

# Exploring the Pathway to Achieve Wide Color Gamut Cadmium-free and Lead-free QLED Devices through Leda

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## Abstract

We used Leda software to explore the microcavity effects on the emission peak FWHM of top-emitting QLEDs. By incorporating a semitransparent silver metal layer, we achieved a 15 nm full width at half maximum (FWHM) for InP QLEDs, narrowing the emission peak. This design increased the color gamut by 47.5%, reaching 117% of the NTSC standard.

## Author Keywords

Leda, Wide Color Gamut, QLEDs, Microcavities

## 1. Introduction

Quantum dot light-emitting diodes (QLEDs) are known for their high luminous efficiency, adjustable emission colors, and narrow emission peaks, making them a promising technology for next-generation displays<sup>[1-4]</sup>. Recently, electroluminescent QLED devices based on Cd-free and lead-free quantum dots have rapidly developed. However, these quantum dots (QDs) typically exhibit a wide full width at half maximum (FWHM), usually greater than 50 nm, and sometimes exceeding 60 nm<sup>[2, 5-7]</sup>. This broad emission spectrum hinders the full potential of quantum dots, especially in achieving wide color gamut displays.

To address this issue, we utilized Leda simulation software to investigate the impact of introducing semi-transparent silver metal electrodes on device performance. The inclusion of a semi-transparent metal layer effectively reduced the FWHM of the QLED device emission spectrum, significantly enhancing the display color gamut of electroluminescent QLED devices based on cadmium-free and lead-free quantum dots<sup>[8, 9]</sup>. Additionally, by further adjusting the thickness of the electron transport layer and hole transport layer, we optimized the light extraction ratio, achieving an external light extraction efficiency greater than 10% while maintaining a narrow electroluminescent emission spectrum.

Our work provides a process for optimizing electroluminescent microcavity device structures using optical simulation software Drepex Leda (hereinafter referred to as Leda), reducing experimental trial-and-error efforts. It offers valuable guidance for the construction of high-color-gamut cadmium-free and lead-free quantum dot electroluminescent devices.

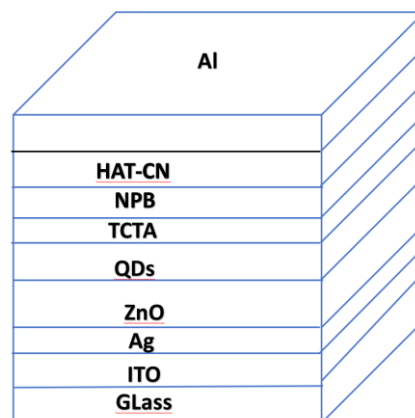


Figure 1. Device structure used in Leda software simulation.

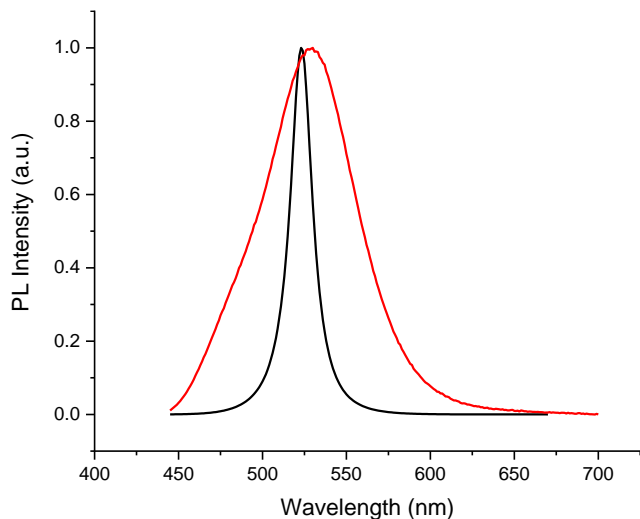
## 2. Results and discussion

In this study, we introduce a bottom-emitting inverted structure QLED, as illustrated in Fig. 1. The reflective cathode and multilayer architecture of the QLED naturally create a microcavity within the confined space due to interference effects. This microcavity enables the spectral narrowing electroluminescent emission spectrum, allowing us to isolate a single color from the white light generated by the combination of red, green, and blue quantum dots.

To achieve a wide color gamut for electroluminescent LED devices while ensuring the use of cadmium-free and lead-free quantum dots, we focused on green-emitting InP quantum dots, as green emission has the most significant impact on the color gamut<sup>[10, 11]</sup>. In this study, we prioritized the modulation of the electroluminescent emission spectrum of green-emitting InP QLED.

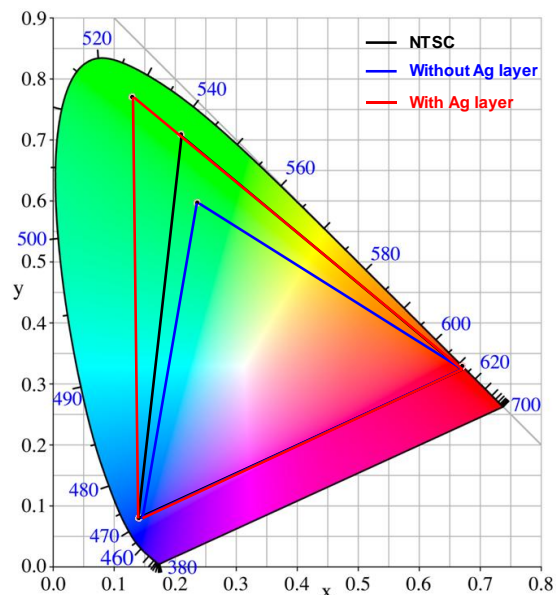
By adjusting the thickness of the semi-transparent silver layer, a microcavity was constructed, enabling spectral selectivity changes in the ELED device and resulting in a narrow FWHM spectrum. Additionally, the effective cavity length and emitter position were further optimized by adjusting the thickness of the transparent spacer layers (e.g., zinc oxide (ZnO) and HAT-CN in our case here), thereby improving light extraction efficiency. Through the integrated optimization of the ZnO layer, the semi-transparent silver layer, and the HAT-CN layer thicknesses, we successfully

achieved effective compression of the FWHM of the electroluminescent spectrum for InP devices. Ultimately, this approach enabled green emission with a FWHM of just 15 nm (Fig. 2). However, in solution, the quantum dots exhibited an emission peak with a FWHM of 67 nm. This demonstrates that through the construction of a microcavity structure, the emission peak FWHM can be compressed by more than fourfold.



**Figure 2.** The effect of incorporating a semitransparent metal layer on the FWHM of the QLED emission peak. The black curve represents the emission peak of the QLED device, while the red on respected to InP QDs in solution.

Based on these excellent results, we analyzed the impact of FWHM compression on the display color gamut. As shown in Fig. 3, we compared the color gamut areas of devices without a semi-transparent silver layer (blue line), with a semi-transparent silver layer (red line), and the NTSC color gamut reference (black line). The figure demonstrates that constructing a microcavity structure effectively reduces the emission peak FWHM, leading to a significant enhancement in the display color gamut. For example, the color gamut area increased from 79% NTSC (blue line) to 117% NTSC (red line), representing nearly a 50% improvement in the color gamut area. Our approach is also applicable to red and blue electroluminescent LED devices, such as those based on red InP quantum dots and blue ZnTeSe quantum dots. By constructing a microcavity structure, the emission spectra of electroluminescent devices utilizing cadmium-free and lead-free quantum dots can be effectively narrowed, thereby providing valuable guidance for research on wide color gamut cadmium-free and lead-free quantum dot displays.



**Figure 3.** Emission from QLED with (red line) and without (blue line) Ag semitransparent layer plotted on CIE chromaticity coordinates and compared to most common color standards (NTSC TV, black line).

### 3. Conclusion

In summary, we presented a novel theoretical simulation method based on Leda software. Using this method, we developed a typical top-emitting QLED to explore the impact of microcavity effects on the device's emission peak FWHM. To address the wide FWHM limitation in InP quantum dots, we designed a QLED structure with a semitransparent silver metal layer, which significantly narrows the FWHM. With this design, we achieved an InP electroluminescent QLED with an FWHM of only 15 nm. As a result, the color gamut increased by 47.5%, reaching 117% of the NTSC standard. Our approach effectively enhances the display color gamut of electroluminescent QLEDs, applicable to both Cd-free systems like InP QDs and Cd-based systems.

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