Progress in Heavy Metal Free NanoLED Development

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ABSTRACT

Quantum dots based on InP and ZnTeSe are rapidly improving in their electroluminescence performance, which enables their application in nanoLEDs as the ultimate display technology.

1 Introduction

Quantum Dots (QDs) continue to attract significant interest as a light-emitting material for display applications. The high internal quantum efficiency and narrow emission spectra of these semiconductor nanoparticles enable displays with high brightness and efficiency as well as wide color gamut. The implementation as a self-emissive electroluminescent nanoLED combines these benefits with high contrast, wide viewing angle, flexible ultra-thin display architecture, and low-cost fabrication.

The development of QD materials for nanoLEDs has made rapid progress over the last few years. In particular heavy metal free QDs have caught up to the device efficiency levels achieved earlier with cadmium-based QDs, and are also improving in lifetime characteristics [1,2]. Here we present improvements of the heavy metal free QDs with respect to stable surface passivation and control of particle shape [3]. We also show improvements in device structure that affect charge balance and reduce interface quenching. Finally, the robustness of the improved materials allowed to fabricate an active matrix nanoLED with QD pixels patterned by photolithography [4].

2 Results

2.1 Optical Properties of Heavy Metal Free QDs

The photoluminescence (PL) properties of QDs in a solution state can serve as a first quality indicator. High PL quantum yield (QY) is a necessary condition for efficient electroluminescence (EL) operation. A suitable peak wavelength (PWL) and a narrow full width at half maximum (FWHM) of the emission peak are the requirements for wide color gamut of a display using such QDs. Table 1 shows the solution PL properties of heavy metal free QDs used for EL devices reported here. Red and green QDs with suitable spectra and high QY were synthesized with indium phosphide (InP) as a core material. For blue QDs, alloyed ZnTeSe cores allow to tune the emission spectrum towards meeting the color coordinates of the blue primary in the BT.2020 standard [5].

Table 1: Photoluminescence properties of heavy metal free QDs in solution.

Color	Material	PWL	FWHM	QY
Red	InP	633 nm	40 nm	95%
Green	InP	532 nm	36 nm	94%
Blue	ZnTeSe	452 nm	27 nm	89%

2.2 Particle Shape and Surface Passivation

As previously reported the shape of the QD nanoparticles affects EL performance [3]. QDs with a cubic shape as shown in Figures 1a) and 1b) have superior efficiency and lifetime. Figure 1c) illustrates the uniformity of the surface structure of a cubic particle, which results in more stable passivation when using a ligand suitable for {100} facets. Spherical particles (Fig. 1d)) require different ligand types for full passivation of the different facets.

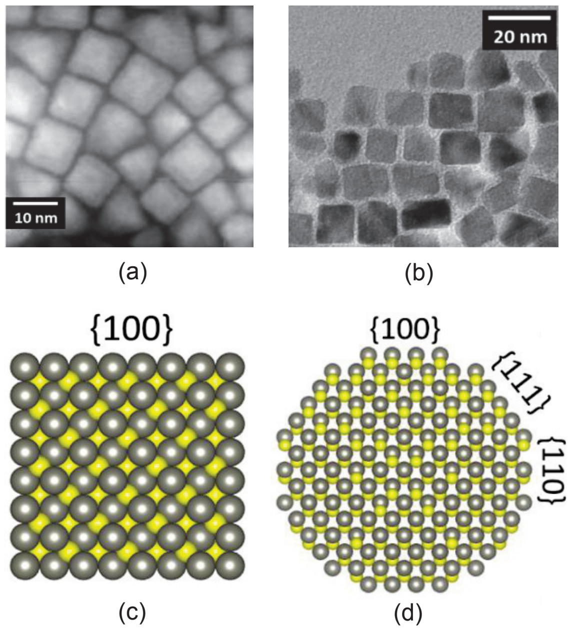

Figure 1: TEM images of (a) blue ZnTeSe/ZnSe/ZnS and (b) red InP/ZnSe/ZnS QDs with cubic shape, and structural diagrams of model zinc sulfide particles in zinc blende structure with (c) cubic and (d) spherical shape labelled with the different surface facets.

2.3 Electroluminescent Device Performance

The high PL QY combined with cubic shape QDs provides good device efficiency. Further improvements were achieved in the uniformity of the size and shape distribution across the ensemble, and in the choice of HTL which improves charge balance. In result, the maximum EQE of blue nanoLEDs using ZnTeSe QDs increased from 14.1% to 16.3% over the last year. As shown in Figure 2, the efficiency roll-off also decreased, for example the EQE at 10000 nits improved from 8.1% to 12.6%. The EL spectrum of those blue nanoLEDs maintains the narrow FWHM of the PL spectrum, resulting in CIE color coordinates of (0.147, 0.048) which are very close to those of the blue BT.2020 primary of (0.131, 0.046).

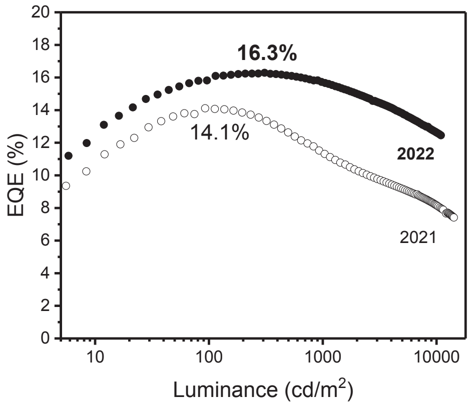

Figure 2: Improvement in EQE vs luminance curve of blue nanoLED.

3 Discussion

The result for blue nanoLEDs reported above is an example of the continuous progress in the performance of electroluminescent nanoLEDs driven by materials and device research. Figure 3 reviews the progress nanoLEDs using heavy metal free QDs over the last years. Red InP nanoLEDs exceed 21% EQE which is in the range of the theoretical limit of 20-25% set by light outcoupling. Green and blue nanoLEDs see rapid progress as well with current record EQEs of 17.6% and 16.3%, respectively.

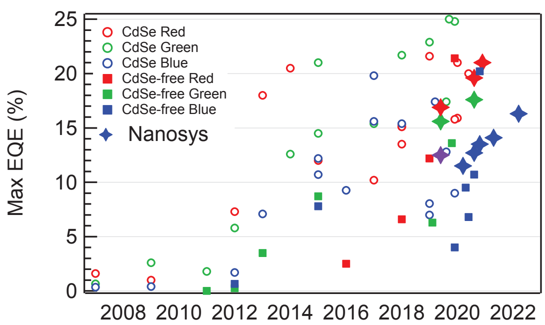

Figure 3: Progress in EQE performance of nanoLEDs using heavy metal free QDs compared to CdSe QDs.

Finally, the improvements in material stability enable more involved fabrication processes with harsher conditions. Figure 4 shows a photograph of an active matrix nanoLED for which the heavy metal free QDs were patterned by a photolithography process.

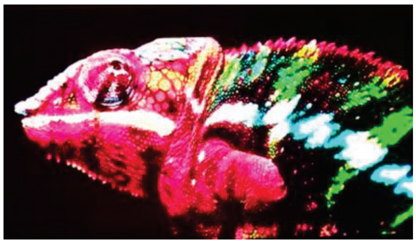

Figure 4: Photograph of a 6.24” active matrix nanoLED with heavy metal free red, green and blue QDs.

4 Summary

The rapid improvement in the electroluminescent performance and stability of heavy metal free QDs enables the realization of nanoLEDs that combine the benefits of QDs and OLEDs in an ultra-thin flexible display architecture without form factor limitations.

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