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Photoluminescence Intensity Enhancement due to Screening of Piezoelectric Field in Si-Doped G227aN/AlGaN Single-Quantum-Wells

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1.Introduction

GaN and related nitrides are currently of great interest for application to visible and ultraviolet (UV) laser diodes (LDs) and light-emitting diodes (LEDs) [1,2]. AlGaN alloy is useful material for applying to optical devices operating in the UV, because direct transition emission can be adjusted between wide energy of 3.4 - 6.2eV. We have already obtained 280nm intense photoluminescence (PL) emission from AlGaN quantum wells (QWs) [3]. However there are some large problems preventing them from achieving UV optical devices, such as difficulty to obtain efficient UV emission from AlGaN QWs or current injection through high Al content AlGaN alloy. Some techniques to enhance the QW emission intensity have been reported [4,5]. Si-doping is one of the most effective ones. The mechanism of PL intensity enhancement due to Si-doping is considered to be explained by screening of the piezoelectric field. In this report, we systematically study on the PL intensity enhancement due to screening of the piezoelectric field by Si-doping into GaN/$Al_{0.10}Ga_{0.90}N$ single-quantum-well (SQW) structures.

2.Experiments and Discussions

The GaN or AlGaN epitaxial layers were fabricated at 76 torr, 1100°C on a 6H-SiC (0001) substrate by horizontal MOVPE system. As precursors, trimethylgallium (TMGa), trimethylalminium (TMAl), tetraethylsilane (TESi) and ammonia (NH_3) were used with H_2+N_2 as carrier gases. PL spectrum was measured under low excitation condition excited with He-Cd laser (325nm) at 77K.

At first, undoped GaN/$Al_{0.10}Ga_{0.90}N$ SQW structures with various well thickness were grown. Fig.1 shows their structure. The PL spectra measured at 77 K as a function of well thickness are shown in Fig.2. The thickness of the emitting layer was simply estimated from the growth rate of the bulk sample. The strongest PL intensity was obtained for 3.5nm-thick SQW. Immediate PL intensity reduction for the thicker SQWs might be explained by the separation of electron and hole wave-functions of QW induced by the larger piezoelectric field [4].

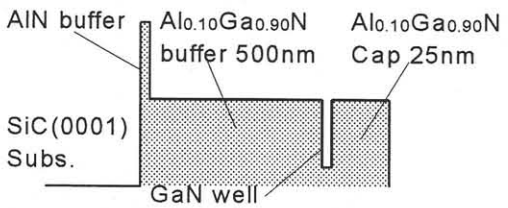

Fig.1 The structure of GaN/$Al_{0.10}Ga_{0.90}N$ SQWs.

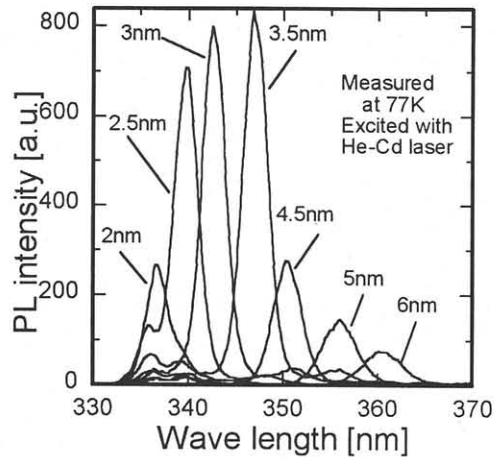

Fig.2 PL spectra of undoped GaN/$Al_{0.1}Ga_{0.9}N$ SQWs measured at 77K as a function of well thickness. The peak energy is strongly depending on the well thickness.

Then, Si-doped GaN/$Al_{0.10}Ga_{0.90}N$ SQW structures with various well thickness were grown. Si was doped only into the well. Figure 3 shows the dependence of Si-doping concentration on PL intensity for various well thickness. The PL intensity enhancement was observed for every series. As seen in Fig.3, the PL intensity enhancement ratio becomes larger as the well thickness becomes large. For the thinner well, the enhancement was soon saturated for higher doping concentration. On the other hand, for the thicker SQW, the ratio was still increases for high concentration of Si-doping. The effect is especially large for 5nm SQWs, and the typical enhancement ratio is 30 times for the Si-doping of 7×10^{18} cm^{-3}. These phenomena is clearly explained by the screening effects of piezoelectric field in the well. It is obviously shown that heavy Si-doping is necessary in order to induce the thick QW PL intensity, because the wave function separation between electron and hole is much larger for thick QW.

Figure 4 shows the dependence of Si-doping concentration on peak energy shift. As shown in Fig.4, peak energy blue shift was observed with the Si-doping range up to $2\times10^{18}cm^{-3}$ for every series of samples. The shift amount was especially large for 5nm-thick SQW due to the screening of large piezoelectric field. The well thickness dependence of PL peak shift is also well explained by the screening of piezoelectric field under low Si-doping condition. It is still unknown for the reason of PL peak stable region for large Si-doping concentration more than $3\times10^{18}cm^{-3}$.

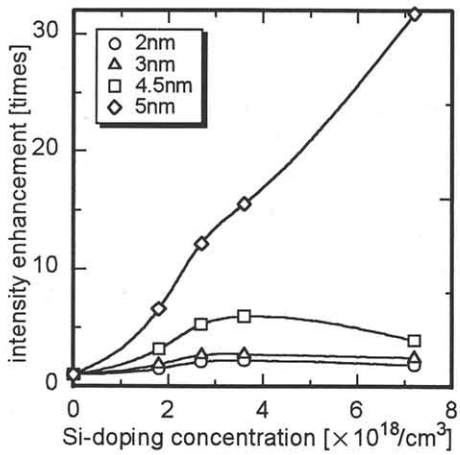

Fig.3 Dependence of Si-doping concentration on PL intensity for various well thickness of $GaN/Al_{0.1}Ga_{0.9}N$ SQWs.

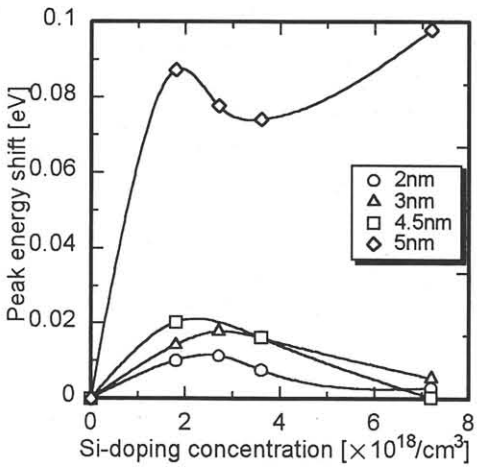

Fig.4 Dependence of Si-doping concentration on PL peak energy shift for various well thickness of $GaN/Al_{0.1}Ga_{0.9}N$ SQWs

Figure 5 shows the temperature dependence of PL peak energy under high and low excitation conditions for Si-doped and undoped $GaN/Al_{0.1}Ga_{0.9}N$ SQW samples. The excitation lasers used were He-Cd laser (325nm, ~$3W/cm^2$) as low excitation conditions and Xe-Cl excimer laser (308nm, ~$500kW/cm^2$) as high excitation conditions. As seen in Fig.5, the PL peak energy shifts to high energy side by excited with excimer laser due to the screening of piezoelectric field by excited electron. However, the difference of PL peak energy between high and low excitation spectrum is much larger for undoped SQW sample in comparison with Si-doped samples. This result shows that the piezoelectric field in the Si-doped QW has been already screened by the electron charge in QW.

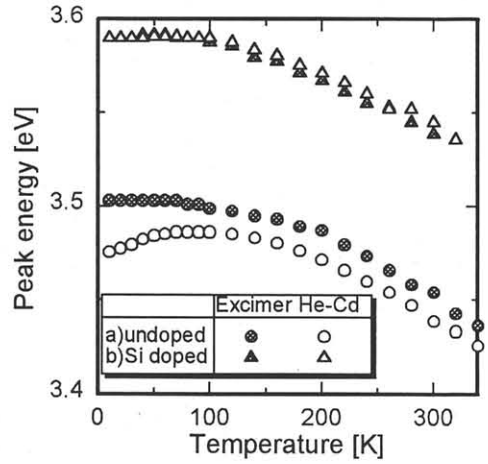

Fig.5 Temperature dependence of PL peak energy for a) undoped and b) Si-doped $GaN/Al_{0.1}Ga_{0.9}N$ SQWs excited with Xe-Cl excimer laser and He-Cd laser.

From these experimental results we confirmed that the screening of the piezoelectric field in the QW region plays a significant role for the increase of PL intensity, and that Si-doping in QW is very effective to screen the piezoelectric field.

3.Conclusion

Effect of Si-doping on PL properties was systematically studied in $GaN/Al_{0.10}Ga_{0.90}N$ SQW structures fabricated by MOVPE. We observed drastic enhancement of PL intensity and PL peak blue shift for Si-doped samples compared to undoped ones. The PL intensity enhancement ratio was especially large for thicker well; the typical value of which was 30 times for 5nm SQW sample with Si-doping of 7×10^{18} cm^{-3}. The PL peak blue shift was also large for thick SQW sample. In addition, we found that the piezoelectric field in the Si-doped QW is screened by the electron charge in QW, from the separation of PL peak energy between high and low excitation spectrum. These results indicates that the screening of the piezoelectric field in the QW region plays a significant role for the increase of transition probability.

References

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