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Deep UV LED-pumped Quantum Well Supraparticles for Visible Light Communication

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***Abstract*—Colloidal quantum well color-converting supraparticles are studied under optical pumping (UVA and UVC LEDs) for visible-light communication applications. Results show similar conversion efficiencies for UVA and UVC pumping, but reveal a modulation bandwidth up to 7 times higher for UVC pumping (60 MHz).**

Keywords—quantum wells, microlasers, light emitting diodes, ultraviolet, communication

I. Introduction

Colloidal quantum wells (CQWs) are 2D semiconductor nanocrystals (NCs) that possess attributes common to other colloidal NCs, including the flexibility of solution processing, high luminescence quantum efficiency, composition and size control of their optical and electronic properties, as well as some advantages such as higher absorption cross-section and a reduced Auger recombination rate due to their 2D geometry [1]. These characteristics make CQWs attractive for the color conversion of blue and UV emitting light-emitting diodes (LEDs), while offering a route to Wavelength Division Multiplexing that could span from the UV-C to the red.[2], [3].

In this work, solid-state assemblies of CQWs were optically pumped with UVA and UVC LEDs to test their performance as color converters for VLC. $CdSe/Cd_xZn_{1-x}S$ core/shell CQWs with an emission peak of 660 ± 10 nm and a near-unity quantum yield (QY) of 98.5% were self-assembled into supraparticles (SPs). These SPs are sphere-shaped clusters of NCs organized in an almost crystalline structure. This structure increases their light absorption and excitonic coupling [4]. The CQW SPs were then combined with a UV LED pump source and their static (forward emission conversion efficiency) and dynamic (modulation bandwidth) characteristics were studied. Two different LEDs were utilized: a UVA µLED (375 nm) and a UVC mini-LED (275 nm). The sizes of the LED emitting areas, 50 µm diameter and 300 µm diameter for the UVA and UVC LED respectively, were chosen so that their optical powers were similar (see section II. B). The UVC LED was fabricated from a commercial AlGaN-based deep-UV LED wafers [5].

While there has been work on perovskite nanocrystals to convert UVC communications signal at the detection end [6], to the authors' knowledge, the testing and implication of such DUV devices as a pump source for CQWs have not been reported yet.

II. Materials and Methodology

A. Synthesis of the Quantum Wells and Supraparticles

CQWs with an emission peak of 660 nm were synthesized *via* a hot-injection shell growth method and yielded NCs of approximately 14 × 15 × 4.2 nm in width × length ×height. These consisted of a CdSe core 4 monolayers thick and a $Cd_xZn_{1-x}S$ shell approximately 8 monolayers thick. QW SPs were synthesized using an oil-in-water emulsion technique at 0ºC and drop cast on a glass slide before characterization [7].

B. Optical Characterization

The number of photons was estimated from optical power measurements on samples (with $E \propto N \cdot \frac{hc}{\lambda}$), where the energy detected E is proportional to the number of photons N. The constants h, c and λ correspond to the Plank constant, speed of light in vacuum and wavelength of the photon, respectively. For these measurements, the sample was placed in close proximity to the LEDs (7 mm) and power meter (6 mm). The powermeter (Thorlabs) had a long pass filter installed (> 600 nm).

For the bandwidth measurements, a network analyzer (Pico Technologies, PicoVNA 106) was used to produce a radio frequency (RF) electrical signal. A bias-T compatible with the bandwidth range of the RF signal was used to insert the DC power (Tektronix, PSPL5675 A) into the RF signal. The modulated signal was plugged to the LED and the photoluminescence (PL) of the sample was collected by an avalanche photodetector (APD, Hamamatsa, C5668 8867), covered by a long pass filter (> 600nm) to cut out the light from the LEDs. The APD sends the data back to the network analyzer where it is processed. The sample was placed 7 mm away from the LEDs and 6 mm away from the long pass filter, which was 9 mm away from the APD.

III. Results and discussion

A. Forward emission of the sample for the UVA and UVC

The forward emission of CQW SPs (fraction of light that is emitted towards the detector) was compared against the light output of the LEDs for both cases (UVA and UVC pumping). Fig. 1 shows that the conversion efficiency was similar (8%) in both cases. The detection efficiency of the powermeter in the UVA and UVC was assumed the same.

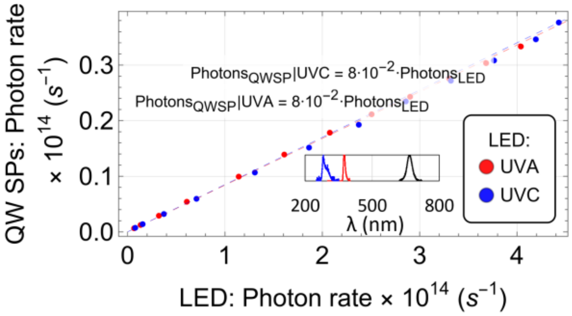

Fig. 1. Forward emission of the CQW SP sample versus light emission of LED (UVA and UVC), with a photon conversion of approximately 8% for both LEDs. The inset shows the normalized PL emission of both LEDs (UVC: 281 nm; UVA: 374 nm) and sample (665 nm).

B. Bandwidth Measurements

The frequency response (FR) of the sample was detected for a range of different LED photon rates by applying different bias currents to the LEDs. Fig. 2 shows the FR of the sample with the UVA/ UVC LED at a photon rate of 6.8/ 8.0·10^{12} s^{-1}.

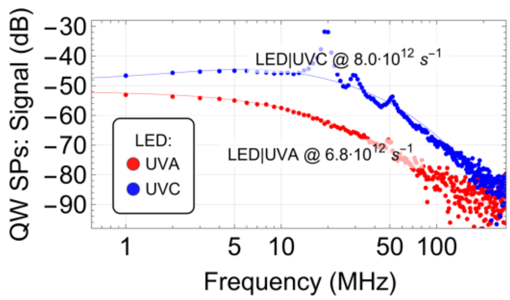

Fig. 2. Frequency response measurements of the device (LED + sample) using UVA and UVC at a photon rate of 6.8 and 8.0·10^{12} s^{-1}, respectively.

An exponential fit was then done to each of those measurements and the bandwidth (BW) of the device (LED + sample) was determined by extracting the BW value from the fit after a signal drop of 3 dB (Fig. 3).

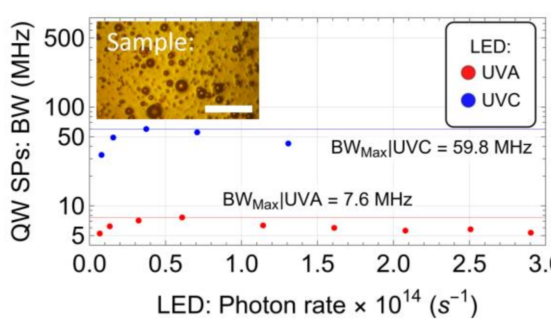

Fig. 3. Bandwidth results of the device (LED + sample) as a function of the photon rate of the LED. The inset shows a microscope image of the sample containing the CQW SPs (the scale bar on the picture corresponds to 50 µm).

C. Lifetimes

The FR of CQW SPs was deconvoluted from the device at BW_{Max} by subtracting the FR from the LED without the sample.

The FR of the CQW SPs was then fitted to [8]:

$$FR = 2 \cdot 10 \cdot Log(\sqrt{n^2 + D^2}) \quad (1)$$

$$n = \frac{\sum_i \frac{\alpha_i \cdot \omega \cdot \tau_i^2}{1+\omega^2 \cdot \tau_i^2}}{\sum_i \alpha_i \cdot \tau_i}; D = \frac{\sum_i \frac{\alpha_i \cdot \tau_i}{1+\omega^2 \cdot \tau_i^2}}{\sum_i \alpha_i \cdot \tau_i} \quad (2)$$

Where α is the probability of decay, τ is the lifetime and ω is the input frequency. The lifetime measurements (Table I) show a short component at 15 ns, which is in agreement with the average lifetime of CQWs in solution [9]. The origin of the longer pathway (82-85 ns) is still not clear, but results suggest that UVC mitigates it and increases the FR of the device.

TABLE I. FIT RESULTS FOR THE LIFETIME MEASUREMENTS AT BW_{MAX}

LED/BW_{Max}	Fitted Lifetimes (i = 2)			
	α_1	τ_1 (ns)	α_2	τ_2 (ns)
UVA/7.6MHz	0.17 ± 0.01	82.4 ± 2.4	0.83 ± 0.01	15.5 ± 0.7
UVC/59.8MHz	0.02 ± 0.05	84.9 ± 96.4	0.98 ± 0.05	15.0 ± 1.3

IV. CONCLUSION

UVC was shown to increase the frequency response of CQW SPs. UVC devices yielded bandwidths up to 7 times higher than UVA. Such results highlight the advantage of UVC pumped devices for applications in communication.

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