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Optical and structural properties analysis of In_2O_3 thin film deposited on GaN substrate and its optoelectronic applications

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***Abstract*: Indium oxide (In2O3) thin films have been prepared by Physical Vapor Deposition technique using e-beam evaporator on the GaN substrate. The structural and morphological properties of In2O3 thin film were studied using X-Ray Diffraction (XRD) and Field Emission Gun Scanning Electron Microscope (FEG-SEM). The FESEM image shows the successful deposition of In2O3 thin film on GaN substrate. The optical properties of In2O3 thin films were investigated by using UV-vis and Photoluminescence (PL) measurements. The In2O3 thin film based photodetector device shows the rectifying behavior which may be due to the Schottky junction formation between Au and In2O3. The dark current ~15 µA was increased to ~ 36.3 µA under light illumination at -2V bias voltage. The In2O3 thin film device shows a fast response upon ON/OFF switching of white light.**

***Keywords*: Indium oxide; e-beam evaporation; nanostructure; FEG-SEM; photoluminescence; photocurrent.**

I. INTRODUCTION

Metal oxide semiconductor materials have been attractive to researchers due to their unique properties for different military and civil applications like UV detector, gas sensors, flat panel displays, light emitting diodes, photo-catalysts, deflectors, electroluminescent and solar cell [1-6]. Amongst the metal oxide, Indium Oxide (In2O3) have become more attractive because of wide band gap ~3.55 eV, transparent in visible region and good thermal and chemical stability [7, 8]. Several deposition techniques have been employed for preparation of In2O3 nanostructure such as thermal evaporation [9], DC and RF sputtering [10], spray pyrolysis [11], sol-gel [12], hydrothermal[13], atomic layer deposition (ALD) [14], chemical vapor deposition (CVD) [15] and pulsed laser deposition (PLD) [16]. However, the growth of In2O3 nanostructures Thin Film (TF) on GaN substrate using e-beam evaporation is less studied for photodetector applications. Therefore, in this work, In2O3 nanostructure on GaN substrate is fabricated using e-beam evaporation for optoelectronic applications.

In this report, we study the In2O3 TF deposition using electron beam evaporation method. The morphological properties were studied by Field Emission Gun Scanning Electron Microscope (FEG-SEM). The structural and optical properties have been investigated in detail using X-Ray Diffraction, UV-visible absorption and photoluminescence spectra. The current(I)-voltage(V) characteristic was studied under white light and dark condition and the photocurrent(I)-time(T) response of the device was also studied under switching mechanism.

II. EXPERIMENTAL

A. Deposition Process

A TF of In2O3 of thickness 150 nm was deposited on the n-type GaN substrate by physical vapor deposition using electron beam evaporator at a base pressure of ~1x10-5 mbar. Before deposition, the n-GaN substrate was cleaned with distilled water for 20 seconds to remove the contaminants present on the substrate. The substrate was placed on the substrate holder at a distance of 24 cm perpendicular from the evaporation source. The growth rate of TF was kept constant at 1.2 Ås-1. The incident e-beam energy was controlled by the e-beam current of the power supply. Au electrode contact was evaporated through an aluminum mask having a whole diameter of 2 mm on the In2O3 TF layer.

B. Measurements

The structural properties were analyzed by X-Ray Diffraction operated at 40 kV and 30 mA using Cu K∞ (1.54 Å) radiation. The morphology of the sample was studied by (FEG-SEM). The optical absorption of the sample was measured by UV-vis spectrometer (Lambda 35) recorded in the wavelength range of (200-900) nm and photoluminescence spectra were recorded by Fluorescence spectrophotometer (HITACHI, F-7000) in the range of (200-900) nm. The I-V characteristic has been measured under white light and dark condition using Keithley 2400 source meter.

III. RESULTS AND DISCUSSION

A. Morphological and Structure Properties

The surface morphologies of In_2O_3 TF prepared by e-beam evaporator on n-GaN substrate was analyzed through FEG-SEM. Fig.1. shows the FEG-SEM images of In_2O_3 TF which indicates the non-uniform deposition of the In_2O_3 particles. The average diameter of the In_2O_3 nanostructure was estimated to be 600 nm. These nanostructure surface increases the surface to volume ratio. The Energy-dispersive X-ray spectroscopy (EDS) spectra analysis shows the presence of Indium (In), Gallium (Ga) and Oxygen (O) as shown in Fig 2.

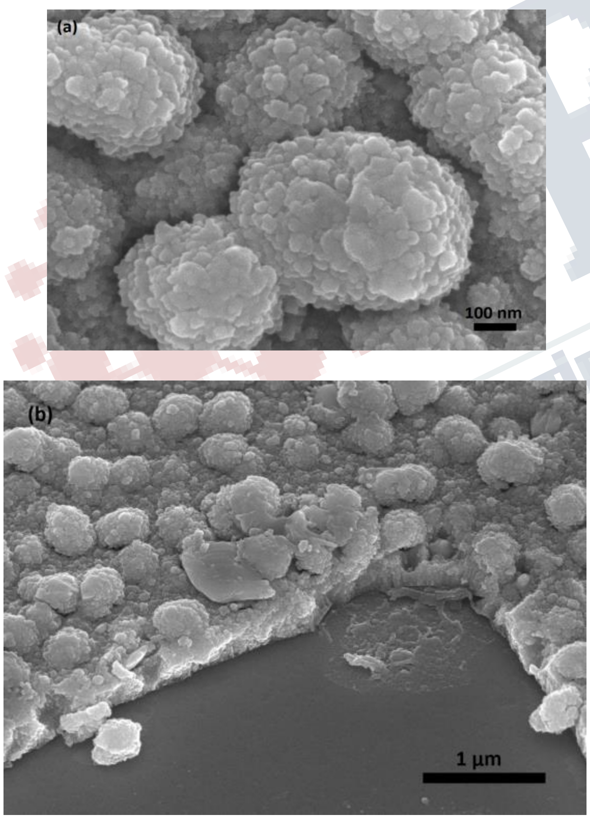

Fig.1. FEG-SEM image of In2O3 thin film deposited on GaN substrate (a) Top view (b) Side view.

Table 1. EDS data of In2O3 thin film.

Element	Weight%	Atomic%
O K	19.74	61.19
Ga L	2.14	2.56
In L	78.12	36.25
Totals	100.00	100.00

Fig. 3 shows the X-Ray Diffraction (XRD) pattern of the In_2O_3 thin film nm which was measured in the range of 10o to 90o. The XRD pattern observed that the deposited In_2O_3 thin film is polycrystalline in nature. The strong diffraction peak observed in XRD pattern may be from GaN substrate. A number of diffraction peaks for In_2O_3 thin film having orientations (211), (400), (432), (440), (622), (442) and (620) are located at 2θ =20.17o, 33, 44.66o, 50.95o, 59.02o, 72.48 o and 73.12 o which agrees with the reported JCPDS card no. 06-0416 [17,18]. The average grain size of In_2O_3 TF can be calculated by Debye-Scherer's formula, $D = 0.94\lambda/\beta\cos\theta$ [19], where λ is the wavelength of the X-ray (1.5406Å), β is the full width at half maximum of the observed peak and θ is the diffraction angle. The average grain size of the In_2O_3 TF was found to be 51.3 nm which agrees with the value obtained from the FEG-SEM analysis.

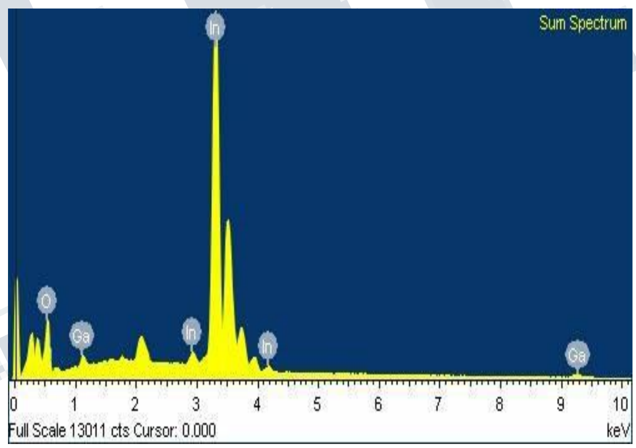

Fig.2. EDS of In2O3 thin film deposited on GaN substrate.

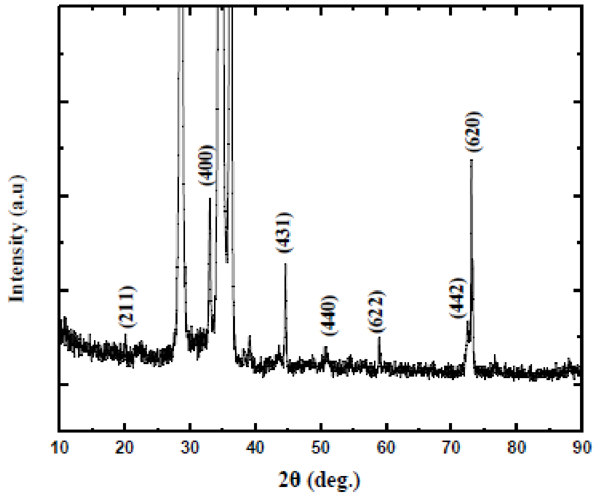

Fig.3. XRD spectra of In2O3 thin film.

B. Optical Properties

The room temperature photoluminescence (PL) spectra of the sample is shown in Fig.4. The PL measurement was performed on the surface of In2O3 thin film sample at an excitation wavelength of 350 nm. The PL emission peaks are observed at 373 nm, 381 nm 394 nm, 468 nm and 483.6 nm. The highest and lowest emission peaks are located at 373 nm and 483.6 respectively. The lower PL intensity has lower recombination rate and higher separation efficiency. The rate of electron-hole recombination is lower due to surface oxygen vacancies and defect thereby preventing direct electron-hole pair recombination and hence, enhancement of the photon trapping in the UV-visible region.

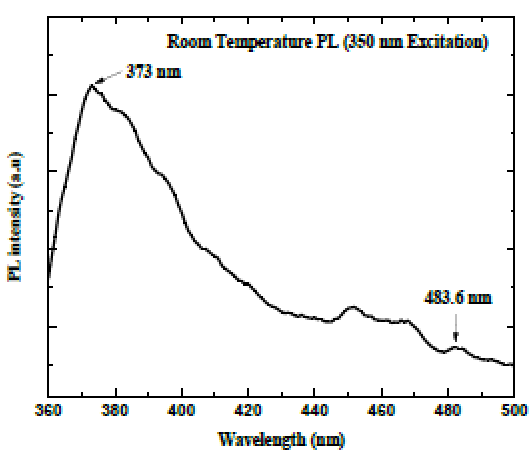

Fig. 4. Room temparature PL spectrum of In2O3 thin film.

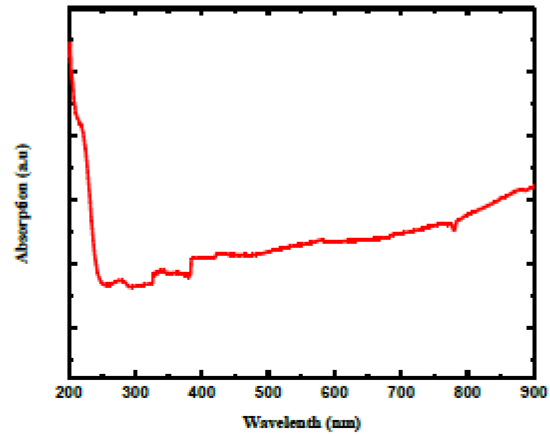

Fig.5. UV-vis absorption of In2O3 thin film.

Fig. 5 shows the absorption spectra of In2O3 TF. The UV-vis absorption of In2O3 TF on n-GaN was measured using UV-vis spectrometer (Lambda 35). The absorption measurement was performed in the wavelength range of wavelength of (200-900) nm. Maximum absorption was observed in the UV region.

C. Electrical Properties

Fig.6. shows the I-V plot of the Au/ In2O3 TF device. The I-V characteristics of the In2O3 TF based detector was studied under reverse bias condition over the voltage range of - 4V to + 4 Vat for both light current and dark current. The height of Schottky barrier of the junction between Au and In2O3 TF was investigated with thermionic emission theory [20-23]. The Schottky barrier formed at the Au-In2O3 interface performs as electron traps to prevent electron-hole recombination. The barrier height depend sensitivity on the work function of the Au. The work function of Au is greater than the work function of In2O3. The rectifying nature of In2O3 TF is due to the transport of electrons over the potential barrier. Under dark

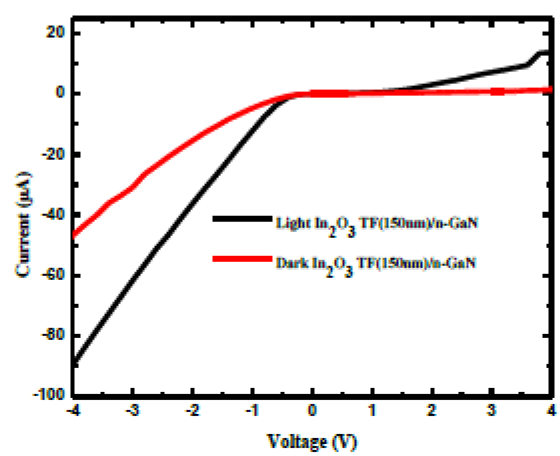

Fig.6. I-V characteristics of In2O3 thin film.

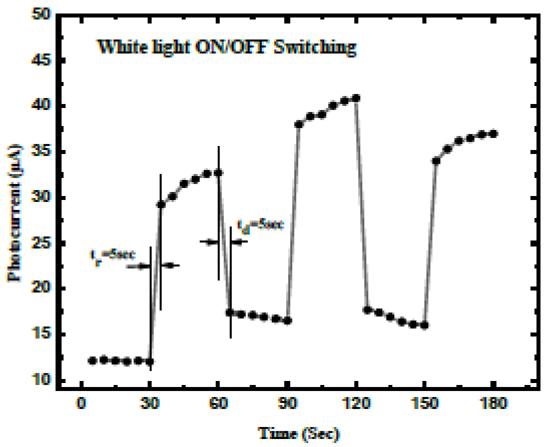

Fig.7. ON-OFF switching under white light (-2V applied bias)

Condition, the Au-In2O3 interface works as a barrier to electron flow from In2O3 TF. The reverse bias increases the barrier height and the small leakage current in the reverse direction. At - 2V, the light current was enhanced to ~2.42 times that of the dark current.

Fig.7. shows the time response plot of In2O3 TF based detector which was measured with several ON-OFF switching condition under white light [24]. The time response of In2O3 TF based device was studied under white light illumination at -2 V on the Au electrode. The photocurrent of the device is increased under white light illumination at -2 V with rise time (tr) and decay time (td) of 5 second. The white light ON/OFF switching of In2O3 thin film device exhibits a fast response.

IV. CONCLUSION

In the conclusion, the In2O3 TF was successfully prepared by e-beam evaporation method. The FEG-SEM shows that the average size of grain of In2O3 is 51.3 nm. The Photoluminescence measurement result shows the 4 enhancement of photon trapping efficiencies. The Schottky barrier formed at the Au- In2O3 TF interface performs as an effective electron traps to reduce the electron-hole recombination. The I-V characteristics plot shows enhanced current for light condition as compared to dark condition. The time response measurement of the Au/In2O3 TF device shows a fast response upon ON/OFF switching of white light.

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