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$In_{2-X}O_{3-Y}$ 1D perpendicular nanostructure arrays as ultraviolet detector

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ABSTRACT

The 1D perpendicular $In_{2-x}O_{3-y}$ nanostructure arrays have been synthesized by using glancing angle deposition (GLAD) technique. A low deposition rate of 0.5 A°/S produced highly porous structure. The characteristics of junction defects and photocurrent were measured to verify the detector performance. The junction capacitance and charge retention due to presence of trap states in the device decreased with an increase in frequency. The high value of D_{it}~ 5.5 × 10^{17} cm^{-2} eV^{-1} was calculated for the device. The detector processes low ideality factor of ~2.04 at 300 K. The maximum photo responsivity of ~15 A/W and internal gain of ~47 were measured for the 1D $In_{2-x}O_{3-y}$ based detector at ~380 nm in UV region. The device shows very high current density ~20 A/cm^2 (−2 V, 300 K) under dark, which deflects to 32 A/cm^2 due to illumination. Under white light on/off switching irradiation, the device operates with rise time of 1.9 s and decay time of 2.3 s. Therefore $In_{2-x}O_{3-y}$ nanostructure arrays can be used as sensitive UV light detector.

1. Introduction

Indium oxide (In_2O_3) is a transparent metal oxide semiconductor, having a direct band gap of ~3.6–3.7 eV [1]. It is an intrinsic n-type semiconductor that is being used as a resistive element in integrated circuits and heterojunction structure with III-V semiconductors like indium phosphide and gallium arsenide [2]. Recently, the wide band gap transparent metal oxide semiconductor materials are getting research interest for their unique optical and electronic properties [3]. Due to its operation in the UV region and comparative higher electron mobility [4] than TiO_2 and ZnO, In_2O_3 is used in low cost transistor applications [4], UV light detection [5]. Fabrication of interconnected In_2O_3 nano-columnar arrays by GLAD and its optical, electronic properties has been described [6]. Again, stratospheric ozone layer absorbs the UV light in the region of 290–400 nm. So, fabrication of high internal gain based photodetector is required to sense the faint light in the UV region (290–390 nm) available near the earth's surface for flame detection, missile tracking and UV astronomy. The fabrication of 1D structures of In_2O_3 was started in the last decade. The In_2O_3 nanowires (NWs) network and nanostructure prepared by CVD technique [4] and VLS [7] respectively were mostly studied. The physical vapor depositions (PVD) were used to synthesize the In_2O_3 nanostructure and their optical properties were also studied [6]. The authors already reported the fabrication of perpendicular In_2O_3 NWs, which was used for the purposes of fabrication of high efficiency optical detector [8].

In this article, the fabrication of porous perpendicular $In_{2-x}O_{3-y}$ nanostructure arrays by GLAD was described. The junction capacitance of the detector was studied and explained. The sensible photon detection was observed from the $In_{2-x}O_{3-y}$ nanostructure based Schottky detector. The visible blind UV detection with a high internal gain has been observed for the detector. The response time of the detector was experimented.

2. Experiments

2.1. $In_{2-x}O_{3-y}$ nanostructure arrays based detector

GLAD technique was employed to synthesize the perpendicular $In_{2-x}O_{3-y}$ nanostructure arrays by evaporating 99.999% pure In_2O_3 (MTI, USA) inside the chamber of e-beam evaporator (Hind High vacuum Co. (p) Ltd., 15F6) on n-type Si < 100 > substrate (~30 Ω-cm) (MTI,USA) at a base pressure of ~2 × 10^{-5} mbar. The deposition

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rate of 0.5 Å s^{-1} was used to synthesize the 500 nm long nanostructure, which was monitored by a quartz crystal. The substrate holder was kept at a distance of 24 cm from the evaporated material source with an azimuthal rotation of 120 rpm and an orientation of 85° with respect to the perpendicular line between the source and substrate. Several successive depositions were carried out to synthesize the perpendicular $In_{2-x}O_{3-y}$ nanostructure on the 30 nm $In_{2-x}O_{3-y}$ thin film (TF). Gold (Au) has been evaporated through the aluminum mask having hole of diameter 1.5 mm on In_2O_3 layers to form the Schottky contact. The area of the Au electrode contact was 1.77×10^{-6} m^2.

2.2. Characterization

The field emission gun-scanning electron microscopy (FEG-SEM) (JEOL, JSM-7600F) and energy diffraction x-ray spectroscopy (EDX) were performed on the samples. The junction capacitance of the detector was measured by using Agilent (E4980A) LCR meter. The current density (J) - voltage (V) characteristics and photocurrent spectrum of the $In_{2-x}O_{3-y}$ nanostructure based detector were investigated by using a Keithley 2400 source-measure unit and lock-in system (SR510 lock-in amplifier, and Sciencetech Inc. MC2000 optical chopper) respectively. The 300 W xenon arc lamp (650-0047) and a monochromator (Sciencetech Inc., Canada) were used in open configuration to characterize the devices. The transient time response of the detector was measured under xenon light on-off irradiation. The temperature dependent J-V characteristics of the device 10–300 K were studied by using closed cycle He-cryostat (Advanced research systems, Inc.).

3. Results and discussion

3.1. Structural depiction

Fig. 1(a) shows the top view FEG-SEM image of the highly porous sample prepared at 85° GLAD. Fig. 1(b) shows the side view of the sample, which contains perpendicular columnar structure of $In_{2-x}O_{3-y}$, having a very rough surface. The fabricated nanostructures were non-symmetrical with top diameter ranging from 45 to 207 nm (Fig. 1(e), constructed from Fig. 1(a)) and average length of ~500 nm (from Fig. 1(b)). The EDX analysis (Fig. 1(c), inset) shows that the oxygen and indium ratio is 4:1 in the sample, which suggests us to write the chemical formula of the as grown material as $In_{2-x}O_{3-y}$ (where, x and y are arbitrary constants).

The growth of interconnected sponge-like perpendicular columnar In_2O_3 on ITO coated glass plate was reported by the authors [6]. A high deposition rate of 1.5 A°/S was used to fabricate the In_2O_3 columns at the extreme shadowing condition and the morphology was similar as expected beyond the classic zone-1 [9]. In such cases the foremost atoms get collided by the subsequent atoms and are frozen. In the present case, due to low deposition rate of 0.5 A°/S, the atoms become free from the successive collision process, which possess small surface diffusion. Therefore, the transport limitation of the atoms prevented filling crystal sites and in consequence of the above, the coating was porous in nature [10]. Fig. 1(d) shows the formation of tightly packed and porous structure of the film for the high and low deposition rates. Again, a careful observation at the top view shows the formation of large and small sized nanostructure, unsymmetrical in shape and sizes. In case of GLAD, some of the columns were not fully grown to the expected height (small sizes) [11], thus leading to an unequal shadowing region (Fig. 1(a) red arrows (in the web version)) which can be attributed to a competitive growth mode procedure during the deposition.

3.2. Detector response

The junction capacitance has important roles in designing the optical detectors. Fig. 2(a) displays the capacitance (C)-voltage (V) measurement for the fabricated $In_{2-x}O_{3-y}$ nanostructures based

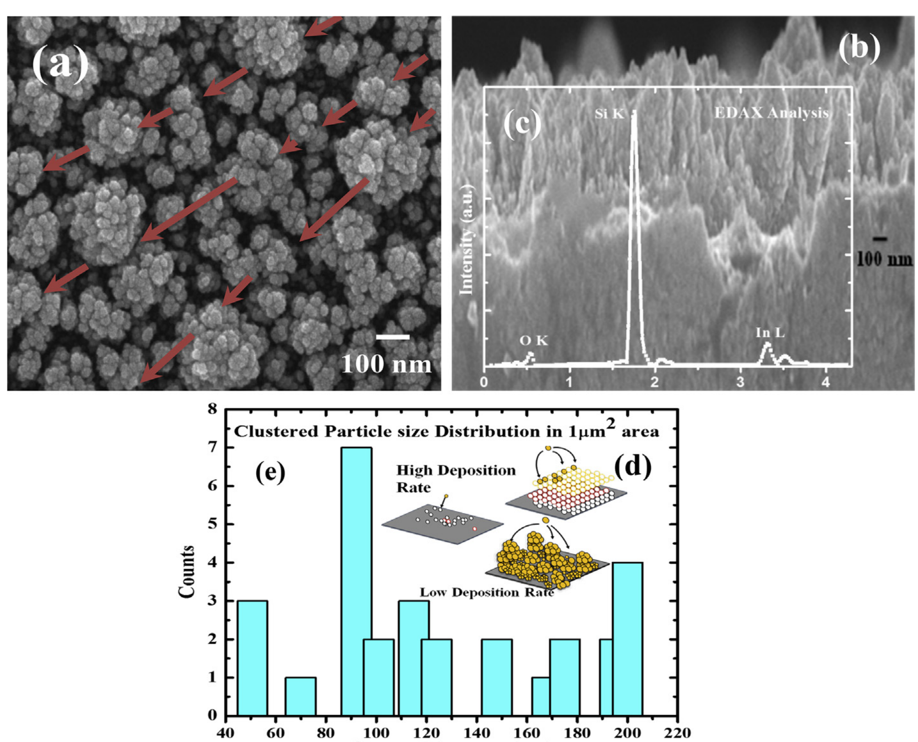

Fig. 1. (a) Top view FEG-SEM images of $In_{2-x}O_{3-y}$ NWs (b) Side View of $In_{2-x}O_{3-y}$ NWs (c) EDAX Analysis (d) Formation of tightly packed and porous structure of the film for the high and low deposition rates. (e) Histogram of Clustered Particle size distribution in 1 μm^2 area.