LED – TECHNOLOGY

Technology

Physics

Like a normal diode, the LED consists of a chip of semiconducting material doped with impurities to create a *p-n junction*. As in other diodes, current flows easily from the p-side, or anode, to the n-side, or cathode, but not in the reverse direction. Charge-carriers—electrons and holes—flow into the junction from electrodes with different voltages. When an electron meets a hole, it falls into a lower energy level, and releases energy in the form of a photon.

The wavelength of the light emitted, and therefore its color, depends on the band gap energy of the materials forming the *p-n junction*. In silicon or germanium diodes, the electrons and holes recombine by a *non-radiative transition* which produces no optical emission, because these are indirect band gap materials. The materials used for the LED have a direct band gap with energies corresponding to near-infrared, visible or near-ultraviolet light.

LED development began with infrared and red devices made with gallium arsenide. Advances in materials science have made possible the production of devices with ever-shorter wavelengths, producing light in a variety of colors.

LEDs are usually built on an n-type substrate, with an electrode attached to the p-type layer deposited on its surface. P-type substrates, while less common, occur as well. Many commercial LEDs, especially GaN/InGaN, also use sapphire substrate.

Most materials used for LED production have very high refractive indices. This means that much light will be reflected back in to the material at the material/air surface interface. Therefore *Light extraction in LEDs* is an important aspect of LED production, subject to much research and development.

Efficiency and operational parameters

Typical indicator LEDs are designed to operate with no more than 30–60 milliwatts [mW] of electrical power. Around 1999, Philips Lumileds introduced power LEDs capable of continuous use at one watt [W]. These LEDs used much larger semiconductor die sizes to handle the large power inputs. Also, the semiconductor dies were mounted onto metal slugs to allow for heat removal from the LED die.

One of the key advantages of LED-based lighting is its high efficiency, as measured by its light output per unit power input. White LEDs quickly matched and overtook the efficiency of standard incandescent lighting systems. In 2002, Lumileds made five-watt LEDs available with a luminous efficacy of 18–22 lumens per watt [lm/W]. For comparison, a conventional 60–100 W incandescent lightbulb produces around 15 lm/W, and standard fluorescent lights produce up to 100 lm/W. A recurring problem is that efficiency will fall dramatically for increased current. This effect is known as droop and effectively limits the light output of a given LED, increasing heating more than light output for increased current.

In September 2003, a new type of blue LED was demonstrated by the company Cree, Inc. to provide 24 mW at 20 milliamperes [mA]. This produced a commercially packaged white light giving 65 lm/W at 20 mA, becoming the brightest white LED commercially available at the time, and more than four times as efficient as standard incandescent. In 2006 they demonstrated a prototype with a record white LED luminous 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 incandescent and better even than standard fluorescents.

Nichia Corporation has developed a white LED with luminous efficacy of 150 lm/W at a forward current of 20 mA.

It should be noted that high-power (≥ 1 W) 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)

Note that these efficiencies are for the LED chip only, held at low temperature in a lab. In a lighting application, operating at higher temperature and with drive circuit losses, efficiencies are much lower. United States Department of Energy (DOE) testing of commercial LED lamps designed to replace incandescent lamps or CFLs showed that average efficacy was still about 46 lm/W in 2009 (tested performance ranged from 17 lm/W to 79 lm/W).

Cree issued a press release on November 19, 2008 about a laboratory prototype LED achieving 161 lumens per watt at room temperature. The total output was 173 lumens, and the correlated color temperature was reported to be 4689 K.

Lifetime and failure

Solid state devices such as LEDs are subject to very limited wear and tear if operated at low currents and at low temperatures. Many of the LEDs produced in the 1970s and 1980s are still in service today. Typical lifetimes quoted are 25,000 to 100,000 hours but heat and current settings can extend or shorten this time significantly.

The most common symptom of LED (and diode laser) failure is the gradual lowering of light output and loss of efficiency. Sudden failures, although rare, can occur as well. Early red LEDs were notable for their short lifetime. With the development of high-power LEDs the devices are subjected to higher junction temperatures and higher current densities than traditional devices. This causes stress on the material and may cause early light output degradation. To quantitatively classify lifetime in a standardized manner it has been suggested to use the terms L75 and L50 which is the time it will take a given LED to reach 75% and 50% light output respectively. L50 is equivalent to the half-life of the LED.

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