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Effect of deposition conditions on properties of nitrogen rich-InN nanostructures grown on anisotropic Si (110)

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ABSTRACT

Nanocrystalline InN were fabricated on anisotropic silicon [Si(110)] substrates by reactive radio frequency sputtering. The effects of deposition conditions on the InN film characteristics were comprehensively studied. The films were prepared using different argon and nitrogen plasma ratios under 8×10^{-3} mbar at different temperatures and RF powers. X-ray diffraction measurements confirmed that all deposited films are wurtzite nanocrystalline InN films with (101) preferred growth orientation. All of the samples obtained under different deposition conditions were slightly N rich. For optimized deposition conditions, InN film on Si(110) substrate shows smooth surface with root-mean-square roughness around 2 nm. The optical properties of InN layers were examined by micro-Raman and FTIR spectroscopy at room temperature. The A_1(TO) and E_1(TO) modes observed were a consequence of the wurtzite nanocrystalline nature of RF-sputtered films.

1. Introduction

Indium nitride (InN) has a wurtzite crystal structure with a small band gap of 0.7 eV [1]. InN is an interesting semiconductor material because of its potential applications in optoelectronic devices, such as high efficiency solar cells, high electron mobility sensors, and transistors [2–5]. However, InN has received less attention compared with gallium nitride (GaN) and aluminum nitride primarily because of difficulties inherent in the preparation of its stoichiometric form. In addition, high-grade single crystal InN is difficult to grow due to its low dissociation temperature and less suitable substrates. Due to its low dissociation temperature, InN film should deposit at low temperatures to avoid N atom re-evaporation [6, 7]. Reactive sputtering is one of the most promising techniques of producing InN from the viewpoint of low-temperature film growth. InN layer synthesis on sapphire and glass substrates using reactive sputtering has been previously reported [8, 9], and InN deposition on different Si substrate orientations has been recently investigated [10–13]. The anisotropic Si(110) surface offers a unique orientation for GaN films compared to Si(001) where it can decrease the defect density and tensile stress for film cracking [14].

Nevertheless, few organized studies of nanocrystalline InN grown on anisotropic Si (110) substrate by radio frequency (RF) sputtering have been reported thus far [15, 16]. In the current study, InN nanostructures were successfully deposited by reactive RF magnetron sputtering on anisotropic Si(110) substrates. The structure and optical properties of the resulting films were investigated under various deposition gas concentrations, RF powers, and substrate temperatures.

2. Experimental

InN films were deposited by the reactive RF sputtering of a pure indium (In) target (99.99%), in an argon (Ar) and nitrogen (N_2) atmosphere. Prior to each deposition process, the In target was cleaned with a 10 min pre-sputter by

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Ar plasma in order to remove any previous target surface contamination. The base pressure was around 2×10^{-5} mbar and the deposition was maintained at constant pressure of approximately 8×10^{-3} mbar. Si(110) substrates were cleaned before putting in the substrate holder. The applied RF power, reactive gas concentration (Ar:N_2) and substrate temperature were varied in the range of 40–50 W, 10:10 sccm to 16:4 sccm, and room temperature to 300 °C, respectively. The obtained films were characterized with X-ray diffraction (XRD, PANalytical X'pert PRO MRD PW3040), atomic force microscopy (AFM, Bruker Dimension Edge), scanning electron microscopy (SEM, FESEM Nova NanoSEM 450) and energy dispersive X-ray spectroscopy (EDX). The optical properties of InN layers were examined by Fourier transform infrared (FTIR, PerkinElmer Spectrum GX) and micro-Raman spectroscopy (Horiba Jobin Yvon HR 800 UV) at room temperature. A standard four-point probe instrument was used to measure the resistivity of InN thin films.

3. Results and discussion

3.1. Effects of RF power

Since, the sputtered films are mostly amorphous; the growth mechanism of crystalline InN using the sputtering technique at room temperature without post-deposition annealing is important achievement which is studied under different deposition conditions in this paper. InN films were deposited on Si(110) substrates at various RF powers to investigate the effects of applied power on the film characteristics.

Fig. 1 shows the deposition rate of the deposited InN films as a function of applied RF power. The thickness of the InN films is around 0.36, 0.42 and 0.55 μm for the RF power of 40, 45 and 50 W respectively. Increasing the RF power result in enhanced deposition rates and subsequently increasing the film thickness. This is due to larger numbers of ionized atoms in the sputtering atmosphere are produced at higher RF power. Generally, the mobility of reactive species increases with increasing sputtering power [17]. However, active elements can also etch the growing surface and deteriorate the surface of the deposited films. As the RF power increases, higher bombardment rates on atoms result in increased atom mobility on the film surface.

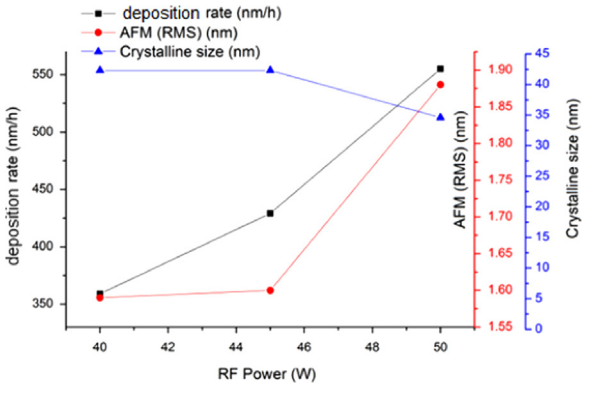

Fig. 1. Effects of RF power on deposition rate and RMS surface roughness of InN on Si(110) substrates.

This increases the atom mobility in the films and helps the films to release stress such that more crystallization is possible. The internal stress of the films is strongly dependent on ion energy [18]. At lower RF power, the lower deposition rates helps in creating films with lower internal stress. Therefore preferential film orientations (InN(101)) will grow more easily which can be observed with bigger crystalline size in Fig. 1. The average crystallite size D can be calculated using the following Scherrer formula [19]:

$$D = \frac{0.89\lambda}{B \cos \theta_B}$$

where B is the full width at half maximum of the InN(101) diffraction peak, λ is the wavelength of the X-ray (1.5406 Å) and θ_B is the Bragg diffraction angle of InN(101).

The root mean square (RMS) surface roughness of the deposited films from the AFM measurements indicated the nanostructure grain growth of the films (Fig. 1). The RMS values and average grain sizes increase with the sputtering power. Factors that may contribute to the increased film RMS roughness at higher sputtering powers include increased thickness and higher surface mobility [17].

The morphology and nanocrystalline structure of the InN thin films deposited on Si(110) were also examined by scanning electron microscopy (SEM). All films consist of agglomerated nanocrystals. Increased RF power results in larger grain sizes, as revealed by the SEM images in Fig. 2. A summary of EDX results for the InN thin films grown on Si substrates is shown in Table 1. In all samples, In, N, and O are observed. All of the samples are slightly N rich. As the RF power increases, the In and N atomic percentages per unit surface of samples gradually increase, providing evidence of the more-stoichiometric form of the films. The O is a common InN contaminant in all samples. It is most probably arise from the silicon oxide, i.e., formed at the substrate interfaces. The Si surface is prevalently oxidized by dissolved O during substrate cleaning by the RCA method. Despite the O contamination, however, no peak corresponding to the presence of In_2O_3 is observed in the X-ray patterns.

The FTIR spectra of InN thin films grown on the Si (110) substrates with different RF powers are shown in Fig. 3. Features corresponding to the E_1(TO) phonon modes of the InN are clearly observed at 480 cm^{-1} for all samples, which is comparable to the reported wurtzite InN values [20]. However, the E_1(TO) peak becomes more significant with increasing RF power, mainly because of the improved crystalline structures obtained at higher RF powers. Our results are consistent with those previously discussed.

The Raman spectra of InN films deposited at different RF powers are shown in Fig. 4. A relatively intense and fairly broad feature corresponding to the InN A_1(LO) mode is observed in all spectra. The frequency value of these peaks approach the frequency value of bulk InN (A_1(LO)= 586 cm^{-1}) [21]. The strong A_1(LO) bands are probably related to the low sample electron mobility in InN films deposited by reactive RF sputtering. InN films can be assigned to uncoupled A_1(LO) modes from the bulk; these modes are resonantly enhanced due to a broad resonance profile that is most likely related to the direct bandgap of the films [21, 22].