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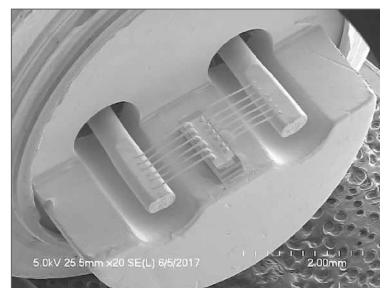
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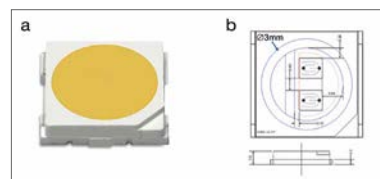
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Intelligent Lighting Designs Enabled by Laser Light

In many applications, solid-state lasers would be the best technical solution but until recently the costs were much too high. Nevertheless, this technology had its niches and is broadening the field of applications entering different specialty lighting, display, and automotive applications. Julian A. Carey, Product Marketing Manager, and Dr. Paul Rudy, Co-Founder & SVP of Soraa Lasers describe and explain the technology, applications and benefits of laser diode pumped phosphor sources that are, for example, used in high-end automotive headlights of luxury cars.

Figure 1:
Examples of
architectural
spotlights

In many lighting applications it is valuable to utilize a high luminance light source with a high number of lumens emitting from a very small physical source extent. High luminance illumination sources provide increased levels of light intensity and smaller beam angles, and also precise control of beam properties. To date, conventional light sources that have been applied to advanced lighting designs have included high intensity discharge (HID), halogen lamps and high brightness light emitting diodes (LED). These sources have limitations in reliability, form factor and luminance. A new solid state lighting technology platform has emerged, laser light, enabling highly reliable, very small form factor light sources, with the highest luminance ever demonstrated in a commercialized product. An overview of how laser light is implemented and how various applications may benefit from increased performance from its use are presented.



Introduction

Specialty lighting applications that make use of very tight beam angles include entertainment and architectural lighting and are some of the most established users of halogen and HID light sources. Outdoor applications including street lighting and stadium lighting utilize very high luminance sources like HID in order to optically control the light to achieve a complex illuminance pattern on the roadway or stadium grounds while maintaining a manageably small luminaire size. Specialty lighting applications like vehicle forward lighting and projection display aim to achieve long illuminance throw, precise beam shaping, and spatial beam modulation. Specialty applications have historically applied HID technology to a great extent. LEDs have been adopted by all of these applications to some degree, and offer their well known benefits of small form factor, reliability and luminous efficacy, but are not able to be utilized in high luminance applications.

However, after significant development time, both HID and LEDs are limited from the standpoint of luminance. Development of Xenon HID light sources for automotive and entertainment lighting applications have reached luminance values of 1.5×10^9 cd/m² [1] or for reference approximately 1000 lm from an arc size of a couple of millimeters in diameter, although the overall size of HID lighting systems is much larger. Despite their luminous efficacy, LEDs offer luminance somewhat less than the HID example above, because efficiency droop with increasing drive power also presents a fundamental challenge for LEDs to achieve higher luminance. As a new solid state high luminance light source, laser light technology has now demonstrated luminance higher than 1.0×10^9 cd/m² or more than six times the highest HID.

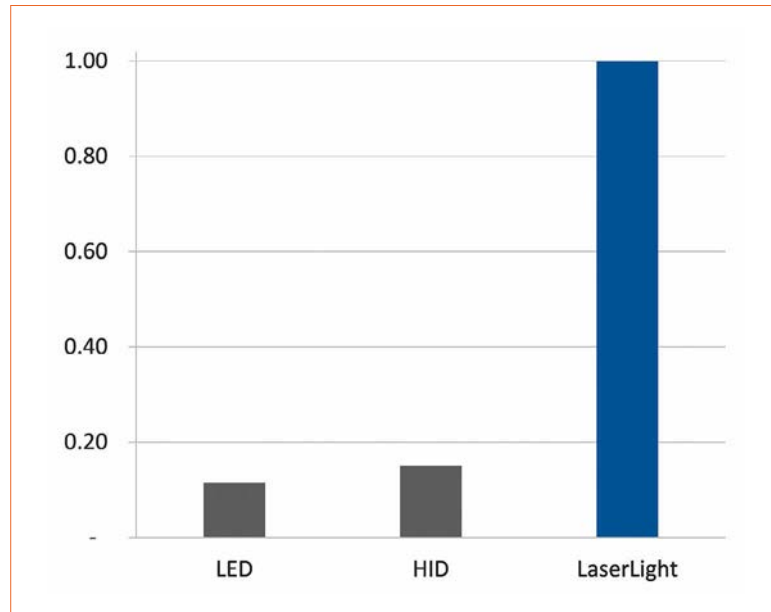


Figure 2:
Relative luminance from source

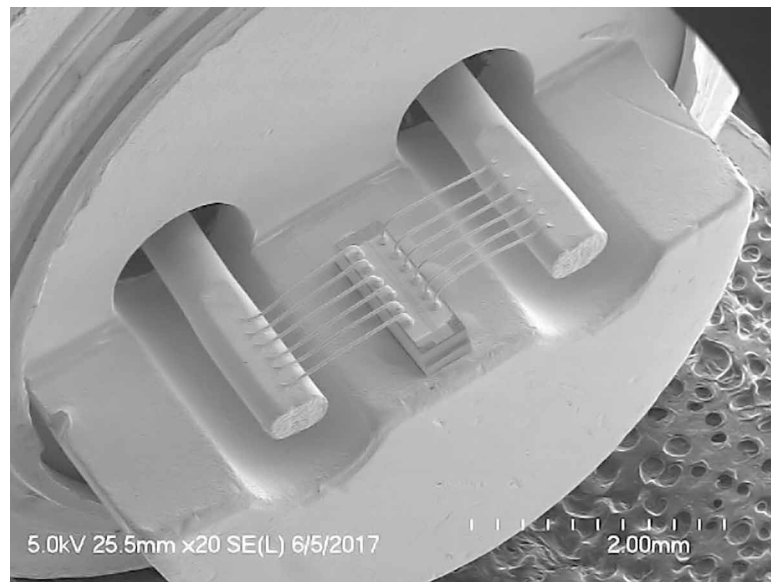


Figure 3:
Laser diode chip on sub-mount, wire bonded in TO package with emitting stripe visible

Fundamentals of Laser Light Technology

By fabricating a blue laser diode from semi-polar orientation Gallium Nitride (GaN), blue laser light is produced at higher levels of power due to the high gain in the device. As importantly, laser diodes show minimal droop characteristics, meaning that, for the first time, high power lasers with very small scale are being implemented in specialty lighting applications. Unlike a blue LED that emits a few watts of diffuse optical energy per square millimeter, the watts of light produced from the laser diode emanate from a light emitting area only microns in width, and can therefore illuminate a tiny spot that is hundreds of microns in diameter.

To complete the spectrum, the blue radiation is partially converted to longer wavelengths by a phosphor element. Innovations in high temperature phosphors and binding materials have enabled phosphors to convert light efficiently at the elevated power densities and temperatures that result from the laser light architecture.

Two implementations of laser light have been developed that both achieve high luminance. The first implementation is composed of a blue laser module that uses a fiber optic of arbitrary length to transport the blue light to the end where the light illuminates the phosphor element. Typical optical fiber carrying laser radiation operates at a transport

Figure 4:
Separable laser module
and phosphor element
linked by fiber optic



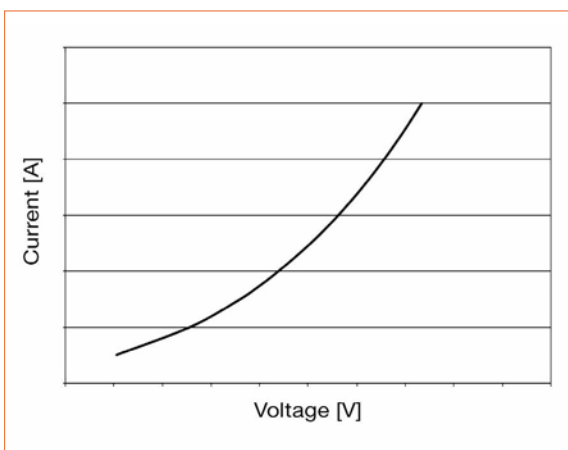
Figure 5:
SMD laser light
component



Figure 6:
Dynamic control of the
beam angle with an
LC lens operated by a
touchpad



Figure 7:
Drive current vs.
voltage for typical LED



efficiency of 99.8% per meter, thus losses are very small even for significant fiber lengths. With this arrangement the white light emitting element may be sealed in a location remote from the laser and its electronics which may be placed in another location that has more favorable physical and thermal characteristics.

In the second implementation, the phosphor element is placed in close proximity to the laser diodes, resulting in a fully integrated surface mount device (SMD) of 7 mm square dimensions. This configuration has been highlighted as particularly novel through its recognition by the LightFair Innovation Award judged by the IES and IALD. In contrast to other solid state light sources, the phosphor is operated as a reflecting element. This placement offers the advantage of straightforward heat sinking of the phosphor element, which is important due to the high levels of power density. Reflectance from the phosphor also enables the configuration of safeguards on the emission of blue collimated laser light. Reflected light can be blocked by beam blocks or observed by sensors both of which can ensure that blue collimated laser light is never released. In each of the two configurations, up to 500 lumens is emitted from a light emitting area only 300 microns in diameter resulting in luminance levels in excess of 1 billion cd/m². Efficacy of the light output also remains roughly constant as power is driven higher, due to the low efficiency droop of the lasers with increasing power.

Complementary Technologies for Laser Lighting Systems

High luminance at the laser light source provides valuable optical system advantages including narrow beam angle, sharp beam cut-off and smaller optical systems. Enabling beam angles smaller than 8 to 10 degrees from 25 to 50 mm optic diameter has been challenging with conventional light sources. Utilizing laser light sources, beam angles of 2 degrees or lower have been demonstrated with total internal reflection optics of less than 30 mm in diameter, well within convenient lighting system form factor. For existing optical systems that seek to maintain the same beam angle, the optics used may be designed to be smaller, lighter and have sharper beam geometries. Since laser light approximates a point source, the optical characteristics lend themselves particularly well to diffractive type optical elements for beam sizing and shaping. For example a light shaping diffuser element can transform the output beam of a 1 degree spotlight module to a rectangle of 1 degree by 10 degrees with efficiency higher than 92%. Moreover, liquid crystal lens technology can be added downstream from laser light modules in order to electronically control and dynamically change the beam angle and/or shape [2].

The electrical and thermal infrastructure required for laser light implementations closely resembles those already established for solid state lighting. Laser light is

a current driven system with very flat voltage characteristics, thus the electronic drivers required must be capable of controlling amperage with high accuracy and stability while disallowing voltage runaway and spikes. Like other solid state illumination devices, the light output of laser light attenuates with increasing temperature and so, heatsinks are required to efficiently transport several watts of thermal energy away from each device.

The figures on the left illustrate the current vs. voltage characteristics for LED and laser light. Where LEDs exhibit gradually increasing current with voltage, lasers show a more pronounced threshold voltage/current behavior. The sharper transition to linear electrical behavior presents a couple of considerations for electronic driver circuit design and operation. For applications where dimming is a required feature, pulse width modulation (PWM) dimming is recommended for the laser.

This is so that the drive characteristics of the device remain in the highly stable region of the curve near the rating of the device. Operating the laser at very low current levels will not offer optimal control. Secondly, the increase in current after the threshold voltage, is very steep and rapid. This slope further encourages the implementation of current control and limitation in the circuit. Current stabilized driver circuits will enhance the precision of light output control. Limiters in the current driver will prevent overdrive conditions, spikes and transients that can adversely affect the lasers reliability

Solutions in Lighting

Vehicles have been introduced with laser light for the high beam extender function and have achieved several times the throw distance previously achieved. With laser light, illuminance sufficient for visibility is thrown out to as high as 1000 meters distance. Driving safety is increased as greater braking distances at nighttime are enabled at high speeds.

Projection display applications implementing laser light are well established where laser light is modulated spatially with very high resolution, usually with a micro mirror array. The first implementations of a laser and a spinning phosphor wheel as a lighting system for projectors date from 2010. As this architecture has further developed, it is becoming more solid state and no longer using a rotating wheel, thus transitioning to more applications where very highly intelligent lighting control is desirable.

From the standpoint of creating a matrix field of controllable light, for example, LEDs have demonstrated efficacy at a relatively coarse level in automotive lighting applications. For example, these applications help to reduce glare for other drivers by using sensors and selectively dimming part of the projected light field. With an approximate point source like laser light, high precision high definition refinement of spatial light

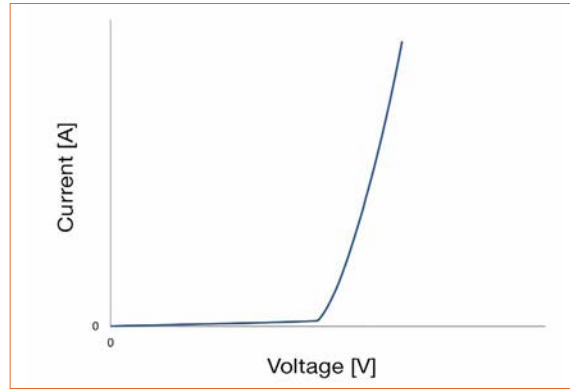


Figure 8:
Drive current vs.
voltage for laser light

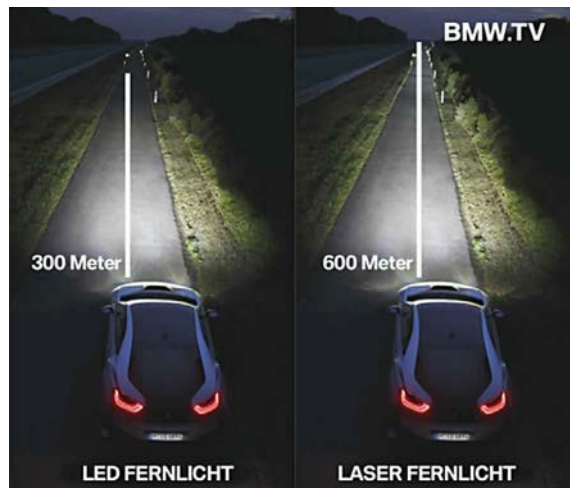


Figure 9:
Comparison between
LED high beam and
laser high beam
(Credit: BMW)

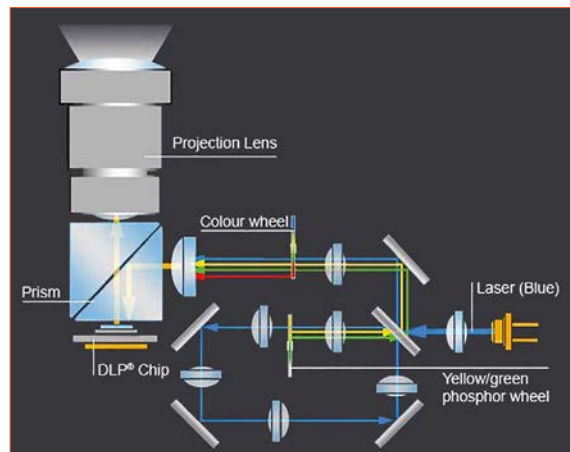


Figure 10:
Projection display
design with blue laser
and reflective phosphor
wheel (Credit: NEC)

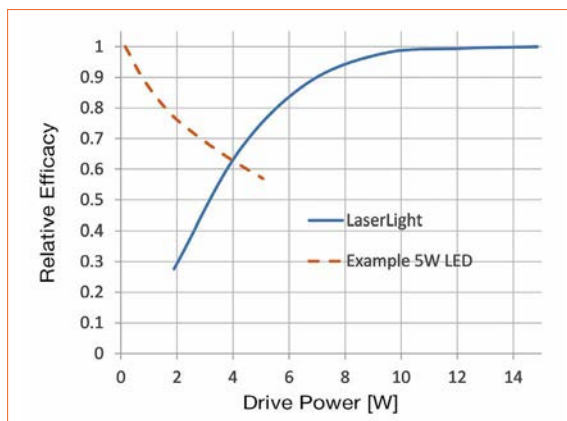
control is enabled, without the need for large arrays of LEDs. By combining laser light and a liquid crystal or micro mirror device in a small form factor, efficient package, automotive and specialty lighting applications may benefit.

With small form factor laser light sources like SMD emitters, architectural, entertainment and venue lighting similarly can harness a higher luminance than that available from HID in order to generate long range illumination or generate distinctive high contrast short throw illumination effects. Spots can be combined with other lensing and diffusing effects to control the beam angle and shape dynamically. Alternatively, fixed installations can use efficient micro featured diffusers to offer specially shaped beam geometries.

Figure 11:
Street light demo with blue laser light transported several meters by fiber to a phosphor element at top with optic (Credit: Society of Light & Lighting)



Figure 12:
Change in efficacy (lm/W) vs. power



Efficient transport of the blue laser light through a fiber optic enables designs where the white light source is purely optical and separable from the laser module and drive electronics. For example, street lights and stadium lights are an application area where this configuration offers a value proposition by reducing service needs at the light head at the top of the pole. The phosphor converting element could be permanently sealed in a lighter, smaller optical structure less subject to wind and costly service visits on a mobile lift. The laser module and electronic assemblies are positioned in the pole, base or underground.

Future Directions for Laser Light

Laser light is in the early days of its implementations in specialty lighting and performance gains are rapid. Efforts are underway to further increase luminance by driving the spot size smaller for a given lumen reference. As LEDs accomplished throughout their history, luminous efficacy will continue to improve from the approximately 40-50 lm/W level of today to 100 lm/W and beyond. Most importantly, as laser light converges with LED technology in efficacy, it will have the additional advantage of not suffering drooping efficacy with increasing power. This stability will help keep emitter populations lower and fixtures smaller as there will not be significant efficacy vs. power trade-offs for individual devices.

Development is also underway of applications that scale to higher levels of lumen output per source. Current implementations emit up to 500 lumens, and applications like venue and stadium lighting would benefit, from a system design standpoint, from individual lighting elements of several thousand lumens. Laser diodes lend themselves particularly well to being combined into a single beam, so as long as the phosphor element is properly matched, overall lumen output per source is expected to rise with new designs.

CCT and CRI for recent laser light applications are around 5700 K and 70CRI respectively, which lends laser light today to outdoor application and specialty applications. Future work in phosphors and laser diode engineering will enable more complete spectrum and allow warmer, higher CRI light for indoor applications.

Conclusions and Summary

Breakthroughs in semi-polar GaN materials have led to reliable, high power blue laser diodes. These lasers, combined with high power density phosphor components, have enabled laser light to take its place as a new platform in solid state lighting. Laser light technology delivers the highest luminance available of any light source. This enables narrower beam angles and longer throw for directional lighting applications of many types, including vehicle lighting and projection display. The success in these high intensity lighting applications, positions the technology to make great contributions to intelligent general lighting by offering higher luminance, more scalable efficacy and the capability to work with complementary technologies in a nearly ideal way to control light spatially. ■

References:

- [1] 11th International Symposium on Automotive Lighting - ISAL 2015 - Proceedings of the Conference: Volume 16
- [2] SoraaLaser Introduces Dynamic Laser Light Source Technology For Specialty Lighting, Photonics Online, May 3, 2017