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Thickness dependence of In content of InGaN mixed films by high-resolution Rutherford backscattering spectrometry

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Abstract

The thickness dependence of the indium (In) content of InGaN ultrathin films has for the first time been studied by high-resolution Rutherford backscattering spectrometry (HRBS). Single layers of InGaN films with different thicknesses under the same growth conditions were grown by radio-frequency molecular beam epitaxy (RF-MBE). The thicknesses of the InGaN films were designed to be 2.5, 5.0 and 10.0 nm, respectively. The In content of InGaN was also designed to be 16%. From the result of HRBS measurement, In composition was differed between among the samples with different film thicknesses, and increased along the growth direction. From the simulation fitting of the spectrum, the increase in In content saturated at a thickness of approximately the 4–5 nm. Channeling angular scanning was also carried out around the $\langle 11-23\rangle$ axis along the $(10-10)$ plane to determine the strain in InGaN ultrathin films (10 nm). By using the channeling angular scanning, the average tetragonal distortion in the InGaN ultrathin films was estimated to be $-2.07 \pm 0.39\%$ (that is, tensile strain along *c*-axis direction).

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Keywords: High-resolution Rutherford backscattering spectrometry; Channeling; Molecular beam epitaxy; InGaN; Strain

1. Introduction

Recently, InGaN mixed crystals have attracted much attention for the realization of commercial blue- and ultraviolet-light-emitting diodes and laser diodes, because the direct wide band gaps of these crystals cover a wide spectral range from red (InN) to UV (GaN). However, III nitrides are commonly grown on lattice- and thermal-mismatched substrates, with sapphire (with ~16% lattice mismatch with GaN) being the most frequently used. This lattice mismatch problem is

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partially overcome by growing an intermediate buffer layer to accommodate strain and defects, where the lattice mismatch between GaN and InN is larger than 10%. Due to this lattice mismatch, the exclusion of In atoms from the 100-nm-thick InGaN film during the growth significantly occurs, resulting two InGaN layers with different In content; The first InGaN layer near the InGaN/GaN interface has a low In content, and in the second layer the In content is raised up to the value determined by the equilibrium between the gas and solid phases [1,2]. In spite of important issues on the emission mechanism of quantum wells, there has been little information about the In exclusion on thin films [3].

The RBS/channeling technique is a powerful tool for the accurate determination of stoichiometry, elemental areal density and impurity distributions of thin films. The channeling effect steers particles along atomic rows under certain geometrical conditions. It can be used to measure the strain of epitaxial layers at normal incidence and tilt angles. Once the crystalline axes are aligned with the incoming beam, the number of backscattering events decreases sharply. In general, good epitaxy can only be achieved when the lattice parameters of the substrate and overlayer are almost the same. For a small lattice mismatch, the epitaxial layer can be accommodated by a vertical elastic strain in the overlayer. When the strained epilayer exceeds the elastic modulus, the strain will be accommodated by the induction of misfit dislocation. Although a depth resolution of 10 nm of RBS is sufficient for many applications, there have been increasing requirements for improving the depth resolution up to the monolayer order for the analysis of ultrathin layers. The high-resolution RBS (HRBS) system is a one of useful technology for evaluating ultrathin layers [4]. We have already studied the diffusion of In atoms in InGaN ultrathin films during post-growth thermal annealing using the HRBS system [5].

In this paper, we will for the first time describe the change in the In content at the InGaN/GaN interface with increasing thickness of the InGaN film using the HRBS method.

2. Experiment

For the HRBS measurements, InGaN films with different thicknesses were grown on a MOCVD-grown GaN template by radio-frequency molecular beam epitaxy (RF-MBE) at a constant substrate temperature of 700 °C. The GaN template, which was chemically etched with buffered hydrogen fluoride for 10 min was annealed at 845 °C for 30 min under nitrogen atmosphere at a nitrogen flow rate of 8.0 sccm, which corresponds to 1.57×10^{-4} Torr. After thermally cleaning the substrate, temperature was decreased to a growth temperature of 700 °C and InGaN was grown. The growth conditions are as follows: Ga flux of 2.70×10^{-7} Torr, In flux of 2.17×10^{-7} Torr, nitrogen flow rate of 1.6 sccm and plasma power of 350 W. The thicknesses of InGaN films were designed to be 2.5, 5.0 and 10.0 nm, respectively. The In content of InGaN was also designed to be 16%. The growth calibration was performed by scanning electron microscopy (SEM) and X-ray diffraction (XRD) analysis with a thick InGaN film grown under the same conditions.

HRBS measurements were carried out for the InGaN thin films with different thicknesses. The RBS/ion-channeling equipment (Kobe Steel, Ltd., MB1010-H) was constructed using a disktron accelerator, a beam line and a specimen chamber. The detector of the system was a micro-channel-plate position-sensitive detector (MCP-PSD) with an analyzing magnet for HRBS measurements. HRBS measurements were performed with a 0.45 MeV He^+ beam at a scattering angle of 80°. RBS/channeling angular scans through the $\langle 11-23 \rangle$ axis of the InGaN films following the $(10-10)$ planar direction were also performed to determine strain in the InGaN epilayer.

3. Results and discussion

The HRBS spectra of InGaN films in random geometry with a sample tilt angle of approximately 30° are shown in Fig. 1. In Fig. 1, solid lines correspond to simulated spectra for each random HRBS spectrum. The thickness and In content