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280 nm UV LEDs grown on HVPE GaN substrates

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We report on the enhancement of optical and electrical properties of 280 nm UV LEDs using low dislocation density HVPE-grown GaN substrate. Compared with the same structure grown on sapphire, these LEDs show ~30% reduction in current-voltage differential resistance, ~15% reduction in turn-on voltage, more than 200% increase in output power slope efficiency and saturation at higher currents. Lower density of defects due to higher material quality and better heat dissipation are believed to be the reason behind these improvements

Keywords: HVPE growth, GaN LEDs.

1. Introduction

UV LEDs are promising candidates for applications such as high-brightness white lighting, secure communication and chemical/biological agent monitoring. To realise these devices, wide bandgap III-Nitride semiconductors have been studied during the past few years. As a result, a few UV LEDs have been demonstrated by different groups [1–5]. One of the major requirements for these devices is low-dislocation-density substrate. UV LEDs grown on free-standing GaN substrates have shown great improvements in the light output power of the devices for wavelengths about 340 nm [1,4]. For some of the applications, light emission at wavelengths as short as 280 nm is essential. High Al composition layers are necessary for realisation of such devices. Differences in lattice parameter and thermal expansion coefficient of AlGaN and GaN along with pronounced problem of p-type doping makes it difficult to demonstrate 280 nm LEDs. Therefore, there have been very few reports on these devices so far [2,5]. Here, we report on enhancement in the characteristics of 280 nm UV LEDs using low-dislocation density hydride vapour phase epitaxially (HVPE) grown GaN as a substrate [6].

2. Experiment

The UV LED structures were grown in a horizontal-flow low-pressure metalorganic chemical vapour deposition (MOCVD) reactor. TMGa, TMAl, TMIn, and ammonia were used as sources for Ga, Al, In, and nitrogen, respectively. SiH_4 and Cp_2Mg were used for n-type and p-type doping, respectively. Growth temperature was ~1000°C and the pressure was 100 mbar. Two different substrates were used in our experiments: a 2-μm-thick GaN/sapphire as a reference and a thick GaN (~14 μm) grown by HVPE method on sapphire. The dislocation density of the HVPE-grown GaN substrate is estimated to be ~5×10^8 cm^{-3}. The structure of the LEDs consists of a 25-period n-type $Al_{0.42}Ga_{0.58}N/Al_{0.38}Ga_{0.62}N$ superlattice, a 5-period quaternary AlInGaN/AlInGaN multi-quantum well (MQW), a 25-period p-type $Al_{0.42}Ga_{0.58}N/Al_{0.38}Ga_{0.62}N$ superlattice, and a 50-nm-thick p-GaN:Mg as contact layer. The complete structure is given in Fig. 1. The superlattices have a period of 40 Å, resulting in total thickness of 100 nm. Thickness of the barriers and wells in the MQW are selected to be 70 Å and 30 Å, respectively. Standard lithography and dry etching techniques were utilised to process the LEDs. Rapid thermal annealing (RTA) at 1000°C in N_2 ambient was performed in order to activate Mg acceptors. Sol-

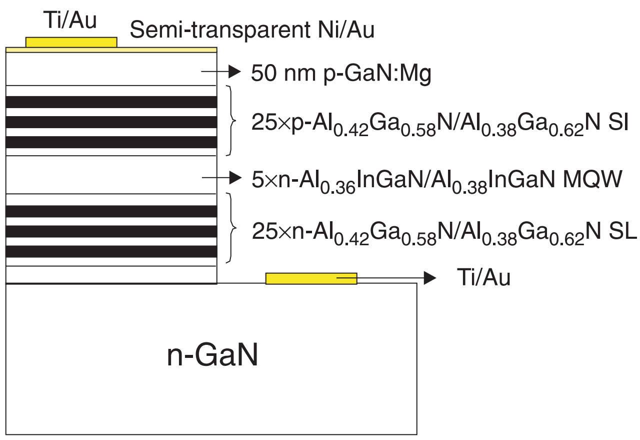

Fig 1. Structure of the 280nm UV LED.

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vent cleaning was done in order to ensure the surface cleanness. Native oxide of the top surface was then removed by a solution of HCl:H_2O (1:1). Semi-transparent Ni/Au (30Å/30Å) was evaporated on the top as an ohmic contact and current spreading layer. In order to transform the characteristics of the contacts from rectifying to ohmic, contacts were annealed in an RTA system at 500 °C. 400×400 µm square mesas were then etched down to n-type GaN. Ti/Au was used as n-type contact layer as well as p-type bonding pad on top of the mesas.

3. Results and discussion

Photoluminescence measurements on the samples show a dominant emission at 280 nm, consistent with the structure design. Current-voltage characteristics of the devices grown on 2 µm GaN/sapphire and 14 µm HVPE-GaN/sapphire are shown in Fig. 2. The device grown on thick GaN shows a lower turn-on voltage (~5.1 volts) and lower differential resistance (~75 Ω) as compared to the reference device (turn-on of ~6 volts and differential resistance of 105 Ω). This is an indication of the improved material quality due to the lower dislocation density in the thick HVPE GaN substrate.

Electroluminescence (EL) spectra of the UV LED grown on HVPE-GaN are shown in Fig. 3. Measurements were done under pulsed injection current and the light was collected from topside of the device. It should be noted that almost 65% of the light is expected to be absorbed by the 50-nm-thick p-GaN contact layer of which another 50% will be absorbed by the semi-transparent Ni/Au ohmic contact layer. Figures 4(a) and 4(b) show the optical transmission curve of annealed Ni/Au (30 Å/30Å) deposited on sapphire and 50 nm p-GaN grown on AlN buffer, respectively. In addition, due to losses in the bottom GaN, no light will be reflected back up to the device to be collected from topside. These losses play a huge role in reducing the quantum efficiency of the LEDs. Despite all these losses, we were able to measure the EL spectrum of the devices. The peak of the spectra are located a λ ~280 nm, as designed. No additional peaks can be observed in these spectra, which is indicative of a monochromatic light source (inset of Fig. 3).

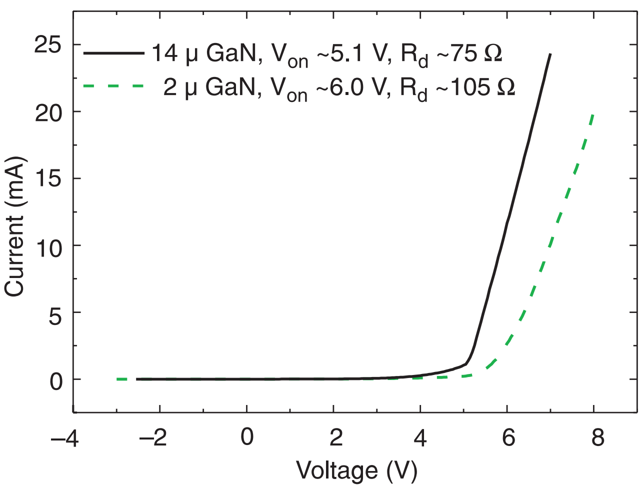

Fig 2. IV characteristics of the 280-nm UV LEDs grown on 14 µm-thick GaN (solid line) and 2 µm-thick GaN (dashed line).

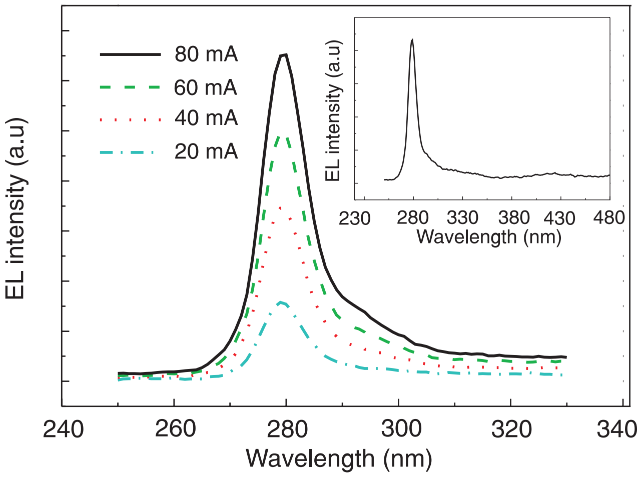

Fig 3. EL spectra of the 280-nm UV LED on HVPE GaN at various injection currents; inset shows a wider scan which exhibits no additional peak other than the main peak.

Power measurement was conducted on the device using an integrating sphere placed very close to the surface of the sample (~1 cm). Shown in Fig. 5(a) is the P-I curve in both pulsed (duty cycle = 1%) and continuous-wave (cw) injection mode. In pulsed injection mode, the output power saturates at a current level of ~400 mA, while the output power of the reference LED saturates at currents as low as 250 mA under the same duty cycle (1%). This suggests better heat dissipation for the LED grown on thick HVPE GaN compared to the reference LED, as the output power saturates at higher injection currents. Thermal conductivity of GaN is approximately 5 times higher than that of sapphire (1.3 W/cm.K for GaN and 0.3 W/cm.K for sapphire), which will result in better heat removal from the device if the GaN layer is thick enough. A slope efficiency of 8.1 nW/mA in pulsed mode and 10.5 nW/mA in cw mode was found for this LED. Theses values for the reference sample (grown on 2-µm-thick GaN) are 2.5 nW/mA in pulsed mode and 1.2 nW/mA in cw mode, which are considerably lower, especially in cw mode [Fig. 5(b)]. This comparison implies that light can be extracted more efficiently, as a result of improved material quality, which in turn will allow for operation at lower injection levels.

Research on 280 nm UV LEDs is just in its early stages and improvements need o be made in order to achieve viable performances from these devices. Minimising the absorptions in top layers, reducing the defect density, optimising the device structure, and using novel fabrication techniques are among the improvements that can be made in order to elevate the performance of such devices.

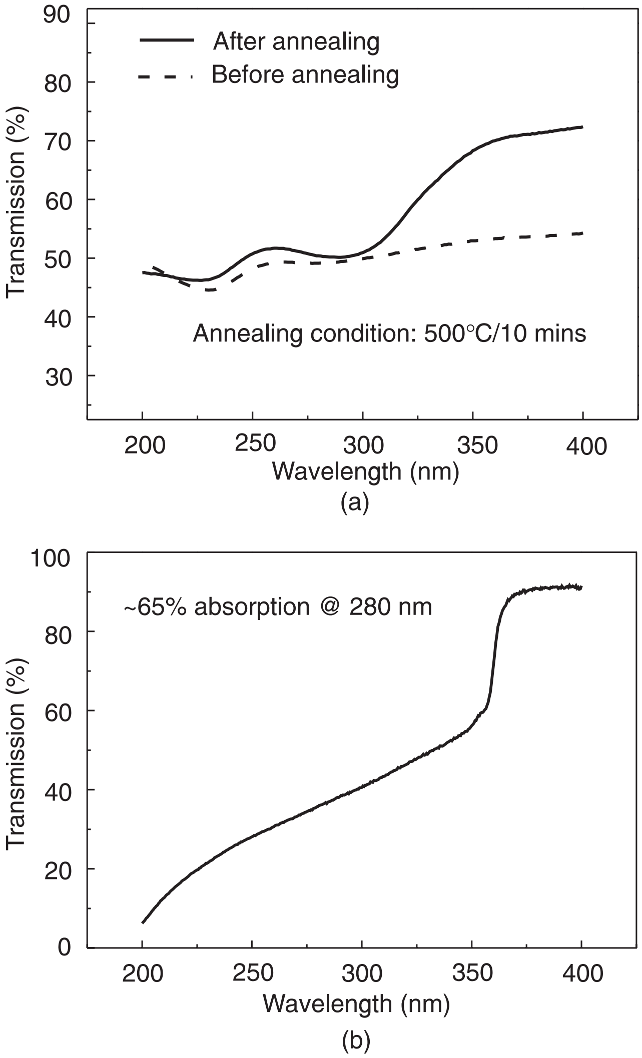

Fig 4. Optical transmission of (a) semi-transparent Ni/Au (30Å/30Å) before and after annealing, and (b) 50nm-thick p-GaN grown on AlN buffer.

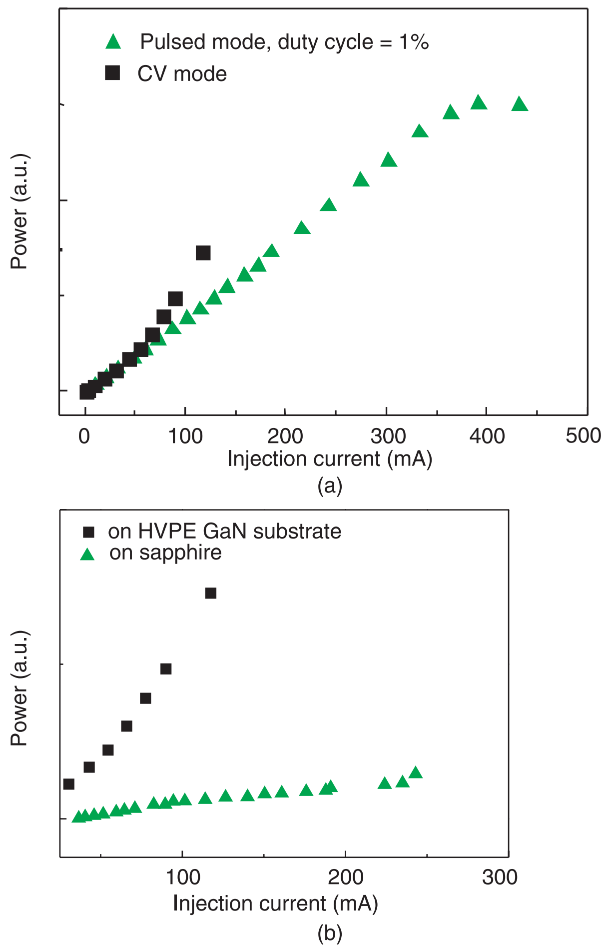

Fig 5. (a) Light output power of the 280-nm UV LED grown on HVPE GaN in pulsed mode (duty cycle of 1%, triangles) and cw mode (squares), and (b) comparison of power of the 280-nm UV LEDs grown on HVPE-grown GaN substrate (squares) and on sapphire (triangles).

4. Conclusions

In summary, we reported on the enhancement of the electrical properties of 280 nm UV LEDs using low dislocation density HVPE-grown GaN substrates. Reduced differential resistance, enhanced light output power, increased slope efficiency, and better heat removal are among the improvement made due to better substrate quality and thicker thermally conductive GaN layer which serves as a heat dissipater.

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6. The HVPE GaN substrates were prepared in the MIT Lincoln Lab.

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