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The comparison of electrical characteristics of Au/n-InP/In and Au/In_2S_3/n-InP/In junctions at room temperature

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ABSTRACT

We fabricated Au/n-InP/In and Au/In_2S_3/n-InP/In junctions and investigated their electrical properties at room temperature. The In_2S_3 thin film has been directly formed on n-type InP substrate with spray pyrolysis method at 200 °C substrate temperature. Detailed structural and optical properties of the film have been investigated by means of scanning electron microscopy (SEM), X-ray diffraction (XRD) and absorption techniques. The band gap energy of In_2S_3 by using spectral data of absorption has been determined to be about 2.80 eV. The values of the ideality factor and barrier height of the Au/n-InP/In and Au/In_2S_3/n-InP/In junctions have been found as $n = 1.01$, $\Phi_b = 0.469$ eV and $n = 1.07$, $\Phi_b = 0.543$ eV, respectively. Likewise, the values of barrier height and series resistance of both samples have been obtained from Norde method and they have been calculated as 0.456 eV, 59.081 Ω for Au/n-InP/In junction and 0.518 eV, 101.302 Ω for Au/In_2S_3/n-InP/In junction, respectively.

1. Introduction

The Schottky diode is a rectifying metal–semiconductor contact formed between a metal and an n-doped or p-doped semiconductor. Since the Schottky diode is formed by the contact between the metal and semiconductor, the metal–semiconductor interface quality has a significant influence on the electrical characteristics of Schottky diodes. The Schottky barrier inhomogeneity in metal–semiconductor contacts is of great technological importance and has been a long-standing topic of research [1,2]. It is well known that the interfacial properties of metal–semiconductor contacts have a dominant influence on the device performance, reliability, and stability. There is always native thin insulating layer of oxide on the surface of the semiconductor in most practical metal–semiconductor contacts. However, thin film interfacial layer between metal and inorganic semiconductor can be constructed by many methods. This film modifies some electrical characteristics of the diodes [3]. The performance of these structures especially depends on the formation of interfacial thin layer between metal and semiconductor, the interface states located at the semiconductor/insulator interface, series resistance and an inhomogeneous Schottky barrier contacts. There are currently a vast number of reports of experimental studies on Schottky barrier height in a great variety of metal–interfacial thin layer–inorganic semiconductor structures [4–13]. Group III–V compound semiconductors, particularly indium phosphide (InP), are promising materials for high-speed electrical and optoelectronic devices. This is due to the superior characteristics of InP, such as the large direct band gap and high electron mobility, substrate velocity, and breakdown voltage, which are very important parameters in electronic devices [12,14]. The potential barrier height of Schottky junctions based on InP is usually smaller than 0.5 eV and but rarely higher values are also available [15–17]. The several attempts have been made in order to modify and control the barrier height by using thin film layer at InP metal–semiconductor junctions. This layer converts a metal–semiconductor structure into a metal–interfacial thin film layer–inorganic semiconductor structures. Up to now, various chemical synthesis methods have been used in preparation of In_2S_3 thin film. However, in the literature there has been no report on preparation of Au/In_2S_3/n-InP/In junction by means of spray pyrolysis method. Spray pyrolysis is a chemical method, which is relatively simple, reproducible, size controllable, low cost and continuous for synthesis of some thin film. In our previous study, we investigated the effects of thermal annealing on the electrical characteristics of Au/n-InP/In diode [18]. In this work, Au/n-InP/In and Au/In_2S_3/n-InP/In junctions have been fabricated by spray pyrolysis method and the effects of the In_2S_3 interlayer on conventional metal–semiconductor contacts have been inquired in terms of electrical properties of the junctions. Therefore, it is aimed to investigate the suitability and possibility of the In_2S_3 thin film for use in barrier modification of metal–n type InP semiconductor devices.

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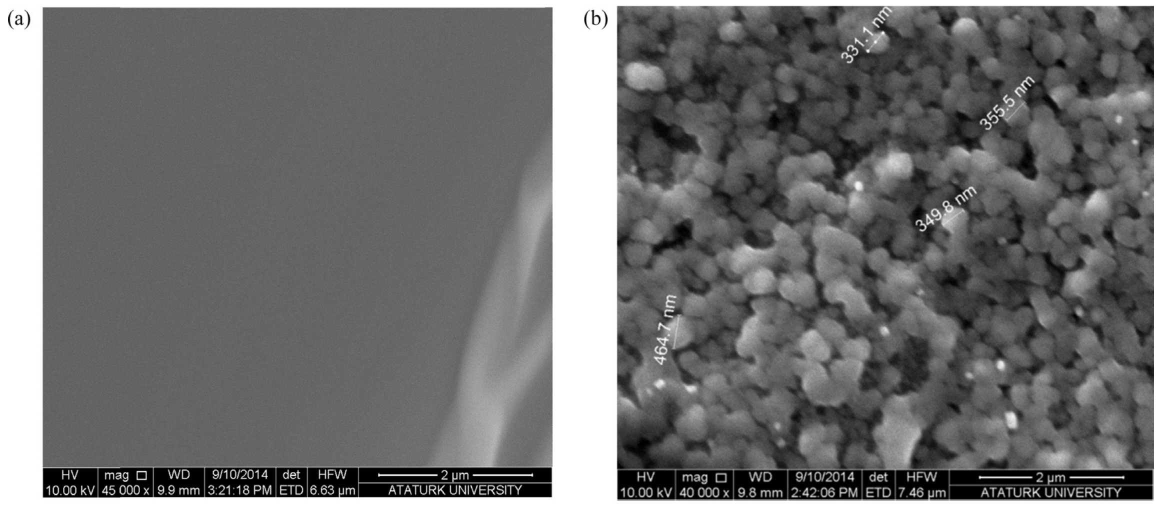

Fig. 1. (a) SEM images of InP surface and (b) SEM images of In_2S_3 thin film grown on n-InP substrate.

2. Experimental procedure

The Schottky barrier junctions were fabricated using n-type InP (1 0 0) wafer. The wafer was degreased consecutively in trichloroethylene, acetone, and methanol for 5 min. The degreased wafer was etched with H_2SO_4:H_2O_2:H_2O (5:1:1) for 1 min to remove the surface damages and undesirable impurities. The low-resistivity ohmic contact to the n-InP wafer was made by evaporating In and annealing at 320 °C under N_2 atmosphere for 3 min. The Schottky contacts with 1 mm diameters were formed by evaporating Au metal on the front face of sample using a shadow mask. In this way, the Au/n-InP/In diode was obtained. Then the In_2S_3 thin film was directly deposited on the surface of n-type InP semiconductor with In ohmic contact by spray pyrolysis method at 200 °C substrate temperature to investigate its effects on the barrier height.

In_2S_3 thin films were deposited by the spray pyrolysis technique from aqueous solutions containing indium chloride ($InCl_3$) and thiourea ($CS(NH_2)_2$) with the molar ratio (In/S) of 1/3 and 1/6 (at an $InCl_3$ concentration of 2×10^{-3} mol/l), using a pneumatic spray set-up and compressed air as a carrier gas. Three different solvents were used: deionized water, H_2O; H_2O with ethanol (H_2O:C_2H_5OH = 1:1, by volume) and H_2O with isopropyl alcohol (H_2O:C_3H_8O = 1:1, by volume). Total volume of the solution sprayed was 50 ml and the rate of spray was 2.5 ml/min in all cases. Then, the Schottky contacts were formed by evaporation of Au dots with diameters of about 1.0 mm (the diode area = 7.85×10^{-3} cm^2) on In_2S_3 thin film. Finally, the Au/In_2S_3/n-InP/In structure was obtained. All evaporation processes were carried out in a vacuum coating unit at about 10^{-5} mbar.

The detailed structural and optical properties of the In_2S_3 thin film were investigated with SEM, XRD and absorption techniques. The *I–V* measurements of the Au/n-InP/In and Au/In_2S_3/n-InP/In junctions performed by the use of a KEITLEY 487 Picoammeter/Voltage Source and the *C–V* measurements were performed with HP 4192A (50–13 MHz) LF Impedance Analyzer at room temperature and in dark.

3. Results and discussion

Scanning electron microscopy (SEM) measurement has been employed to reveal the surface of the In_2S_3 thin film. Fig. 1(a) shows SEM image of the InP surface and Fig. 1(b) shows SEM images of the In_2S_3 thin film. At Fig. 1(b), the film's grain size is small and thus achieving a smooth surface morphology covered well with substrate. From the image of thin film, it is clearly seen that the particles forming the film are in nano scale. One of the important applications of the SEM is to obtain the knowledge of the material composition. This microanalysis mode of SEM replied upon the monitoring X-ray emitted by surface of the sample under electron irradiation. These X-ray may be collected and analyzed to give information on the elemental compounds present in the sample [19]. The quantitative analysis of the film was carried out by using the EDAX technique to study stoichiometry of films. The typical EDAX spectra shown in Fig. 2 indicates that expected elements have been detected in the thin films.

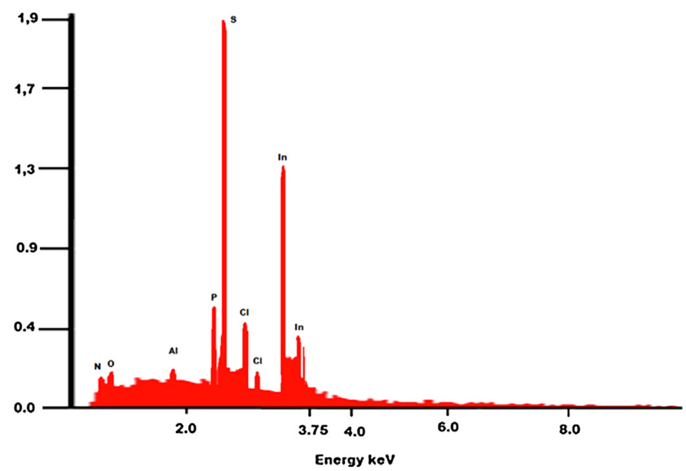

Fig. 2. EDAX spectrum of the In_2S_3 thin film.

Table 1
The results of the elements detected in In_2S_3 thin film.

Element	Wt%	At%
NK	02.75	10.58
OK	03.11	10.48
AlK	00.65	01.30
PK	00.60	01.05
SK	22.39	37.67
ClK	05.51	08.39
InL	64.99	30.54

The result of the EDAX measurement for In_2S_3 is listed in Table 1 which represents the constituent elements percentage. The elemental analysis was carried out In and S; the average atomic