GaN Based Cyan Light-Emitting Diodes with GHz Bandwidth

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Abstract: Carrier lifetime limited bandwidth in proposed III-Nitride LED is relaxed with further improvement in its internal quantum efficiency. Moderate output power (1.7mW) with record-high 3-dB electrical-to-optical bandwidth (1GHz) among all reported visible LEDs is demonstrated.

OCIS codes: (230.3670) Light-emitting diodes, (060.2330) Fiber optics communications

I. Introduction

Visible light communication (VLC) are considered to be one of the candidates to meet the demand of future ultra-broadband indoor wireless access networks [1,2]. By using the numerous white-light light-emitting diode (LED) lamps installed on the ceiling of buildings as transmitters, the indoor optical wireless acttocell network might be realized [1,2]. By installing an optical filter in the receiver-end of VLC system to exclude the slow fluorescent lifetime of phosphor [1,2], which is coated on the LEDs lamps, the direct modulation speed of visible LED inside lamp would become one of the major bandwidth limiting factors in VLC system. On the other hand, high-speed visible LEDs at red [3] or blue/cyan [4-6] wavelength regime also play vital role in in polymethylmethacrylate (PMMA) based plastic optical fiber (POF) communication system. To pursue the high-speed visible LEDs with GHz bandwidth under lower driving current (density) than that of laser diode (LD) is thus the key issue in their development. For most cases, the modulation speed of LEDs is limited by the spontaneous recombination time in the active layer and their reported maximum 3-dB electrical-to-optical (E-O) bandwidth is usually less than 500 MHz [7], which corresponds to around 320 ps carrier recombination time. In order to further shorten such time constant, by performing the heavily p+ doping ($>1 \times 10^{19}cm^{-3}$) in the active layer of GaAs or InP based LEDs at infrared wavelength regime, > 1 GHz E-O bandwidth has been demonstrated [7]. However, the internal quantum efficiency (output power) would be seriously sacrificed due to the enhancement in non-radiative recombination process induced by p-type dopant (defects) [7]. In this work, a novel design in the active layers of III-Nitride based cyan LED has been demonstrated to simultaneously shorten the response time and enhance its internal quantum efficiency. The achieved 3-dB E-O bandwidth (1 GHz) of such device should be record among all the reported visible LEDs [3-6] and even faster than that of reported GaN based green laser diode (1 vs. 0.4 GHz) [8].

II. Device Structure

In order to enhance the external quantum efficiency and sustain the output optical power of a miniaturized size LED for POF communication, our device structure was grown on the patterned sapphire (PS) substrate [4]. The detail thicknesses of the four-period $In_xGa_{1-x}N$/GaN cyan multiple quantum well (MQW) region, bottom n-type GaN layer and topmost p-type GaN layer of both device structures were specified in Figure 1. Compared with that of traditional LED, the GaN barrier layer thickness in the novel device structure has been greatly narrowed down from 17 to 5 nm. By thinning down the barrier layer, the total active layer thickness has been greatly reduced to 37 nm, this would lead to the increase in the injected carrier density, radiative recombination rate, and modulation speed of device. Furthermore, such thin barrier layer should uniform the hole distribution among different wells and enhance the total output power. Figure 2 (a) shows the top-view of the demonstrated LED chip and the zoom in picture of the periodical structures on PS substrate. Each LED has an active diameter of around 50 μm. During device fabrication, each LED is etched down to the insulating sapphire substrate to minimize the parasitic capacitance of device. For details of the fabrication processes please refer to our previous work [4].

III. Measurement Result:

Figure 2 (b) shows the measured bias dependent electroluminescence (EL) spectra of our device. The measured central wavelength at around 480 nm, which is around the loss minimum window of standard PMMA POF (<4dB/50m) [4]. Figure 3 (a) shows the total free-space light output power (L) and bias voltage (V), as measured by the integrating sphere, versus the bias current (I). The curves in this Figure with solid and open symbols, represent the measurement results under room temperature (RT) and 110°C operations, respectively. As can be seen, the degradation in maximum output power (~19%) under 110°C operation is comparable with that of our reported cyan LED with a thicker barrier layer (17 vs. 5 nm) and at the same central wavelength (~480 nm) [4]. This result implies that our demonstrated thin barrier design would not significantly increase the probability of carrier escaping under high junction temperature. Figure 3 (b) and (c) shows the measured bias dependent electrical-to-optical (E-O) frequency responses of device A under RT and 110°C operation, respectively. Under RT operation and when the bias current reaches 90 mA, the maximum 3-dB E-O bandwidth of device A can be as high as nearly 1 GHz. Such bandwidth performance is over two

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times faster than that of reported high-speed red RCLED (0.35 GHz [3]) and GaN based green LEDs/laser diodes (LDs) (~0.5 GHz [5,8]). The achieved speed performance should be the highest ever reported for any visible LEDs [1-7]. Furthermore, as can be seen in Figure 3, both the degradation of maximum bandwidth (1 to 0.7 GHz) and power (1.7 to 1.4 mW) is not serious in demonstrated device when the temperature rises up to 110℃. Such result is quite different with the behavior of high-speed red RCLED [3], which shows a bandwidth enhancement (110 to 130 MHz) with a (~ 40%) serious degradation in output power when the temperature increases from 10 to 70℃ [3]. This indicates the larger bandgap difference in the active layer of our III-nitride LED can really suppress the carrier leakage and has superior high-temperature performance than that of GaAs based high-speed red LED [3].

IV.Summary:

By narrowing down both the thicknesses of GaN barrier layer and total active region of III-nitride based cyan LEDs, strong enhancement in modulation speed is experimentally verified. With such device structure, we successfully demonstrated cyan LED with record-high 3-dB E-O bandwidth (1 GHz) among all the reported high-speed visible LEDs, which usually have an E-O bandwidth less than 0.5 GHz.

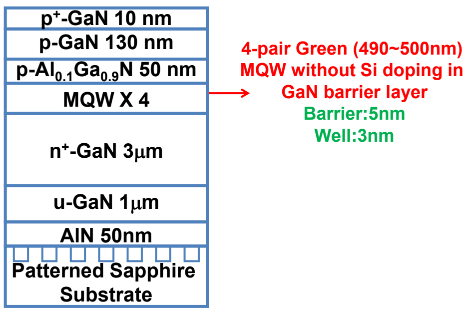

Figure 1. The conceptual cross-sectional view of epitaxial layer structure of demonstrated device. Such Figure was not drawn according to scale for clearness

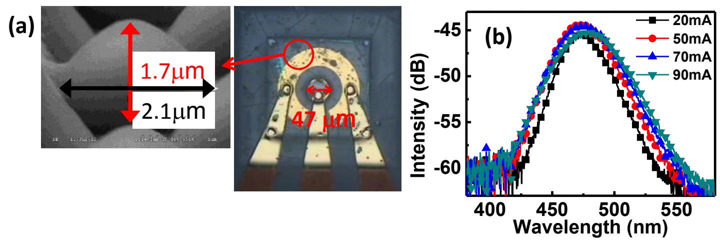

Figure 2. (a) A top-view of the demonstrated LED chip and the zoom in picture of light-emitting aperture and PS substrate. (b) Measured EL spectra of demonstrated LED.

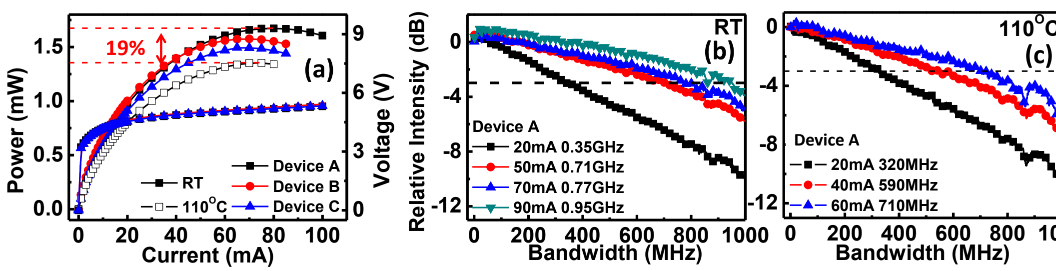

Figure 3. (a) Measured L-I-V curves under RT (solid symbols) and 110℃ (open symbols) operations of demonstrated LEDs. Measured bias dependent E-O frequency responses of device A under RT (b) and 110℃ operations, respectively.

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