International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

Barrier Height and Changing Insulator Thickness of Thin Film MIS Junctions

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Abstract: ***Using thermal evaporation, metal-semiconductor and metal-insulator-semiconductor thin-films were prepared. By using experimental I-V and activation energy measurements, it was determined that barrier height ($\emptyset_{bn}$) increases as the thickness of the insulator increases.***

Keywords: Thin Film MIS Junctions

1. Introduction

Because of their industrial significance in a variety of functions, notably in the manufacturing of devices as diverse as TVs, radios, computers, detectors, etc. [1], metal-semiconductor and metal-insulator-semiconductor junctions have had extensive analysis—the rectifying function of metal-semiconductor contacts is of vital consequence in most of these technologies. However, the Schottky barrier height ($\emptyset_{bn}$) of these contacts is significantly lower than preferable for applied use [2]. By inserting a thin insulating layer between metal and semiconductor, not only is current leakage reduced, but barrier height increases [2,3].

This paper examines the relationship between insulator thickness and barrier height ($\emptyset_{bn}$) on Al/a-Se/n-CdTe junctions, created using thermal evaporation.

2. Sample Preparation and Measurements

The data analysed in this research was gathered on Al/a-Se/n-CdTe junctions, prepared using vacuum deposition with an Edward (E306) high vacuum coating unit at a pressure lower than 10^{-5} mbar on glass substrate. Four separate evaporation processes allowed the obtaining of four different layers, from which the whole sample used in this study was produced.

The bottom electrode of high-purity Aluminium wire was evaporated from a Tungsten spiral. Then Cadmium Telluride films were deposited by thermal evaporation using a molybdenum boat as a semiconductive layer. To prepare the insulator layer, Amorphous Selenium (a-Se) was deposited utilising a tungsten boat as a source of evaporation. The metal, Aluminium layer was then deposited over the system

Only materials with purity of over 99.999% were used in the research. Current-voltage characteristics were reported at a range temperatures between 303-413^{o}K.

Barrier heights are critical components in defining electrical properties of MIS diodes. The barrier height of an MIS junction is determined as the required energy for an electron at the Fermi level in the metal to enter the conduction band of the semiconductor [4]. As a crucial element for a variety of applications, the barrier height of MIS structures [4,5] can be measured using one of four methods:

a. Current-Voltage
b. Activation energy
c. Capacitance–Voltage
d. Photoelectric effect

This study uses the first and second methodologies (current-voltage and activation energy measurements, respectively).

a. Current-Voltage
The I-V characteristics in the forward direction with V>3k$_\beta$T/q for moderately doped semiconductors, are provided by [2,4,6]:

$$I = I_o\left(exp.\left({}^{qV}/_{nk_\beta T} - 1\right)\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where q is the electronic charge, n is a quality factor and I_o is the saturation current, which is established by:-

$$I_o = AA^{*}T^{2}\exp\left({}^{-q\emptyset_{bn}}/_{k_\beta T} \quad \ldots(2)\right)$$

Where A* ,A,k$_\beta$,T, $\emptyset_{bn}$ denote the Richardson constant, effective area of the junction, Boltzmann constant, Temperature and barrier height of the junction respectively.
Thusly, the barrier height, ($\emptyset_{bn}$) is obtained from eq.(2) as:

$$\emptyset_{bn} = \frac{k_\beta T}{q}.\ln\left(\frac{AA^{*}T^{2}}{I_o}\right) \quad \ldots\ldots(3)$$

b. Activation Energy
Determining the barrier height using activation energy has a primary advantage since an electrically active area is not assumed in the calculation. For example, the electrically active area on surfaces that are poorly cleaned or very small may only be a tiny fraction of the total geometric area.
From eq(2), we can assess [4,7,8]:

$$\ln\left({}^{I_o}/_{T^{2}}\right) = \ln(AA^{*}) - {}^{q\emptyset_{bn}}/_{k_\beta T} \quad \ldots(4)$$

A graph of ln($^{I_o}/_{T^2}$) against (1/T) is thus a straight line with a gradient of $\left(-^{q\phi_{bn}}/_{k_\beta}\right)$. The intersection of this line at (1/T=0) allows the electrically active area (A) and the effective Richardson constant (A^*) to be obtained. This graph is commonly defined as a Richardson plot[8].

3. Results and Discussion

I-V characteristics for MS (Al/n-CdTe) junctions and for MIS (Al/ Se/n-CdTe) junctions with insulator thicknesses of 250, 750, 1000, and 2000A°, were obtained (Fig.1) (measured at atmospheric pressure, room temperature, and with ordinary light of power intensity =1 mW/cm^2. It was revealed that a low and stable current with respect to time was produced when the sandwich system was connected to voltage. Increasing voltage intermittently conduced a varying current as a result of a space charge. As a comparison, Fig. 1 demonstrates that the magnitude of the current(I) decreases alongside decreasing insulator thickness at a fixed voltage. The saturation current (I_o) will as a consequence decrease, as an effect of electrons having to penetrate through the additional barrier in the form of increased thickness.

A further verification of these findings is in Fig.2, where I-V characteristics were replotted with semilogarithmic scale for the current (I) for different junctions. From the data found in Fig.2 and Eq.3, we can ascertain the barrier height (ϕ_{bn}).

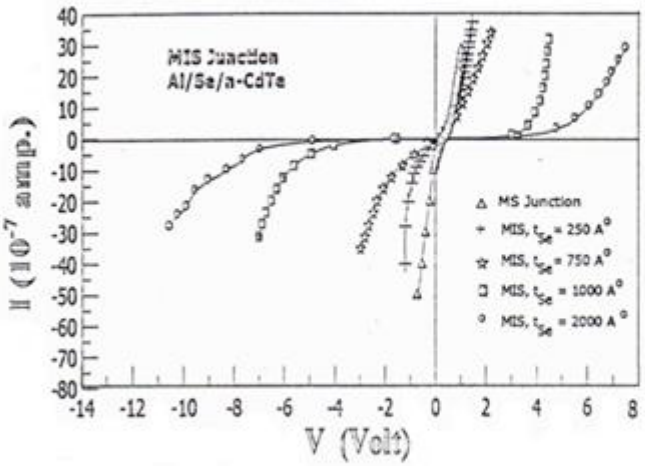

Figure 1: Current-voltage characteristics of AI/Se/n-CdTe junctions of different thicknesses at room temperature

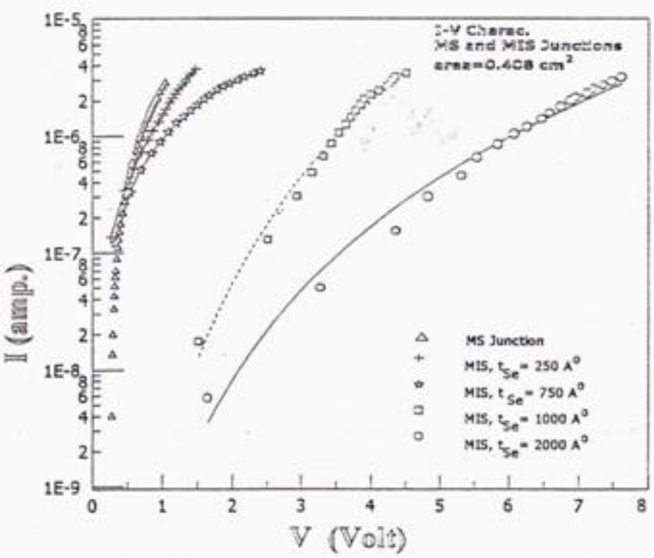

Figure 2: Log I-V characteristics for a forward biased AI/Se.n-CdTe junctions of different thicknesses.

The findings showed that current-voltage characteristics are temperature-dependent. Fig.3 and Fig.4 communicate that the current increases with temperature. This correlation can be credited to both current flow being regulated by a dominant thermionic emission at high temperatures, and also a subsequent lowering of junction resistance.

A further confirmation of these findings is in the linearity of ln(I_o/T^2) against (1000/T) graph as in Figs.5,6. The graph's gradient is calculated as ($-q\phi_{bn}/k_\beta$); an example of a Richardson plot. From the data found in Fig.5 and Fig.6, we can calculate the value of the barrier height (ϕ_{bn}).

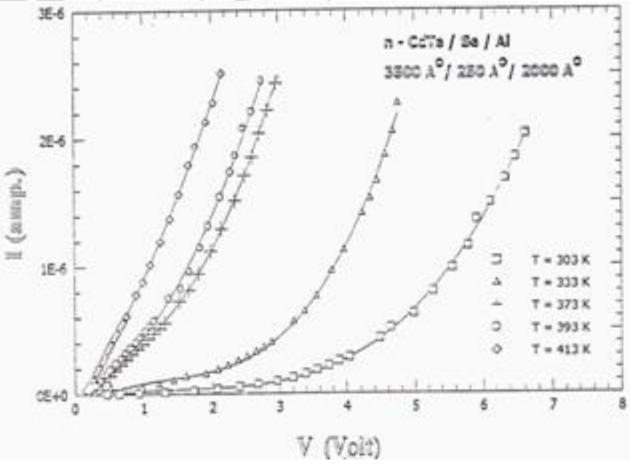

Figure 3: current-voltage characteristics of a forward biased AI/Se/n-CdTe junctions at different temperature, insulator thicknesses 250A°.

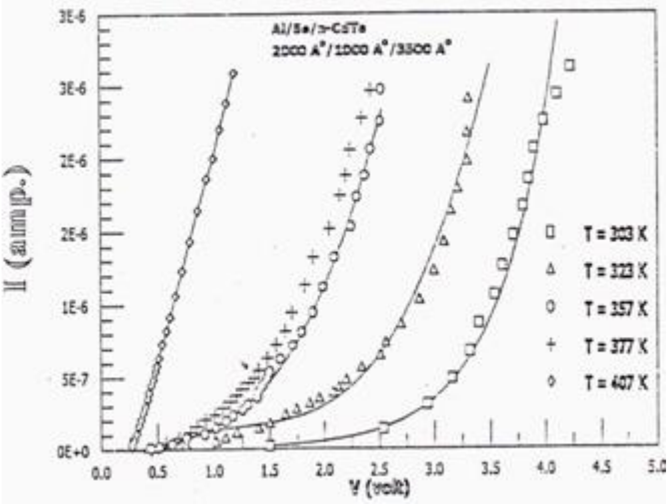

Figure 4: Current-voltage characteristics of a forward biased AI/Se/n-CdTe junctions at different temperature/ insulator thicknesses 1000A°.

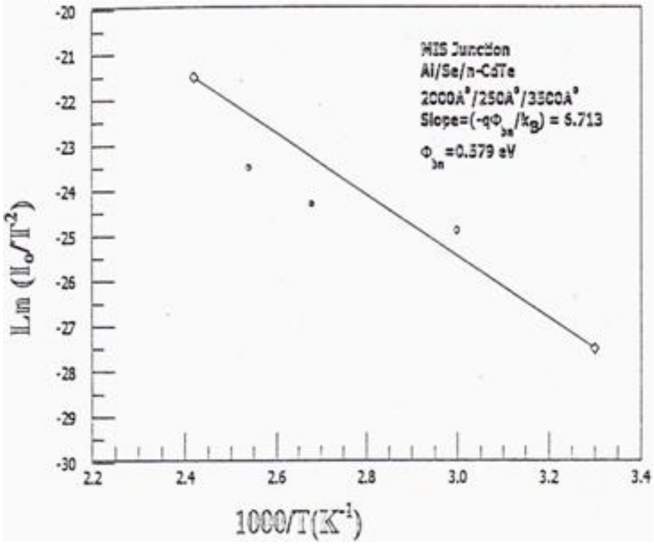

Figure 5: Richardson plot for AI/Se/n-CdTe junctions for insulator thicknesses 250A°.

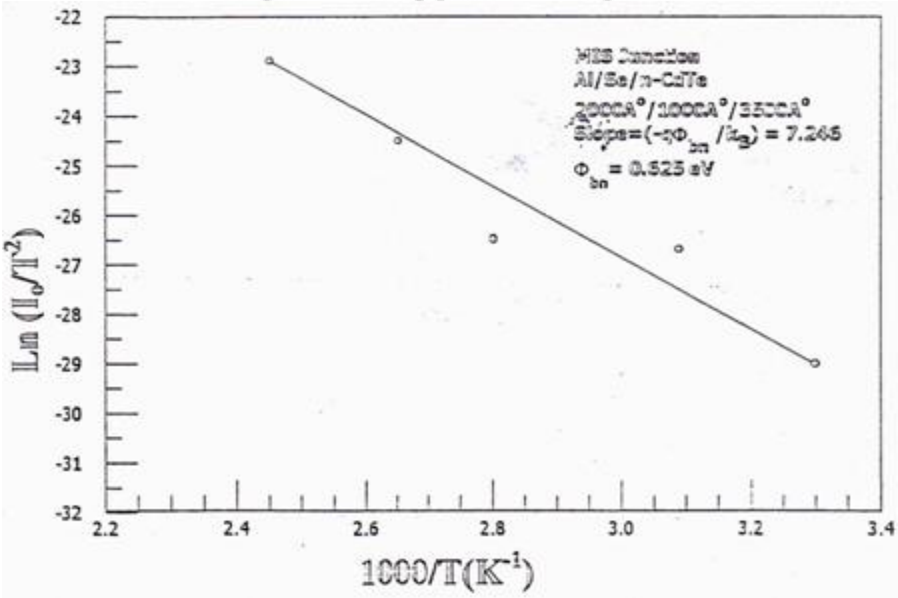

Figure 6: Richardson plot for AI/Se/n-CdTe junctions for insulator thicknesses 1000A°.

These different techniques determined that (ϕ_{bn}) for AL/Se/n-CdTe junctions was found to be in the range 0.544-0.792 eV, which is concurrent with past literature [2,4,9,10]. Where (ϕ_{bn}) increased with increasing insulator thickness, general characteristics of (ϕ_{bn}) were approximately the same Fig.7. This finding is possibly the result of carrier electrons being blocked by the increased thickness: it may fundamentally decrease the tunneling capacity of electrons through the insulator.

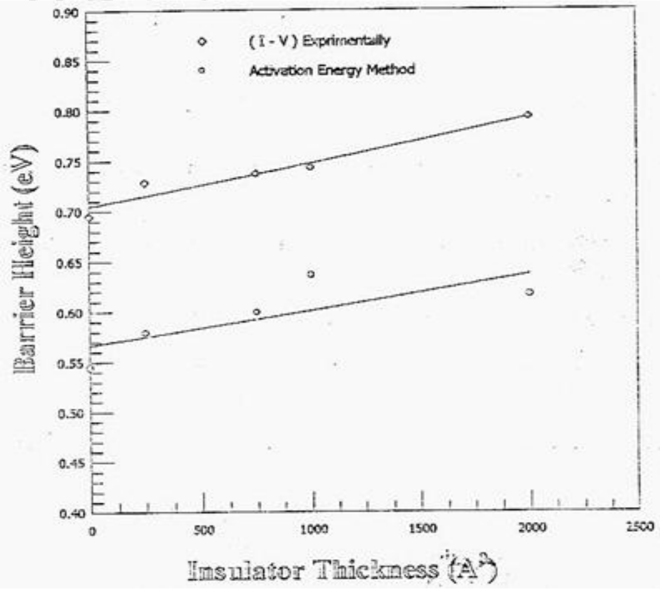

Figure 7: Barrier height variation with insulator thickness for AL/Se/n-CdTe junctions

4. Conclusion

1) V measurements revealed a notable effect on the junction current by the presence of insulator film.
2) Barrier height (ϕ_{bn}) measurements indicate that the barrier consists of two components: firstly, the space charge in the semiconductor's depletion region; and secondly from the insulator.
3) Both techniques showed a marked difference in barrier height measurements; I-V and activation energy measurements. From this, we can imply that the discrepancy in (ϕ_{bn}) values result from the increased mobility of carrier electrons with elevated temperature in the case of the activation energy measurement technique.

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