White light from near-UV and blue laser diodes and phosphors

Researchers at UCSB seek ways to avoid efficiency droop in high-brightness devices.

University of California Santa Barbara has been exploring the use of laser diodes (LDs) in combination with phosphors as a means to produce white light [Kristin A. Denault et al, AIP Advances, vol3, p072107, 2013].

Commercial 'white' light-emitting diodes (LEDs) generally use a blue or near-ultraviolet (near-UV) III-nitride LED to excite a phosphor target that converts the relatively narrow spectrum of the LED into something that approaches a white light spectrum of varying quality.

UCSB believes that using laser diodes instead of LEDs could have a number of advantages such as avoiding the 'efficiency droop' problem of nitride semiconductor LEDs at high current injection. Further, the use of laser diodes could allow better thermal management, with the exciting laser diode being separated from the phosphor target material, due to the higher directionality of laser light. In LEDs, self-heating effects cause shifts in wavelengths that alter the color-rendering quality, along with reducing the efficiency.

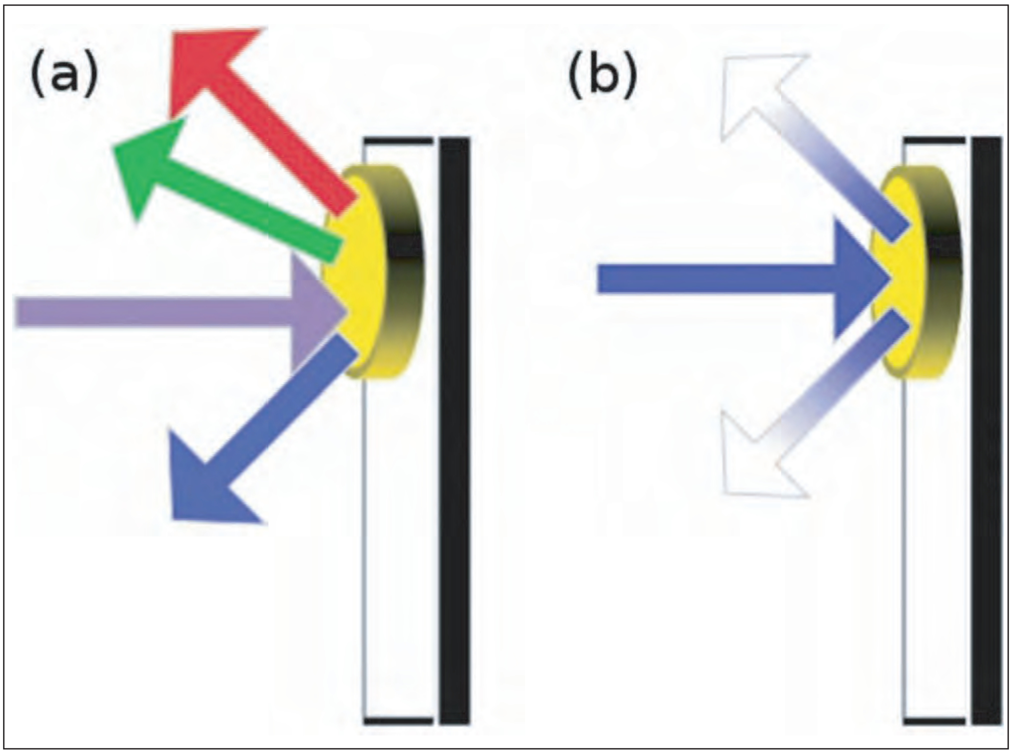

Figure 1. Experimental schematic for laser-excited phosphor samples in an integrating sphere for (a) near-UV-excited RGB phosphors and (b) blue-excited YAG:Ce.

Table 1. Parameters of commercial LDs used.

	Peak wavelength	Full-width at half-maximum	Threshold current	Wall-plug efficiency
Near-UV	402nm	2.6nm	30mA	20%
Blue	442nm	2.7nm	150mA	30%

Commercial near-ultraviolet (UV) and blue LDs (Table 1) were used to excite phosphors in disk form (Figure 1). The UV LD was used in combination with two types of red-green-blue phosphor mixed in silicone resin with respective weight ratios of 1.65:1:3.45 (RGB_1) and 3.3:1:2.3 (RGB_2). The phosphors that were used were a proprietary formulation developed by Mitsubishi Chemical Corp.

The blue LD was used on standard yellow-emitting cerium-doped yttrium aluminium garnet phosphor, as used for low-cost white LEDs ($Y_3Al_5O_{12}$:Ce_3+/YAG:Ce = $Y_{2.94}Ce_{0.06}Al_5O_{12}$). The powdered YAG:Ce was formed into pellets and heated at 1500°C for 5 hours to make the phosphor target.

The measurements were taken with the phosphor mounted in an integrating sphere. The laser light came in through a side port, hitting the phosphor disk at a slight angle to avoid reflection back out of the side port. The measurements (Table 2) included values for correlated color temperature (CCT), color rendering (R_a), luminous flux (ϕ_v) and luminous efficacy (η_v) of the resulting 'white' light.

The near-UV LD was operated at peak efficiency with an injection current of 450mA. The near-UV results are described as showing excellent color temperature and color-rendering capabilities. "The luminous flux produced is comparable to current commercially available bright white LEDs of similar color temperatures," the researchers write. The use of near-UV allows a range of color temperatures to be achieved with high color rendering.

However, the LDs have relatively low wall-plug efficiency (WPE), impacting luminous efficacy. The researchers hope that future development in laser technology may lead to efficacies exceeding those of commercial LEDs.

White-light emitting devices using near-UV LD excitement would presumably contain filters that would remove the unconverted laser light, avoiding concerns about eye safety.

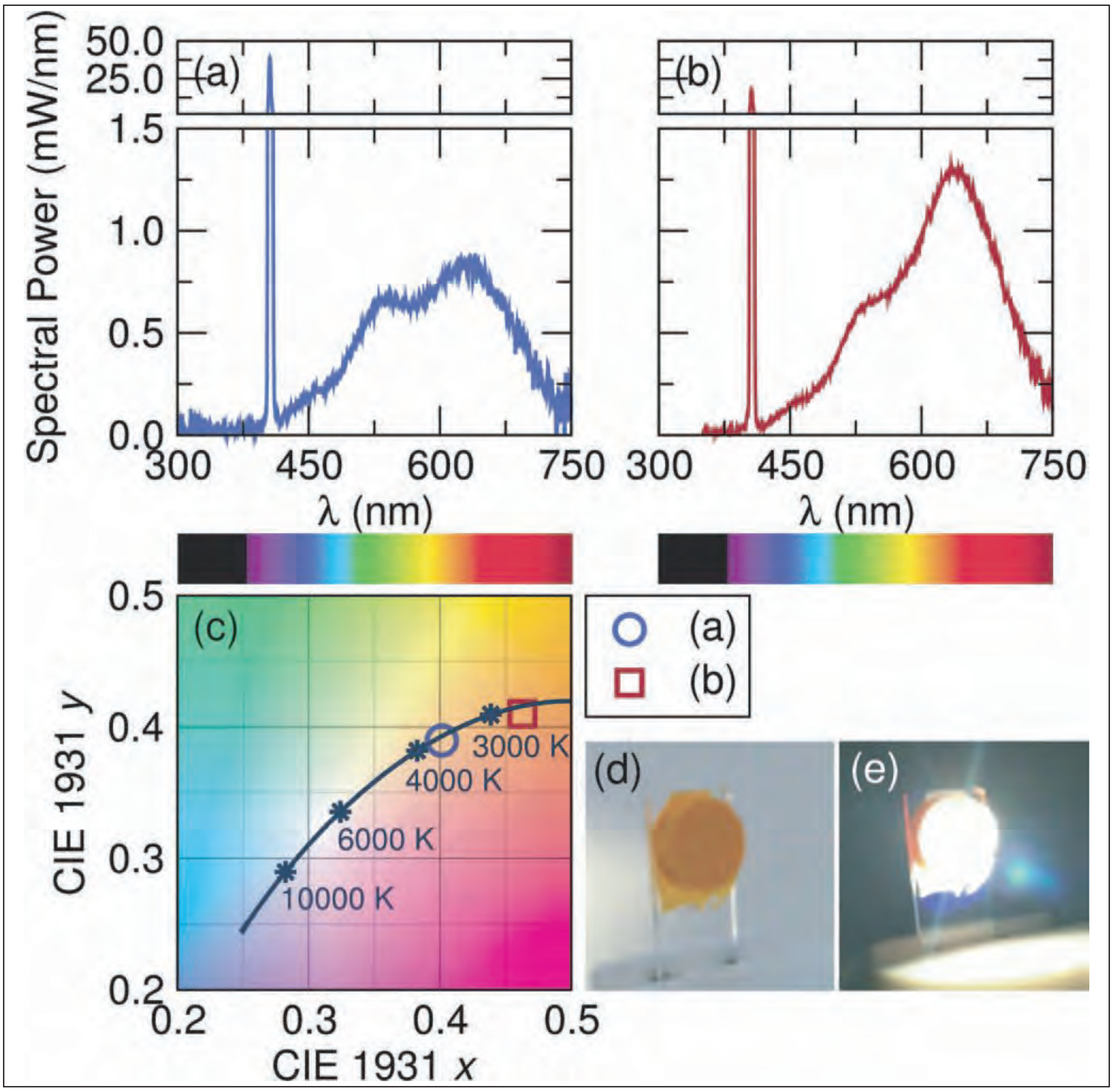

Figure 2. Spectral power distribution for phosphor samples (a) RGB_1 and (b) RGB_2 excited using a near-UV LD and (c) corresponding CIE (Commission Internationale de l'Éclairage) chromaticity coordinates. Photographs of RGB_2 phosphor sample (d) without and (e) with laser excitation.

Table 2. Measured correlated color temperature (CCT), color rendering (R_a), luminous flux (ϕ_v) and luminous efficacy (η_v).

Sample	CCT (K)	R_a	ϕ_v (lm)	η_v (lm/W)
RGB_1	3600	91	47	16
RGB_2	2700	95	53	19
YAG:Ce	4400	57	252	76

The blue-LD setup with a peak efficiency injection current of 750mA had much better efficacy, but the cost was a cool color temperature and poor color rendering due to the absence of a strong red component. LEDs that only use YAG:Ce phosphors suffer from a similar problem. A further problem for blue laser excitation is that the blue component covers a smaller range of wavelength due to narrower width of the laser spectral line compared with that resulting from spontaneous emissions from an LED.

The researchers performed calculations to gauge the possible improvements in efficacy for a blue-LD on YAG:Ce phosphor setup if the WPE could be increased from 30% to 75%. At 30% WPE, the calculations gave an efficacy of 78lm/W for a device of CCT of 4555K and R_a of 58. The efficacy at 75% WPE was almost 200lm/W. The calculated performance with 30% WPE is close to the experimental measurements achieved with the blue LD. ■

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