Size-Dependent Characterization of Deep UV Micro-Light-Emitting Diodes

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***Abstract*—Deep UV Micro LEDs (DUV-µLEDs) are attractive for optical wireless communications, however not much is known about their size-dependent characteristics. Here we study spectra, power output and bandwidth as a function of device size and achieve a bandwidth of 570MHz with a 20µm diameter device.**

Keywords— Deep UV, UV communications, Size dependence, Optical wireless communications (OWC), characterisation, External quantum efficiency (EQE).

I. Introduction

In recent years, AlGaN-based LEDs which emit at ultraviolet (UV) wavelengths have begun to mature and have had a notable impact on several fields such as medicine, water purification, sensing and optical communications [1]. The benefit of using deep UV (DUV, UVB 280-315 nm, UVC 100-280 nm) for optical communications is that the ozone layer strongly absorbs most of this region of the electromagnetic spectrum; as a result, terrestrial DUV communications can operate in a low noise environment and can also be used in non-line of sight (NLOS) communications due to the substantial scattering of DUV light in air. Our previous work has also demonstrated that it is possible to achieve Gb/s data rates using a DUV micro-LED [2]. µLEDs are LEDs with dimensions <100 µm. Their characteristics, such as output power, emission spectra and modulation bandwidth, vary with LED dimensions as well as operating conditions (e.g. bias) and determine how effectively these devices perform in applications such as optical communications. These characteristics have been extensively studied in visible-emitting µLEDs [3]. However, these features have not hitherto been explored in detail for DUV devices, to our knowledge. Here we present a study of the characteristics of DUV-emitting micro-LEDs ranging in diameter from 20 to 200 µm with peak emission around 283 nm. The optical output power and -3 dB modulation bandwidth of the pixels were measured, these characteristics being of particular importance for optical communications. As might be intuitively expected, the largest µLEDs exhibited the highest continuous-wave output power, up to 1.4 mW for a 200 µm diameter pixel compared to 0.13 mW for one of 20 µm. Bandwidth measurements also demonstrate a size dependence with the smallest devices having higher modulation bandwidths of up to 570 MHz. The size-dependent bandwidth behaviour can be attributed to the higher operating current density in the smaller devices and, as a result, shorter differential carrier lifetimes [3]. The highest External Quantum Efficiency (EQE) occurs at a current density of 14 A/cm^2 for devices of 80 µm or larger however for the smaller device the highest EQE is found at larger current densities eg. 95A/ cm^2 for the 20µm device. Other size-dependent characteristics, such as the emission wavelength as a function of bias current will also be presented, and the implications of these characteristics in the context of optical communications, will be discussed.

II. Experimental Method

The data used in this paper was captured in several experiments. The L-I-V data was recorded using a Thorlabs PM100A power meter, and the LED arrays were placed on top of the Thorlabs S120VC power meter head. The µLEDs were powered with a Yokogawa GS610 Source Measure Unit. A common way of determining the optical power is to use an integrating sphere as this gives an exact figure of the power output, however for communications links it is appropriate to concentrate on measuring the forward-directed output power. Using the power recorded, the relative external quantum efficiency (EQE) was also calculated [4], using the following equation

$$\mathrm{EQE}=\frac{p/hv}{I/e} \quad (1)$$

Where P is the optical power recorded by the detector, h is Planck's constant, v is the frequency of the photon, I is the current input into the device and e is the electron charge. To record the power, two techniques were used, one using a power meter and the other being using a Thorlabs SPCM20A/M single-photon avalanche detector (SPAD), with the number of counts being treated as the power variable in the equation 1. The EQE is relative due to the reasons mentioned above regarding the power collection. The spectra were measured using an Avantes Avaspec-20482 spectrometer with an Ocean Optics QP600-2-SR-BX fibre optic. The bandwidth measurements were carried out using a Network Analyser, and a Hamamatsu C5668 8867 avalanche photodiode (APD) with a bandwidth range of 100 kHz to 1GHz as the detector.

III.RESULTS

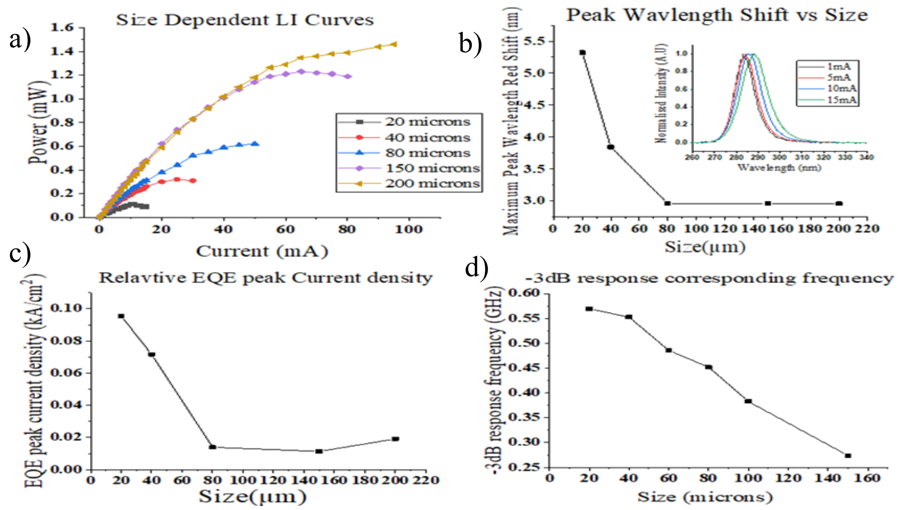

Fig1. a) The optical output power of the devices as a function of current for different pixel sizes. b) The maximum redshift in peak wavelength with DC bias current, as a function of pixel diameter with (inset) full spectra of the 20 microns device at several currents. c) The current density (J) at which the EQE peaks, as a function of pixel diameter. d) The frequency at which a -3db response occurs for various pixel sizes, all taken at 10 mA.

Fig. 1a) demonstrates a size dependent L-I characteristic, where it is evident that the power output of the larger devices is notably higher In Fig.1b) the spectra of the LEDs show some change with increased current with all devices showing a shift toward longer wavelengths as the current increases. This spectral shift can be explained by thermal and band filling effects. However, for communications purposes, these devices are relatively spectrally stable. In Fig.1c) there is a definite size dependence in the peak position of the relative EQE recorded using the SPAD, and it is noted that in the smaller device the peak appearing at higher current densities may be due to increased non-radiative recombination at the etched sidewalls [5]. Fig.1d) shows a clear size dependence in the bandwidth of the device with the smaller devices having the higher bandwidths. The bandwidth of 570 MHz achieved for the 20 microns devices is, to our knowledge, the highest µLED bandwidth recorded in the deep UV.

IV.CONCLUSION

We report initial size-dependent studies on DUV µLEDs demonstrating bandwidths as high as 570 MHz for 20µm diameter devices. These results will inform the development of NLOS and line of sight (LOS) communications systems using a range of modulation and multiplexing techniques.

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