Giant Shell Quantum Dots for color conversion and as active material in QLEDs

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Abstract
We present an automated and up-scaled synthesis of giant-shell QDs (GSQD). For color conversion, these particles will be incorporated in a suitable matrix with high QD content and transferred onto a blue light LED. We will also show results of QLEDs with a thin film of GSQD as active material.

Author Keywords
Quantum dot, giant shell, emitter, color conversion, QLED emitter

1. Background and objectives
In 2013 Sony released the first quantum dot TV (QDTV) based on zero-dimensional, spherical semiconducting nanocrystals (QDs) with improved color gamut. Today especially Samsung is pushing the technology within their QLED TV range. Despite their naming these displays still use QD sheets in the back light unit to produce white light suitable for a wider color gamut. In figure 1 the stacked composition of an established QDTV is schematically shown. The blue light (~ 450 nm) of the back light unit (BLU) interacts with the QDs in polymer film leading to white light. As in traditional TV panels this light is used to illuminated the single pixels of the LC unit. However more advanced approaches to use QDs in a TV like electroluminescence, on chip color conversion or as a replacement for the color filters lack of QDs with suitable properties. Especially the stability at high flux is a mayor issue.

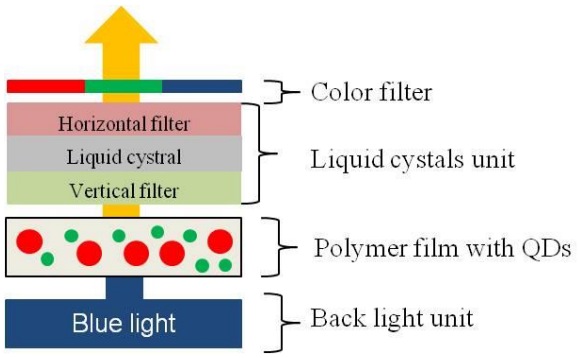

Figure 1. Simplified schema of established QDTV

Therefore, the next generation of optoelectronic display devices have to use more advanced quantum dots, which can face these challenges. Beside the possibility of using particles with an elongated shell (1D), another superior particle design consists of a core with a typical spherical, but very thick shell (giant shell quantum dot, GSQD). These 3D structures still show the quantum size effect due to the small size of the core, but the giant shell leads to enhanced stability and huge absorption coefficients in the blue while the reabsorption rate remains neglectable. [1, 2]

For the integration of GSQDs for color conversion in QDTV they need to be incorporated into a suitable polymer film with a very high QD load to allow high absorption rates within a thin composite film. The polymer matrix also offers protection against moisture and oxygen extending the lifetime of the QDs.

Figure 2. CdSe/CdS nanorods in monomer (top) and polymer (bottom)

For the integration into a QLED, a thin and homogeneous QD film has to be deposited into the stack as active material (figure 3).

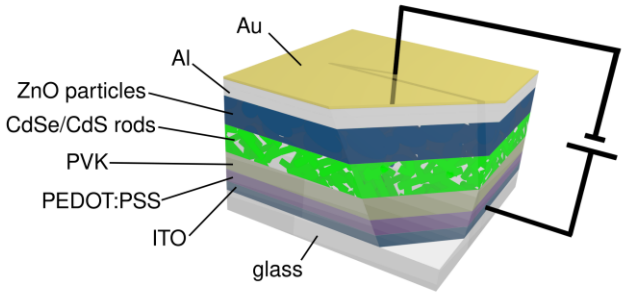

Figure 3. QLED stack used

2. Results
To allow the fabrication of suitable QDs for these demanding applications, Fraunhofer CAN has developed an automated synthesis for GSQD. The diameter of the core particles can be varied between 1.6 and 5 nm so that the band gap is strongly influenced by the size quantization effect. On this core, a shell is grown expanding the particle diameter up to 20 nm. The continuous addition of the precursors allow a defect free growth of the shell with a pronounced crystallinity (figure 4).

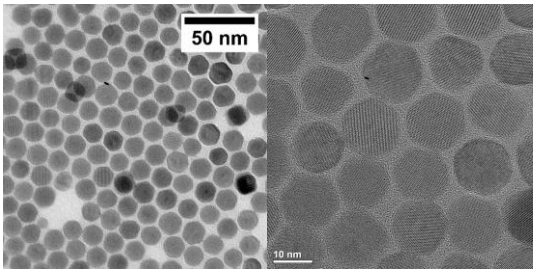

Figure 4. TEM (left) and HRTEM (right) images of a typical GSQD sample

The QY of the resulting GSQD is close to 1, absorption in the blue is high, while the reabsorption rate is low (figure 5). Stability measurements of these GSQDs prove that this shape is superior to 0D, 1D and 2D particles, especially concerning photoluminescence stability at high flux. However, the shell growth also results in a tremendous red shift of the emitted light compared to the core prior to shell growth. This effect makes the synthesis of red emitting GSQD favorable, while the synthesis of green emitting GSQD is a major problem. Fraunhofer CAN has solved this problem by adapting the intermediate layer between core and shell. So far, we were able to produce GSQDs with an emission between 530 and 635 nm in gram scale. The synthesis of GSQD with red and green emission will be discussed and measurements of the resulting particles will be shown.

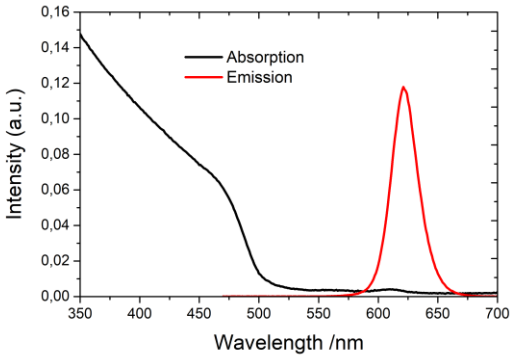

Figure 5. Absorption and emission spectra of a typical red emitting GSQD

To utilize these particles for color conversion applications, Fraunhofer CAN has incorporated them into a silicon matrix with a QD load above 1% suitable for high flux applications. The resulting hybrid material can be used to form thin films with high absorbance in the blue and emission in red or green. We will show measurements of blue light LEDs covered with this matrix so underline their unique properties as color conversion material.

After ligand exchange, the QSQDs can also be used as an active material in QLED devices. The ligand exchange allows the formation of closely packed QDs in the film and accelerates the charge transfer from the electrodes to the GSQDs. We will show QLEDs based on GSQD with a light emitting areal up to 10 cm^2 (figure 6). These QLEDs exhibit a luminance above 20.000 nits, which makes them an interesting candidate for many demanding applications.

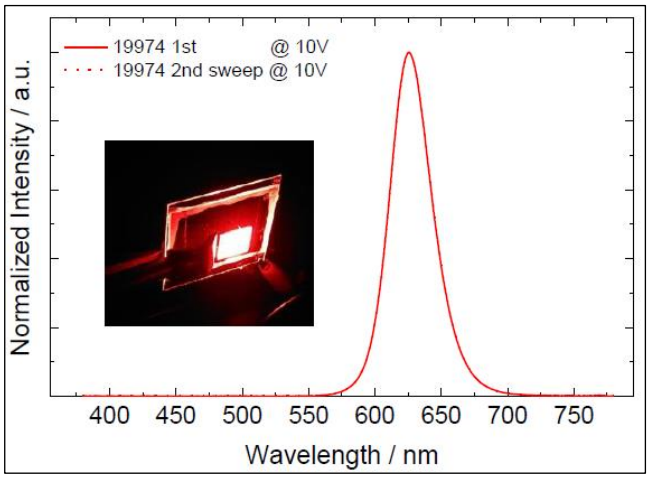

Figure 6. Red-emitting QLED (10 cm^2 area) based on GSQD

3. Impact

The controlled synthesis of a giant shell QD system in gram scale with excellent emission properties (QY and stability) in red AND green allows moving on from using a QD sheet in the TV backlight to color conversion at a high flux. This is not limited to blue light LEDs, it is also a very interesting opportunity to combine this technology with OLED and especially µLEDs.

The improved stability and luminance of the GSQD can also help to address demanding applications with QLEDs.

4. Prior Publication

Most prior talks at the SID Display week or IDW were focused on our work with elongated 1D quantum rods and their properties, especially their polarized emission. [3,4] One talk about this topic was given at the SID online meeting in 2020. However many new results were obtained during the last two years, so this talk will cover the latest development on this topic. The above-mentioned work on GSQD, especially with green emission, is not published so far.

5. References

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