Gb/s Single-LED OFDM-based VLC Using Violet and UV Gallium Nitride µLEDs

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***Abstract* – We present data transmission achieved using orthogonal frequency division multiplexing (OFDM) together with violet (405 nm) and ultraviolet (370 nm) micro-sized light-emitting diodes (µLEDs), at data rates of 3.32 and 1.31 Gb/s, respectively.**

I. INTRODUCTION

Visible light communications that utilize white light-emitting diodes (LEDs) for both illumination and communication ('Li-Fi') has emerged as a timely solution for addressing the challenges posed by the exponential growth in wireless data traffic. Li-Fi allows lighting infrastructure to provide access to 100s of THz of licence-free bandwidth for wireless communications, in a configuration that does not interfere with existing RF technology, thereby addressing the impending "spectrum crisis".

The most common format of white LED consists of a blue-emitting LED integrated with a yellow-emitting phosphor. The blue emission from the LED is partially converted to yellow, giving an overall white emission. One shortcoming of this implementation is that these LEDs have a poor color-rendering index (CRI). In addition, the yellow phosphor has a long (µs) excited-state lifetime, so it is not well suited for high-speed VLC.

An alternative approach would be to combine short-wavelength LEDs with alternative color-converters such light-emitting polymers (LEPs) or inorganic semiconductor membranes. We have previously demonstrated blue µLEDs combined with LEPs [1] and inorganic semiconductor membranes [2] for VLC. Here we report µLEDs emitting at shorter wavelengths, ultraviolet (UV, approximate peak wavelength 370 nm) and violet (405 nm). These wavelengths are viable alternatives for generating white light via color-converters, whilst also enabling techniques such as self-aligned patterning of LEPs [3]. Using orthogonal frequency division multiplexing (OFDM) data rates of 3.32 and 1.31 Gb/s, are achieved using violet and UV µLEDs, respectively. This work provides a baseline for future work utilising white LEDs based on UV/violet LEDs and color-converting materials.

II. µLED DESIGN AND PERFORMANCE

Conventional LED die typically consist of a single active area of the order of 1 mm^2. In contrast, the Gallium Nitride (GaN)-based µLED devices used in this work are comprised of arrays of individually-addressable pixels, each with dimensions <100 µm. We have previously shown that, due to their small size and ability to be driven at much higher current densities than conventional LEDs, µLEDs offer significantly higher modulation bandwidths, in excess of 400 MHz in some cases [4]. Furthermore, the array format of the µLEDs also offers the possibility to use multiple pixels within the array to transmit multiple data streams simultaneously.

For these reasons µLEDs were chosen as the optical transmitters as opposed to a more conventional LED. The UV and violet µLED arrays had peak wavelengths of approximately 370 and 405 nm, respectively. Single pixels from each array were used, with diameters of 60 and 40 µm for the UV and violet devices, respectively. The light output power-current-voltage (L-I-V) characteristics of the devices are shown in Figure 1 (a). Maximum output powers were measured to be 1.5 mW for the UV µLED, and 2.5 mW for violet.

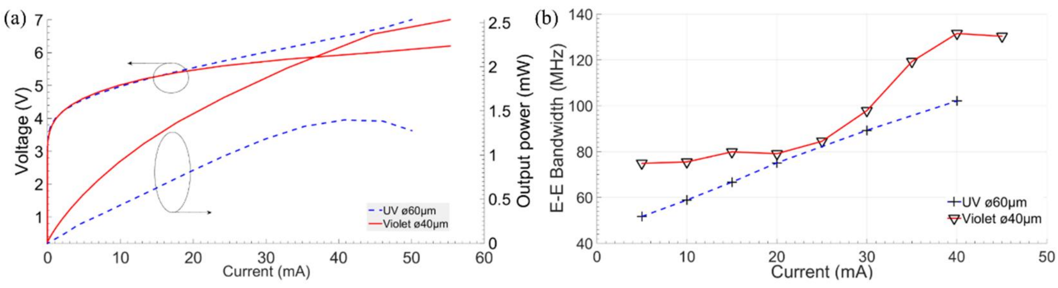

Figure 1 – (a) output power and voltage vs. current and (b) electrical -3dB bandwidth versus current for UV and violet µLEDs.

The small-signal modulation bandwidths of the µLEDs were measured using a similar method as described in [4]. As shown in Figure 1(b), the modulation bandwidths of the devices increase with increasing carrier density, as discussed in [4]. Maximum electrical-to-electrical -3dB bandwidths of 100 and 130 were found for the UV and violet devices, respectively.

III. DATA TRANSMISSION USING OFDM

With the exception of different optics and photoreceiver the experimental setup used for transmission of data using the µLEDs is otherwise the same as in our previous publication [5], and for brevity will not be described in full detail here. Using MATLAB® a pseudo-random bit stream is encoded into *M*-ary quadrature amplitude modulation (*M*-QAM) symbols, and converted to a discrete time-domain signal by an inverse fast Fourier transform (IFFT). This signal is subsequently used to modulate the µLED output via an arbitrary function generator, amplifier and bias-tee. The optical emission from the µLEDs were then collected and imaged onto a fast photoreceiver (Femto HAS-X-S-1G4-Si, 1.4 GHz bandwidth), amplified and the received waveforms recorded by a digital oscilloscope. Finally, the received waveforms were processed in MATLAB® to obtain the received equalized *M*-QAM symbols.

For the 60 µm diameter UV µLED, optimum bias conditions were found to consist of a 2 V peak-to-peak (V_{pk-pk}) signal with an average DC current of 15 mA. Similarly for the 40 µm diameter violet µLED, an optimum 3 V_{pk-pk} and DC current 25 mA was used.

An adaptive algorithm was used to estimate the optimal bit and energy loading of the sub-carriers by attempting to ensure a constant (signal-to-noise ratio) SNR for all subcarriers of a particular QAM constellation size. Using this method, for the UV device a data rate of 1.41 Gb/s with a bit-error rate of 2.46×10^{-3} was achieved, and 3.57 Gb/s with a BER of 2.1×10^{-3} for the violet µLED. Taking into account a 7% overhead for forward-error correction (FEC) the overall data rates are 1.31 and 3.32 Gb/s for the UV and violet µLEDs, respectively. These represent the fastest single-link LED-based communication system demonstrations operating at UV and violet wavelengths.

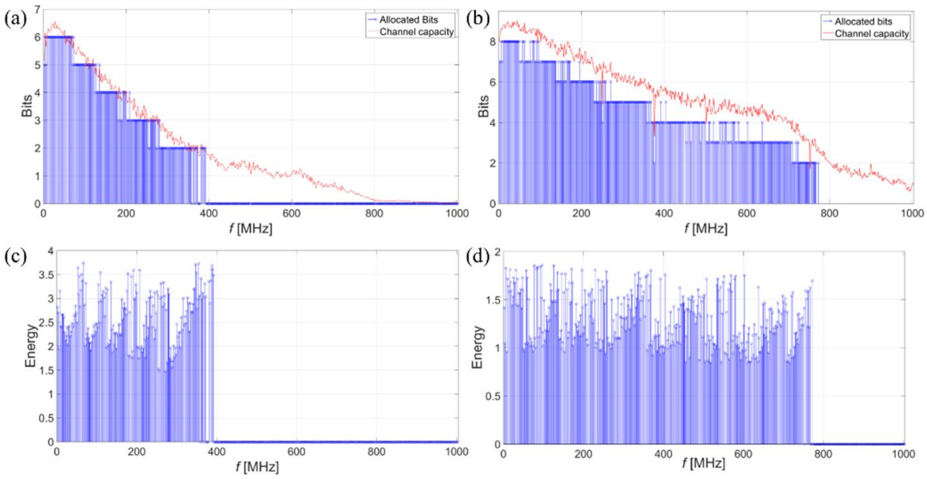

Figure 2 – allocated bits (a,b) and energy (c,d) for UV and violet µLEDs, respectively. The energy is normalized to the average energy in the OFDM frame.

IV. SUMMARY

Wireless VLC links using single GaN µLEDs emitting at 370 and 405 nm have been demonstrated transmitting data at rates of 1.31 and 3.32 Gb/s, respectively. These results represent the fastest transmission rates demonstrated using a single LED at these wavelengths, and provide baseline results for future work converting these wavelengths to white light.

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