SSL Postings
U.S. DEPARTMENT OF ENERGY

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The Prospects for Creating Efficient Color-Mixed White LEDs

The efficacy of LED lighting products has already surpassed that of traditional technologies for most applications, but there remains significant headroom for improvement. DOE has set ambitious efficacy targets for SSL, and ongoing R&D is necessary to meet those targets. One area worth exploring is LED lighting based on color-mixed (CM) LEDs. The SSL market is currently dominated by phosphor-converted (PC) sources that employ blue or violet LEDs with phosphor materials to generate white light. While such sources can achieve very high levels of efficacy (with room still to improve) and excellent color quality, the use of multiple direct-emitting, narrowband LED sources covering the visible spectrum — such as a combination of red, green, blue, and amber (RGBA) — could achieve even higher levels of efficacy while also offering other benefits, such as color-tunability. An analysis of the possible efficacy levels is provided in the DOE SSL R&D Plan.

The performance of CM systems has been limited by the low power conversion efficiency (PCE) of green and amber LEDs. In order for a CM approach to match and exceed the PC-LED approach, improvements in PCE for green and amber are critical. PCEs for red, green, and amber sources are currently limited to around 44%, 22%, and 8% respectively and would all need to be increased to around 55–60% (the current level of blue LEDs) to reach the ultimate DOE efficacy goal of 230–250 lm/W.

Several approaches are being considered for improving red, green, and amber LEDs. One concept is to work to extend and improve efficient emission of InGaN-based LEDs beyond blue wavelengths and into the green, amber, and even red parts of the spectrum. The use of a common materials system for all wavelengths would simplify production and integration of the LEDs. However, a more fundamental understanding of the physical processes limiting efficiency at these wavelengths (the so-called “green gap”) will be required, and approaches to mitigate or solve these limitations will be necessary. Recent results for InGaN-based LEDs show that it’s possible to extend the operation of such devices out into the red portion of the spectrum using conventional growth methods and planar device geometries. Yet despite the good progress in extending the spectral reach of this technological approach, the required efficiency gains remain stubbornly difficult to achieve.

A related approach to improve amber and green LED efficiency in the InGaN material system is the use of non-polar or semi-polar crystal growth orientations for the LED. Growing the LED in these orientations can reduce polarization fields within the LED structure, possibly enabling improved LED performance. One challenge with this approach is finding suitable substrates that match the desired crystal orientation and are stable within the MOCVD growth process.

The use of nanostructures, such as nanorods or nanosheets, is an alternative approach for improving green and amber LEDs. These nanostructure geometries enable access to the alternative crystal growth orientations described above and can also suppress defects in the crystalline LED material. Another interesting direction would be to use high-quality substrates with more appropriate lattice parameters to better match the active region material, in order to reduce the dislocation density and reduce strain during LED growth. One example is $ScAlMgO_4$, which has the same lattice constant as InGaN, corresponding to an emission wavelength of around 500 nm.

All of these approaches will require new scientific understanding as well as advancements in technical approaches, but success in these areas could create the prospect of CM-LEDs that enable the ultimate possible efficacy — i.e., greater than 250 lm/W — as well as enabling efficient spectral-tuning features in next-generation lighting products.

As always, if you have questions or comments, you can reach us at postings@akoyaonline.com.