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Electrical and photovoltaic characteristics of Ni/(n)Bi_2S_3 Schottky barrier junction

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ABSTRACT

Ni doped nanocrystalline Bi_2S_3 thin films are chemically deposited on Fluorine Doped Tin Oxide (FTO) substrate from the solution containing $Ni(NO_3)_2$, $Bi(NO_3)_3.5H_2O$, $C_6H_{15}NO_3$ and $CH_2CS.NH_2$ at deposition temperature 318 K. The Current–voltage (*I–V*) characteristics of the junctions are measured in the temperature range 300–340 K and junction parameters are calculated. The ideality factor (n) and barrier height (ϕ_b) at different temperature are found to vary from 4.7 to 3.8 and 0.74 to 0.79 respectively. It is observed that the ideality factor decreases while the barrier height increases with increase of temperature. The calculated junction parameters are strongly temperature dependent. The discrepancy between the barrier height obtained from capacitance–voltage (*C–V*) and current–voltage (*I–V*) characteristics is analyzed. The carrier concentration determined from the *C–V* plot is found to be of the order $10^{17}/cm^3$.

1. Introduction

In the last decade, researches on nanocrystalline semiconductor thin films have been increased due to their future applications in the diverse fields of science and technology. One of the main factors driving the current interest for semiconducting nanocrystalline materials is due to the fact that optimization of devices such as solar cells, super capacitors, photo catalytic coating and electro chromic windows requires control of the physical and chemical properties of the employed materials [1–3].

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Bismuth sulphide is a member of V–VI semiconductor compound whose band gap energy 1.7 eV lies in the visible range of the solar energy spectrum which makes it very useful for solar energy conversion devices [4–6]. It is widely used in optoelectronics, photoelectrochemical devices, thermoelectric cooler, electrical switching, solar selective coatings, decorative coatings [7,8]. Nanostructures of Bi_2S_3 have potential applications in electrochemical hydrogen storage, hydrogen sensors, biomolecule detection, photo responsive materials etc. [9]. Several techniques for synthesis of Bi_2S_3 thin films have been published in the literature such as vacuum evaporation [10], cathodic electrodeposition [11], anodic electrodeposition [12], hot-wall method [13], solution gas interface [14], spray deposition [15,16], and Chemical bath deposition [17–23]. Compared with the other techniques of thin film preparation, the proposed chemical bath deposition technique (CBD) in the present paper has several advantages. CBD method can easily control the crystal size by controlling the deposition parameters.

Metal–semiconductor (MS) contacts are the most widely used rectifying contacts in the electronics industry [24–27]. The performance and reliability of a Schottky diode is drastically influenced by the interface quality between the deposited metal and semiconductor surface [28]. The main electrical parameters such as barrier height (ϕ_b), ideality factor (n), series resistance (R_s) and saturation current density (J_o) are the most important parameters of the Schottky barrier diodes and especially change with temperature and bias voltage. Therefore analysis of *I–V* characteristics of the Schottky barrier diodes at room temperature does not give detailed information about their conduction processes and hence temperatures dependence of the *I–V* characteristics allow us to understand different aspects of conduction mechanisms. *Kachari* et al. [29] reported the fabrication of Al/(p)Bi_2S_3 Schottky barrier junction by vacuum evaporation method. They have evaluated the various junction parameters from the *I–V* characteristics of the junction. Further, they investigated the photovoltaic performance of the junction. *Bao* et al. [30] reported the formation of Schottky contact between Bi_2S_3 nanowires and gold (Au) electrode. The photo-switchable conductivity of individual Bi_2S_3 nanowires was studied, indicating possible applications in optoelectronic nano-devices. Upto our knowledge there is a limited literature on the properties of Ni/(n)Bi_2S_3 Schottky junction fabricated by CBD. Therefore, our main aim in this work is to investigate the electrical and photovoltaic properties of the Ni/(n)Bi_2S_3 Schottky junction prepared by chemical bath deposition technique.

2. Experimental details

For the preparation of Ni doped nanocrystalline Bi_2S_3 thin films, bismuth nitrate ($Bi(NO_3)_3$), thioacetamide ($CH_2CS.NH_2$) and nickel nitrate ($Ni(NO_3)_2$) are used as Bi^{+3}, S^{-2} and Ni^{+2} ions sources respectively, Triethanolamine (TEA) ($C_6H_{15}NO_3$) is used as a complexing agent. For this 5 ml of 0.5 M ($Bi(NO_3)_3$) is mixed with 2 ml of TEA and stirred for 20 min at room temperature to dissolve $Bi(NO_3)_3$ into the solution. Again 4 ml of $CH_2CS.NH_2$ and 1.5 wt% of $Ni(NO_3)_2$ is added and the resultant solution is stirred for 2 min to get uniform mixture solution.. Finally, 39 ml of distilled water is added to the resultant solution to obtain a total volume of 50 ml. The FTO substrates are immersed vertically into the mixture solution supported by the wall of the beaker. The mixture solution is heated at 318 K for 20 min. The resultant solution changes from brown to dark brown color which indicates the initiation of Bi_2S_3 film formation. The solution is kept at room temperature for 2 h for further deposition. In this way, three sets of Ni-doped (1.5 wt%, 2 wt% and 2.5 wt%) nanocrystalline Bi_2S_3 thin films are deposited on Fluorine doped tin oxide (FTO) substrates by chemical bath deposition technique. The type of electrical conductivity is determined by simple hot probe method as discussed in our earlier paper [31]. The reported work function of FTO is 4.4 eV [32] which is lower than the work function of Bi_2S_3 4.93 eV [33]. Hence, FTO makes ohmic contact with the Bi_2S_3 films. Nine nickel 'Ni' electrodes each of area 0.04 cm^2 are vacuum deposited over the Ni doped Bi_2S_3 thin films through a suitable mask to form the structure of Ni/Bi_2S_3/FTO as shown in Fig. 1. The reported work function of Nickel 'Ni' metal is 5.15 eV [34] which is higher than the work function of Bi_2S_3. So, it is expected that Schottky barrier junction is formed between Bi_2S_3 film and 'Ni' electrode. Thus nine junctions of equal area 0.04 cm^2 are obtained on the same substrate. *I–V* characteristics at different temperatures are measured by using Keithley electrometer (6514) and rishabh multimeter (14S). The temperature on the sample surface is measured by Instron (IN-303) digital temperature controller using PT-100 sensor.