

## LEDs Provide Scientific Illumination

By Randall Wilcox, Product Manager, Lightspeed Technologies



LEDs are increasingly being used for commercial applications in our daily lives such as in display systems, traffic lights, interior and exterior automobile illumination, flashlights, general lighting, biomedical applications and more. This tendency is a result of a new generation of LEDs that are bright, robust, fast and compact light sources available in various colors as well as white. What was previously available to produce microwatts or milliwatts of light are now available to provide hundreds of milliwatts, even watts of optical power.

LEDs not only have longer lifetime, but also a predictable one, which is characterized as slow degradation rather than sudden failure typical for incandescent lamps. This translates into two important qualities: reliability and lifetime. The reliability factor is critical for applications such as traffic lights, TV/radio station towers, marine buoys and control panels for industrial, medical and military applications. Although the LED-based unit may cost more than incandescent equivalents, potential losses caused by equipment failure would justify the use of LEDs. For applications such as interior lighting on cars and planes, longer lifetime translates into low maintenance. In this case, higher initial cost offsets the long-term savings on maintenance and equipment downtime.

Other key features of LEDs are size, speed and color. Small size makes LEDs an obvious choice for ever-miniaturized electronics. Speed is critical for some applications, for instance, LED-based brake lamps in the motor vehicle turn ON in

about 50  $\mu$ s, instantaneous compared to 0.3 seconds typical for an incandescent lamp. In emergency braking situations, the motorists behind would be warned 0.3 seconds earlier. Although this may not seem like a long time, at 65 MPH it could save almost 10 meters of braking distance. The ability of LEDs to emit specific colors is important where optical filtering of white light would lead to low overall efficiency. Moreover, the color of light emitted by LED does not change with the current.

In their early years, visible LEDs were red and limited in power to being used as indicators. First commercial visible LEDs were designed in 1960's with Gallium Arsenide Phosphide (GaAsP) structures, derived from Gallium Arsenide (GaAs) infrared LEDs. As many recipes developed, advances with Gallium Phosphide (GaP) increased brightness and color variations to include orange and green. Gallium Aluminium Arsenide Phosphide (GaAlAsP) was used for brighter LEDs in the 1980's and Gallium Arsenide Phosphide (GaAsP) variations in the 1990's were used to produce the first very bright LEDs. Shuji Nakamura at Nichia Corporation invented the blue LEDs with advances in Gallium Nitride (GaN) LEDs and Indium Gallium Nitride (InGaN) in 1993. The next major milestone was reached in the late 1990's, when further improvement of InGaN structures lead to development of true high-power LEDs with hundreds of milliwatts of optical power in blue, green and cyan. Similar power levels were achieved in red, red-range and amber with InGaAlP structures.

White light LEDs soon followed the development of the blue LEDs with a process of adding a phosphor that emits a broad, white light spectrum.

Philips Lumileds patented this process. LED technology continues to advance with Organic LEDs, (OLEDs) and other configurations. The structures listed are most common and available (with some variations) from companies like Philips Lumileds, Nichia, Cree, Osram and others, as well as companies that do not grow wafers themselves, but rather buy LED chips from major suppliers and package them onto their own emitters and LED lamps.

The same benefits of LEDs for consumer uses also benefit scientific applications. Existing light sources, broadband (the high intensity discharge HID and halogen incandescent lamps) and narrowband (lasers), utilized extensively in scientific applications, are seeing competition from the LEDs. The same applications can sometimes utilize LEDs with equal or better results at lower cost and higher longevity. LEDs are beginning to see use for fluorescence imaging, high-speed imaging, photosynthesis research, solar simulation and metrology. Some examples of these applications use the High Power Light Source (HPLS) series of high intensity LED systems from Lightspeed Technologies.

The HPLS series is designed as flexible system of interchangeable components (Fig. 1) for applications where it is hard to standardize the requirements for mass-production. Some examples include testing of LEDs themselves, testing the LED for a certain application and flexibility required in challenging environments such as research labs.

There are three parts to every application: the driver, the LED and the optics delivering the output light to the desired location. The HPLS drivers can be configured for continuous output with fixed or variable control (switch, potentiometer or voltage control). These configurations are used in applications such as microscope illumination or other fluorescence imaging that does not require modulation of the light source. As an analog controller with modulated optical output, an 'optical function generator' version of the driver provides continuously variable optical output linearly following voltage or current input (0 to 5 V, 0 to 10 V, 0 to 20 mA, 4 to 20 mA). The third driver configuration is a digital mode that delivers full scale optical output following a TTL or CMOS input with the opportunity for a short pulse, high intensity operating mode that provides intense

<300 ns pulses for high speed imaging

The HPLS driver unit is designed to be flexible in accepting most LEDs available on the market. In order to work, every LED needs electrical connection, mechanical mounting and for high power LEDs, heat dissipation. Many LED models are available from different manufacturers and the pin spacing varies so a method for interchanging different LEDs is provided, as well as heat removal and dissipation. Some

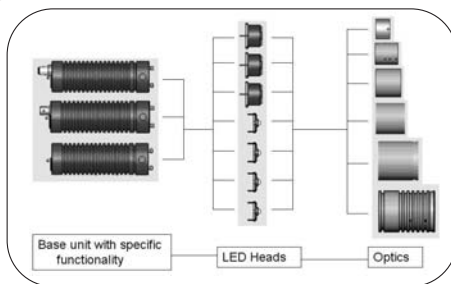


Fig 1. HPLS family configuration

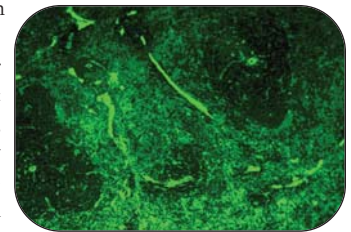


Fig 2. Microscope Fluorescence - LED Illumination of a tissue sample at 250 ms exposure time (Technical Instruments - R. Allen)

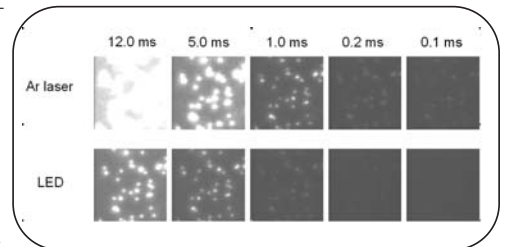


Fig. 3. Comparison of Ar Laser to Blue LED. Illuminated 1  $\mu$ m fluorescent beads (UC Davis- J. Zheng)

LEDs are provided with manufacturer optics, reflectors, or may be a basic package with the LED itself.

The most application-specific requirements are for beam delivery and may vary widely from uniform illumination at 3-cm distance, to collimated beam within 20 cm, to a tightly focused spot some 3 meters away. Many LEDs emit a narrow bandwidth, but applications may require filtering to an even narrower output. The HPLS optics sets (Fig. 1) include filter/diffusers holders, collimators, focusing optics, C/CS mounts for customer objectives and microscope adapters. This allows many configurations to be tested "out-of-the-box", thus allowing quick proof-of-concept. Subsequently, a better configuration can be derived from the results of the first test.

Fluorescence imaging requires an excitation light source. These excitation sources are often in the blue or green region. In the case of blue excitation, the fluorescence observed is usually green. A broadband white light source can be filtered so that just the blue light needed for excitation can be exposed to the sample. To achieve adequate power, a very high power white light source is required. Usually, high intensity discharge (HID) or halogen incandescent lamps are used. They are hot, requiring thermal management, limited in lifetime (100 to 1,000 hours), and brittle or even prone to explosion. In addition, all unused light outside of desired band needs to be blocked and therefore wasted. Blue lasers such as a lasing line of an Argon Ion laser can also provide the blue excitation but have a much higher initial cost as well servicing costs. High intensity blue LEDs can achieve similar results (Fig. 2, 3) at lower initial cost, low-maintenance and compact design.

Controlled illumination can be achieved with the dual operation mode of the HPLS system. In the analog mode, the LED is turned on when the input signal is on and follows this input for intensity (Fig. 4). The LED can be turned on to full of any intermittent power and left on as long as the input signal is applied. In digital mode, the system will follow a TTL input with the LED on when the signal is high, off when the signal is low (Fig. 6). The advantage of the digital mode is faster response. Multi-channel analog drivers can be used to control the current delivered to the LED cluster so a user can control one or more colors of LEDs. One configuration of the HPLS allows computer control of three-color LED cluster for an application of solar simulation. Nine high intensity LEDs are utilized in the system to match the solar intensity on a sample plate below the system. The system does not reproduce all details of the solar spectrum but does match solar intensity in blue, green and red.

For high speed imaging, users can select the digital mode of the HPLS, where the current delivered to the LED is increased as many as eight times, with protection circuitry limiting the ON time to keep the LED from burning out. With 150 ns rise time, this can configuration can provide a fast strobe for high speed imaging (Fig. 5). Users can sacrifice optical output and shorten the pulses to 100 ns, even 20 ns if their equipment can acquire the data at lower light levels.

Lasers are often used for high speed imaging because they can deliver high

intensity light in short duration at high repetition rates. Often, they can be substituted by pulsed LED light sources. But there are more advantages than cost and size when LEDs are used for high-speed imaging. The types of lasers used in these applications run on an internal repetition rate. An experiment must be synchronized to the laser and this is often difficult when experiment has its own timing requirements (arbitrary repetition rate) or even has to be able to respond to the random event. The LEDs respond instantaneously to a trigger input and in this case, the light source is easily synchronized to the experiment. Another limitation of lasers is a minimum waiting period between pulses, while the energy is being accumulated within the active media. Even simple protocols such as generating pairs of 1  $\mu$ s pulses 10  $\mu$ s apart every 100 ms, for applications such as velocity measurements or background subtraction are often impossible with a pulsed laser, while easily achievable with an LED. In addition, images captured with laser light have speckles (parasitic effect, when coherent light, reflected from different parts of the object interfere producing grain-like spots in the image), which decreases the quality of an image considerably. The LEDs are not a coherent light source and speckles are not an issue in these images.

Metrology applications for LEDs include solar cell testing and calibrated illumination. The optical output of an LED has a direct relation to the current input. This relationship between input current and optical output

can be used for calibration even to extremely low levels. Solar cells can be tested for their response to different colors. In the low power regime, LEDs can be used for testing photodiodes and sensitive detectors such as avalanche photodiodes (APD) or photomultipliers (PMT). Exposition of such sensitive detectors to the room light can cause permanent damage. To test them, just a few microwatts of optical power is required (can hardly be seen by the eye). It is not easy to

generate accurate light levels on this power scale using incandescent lamps as some sort of light attenuation is required which is inherently inaccurate. LEDs, on the other hand, can generate such power levels directly, without additional attenuation. Because there is still a direct relationship between the current and optical power, the output of the LED can be controlled in the microwatt regime.

The market for high-brightness LEDs has been the success story in compound semiconductors over the past decade. The average annual growth rate since 1995 has been over 46 percent. It is expected that in 2007, GaN-based LEDs will reach a higher luminous efficiency than fluorescents. If this happens, the ramping-up of solid-state lighting business would greatly expand for general lighting applications. As the market for high-brightness LEDs continues to grow, new developments are going to benefit scientific applications as well. In the past, applications of LEDs in research labs were mostly limited to indicators on front panels of instruments. But those days are over. Expect to see a wider adoption of LEDs in science, medicine and industry for illumination, processing, machine vision and many other applications.

**Randall Wilcox has worked in the photonics industry for companies including Heraeus Noblelight, Positive Light, and Coherent. He is a partner in Lightspeed Technologies which was established in 2005 as a supplier of light sources, spectrometers, wavefront sensors, optomechanics, and systems including optical tweezers and precision vapor monitors.**

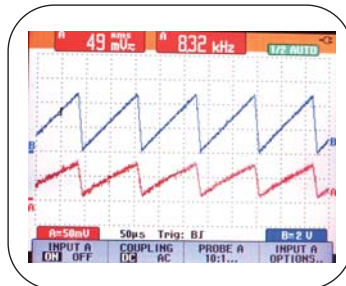


Fig. 4. Analog Mode: Optical output of LED (red) follows voltage input (blue). Sawtooth function shown.

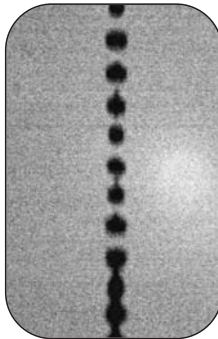


Fig. 5 High Speed Imaging of Microjet. 100 nanosecond LED Pulses Illuminate High Speed Jet Image (Georgia Tech- H. Hunter)

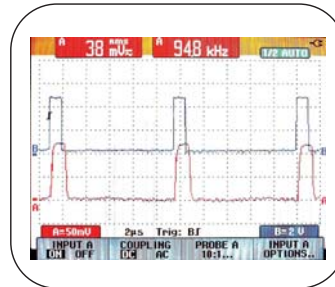


Fig. 6. Digital mode: Optical output of LED (red) follows 1  $\mu$ s trigger input (blue)