InN Thin Films Deposition by rf Magnetron Sputtering

Mariana T. Braic[a], Catalin N. Zoita[a], Viorel T. Braic[a], Mariana I. Toacsan[b] and Andrei T. Ioachim[b]
[a] National Institute of Optoelectronics, Magurele-Bucharest, RO-77125 Romania
[b] National Institute of Materials Physics, Magurele-Bucharest, RO-77125 Romania

***Abstract*— InN thin films were grown by reactive magnetron sputtering in a UHV system, using Ar and N_2 as working gases. Electrical and optical investigations of the films were correlated with their structural and morphological characteristics in order to obtain good quality films for THz applications.**

I. Introduction And Background

Of all the III-nitride materials, InN is the least studied at the moment, but the interest it attracts is quickly picking up[1-3]. Finally, InN films have received the same attention as GaN and AlN. Because of their low dissociation temperature (as low as 823 K at the pressures characteristic of PVD processes), the growth of high-quality InN films has proven difficult. However InN has some promising transport and electronic properties, making it suitable for solar energy conversion and optoelectronic applications, including THz emission and detection[4,5].

The aim of this paper is to investigate the growth of InN films containing a variety of amounts of nitrogen, using in-situ monitoring by optical emission spectroscopy of active species in the deposition plasma.

II. Results

The films were grown by RF sputtering, the same method used to produce the highest mobility nitride material ever grown[6]. We used an UHV magnetron deposition system, with AlN and In cathodes. The base pressure into the deposition system was less than 2.10^{-6} Pa. During the deposition the working gas pressure was kept constant 5.10^{-1} Pa ($Ar+N_2$). The AlN buffer was deposited onto the bare substrates during the same deposition cycle. InN films were deposited at different partial pressures of nitrogen (2.10^{-1} Pa and 3.10^{-1} Pa) on glass or Si substrates, at different substrate temperatures (400 - 500 K).

The plasma carrier concentration and temperature were determined by Langmuir plane probes at different nitrogen concentrations, according to the equation:

$$j_e = n_g e\left(\frac{kT_e}{2\pi me}\right)^{1/2}\exp\left(-\frac{eV}{kT_e}\right)$$

The same plasma parameters were determined by optical emission spectroscopy in the magnetron deposition plasma, using a CVI LASER monocromator. The light emitted by plasma was collected by a collimator and focused by a lenses system on the entrance of the monocromator entrance slit. An R446 Hamamatsu photomultiplier tube and an aquisition system fitted with a computer were used to record the spectra and to compare the relative intensities of different optical lines. The electron temperature in the plasma was determined from the ratio between the relative intensitity of two Ar lines, using the equation[7]:

$$\frac{I_1}{I_2} = \frac{A_1 g_1 \lambda_2}{A_2 g_2 \lambda_1}\exp\left(-\frac{E_1 - E_2}{kT}\right)$$

$\lambda 1$ = 696.54 nm and $\lambda 2$ = 687.9 nm were de Ar lines. The values for the constants used are given in the table bellow[8,9]:

$A_1*10^{-6}s^{-1}$	$A_2*10^{-6}s^{-1}$	g_1	g_2	E_1 (eV)	E_2 (eV)
2.78	6.39	3	3	13.33	14.71

The electron concentration in the deposition plasma was shown by both of the investigation methods used to be about 10^{11} cm^{-3}, and the mean electron temperature was determined to be around 11 eV. As the nitrogen partial pressure increased, the electron mean temperature decreased (with about 2 eV), as well as the plasma concentration.

The XRD measurements have been performed using a Bruker-D8 Advance type X-ray diffractometer, equipped with a copper target X-ray tube, and a scintillation detector. For thin film measurements, parallel beam geometry at grazing incidence $\alpha=2^o$ was used, with a Göbel mirror in the incident beam. An asymmetric channel cut installed after the mirror provided a strictly monochromatic CuKαı primary X-ray beam. The polycrystalline films exhibited a wurtzite type structure, independent of substrate temperature. The sharp (101) line of the hexagonal InN indicates a good crystallinity of the deposited films, as can be seen in Figs.1-2.

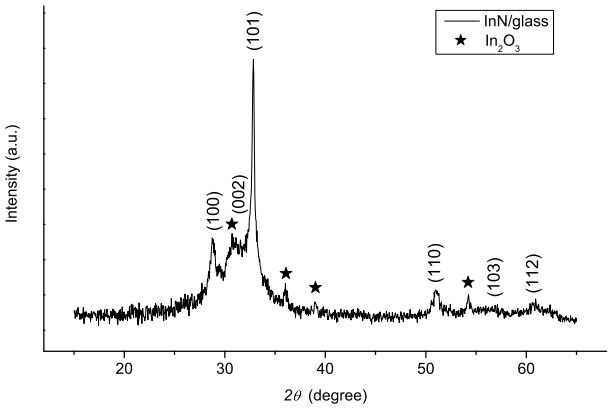

Fig. 1. X-ray diffraction patterns of InN film deposited at 400 K on glass substrate

The weak peaks of In_2O_3 can be observed for InN films deposited on glass substrate (Fig.1). On the other hand, the XRD patterns of InN films deposited on Si substrate (Fig. 2) shown only indium nitride peaks (JCPDS 79-2498).

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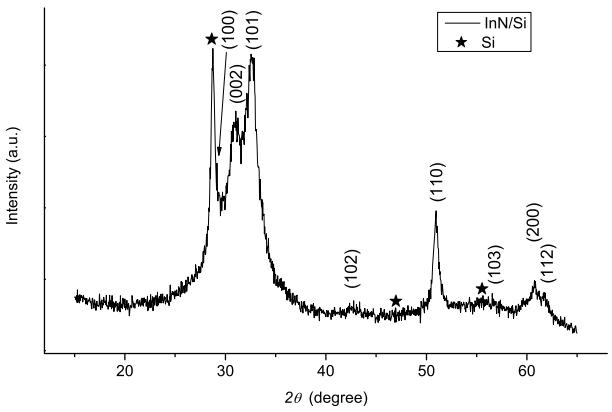

Fig. 2. X-ray diffraction patterns of InN film deposited at 400 K on Si substrate

The morphology of the InN films surface was revealed by atomic force microscopy (AFM) using a Quesant microscope. The roughness of the films increases with the deposition temperature. For the films deposited at 400 K, a rms=3 nm was determined, while at 800 K a rms value of abour 10 nm was measured. The AFM image of InN film deposited at 800 K is presented in Fig. 3.

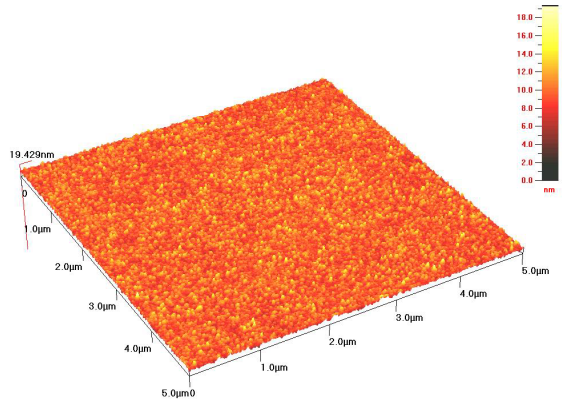

Fig. 3. AFM image of InN film deposited at 800 K (rms= 10 nm)

Auger electron spectroscopy (AES) was used to determine the elemental films composition, by using a PHI Auger electrons spectrometer model 3017. Before investigation the surface of the samples was sputter-cleaned with 3 keV Ar ions for 20 minutes, using a PHI Model 04-191 ion gun. The AES spectrum of InN sample deposited on glass at 400 K is presented in Fig. 4 and corresponds to the following concentration of elements: In=52.07%. N=46.03%, O=1.9%.

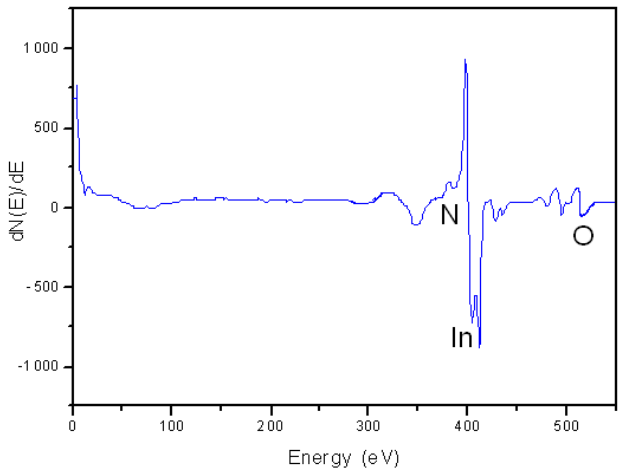

Fig.4 AES spectrum of InN sample deposited on glass at 400 K

The resistivity of the Si deposited film at 400 K was measured by the Van der Pauw method; the Hall mobility was measured at 295 K. The films exhibited a "n" type conductivity with $R_H^{(S)} < 5.3$ m^2/C, $\rho_S < 5.6.10^{-3}$ Ω/□ and $\mu_H >$ 10 cm^2/V. The bulk carrier concentration was about 10^{20} cm^{-3}, while the surface carrier concentration was about 10^{16} cm^{-2}.

The band gap was determined by UV-VIS and VIS-IR absorption spectroscopy. A mean value of 1.2 eV was determined, with no detectable influence of the nitrogen concentration.

With a band gap bellow 1.2 eV InN is an attractive material amenable to 1550 nm photoexcitation that has not been explored yet for THz applications.

Acknowledgments

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