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Sputtered growth of high mobility InN thin films on different substrates using Cu-ZnO buffer layer

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A R T I C L E I N F O

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A B S T R A C T

This work reports the growth of c-plane textured InN thin films on Cu-ZnO buffered silicon, c-sapphire, bulk GaN and quartz substrates. A Cu-ZnO buffer layer was deposited on all the substrates before the growth of InN film. A highly c textured film was obtained on sapphire and quartz substrates. Structural properties were calculated using XRD and Raman analysis. It was observed that, induction of Cu-ZnO buffer layer reduced the lattice mismatch between Si/GaN substrates and InN film. The bandgap of the films was obtained using UV visible reflectance spectroscopy. Hall measurements show high mobility films in the range of 119–223 cm^2/Vs and an electron concentration of 10^{19}. These results are in good agreement with previous results but are first time recorded using RF magnetron sputtering. Surface topography of the films showed smooth surfaces, which are due to reduced lattice mismatch between film and the substrate.

1. Introduction

III-V nitride semiconductors are widely used for optoelectronic applications due to their direct bandgap. Nitride based devices can be used to emit and detect light in the large spectrum range spanning from ultraviolet to infrared by tailoring their band gap and can also be used for high speed power electronics [1–4]. Therefore, III nitride materials have a great demand in research and industry. Among all the III nitride materials, InN and its alloys, InGaN and InAlN have not received much attention, owing to their challenging growth process [5]. Recent research has proved that InN possesses a heavy effective mass of holes and slow relaxation time of hot carriers, Which makes it a promising candidate for hot carrier based next generation photovoltaics [6].

Despite all the promising features, there are some obstacles that prevent the full realization of InN based devices, which include high quality single-phase growth of InN due to lack of suitable substrate and low dissociation temperature due to weak In-N bond energy (1.93 eV) [7,8]. The commonly used substrates for InN growth are sapphire, silicon, gallium nitride and silicon carbide with a lattice mismatch of 25%, 8%, 11% and 15%, respectively [9,10]. To overcome these difficulties, different growth methods were employed including radio frequency (RF) sputtering, molecular beam epitaxy (MBE), metal organic chemical vapor deposition (MOCVD), metal organic vapor phase epitaxy (MOVPE) and pulsed laser deposition(PLD). Generally, MBE and MOVPE has produced better results, but RF sputtering can grow InN even at room temperature which was not found with other techniques [11]. Also, RF sputtering is a low cost and easy technique to produce high quality InN films [12].

Another approach for the improvement of crystal quality is the use of inter/buffer layer. In case of MBE, MOVPE and MOCVD growth methods, AlN, GaN and In_2O_3 buffer layers were used [13–15]. Low temperature InN buffer layers and AlN/AlGaN/GaN stacks were also used to accommodate the lattice mismatch of InN with substrate [13–16]. For RF sputtering, InN, AlN, GaN and ZnO-Al buffer layers were reported [11,17,18]. The use of buffer layers is a common practice. However, a discrepancy of doped buffer layers is found in the literature. On the other hand, doped ZnO buffer layers have a less lattice mismatch with InN. Its wurtzite structure also makes it a suitable choice to be used as buffer layer [17,19]. For the enhancement of optical performance of nitride based devices such as LEDs and LDs, high transparency electrodes with low resistance are needed. The reason is, to increase transparency, metal thickness must be reduced, contact resistance increases and thus reducing long term stability. Therefore, transparent conducting metal oxides (TCOs) are promising materials for contacting purposes. These TCOs provide great transmittance in the visible range and excellent electrical conductivity. The commonly used TCO is Al doped ZnO. Here we will be using Cu doped ZnO (Cu-ZnO) as a buffer layer for InN growth. We will be looking at the overall impact of Cu-ZnO buffer layer on InN film and whether it can be used as a contact layer for the InN film.

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In this study, InN films were grown on different substrates namely, c-sapphire, p-type silicon (111), bulk gallium nitride and quartz. Prior to the deposition, Cu-ZnO buffer layer was deposited on all the four substrates. To the best of our knowledge, Cu-ZnO layer was first time used as a buffer layer for InN epitaxy. No previous reports of Cu-ZnO as buffer layer were found in any growth technique and at least not in RF sputtering.

2. Experiment

This experiment involves two steps, first step involves the deposition of a Cu-ZnO buffer layer followed by the growth of an InN film on Cu-ZnO buffered substrates. The substrates used include c-sapphire, bulk GaN, p type-Si (111) and quartz glass. Prior to deposition, the substrate cleaning was carried out by the following methods [20–23]. After cleaning, the samples were separately rinsed in deionized water and then blow dried with nitrogen gas.

The samples were loaded inside the RF sputtering chamber (Model: APX). A target of Cu-ZnO alloy with Cu and ZnO ratio of 10% and 90% respectively was also loaded in the chamber. The growth of Cu-ZnO buffer layer was carried out in an argon atmosphere. The growth parameters of the Cu-ZnO buffer layer are given in Table 1. After the deposition of buffer layer, an InN target of 99.9% purity was loaded inside the camber. An InN thin film was grown on the buffered substrates under nitrogen and argon environment. Table 2 shows the growth parameters for InN film.

The structural analysis of Cu-ZnO buffer layer and InN film was carried out by XRD using PANanalytical X'pert X-ray diffractometer which uses a CuKα radiation of 1.54 Å. The surface analysis of the films was evaluated using atomic force microscopy (AFM) (Model: Dimension Edge, Bruker). Raman analysis and UV visible spectroscopy using a Jobin Yvon HR 800 UV spectrometer system and Cary 5000 spectrophotometer respectively were used to investigate the optical properties. Hall effect measurements (Model: Lakeshore Controller 601/DRC-93CA) were carried out to study the electrical properties of the films. The transmittance spectra of Cu-ZnO buffer layer was also investigated using UV visible spectroscopy.

3. Results and discussions

The structure of InN and Cu-ZnO buffer layer on all the four substrates was confirmed from XRD 2 θ scans as shown in Fig. 1. From the XRD pattern, the Cu-ZnO buffer layer has a wurtzite structure and InN diffraction peak occurs along (002) plane. This shows that InN film grown by using RF sputtering has preferred orientation towards (002) plane. No other peaks were observed for Cu-ZnO buffer layer and the layer was highly textured along c plane. The hexagonal wurtzite structure of the film was also confirmed from the XRD reference code (00-036-1451). The XRD pattern shows that the peak intensities are weak for silicon and glass substrates. In case of GaN, the (002) peaks of Cu-ZnO buffer layer and GaN substrate seems overlapping at a 2 θ angle of 34.48 °. In case of InN films, a strong peak is observed at 31.2 ° which belongs to (002) plane of hexagonal wurtzite InN. Although a small low intensity peak is observed at 56.6 ° which belongs to (103) plane of hexagonal InN, but the film is highly textured along c-plane. The hexagonal wurtzite nature of the InN film was again confirmed from the XRD reference code (00-050-1239). All other substrate peaks are mentioned in Fig. 1. The XRD pattern also shows a small peak at 30.5 ° for quartz substrate, this peak belongs to (222) plane of cubic indium oxide (In_2O_3) as confirmed from XRD reference code (00-006-0416). But no In_2O_3 peaks were observed on sapphire, gallium nitride and silicon substrates.

Table 1
Growth parameters for Cu-ZnO buffer layer.

Target	Cu-ZnO alloy
Target ratio (Cu: ZnO)	**10%:90%**
Chamber pressure	**3 × 10^{-5} mbar**
Argon flow	**10 sccm**
Target to substrate distance	**8 cm**
RF power	**100 W**
Temperature	**Room temperature (25 °C)**
Thickness	**100 nm**

Table 2
Growth parameters for InN film.

Indium target	99.9% purity
Base pressure	**2.5 × 10^{-5} mbar**
Argon flow	**12 sccm**
Nitrogen flow	**8 sccm**
Working pressure	**2 × 10^{-2} mbar**
Target to substrate distance	**8 cm**
RF power	**55 W**
Temperature	**250 °C**
Deposition rate	**2–4 Å/s**

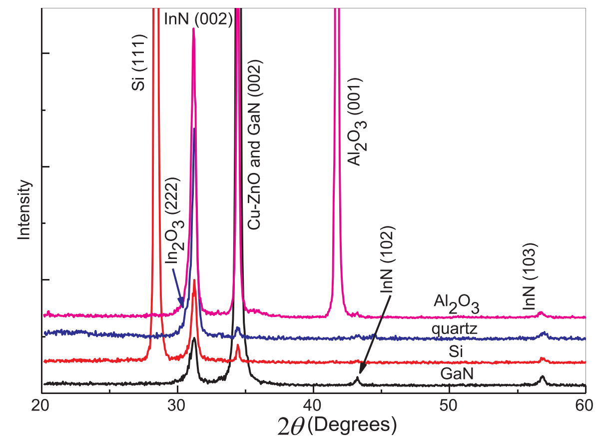

Fig. 1. XRD pattern of InN on different substrates with Cu-ZnO buffer layer.

The lattice parameters (c) and (a) along the (002) plane of hexagonal wurtzite structure of InN were calculated using the following equations [24]

$$c = c_o(\epsilon + 1) \quad (1)$$

here, c_o is the lattice parameter of strain free InN which is equal to 5.70 Å, λ is the x-ray wavelength (0.154 nm), θ is the Bragg angle in degrees and ϵ is the strain of InN film, which is given by the equation [25]

$$\epsilon = \frac{\beta cos\theta - (\frac{k\lambda}{D})}{2sin\theta} \quad (2)$$

where β is the full width at half maximum (FWHM) taken in radians, k is a constant (0.9) and D is the crystallite size given by Scherrer's formula [26]

$$D = \frac{k\lambda}{\beta cos\theta} \quad (3)$$

Table 3 shows the highest crystallite size for the films grown on

Table 3
FWHM, crystallite size, strain and lattice parameters for InN films grown on different substrates with Cu-ZnO buffer layer.

Substrate type	FWHM (deg.)	D (nm)	strain (ϵ)	c (Å)	a (Å)
Silicon	0.42	22.116	1.235e^{-8}	5.07042	3.149329
Sapphire	0.39	23.817	−4.333e^{-8}	5.75298	3.573279
Quartz	0.40	23.222	6.14e^{-8}	5.34998	3.322968
Bulk GaN	0.44	16.586	−4.697e^{-7}	5.32235	3.305807