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Fabrication of nitride-based UV LEDs with low dislocation GaN buffer layers

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We have studied $Al_xGa_{1-x}N$ superlattice epilayers which are grown around the $Al_y(GaIn)_{1-y}N$ active layer and their effects on the characteristics of UV (ultra-violet) LEDs. This new MOCVD-grown UV LEDs using low dislocation density GaN buffer layers on sapphire have been investigated. Characteristics of two different GaN LED substrates, i.e. 5 μm-thick and 20μm-thick buffer layers, on sapphire are compared with each other. Enhanced LED characteristics show ~29.5% reduction in current-voltage resistance, ~8.5% reduction in turn-on voltage and output power saturation at higher current. The better GaN buffer quality results in the lower defect density and the heat dissipation which are believed to the enhanced reasons.

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1. Introduction

There are many III-V nitride materials are promising for the applications in both optoelectronic and electronic devices because they are direct bandgap transitions. Among them, wide-bandgap III-V nitride-based gallium nitride (GaN) semiconductor materials have attracted much attention in the production of blue, green and white light emitting diodes (LEDs) during the past few years [1-3]. The ultraviolet (UV) LEDs are suitable and promising candidates for applications in high-brightness white lighting and biological agent monitoring [4-5]. For actual applications, emitted light wavelength under 300 nm is essential but higher Al composition is also relatively necessary for material growth. Efficient emission at 280 and 340 nm would meet certain requirements in these applications. Although, there has been much effort done in the fabrication of UV LEDs by using the quaternary AlInGaN system [6-7] to achieve emission wavelengths below 340 nm, there have been few reports of a ternary AlGaN UV LED to approach 340 nm and shorter. One of the difficulties in the development of efficient nitride UV emitters is the relatively low hole concentrations reported for p-type AlGaN layers, and thus higher device series resistance and limited current injection through p-AlGaN materials. It is well known that the three binary nitrides (InN, GaN, AlN) have the wurtzite crystal structure and a direct band gap of 2.0 eV for InN, 3.4 eV for GaN, and 6.2 eV for AlN, respectively. The radiation wavelength from alloys and heterostructure prepared from these materials can be expanded over a wide spectral range from the visible to the ultraviolet. Ultraviolet (UV) LED fabricated by $Al_xGa_{1-x}N$/GaN double heterostructures can be used for the light source exciting various phosphores of white LED [8-10]. Moreover, they are also expected to be applied in medical science for blood analysis and other applications. The $Al_xGa_{1-x}N$ layers are responsible for carrier confinement against UV active layer such as GaN or another $Al_xGa_{1-x}N$ in order to enhance the quantum efficiency of UV LED. Therefore, in order to fabricate high quality and appropriate $Al_xGa_{1-x}N$ cladding layers, it is most critical to apply various growth techniques for enhancing the optical power efficiency of UV LED [11-13]. In this report, 290 nm UV LEDs using low dislocation density MOCVD grown GaN layers as buffer combined with superlattice structure is demonstrated.

2. Experimental

The epitaxial films of the UV LED structures were grown in a MOCVD reactor [14]. NH_3 and MO-sources flow were separated to reduce undesirable parastic reaction. Trimethylgallium (TMGa), trimethylaluminum (TMAl), bis-magnesium (Cp_2Mg), silane (Si_2H_6) and ammonia (NH_3) were used as Ga, Al, Mg, Si and N sources, respectively. The structure of the UV LEDs mainly consists of a 20-period n-type $Al_{0.4}Ga_{0.6}N/Al_{0.37}Ga_{0.63}N$ superlattice layers, a n-$Al_{0.35}(InGa)_{0.65}N$ active layer, a 20-period p-type $Al_{0.4}Ga_{0.6}N/Al_{0.37}Ga_{0.63}N$ superlattice layers and a 100nm-thick p-GaN as contact layer. The schematic structure is shown in the left of Fig. 1. Traditional lithography and etching techniques were used to form the UV LEDs. The top surface oxide was removed by 1HCl:1H_2O etching solution. Ni/Au was deposited as the semi-transparent ohmic contact and current spreading layer. To form the metal ohmic contact, the device was then annealed in a furance at 450^0C. Ti/Au was evaporated as n and p layer contacts on the top of the mesa region. Samples were processed with conventional photolithgraph to define square device geometry. The overall device area is 500μm × 500μm. The dislocation density of the MOCVD grown GaN buffer layer is estimated to be about $5 \times 10^{18}cm^{-3}$. In our experiments, two different GaN buffers in thickness are compared, one is 5 um-thick GaN/sapphire and the other is 20um-thick GaN/sapphire. The thickness of superlattice in a period is 4 nm and the thickness of active layer is 20 nm, respectively. The TEM view of superlattice and active layers is shown in the right of Fig. 1. In Fig. 1, it also shows the obvious interfaces grown by MOCVD and confirms the high quality of grown films.

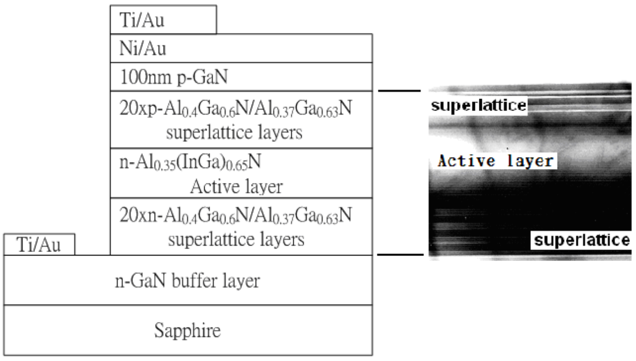

Fig. 1. UV LED schematic structure with twenty p and n superlattice pairs, containing $Al_{0.4}Ga_{0.6}N/Al_{0.37}Ga_{0.63}N$ structure in the left. The corresponding TEM figure is also shown in the right.

3. Results and discussion

From experiment, it is obvious that the turn-on voltage of the UV LED becomes higher as the X value of each $Al_xGa_{1-x}N$ superlattice epilayers increases. In the meanwhile, current-voltage (I-V) characteristics of the UV LEDs with 5 μm-thick GaN and 20 μm-thick GaN are respectively shown in Fig. 2. The 20 μm-thick GaN LED has a lower turn-on voltage (~5.3V) and lower resistance (~95Ω) as compared to the 5μm-thick GaN LED which has a turn-on voltage (~5.8V) and resistance (~135Ω), respectively. From experimental results, it is found that the reduction ratio in I-V resistance is ~29.5% and turn-on voltage is ~8.5%, respectively. It can be resonably deduced that the thicker GaN buffer layer posseses fewer interface dislocation which results in the lower turn-on voltage [15-16]. During the device fabrication, we also use the ITO to replace the Ni/Au and investigate the influence of light output. It can be seen that ITO was more transparent than Ni/Au. At λ =290 nm, the transmittance of Ni/Au is about 30%, while the transmittance of ITO is 45%. But, using the ITO method will result in higher specific contact resistance than that of Ni/Au on top of p-GaN layer.

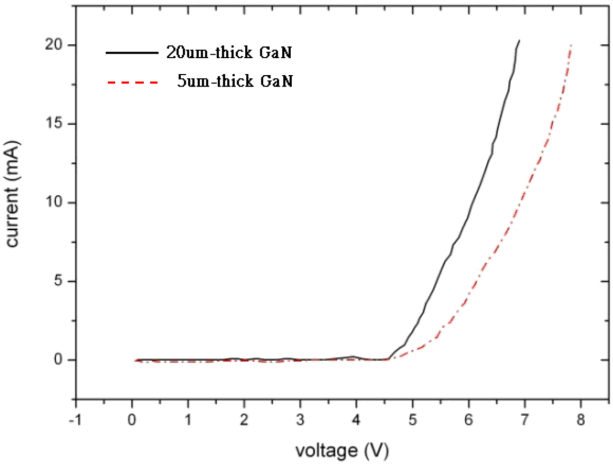

Fig. 2. Current-voltage characteristics of the 290 nm UV LEDs with 5 μm-thick and 20 μm-thick GaN buffer layers. It is found that the turn-on voltage is slightly low with thicker buffer layer.

The electroluminescene (EL) spectra measurement of the UV LEDs are shown in Fig. 3. In studying EL spectra, it is important to regard quantum efficiency, integral out-put power for an accurate and classic characterization of LEDs. It is worth to be more effective the novelty of this work in superlattice UV LEDs is obtained an enhanced light power output achieved with thicker GaN buffer layer. The LED output light is collected from the top side of the device and is operated under pulsed injection current. As we know, there are several losses in LED light output. If we can reduce these losses, the quantum efficiency of the LED will be promoted. From the spectra, the peak of wavelength is located at λ =290 nm as we designed and the larger injection current will result in the larger peak intensity. In addition, there is no other peaks appeared which indicate the mono-chromatic property.

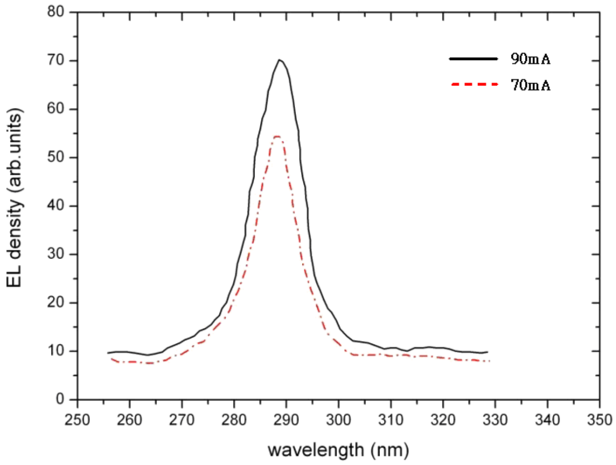

Fig. 3. EL spectra measurement of the UV LEDs with various injection levels.

The power measurement is performed by using an integrating sphere which is placed close to the surface of LEDs with a distance of 1cm. From Fig. 4, the output power of the 20 μm-thick GaN will saturate at a injection current level of ~300 mA, while the output power of the 5μm-thick GaN saturates at 150 mA under pulsed injection mode. This experimental result suggests that the thicker buffer layer will have better LED heat dissipation and result in the output power saturation appeared at higher injection currents.

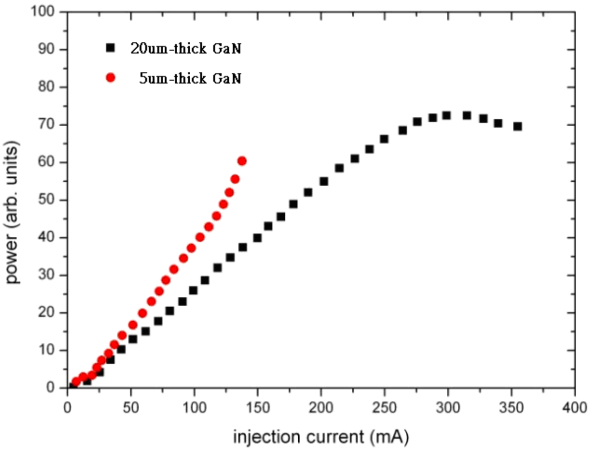

Fig. 4. UV LEDs light output power under pulsed injection mode for 5 μm-thick and 20 μm-thick GaN buffer layers, respectively.

4. Conclusion

In summary, it is demonstrated 290 nm UV LEDs using low dislocation density MOCVD grown GaN layers as buffer combined with superlattice structure. We have successfully fabricated and characterized superlattice AlGaN ultraviolet (UV) LEDs grown by metalorganic chemical vapor deposition (MOCVD) on sapphire substrates. It is found that this kind of UV LED structure exhibits a peak emission wavelength at λ =290 nm with a narrow line width of $\Delta\lambda$ =15 nm. From experiment, it is found that reduced I-V resistance, turn-on voltage and enhanced light power output are achieved with thicker GaN buffer layer. This larger improvement occurring in the superlattice UV LEDs is due to the lower dislocation density and higher thermal dissipation when using thicker GaN buffer layer.

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