Fabrication of GaInN multiple-quantum well LEDs on Si (111) by MOCVD

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GaN-based compound semiconductors are appropriate for short wavelength LEDs and laser diodes. In the past a few years, high-efficiency blue and green LEDs have been developed using these materials. GaN-based materials were successfully grown on sapphire or SiC substrates by MOCVD using either a two-step growth technique or several intermediate layers. Si substrates are much lower cost than sapphire and SiC substrates that are used for commercially available short wavelength LEDs. However, it is more difficult to grow high-quality GaN film on Si substrate than that on sapphire. It is caused by the lattice mismatch larger than that between GaN and sapphire, the tension to a large difference in thermal expansion coefficient and so on. In this study we have fabricated MOCVD-grown GaN-based LEDs on Si substrates with AlN/AlGaN intermediate layer.

In a previous study, we reported the intermediate layer consisting of AlN/$Al_{.26}Ga_{.74}$ in the growth of GaN on Si (111) substrate by MOCVD plays an important role. We fabricated the LEDs on Si (111) substrate with AlN/AlGaN intermediate layer. The LED structure consists of 400-nm-thick n-GaN, undoped 3 quantum well active layers consisting of 5-nm-thick $Ga_{.99}In_{.01}N$ barriers and 3-nm-thick $Ga_{.87}In_{.13}N$ wells, a 20-nm-thick p-$Al_{.15}Ga_{.85}N$ guide layer and 100-nm-thick p-GaN cap layer. Figure 1 shows a surface morphology of this sample. Some cracks are observed, which is caused by the tension due to mismatch of lattice and thermal expansion. However the surface morphology is smooth. Figure 2 shows the photoluminescence (PL) of the GaInN 3QW on Si substrate with AlN/AlGaN intermediate layer at room temperature. The intense peak is 435 nm and FWHM is18 nm.

Ni/Au is used as the electrode on the cap layer for the p-type contact. Ti/Al/Ni/Au on the n-GaN and AuSb/Au on the n-Si substrate for n-type contact are used for the electrodes. Two type n-contacts were used for the top-contact and the backside-contact. Figure 3 shows the schematic cross-sectional structure of the GaInN MQW LED on Si (111) substrate with the n-$Al_{.26}Ga_{.74}N$/n-AlN intermediate layer. The I-V characteristics are shown in Fig. 4. The turn-on voltages are 3 V for the both LEDs with top-contact and the backside-contact. The series resistance of the top-contact and the backside-contact are 200 Ω and 1 kΩ, respectively. This difference is caused by high resistance in intermediate layer. The L-I characteristics at room temperature are shown in Fig. 5. The output power in the backside-contact is twice less than that in the top-contact. This is caused by the generation of thermal energy due to high series resistance. Figure 6 shows the electroluminescence at room temperature operation for the bias current of 10 mA. The peak emission wavelength is 430 nm and FWHM is 20 nm, which correlate with the PL spectra.

In summary we reported on GaInN 3QW LED on Si (111) substrate with AlN/AlGaN intermediate layer. The surface morphology and PL spectra indicated that the high-quality LED has been successfully fabricated on Si substrate. The emission from the LED at 20 mA is bright enough to be observed in room light. By reduction of the resistance of the intermediate layer, the characteristics can be improved for the LED on Si substrate with the backside-contact.

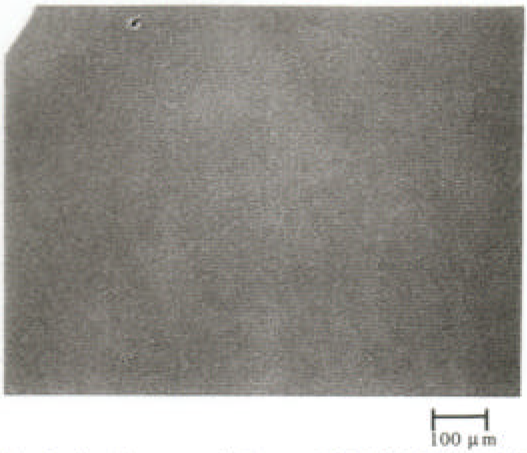

Fig. 1. Surface morphology of GaInN 3QW LED on Si with AlN/AlGaN intermediate layer

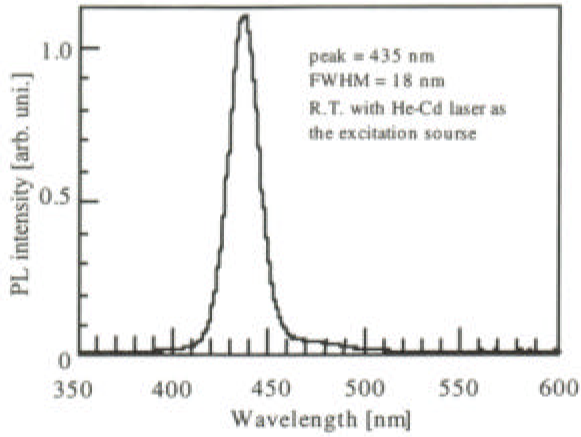

Fig. 2. Photoluminescence from GaInN 3QW on Si substrate with AlN/AlGaN intermediate layer

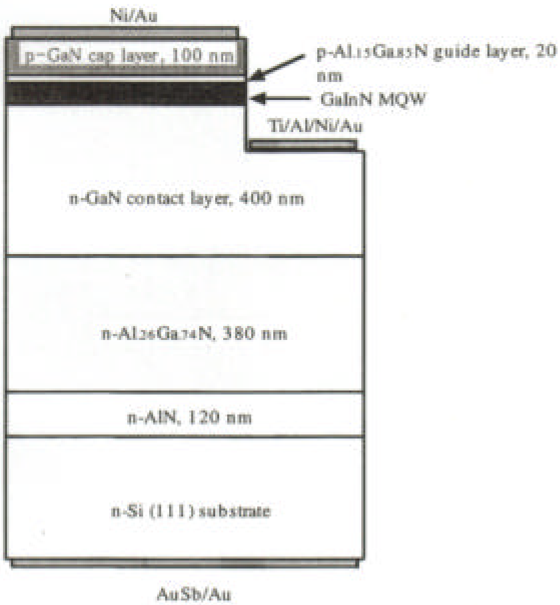

Fig. 3. Schematic cross-sectional structure of the GaInN MQW on Si (111) substrate with AlN/AlGaN intermediate layer

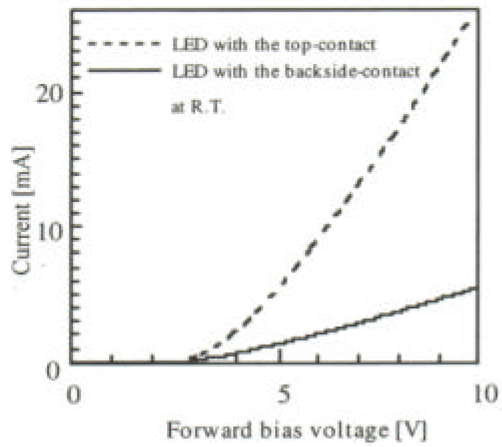

Fig. 4. Forward bias voltage vs. current characteristics of the LED on Si (111)

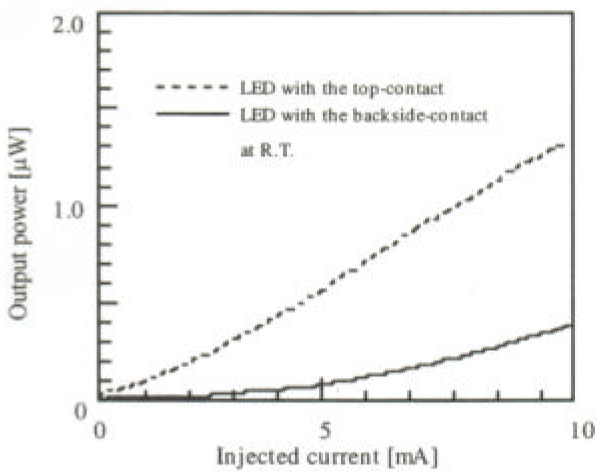

Fig. 5. Injected current vs. output power characteristics of the LED on Si substrate

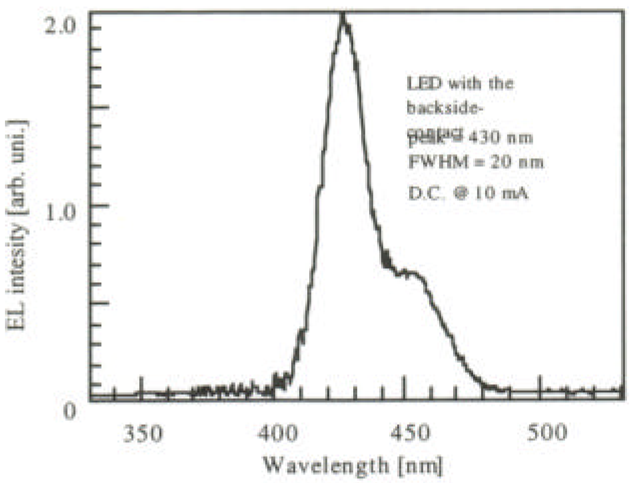

Fig. 6. Electroluminescense of the LED on Si substrate