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GaN-Based Green Resonant Cavity Light Emitting Diodes

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1. Introduction

Gallium nitride series materials have become the dominant semiconductor systems used to achieve ultraviolet, blue, green and white light emission. Recently, resonant cavity light-emitting diodes (RCLEDs) have shown considerable potential as light source for plastic optical fiber (POF)-base local area network [1, 2]. The RCLEDs present several advantages as compared with conventional planar LEDs, such as a narrow spectrum linewidth, a superior directionality of the emitted light, and high light extraction efficiency. In additional, the POF transmission windows with absorption minimum exist at 510 and 570 nm [3-5]. These wavelengths are easy to obtain using III-V nitride semiconductors suitable for new generation of POF whose emission properties are less temperature dependent than that of the commercial light source of the AlGaInP materials. In this work, we present the results on the electroluminescence (EL) characteristic of GaN-based RCLED was fabricated on Si by laser lift-off and wafer bonding techniques.

2. Experimental

Fig. 1 (a) shows a schematic diagram and (b) a plane view image of scanning electron microscopy of the green RCLED (λ_p=525 nm) structure. The LED epi-wafer was bonded to a glass carrier using an adhesive, subjected to the laser lift-off process. The lift-off process was performed using a UV laser. The RCLED structure composed of an InGaN/GaN multiple-quantum-well active layer has been grown by metal organic chemical vapor deposition; between the top 5-pairs dielectric TiO_2/SiO_2 distributed Bragg reflectors (DBR) and bottom Ag metal mirror layer. The thicknesses of TiO_2 and SiO_2 film were measured by simulation via an in-situ optical reflectance trace and quartz monitor. The p- and n-contacts were deposited Ni/Au and Ti/Al by e-beam evaporation, respectively. A patterned SiO_2 layer was deposited as a light emission confinement layer to define the aperture region. The RCLED sample used in this research had a chip size of 356 × 356 μm^2.

3. Results and discussion

Fig. 2 presents forward *I-V* characteristics of the RCLED on Si and the RCLED without top TiO_2/SiO_2 DBR layers. The corresponding forward turn-on voltage at 20 mA dc current injection were determined about 4.45 and 4.55 V, respectively. The result indicated that the RCLED has similar *I-V* characteristics as compared with that of the conventional LED. Fig. 3 shows the reflectance spectra of the top mirror of 5-pairs TiO_2/SiO_2 DBR layers simulated and measurement (normal incidence by the n&k analyzer). The reflectance spectrum of bottom Ag metal mirror is also depicted for comparison. As can be seen, a peak reflectivity of 85% was obtained to very close the target wavelength (525 nm), with a lager stopband of 100 nm. However, the measured main peak-wavelength shows in good agreement with the calculated one. Furthermore, the reflectance of the top 5-pairs TiO_2/SiO_2 DBR was designed lower than that of the bottom Ag metal mirror (99%) at 525 nm which for measured the EL spectrum from the top of RCLED device.

Fig. 4 shows the room temperature EL spectrum from a nonencapsulated RCLED at operation current density 0.6 KA/cm^2 which the emission peak was located at 525 nm. The emission light was observed in the direction from the top of the device. It can be seen clearly that the emission spectrum from RCLED was periodically modulated with several narrow resonant wavelength peaks. However, the modulation is the result of Fabry-Perot oscillation. The electroluminescence linewidth of RCLED is 35 nm, thus all of the quantum well emission is inside of DBR stopband. Furthermore the modes spectrum for this resonant cavity structure are well defined and exhibit a linewidth of approximately 5.5 nm for the dominant mode at λ=525 nm, which give a quality factor for the structure of approximately 100.

Fig. 5 shows the room temperature output power of these RCLEDs as a function of injection current density. It can be seen clearly that the EL intensity of RCLED is higher by a factor of 1.5 as compared to the RCLED without top TiO_2/SiO_2 DBR layers under 0.6 KA/cm^2 inject current density. The enhancement in EL intensity is mainly attributed to the more emission directionality by the resonant cavity effect. Fig. 6 shows the wavelength of EL emission taken form these LEDs as a function of injection current density. The EL emission peak wavelength of a RCLED sample without top TiO_2/SiO_2 DBR layers was exhibited a large blue shift from 517 to 508 nm with increasing the injection current density. The strong EL emission peak blue shift is due to the localization effect or filling the band-tail states. The localization effect could be attribute to the In composition fluctuation in the InGaN well. Instead, a more stability of the EL emission peak was observed in the full RCLED structure. This result indicated that the stability of EL emission wavelength was caused by resonant micro-cavity effect.

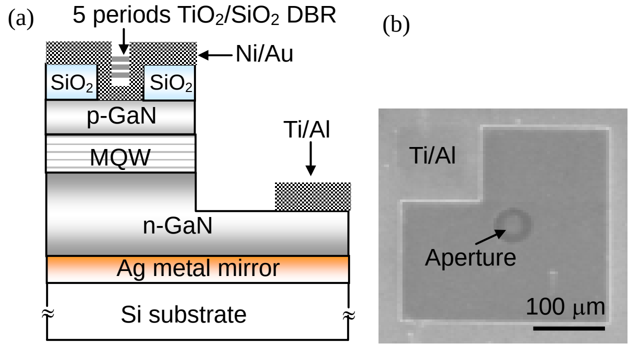

Fig. 1 (a) Schematic diagram and (b) top view SEM micrograph of the GaN RCLED on Si.

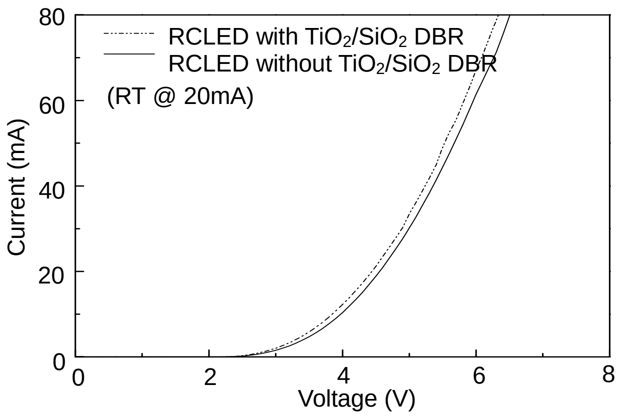

Fig. 2 Forward *I-V* characteristics of the RCLEDs with and without top TiO_2/SiO_2 DBR layers.

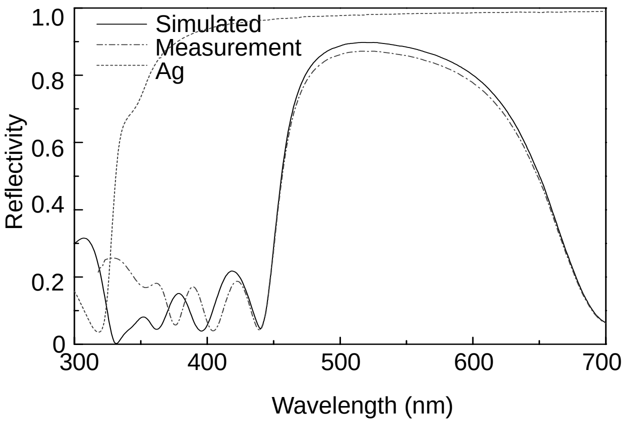

Fig. 3 Simulated and measured reflectivity spectra of 3.5-pairs TiO_2/SiO_2 DBR. The bottom mirror of Ag metal layer is also presented.

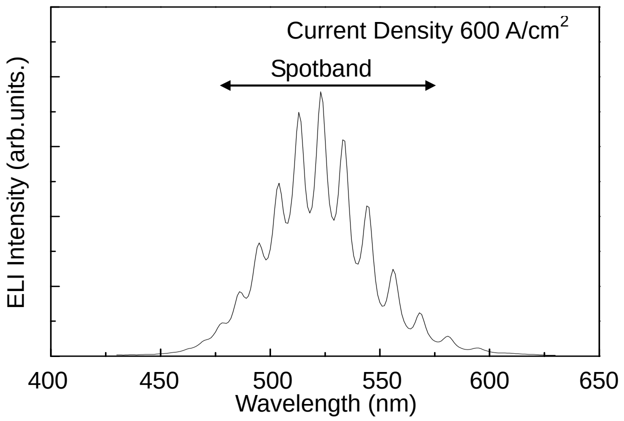

Fig. 4 Electroluminescence spectrum of the GaN RCLED on Si.

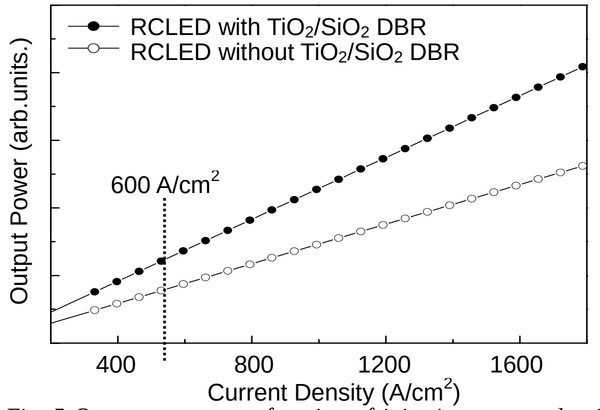

Fig. 5 Output power as a function of injection current density of green RCLEDs with and without top TiO_2/SiO_2 DBR.

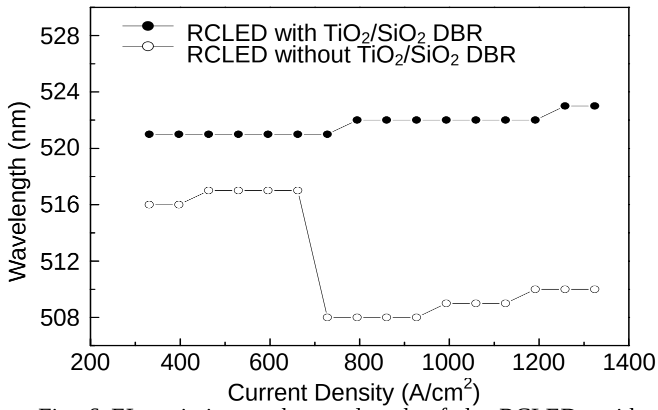

Fig. 6 EL emission peak wavelength of the RCLEDs with and without top TiO_2/SiO_2 DBR layers, measured at various forward current injections.

Conclusion

We demonstrated the characteristics of the InGaN-based RCLEDs fabrication on silicon substrate. The light output intensity at 0.6 KA/cm^2 of the RCLEDs was enhanced by a factor of 1.5 due to microcavity effect. Meanwhile, the low thermally induce wavelength red shift was also observed from our sample. The Q factor for this resonant cavity structure was estimated to be approximately 100. As a result, RCLED are not only suitable for POF communication system, but could be replacement the standard LEDs in many applications.

Acknowledgements

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