Applied Surface Science 459 (2018) 830–834

Contents lists available at ScienceDirect

Applied Surface Science

journal homepage: www.elsevier.com/locate/apsusc

Full Length Article

Low temperature growth of polycrystalline InN films on non-crystalline substrates by plasma-enhanced atomic layer deposition

Hong Peng[a], Xingcan Feng[a], Jinhui Gong[a], Wei Wang[a], Hu Liu[a], Zhijue Quan[b], Shuan Pan[b], Li Wang[a,*]

[a] School of Material Science and Engineering, Nanchang University, Nanchang 330031, China
[b] National Institute of LED on Si Substrate, Nanchang University, Nanchang 330047, China

ARTICLE INFO

Keywords:
Indium nitride
Thin films
PE-ALD
Polycrystalline

ABSTRACT

Indium nitride (InN) has attracted much attention due to its high electron mobility and peak electron velocity, which make it suitable for fabrication of high-speed electronic devices. In this work, we report the low temperature growth of polycrystalline InN on non-crystalline substrates by plasma-enhanced atomic layer deposition (PE-ALD). InN thin film is amorphous in nature during the initial growth stage. With the increasing growth cycles, the starting nuclei compete for space respectively and select orientations of crystal. After about 800–1200 cycles, the nuclei will grow on the suitable planes and the film turn into polycrystalline. The amorphous to polycrystalline transition of InN film is revealed definitively by the evolution of XRD patterns and the intensity of diffraction peaks with the growth cycles.

1. Introduction

Thin-film transistors (TFT) are the key components of flat panel display [1]. To a large extent, the performance of a TFT is determined by its active layer. In 1979, Lecomber et al. [2] described the characteristics of TFT using amorphous silicon as the active layer. Since then, amorphous silicon has been the most widely used active layer material for TFT in panel displays due to the advantages of low cost and excellent uniformity [3–5]. However, the electron mobility of amorphous silicon is only about 0.5 cm^2/Vs [6,7], which is too low for high-speed or large-current applications, such as the driving circuit of organic light emitting diode (OLED) display [8]. To enhance the mobility of the active layer, low temperature polysilicon (LTPS) technology has been introduced in the fabrication of TFTs [9,10]. The LTPS is a process which can get high electron mobility up to 350 cm^2/Vs [11]. But its complexity makes it an expensive process [9]. So, it is important to seek other active layer materials with high electron mobility.

Recently, indium nitride (InN) began to receive attention from the TFT community [12], due to its high electron mobility and peak electron velocity, which make it suitable for fabrication of high-speed electronic devices. InN has a high electron mobility of about 3500 cm^2/Vs at room temperature in experiment [13]. Polyakov et al. predicted that the room temperature electron mobility of InN may be as high as 14,000 cm^2/Vs by theoretical calculations [14]. Generally, InN thin films are grown on monocrystal substrates like sapphire [15,16] and Si [17–19], because the proper orientation of the film can be offered by the monocrystal substrates. However, to meet the cost requirement of the display industry, TFT are required to be grown on low cost non-crystalline substrate, such as glass or polymers [20–22]. The traditional growth techniques for InN, such as metal organic chemical vapor deposition (MOCVD) [23] and molecular beam epitaxy (MBE) [15,16,18], usually need a high growth temperature, which are not suitable for growth on glass or polymer substrates. Magnetron sputtering is a film growth technique that can work at even room temperature. Lye et al. [12] has reported the preparation of polycrystalline InN thin film on polyimide by magnetron sputtering at room temperature. But, the polycrystalline InN thin films fabricated on polyimide in their work are too rough that are not suitable for TFT fabrication. Therefore, it is necessary to find another low temperature growth method to fabricate polycrystalline InN thin films on non-crystalline substrates.

ALD is a method in which the gas phase precursors are pulsed alternately into a reaction chamber and a surface chemical adsorption reaction occurs on the deposition substrate [24]. The advantages of ALD include its ability to grow conformal, uniform, crystalline thin film with good surface morphology at low temperature [25]. Plasma-enhanced atomic layer deposition (PE-ALD) utilizes an additional energy source of the plasma induced by an electric field to acquire high quality thin film [26,27]. In this study, we fabricated InN thin films on glass

* Corresponding author.
E-mail address: wl@ncu.edu.cn (L. Wang).

https://doi.org/10.1016/j.apsusc.2018.08.093
Received 25 June 2018; Received in revised form 3 August 2018; Accepted 8 August 2018
Available online 09 August 2018
0169-4332/

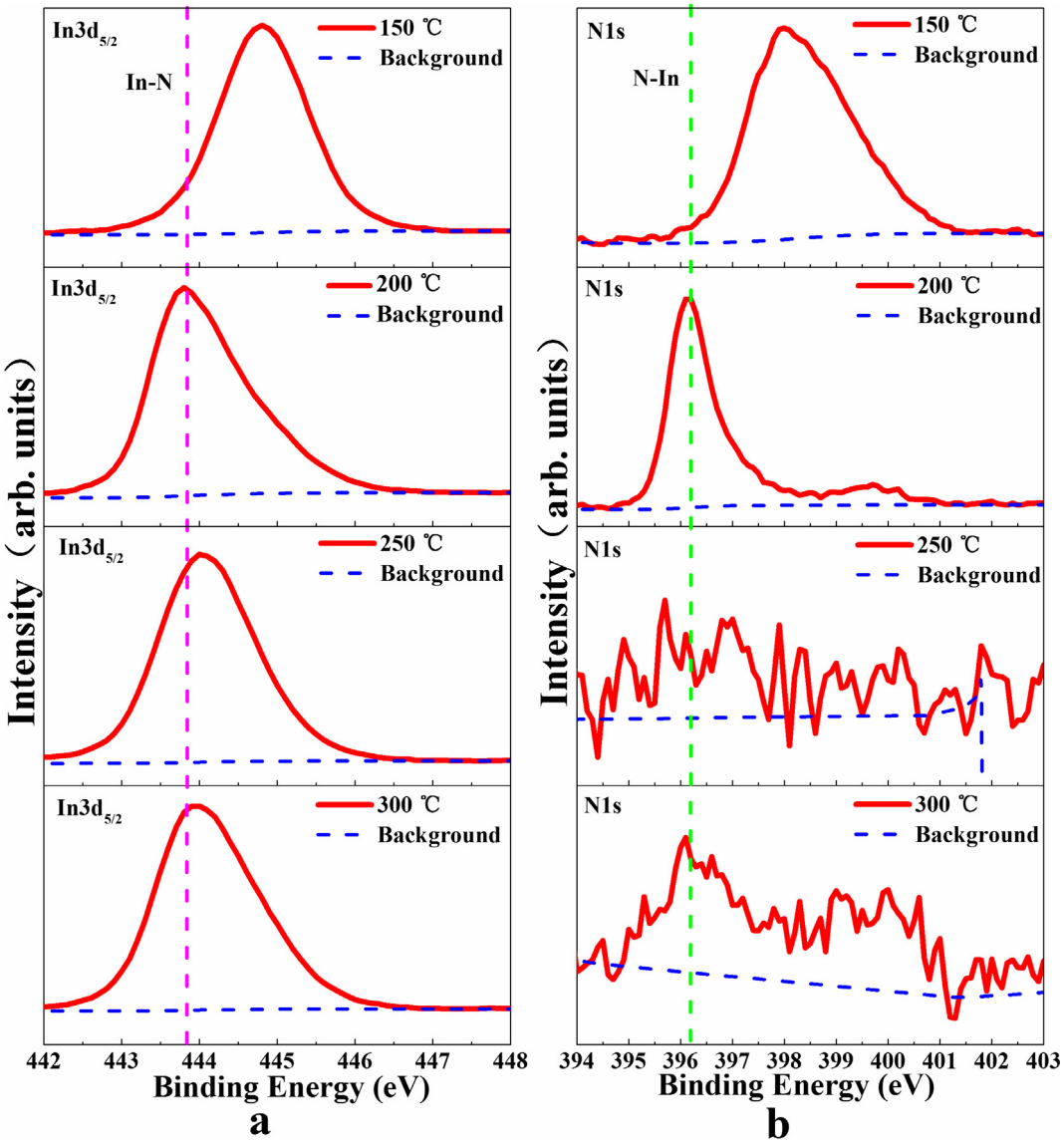

Fig. 1. XPS spectra for InN thin films deposited on glass at different temperatures. (a) In $3d_{5/2}$ peak obtained from InN thin film grown at 150–300 ˚C. (b) N1s peak obtained from InN thin film grown at 150–300 ˚C.

and polyimide substrates using PE-ALD. By X-ray diffraction measurements, we found that polycrystalline InN thin film can be grown by PE-ALD on glass and polyimide at a low temperature of 200 ˚C.

2. Experimental

InN thin films were deposited on glass and polyimide substrates, the substrate size was 20 × 20 mm^2. Before deposition, the substrates were cleaned by sonication in acetone and alcohol for 10 min to remove surface contaminants, and then dried by N_2. TriMethylIndium (TMI) precursors and N_2 plasma were carried from separate lines using 45 and 20 sccm Ar, respectively. Ar is used as the carrier gas for N_2 plasma so the plasma is a mixed N_2/Ar plasma. The plasma power was 200 W, the dose time for TMI and N_2 plasma were 0.025 s and 100 s, respectively, the purge time after TMI and N_2 plasma dose were both 60 s. The temperature of the TMI source bottle was kept at 45 ˚C. The composition of the films were measured by X-ray photoelectron spectroscopy (XPS, ESCALAB250xi, Thermo Fisher Scientific). The surface morphologies of the films were observed by scanning electron microscope (SEM, JSM 6701F) and atomic force microscope (AFM, Dimension Edge). The structural properties of the films were evaluated by X-ray diffractometer (XRD, PANalytical X'pert powder) and Raman spectra (LabRAM HR Evolution).

3. Results and discussion

Fig. 1 shows the XPS spectra of the InN films grown on glass at different temperatures. The films were grown at 150, 200, 250, and 300 ˚C, respectively, and all with 200 growth cycles. Previous studies have reported that the binding energy of $In3d_{5/2}$ peak in In-N state is about 443.8 eV [28–30]. From Fig. 1(a) we can see that the $In3d_{5/2}$ peak of the samples grown at 200 ˚C, 250 ˚C and 300 ˚C are all very close to the previous reported binding energy. But in the sample grown at 150 ˚C the $In3d_{5/2}$ peak appears at 444.8 eV, which is remarkably shifted to higher energy. This indicates that the local bonding environment of the Indium atoms in this sample are significantly deviated from the pure In-N state. Fig. 1(b) shows the N1s spectra of the same four samples. Again, the N1s peak of the InN film grown at 200 ˚C is very close to the previously reported energy position, 396.2 eV [31], while the N1s signal of the sample grown at 150 ˚C is shifted to higher energy. The N1s signal from the samples grown at 250 ˚C and 300 ˚C are too weak to determine their precise positions. We calculated the In/N