Lasers versus LEDs for Bio-Instrumentation

Laser Advantage Note No. 3 - Practical Cost Issues

A laser offers high unit to unit consistency, and predictable performance parameters tailored to specific bio-instrumentation applications. In contrast, the LED is a mass-produced component optimized for the lighting and display markets with very limited customer control over detailed performance specifications.

Light Sources for Bio-Instrumentation

In any instrument based on the detection of fluorescence and/or light scatter, the key to successful operation is the ability to maximize signal-to-noise ratio. This, in turn, is accomplished by delivering the necessary amount of useable excitation light (that is, light that actually excites the fluorescent probe), while minimizing the amount of wasted light that is of the wrong wavelength or in the wrong spatial location. There are several inherent characteristics of the laser that make it a much more efficient source for accomplishing this task than the LED, resulting in *lower instrument costs and superior performance (speed and sensitivity).* Here we examine several practical issues including specifications, product variability, and potential impact on detector costs.

Output power vs. Rated Power

For instruments based on fluorescence and/or scattered light signal, a key cost metric is cost per watt of usable light, rather than just component cost. And one very important difference between lasers and LEDs is in how their output is traditionally specified. Lasers, which were originally developed by the photonics community as light sources for photonic applications, have always been specified by their output power. Simply stated, a 1 watt laser delivers 1 watt of light output.

In contrast, LEDs originated as components in the electronics industry and are specified by their power consumption. Since even the best LEDs rarely surpass 10% efficiency, a 1 watt LED usually outputs 100 milliwatts or less of light. Moreover, the maximum current and voltage specifications are often specified for pulsed operation. Thus, a “1 watt” LED might only be continuously operable at 750 milliwatts or less, which translates into an optical output of only 75 milliwatts!

But that is just the difference in raw power. As discussed in Advantage Notes No.1 and 2, the majority of the LED raw output is unusable because it cannot be collected and refocused into the sampling region, and a significant portion of the remaining light must be discarded using a filter because it’s in the “wrong” wavelength region.

Impact on Detector Costs

The choice between a laser and a LED can also impact the cost and complexity of the photodetection system used to sense the fluorescence and/or scatter, particularly in applications with a small illuminated interaction zone. As explained in Advantage Note No.1, the brightness of a focused LED is orders of magnitude lower than for a laser; this means that the signal will be correspondingly lower. And lower signal means lower sign to noise data, i.e., a higher noise floor for the measurement, and/or resorting to longer signal integration times and slower throughput. Where longer integration times are not possible for practical reasons, as in flow cytometry, achieving target speed and/or signal-to-noise performance may require “boosting” the signal in some way. This might include using larger aperture optics or parabolic mirrors to collect as much of the weak fluorescence as possible. More importantly, it may also mean using a photodetector with higher gain and/or lower noise. For example, a particular instrument may only require a zero-gain photodiode or low-cost photodiode array when based on laser excitation, but may need a photomultiplier tube or a CCD array when used with a LED source. For instances where a laser-based instrument uses a room- temperature CCD array, the LED version of the same instrument might need an actively-cooled CCD array.

Unit-to-Unit Variability – Supply Chain Realities

Today’s lasers are characterized by incredible unit-to-unit consistency. All solid state laser construction and the implementation of automated, robotic assembly and testing methods have largely eliminated individual variations. And, just as important, laser manufacturers like Coherent recognize bio-instrumentation as an important market for our products. For example, lasers are optimized for specific biotech applications and market segments (e.g., research, clinical, point of care). Additionally, specific laser models have a long (multi-year) life cycle with a minimum seven-year life cycle on spare parts and replacement units. This continuity is critical for OEM instrument manufacturers; it allows them to confidently design new instruments and upgrades with no fear of component obsolescence and enables them to service instruments in the field for many years after initial purchase.

In contrast, the performance of LEDs in terms of both optical and wavelength characteristics can vary significantly from batch to batch. That's because LEDs are produced by the millions and even billions to support high volume application such as displays and lighting fixtures. They are designed specifically to service these high volume applications, which typically have very different performance requirements and tolerances than a precision biotech instrument. Indeed, the entire bioinstrumentation market is an irrelevantly small size in the eyes of these LED manufacturers. They do not even directly sell their products at these small (thousands) volumes. Instead, instrument builders have to purchase any LEDs through third party re-sellers, who have no control over product development and product continuity. And their only "control" over product quality is by occasionally offering testing and pre-selection at a price premium, of course.

So, while two LEDs might have the same nominal center wavelength, this can vary by several nanometers, and the shape of the entire output spectrum can be very different. Switching between two LEDs that differ in this way often necessitates installing one or more new filters and complete re-calibration.
LEDs are manufactured in large batches called bins and are assigned a bin number. The only way to know that two LEDs are going to be the same is to buy them from the same bin. If a LED-based instrument design is chosen and ready to go into production, the instrument maker needs to advance purchase a lifetime supply of thousands of identical LEDs, i.e., an entire reel of LEDs from the same bin

Lasers: Scalable Performance
In several applications (e.g., cytometry), instrument makers need to supply instruments to quite a number of different market sectors, such as advanced research, pre-clinical uses, clinical labs, and even point of care tools. These different sectors can have diverse needs which, in turn, put different demands on the characteristics and acceptable cost of the light source. With over 50 years supporting life sciences, laser manufacturers like Coherent understand this challenge and provide a very wide range of laser technologies and products to optimally match the needs of all the different instrument types, from the highest performance research instrument to the lowest cost point of care analyzer.

In contrast, with LEDs there is virtually no range of optical performance to choose from, other than size (power) and center wavelength.

BioRay for Cost-Sensitive Instruments

In many bioinstrumentation applications, there is a shift from the research laboratory to the clinical laboratory, and, subsequently, to the point of care. This trend manifests itself in greater streamlining, miniaturization and automation. To support this trend, Coherent has recently introduced the BioRay series of lasers that emphasize economy, compact packaging, and simple integration over bleeding-edge performance. These lasers deliver a few tens of milliwatts, and are available at several visible wavelengths (e.g., 405 nm, 450 nm, 488 nm, 520 nm, and 640 nm) that match the optimum excitation of common fluorescent probes and genetically encoded markers. These products are based on laser diode technology, as that is the simplest and lowest cost method of generating CW laser output at these wavelengths and in this power range. Laser diodes also offer the highest efficiency, lowering the required power budget for the final instrument. Since edge emitting laser diodes emit a highly divergent and asymmetric (elliptical) beam, optics are used in the laser head to produce a collimated, elliptical beam. To reduce the complexity of downstream beam delivery optics, each head has an adjustable output lens in order to enable smooth adjustment of the beam waist location.

Conclusion

Although a laser will deliver superior performance and speed, there's no question that it's cheaper to buy a LED than a laser. But, when the total cost of design, the complete bill of materials (BOM), the service strategy, and the true cost of ownership are considered, lasers are often a more cost effective option than LEDs. This is even true for next generation, point of care instrumentation, where component costs are paramount.

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