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Investigation of beryllium implanted P-type GaN

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Abstract

We report the preliminary results of beryllium implanted into P-type GaN and the effects on the characteristic of Mg-doped P-GaN. These samples were implanted with Be ions were implanted with two different energies of 50 and 150 keV at two different doses of $\sim 10^{13}$ and 10^{14} cm^{-2} at room temperature. Surface morphology and photoluminescence measurements are presented.

Keywords: Beryllium; Implant; GaN; Photoluminescence

1. Introduction

Gallium nitride (GaN) and other group III-nitrides have been successfully employed to realize high-efficiency blue–green light-emitting diode (LEDs) and blue laser diodes (LDs) [1–3]. Generally, P-type GaN is typically achieved by doping Mg in metal–organic chemical vapor deposition (MOCVD). However, high resistance ohmic contact for P-type GaN is a critical problem for these devices. P-type ohmic contact with resistance lower than 10^{-4} Ω is required. There are various methods such as different metal/semiconductor technology [8–10] and optimum anneal temperature reported. An alternate approach using ion implantation with precise control of dopant concentration and depth distribution offers a solution to lower contact resistance through enhancement of the carriers concentration and mobility. As for implanted species, beryllium (Be) has lower theoretical ionization energy (~ 60 meV) [4] than Mg (~ 250 meV) [5–7]. Therefore, Be is a promising candidate for P-type doping. This report presents the results of surface morphology and photoluminescence (PL) of Be implanted P-type GaN.

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 30 nm 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 min 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^{-1} s^{-1}, 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, 1000 and 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 PL and Hall measurement. The samples were excited by 325 nm He–Cd laser. For as-grown GaN samples, the PL spectrum showed several typical Mg-related emission lines at 380, 390, 420 and 440 nm. The 380, 420 and 440 nm peaks are related to the donor–acceptor (D–A) pair of Mg and the 390 nm peak is the phonon replica of the 380 nm peak. For the implanted un-annealed samples at 18 K, it has a similar Mg-related peaks as the as-grown samples. However, for the annealed samples, a broad spectrum emerged near 530 nm, which is different from traditional yellow band. This could be due to additional lattice disorders induced by ion implantation. This 530 nm peak gradually quenches as the annealing temperature increases up to 1100°C and annealing time at 60 s.

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Fig. 1(a) shows the temperature dependence of PL for the samples with annealing temperature of 900°C for 30 s annealing time. Fig. 1(b) shows the relation between the emission intensity of 440 nm peak and temperature. Below the temperature 100 K, the emission intensity is nearly constant. The emission intensity decreases rapidly with the increasing temperature above 100 K. We use two decay constants formula to fit Fig. 1(a) data and to estimate the activation energy of Mg-dopant. For those samples annealed at 900 and 1100°C for 30 s, the estimated activation energy is around ∼180 meV. This activation energy of Mg dopants is about 30% lower than the previous reported value of 250 meV, 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^{-1} s^{-1}, respectively. After the annealing temperature of up to 1100°C and annealing time of 60 s the carrier concentration reach to 2.71×10^{18} cm^{-3}.

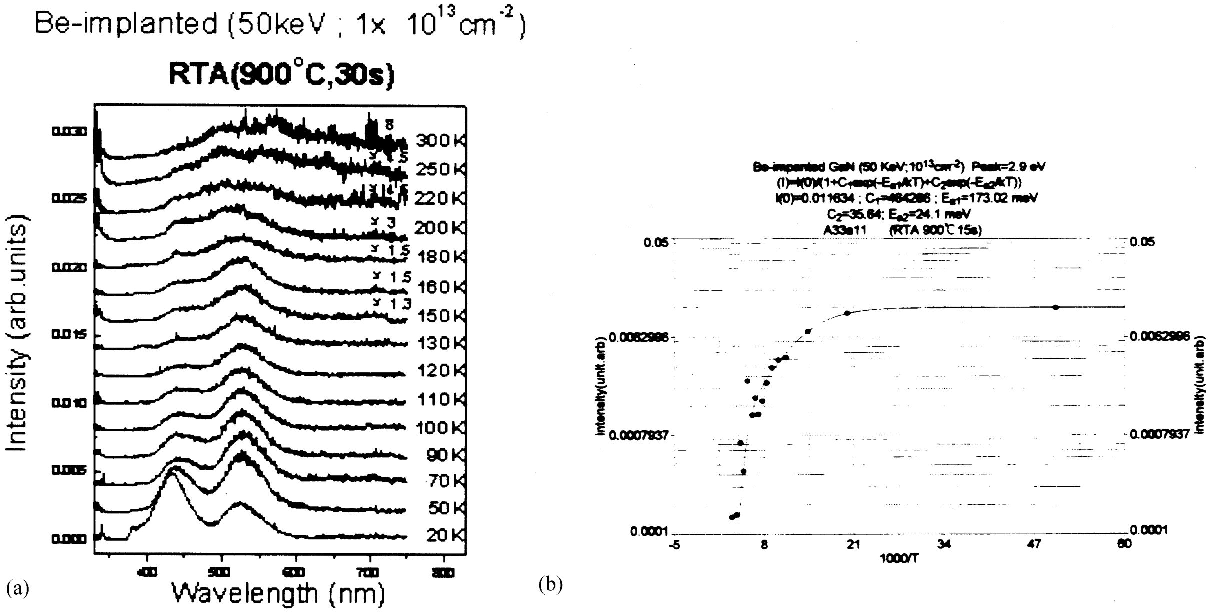

Fig. 1. (a) the temperature dependence of PL for the samples with annealing temperature of 900°C for 30 s annealing time, and (b) the relation between the emission intensity of 440 nm peak and temperature

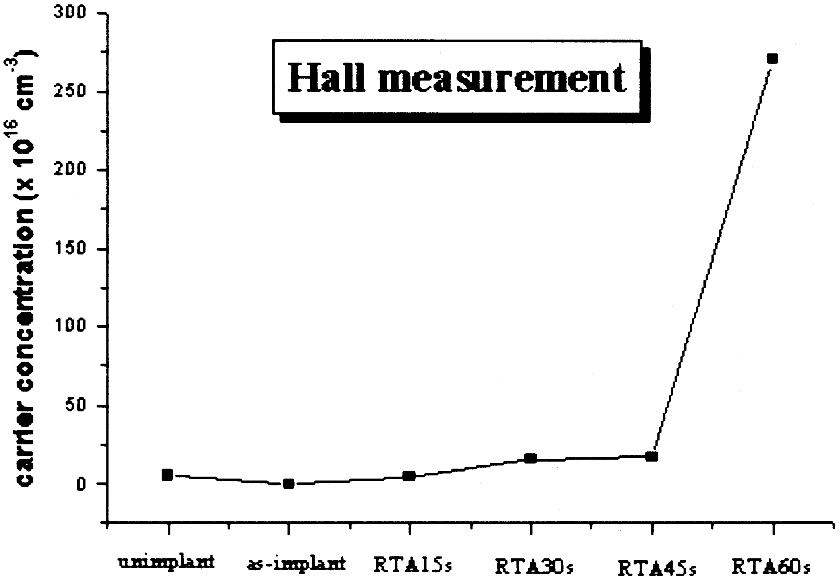

Fig. 2. The result of Hall measurement for as-grown and annealed implanted samples with diffferent annealing conditions

In summary, we investigated Be implantation of P-type Mg-doped GaN and obtain a reduction in Mg dopants activation energy of about 30% lower than the previous reported value of 250 meV. The carrier concentration also increases from 5.4×10^{16} for as-grown GaN to 2.58×10^{18} cm^{-3} for 1100°C annealing temperature at 60 s. Therefore, we believe Be is an alternate and viable method for improving p- contact for GaN.

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