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High Efficiency Blue Light Emitting Diodes with Maskless Defects Passivation layer

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1. Introduction

III-V nitride semiconductors are widely fabricated as short wavelength optoelectronic devices like light emitting diode and laser diode [1-3]. The large lattice mismatch between sapphire substrate and GaN epitaxial layers result in the as-grown GaN epitaxial layers with a high density of threading dislocations (TDs), typically 10^8 - 10^{10} cm^{-2}. The high dislocation density led to the poor performance of LED because the TDs act non-radiative centers and reduce the radiative recombination efficiency. The improvement of crystal quality and reduction of defect density have some methods include epitaxial lateral overgrowth (ELOG) [4], patterned sapphire substrates [5]. But these methods can not overall suppress threading dislocations but only in the pattern regions. Moreover, traditional ELOG process requires photolithography process, with more complicated steps. In his paper, we demonstrated the blue LED with maskless SiO_2 defects-passivated (DP) layers by wet etching and ELOG regrowth process. The light output power of mask-less DP-LED was enhanced by 44.8% at 20 mA compared with the commercial LED (C-LED), and the threading dislocation density was down to ~1×10^7 cm^{-2}.

2. Experiments

The DP-LED structure was grown by low pressure metal-organic chemical vapor deposition (LP-MOCVD). First, we grew 2 μm GaN on sapphire as a template, and the GaN epilayer was etched in molten KOH for 10 min at high temperature (approximate 250 ~ 300 degree). In order to surpass the activation energy of GaN defects, higher thermal kinetic energy is required, and the applicable temperature of wet etching was dependent on the quality of GaN layer [6]. After several minutes of etching by KOH, defects on the surface of GaN epilayer were etched into pits, and the etching depth was approximately 1μm. Afterward the 0.5 μm thickness SiO_2 film was deposited on the etched surface by plasma enhanced chemical vapor deposition (PECVD). The SiO_2 film was used as DP layer. This passivation layer can widely suppress the etched defects to affect the quality of subsequent epilayer. And then we remove the sacrificial SiO_2 film on top of the GaN by chemical mechanical polishing (CMP) to expose the GaN top surface which acts as the regrowth seed layer for next step epitaxial lateral overgrowth. Finally, a 2 μm-thick-GaN Si-doped n-type GaN layer, an 10 period InGaN/GaN MQWs active region, a 30-nm-thick Mg-doped p-typed AlGaN cladding layer, a 0.2-μm-thick Mg-doped GaN contact layer were grown on DP template. Indium–tin oxide (ITO) and Ni/Au were subsequently evaporated onto the sample surface to serve electrode. The dimension of the LEDs is 300×300 μm^2.

3. Results and Discussion

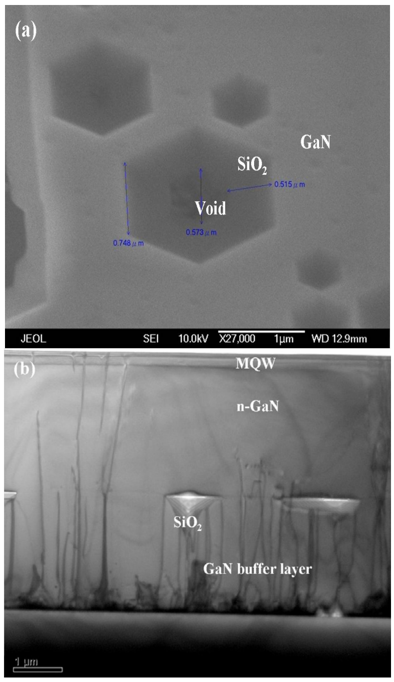

Fig.1. (a) SEM image of the defects-passivated GaN template after CMP process. (b) TEM image of the entire epistructure.

Figure (a) shows the scanning electron microscope

(SEM) image of the 2 μm GaN template with SiO2 DP layers after CMP process. The defects on the GaN surface etched by KOH appear to be hexagonal pits, and the micro pits density was about 1×10^8 cm^{-2}. After the CMP process, the SiO_2 film remains in the etched pits. These SiO_2-passivated regions can effectively prevent the threading dislocation passing through the MQWs to the top surface. [4]

To further investigate the dislocation propagation, we also measured the cross-section transmission electron microscopy (TEM) image of DP-LED smaple as shown in Fig 1(b). It is obvious that the dislocation density was about 10^9 cm^{-2} beneath the SiO_2 passivation layer. Due to the SiO_2 passivation, the dislocation density was down to 10^7 cm^{-2} around the MQWs regions. Note that not every pit corresponding to one dislocation but to a bunch of dislocations, this might be because of several smaller pits assembling into lager one. The etching mechanism of GaN in high temperature molten KOH was published elsewhere [7]. The high temperature molten KOH can only etch the screw type of dislocations, that's why there still remain dislocations of other types [8].

Current-voltage (*I-V*) and intensity-current (*L-I*) characteristics of LEDs fabricated by conventional and defects-passivated GaN substrate are shown in Fig. 2. It was found that the DP-LED have better electrical property than C-LED, this was due to lower threading dislocation density in the GaN epilayers, leading to a lower sheet resistance. The total optical output powers of DP-LED and C-LED were 7.05 and 10.15 mW respectively at 20 mA. The output power shows that the light output of DP-LEDs had 44.8% enhancement at 20 mA compared to C-LED. It's convinced that this result attributed to lower threading dislocation density, leading to MQWs with better quality.

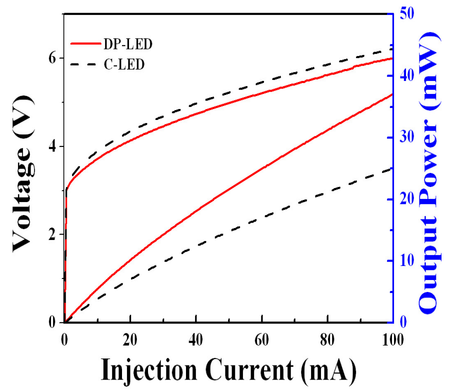

Fig.2. I-V curve and L-I curve of the LEDs fabricated by defects-passivated GaN substrate and conventional GaN substrate.

3. Conclusions

In summary, we fabricated the DP-LED with low TD density at about 1×10^7 cm^{-2}. Differing from conventional ELOG technique with SiO_2 passivation, we used the high temperature molten KOH to etch the defects on the surface of GaN template into pits, and then we deposited masklessSiO$_2$ as a DP layer in order to suppress the threading dislocations passing through MQWs. The output power of the DP-LED was increased 44.8% compare to C-LED at injection current of 20 mA, and the emission peak was 425.3 nm.

Acknowledgements

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