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Structural modifications of AlInN/GaN thin films by neon ion implantation

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ABSTRACT

To study ion beam induced modifications into MOCVD grown wurtzite AlInN layers, neon ions were implanted on the samples with four doses ranging from 10^{14} to 9×10^{15} ions/cm^2. Structural characterization was carried out by X-ray diffraction and Rutherford backscattering spectroscopy (RBS) techniques. XRD analysis revealed that GaN related peak for all samples remains at its usual Bragg position of $2\theta = 34.56°$ whereas a shift in AlInN peak takes place from its position of $2\theta = 35.51°$ for as-grown sample. Rutherford back scattering (RBS) analysis indicated that peak related to Ga atoms in capping layer provided evidence of partial sputtering of GaN cap layers. Moreover, Al peak position is shifted towards lower channel side and width of the signal is increased after implantation, which pointed to the inwards migration of Al atoms away from the AlInN surface. The results suggested that partial sputtering of cap layer has taken place without uncovering the underneath AlInN layer.

1. Introduction

Group III-nitride alloy AlInN has been a topic of research and commercial interest for material growers since its first consistent fabrication by Kubota et al. [1]. This material is not only important due to its ability to be lattice matched to GaN with 17% indium content but also attractive for use in distributed Bragg reflectors (DBRs), cladding layers and other electronic as well as optoelectronic devices [1–3]. Though the research on AlInN is limited to some extent due to problems of its growth, the study of ion implanted AlInN is even rarer [4–6]. 'Ion implantation into material' in addition to its conventional benefits of selective area doping, electrical isolation, ion cut, etc., is an important field which reveals many important properties of the material and provides a tool to explore real power of the material in study [7]. Indium content of AlInN is a key factor for modifying the properties of this alloy. In previous studies we reported the change of indium content in AlInN layer caused by ion implantation [6,8]. Implantation of neon into AlInN is expected to provide pure information about implantation induced modifications of material due to the inert nature of neon ions. Although study of strain variations caused by neon implantation and thermal annealing is reported previously [9] but detailed study to explore the system is still needed. Here a study of structural changes caused by neon implantation into AlInN studied by Rutherford backscattering spectroscopy is reported.

2. Experimental

AlInN thin films (~200 nm thick) grown on GaN/sapphire substrates in low pressure metal organic chemical vapor deposition (MOCVD) system were used in this study. A thin cap layer (~10 nm) of GaN was also grown in order to avoid the decomposition during ion implantation and thermal annealing of AlInN layer. Detailed XRD analysis was made to select high crystalline quality samples for ion implantation. The estimated value of Indium content in AlInN is 8.3%. Five pieces were cut from a wafer, out of which one was kept as-grown and the other four were implanted with neon ions using LC-4 high energy ion implanter at 250 keV. The doses received by four samples were 1×10^{14}, 2×10^{15}, 5×10^{15} and 9×10^{15} ions/cm^2. The implantation was carried out at room temperature and the ion beam was incident at 7 degrees off the c-axis of the samples to avoid the ions channeling into the substrate. The samples were annealed at 750 °C for 30 s in a nitrogen atmosphere after implantation for lattice

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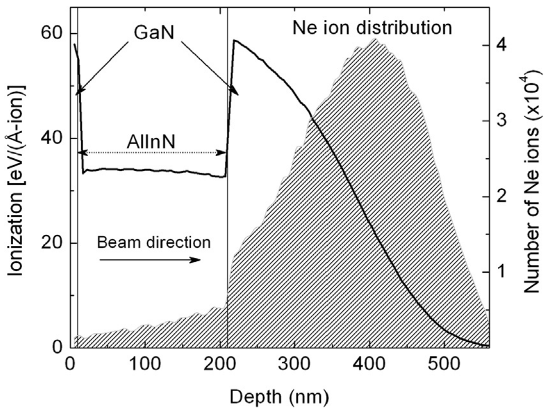

Fig. 1. SRIM estimated Ne ion distribution (right y-axis) and ionization produced in the materials (left y-axis).

recovery. A Rigaku SLX-1A X-ray diffractometer was used to record XRD curves and (0002) reflections to study the structural properties of the implanted samples. For RBS measurements a 2 MeV He ions beam of 1 mm diameter was used where backscattered particles were detected at 165° using a silicon detector of 18 keV resolution. The detector of aperture diameter 5 mm was placed 80 mm away from the samples holder.

3. Results and discussions

In order to understand the depth distribution of implanted Ne ions and to tune the right energy for the experiments, the SRIM simulations were performed on the same system of materials. In these simulations, it has been observed that the Ne ions with 250 keV pass through AlInN layer and stop in GaN substrate layer as shown in Fig. 1.

The XRD results published elsewhere [9] are given in Fig. 2 for sake of completeness. These results indicate the dose dependent increase in FWHM and shift of AlInN related peak towards lower angle side. Peak positions were exploited to find the strain and detailed analysis of variation of strain in AlInN layer was discussed there as a function of dose [9]. It is well known that an XRD peak position in such hetero epitaxial layers is a strong function of concentrations of contents of the layers. The shift of AlInN peak with dose may indicate the variation in indium content of the layer but presence of capping layer minimizes this possibility. The dose dependent shift in AlInN layer may be interpreted by strained induced in the layer by ion implantation damages as reported by Partyka et al. when they studied dose dependent strain analysis for argon implanted AlGaAs/GaAs [10]. Moreover, the increase in FWHM points to degradation of crystalline quality of the material. In order to further study the system, detailed RBS measurements were carried out on same samples.

The additional peak structure, seen on lower angle side of GaN (0002) peak, points to expansion of GaN cap layer lattice [11]. The presence of such peaks for all implanted samples indicates that cap layer is not removed after implantation and subsequent annealing. Fig. 3 shows normalized RBS random spectra of as-grown and neon implanted samples displaying signals coming from indium, aluminum and Ga atoms. Typical RBS spectrum of AlInN films exhibits uniform peak of Indium signal [12] pointing to the uniform indium distribution as a function of depth. However, in the present situation, appearance of two peaks indicated that the signal (channel number 380–440) related usually to indium atoms in AlInN layer is bifurcated into two parts. This may provide a wrong interpretation of results pointing towards non-uniform indium distribution throughout the AlInN layer. However, RUMP simulation of the data indicated that for as-grown samples, the peak present at channel number ∼395 is related to Ga atoms of the cap layer. Whereas, the peak at channel number ∼415 is due to signal coming from indium atoms present in AlInN layer. It is observed that yield ratio of Ga to In signal decreases after implantation. Since the height of the RBS signal is related to the atomic concentration, it can be said that the concentration of Ga atoms decreases after implantation which is due to sputtering of the GaN cap layer. On the other hand no sizeable change in height of indium related RBS signal is observed. Furthermore, it is observed that midpoint of Ga edge do not show a remarkable change which indicates that significant sputtering has not taken place. Therefore, we propose that a minor sputtering of cap layer has taken place and AlInN layer is not exposed after implantation and annealing. Signal coming from Al atoms also shows modifications as a result of implantation in such a way that Full Width at Half Maximum (FWHM) of Al related peak decreases.

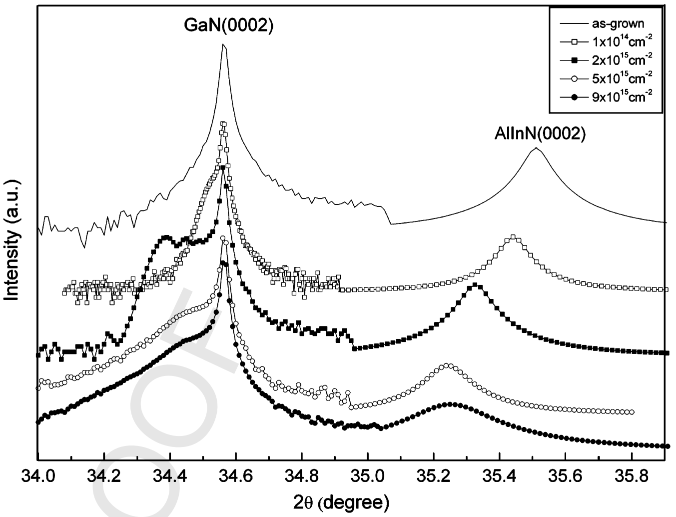

Fig. 2. X-ray diffraction curves showing (0002) peaks of as-grown and neon implanted AlInN/GaN samples [9].

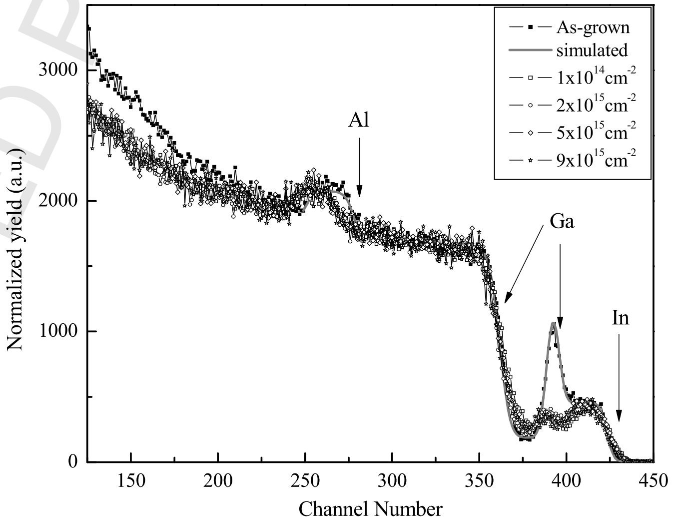

Fig. 3. RBS random spectra (normalized) of as-grown and neon implanted samples with doses mentioned in the inset. Simulation was carried out using RUMP.

Fig. 4 shows highlighted portion of RBS random spectra in channel number 380–440. This figure clearly shows Ga and In peaks for as-grown samples and modifications faced by them after implantation and annealing. Peaks are Gaussian fitted to find information about their position, FWHM and area under the curve which are given in Table 1.

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