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The structural and morphological characteristics of 90 keV Mn^+ ion implanted GaN films

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Abstract

Wurtzite gallium nitride (GaN) films are grown by low-pressure MOCVD on (0001)-plane sapphire substrates. The GaN films have a total thickness of 4 μm with a surface Mg-doped p-type layer, which has a thickness of 0.5 μm. At room temperature, 90 keV Mn^+ ions are implanted into the GaN films with doses ranging from 1×10^{15} to 1×10^{16} cm^{-2}. After an annealing step at 770 °C in flowing N_2, the structural characteristics of the Mn^+-implanted GaN films are studied by X-ray diffraction (XRD), Rutherford backscattering spectrometry (RBS), atomic force microscopy (AFM) and scanning electron microscope (SEM). The structural and morphological changes brought about by Mn^+ implantation and annealing are characterized, which lay a foundation for the magnetic characteristics study of GaN.

Keywords: GaN; Ion implantation; Structure and morphology

1. Introduction

Gallium nitride (GaN) is a wide band-gap III–V compound semiconductor material, which can be used to produce blue-light-emitting diodes and lasers, as well as high-temperature and high-power devices [1]. While manganese (Mn) represents a potential acceptor in GaN, Mn-doped GaN may form an interesting diluted magnetic semiconductor, which might have a Curie temperature above room temperature and thus have a great potential for the fabrication of magneto-electrical and magneto-optical devices [2–4]. However, there is a major obstacle in making III–V semiconductors magnetic, i.e., the low solubility of magnetic elements (e.g., Mn) in these compounds [5].

It is well known that ion implantation has the advantage to introduce impurities without any limitation of solubility. Additionally, it provides the advantage to reproducibly generate high doping level. So ion implantation into GaN, followed by an annealing step, can be successfully applied for several technological steps in the fabrication of GaN-based devices [6].

The Mn^+ implantation characteristics of GaN have been investigated [7], and it is suggested that low energy and low dosage of implantation is favorable of the recovery of implant damage. As there are few reports about the implantation of p-type GaN by now, 90 keV Mn^+ ions are implanted into p-type GaN films at room temperature with doses ranging from 1×10^{15} to 1×10^{16} cm^{-2}. After an annealing step at 770 °C in flowing N_2, the structural characteristics and morphological changes of the Mn^+ implanted GaN films are studied.

2. Experimental

The GaN films were grown by low-pressure metal organic chemical deposition (MOCVD) on (0001)-plane sapphire substrates. A GaN buffer layer of about 30 nm thick was deposited at 530 °C. Subsequently an undoped GaN layer with a thickness of 3.6 μm was grown at 1030 °C. Then the Mg-doped GaN, which has a thickness of 0.5 μm, was grown upon the undoped GaN at 1010 °C. Electrical activation of the prepared GaN layers was achieved by annealing in

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nitrogen at 760 °C for 30 min. Hall measurements showed that the hole concentration in the p-type GaN film was in the range of 1×10^{17}–3×10^{17} cm^{-3}.

Mn^+ ions with beam flux of 5 μA were implanted into the Mg-doped p-type GaN films at room temperature with an energy of 90 keV and doses ranging from 1×10^{15} to 1×10^{16} cm^{-2}. The subsequent rapid thermal annealing (RTA) was carried out at 770 °C for 45 s and 90 s under flowing N_2. During the annealing, the samples were covered by another p-type GaN sample to suppress the escape of the volatile component. The effects of Mn^+ implantation and annealing on the structural characteristics of the GaN films were studied by X-ray diffraction (XRD), Rutherford backscattering spectrometry (RBS), atomic force microscopy (AFM) and scanning electron microscope (SEM).

3. Results and discussions

XRD spectra measured using Cu $K_{\alpha1}$ line are shown in Fig. 1. For all the GaN films, either implanted or unimplanted, the XRD spectra exhibit a sharp peak of wurtzite GaN(0002) at 2θ=34.6°, which can be used to judge the crystallinity of GaN films. When the implanted samples are annealed at 770 °C for 45 s, the intensity of the GaN(0002) peak has little change, but the peak width increases with the implant dose, as shown in Fig. 1(a). This means the coherent length in the GaN lattice decreases with the increasing implant dosages. Obvious changes of GaN(0002) peak intensity occur in Fig. 1(b), where the annealing of 90 s at 770 °C affects the crystallinity of implanted GaN films, especially for the samples implanted with relatively high dose of 1×10^{16} cm^{-2}. So the structure of the implanted GaN films is controlled by both the implant dosage and annealing condition.

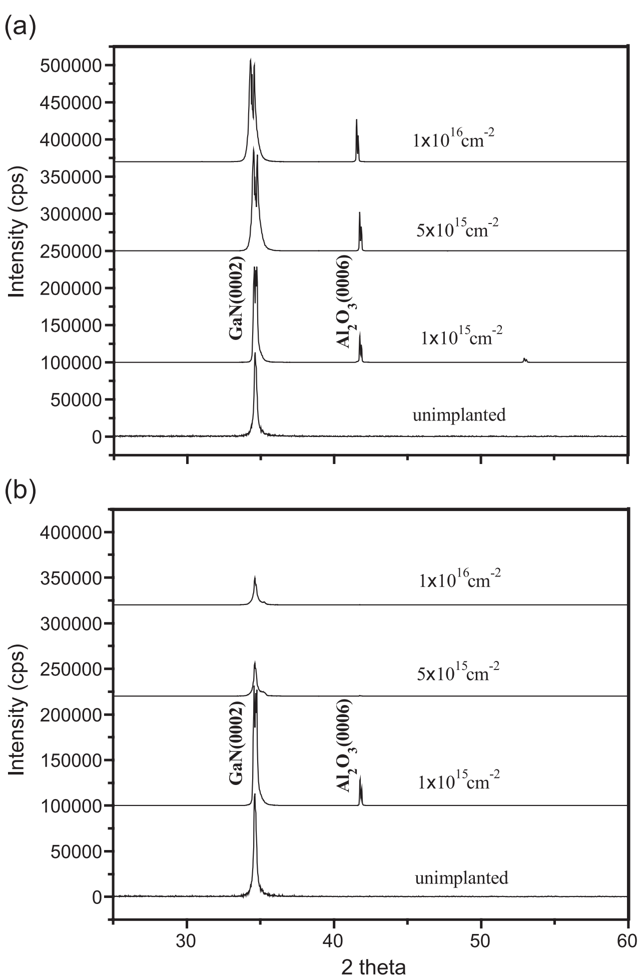

Fig. 1. XRD spectra of GaN films. Different implanting dosages are labeled above the curves. The implanted GaN films are annealed at 770 °C for (a) 45 s and (b) 90 s.

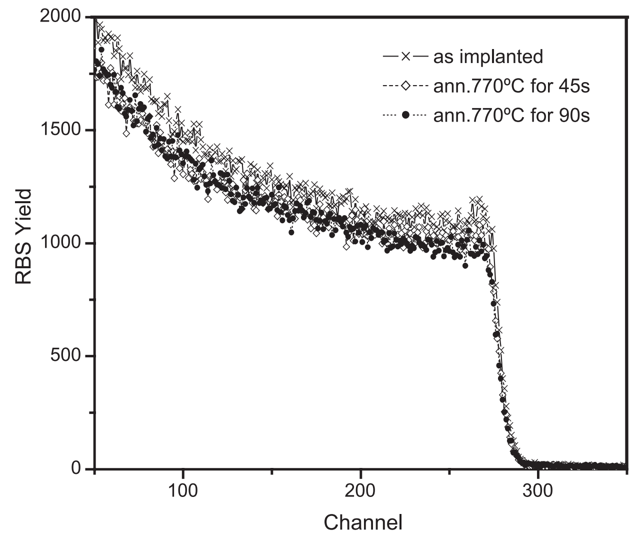

Fig. 2. RBS spectra of Mn^+-implanted GaN films with the same dose of 1×10^{16} cm^{-2} but with different annealing time.

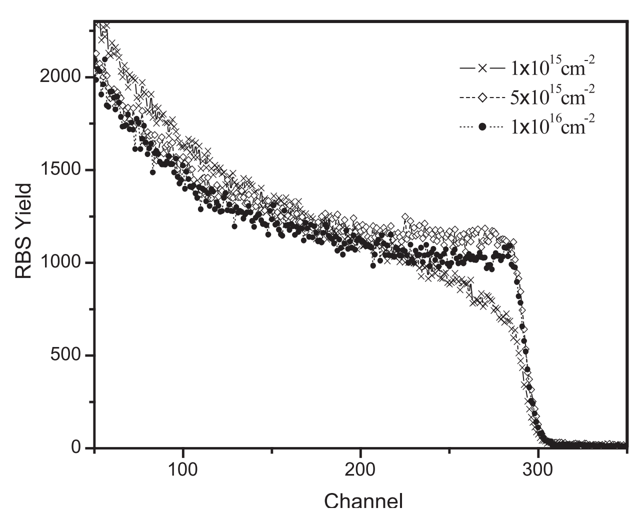

Fig. 3. RBS spectra of Mn^+-implanted GaN films, which are annealed at 770 °C for 90 s.