in an aircraft cabin a near term reality.

Additionally, improved LED light output lifetimes are being obtained by better heat sinking and by the replacement of the typical epoxy encapsulants and phosphor dispersants that deteriorate and yellow with age, with blue and UV light resistant polymers, many of which are siloxane based.

In the use of optics with LEDs, the key adage is 'do not waste photons, put them where the light is needed.' Here the trends are an increased use of integrated LED and optics units, a wider use of lensed modules, pre-cast lens fixtures and/or lenses that provide complete optical systems for diverse applications (e.g. the production of 3° angle LEDs for long distance signaling or beam control) or new styles of luminaire fixtures (e.g. light integrated ceiling or floor tiles, aircraft runway fixtures and sealed marine lighting systems).

A key optical trend is the move to extend car lighting use and one of the biggest optics challenges for an LED lighting application is the development of the low beam vehicle headlamp, where a directionally movable flat beam is required, together with some side lighting.

Today's worldwide white lighting market is widely reported to be about $12bn and most of it represents the ultimate goal (2010 to 2015) of the 'white' LED.

However, the new methods and types of lighting offered by the HBLED, that cannot be accessed by other lighting types, should substantially increase the total lighting market value within the same time frame. From the goals already achieved plus the worldwide levels of research and development that are underway, the future of HBLED lighting is assured.

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