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Structural, Optical and Electrical Characterization of Glancing Angle Deposited In2O3Nanowire arrays for Photo Detector Applications

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***Abstract*: Indium Oxide (In_2O_3) Nan wire (NW) arrays have been fabricated on n-Si substrate using the e-beam evaporation system. Glancing Angle Deposition (GLAD) technique was employed to synthesize the In_2O_3 NWs. The polycrystalline nature was observed from X-Ray Diffraction analysis of In_2O_3 NWs deposited on Si substrate. The Photoluminescence (PL) analysis shows the emission peak in the visible region ~ 434 nm which may be the band to band transition energy (2.85eV) of the In_2O_3 NWs. Optical absorption measurement shows the In_2O_3 NW sample absorbed much light ~1.5 times in UV and visible regions as compared to In_2O_3 TF sample. The Current-Voltage (I-V) measurement of the NW Device (Au/In_2O_3-NW/ In_2O_3-TF/Si) shows the photocurrent enhancement in both forward and reversed biased conditions. . The NW device shows fast rise and fall response time ~3 sec under on/off switching at -3V respectively.**

***Index Terms*— Glancing Angle Deposition (GLAD); Indium Oxide (In2O3); Nanowire (NW); Thin film (TF); Response time..**

I. INTRODUCTION

Metal oxide nanostructures based device have become more interesting research area due to their unique properties. Researchers have increased attention for the preparation of nanostructure materials due to its large surface areas, high sensitivity, good response speed and minimum consumption of energy. Due to the excellent optical and electrical properties of metal oxide nanostructures, they are used in a wide range of applications in optoelectronic devices such as UV detector, sensor, solar cells, electronics and space research [1].

Metal oxide semiconductors like ZnO, In2O3, CdO have been extensively used in research. Of these metal oxides, In2O3 a wide band gap metal oxide semiconductor (a direct bandgap of 3.55-3.75eV [2] and indirect band gap of 2.62 eV [3]) has great importance because of its high transparency and electrical conductivity. It has features that can give photodetection in ultraviolet and visible light range which has many applications as detectors and sensors [4-6]. Using schotky contact, the devices working as detectors give high sensitivities with short response time due to oxygen absorbing nature at the contact interface and from the environment at Nanowires (*NWs*) surface under light illumination [7].

Many techniques are employed for fabricating of one dimensional In2O3 nanostructures. The different techniques such as chemical vapor deposition [8], atomic vapor deposition [9], thermal evaporation [10, 11], sputtering [12], vapor liquid solid condensation [13], pulsed laser ablation [14] have been proposed. However, the nanostructures obtained from the above techniques are not perpendicularly grown on the substrate. Perpendicular and well patterned [15] NW have the capability to trap the incident radiation between two consecutive NWs and enhance the photoexcited electron hole pair generation due to multiple scattering and channeling the generated electron hole pair inside the structures for fast response.
The vertically grown *NWs* based detector has the potential to reduce the noise by limiting the gathering of minority carriers at the electrodes. The GLAD Technique can effectively control the growth and orientation of the nanowires [16]. It has been found that vertically growing nanowire can be obtained using GLAD technique to give the best structural and optical properties. The *GLAD* technique is an efficient technique for vertically growing well patterned NWs on the substrate. There are few

reports regarding the synthesis of vertically growing In2O3 NW using GLAD techniques.

In this paper, we have synthesized the well patterned vertically grown In2O3 NWs on Silicon (Si<100>) substrate. Gold (*Au*) Schotky contact was made on the In2O3 columns. The optical absorption study was done on the sample to show in which part of the wavelength the light is mostly absorbed and the main band related transition in the material. The X-Ray Diffraction (*XRD*) measurement of the sample gives the polycrystalline nature of the deposited In2O3. The photoluminescence measurement shows band to band and sub-band gap transition due to oxygen related defect. The current conduction under light and dark condition is studied. The device shows fast switching action taken under light and dark condition.

II. EXPERIMENTAL PROCEDURE

A. Synthesis of In2O3 NW and device fabrication

In2O3 NW arrays were synthesized on the N-type Si<100> substrate of 1-35Ω cm substrate. The GLAD technique have been used to deposit In2O3 NW using pure In2O3 (99.999o/o, MTI, USA) source on cleaned Si substrate (1cm x1 cm) inside E-beam evaporator chamber. The deposition was carried out at a base pressure of ~2x10-5 mbar. The growth rate and deposition thickness were observed through a quartz crystal. The distance between the In2O3 source and the Si substrate holder was maintained at a distance of 24 cm inside the e-beam chamber. The growth rate of 1.5 A˚s-1 was kept constant for all the deposition. The substrates were oriented at 85º with respect to the perpendicular line between the material source and the planar substrate to achieve perpendicular growth of the nanowire. The substrates were rotated azimuthally at 460 rpm. For photocurrent measurement, using normal deposition In2O3 Thin Film (TF) was deposited on Si substrate. Then In2O3 NW using GLAD was grown over the deposited In2O3 TF and lastly Au schotky contact was made. The Au was evaporated through the aluminum (Al) mask having a hole of diameter 1.5 mm on the top of In2O3 NW to get the schotky contact. Au contact area was of ~1.7 x 10-6 m2.

B. Characterisation

XRD analysis was done by XPERT-PRO DIFFRACTOMETER SYSTEM using CuKα radiation. The Photoluminescence (PL) study was carried out at room temperature using F-7000 FL Spectrophotometer. The optical absorption analysis was carried out using UV-Vis spectrophotometer. The Current-Voltage characteristics of the device (Au/In2O3-NW/In2O3-TF/Si) were studied by using Keithley 2400 source measure unit. The response of the device was investigated under On/Off switching conditions.

III. RESULTS AND DISCUSSION

A. Structural characterization

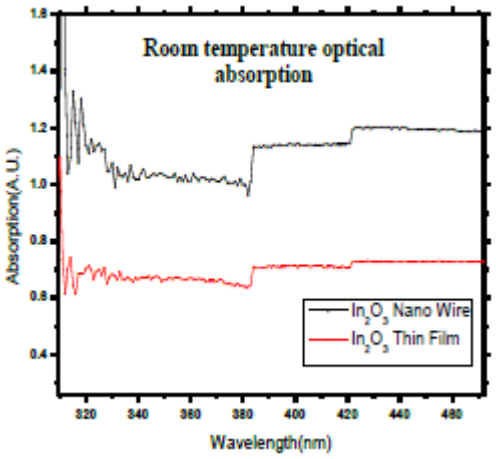


Fig. 1: XRD pattern of In2O3 NW deposited on Si substrate.

Fig. 1 shows the XRD pattern of the In2O3 NW deposited on Si substrate. The pattern shows different phase of the In2O3 NW i.e. (211), (222), (431), (440) and (611) which have indexed to JCPDS: 06-0416 [17]. The diffraction pattern shows the polycrystalline nature of the as-deposited In2O3 NW. The diffraction pattern also shows the presence of different phases from Si substrate i.e. (220) and (400) indexed to JCPDS: 27-1402 [18, 19].

B. Optical Characterization

Optical absorption was studied separately for In2O3 NW and In2O3 TF deposited on Si substrates. Fig. 2 shows the absorption spectra of the In2O3 NW array and In2O3 TF. Enhanced absorption was observed from In2O3 NWs sample in the UV region and visible region compared to the In2O3 TF. This is due to their large surface area to volume ratios of the In2O3 NW [20]. Moreover, multiple scattering of incident photon occurs between consecutive vertically grown nanowires. As a result, the NW absorbed most of the incident photon.

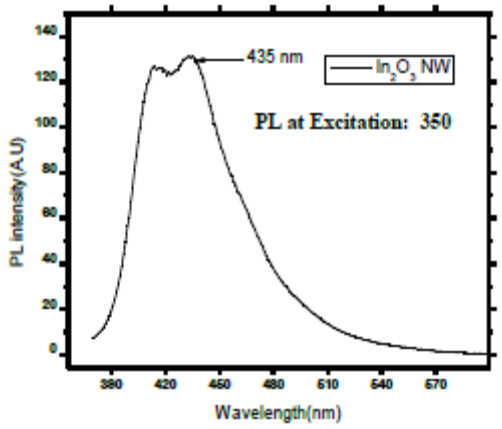


Fig. 2: Optical absorption spectrum of the In2O3 Nanowire (NW) and Thin Film (TF) on Si substrate

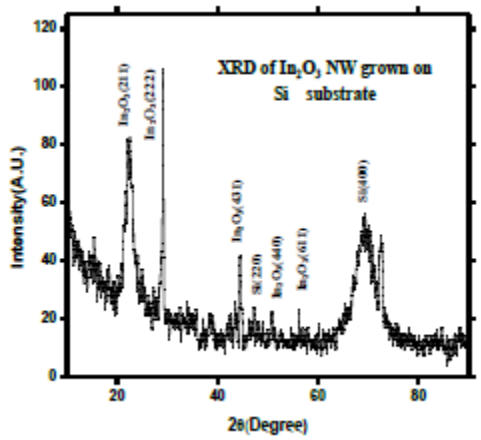


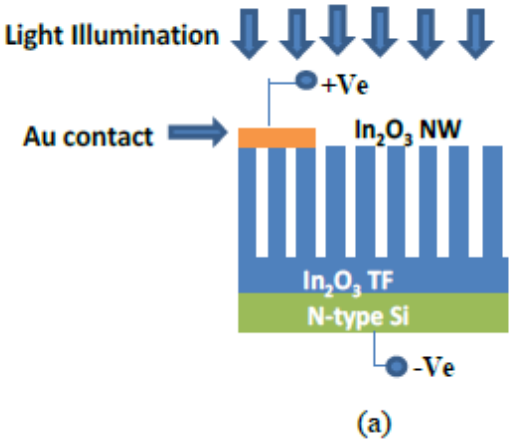
Fig. 3: Room temperature PL spectrum of In2O3 NW on Si substrate at 350nm excitation.

Fig.3 shows the PL spectrum of In2O3 NW grown on Si substrate. The PL measurement has been carried out at room temperature on the as deposited In2O3 NW using an excitation wavelength of 350 nm. Maximum PL emission peak was found at 430 nm (2.84 eV). PL emissions are possibly due to the effect of oxygen vacancy [21].

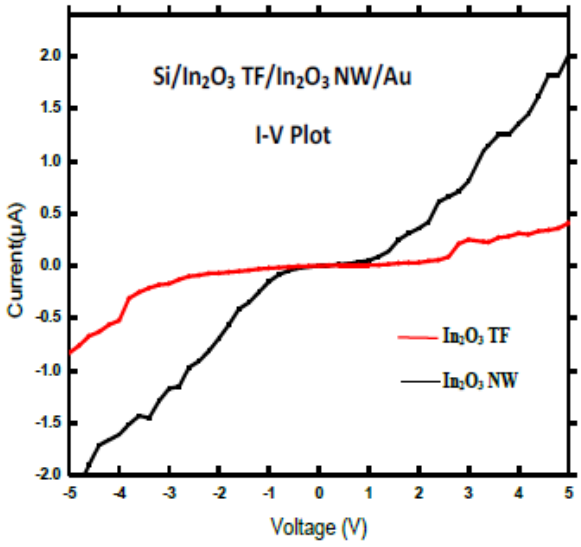
Here, the oxygen vacancies would play as donors forming a new energy level in the band gap of the In2O3 NW. The incident photon will generate electron hole pairs. Thus, PL emission results by the radioactive recombination of the photo excited holes with electron occupying the oxygen vacancies. The energy emitted by the radiative recombination is less than the main energy band gap of the bulk In2O3 as shown by the Fig 3. It is reported that the low energy PL emission is due to the near band gap transition [22].

C. Electrical characterization

Fig. 4(b) shows Current-Voltage (I-V) characteristic Of Au/In2O3-NW/In2O3-TF/Si device shown in fig. 4(a) taken under dark and light illumination for both forward and reverse biased condition. The I-V plot shows rectifying behavior due to the schotky contact formation at the Au and In2O3 NW junction [23]. I-V characteristic of the device shows the photocurrent enhancement in both forward and reverse biased condition.



(a)



(b)

Fig. 4: (a) Cross-sectional diagram of Si/In2O3 TF/ In2O3 NW/Au device (b) I-V characteristics of Si/In2O3 TF/ In2O3 NW/Au device under dark and light irradiation.

Under light illumination, Au contact will absorb most of the oxygen molecules from the In2O3 surface and produce electron-hole pairs at the metal-semiconductor interface which forms small active region at In2O3 NW and separate efficiently the photogenerated electron hole pairs resulting in large photocurrent.

Under forward biased condition, there is reduction in the schotky barrier height at the Au and In2O3 junction because of large generation of electrons due to light illumination and thus enlarges the current under forward bias condition [24]. In reverse current conduction, the interface density of state acts a vital role. So, under reverse bias, the interface states trapped efficiently most of the holes leading to the shrinkage of the depletion region [25] and permit tunneling of electron across the junction. Here, surface to volume ratio is very large for 1-D nanostructure and the presence of large number of trap states in the nanostructure makes most of the light incident on the structure to absorb leading to the increase in photogenerated electron-hole pairs and thus there is a rise in photocurrent.

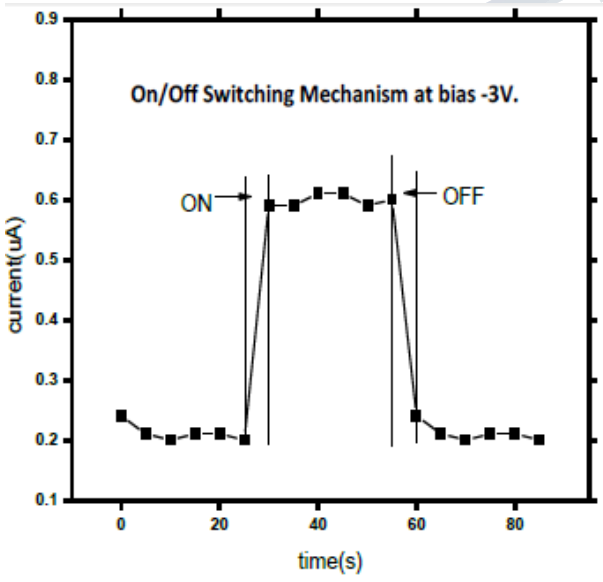


Fig. 5: Time response of the NW device under on/off switching.

Fig. 5 represents the current and time (I-T) characteristic of the NW device under on/off switching at bias -3V. The current increased from 0.2 µA to 0.6 µA under light illumination with quick rise time of ~3 sec. and decay time of ~3 sec. In most of the case, the photodetector give shorter rise time then decay time that indicates the presence of defect state in the active region of the device [26]. In our case, the rise time is equal to the decay time which shows that In2O3 NW layer has less defect state which will help in the quick performance of the detector.

IV. CONCLUSION

GLAD was adopted for the growth of In2O3 NWs on Si substrates. The XRD analysis shows that the In2O3 NW is crystalline in nature. Enhanced absorption was observed from In2O3 NWs sample in the UV region and visible region compared to the In2O3 TF due to their large surface area to volume ratio. Maximum PL emission peak was found at 430 nm (2.84 eV). PL emissions are possibly due to the effect of oxygen vacancy. The Current Voltage (*I-V)* measurement of the NW Device (Au/In2O3-NW/ In2O3-TF/Si) shows the photocurrent enhancement in both forward and reversed biased condition because of the presence of trap states and large surface to volume ratio. Most of the light is absorbed leading to increase in the generation of electron-hole pairs and thus enhance the photocurrent. The device shows quick response due to little defect in the active area and quick diffusion of carriers.

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