Quantum dot LEDs get brighter, more efficient

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Red, green, and blue QLEDs, with the applied voltages in the upper left corner. The green QLED has a luminance of 168,000 candelas per square meter, which is more than three times higher than the previous best QLED brightness. Image credit: Jeonghun Kwak, et al. ©2012 American Chemical Society

(Phys.org) -- While quantum dot-based light-emitting diodes (QLEDs) are not made of organic materials, they share many of the same advantages as organic LEDs (OLEDs). For instance, both QLEDs and OLEDs outshine semiconductor-based LEDs in terms of their greater flexibility, better color quality, and potential for lower cost since they can be fabricated using a simple process on a large-area substrate. But ever since the first QLEDs were demonstrated in the mid-'90s, about a decade after OLEDs, their performance has lagged behind OLEDs despite ongoing improvements. Now in a new study, a team of researchers from South Korea has designed and demonstrated QLEDs with an improved efficiency and unprecedented brightness that matches the brightness of today's best fluorescent OLEDs.

The research teams at Seoul National University, South Korea, led by Changhee Lee, Kookheon Char, and Seonghoon Lee, have published their study in a recent issue of *Nano Letters*.

As the researchers explain in their study, the key to improving the brightness and efficiency of the QLEDs is improving the injection of current-carrying electrons and holes into the quantum dots. The more efficiently the electrodes can inject electrons and holes into the quantum dots, the more efficiently the device can emit light. Usually, the anode is made of indium tin oxide, whose transparency allows light to escape. But here, the researchers inverted the device by making the indium tin oxide the cathode with the help of zinc oxide nanoparticles as an electron transport layer, which performed charge carrier injection much more efficiently than before.

"The most important cause of the low performance of QLEDs is the poor injection of holes into the quantum dots (QDs) from the anode and neighboring hole transport layer due to a huge potential energy barrier," Changhee Lee told *Phys.org*. "Because of that, the electron-hole balance is not achieved, resulting in low quantum efficiency and low maximum brightness. Furthermore, the excess electrons or holes, which do not recombine in the QD layer and enter the neighboring organic hole-transport or electron-transport layers (HTL or ETL), can cause leakage current and device degradation, resulting in poor efficiency and stability. Therefore, good carrier injection is a key factor for realizing high-performance QLEDs."

By patterning different sized quantum dots on the layer of zinc oxide nanoparticles, the engineers could fabricate QLEDs of three different colors: red, green, and blue. Whereas previous QLED brightness levels were in the range of 10,000 candelas (cd) per m^2, the new red QLED displayed a brightness of 23,000 cd/m^2 and the green achieved a remarkable 218,000 cd/m^2 – the highest ever for a QLED and comparable to the best OLEDs. The previous highest QLED brightness is 68,000 cd/m^2, which was for a green QLED reported last year by Lei Qian, et al. The new blue QLED displayed a lower brightness of 2,000 cd/m^2, but low blue performance has been one of the biggest disadvantages of both QLEDs and OLEDs.

In areas besides brightness, the QLEDs have also improved but still lag behind OLEDs. The new QLEDs' efficiencies (7.3%, 5.8%, and 1.7% for red, green, and blue devices, respectively) improve over previous QLEDs, although OLEDs can have efficiencies of up to 20%. Another challenge for both QLEDs (and OLEDs to a lesser extent) is lifetime. Since the early research of the '90s, QLED lifetimes have not improved past a few tens of hours, and they experience rapid deterioration within a few hours of operation. QLEDs with inverted structures, like those used here, can have half-lifetimes of up to 600 hours, compared with tens of thousands for OLEDs.

Although QLEDs don't match the performance of OLEDs, the engineers explain that QLEDs have a few potential advantages that make them worth investigating further.

“The luminous efficiency of the best OLEDs (phosphorescent OLEDs) and inorganic LEDs are comparable, up to ~100 lm/W for white emission,” Changhee Lee said. “However, the efficiency of QLEDs is still way behind, about 10 times lower. The efficiency of red and green QLEDs reported in our paper is comparable to the efficiency of the best 'fluorescent' OLEDs, which use fluorescent organic dyes as emitters. Of course, the lifetime of QLEDs is much lower than OLEDs and inorganic LEDs at this time. The potential advantages of QLEDs are: (1) much narrower emission bandwidth (full width at half maximum ~30 nm compared with 60-80 nm of OLEDs), which means that QLEDs have more saturated and purer color than OLEDs; (2) easier tunability of emission colors in the entire visible range by simply controlling the particle size and shape with the same chemical composition for the QD; (3) and therefore the cost of emitters are much lower for QLEDs while organic phosphorescent emitters used for best OLEDs are very expensive."

Overall, the brightness, efficiency, lifetime, and low turn-on voltage of the new QLEDs suggest that the quantum dot devices could have promising applications as TV, computer, and phone displays as well as lighting devices. Since quantum dots can be printed as ink, these displays and devices could also benefit from low-cost production methods.

"Our future plan is to further improve the efficiency and reliability of QLEDs, in particular, blue QLEDs," Changhee Lee said. "In parallel, we will make a full-color active matrix QLED display using our improved RGB QLED technology. We will also work on developing Cd-free QLEDs because of environmental and safety concerns related with Cd. We recently reported InP QLEDs in *Chemistry of Materials*, but their efficiency is very low. Therefore, we will work on developing new precursors for InP QDs and improving the performance of Cd-free OLEDs."

More information: Jeonghun Kwak, et al. "Bright and Efficient Full-Color Colloidal Quantum Dot Light-Emitting Diodes Using an Inverted Device Structure." *Nano Letters*. DOI: 10.1021/nl3003254