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MicroLED-pumped perovskite quantum dot color converter for visible light communications

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Abstract— ***The visible light communications properties of a microLED-pumped inorganic perovskite quantum dot color converter are reported. Free-space data communications at 364 Mb/s, using solely the color-converted light as the data signal optical carrier, is demonstrated.***

Index Terms—Visible light communications, quantum dots, semiconductor nanocrystal, GaN, LED, OFDM

I. INTRODUCTION

InGaN-based LEDs and laser diodes are replacing legacy technologies in solid-state lighting applications, due to their higher efficiency, longer working life and ease of integration. An emerging application field is visible light communications (VLC), where these devices act as both lighting sources and data transmitters. Blue colored LEDs with micron-sized emitting areas (µLEDs) have been shown to possess optical bandwidths of hundreds of MHz, recently enabling VLC at 11 Gb/s data rates [1]. In order to efficiently generate longer wavelength colors, phosphors can be used to downconvert the blue LED light, as is done in commercial white LEDs, for example. However, conventional phosphors only respond at MHz modulation rate. Alternative, faster color converters are therefore needed and are being explored, including colloidal quantum dots (QDs) [2]. Here, we report a novel inorganic perovskite quantum dot (IPQD) material for such application.

The capability of chalcogenide QDs as color converters for VLC has been explored [2]. QDs have the added advantages of size tunable and narrow emission, desirable for conversion with high color purity. IPQDs were first reported two years ago and have since emerged as a promising photonic material system, matching chalcogenide QDs' spectral range and quantum yield [3], [4]. In addition, they typically have a similar, or possibly shorter, photoluminescence (PL) lifetimes, which has led to their use as fluorophores in a laser-pumped VLC experiment [5]. Despite these rapid developments, there is a wide design range to explore and a need to better understand the material dynamic and static optical properties, and how these subsequently impact on device performance for VLC.

In this paper, we develop and study an IPQD color converter photo-pumped by a 450nm InGaN µLED. Crystallites of $CsPbBr_3$ QDs in a $CsPb_4Br_6$ matrix constitute the active color-converting elements. This design is beneficial to QD stability, e.g. by preventing aggregations and/or anion-exchange during processing. These crystallites are incorporated into a polymer to form the color-converting material.

II. MATERIALS AND METHODOLOGY

The IPQDs were synthesized [6] and made into a powder. It was then mixed with PMMA (20% IPDQ/PMMA weight ratio) in chloroform. Using a micro-pipette, a 10 µL droplet of the solution was deposited onto a glass slide and dried in air. Sample absorption of 450nm light was around 95%. The sample under µLED excitation can be seen in Fig. 1, and under UV light in the inset of Figure 2. SEM images of the IPQD crystallites are also displayed in Fig. 2.

A 100x100µm^2 450nm-emitting µLED was used to remotely pump (~2mm excitation spot) and characterize the sample (see Figure 1). The forward emitted converted optical power and spectral emission were obtained using, respectively, a power meter and a spectrometer for detection.

The recombination dynamics of a color converter are important, as, along with the optical power, they will determine the VLC performance of the color-converted source. The frequency response of the IPQD converter was therefore tested to determine the optical bandwidth and extract the photoluminescence (PL) dynamics. The frequency response was obtained by DC-biasing the µLED and modulating it with a 0.25 Vpp frequency swept signal, which, once down-converted by the IPQDs, was detected by a high-speed photodiode (1.4 GHz bandwidth). The optical bandwidth is the modulation frequency for which the modulated amplitude of color-converted light is halved. The data was fitted considering a multi-exponential temporal PL decay model [7].

The set-up for the free-space VLC demonstration is shown in Figure 1 where an avalanche photodiode (APD) was used for detection. DC-biased Optical Orthogonal Frequency Division Multiplexing (DCO-OFDM) [8], a multi-carrier modulation

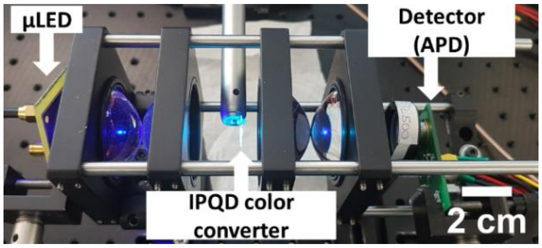

Figure 1 – setup used for the characterization of the color converter.

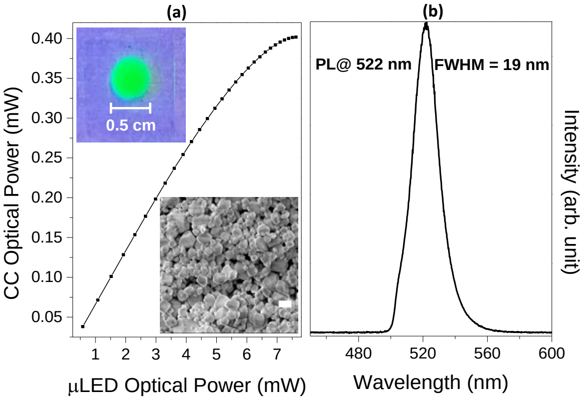

Figure 2 – (a) Color converted optical power vs µLED pump power; scale bar in SEM image = 1µm. (b) spectral emission of the IPQD converter.

scheme based on adaptive bit and energy loading, enabled utilization of a 75MHz modulation frequency span. The OFDM signal was generated offline using Matlab® and fed into an arbitrary waveform generator. A 4.97V DC component was combined with the OFDM signal to drive the µLED. The converted light carrying the ODFM signal detected by the APD was demodulated using Fast Fourier Transform and post-equalized. An optical filter was placed before the APD to remove any unabsorbed LED transmitted through the converter. In this way, only the light converted by the IPQDs was used as the carrier for VLC.

III. RESULTS AND DISCUSSION

In Figure 2 (a), the converted power is plotted against the µLED optical power, reaching a maximum of 0.4 mW (~5% forward conversion efficiency). The spectral emission of the perovskite converter is presented in Figure 2 (b). The peak emission is at 522 nm with a FWHM of 19 nm. Comparing to typical Cd-based color converters [2], this is ~30% lower, a desirable feature to achieve high color purity, which is also attractive to enable wavelength division multiplexing in VLC.

The color converter frequency response for a µLED bias of 5.40 V is shown in Figure 3, along with the parameters of the fitting function [7]. The latter assumes a triple exponential decay, with lifetimes of 1.77 ns (76.7%), 5.82 ns (22.3 %) and 38.30 ns (1.0%). At such a bias level, the frequency response is dominated by the IPQDs (the µLED optical bandwidth being around 140 MHz). Determining the point at which there is a 6dB drop gives a bandwidth of 24.6 MHz (the frequency response is given in terms of the detected electrical power in Fig. 3, hence -6 dB), a value higher than that obtained for a green-emitting CdSSe/ZnS QD converter under the same conditions (~15 MHz) [2].

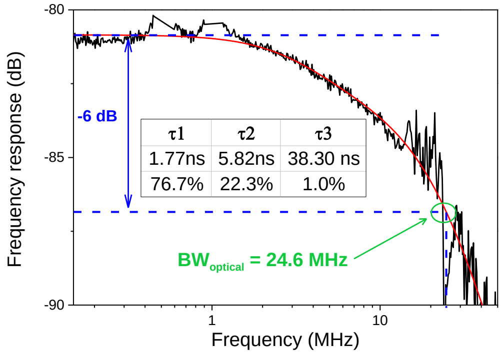

Figure 3 - Frequency response of the color converter + µLED.

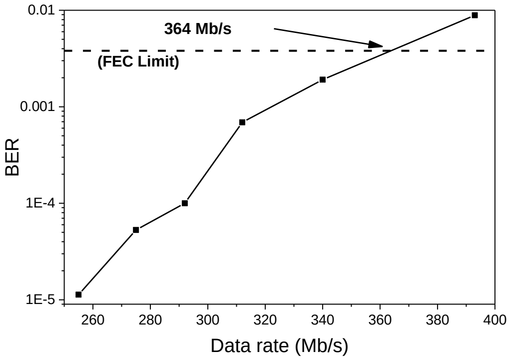

Figure 4 - Data rates obtained for the IPQD color converter using OFDM.

In Figure 4, the bit error rate (BER) for the VLC experiment is plotted against data rates obtained. Considering that Forward Error Correction (FEC) can be applied, 364 Mb/s VLC is achieved, crucially here, *using light from the color converter alone* (and not from the µLED). Removing the filter to mix the color-converted and the µLED light arriving at the APD, data rates above 1 Gb/s are obtained.

IV. CONCLUSIONS

A µLED-pumped perovskite QD color converter was demonstrated for VLC. 364 Mb/s was achieved using solely the color converted light as the modulation carrier. Data rates in excess of 1 Gb/s when color mixing with unabsorbed µLED light is readily achievable and will also be shown.

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