SCHOTTKY BARRIER JUNCTIONS OF GOLD WITH LEAD CHALCOGENIDES: GROWTH AND CHARACTERISTICS

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Lead chalcogenides and their solid solutions having detecting and lasing capabilities are of great scientific and technological importance. High-quality polycrystalline thin films of semiconductor lead chalcogenides (PbS, PbSe and PbTe) have been deposited onto ultra-clean conducting glass substrates by vacuum evaporation and then metal (gold) contacts were deposited over the films so obtained. The I-V characteristics of Schottky barrier junctions of metal 'gold' with semiconductor 'lead chalcogenides' have been investigated and parameters such as barrier height and ideality factor were determined. It has been suggested that in all the undertaken Schottky barrier junctions, the current transport is through thermionic emission.

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1. Introduction

Chalcogenides, especially, of cadmium, lead, zinc, gallium, indium and their solid solutions are technologically important materials for micro- and opto-electronics [1]. Lead chalcogenides have been used as sensors for infrared radiation, photoresisters, lasers, solar cells, optoelectronic devices and thermoelectric devices [2-4]. Thermoelectric devices have been used in broad areas such as in consumer products like small refrigerators and in cooling units for fiber junctions in optical fiber communication technology [5, 6]. Furthermore, lead chalcogenides have been utilized in IR gas spectroscopy, long- wavelength imaging [7], thermo-photovoltaic energy converters [8] and photovoltaic and photoconductive detectors [9]. Narrow band gaps and high carrier mobilities identify lead chalcogenides as basic materials for infrared optoelectronic devices [10] and thermoelectric materials in quantum-well systems [11]. Photovoltaic lead chalcogenides sensors are rather tolerant to structural defects in contrast to HgCdTe and InSb material families [12].

The development of laser technology has opened up new applications for IV-VI compounds. Laser diodes based on lead chalcogenides and their solid solutions are important sources for tunable radiation in the mid-infrared wavelength region. The lead chalcogenides PbS, PbSe and PbTe together with other IV-VI compounds possess an exceptional set of physical properties described in many reviews [13,14]. From these materials, laser diodes [15] as well as detectors [16] have been fabricated. Over the years, great efforts have gone into providing a microscopic understanding of the rectification at metal-semiconductor interfaces, i.e., Schottky barrier junctions. Metal-semiconductor contacts showing rectifying properties are finding more and more applications in modern semiconductor devices technology.

Metal-semiconductor (MS) contacts are one of the most widely used rectification devices employed in the electronic industry [17, 18]. In general, the performance and reliability of a

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Schottky contact is determined by the quality of the interface between the deposited metal and the semiconductor surface; and many attempts have been made to understand the nature of the current transport across this interface [19]. Although several studies related to Schottky contacts have been carried out during the last two decades [20-22], the conduction mechanism and Schottky parameters remain a topic of current interest. In the present work, attempts have been made to optimize the deposition parameters to obtain good quality thin films of PbS, PbSe, PbTe and to prepare and characterize the Schottky barrier junctions formed between these films and gold.

2. Experimental details

Highly pure semiconducting materials PbS, PbSe, PbTe and the metal Au (99.999%, Sigma-Aldrich) has been employed. Good quality polycrystalline thin films of lead chalcogenides were deposited by vacuum evaporation onto ultra-clean conducting glass substrates kept at room temperature in a vacuum of the order of 10^{-6} Torr (Hind Hivac, 12A4D). The deposited thin films were annealed in the same vacuum chamber at about 110°C for 1 h and then left inside the vacuum chamber for one day to attain thermodynamic equilibrium. The thickness (~ 200 nm) of the films has been measured using a quartz crystal thickness monitor. The deposition parameters were kept same for all thin films. The polycrystalline nature of the films has been confirmed by X-ray diffraction.

For the fabrication of Schottky barrier junctions, metal (gold) contacts were deposited over the films of semiconducting lead chalcogenides (PbS/PbSe/PbTe) using appropriate masks. No thermal treatment was given to the Schottky contacts. The current-voltage (I-V) characteristics were measured to characterize the fabricated junctions. These measurements were carried out at room temperature in a vacuum of 10^{-3} Torr in a specially designed sample holder using a Picoammeter with a voltage source (Keithley, 6487).

3. Results and discussion

The current-voltage (I-V) characteristics of the barrier junctions formed between PbS, PbSe and PbTe and gold were determined under forward and reverse bias and are shown in Fig. 1. The results have been analyzed according to thermionic emission theory [23-25] described by the following equation

$$I=AA^{*}T^{2}\exp\left(\frac{-q\phi_b}{kT}\right)\left[\exp\left(\frac{qV}{\eta kT}\right)-1\right]$$

$$\text{or} \qquad J=J_s\left[\exp\left(\frac{qV}{\eta kT}\right)-1\right] \qquad (1)$$

where J is the current density, $J_s = I_s/A$ is the saturation current density, A is the area of the junction, V is the applied voltage, q is the electron charge, η is the ideality factor, k is the Boltzmann constant and T is the absolute temperature.

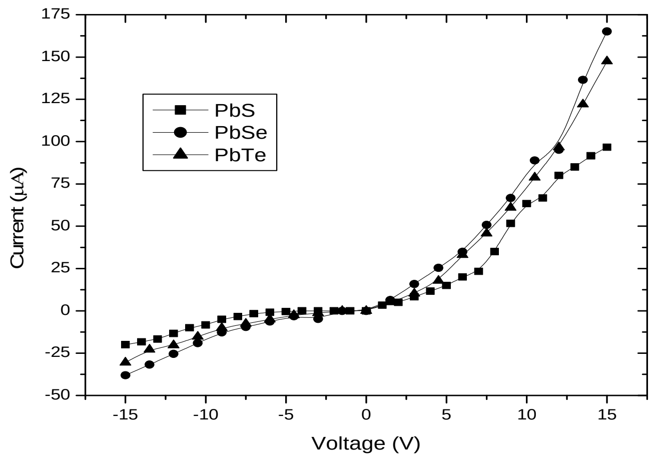

Fig. 1: I-V characteristic of Au-PbS, Au-PbSe, Au-PbTe Schottky Barrier Junction.

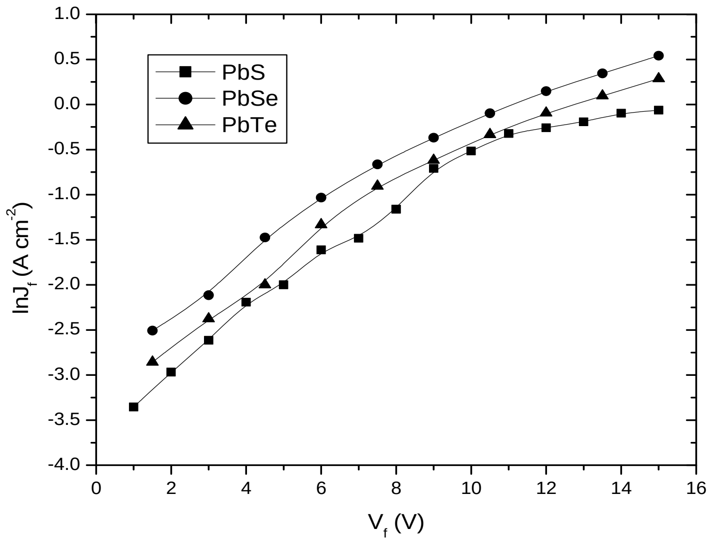

Fig. 2. Semilog plot of forward current density (J_f) versus forward voltage (V_f) for Au-PbS, Au-PbSe, Au-PbTe Schottky barrier junction.

The saturation current density, $J_s(T)$ is mainly determined by the barrier height ϕ_b and the effective Richardson constant A* as

$$J_s = A^*T^2\exp\left(\frac{-q\phi_b}{kT}\right) \tag{2}$$

where $A^* = 4\pi m^* qk^2 h^{-3}$ is the effective Richardson constant for thermionic emission corresponding to an electron effective mass m* in the semiconductor and h is the Planck constant.

It is clear from these expressions that the current I depends on the values of the two basic parameters ϕ_b and η, which are two important parameters from the standpoint of devices. For the calculation of barrier height from our data, the current density J was plotted on a logarithmic scale versus the applied forward voltage V. The resulting plot (see Fig. 2) exhibits a linear region in the low- voltage range. The barrier height was calculated from the expression [23-25]

$$\phi_b = \frac{kT}{q}\ln\left(\frac{A^*T^2}{J}\right) \tag{3}$$

From Fig. 2, the extrapolated value of current density J_f to zero voltage gives the saturation current density J_s. The barrier heights of the junctions at room temperature have been determined using equation (3) and have the values 0.29, 0.37 and 0.34 respectively.
The ideality factor η, which is a measure of the quality of the metal-semiconductor junction, is introduced to describe the deviation of the experimental data from the ideal thermionic emission model (η =1 for the ideal case); and may be calculated from the slope of the linear region of the forward bias lnJ-V characteristics through the relation [23-25]:

$$\eta = \frac{q}{kT}\left[\frac{dV}{d(\ln J)}\right] \tag{4}$$

The ideality factors of these junctions at room temperature have been determined using equation (4) and the slope of ln J_f versus V_f plots and have the values 1.86, 2.14 and 1.98 respectively.

It is well known that electronic states and other factors at interfaces play an important role in the electrical properties of devices. Ideality factor larger than unity may be attributed to inhomogeneities in the barrier, non-stoichiometric defects at the interface, series resistance etc. [26-28]. Discrepancies in the values of Schottky barrier heights may be attributed to the image force lowering of the barrier height [25, 26, 29]. In our case, it is found that the current transport is controlled by thermionic emissionin in all the undertaken Schottky barrier junctions. There may be several causes of departure from the ideal behaviour $J_s = A^* T^2 \exp\left(-\frac{q\phi_b}{kT}\right)$, including those mentioned above. Factors which make η larger than unity may be the field dependence of barrier height, quantum mechanical tunneling of electrons through the barrier, and the carrier recombination within the depletion region. The field dependence of barrier height arises either due to the presence of the insulating interfacial layer or due to image force lowering of the barrier.

4. Conclusions

The work presented in this report has been focused on (i) fabrication of Au-PbS, Au-PbSe and Au-PbTe Schottky barrier junctions, (ii) analysis of current-voltage (I-V) characteristics, and (iii) determination of Schottky parameters such as barrier height and ideality factor. These junctions showed non-ideal behaviour at room temperature having ideality factors of 1.86, 2.14 and 1.98 respectively. The barrier heights of these junctions at room temperature were found to be 0.29, 0.37 and 0.34 respectively. It has been suggested that in all the undertaken Schottky barrier junctions, the current transport is through thermionic emission.

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