# Light Emitting Diodes (LEDs)

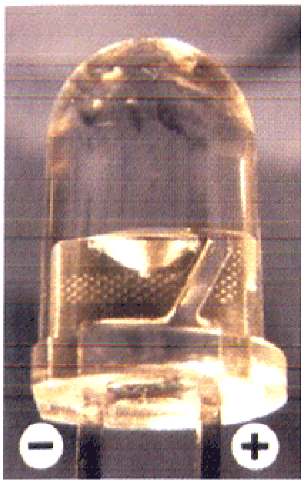
*…The future of lighting?*

Say the word LED and it brings to mind tiny and reliable, red, yellow, blue, green coloured lights used for indicating/ signaling/ decorative purposes. The scenario has changed completely in the last decade, the LEDs have come a long way and could be serious contenders for domestic, commercial and industrial lighting applications, in addition to the current task lighting. Bright LEDs have, however, become more complex in construction with integrated heat sinks for efficient heat dissipation.

## History

For the past 150 years, lighting technology was mainly limited to incandescence and fluorescence. While derivative technologies such as high-intensity discharge lamps (HID) have emerged, none has achieved energy efficacies exceeding 200 lm/W (for monochromatic low pressure sodium lamps), with of less than 28 lm/W. With the advent of commercial LEDs in the 1960s, however, a new kind of lighting became available.

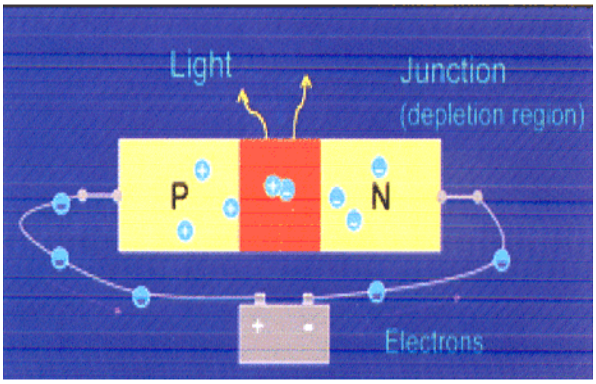
LEDs can consume less electricity than conventional lighting and can produce less of the parasitic by-product heat. However, at present, commercial LED systems are not as efficient as fluorescent lighting. Initial LEDs were red in color, with yellow and orange variants following soon thereafter. To produce a white SSL device, however, a blue LED was needed, which was later discovered through materials science and extensive research and development.



In 1993, Shuji Nakamura of Nichia Chemical Industries came up with a blue LED using gallium nitride (GaN). With this invention, it was now possible to create white light by combining the light of separate LEDs (red, green, and blue), or by placing a blue LED within a special package with an internal light conversion phosphor – some of the blue output becomes red and green with the result that the LED light emission appears white to the human eye.

## How LEDs Work

LEDs differ from traditional light sources in the way they produce light An LED, is a semiconductor diode. It consists of a chip of semiconducting material treated to create a structure called a p-n (positive-negative) junction. When connected to a power source, current flows from the p-side or anode to the n-side, or cathode, but not in the reverse direction. Charge-carriers (electrons and electron holes) flow into the junction from electrodes. When an electron meets a hole, it falls into a lower energy level, and releases energy in the form of a photon (light). The specific wavelength or color emitted by the LED depends on the materials used to make the diode.



## Developments over last decade – Luminous Efficacy of LEDs

Energy efficiency of light sources is typically measured in lumens per watt (lm/W), meaning the amount of light produced for each watt of electricity consumed by the light source. This is known as luminous efficacy. In September 2003 a new type of blue LED was demonstrated to give 24 MW at 20 mA. This produced a commercially packaged white light giving 65 lumens per watt at 20 mA, becoming the brightest white LED commercially available at the time, and over four times more efficient that standard incandescent.

For a rough comparison on current scenario on the range of system (lamp and ballast or LED and driver) efficacies for traditional and LED sources are shown below:

| Light Source | Typical System Efficacy Range in lm/W |
|---|---|
| | (varies depending on watt-age and lamp type |
| Incandescent | 10-18 |
| Halogen incandescent | 15-20 |
| Compact fluorescent (CFL) | 35-60 |
| Linear fluorescent (T8, T5) | 50-100 |
| Metal halide | 50-90 |
| White LED 5000K | 45-59* |
| Warm white LED 3300K | 22-37* |

*as of October 2006

In 2006 a company demonstrated a prototype with a record white LED efficacy of 131 lm/W at 20 mA. Also Seoul Semiconductor has plans for 135 lm/W by 2007 and 145 lm/W by 2008, which would be approaching an order of magnitude improvement over standard incandescents and better even than standard fluorescents. Nichia Corp. has developed a white light LED with efficacy of 150 lm/W at a forward current of 20 mA.

It should be noted that high-power (1 Watt) LEDs are necessary for practical general lighting applications. Typical operating currents for these devices begin at 350 mA. The highest efficiency high-power white LED is claimed by Philips Lumileds Lighting Co. with a luminous efficacy of 115 lm/W (350 mA).

Researchers are targeting white-light LEDs, producing 160 lm/W in cost-effective, market-ready systems by 2025. In the meantime, how does the luminous efficacy of today's white LEDs compare to traditional light sources? **Currently, the best white LEDs approach the efficacy of compact fluorescent lamps (CFLs).**

## Color Quality

To date, LED luminous efficacy similar to that of CFLs has been achievable only with higher color temperature products, which produce a "cool" or bluish-toned light and relatively low color rendering index (CRI) in the 70s. LEDs with warmer color appearance and higher CRI are only marginally more efficacious than incandescent sources. However, this is changing rapidly, with new performance improvements being announced on a regular basis by the industry.

## Driver Losses

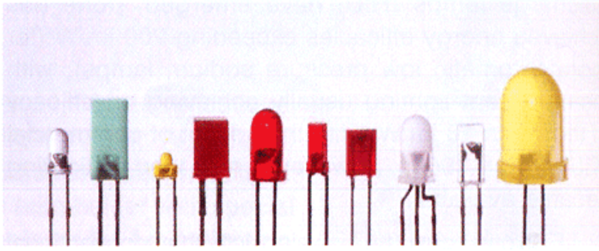
Fluorescent and high-intensity discharge (HID) light sources cannot function without a ballast, which provides a starting voltage and limits electrical current to the lamp. LEDs also require supplementary electronics, usually called drivers. The driver converts line power to the appropriate voltage (typically and current (generally 200-1000 milliamps or mA), and may also include dimming and/or color correction controls.

**Currently available LED drivers are typically about 85% efficient. So LED efficacy should be discounted by 15% to account for the driver.**

### Thermal Effects

The luminous flux figures cited by LED manufacturers assume an LED junction temperature (Tj) of 25°C. Well-designed systems with adequate heat sinking will maintain Tj well below the manufacturer's rated maximum temperature (typically 125°C).

## Common LED Types and Packages



## LEDs come in two basic categories

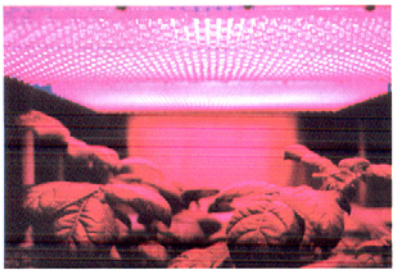
Low power LEDs commonly come in 5 mm size, although they are also available in 3 mm and 8 mm sizes. These are fractional wattage devices, typically 0.1 watt, operate at low current (-20 milliamps) and low voltage (3.2 volts DC), and produce a small amount of light, perhaps 2 to 4 lumens.

High power LEDs come in 1-3 watt packages. They are driven at much higher current typically 350, 700, or 1000 mA, and –with current technology-can produce 40-80 lumens per 1-watt package.

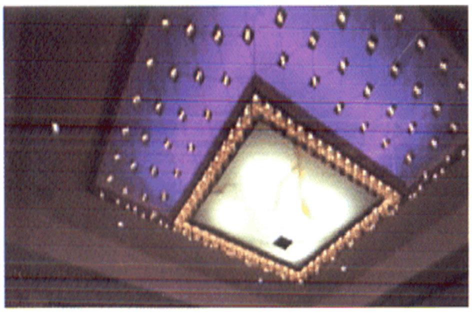
High power LEDs come in many different shapes and sizes. Some current Bright White LED products available are shown below:

## LED applications

Due to their monochromatic nature, LED lights have great power advantages over white lights when a specific color is required. One of the most recently introduced colors is the emerald green (bluish green, about 500 nm) that meets the legal requirements for traffic signals and navigation lights.



*LED panel light source used in an experiment on plant growth. The findings of such experiments may be used to grow food in space on long duration missions.*



*Pictured above are examples of three Color - Changing LED systems*

*The 1,500 foot long LED display on the "Fremont Street Experience" Las Vegas, USA is currently the largest in the world*


*A Large LED Display Screen*

*Single high-brightness LED with a glass lens creates a bright carrier beam that can stream DVD-quality video over considerable distances*

## Organic light-emitting diodes (OLEDs)

What's interesting about this light source still in development is that it may challenge our very perception of lighting and architecture in the future. OLEDs are similar to electroluminescent lighting, in which a sheet of material is excited so that it emits light. An OLED light source is a thin, flexible sheet of material consisting of three layers, a polymer or sublimed molecular film sandwiched between two layers of electrodes, one of them transparent. Current passes through the material until it emits light through its transparent layer OLEDs have been used to produce visual displays for portable electronic devices such as cellphones, digital cameras, and MP3 players.

***Pictured on below is a very tiny OLED screen for use on digital cameras and the like.***

Compared with regular LEDs, OLEDs are lighter, and polymer LEDs can have the added benefit of being flexible. Some possible future applications of OLEDs could be:

- Inexpensive, flexible displays
- Light sources Wall decorations
- Luminous cloth

Lighting designers often try to integrate lighting hardware and architecture in a cohesive manner; with OLEDs, the architecture may be the lighting hardware. Sheets of material can be cut and placed like “lighting wallpaper” or integrated with building materials such as wood, glass and other materials, converting them into luminous surfaces.

Manufacturers are actively engaged in the development of OLED and inorganic light emitting diode (LED) technologies for general lighting. LEDs can make very effective “point source” lights and OLEDs may be excellent “diffuse” large-area light emitters. Larger displays have been demonstrated, but their life expectancy is still far too short (<1,000 hours) to be practical. In the meanwhile, very recently OLED TVs have made an appearance in market, although currently, they are quite expensive.

### Advantages of LEDs

- LEDs produce more light per watt than do incandescent bulbs; this is useful in battery powered or energy-saving devices.
- LEDs can emit light of an intended color without the use of color filters that traditional lighting methods require. This is more efficient and can lower initial costs.
- The solid package of an LED can be designed to focus its light. Incandescent and fluorescent sources often require an external reflector to collect light and direct it in a usable manner.
- When used in applications where dimming is required, LEDs do not change their color tint as the current passing through them is lowered, unlike incandescent lamps, which turn yellow.
- LEDs are ideal for use in applications that are subject to frequent on-off cycling, unlike fluorescent lamps that burn out more quickly when cycled frequently.
- LEDs, being solid state components, are difficult to damage with external shock. Fluorescent and incandescent bulbs are easily broken if dropped on the ground.
- LEDs have an extremely long life span. One manufacturer has calculated the ETTF (Estimated Time to Failure) for their LEDs to be between 100,000 and 1,000,000 hours Fluorescent tubes typically are rated at about 10,000 hours, and incandescent light bulbs at 1,000-2,000 hours.
- LEDs mostly fail by dimming over time, rather than the abrupt burn-out of incandescent bulbs.
- LED light up very quickly. A typical red indicator LED will achieve full brightness in microseconds; LEDs used in communications devices can have even faster response times.
- LEDs cam be very small and are easily populated onto printed circuit boards.
- LEDs do not contain mercury, as compact fluorescent lamps do.

### Disadvantages of using LEDs

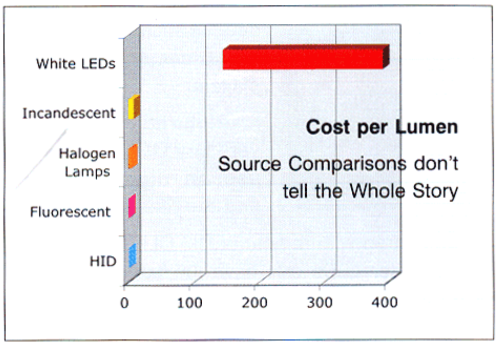
- LEDs are currently more expensive, price per lumen, on an initial capital cost basis, than more conventional lighting technologies. The additional expense partially stems from the relatively low lumen output and the drive circuitry and power supplies needed. However, when considering the total cost of ownership (including energy and maintenance costs), LEDs far surpass incandescent or halogen sources and begin to threaten compact fluorescent lamps.
- LED performance largely depends on the ambient temperature of the operating environment. “Driving” a LED “hard” 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. This is especially important when considering automotive, medical, and military applications where the device must operate over a large range of temperatures, and are required to have a low failure rate.
- LEDs typically cast light in one direction at a narrow angle compared to an incandescent or fluorescent lamp of the same lumen level.
- The spectrum of some white LEDs differs significantly from a black-body radiator, such as the sun or an incandescent light and can cause the color objects to be perceived differently under LED illumination than light sources.

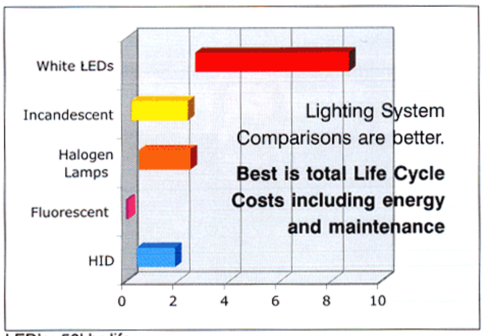
### LEDs Vs Traditional Light Sources in the contemporary Indian Urban/ Rural scenario

LEDs used as a replacement for incandescent light bulbs and fluorescent lamps are known as solid-state lighting (SSL) – packaged as a cluster of white LEDs grouped together to form a light source. LEDs are moderately efficient; the average commercial SSL currently outputs 32 lumens per watt (lm/W), and new technologies promise to deliver up to 80 lm/W. The long lifetime of LEDs make SSL very attractive. They are also more mechanically robust than incandescent light bulbs and fluorescent tubes. Currently, solid state lighting is becoming more available for household use but is relatively expensive, although costs are decreasing.

**However the high cost is a major obstacle but the benefits could outweigh the cost disadvantage.**

**LED Penetration to General Lighting Obstacles: Price**




LED's: 50khr life

**We compare below in brief select lighting sources currently in use in India**

Incandescent lamps are very popular and widely used in India and due to its very cheap price (Rs 10) and easy availability. But they are highly inefficient and do not last long. The Indian Government is reportedly considering a slow phase out of incandescent lamps replacing them with CFLs and LED lighting.

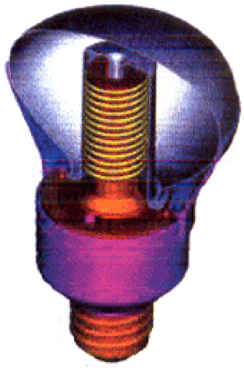
Fluorescent Tubes (Tube Lights) are more efficient, providing 50 to 100 lm/W for domestic tubes (average 60 lm/W), but are bulky and fragile and require starter or ballast circuits. Available in 2ft and 4 ft sizes with Aluminium, Copper and electronic ballasts, they very well entrenched in both urban and rural India.

Compact Fluorescent lamps, which include a quiet integrated electronic ballast, are relatively robust and efficient and fit in standard light bulb sockets and currently appear to be most attractive energy efficient option. CFLs are becoming cheaper and more accessable by the day and with a number of new manufacturers entering the arena, prices are dropping. Branded CFLs with 1 year warranty are available in retail, from Rs 80-Rs 200, depending on wattage from 2W to 36W.

The CFLs have been promoted by governments/ Discoms due to their high power saving capability. Recently, the Indian government has gone one step ahead and has proposed a private public partnership scheme between distribution utilities and CFL manufacturers to provide CFLs at Rs 10 to 20 a piece and one time buyback and disposal charge of Rs 2 per CFL, some state governments have reportedly gone even further and are planning to offer CFLs free, subject to some conditions. This shows the resolve of the government to save energy through innovative methods. These schemes if successful, could be a windfall for the CFL manufacturers and could result in CFLs substituting incandescent lamps at a faster pace.

But CFLs do have a few problems like lower power factor, which is some what expensive to correct, generation of harmonics due to electronic ballasts and mercury content which is hazardous to environment. A compact fluorescent bulb generally contains only a few milligrams of mercury. As long as the bulb remains intact, this mercury is not released to the environment. When the lamp 'burns out' (and they are designed to have a much longer life than conventional bulbs), they should be disposed of in an environmentally sound way. Governments are giving serious consideration to such disposal issues. Manufacturers on their part, are currently working on reducing mercury in CFLs to the minimum.

Induction lamps are electrodeless fluorescent lamps driven by high-frequency current, typically between 250 kHz and 2.65 mHz, usually via an external generator. They are available in limited wattages and are known for exceptionally long service life: up to 100,000 hours, Lamp efficacies typically range from 64 to 88 lumens per watt.



Color rendition with induction lamps is very good. Although not easily optically controllable in a luminary because of the large lamp size, induction lighting is often employed in applications where luminaries may be very difficult to access or where maintenance costs are a strong factor in the lighting design and installation. Initial system purchasing costs are high compared to the best HID or fluorescent systems. Although induction lamps could be a serious contender for future lighting, some how, induction lamps have not caught the fancy for larger usage.

The white LEDs are slowly bur surely establishing their presence in India. In addition to signal and indicator lighting, LEDs are increasingly finding use in commercial and industrial environments. Considering the current power shortages, Ministry of Power & Bureau of Energy Efficiency and state governments have, shown interest in adopting LED lighting due to its many advantages.

In the rural environments LED lights are an ideal match to a solar / battery power system, because of their very low power consumption. This, coupled with their very long life, and strong resistance to heat, cold, vibration and moisture, make LED forms of lighting suited to any solar applications, but particularly to remote areas, where normal power supply is non-existent. LEDs continue to emit light even when the battery has drained out to the level of 80%. Batteries are easy to recharge /maintain. BIS has also drafted specifications for LEDs with a sealed battery and PV Solar Modules for power / charging with an average duty cycle of 4 hrs / day.

Some state governments have reportedly announced funding programmes for increased use of LED lighting through innovative solutions in rural areas for emergency and regular lighting applications. This trend is likely to gather pace with white LEDs becoming cheaper.

| Below, in table 1, we compare a 10 W LED to GLS, CFL and Induction Lamp | | | | |
|---|---|---|---|---|
| Comparison of Light Source to Deliver Lighting Equivalent 60w Gls | | | | |
| Type of Lamp | GLS 60W | CFL 13W | Induction lamp 12W | LED 10 W |
| Efficacy Lumen per Watt | 13 | 55 | 68 | 55 |
| Total lumens | 780 | 715 | 816 | 550 |
| Life of lamp (burning hours) | 1000 | 6000 | 30000 | 50000 |
| Cost of lamp (Rupees) | 10 | 90 | 1000 | 3000 |
| Number of lamps for 50000 hours | 50 | 8 | 2 | 1 |
| Cost of lamps for 50000 hours of burning | 500 | 750 | 1667 | 3000 |
| Incremental cost (Rupees) | 0 | 250 | 1167 | 2500 |
| Yearly power consumption (kWh) | 87.6 | 18.98 | 17.52 | 14.6 |
| Power consumption over 50000 burning hours (kWh) | 3000 | 650 | 600 | 500 |
| Yearly power savings (kWh) | 0 | 68.62 | 70.08 | 73 |
| Power saved over 50000 burning hours (kWh) | 0 | 2350 | 2400 | 2500 |
| Cost to save one kWh over 50000 burning hour | NA | 0.04 | 0.416666667 | 1.2 |

Assumptions: domestic rural household would use the lamp for all 365 days at 4 hours a day

1[1] Lighting equivalence to 75 W incandescent lamp, since induction lamps are only available in 12 W size.

**From the above, currently, CFLs appear to be the best choice for Energy efficient general lighting, at a reasonable cost.**

### Solid State Lighting (SSLs) – The Future of Lighting?

Rapid progress in solid-state lighting (SSL) research and development (has resulted in the advent of light-emitting diodes (LED) for general lighting applications. High output LED fixtures suitable for general architectural lighting applications are beginning to appear on the market with system efficacies of up to 36 lumens per watt, which is comparable to fluorescent systems.

LEDs used as a replacement for incandescent light bulbs and fluorescent lamps are known as solid-state lighting (SSL) – packaged as a cluster of white LEDs (Multicooured LEDs) grouped together to form a white light source.

The good news is that progress is being made, faster than originally anticipated. Researchers have already improved the efficacy of white LEDs to approximately 56 lumens per watt, almost four times more efficient than incandescent sources. However, costs are still high, but continue to drop significantly, from approximately $250/kilo-lumen in 2004 to around $50/kilo-lumen in 2006 (based on manufacturer estimates for volume purchase). For comparison, conventional light sources (incandescent, fluorescent) cost around $1/kilo-lumen.

### Advantages of SSL – A Technical Comparison

- SSL is intended to be a cost-effective yet high quality replacement for incandescent and fluorescent lamps.
- SSL achieves its purpose by grouping smaller LEDs in an orderly fashion, thereby creating a unified beam. The SSL can be comprised of multiple white LEDs, or from ones that are color-mixed-where LEDs of different colors are mixed to produce white light. The inherent advantages and disadvantages of SSL are the same as those of an LED.

The following projection Matrix, Table 2, derived from currently available information gives an interesting insight in the future of lighting (could be available before 2025) and compares a perfected SSL device with incandescent and fluorescent lights.

| Table 2 | | | |
|---|---|---|---|
| Technology | Future solid state lighting | Incandescent | Fluorescent |
| Luminous efficacy (lm/W) | 200 | 16 | 85 |
| Lifetime (kh) | >100 | 1 | 10 |
| Flux (lm/lamp) | 1,500 | 1,200 | 3,400 |
| Input power (W/lamp) | 7.5 | 75 | 20 |
| Lumen cost ($/klm) | <2 | 0.4 | 1.5 |
| Color Rendering Indiex (CRI) | >80 | 95 | 82 |

## Conclusion

Currently, however, there is no SSL on the market that can be offered as a true replacement for incandescent or fluorescent lamps, even though several manufacturers have gone forward with the introduction of such products. White LEDs produced today are too expensive to be considered affordable, and the lumens produced by the LEDs today are not as bright as traditional lighting.

With present day technologies, CFL seems to be the best choice for energy efficient lighting. Induction lamp with the highest lumen efficacy has the potential to became the choice of lamp with large scale of operation.

Table 2 above project's that LEDs could be better than CFLs by 2025. However the future may arrive even earlier. Currently developments in LED technology are doubling lumen efficacy of every four years. By 2015, LEDs with a lumen efficacy of 150 lumens could become a reality

**With attributes like high energy efficiency and long life and no environmental hazards, LEDs could well become the preferred lighting option of the future.**

## Reference Book:

IEEMA Journal
Volume XXVII no. 10
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