Improved brightness and color saturation for blue quantum-dot LEDs

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A multi-layer configuration yields blue quantum-dot LEDs with qualities that are comparable to red and green ones, thus facilitating applications in full-color displays and solid-state lighting.

The next generation of flat-panel displays and solid-state lighting will have challenges in the areas of maximizing efficiency, brightness, color saturation, area, and flexible-substrate compatibility. Recent studies on the electroluminescence (EL) behavior of colloidal nanocrystal quantum dots (QDs) of compounds in columns II-VI of the periodic table have suggested that quantum-dot LEDs (QD-LEDs) could be a cost-effective alternative. In particular, due to the extremely narrow emission band of monodisperse nanocrystal QD populations—full width at half maximum (FWHM) of ∼18–30nm—QD-LEDs have been reported to produce color-saturated red and green emissions of much higher spectral purities than those of liquid crystal displays and organic LEDs. QD-LEDs even have spectral purities that are 30% greater than the bulky cathode ray tubes that are still favored for their excellent color rendition. Since the QD-LED display system creates a variety of colors by varying the relative intensities of the red-green-blue (RGB) subpixels in each screen pixel cell, the enhanced color purity of RGB QD-LEDs will result in an unprecedented improvement in the number of colors that can be displayed. Such a prospect is dimmed, however, by the slow development to date of bright, color-saturated, blue QD-LEDs. Unlike its green and red neighbors, the blue component (440–490nm) of the visual spectrum is characterized by low luminous efficacies. To compensate for this low luminous efficacy, a blue QD-LED demands a higher radiant power, I, than green or orange/red QD-LEDs of the same brightness. The low efficacy of the blue emission also requires the QD-LED output to have a narrow emission bandwidth and ‘clean’ spectral line shapes to achieve the desired blue saturation.

In collaboration with Ocean Nanotech LLC, the nanophotonics research group at Penn State University recently reported the design and processing of QD-LEDs whose brightness and blue purity far exceed previously reported values. The LED in this experiment was configured with a multiple-layer structure employing structurally engineered core/shell-CdS/ZnS QDs in the emissive region. At a low operation voltage of 5.5V, the device emitted spectrally pure blue with a strikingly narrow FWHM-bandwidth of 20nm and a high brightness of up to 1600 cd/m² (see Figure 1). The long-wavelength tail of the LED output was minimized to less than 5% of the total emission, leading to the highly saturated blue emission from the QD-LEDs.

Figure 1. Electroluminescence (EL) spectrum of the QD-LED measured at a bias of 5.5V. Top insets: Photomicrographs of the LED surface recorded at brightness values of 100 cd/m² and 1600 cd/m². Bottom inset: A high-resolution transmission electron microscopy image of a core/shell-CdS/ZnS QD.
comparison to previously described blue QD-LEDs, our devices achieved significant improvements in performance. These can be attributed to the reduced defect density in the core/shell QDs, the minimized concentration of free ligands in the QD films, and the multi-layer LED configuration, which leads to efficient and organic-free LED emission. In addition, the low operating voltage and the high brightness achieved in our blue QD-LEDs was comparable to that of red and green QD devices, closing the performance gap between blue and red/green QD-LEDs.

These results represent a significant improvement over the performance of existing blue QD-LEDs. Our blue LED study also marks a further step toward the practical application of QD-LED technology in full-color displays and solid-state lighting.

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References