STUDY ON THE LIGHT EMITTING DIODE (LED) INDUSTRY

PART ONE: INTRODUCTION ON LED

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Part One of the "Study on the LED Industry" is an introduction to the LED Industry. This report gives an explanation on what is an LED, what goes inside the LED, the production process, its uses as well as advantages and disadvantages of LEDs. This report also attempts to discuss the drivers and challenges pertaining to the adoption of LED lighting technology as well as highlights LED trends and opportunities

1. INTRODUCTION

1.1 The Light Emitting Diode (LED) is an electronic light source. LEDs work by the effect of electroluminescence. Electroluminescence is the effect when electrons are recombined with holes and energy is released in the form of light.

1.2 In short, LEDs emit light when an electric current passes through them.

1.3 LEDs come in many colours – red, orange, amber, yellow, green, blue and white. The colour of an LED is determined by the semiconductor material and **not** by the colouring of the 'package' (or plastic body).

1.4 LEDs of all colours are available in uncoloured packages, which may be diffused (milky) or clear. The coloured packages are also available as diffused (which is the standard type) or transparent.

2. WHAT IS INSIDE AN LED?

2.1 The most important part of a Led is the semiconductor chip located in the centre of the bulb.

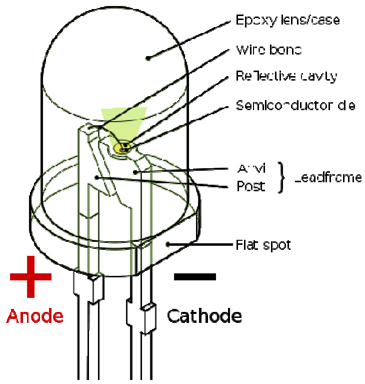
2.2 A clear or coloured epoxy case enclosed the semiconductor chip.

2.3 A substrate – normally ceramic or sometimes could be aluminium or in the form of a PCB (printed circuit board)

2.4 Two wires extend below the LED epozy enclosure (or the bulb).

LED leads

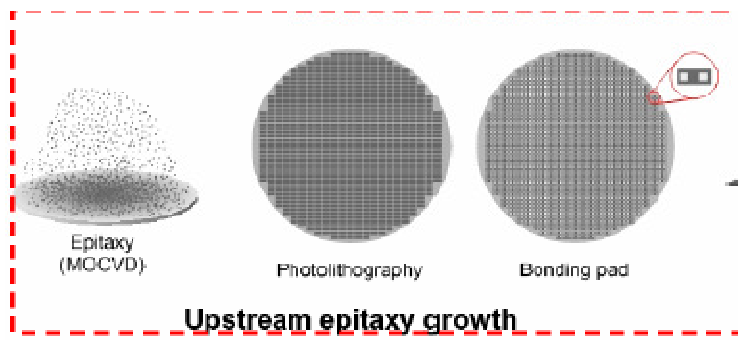
<-- -->
side lead on
flat
side of bulb
= negative



3. LED PRODUCTION FLOW

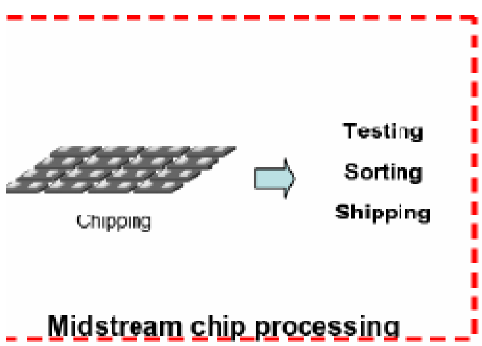
3.1 Upstream:

Epitaxy (MOCVD) → Photolithography → Bonding pad



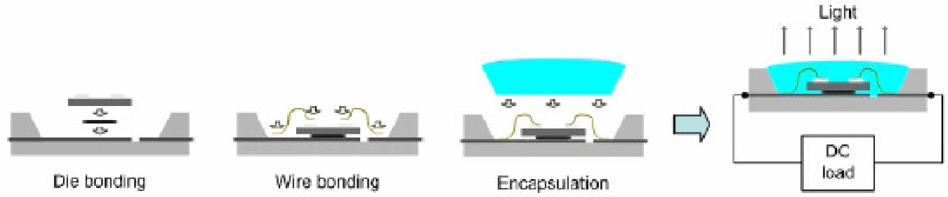
3.2 Midstream:

Chipping → Testing, Sorting, Shipping



3.3 Downstream Packaging:

Die bonding[1] ⟶ Wire bonding[2] ⟶ Encapsulation ⟶ DC load



Downstream packaging

4. APPLICATIONS

4.1 Applications of LEDs fall under 3 major categories:

4.1.1 Visual **signal / indicator** application where the light goes more or less directly from the LED to the human eye to convey a message or meaning. For example message displays, traffic lights & signals, brake lights.

4.1.2 **Illumination** where LED light is reflected from the object to give visual response of these objects such as **lighting**. Examples include street lighting, backlighting for LCD televisions and laptops, light source of DLP (digital light processing) projectors, decorative lights. Other lightings also include smart lighting to transmit broadband data and sustainable lighting / efficient lighting. Eg. A 13W LED lamp produces 450 – 640 lumens which is equivalent to a standard 40W incandescent bulb, thus making LED an environmentally friendly option (e.g. 1kWH of electricity generates 1.34 pound (610 gms) of carbon dioxide emission). LEDs are also non-toxic compared with the more popular energy efficient bulb, namely the CFL (compact fluorescent lamp) which contains traces of harmful mercury). Due to its long lifetime, LED could be a cost effective lighting for home or office.

4.1.3 Generate light for measuring and interacting with processes that do not involve the human visual system. These application fall under 3 groupings, namely communication, sensors and light matter interaction.

[1] The attachment of an IC chip to a substrate.
[2] The use of tiny wires that are soldered to the bare die on one end and to metal leads of the chip package on the other.

5. ADVANTAGES AND DISADVANTAGES OF LEDs

5.1 The advantages of LEDs are as follows:

5.1.1 Produce more light per watt than incandescent bulbs.

5.1.2 Can emit light of an intended colour without the use of colour filters that traditional lighting methods require. Thus more efficient and can lower initial costs.

5.1.3 Can be very small (i.e. smaller than $2mm^2$) and are easily populate onto printed circuit boards.

5.1.4 Light up very quickly. LEDs used in communications devices have even faster response time.

5.1.5 Ideal for use in applications that are subject to frequent on-off cycling, unlike fluorescent lamps that burn out more quickly when cycled frequently or HID (high intensity driving) light that require a longer time before restarting.

5.1.6 Can very easily be dimmed.

5.1.7 Radiate very little heat in the form of IR (infrared) that cause damage to sensitive objects of fabrics.

5.1.8 Mostly fail by dimming over time rather than the abrupt burn-out of incandescent bulbs.

5.1.9 Have relatively long useful life, estimated to last for 35,000 – 50,000 hours of useful life compared with 10,000 – 15,000 hours for fluorescent tubes and 1,000 – 2,000 hours for incandescent bulbs.

5.1.10 Difficult to damage with external shock, unlike fluorescent and incandescent bulbs which are fragile.

5.1.11 Solid package of LED can be designed to focus its light while incandescent and fluorescent sources often require and external reflector to collect light and direct it in a usable manner.

5.1.12 Do not contain mercury, unlike fluorescent lamps.

5.2 The disadvantages of LEDs are as follows:

5.2.1 Initial high price per lumen compared with more conventional lighting technologies. The additional expense partially stems from the relatively low lumen output and the drive circuitry and power supply needed. However, when considering the total cost (energy and maintenance), LEDs are cheaper than incandescent or halogen sources.

5.2.2 LED performance largely depends on the ambient temperature of the operating environment. Over-driving the LED in high ambient temperatures may result in overheating of the LED package, eventually leading to device failure. Adequate heat-sinking is required to maintain long life.

5.2.3 LED must be supplied with the voltage above the threshold and a current below the rating. This can involve series resistors and current-regulated power supplies.

5.2.4 The spike at 460 nm (nanometers) and dip at 500 nm can cause the colours of objects to be perceived differently under cool-white LED illumination.

5.2.5 LEDs do not approximate a 'point source' of light but rather a lambertian[3] distribution. Thus LEDs are difficult to use in applications requiring a spherical light field. LEDs are not capable of providing divergence below a few degrees, compared with lasers, which can produce beams with divergences of 0.2 degrees or less.

5.2.6 There is increasing concern that blue LEDs and cool-white LEDs are now capable of exceeding safe limits of the so-called blue-light hazard as defined in eye safety specifications such as NSI/IESNA RP-27.1-05: Recommended Practice for Photobiological Safety for Lamp and Lamp System.

5.2.7 Because cool-white LEDs (i.e. LEDs with high colour temperature) emit much more blue light than conventional outdoor light sources such as high-pressure sodium lamps, the strong wavelength dependence of "Rayleigh scattering"[4] means that cool-white LEDs can cause more light pollution than other light sources.

6. DRIVERS AND CHALLENGES

6.1 The capabilities offered by LED technology is one of the key driving factors enabling the adoption of LED lighting applications and this can be attributed to its lifetime (up to 50,000 hours), efficacy (over 100 lumens/watt), and energy saving.

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[3] If a surface exhibits **Lambertian reflectance**, light falling on it is scattered such that the apparent brightness of the surface to an observer is the same regardless of the observer's angle of view. More technically, the surface luminance is isotropic.)

[4] **Rayleigh scattering** (named after the English physicist Lord Rayleigh) is the elastic scattering of light or other electromagnetic radiation by particles much smaller than the wavelength of the light, which may be individual atoms or molecules. It can occur when light travels in transparent solids and liquids, but is most prominently seen in gases. Rayleigh scattering is a function of the electric polarizability of the particles. Rayleigh scattering of sunlight in clear atmosphere is the main reason why the sky is blue:

6.2 Another driving factor is legislation. Among the legislations include:

6.2.1 Restriction of Hazardous Substances (RoHS)

6.2.2 Waste Electrical and Electronic Equipment (WEEE)

6.2.3 Phasing out incandescent lights by European Union starting in 2009 and end by 2012;

6.2.4 The Energy End-use Efficiency and Energy Services Directive (the EU member states should aim to achieve an overall end user energy savings of 9% over the period between 2008 and 2017 according to the 2006/32/EC directive)

6.2.5 Energy Performance of Buildings (EPBD) Directive (the EU member states should aim to achieve an estimated 22% potential power savings by 2020 according to the 2002/91/EC directive)

6.2.6 Impact of anti-dumping duties on light bulbs

6.2.7 Energy Star certification

6.3 Cost is the main challenge.

6.4 Other challenges include issues pertaining to achieving the desired performance in terms of light extraction efficiency, colour performance and quality.

6.5 It is also important to ensure that thermal resistance is minimized from the junction to the external package. This is mainly because for LEDs, heat is transferred via conduction from the junction to the system enclosure unlike traditional lighting technologies wherein the heat is radiated.

6.6 The light extraction efficiency of the LED is affected by the mismatch in refractive index[5] between the semiconductor chip and the encapsulant. More than 60% of the photons generated by the semiconductor chip is reflected internally and lost inside the LED package. High-index encapsulants, shaping the LED chip, and roughening the top surface of the LED chip are some of the techniques investigated to reduce refractive index mismatch.

6.7 Although there are regulations emphasizing on the phasing out of incandescent lights, there is still a strong presence / established market for traditional lighting technologies.

[5] Refractive Index is the ratio of the velocity of light in a vacuum to that in a medium.

7. Trends

7.1 Technology adoption is primarily driven by the increasing demand for reducing electrical energy consumption.

7.2 LED is regarded as a viable alternative for incandescent and fluorescent lights due to its enhanced performance.

7.3 Initiatives are undertaken to reduce the initial cost, which is high compared to existing lighting technologies and the payback period to 2 years or less.

7.4 Mass volume production or improvements in the semiconductor material, chip and packaging technologies would facilitate effective generation of light output from small area of semiconductor material.

7.5 Higher efficacies such as 150 lumens / watt are preferred with high colour rendering index[6] (now over 100 lumens / watt).

7.6 It is desirable to have LEDs for lighting applications with lifetimes of over 100,000 hours (now up to 50,000 hours).

7.7 The LED market is highly fragmented and competitive. As such, probability of companies entering into collaborative developments / agreements (mergers and acquisitions, cross licensing agreements, intellectual property and distribution partnerships) are likely to be high.

7.8 LED Demand Model

7.8.1 LED market ($Million) in 2008 vis-à-vis 2011(e)

	2008 ($ million)	2011(e) ($ million)
Mobile handsets	1982	1325
Notebook	95	608
Netbook	35	170
TV	153	1304
Automotive	742	675
General lighting	358	776
Others	1733	1617
Total	5098	6475

Source: Strategies Unlimited, Credit Suisse estimates

7.8.2 According to another report, the LED market is forecasted to grow to $14 billion by 2013. (source: www.displaybank.com)

[6] Color rendering index, or CRI, is a measure of the quality of color light, devised by the International Commission on Illumination (CIE). It generally ranges from zero for a source like a low-pressure sodium vapor lamp, which is monochromatic, to one hundred, for a source like an incandescent light bulb, which emits essentially blackbody radiation. It is related to color temperature, in that the CRI measures for a pair of light sources can only be compared if they have the same color temperature. CRI is a quantitatively measurable index, not a subjective one.

7.8.3 LED share application in 2008 vis-à-vis 2011(e)

	2008 (%)	2011(e) (%)
Mobile handsets	38.9	20.5
Notebook	1.9	9.4
Netbook	0.7	2.6
TV	3.0	20.1
Automotive	14.5	10.4
General lighting	7.0	12.0
Others	34.0	25.0
Total	100.0	100.0

Source: Strategies Unlimited, Credit Suisse estimates

8. Appendix

8.1 Appendix 1: Profile of Key Providers / Developers of LED Lighting Technologies

Appendix 1: Profile of Key Providers / Developers of LED Lighting Technologies

Company & Location	Applications	Comments / Additional Details
Osram Opto Semiconductors, Germany	Home lighting, automotive lighting, general lighting, signage and illuminated advertising	Osram demonstrated the complete life-cycle assessment (LCA) results for LED lamps. The study involved analysis of the energy and raw material consumption in context with production, usage and disposal and its impact on the environment.
Cree, North Carolina, USA	Residential and commercial application	Cree white power LEDs has demonstrated 186 lumens / watt efficacy at a temperature of 4577 K[7]
Philips Lumileds, San Jose, California, USA	Indoor, outdoor, automotive, digital, portable lighting solutions	
Nichia, Japan	Ultraviolet LEDs, Indium Galium Nitride (InGaN) LED	
Bridgelux, Sunnyvale, California, USA	LED Arrays – track, wide area, task, spot, down light and security lighting LED Chips – back lighting units, signage, automotive, general lighting and camera flash for mobile appliance	
Ilumisys, Michigan, USA	Solid state lighting applications	Altair and Ilumisys share fundamental patents on replacement of fluorescent tubes using LEDs
Seoul Semiconductor, Korea	Lighting, backlight, automotive, mobile signs	10% of the revenues are utilized for research and development activities every year
Toyoda Gesei, Japan	LED backlight for laptop computers, traffic signals, backlight for meters, solar street lights, museums, shops	Patent agreement with Showa Denko and Cree
Source: Frost & Sullivan 2009, Technical Insights, Futuretech Alert, 31st December 2009		

[7] The color temperature of a light source is the temperature of an ideal black-body radiator that radiates light of comparable hue to that light source. The temperature is conventionally stated in units of absolute temperature, kelvin (K).

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Note: Part Two of the Study on the LED Industry will discuss the local LED scenario in Penang.