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Low-temperature growth of highly c-oriented InN films on glass substrates with ECR-PEMOCVD

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A B S T R A C T

High quality InN films are deposited with an interlayer of high c-orientation (002) AZO (Aluminium-doped Zinc Oxide; ZnO:Al) films on glass substrates by electron cyclotron resonance plasma-enhanced metal organic chemical vapor deposition (ECR-PEMOCVD) at low temperature. AZO films used as a buffer layer are effective for the epitaxial growth of InN films. The influence of Trimethyl Indium (TMIn) flux on the properties of InN films is systematically investigated by reflection high energy electron diffraction (RHEED), X-ray diffraction analysis (XRD), atomic force microscopy (AFM) and optical transmittance spectra. The results indicate that high quality InN films with high c-orientation and small surface roughness are successfully achieved at an optimized Trimethyl Indium (TMIn) flux of 5.5 sccm. The InN/AZO structures have great potential for the development of full spectra solar cells.

1. Introduction

III-Nitride (InN, GaN and AlN) semiconductors have attracted significant academic and commercial interests and led to the developments in optoelectronic devices due to their highly attractive inherent properties [1]. InN has attracted much more attention due to its highest electron drift velocity, smallest effective mass and the smallest direct band gap in the III-nitride group. These properties make it be a very significant material with potential new applications for photonic and electronic devices in the near future [2–5]. Recently, it has been reported that the band gap of InN is between 0.6 eV and 0.7 eV, much smaller than the previously accepted value of 1.9 eV. So the direct band gaps of the III-nitride group span the range from 0.6 eV to 6.2 eV, including the whole of the visible region and extending well into the ultraviolet range to make full spectra solar cells possible [6]. TCO (transparent conductive oxide) films, due to their excellent photoelectric properties, are now frequently used in the display and solar cell industry. Compared to the widely used ITO films [7], AZO (Aluminium-doped Zinc Oxide) films have high transmittance in the visible region, low resistivity, higher chemical and mechanical stability, and are easily doped [8–11]. AZO films are expected to be one of the most promising TCO films to be applied as transparent electrodes in solar cell and LCD (liquid crystal displays).

It is worthwhile to mention here that there have been limited reports on high quality InN films deposited at low temperature. In this study, the high quality InN films are successfully achieved at the low temperature by electron cyclotron resonance plasma-enhanced metal organic chemical vapor deposition (ECR-PEMOCVD) with different Trimethyl Indium (TMIn) flux. The ECR-PEMOCVD system combines advanced features of MBE and MOCVD, which is a new type of as-grown film deposition technology, and this method can produce high-density charged and excited particles by using a microwave electron cyclotron resonance discharge at low pressure. Since the multicusp cavity-coupling ECR plasma source was adopted to provide active precursors, the growth temperatures were effectively decreased and the N_2 reactivity can be significantly enhanced by the ECR process, this method was necessary for the formation of InN films at low temperature.

However, the low dissociation temperature, the extremely high equilibrium vapor pressure of nitrogen and the suitable substrate material make the growth of high quality InN films be very difficult [12]. In this study, AZO films and InN films were prepared by radio-frequency magnetron sputtering and electron cyclotron resonance plasma-enhanced metal organic chemical vapor deposition (ECR-PEMOCVD), respectively. The N_2 reactivity can be significantly

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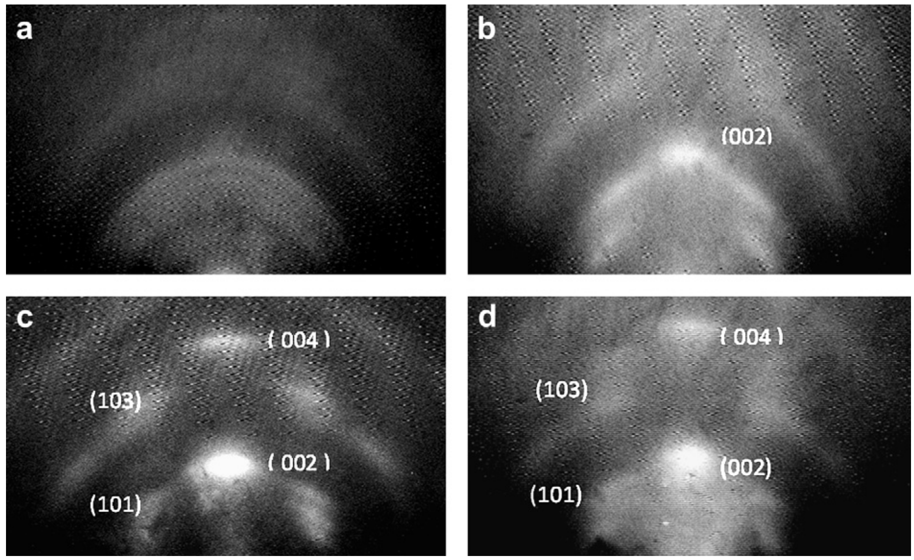

Fig. 1. The RHEED images of InN films deposited at different TMIn flux of 4.5 sccm (a), 5.0 sccm (b), 5.5 sccm (c), and 6.0 sccm (d), respectively.

enhanced by the ECR process, which was necessary for the formation of InN films at low temperature. The AZO films as the buffer layer between the glass substrates and InN films have advantages over other materials. For example, compared with the 25% for sapphire, the lattice mismatch between InN and ZnO on the c-plane is as low as 8.8% [13,14]. The influence of the Trimethyl Indium (TMIn) flux on the characteristics of the InN epitaxial layers is investigated. The results demonstrate that the high c-orientation InN films are successfully achieved at the optimized Trimethyl Indium (TMIn) flux of 5.5 sccm.

2. Experiment

The AZO films were prepared on glass substrates by radio-frequency magnetron sputtering with thickness about 150 nm. Prior to the growth of the AZO films, the substrate was cleaned ultrasonically with acetone, ethanol and deionized water sequentially [10]. The InN films were grown on AZO (002) films deposited on glass substrates by the home-made electron cyclotron resonance plasma-enhanced metal organic chemical vapor deposition (ECR-PEMOCVD) system [15–18]. And the insertion of a low temperature InN buffer layer in the initial growth process has been proposed as a method of alleviating the lattice and thermal mismatches between AZO films and InN epitaxial layers, and this method also used to supply nucleation centers with the same crystallographic orientation as the substrates [19–22]. Trimethyl indium (TMIn) and N_2 were employed as the reactant source material for In, and N, respectively, and H_2 was used as the carrier gas. The temperature of Trimethyl indium (TMIn) was kept at 20 °C with semiconductor well. The reactivity of N_2 can be remarkably enhanced by the ECR process, which can lower effectively the temperature for InN film formation. Prior to initiation of the growth of epitaxial layer, the growth of buffer layer was performed by exposing the glass substrates to In flux of 4.0 sccm, and N_2 flux of 80 sccm for 30 min at 350 °C with thickness about 60 nm. Subsequently, the InN growth was carried out at about 450 °C for 200 min with the N_2 flux of 100 sccm controlled precisely by mass flow controller. The Trimethyl indium (TMIn) flux varied in the range from 4.5 to 6.0 sccm in order to investigate the effect of Trimethyl indium (TMIn) flux on the properties of as-grown films. The films thickness is investigated by step meter. The thickness of the as-

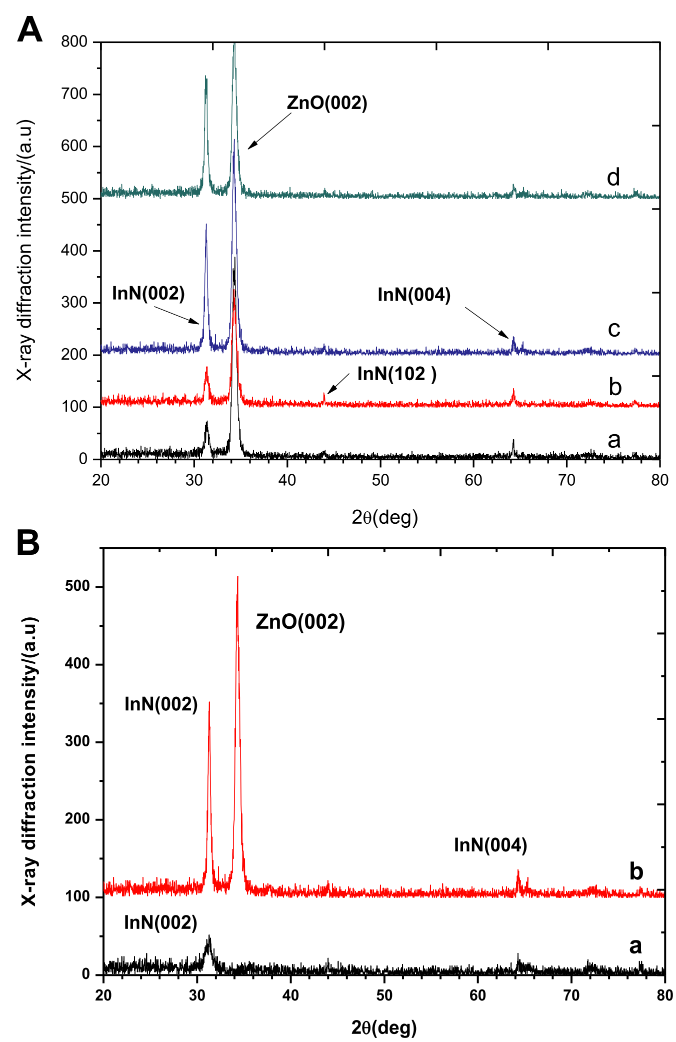

Fig. 2. (A) XRD patterns of the InN thin films grown at the TMIn flux of 4.5 sccm (a), 5.0 sccm (b), 5.5 sccm (c), and 6.0 sccm (d), respectively. (B) XRD patterns of the InN thin films grown with the AZO buffer layer (a) and without AZO buffer layer (b), respectively.