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Fabrication and characteristics of GaN-based Microcavity LEDs with high reflectivity AlN/GaN DBRs

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`Abstract

GaN-based micro cavity light emitting diodes (MCLEDs) which composed of 25 pairs of in-situ epitaxially grown GaN/AlN Distributed Bragg Reflector (DBR) with high reflectivity (94%), and 6 pairs ex-situ deposited SiO2/TiO2 dielectric mirrors (97.5%) was reported. The electroluminescence peak of this structure well matched with the dip of the reflectance within the stop band and the fabricated device showed excellent optical performances including the narrowed emission width (6.7 nm), and more stable emission peak wavelength (redshift free) as varying injection current density and operating temperature than the regular LED.

1. Introduction

GaN-based light emitters, both light emitting diodes (LEDs) and laser diodes (LDs), are now used widely in many applications such as illumination, exterior automotive lighting, traffic signals, back light of liquid crystal display and high density data storage. Recently, many efforts were devoted to GaN-based vertical cavity surface emitting lasers (VCSELs) and VCSEL-like micro cavity light emitting diodes (MCLEDs) [1-5]. Although optically pumped GaN-based VCSELs have achieved, there are still some issues to form electrical pumped GaN-based VCSELs, which require a low loss resonant cavity composed of high reflectivity and large stop band width mirror. In contrast, some GaN-based MCLEDs with an in-situ epitaxially grown nitride-based DBRs and dielectric DBRs as the bottom and upper mirror of the cavity were reported. Nurmikko et al. used 60 pairs of GaN/Al0.25Ga0.75N DBR to form the bottom mirror with 99% reflectivity, Arakawa et al. increased the Al content of the DBRs to low down the pairs of DBRs and employed 26 pairs of GaN/Al0.40Ga0.60N DBR to form bottom mirror with 91% reflectance. Recently, we have achieved high-reflectivity AlN/GaN DBR structure with a peak reflectance of 94% and a stop band about 18nm with relatively smooth surface morphology. Here, we show the fabrication of GaN-based MCLED with hybrid structure, composed of high reflectivity, crack-free, wide stopband width in-situ grown AlN/GaN bottom DBRs and ex-situ deposited SiO_2/TiO_2 top DBRs, could be used as basis for the GaN-based VCSEL. In addition, the fabricated MCLED showed relative stable EL than the conventional LED while varying injection current and operating temperature.

2. Experiments

The nitride heterostructure was grown by metal-organic chemical vapor deposition (MOCVD) system (EMCORE D-75) on the polished optical-grade C-face (0001) 2” diameter sapphire substrate. The 30nm thick GaN buffer layer was first grown on the sapphire substrate, then 1 μm-thick undoped GaN was grown on it. After that, the 25 pairs $\lambda/4$ AlN/GaN stack and the 3λ InGaN/GaN micro cavity structure which was consisted of the GaN:Si n-type layer, ten pairs of InGaN/GaN MQW and the GaN:Mg p-type layer were deposited. The reflectance of 25 pairs AlN/GaN DBR and the PL spectrum of the InGaN/GaN MQWs MCLE were measured as shown in Fig. 1. The reflectance of 25 pairs AlN/GaN DBR centered at 452nm with 95% high reflectivity and 20nm stop band width. The PL spectrum was located at 458.5nm with 10.5nm FWHM and well matched to the high reflectance area. The MCLE was fabricated by six process steps. First, mesa etching was performed in an ICP dry etching system and then the SiNx layer was grown by PECVD as the current confinement layer. After that, the thin metal film Ni/Au, Ti/Al/Ni/Au and Ni/Au metal deposited by E-Gun Evaporation System were used as the transparent contact layer, n-type and p-type contact metal, respectively. At last, the MCLE was completed after the 5 pairs SiO2 /TiO2 DBR with high reflectivity (as shown in Fig. 1) were deposited. the EL emission spectrum of the MCLE was measured by Alpha-SNOM system and the L-I-V curves were measured by the probe station and drove by Keithley 238 CW Current Source.

3. Results and discussion

The electroluminescence (EL) of the fabricated MCLED with 30μm diameter at 20mA injection current is shown in figure3. The emission spectrum measurement was performed by collecting the EL into a 100μm diameter core fiber placed atop the surface emission device. The emission peak wavelength of the MCLED was located at 458.5nm with a narrow wavelength width of 6.7nm. The wavelength width narrowing was caused by the micro resonant cavity effect. Note that the wavelength width of the regular GaN-based MQW blue LED (with $300\times300\mu m^2$ emission area) was 18nm. The current-voltage (I-V) characteristic is shown in figure 4. The forward voltage and resistance of the MCLED are 3.5V and 530Ω. Figure5 shows emission peak wavelength of the MCLED and the conventional LED as function of operating current density from $0.14KA/cm^2$ to $4.24KA/cm^2$ at 25^oC temperature. To the LED, a redshift about 8nm was observed with increasing current density due to heat effect. Compared to the regular LED, the emission peak wavelength of the MCLED was free of the redshift at high current density injection. In other words, the emission peak wavelength of the MCLED dominated by resonant cavity mode is well stable than conventional LED as varying injection current density. Figure6 shows emission peak wavelength of the MCLED and the conventional LED as function of operating temperature at 1KA/cm2 injection current density. The emission peak wavelength of the LED showed a clear redshift of about 2nm from temperature of 20°C to temperature of 70°C. While, the emission peak wavelength of the MCLED showed a relative stable. The redshift of the emission peak wavelength of the LED is due to the bandgap narrowing caused by increasing temperature. These results indicated the MCLED do have a stable cavity mode and perform better than the regular LED on emission peak wavelength as arising operating temperature.

4. Conclusions

In summary, 3λ GaN-based MCLED structures were grown by MOCVD. The GaN-based MCLED composed of high reflectivity (94%) AlN/GaN bottom DBRs and SiO_2/TiO_2 top DBRs have been fabricated. The emission peak wavelength of the MCLED was well matched with the high reflectance area of the top and bottom DBRs, and the emission wavelength width was narrower (about 6.7nm) than the regular LED (about 18nm), due to the resonant cavity effect. The MCLED also showed stable emission peak wavelength, while varying the injection current density and operating temperature. It indicated that a good resonant cavity was fabricated. Such MCLED could be the basis for GaN-based VCSELs.

5. References

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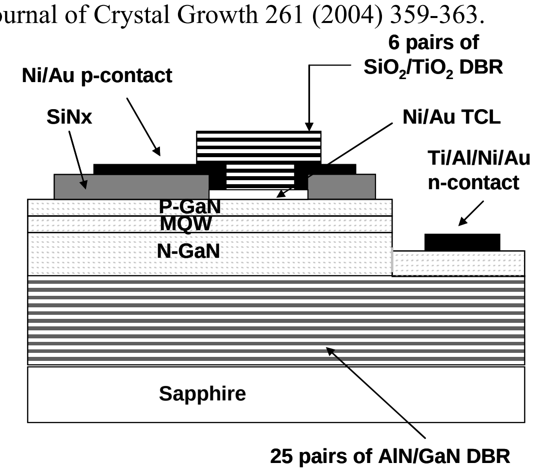

FIG1. Schematic of the GaN-based MCLED.

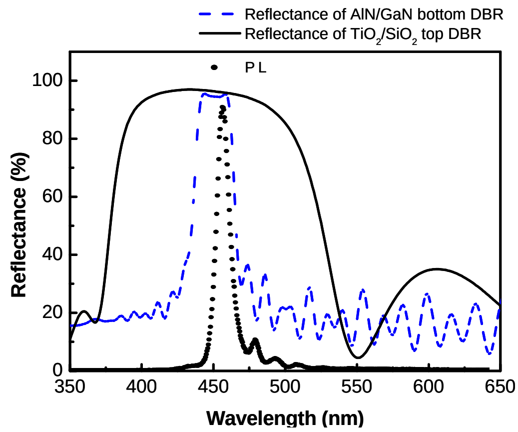

FIG2. Reflectance of 25 pairs of AlN/GaN bottom DBR and 6 pairs of TiO_2/SiO_2 top DBR. The PL spectrum was also shown in the figure.

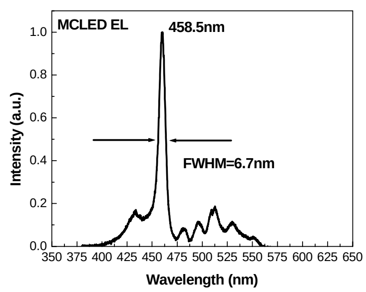

FIG3. Room temperature EL spectrum of the GaN-based MCLED with narrow FWHM of 6.7nm.

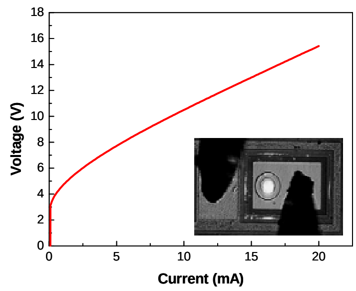

FIG4. Room temperature current-voltage characteristic of the GaN-based MCLED. The inset shows the top view photograph of the MCLED.

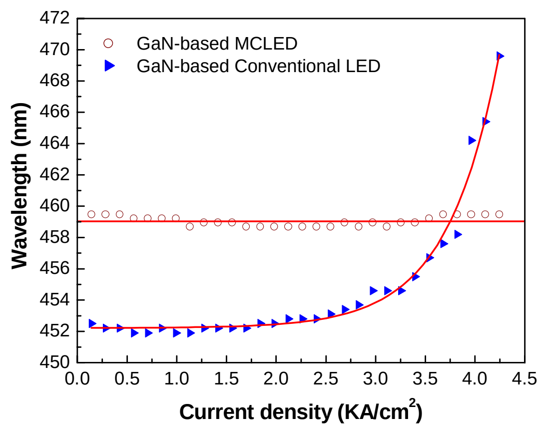

FIG5. EL of the GaN-based MCLED and the conventional LED as varying injection current density at 25°C.

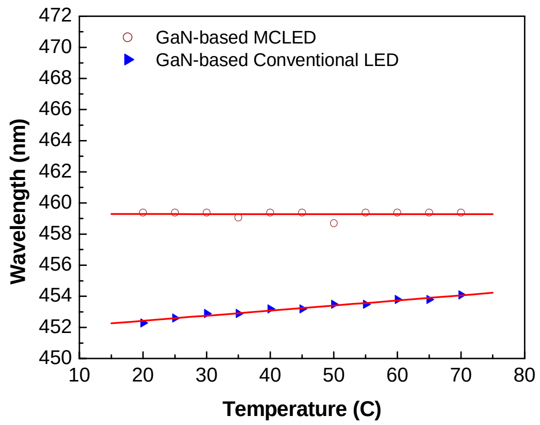

FIG6. EL of the GaN-based MCLED and the conventional LED as varying operating temperature at 1KA/cm2 injection current density.