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Letter

Indium flux, growth temperature and RF power induced effects in InN layers grown on GaN/Si substrate by plasma-assisted MBE

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ABSTRACT

In the present work, we report the growth of wurtzite InN epilayers on GaN/Si (1 1 1) substrate by plasma-assisted molecular beam epitaxy (PAMBE). The growth parameters such as indium flux, substrate temperature and RF power affect the crystallographic and morphological properties of InN layers, which were evaluated using high resolution X-ray diffraction (HRXRD) analysis and atomic force microscopy (AFM). It is found that excess indium (In) concentrations and surface roughness were increased with increase in In flux and growth temperature. The intensity of HRXRD (0 0 0 2) peak, corresponding to *c*-axis orientation has been increased and full width at half maxima (FWHM) has decreased with increase in RF power. It was found that highly *c*-axis oriented InN epilayers can be grown at 450 °C growth temperature, 450 W RF power and 1.30×10^{-7} mbar In beam equivalent pressure (BEP). The energy gap of InN layers grown by optimizing growth conditions was determined by photoluminescence and optical absorption measurement.

1. Introduction

Indium nitride (InN) epitaxial layers and devices are currently under intense investigation, mainly due to the material's promising properties such as small effective mass, high electron drift velocity, and small band gap energy [1,2], which make it ideal for fast electronic devices, high efficiency solar cells and infrared laser diodes [3,4]. This narrow bandgap allows the group III-nitrides alloy system, such as (AlGaIn)N-based light emission devices, the possibility to operate in an extremely wide wavelength range from near-infrared to deep ultraviolet (0.7–6.2 eV). Initially, the InN films have been deposited by sputtering techniques, in which oxygen incorporation is a severe problem and the optical absorption was predominantly found at around 1.9 eV [5]. In contrast, the InN films grown by molecular-beam epitaxy (MBE) and metalorganic vapor phase epitaxy (MOVPE) techniques show much narrower direct bandgap as well as a significant improvement of the crystalline quality. However, in growing pure InN layers, the main difficulty lies with its thermal decomposition, which becomes excessive above 500 °C and its impurity incorporation problem, especially by oxygen [6]. Plasma-assisted molecular beam epitaxy (PAMBE) is a suitable method for producing InN, because low growth temperatures are possible in combination with an ultra high vacuum (UHV) growth environment, thus reducing the impurity incorporation [7]. The variations in the band-gap measurements were mainly attributed to the Burstein–Moss energy shift [8], the presence of oxide precipitates [9,10], the formation of indium (In) clusters [11] and other stoichiometry-related defects [12].

In this paper, we have studied the effect of growth parameters such as indium flux, substrate temperature and RF power on the crystallographic and morphological properties of InN layers. The energy gap of InN layers grown by optimizing growth conditions was determined by photoluminescence (PL) and optical absorption measurement.

2. Experimental details

The samples used for this study were grown by PAMBE system equipped with a radio frequency plasma source. The undoped Si (1 1 1) substrates were chemically cleaned followed by dipping in 5% HF to remove the surface native oxide. The substrates were thermally cleaned at 900 °C for 1 h in ultra-high vacuum. In all samples, first we have grown ultrathin layer of β-Si_3N_4 on Si (1 1 1) surface by exposing the surface to RF nitrogen plasma with a high content of nitrogen atoms. Then, a low temperature GaN buffer layer of thickness ~20 nm was grown at 500 °C followed by ~225 nm of GaN epilayers at 700 °C and details of growth conditions can be found elsewhere [13]. Afterwards, in samples (a), (b) and (c), the LT-InN buffer layers of thickness 30 nm were grown at 400 °C followed by 250 nm of InN films at 450 °C and indium (In) beam equivalent pressure (BEP) was kept at 3.45×10^{-7}, 2.20×10^{-7}, and 1.30×10^{-7} mbar, respectively. Nitrogen flow rate and plasma power were kept constant at 0.5 sccm and 350 W. In samples (d) and (e), the LT-InN buffer layers of thickness 30 nm were grown at 400 °C followed by 250 nm of InN films at 500 °C and

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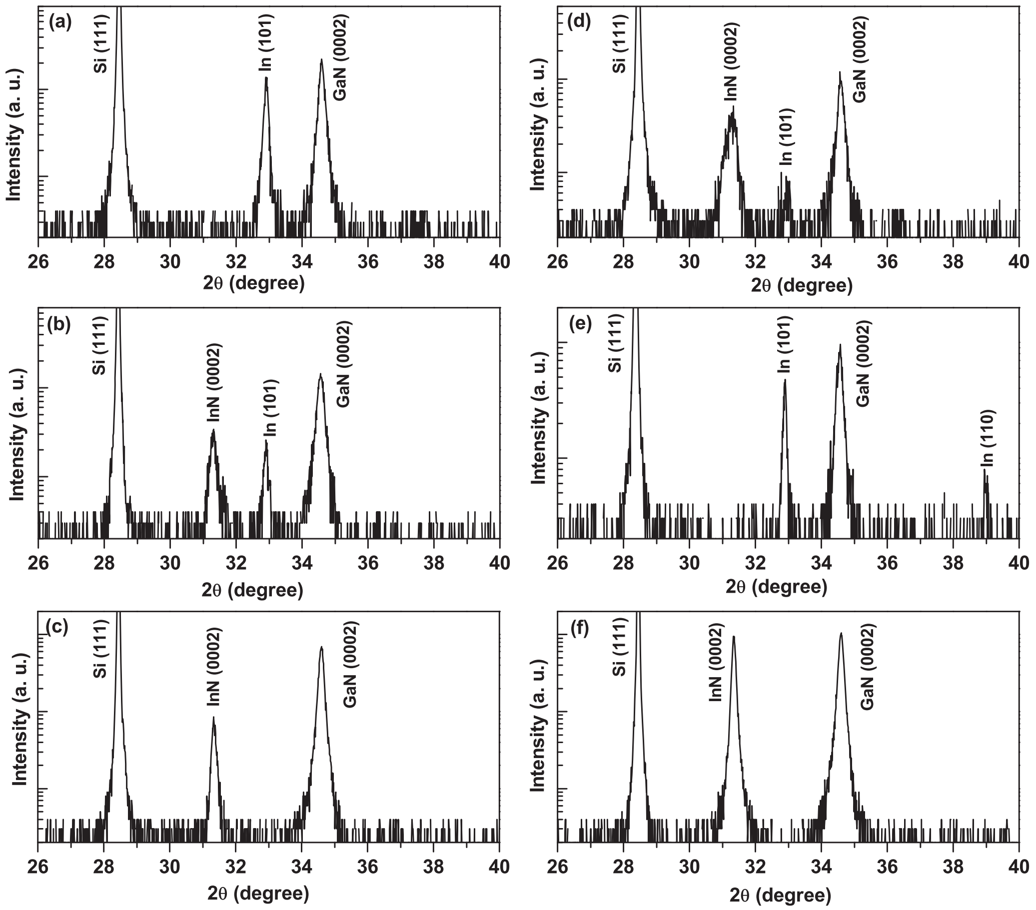

Fig. 1. (a)–(f) HRXRD 2θ–ω scans of InN heteroepitaxial layers of sample (a)–(f), grown on GaN/Si (1 1 1).

525 °C, respectively. The In BEP, nitrogen flow rate and plasma power were kept constant at 1.30×10^{-7} mbar, 0.5 sccm and 350 W as shown in Table 1. In sample (f), the LT-InN buffer layers of thickness 30 nm were grown at 400 °C followed by 250 nm of InN films at 450 °C. The In BEP, nitrogen flow rate and plasma power were kept at 1.30×10^{-7} mbar, 0.5 sccm and 450 W. The structural characterization and surface morphologies of the samples were carried out by high resolution X-ray diffraction (HRXRD) and atomic force microscopy (AFM), respectively. HRXRD measurements were carried out using a double crystal four-circle diffractometer (Bruker-D8 DISCOVER). AFM measurements were carried out using a VECCO (CP II) system. The PL spectra were recorded at 10 K using a closed cycle optical cryostat and He–Cd laser of 325 nm excitation wavelength with a maximum input power of 30 mW and optical absorption spectra were measured at room temperature for sample (f) by Bruker IFS 66v/s vaccum Fourier transform interferometer.

3. Result and discussion

Fig. 1(a)–(f) shows a typical 2θ–ω HRXRD scans of InN heteroepitaxial layers of sample (a)–(f), respectively. The peaks at $2\theta = 28.45°$, 31.33°, 32.95°, 34.58° and 39.03° are assigned to the Si (1 1 1), InN (0 0 0 2), In (1 0 1), GaN (0 0 0 2) and In (1 1 0) planes, respectively. From the figure it can be seen that the HRXRD diffraction intensities of InN layers decreased, when the In BEP was

Table 1
Growth parameters of InN layers grown on GaN/Si (1 1 1) substrate.

Sample name	In BEP (mbar)	Growth temp. (°C)	RF power (W)
(a)	3.45×10^{-7}	450	350
(b)	2.20×10^{-7}	450	350
(c)	1.30×10^{-7}	450	350
(d)	1.30×10^{-7}	500	350
(e)	1.30×10^{-7}	525	350
(f)	1.30×10^{-7}	450	450

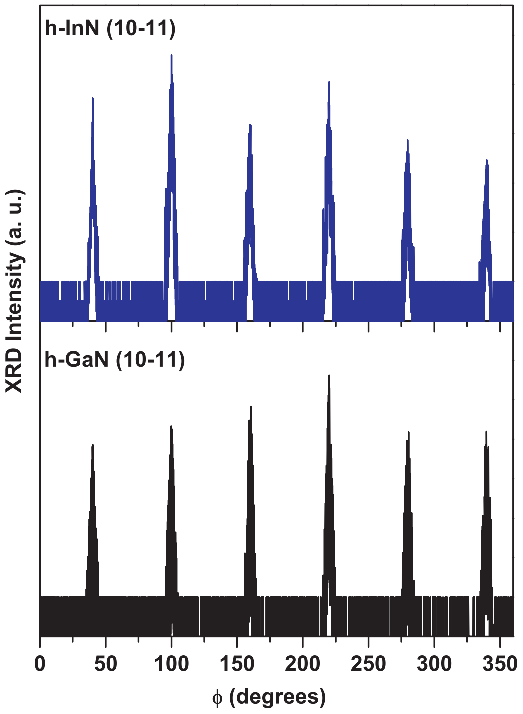

Fig. 2. In-plane Phi-scan measured from InN and GaN epilayers showing a sixfold symmetry.