Dual color micro-LED transmitter for Visible Light Communication

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***Abstract*— We report the integration of blue micro-LED onto to the substrate of green micro-LED, by transfer printing. This dual color device fabrication and performance as a visible light communication transmitter is demonstrated.**

Keywords—micro-LED; transfer printing; VLC;

I. INTRODUCTION

Gallium nitride-based light emitting diodes (LEDs) have shown great potential in Visible Light Communications (VLC), with over Mbit/s data transmission rates achieved by a single broad area LED. Further increase of transmission rates is limited by the low optical modulation bandwidth (BW) of these broad area LEDs, around the tens of MHz [1]. In the past years, we have shown that simply by reducing the size of the LED down to the micro scale (micro-LEDs) a tenfold increase in bandwidth is observed. This has led to a whole new field of VLC transmitters, with several reports of multi-Gbit/s data rates achieved by micro-LED devices [1], [2]. In this work we report a dual color micro-LED array VLC transmitter that combines green and blue emitting micro-LED on the same substrate. By a pick-and-place technique, we have successfully transfer printed a blue-emitting micro-LED platelet from its silicon growth substrate onto the sapphire substrate of the green-emitting micro-LED. The electro-optical characteristics of this device are assessed and its performance as a VLC transmitter is evaluated by BW and data rate measurements.

II. EXPERIMENTAL DETAILS

The dual color micro-LED device reported in this work results from the integration of a blue micro-LED onto the substrate of a fully operational green micro-LED (Fig.1 a)). The fabrication processes of the green and blue micro-LEDs are, until the dual color integration step, independent of each other. As such, they will be described separately.

The green micro-LED is fabricated from green emitting (505 nm) commercial InGaN epistructures grown on c-plane sapphire. A 20 µm diameter flip-chip micro-LED is defined by conventional photolithography techniques, as described elsewhere [3]. An important additional step is the deep etching of the mesa structure (90x90 µm^2) down to the patterned sapphire substrate (PSS). This allows to reduce the green micro-LED capacitance [2] as well as to compensate for height differences between the green and blue micro-LED in further processes [4].

Blue micro-LED platelets (100x100 µm^2) are fabricated from commercially available blue emitting (450 nm) InGaN epistructures grown on (111)-oriented silicon (Si). The process is similar to the conventional GaN-based LED fabrication, with 3 main differences: 1) during mesa etching, supporting "anchors" are defined and etched down to the silicon substrate; 2) next, an extra etching step is introduced, exposing the Si(110) planes; 3) followed by a hot (80 °C) 30% potassium hydroxide bath used to underetch the Si(110) planes. Upon completion of the underetching, the micro-LED platelets (2 µm thin) are held suspended, above an air gap, by the two diagonally opposed sacrificial anchors [5].

The dual color micro-LED fabrication is enabled by transfer printing (TP). In this technique, an elastomer stamp is used to pick-up one of the suspended blue micro-LED platelets and print it on the PSS of the green micro-LED (Fig.1 b)). It is worth mentioning that, due to the rough nature of the PSS a thick adhesion enhancement layer of SU-8 (4.5 µm) is spin coated prior to the printing. The distance between these two micro-LEDs is set to 50 µm, however our TP system is capable of nanoscale placement accuracy [5]. After printing, a highly conformal film of parylene-C (4 µm thick) is deposited, electrically insulating the sidewalls of the blue micro-LED. Localized apertures on the parylene-C layer, above the *n* and *p* contacts of the micro-LED, are lithographically defined and electrically addressed by Ti/Au (50/250 nm) metal tracks.

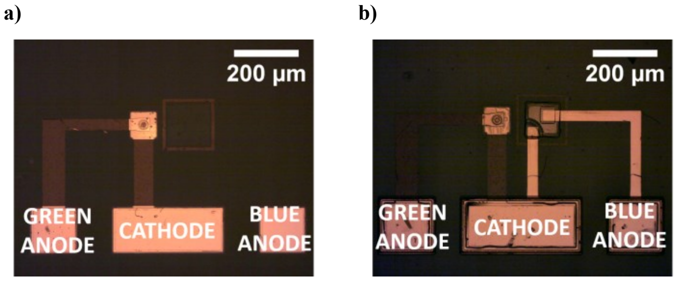

Fig. 1 – Optical photographs of the green micro-LED before transfer printing; b) of the dual color device after transfer printing the blue micro-LED.

III. RESULTS AND DISCUSSION

A. *Electro-optical perfomance*

The electro-optical response of the dual color micro-LED array is shown in Fig. 2. The green micro-LED is able to sustain much higher current density than the blue micro-LED, due to their difference in size. Despite this size difference the maximum optical power of the two micro-LEDs is quite similar, 0.45 mW (at 3.8 kA/cm^2) and 0.6 mW (at 120 A/cm^2), for the green and blue micro-LED, respectively.

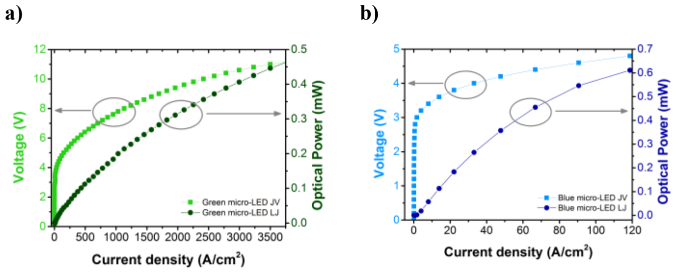

Fig. 2 – Current density-voltage (JV) and current density – optical power (LJ) of a) the green micro-LED and b) the blue micro-LED.

B. *VLC Application*

The capability of the dual color micro-LED array on VLC has been evaluated in terms of the LEDs electrical-to-optical modulation BW, data transmission rate, and electroluminescence (EL).

Both micro-LEDs exhibit BW values above 100 MHz (Fig. 3a)). These extremely high values have been attributed to the ability of micro-LEDs to sustain high current density as well as to their low capacitance [3]. Data transmission experiments have been performed by driving the micro –LEDs with a direct current bias from a power supply combined, by a bias-tee, with a modulated signal from a signal generator. The modulated signal is based on an orthogonal frequency-division multiplexing (OFDM) data encoding scheme. The bit-error-ratio (BER) as a function of the data rate is shown in Fig. 3b). The blue micro-LED (blue-squares), operating at 10 mA driving current, can achieve 800 Mbit/s before reaching the 3.8x10^{-3} forward-error-correction (FEC) threshold. The influence of the green micro-LED, operating at 11 mA, and a bandpass filter centered at 470 nm on the blue micro-LED data rate is also shown (light blue circles). In this case, the maximum achieved by the blue micro-LED data rate is around 500 Mbit/s. The corresponding EL spectra (Fig. 3c) – Blue/Green curve) shows that the bandpass filter effectively blocks the light from the green micro-LED, and as such, the lower values for data rate are likely due to the blue micro-LED optical power losses at the filter. The same measurements have been performed for the green micro-LED. A maximum data rate of 613 Mbit/s and 480 Mbit/s is achieved, for single green micro-LED (green triangles) and green micro-LED with a 480 nm longpass filter and blue micro-LED (light green stars). When in ganging mode (both LEDs transmitting the same input signal) the maximum achieved data rate below the FEC threshold is 430 Mbit/s (Fig. 3b)).

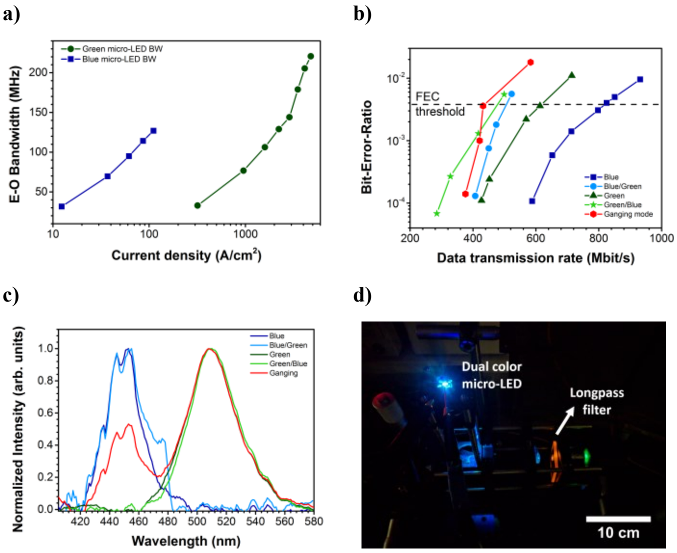

Fig. 3 – a) BW as a function of current density; b) BER as a function of data rate; c) EL spectra of single micro-LED and dual color pair; d) picture of the micro-LEDs driven at the same time with a 480 nm longpass filter before the spectrometer.

IV. CONCLUSION

We have successfully transfer printed a blue emitting micro-LED onto the growth substrate of a green emitting micro-LED, creating an individually driven dual color array. The potential of this device as a VLC transmitter has been demonstrated with data rates of 800 Mbit/s and 600 Mbit/s for the blue and green micro-LED, respectively.

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