4 Gbps wireless optical communications up to 5 m using a UV-C micro-light-emitting diode array

Jonathan J.D. McKendry
University of Strathclyde
Glasgow, UK
jonathan.mckendry@strath.ac.uk

Enyuan Xie
University of Strathclyde
Glasgow, UK
enyuan.xie@strath.ac.uk

Mohamed Sufyan Islim
University of Strathclyde
Glasgow, UK
m.islim@strath.ac.uk

Xiaobin Sun
Fraunhofer Centre for Applied Photonics,
Glasgow, UK
xiaobin.sun@fraunhofer.co.uk

Daniel MacLure,
University of Strathclyde
Glasgow, UK
daniel.maclure@strath.ac.uk

Erdan Gu
University of Strathclyde
Glasgow, UK
erdan.gu@strath.ac.uk

Harald Haas
University of Strathclyde
Glasgow, UK
harald.haas@strath.ac.uk

Martin D. Dawson
University of Strathclyde
Glasgow, UK
m.dawson@strath.ac.uk

***Abstract*— Optical wireless communication using an ultraviolet UV-C micro-light-emitting diode, and an Orthogonal Frequency Division Multiplexing modulation scheme, is reported for data rates exceeding 4 Gbps at distances up to 5 m.**

Keywords—micro-LED, OFDM, Optical Communications, Ultraviolet Communications.

I. INTRODUCTION

Optical wireless communications (OWC) using "Deep Ultraviolet" (DUV) light (UV-C, 100-280 nm and UV-B, 280-315 nm) has attracted increasing interest due to the unique properties of radiation in these bands, and continuing developments in both sources and detectors. At ground level there is negligible background UV-B or UV-C light, due to the Earth's upper atmosphere absorbing most DUV solar radiation and a lack of man-made sources. As such, DUV OWC can take advantage of a near noise-free channel, unlike equivalent visible and infrared communications. Furthermore, due to strong scattering of DUV light by the atmosphere, non-line-of-sight (NLOS) communications can be implemented, allowing optical tracking and alignment constraints to be relaxed or even enabling wireless communication around obstructions such as buildings.

To advance the development of DUV OWC systems, robust transmitters with small size and weight, low power consumption and low cost are desirable. Conventional DUV optical sources such as mercury flash tubes are relatively bulky, fragile and power-hungry, and are further held back by low modulation bandwidths of typically less than 40 kHz. AlInGaN light-emitting diodes (LEDs) emitting at DUV wavelengths have continued to improve in terms of efficiency and output power and now offer a compelling alternative to the aforementioned sources [1]. Furthermore, micro-pixilation of LEDs, i.e. reducing their active areas to dimensions ≤ 100 µm, has been shown to allow their modulation bandwidths to be increased from a few tens of MHz for a conventional LED, to many hundreds of MHz for a micro-LED [2].

In this work we report on recent work using a micro-LED array emitting at 285 nm. Utilising the high micro-LED bandwidth of up to 600 MHz and an Orthogonal Frequency Division Multiplexing (OFDM) encoding scheme, optical wireless data rates >4 Gbps at distances up to 5 m are demonstrated.

II. EXPERIMENTAL CONFIGURATION

A. Micro-LED fabrication and characterization

The micro-LEDs were fabricated from a commercial AlGaN-based wafer grown on a 2" *c*-plane sapphire substrate using standard microfabrication techniques. A detailed description of the wafer and the fabrication process is given in our previous publication [3]. The micro-LED array used here consists of 8 individually-addressable pixels, each of a trapezoidal shape and an approximate active area of 1369 μm^2. The pixels were arranged in a circle with an outer diameter of 200 µm. Each pixel has an independent anode and a shared common cathode.

The optical output power was measured by placing the micro-LEDs in proximity to a calibrated power meter sensor, the maximum measured output power per pixel was approximately 0.25 mW. The current-voltage relationship was measured using a Source-Measure Unit. The relationships between output power, current and voltage from a representative pixel is shown in Figure 1(a). The normalized electroluminescence spectrum taken at 20 mA is shown in Figure 1(b), showing a peak wavelength and full width at half maximum of 285 and 12 nm, respectively.

The frequency response versus current was measured using a Network Analyser (PicoVNA 106) and a 1 GHz bandwidth avalanche photodiode (APD, Hamamatsu C5658). From this, the Electrical-to-Electrical (E-E) and Electrical-to-Optical -3dB bandwidths were estimated to be 300 and 600 MHz, respectively.

This work was supported by Engineering and Physical Sciences Research Council (EPSRC) under Grant EP/M01326X/1 (QuantIC). Supporting data can be downloaded at https://doi.org/10.15129/47a3e0b8-06e3-4cb4-af4e-c79fdad03f55

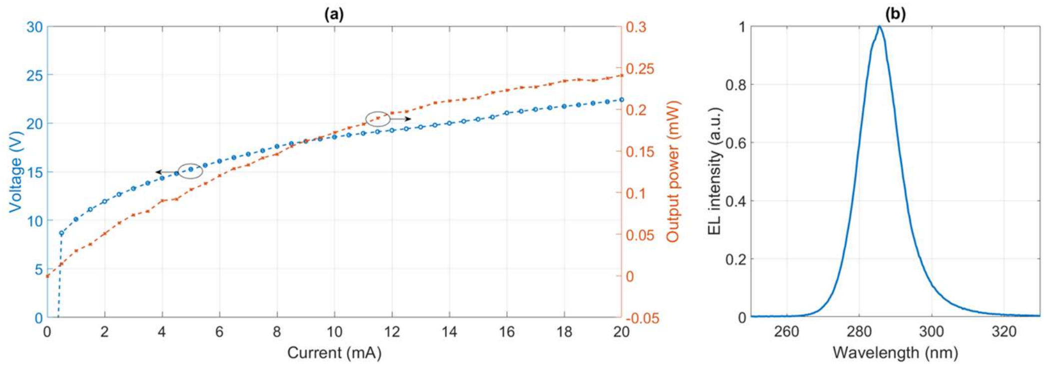

Figure 1(a) L-I-V relationships and (b) normalized EL spectrum taken at 20mA, for a single micro-LED pixel.

B. *OFDM data transmission*

A detailed description of the OFDM modulation and demodulation process is provided in our previous publication [3], and is summarised as follows. An individual micro-LED was modulated using an OFDM signal provided by an Arbitrary Waveform Generator, combined with a DC offset via a bias-tee. The emission from the LED was collected and imaged onto a 1 GHz bandwidth avalanche photodiode (Hamamatsu C5658) using UV-transmissive lenses (Thor Labs LA4052-UV). The distance from the LED transmitter to the receiver was varied from 0.3 to 5 m, with the receiver being aligned to maximise the received signal. The OFDM data rate was varied and the Bit-Error Rate (BER) was measured at the corresponding distance.

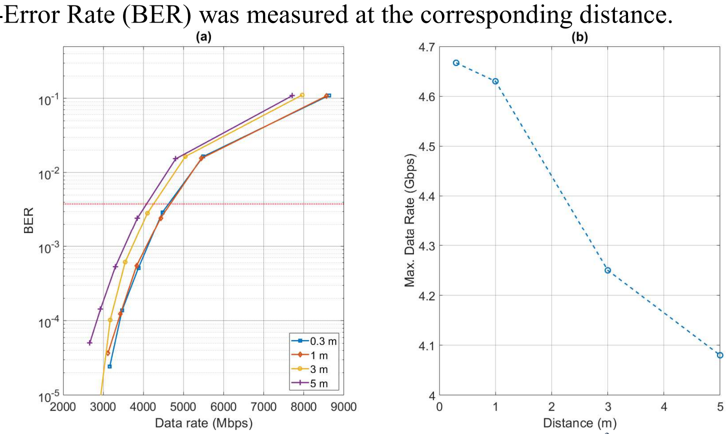

Figure 2(a) - BER versus data rate for each transmission distance. The FEC threshold of 3.8×10^{-3} is represented by the horizontal red line, and (b) the maximum error-free data rate versus distance.

The BER versus data rate for each distance is shown in Figure 2(a). Data rates with a corresponding BER below the horizontal red line, which represents the Forward-Error Correction (FEC) threshold at 3.8×10^{-3}, can be considered "error-free" once FEC with a 7% overhead is applied. The corresponding maximum error-free data rate at each distance is shown in Figure 2(b). A maximum data rate at 0.3 m of 4.667 Gbps (before FEC) was achieved, greatly exceeding our previous demonstration of 1.1 Gbps and, to the best of our knowledge, representing the highest reported data rate for a UV-C LED. Furthermore, > 4 Gbps was maintained even at a distance of 5 m, indicating that this UV-C link can be extended to further distances. Based on our previous work using visible micro-LEDs, transmission distances of tens of meters may be possible, and work to investigate distances >5 m is ongoing [4].

III. CONCLUSIONS

Optical wireless data transmission at distances up to 5 m, using a UV-C-emitting micro-LED pixel and OFDM modulation, has been demonstrated at > 4 Gbps. The corresponding data rate at 0.3 m of 4.667 Gbps represents the highest rate yet reported for a UV-C-emitting LED. Work is currently ongoing to further increase these transmission distances, and to improve the performance of the UV-C micro-LEDs.

REFERENCES

[1] H. Amano *et al.*, "The 2020 UV emitter roadmap," *J. Phys. D. Appl. Phys.*, vol. 53, no. 50, 2020, doi: 10.1088/1361-6463/aba64c.

[2] R. X. G. Ferreira *et al.*, "High Bandwidth GaN-Based Micro-LEDs for Multi-Gbps Visible Light Communications," *IEEE Photonics Technol. Lett.*, vol. 28, no. 19, pp. 2023–2026, Oct. 2016, doi: 10.1109/LPT.2016.2581318.

[3] X. He *et al.*, "1 Gbps free-space deep-ultraviolet communications based on III-nitride micro-LEDs emitting at 262 nm," *Photonics Res.*, vol. 7, no. 7, p. B41, Jul. 2019, doi: 10.1364/PRJ.7.000B41.

[4] E. Xie *et al.*, "Over 10 Gbps VLC for Long-Distance Applications Using a GaN-Based Series-Biased Micro-LED Array," *IEEE Photonics Technol. Lett.*, vol. 32, no. 9, pp. 499–502, 2020, doi: 10.1109/LPT.2020.2981827.