Photoluminescence and electrical property of Beryllium implanted P-type GaN

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Gallium nitride (GaN) and other group III-nitrides have been successfully employed to realize blue-green light-emitting diode and blue laser diodes [1-3]. Generally, p-type GaN is typically achieved by doping Mg during metal-organic chemical vapor deposition (MOCVD) process. However, for high performance devices a low resistance p-type ohmic contact is required. Typically, a p-type ohmic contact with resistance lower than 10^{-4} Ω is required. Most of the reported methods for reducing contact resistance rely on the improvement of metal semiconductor interface [8~10] and optimization at the contact annealing temperature. An alternate approach using ion implantation with precise control of dopant concentration and depth distribution can offer a solution to lower contact resistance through enhancement of the carriers concentration and mobility. In this paper, we report the results of implantation of beryllium (Be) on p-type GaN. Be was chosen for its lower theoretical activation energy (~60meV) [4] than Mg (~250meV) [5~7]. Substantial reduction of Mg activation energy and increase of carrier concentration were obtained for the implanted GaN samples.

All p-type Mg-doped GaN samples with 1 μm thick were grown on c-axis sapphire substrates by MOCVD at 1080°C. Prior to the deposition of the P-type layer was a 30nm thick low temperature buffer layer. Trimethygallium and ammonia are used as Ga and N source respectively. CP_2Mg was used as the Mg source. These as-grown p-type samples were annealed for 40 minutes at 700°C. The initial hole concentration and mobility at room temperature measured by Hall measurement are 5.46×10^{16} cm^{-3} and 7.55 cm^2/v-s respectively. These p-type GaN samples were implanted with Be ions for two different doses of $\sim 10^{13}$ and 10^{14} cm^{-2} at different energies of 50 and 150 kev . These implanted samples were subsequently rapidly thermal annealed (RTA) at 900°C, 1000°C, 1100°C for various periods to remove the implantation damage and to activate the dopants. The surface morphology of samples were investigated by atomic force microscopy and found no major surface deterioration after Ion implantation and RTA process.

Both as-grown and implanted samples were investigated by photoluminescence (PL) and Hall measurement. The samples were excited by 325nm He-Cd laser. For as-grown GaN samples, the PL spectrum showed several typical Mg-related emission lines at 380nm, 390nm, 420nm and 440nm. The 380nm, 420nm and 440nm peaks are related to the donor-acceptor (D-A) pair of Mg and the 390nm peak is the phonon replica of the 380nm peak. For the implanted un-annealed samples at 18K, it has a similar Mg-related peaks as the as-grown samples. However, for the annealed samples , a broad spectrum emerged near 530nm which is different from traditional yellow band. This could be due to additional lattice disorders induced by ion implantation. This 530nm peak gradually quenches as the annealing temperature increases up to 1100°C and annealing time at 60 sec.

Fig. 1(a) shows the temperature dependence of PL for the samples with annealing temperature of 900°C for 15 sec annealing time. Fig. 1(b) shows the relation between the emission intensity of 440nm peak and temperature. Below the temperature 100K, the emission intensity is nearly constant. The emission intensity decreases rapidly with the increasing temperature above 100K. We use two decay contants formula to fit Fig. 1(a) data and to estimate the activation energy of Mg-dopant. For those samples annealed at 900°C and 1100°C for 30s, the estimated activation energy is around ~180meV. This activation energy of Mg dopants is about 30% lower than the previous reported value of 250meV, indicating reduction in activation energy as the results of Be implantation.

Fig. 2 shows the result at room temperature Hall measurement for as-grown, and annealed implanted samples with different annealing conditions. The data showed the mean carriers concentration and mobility of as-grown are 5.46×10^{16} cm^{-3} and 7.55 cm^2/v-s respectively. After the annealing temperature of up to 1100°C and annealing time of 60 sec the carrier concentration reach to $2.71 * 10^{18}$ cm^{-3} .

In summary, we investigated Be implantation of p-type Mg-doped GaN and obtain a reduction in Mg dopants activation energy of of about 30% lower than the previous reported value of 250meV. The carrier concentration also increases from $5.4 * 10^{16}$ for as-grown GaN to $2.71 * 10^{18}$ cm^{-3} for 1100°C annealling temperature at 60sec. Therefor, we believe Be is an alternate and viable method for improving p-contact for GaN.

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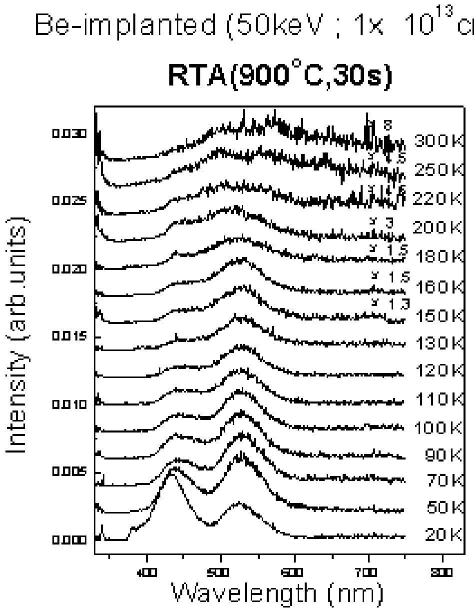

Fig1(a)

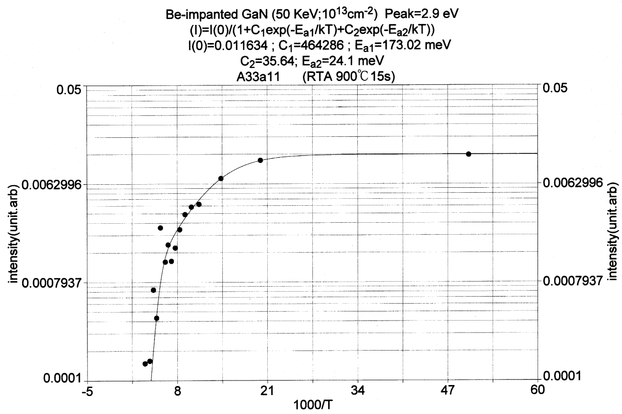

Fig1(b)

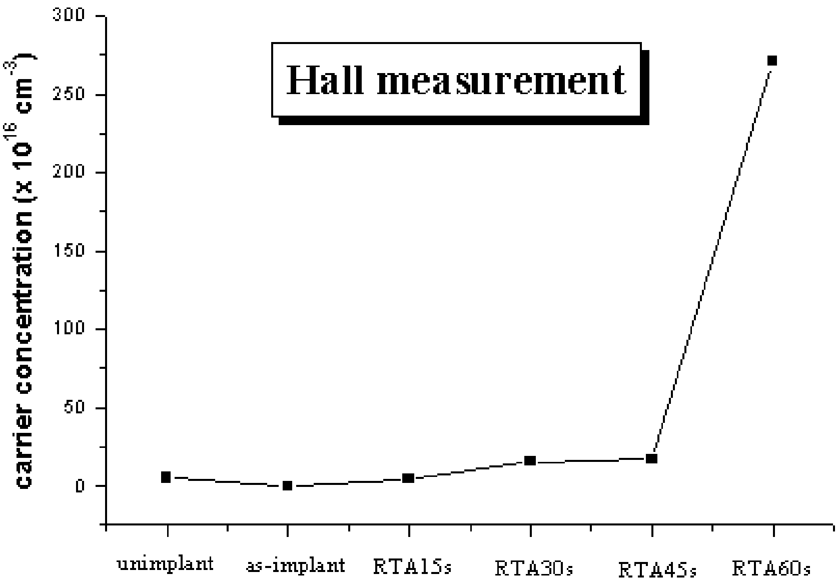

Fig 2