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Growth of semipolar InN (10-13) on $LaAlO_3$(112) substrate

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In this study, we report the growth and characterization of semipolar (10-13) InN films grown on $LaAlO_3$ (112) substrate by metalorganic molecular beam epitaxy. InN films were grown at various substrate temperatures in the range of 465~540 ^oC. Structural and optical properties of semipolar InN were investigated by high resolution x-ray diffraction (XRD), scanning electron microscopy (SEM), and photoluminescence (PL) measurements. The results show that semipolar (10-13) InN layers can be grown at 510^oC with the full-width at half maximum of the x-ray rocking curve about 1400 arcsec and electron mobility of 494 cm^2/V-s.

1. Introduction

Indium nitride (InN) has received an increasing attention among the group III-nitrides, thanks to its small effective mass and the highest electron drift velocity [1]. Recently, indium nitride (InN) has received intensive research interest mainly due to its potential applications in high-speed, high-frequency electronics, light-emitting diodes (LEDs) and high efficiency solar cells [2]. InN is a direct band-gap material and the band-gap of InN has been recently recognized to be than loss 0.67 eV [3].

There are some difficulties in growing single crystalline InN films, related to the low decomposition temperature of InN, which makes growth at high temperature impossible and the lack of suitable substrate material that are lattice matched and thermally compatible with InN. InN is known to have a quite low growth temperature, as compared to other nitrides [4].

Generally, InN has hexagonal wurtzite crystal structure, and is most commonly grown along the (0001) orientation. However, c-axis oriented optoelectronic devices suffer large piezoelectric polarization field. Also, it results in the low electron–hole recombination efficiency. A useful approach for reducing the deleterious effects of the built-in field is to grow along the nonpolar or semipolar direction. However, nonpolar InN often contains a high density of stacking faults and edge dislocations. These defects certainly degrade the device performance. On the other hand, semipolar InN is expected to have a low piezoelectric polarization effect as well, and might be grown with reasonable quality in view of semipolar GaN growth.

Though growth of nonpolar and semipolar III-group nitride films has gained much interest in recent years, very few studies on nonpolar InN have been reported and there are only a couple of reports on semipolar InN growth [5-6]. The growth of high quality nonpolar and semipolar InN is very challenging, especially for metalorganic molecular beam epitaxy (MOMBE) in which the growth window is very narrow even for c-plane InN growth.

In this work, we established the metalorganic molecular beam epitaxy (RF-MOMBE) to fabricate semipolar (10-13) InN thin films and characterized the film crystallinity and surface morphology by x-ray diffraction (XRD) and scanning electron microscopy (SEM). Also, we report on the effect of substrate temperature on the growth of InN thin films on $LaAlO_3$ (LAO) substrate. LAO is a pseudo cubic perovoskite crystal with lattice parameter of 0.379 nm which has been used to grow nonpolar ZnO and GaN.

2. Experiment

Semipolar InN films were grown on LAO (112) substrate in a MOMBE system with a base pressure of ~10^{-9} Torr. The trimethylindium was used as the group-III source, and the group-V source was atomic nitrogen generated by radio-frequency (RF) plasma. Prior to the growth of InN, the $LaAlO_3$ substrate was cleaned by heating at 550 ^oC for 30 min in vacuum. The growth temperature was set at a temperature in the range of 465~540 ^oC to grow InN films for 2 hours at working pressure about 2.0 × 10^{-5} Torr. During the deposition, the substrate temperature was monitored using a thermal couple on the heater. XRD and field-emission SEM were used to investigate crystal qualities and structural properties of the semipolar InN films. We also measured electrical properties of the samples by Hall measurement using the van der Pauw configuration. The optical properties were measured by photoluminescence at room temperature.

3. Results and discussion

Fig. 1(a) exhibits XRD theta-2 theta patterns of InN

samples grown on LAO (112) substrate at different temperature from 465 to 540°C. All InN films were grown under In-rich condition. For the sample grown at 510 °C, it can be clearly seen in the pattern only a highly preferred orientation diffraction peak of InN (10-13) at 56.9°. However, for 465 and 540°C grown InN films, the diffraction peaks other than InN (10-13) appear, including the InN (0002) diffraction peak at approximately 31.3°. The results are similar to report of Takagi et al. on m-plane growth of InN on $LiAlO_2$ [7]. Also, x-ray phi-scan of InN (002) as shown in Fig. 1(b) reveals that 510°C InN can be in epitaxy with LAO substrate with epitaxial relationship of InN(10-13) // LAO (112) and $[1\text{-}210]_{InN}$// $[11\text{-}1]_{LAO}$, and the (10-13) rocking curve measurement of the film in Fig. 1(c) shows that the narrow full-width at half maximum is about 1400 arcsec.

Figures 2(a)-(c) are SEM images showing top-down view of InN films grown on LAO at different growth temperatures. The surface morphology is obviously varied with growth temperature, and the surfaces in all cases are rough. Interestingly, both the film surfaces of 510 and 540°C InN films exhibit strong faceted morphology. Also, it is observed that the 540°C InN film has developed to include some hexagon crystallites. The result is in agreement with the report of c-plane InN growth on sapphire by Kuo et al. [8].

Fig. 3 is a plot of Hall mobility of InN films versus from growth temperature, showing that 465°C InN has the lowest mobility of 80 cm^2/V-s, and the 510 °C InN exhibits the highest Hall mobility of 494 cm^2/V-s probably due to its good crystallinity. Furthermore, PL data at room temperature showed a maximum of near band-edge at energies between 0.7 - 0.75 eV for the InN films deposited.

3. Conclusions

In summary, the semipolar (10-13) InN films was successfully prepared on $LaAlO_3$ (112) substrate in the range of 465-540°C by MOMBE without nitridation process. The XRD and SEM indicate that the growth of InN (10-13) films is highly dependent on the growth temperature, and epitaxial (10-13) InN can only be grown at 510°C with rough and faceted surface morphology.

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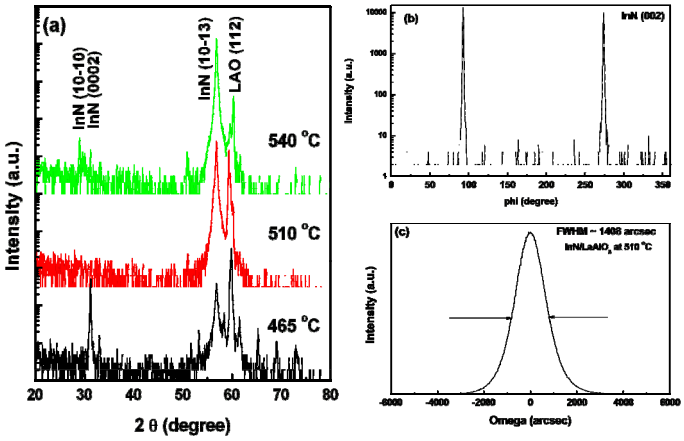

Fig. 1 (a) XRD patterns of InN films deposited at different temperatures. (c) XRD ϕ-scan profiles of InN (0002) on LAO substrate at 510 °C. (b) ω-scan XRD profile of (10-13) InN at 510°C.

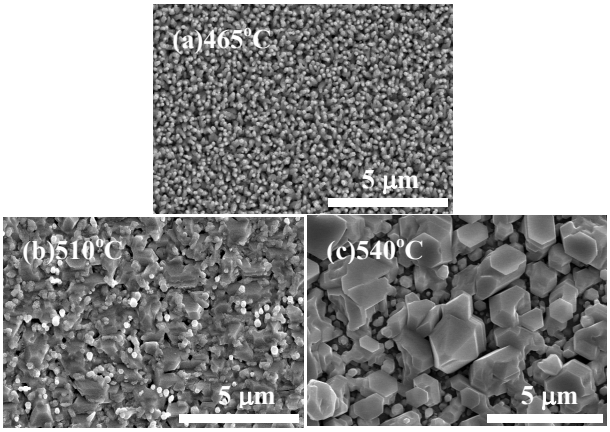

Fig. 2 SEM images of InN films grown at different substrate temperature.

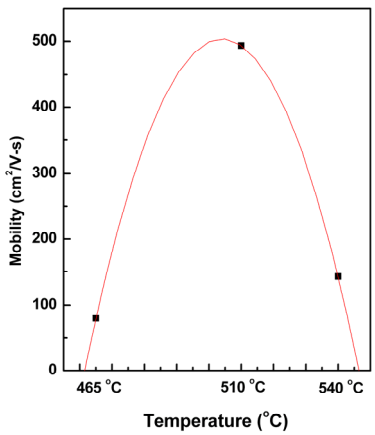

Fig. 3 Hall mobility of InN films grown at different substrate temperature.