Technology Brief 5
Light-Emitting Diodes (LEDs)

How LEDs Are Made

LEDs are a specific type of the much larger family of semiconductor diodes, whose basic behavior we discussed earlier in Section 2-6. When a voltage is applied in the forward-biased direction across an LED, current flows and photons are emitted (**Fig. TF5-1**). This occurs because as electrons surge through the diode material, they recombine with charge carriers in the material and release energy in the form of photons (quanta of light). The energy of the emitted photon (and hence the wavelength/color) depends on the type of material used to make the diode. For example, a diode made of indium gallium aluminum phosphide (InGaAlP) emits red light, while a diode made from gallium nitride (GaN) emits bluish light. Extensive research over many decades has yielded materials that can emit photons at practically any wavelength from the infrared through ultraviolet (**Fig. TF5-2**). Various "tricks" have also been employed to modify the emitted light after emission. To make white light diodes, for example, certain blue light diodes can be coated with crystal powders which convert the blue light into a broad-spectrum "white" light. Other coatings such as ***quantum dots*** are still the subject of today's research. In a traditional package, the LED transmits light in a hemispherical pattern, but numerous other light-focused packaging methods are available that can focus the light in virtually any way imaginable. LEDs can be focused using highly reflective coatings to intensify their light for higher power applications.

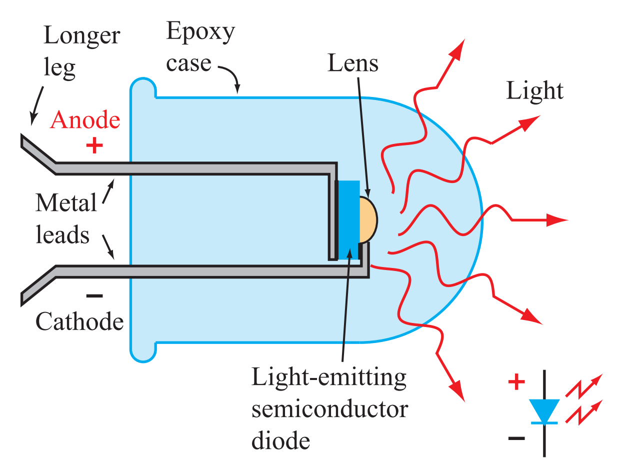

Figure TF5-1: Basic configuration of an LED.

In addition to semiconductor LEDs, a newer class of devices called ***organic light emitting diodes*** (OLEDs) are the subject of intense research efforts. OLEDs operate in a manner that is analogous to conventional LEDs, but are made from organic molecules (often polymers). Because OLEDs are lighter weight than conventional LEDs and can be made to be flexible, they have the potential to revolutionize handheld and lightweight displays, such as those used in phones, PDAs and flexible screens. Imagine a flexible contact lens that could allow you to see a heads-up display or augmented reality!

LED Advantages

LEDs have several major attributes that have made them a key element of many applications. First, they can be

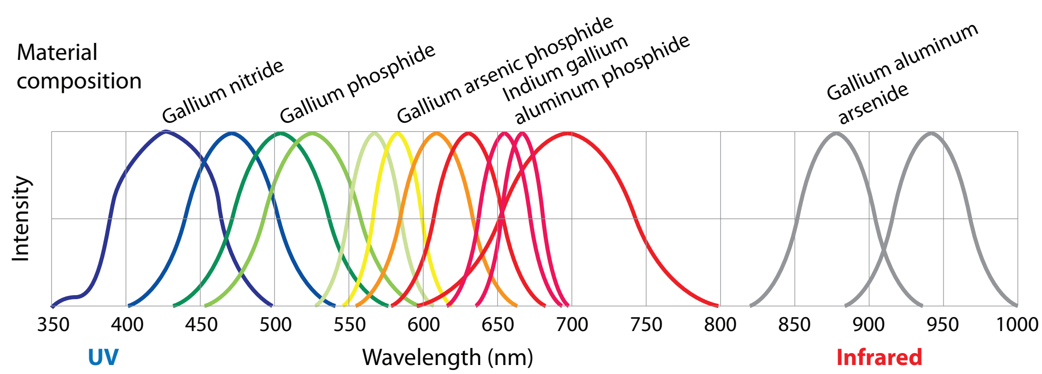

Figure TF5-2: Emission spectra of LEDs made of different material composites.

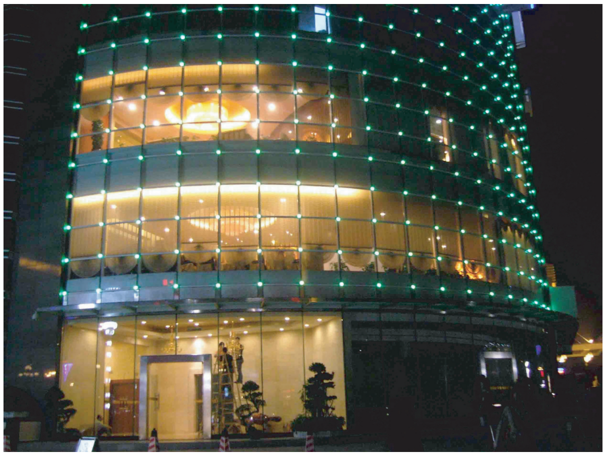

Figure TF5-3: LED-lit building.

produced in a wide variety of wavelengths from infrared through ultraviolet. Targeted or broad spectra can also be produced, making them applicable to virtually any optical application. Second, they are energy efficient. An incandescent lightbulb uses 80% of its energy for heat and 20% to produce light. LEDs use only about 20% of their energy for heat and 80% for light. This also makes them cool, requiring less energy to remove the excess heat. Third, they are manufactured in a huge array of colors, sizes, shapes, designs, and more. They are affordable (not yet less expensive than incandescent bulbs in the initial purchase price, but definitely less expensive over the lifetime of the bulb). Fourth, they last longer (often > 100k hours) than incandescent bulbs, which is particularly important in hard-to-reach applications. Fifth, they can be integrated directly into semiconductor circuits, printed circuit boards, and light-focusing packages. Various combinations of these advantages are key to the following broad range of applications of LEDs.

LEDs for Lighting

In an era where energy efficiency matters financially, environmentally, and practically, LEDs have become a popular mainstay in home and office lighting, street lighting and consumer products from home appliances and toys to high-efficiency tail lights for cars and flashlights. Of growing importance is the replacement of traditional incandescent bulbs with LEDs in homes and buildings (**Fig. TF5-3**), because of their energy efficiency.

Figure TF5-4: LED eyelashes can be worn in many colors, and can be made to turn on or off with a tip of the head. (Credit: Soomi Park.)

But lighting is more than just enabling us to see at night. LEDs can be used in horticulture to efficiently target ideal wavelengths for plant growth, and exposing produce to certain wavelengths of light can help it ripen on demand, or can extend its ripened shelf life. UV LEDS are being explored to enhance development of polyphenol, which are believed to have antioxidant qualities, in growth of green, leafy vegetables. LEDs provide high visibility bike lights, safety vests, tennis shoes, and more. They are also used artistically for decoration and advertising on buildings and signs, woven into clothes often augmented by plastic fiber optic threads (e.g., Philips Research Lumalive textiles), or even worn with LED eyelashes (see **Fig. TF5-4**)!

LEDs for Medical Applications

LEDs are used for a variety of medical applications. One particularly important application is the pulse oximeter (**Fig. TF5-5**), which measures blood oxygen level and pulse rate. Oxygenated blood absorbs light at 660 nm (red light), whereas deoxygenated blood absorbs light at 940 nm (infrared). Pulse oximeters use two LEDs, one at 600 nm and another at 940 nm, which are arranged to transmit through a translucent section of the body such as the finger or ear lobe. Two associated light collecting sensors are placed on the opposite side to measure the amount of each wavelength that is transmitted through the body. The ratio of the red and infrared light indicates how much oxygen is in the blood. To insure that the received light signals are actually from the blood, the measurement is made over several seconds (several pulses), focusing in on the pulsing blood rather than the static surrounding tissues.

Figure TF5-5: Pulse oximeter used to measure blood oxygen content.

Figure TF5-6: Large LED display.

LEDs are also used to treat many superficial (skin) conditions. Red light in the range of 600–950 nm can be used to treat acne, rosacea, and wrinkles. The red light works by stimulating the mitochondria in the skin to make older cells behave like younger cells. Blue-light therapy in the 405–420 nm range is used for acne treatments and “anti-aging” skin therapies because of its ability to stimulate collagen in the skin. Green to yellow light (532–595 nm) can reduce skin redness (rosacea). Combining LED light sources with topical drug treatments that are ***photoactivated*** may be used to treat a variety of skin conditions including skin cancer and pre-cancer.

LEDs are also used extensively in dentistry. Blue LEDs can be used to cure (harden) polymer composite materials used for fillings. The rate at which the filling material cures is proportional to the power carried by the LED light, so high power LEDs are used to speed up the curing process.

Ultraviolet (UV) LEDs

The UV range provides a wealth of applications, and low-cost high-power UV LEDs are enabling many of these applications. Inks (printing), adhesives and coatings are often cured with LEDs in the UV range (primarily 395 nm, 385 nm or 365 nm). UV LED flashlights are used to detect fraudulent identification (at the airport, for example) and currency. UV-LEDs are used extensively in forensic analysis and drug discovery. In the lower UV spectral range (100–280 nm) LEDs sterilize air and water by breaking up the DNA and RNA of microorganisms and preventing their reproduction. For example, 275 nm is believed to be the most effective wavelength for eradicating pathogens such as E-coli in water. LEDs in this range are also used for spectroscopic and fluorescence measurements and for chemical and biological detectors.

LED Displays

LEDs, with their wide range of colors, efficiency, low cost, flexibility, low profile and light weight, are ideal for both handheld displays and much larger displays (such as billboards and signage, as shown in **Fig. TF5-6**). Some LED displays use edge lighting where LEDs shine light across the screen (allowing the display to be thinner than traditional screens but not improving picture quality). Others use RGB LEDs. These LEDs use a common anode but have separate cathodes for red, green and blue LEDs (making the composite a 4-pin LED). They can be made to generate light with almost any color, depending on the voltages applied across the combination of RGB pins. This greatly enhances picture color. RGB LEDs can also be dimmed independently and instantly (giving a more dynamic picture, especially great “black” levels for dark scenes). The flexibility and bendability of OLEDs promise new, creative options for the next generation of TVs and smart phones—can you imagine rolling your TV up like a poster and carrying it with you anywhere? Or wearing it? Or . . . ?