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# ELECTRICAL PROPERTIES OF ANTIMONY (Sb) METAL CONTACTS TO SILICON (Si) THIN FILMS

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**Abstract.** The study investigates the behaviour of the contacts formed by Antimony (Sb) metal to Silicon (Si) thin films for electric field values 10 – 100V/m. Measurements of I-v characteristics were obtained at temperatures 303, 313, 323, 333, 343 and 353K respectively. The results show linear I – V relationship over a specified range of voltage (10 – 60V) and at higher voltage (>60V), there was deviation from linear behaviour for each of the temperature. The electrical surface conductance of the samples increases with temperature while the saturation current density decreases with temperature. Nonetheless, the study revealed very little increase in the values of the barrier heights with increasing temperature.

## 1. INTRODUCTION

Metal – Semiconductor contacts have been of great interest to scientists because of their technological applications in various forms. Their ohmic behaviour had been found to be reliable and reproducible [1]. In particular, ohmic contact materials should not undergo electromigration under high electric fields nor modify that active structure characteristic during device operation [2]. Several possible ways of achieving ohmic contact have been reported. One method is by having a layer of heavily doped semiconductor immediately adjacent to the metal, so that the depletion region in the semiconductor becomes so thin that even in a high barrier, field emission dominates and the contact is ohmic. An introduction of recombination centre near the metal-semiconductor interface and having a negligible potential barrier at the metal-semiconductor interface [3,4,5,6,7,8] are other methods employed in Ohmic contacts.

Silicon (Si) is of great importance because of its increasing numerous applications. Most industries use it as conduction controlled devices and detectors, for the fabrication of solar cells photovoltaic cells for direct conversion of solar energy to electricity [9] and various forms in electronics. Studies have been carried out on the behaviour of some metal contacts to evaporated semiconductor thin films. It has been shown that some metals formed Ohmic contacts to semiconductor films [10,11,12,13,14]. Heiland and Lamatsch [14] in their electrical resistance measurement on silicon materials found that absorption of oxygen causes the resistance of a p-type sample to decrease initially and then increase. Phahle [15] reported on the electrical conductivity, Hall voltage and thermoelectrical power of thin vacuum deposition tellurium films. The films were found to be p-type with crystallographic defects providing additional acceptor centers and terminal assisted hopping conduction was found to be predominant at temperature below 150K, above which intrinsic conductivity predominated.

The present study investigates the behaviour of Sb metal contacts to Silicon thin films at temperature range 303K to 353K. The desired pattern of the films was generated using mica mask. The nature of the contact was determined using the Current (I) – Voltage (V) characteristics at the required temperature.

## 1. EXPERIMENTAL

The mica mask used to generate the desired pattern was washed with soap detergent and rinsed with distilled water. This was followed by ultrasonic agitation in de-ionized water, acetone and ethyl alcohol for twenty minutes each before drying. The polished glass slides, which were used as substrate, were first boiled in chromic acid and then ultrasonically cleansed as described above. After cleaning, the substrates were then enclosed in a vacuum chamber (Edward coating Unit model 306) and Silicon films thickness 1000A$^0$ were deposited on the substrate from a tungsten filament at a pressure of 5 x 10$^{-5}$ torr. Contacts were made at opposite ends of the films by depositing antimony metals on the electrode width. The final configuration of the films is as shown in Fig. 1. The deposition rate, which was about 500A$^o$/ min., was determined with an Edward model FTM3 film thickness monitor. All the evaporant were of 5N9 purity (Ventron, Germany). The experiment was conducted in a closed controlled atmosphere where the temperature could be varied from 303K to 353K. The samples temperature was determined with a constantan thermocouple with its cold junction maintained at O$^o$C. At each desired temperature, the Current (I) – Voltage (V) characteristics of the samples were measured with a digital electrometer (Keithley type 160B) and a digital multivoltimeter (Hewlett – packerd type 3465A).

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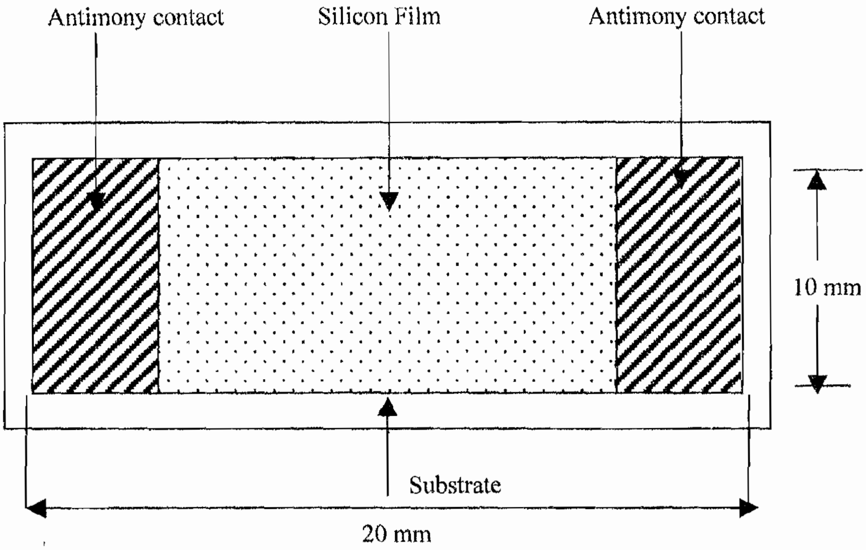

Fig 1. Final configuration of deposited samples.

## 2. RESULTS AND DISCUSSION

The results of the Voltage V (volts), Current I (mA), Current density I (mA/mm$^2$) of all the samples at 303K, 313K, 343K and 353K are recorded in Table 1. The current in all the samples increases with increase in voltage. This increase is seen to be pronounced at low voltage < 60V than at high voltage > 60V (within the range 0 – 100V for the study). There is also measurable increase in current with temperature for the sample. The Current (I) – Voltage (V) plots are shown in Fig. 2. In this Fig., all the samples show linear I – V relationship over specified range of voltage (10 – 60V). At higher voltage (i.e.>60V) there is a deviation from this linear relationship to rectifying characteristics. Ormar [16] showed that for Ge at high field, considerable deviation from ohm's law (linear relationship) to rectifying behaviour is observed and that the current actually saturate at some constant values followed by an electrical breakdown at some relatively high voltage. Traces of this had also been recorded by Oberafo et al [2] for Bi/Te samples even at relatively low field measurements at temperatures above 303K. Furthermore, factors such as temperature, pressure, presence of impurities, and concentration of carriers had been reported to affect the electrical properties of semiconductors [17]. The present study for Sb/Si samples at temperature between 303K and 353K agree with these results as evidence of saturation is observed in figure 2 at voltage range 60 – 100V. However, available records for Ge and Te showed deviation from ohmic characteristics at very high fields (>100V) at temperature above 330k, but Si samples showed deviation from Ohmic characteristics at field above 60V. Hence Sb/Si contacts responds faster to rectifying behaviour than Ge and Bi/Te contacts. The values of the temperature (K), surface conductance $\delta_S$ (A/mm$^2$), saturation current density and barrier heights $\Phi_B$ (Volts) are shown in Table 2. The values of the surface conductance and the barrier height increase with increasing temperature while the values of the saturation current density (J) decreases with increasing temperature. Although, the increase in barrier height with temperature was very small and seems insignificant. Evidence of this had been reported by [13] for Sb/Te contacts at room temperature. The increase in the surface conductance could be attributed to the usual expected increase in carrier density with increase in temperature. In addition, the conductivity of a system increases with increase in thermal energy, which enables some electrons within the valence band to gain energy. These electrons are excited into the conduction bands thereby leaving holes within the valence band.

The surface conductance of the samples were obtained by taking the slope of the line of best –fit of the Current (I) – Voltage (V) plots and then using the relationship [18].

$$\delta_S = \frac{\ln 2}{\pi}\frac{I}{v} = \frac{\ln 2}{\pi}(\text{slope of line of best fit}) \qquad (1)$$

The slope of line of best – fit is obtained from the ohmic region of the graph (Fig.2). The barrier height was calculated from the Current (I) – Voltage (V) characteristics using the thermionic emission theory for high mobility semiconductors such as Te and Si with I – V relationship given by,

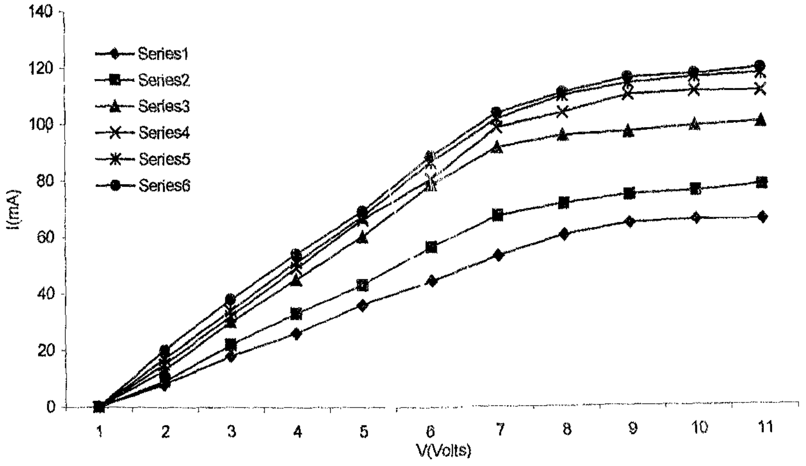

Fig.2: Current (I) - Voltage (V) plots for the samples

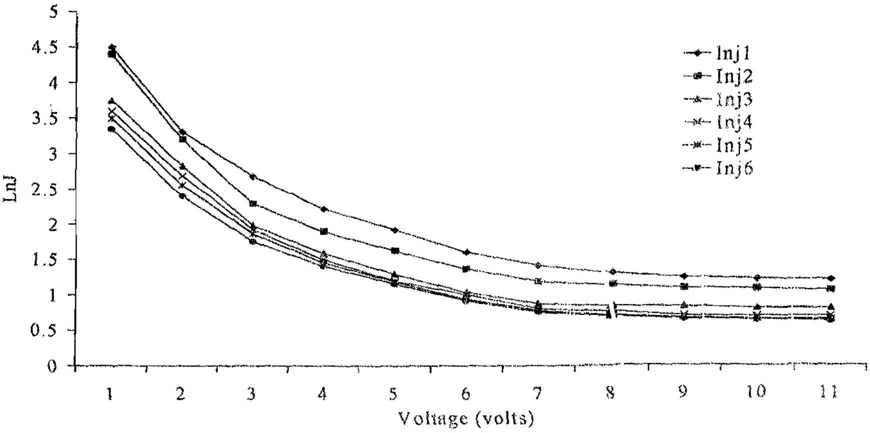

Fig.3: LnJ – Voltage (V) plots for the samples

$$J = J_S\{\exp(\frac{qV}{kT}) - 1\} \qquad (2)$$

where V is the voltage across the device terminals. For negligible series resistance,

$$J = A^{**}T^2 \exp(\frac{-q\phi_B}{kT}) \qquad (3)$$

$\phi_B$ is the zero field asymptotic barrier height, $A^{**}$ is the effective Richardson constant, k the Boltzmann's constant, T the temperature and q the magnitude of the electronic charge. LnJ – Voltage (V) plots (Fig 3) gives curves which is expected at the region V< $\frac{3kT}{q}$ for the study. The saturation current density $J_s$ is obtained from the extrapolated value of LnJ to zero voltage while the barrier height is estimated using the relationship,

$$\phi_B = \frac{kT}{q}\ln\frac{(A^{**}T^2)}{J_S} \qquad (4)$$

Table 1: Voltage V (volts), Current I (mA), Current density J (mA/mm$^2$) values at different temperature (LnJ gives the magnitude only)

| | 303 K | | | 313 K | | | 323 K | | | 333 K | | | 343 K | | | 353 K | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| V | I1 | J1 | LnJ1 | I2 | J2 | LnJ2 | I3 | J3 | LnJ3 | I4 | J4 | LnJ4 | I5 | J5 | LnJ5 | I6 | J6 | LnJ6 |
| 10.00 | 8.00 | 0.036 | 3.31 | 9.00 | 0.040 | 3.20 | 13.00 | 0.059 | 2.83 | 15.00 | 0.068 | 2.69 | 17.00 | 0.077 | 2.56 | 20.00 | 0.091 | 2.40 |
| 20.00 | 18.00 | 0.068 | 2.69 | 22.00 | 0.100 | 2.30 | 30.00 | 0.136 | 1.99 | 32.00 | 0.146 | 1.93 | 34.00 | 0.155 | 1.87 | 38.00 | 0.173 | 1.76 |
| 30.00 | 26.00 | 0.109 | 2.22 | 33.00 | 0.150 | 1.90 | 45.00 | 0.205 | 1.59 | 49.00 | 0.223 | 1.50 | 51.00 | 0.232 | 1.46 | 54.00 | 0.246 | 1.41 |
| 40.00 | 36.00 | 0.146 | 1.93 | 43.00 | 0.196 | 1.63 | 60.00 | 0.273 | 1.30 | 66.00 | 0.300 | 1.20 | 67.00 | 0.305 | 1.19 | 69.00 | 0.314 | 1.16 |
| 50.00 | 44.00 | 0.200 | 1.61 | 56.00 | 0.255 | 1.37 | 78.00 | 0.355 | 1.04 | 80.00 | 0.364 | 1.01 | 86.00 | 0.391 | 0.94 | 88.00 | 0.400 | 0.92 |
| 60.00 | 53.00 | 0.241 | 1.42 | 67.00 | 0.305 | 1.19 | 91.00 | 0.414 | 0.88 | 98.00 | 0.446 | 0.81 | 101.00 | 0.459 | 0.78 | 103.00 | 0.468 | 0.76 |
| 70.00 | 60.00 | 0.273 | 1.30 | 71.00 | 0.323 | 1.13 | 95.00 | 0.432 | 0.84 | 103.00 | 0.468 | 0.76 | 109.00 | 0.496 | 0.70 | 110.00 | 0.500 | 0.69 |
| 80.00 | 64.00 | 0.291 | 1.24 | 74.00 | 0.336 | 1.09 | 96.00 | 0.436 | 0.83 | 109.00 | 0.496 | 0.70 | 113.00 | 0.514 | 0.67 | 115.00 | 0.523 | 0.65 |
| 90.00 | 65.00 | 0.296 | 1.22 | 75.00 | 0.341 | 1.08 | 98.00 | 0.446 | 0.81 | 110.00 | 0.500 | 0.69 | 115.00 | 0.523 | 0.65 | 116.00 | 0.527 | 0.64 |
| 100.00 | 65.00 | 0.300 | 1.20 | 77.00 | 0.350 | 1.05 | 99.00 | 0.450 | 0.80 | 110.00 | 0.500 | 0.69 | 116.00 | 0.527 | 0.64 | 118.00 | 0.536 | 0.62 |

Table 2: Temperature (K), surface conductance $\delta_s$ ($\Omega^{-1}$/mm$^2$), saturation current density J (mA/mm$^2$) and the barrier height $\Phi_B$ (volts) values of the samples

| Temperature (K) | Surface conductance x $10^{-1}$ ($\Omega^{-1}$/mm$^2$) | Saturation current density J (mA/mm$^2$) | Barrier height $\Phi_B$ (Volts) |
|---|---|---|---|
| 303 | 1.91 | 90.02 | 1.01 |
| 313 | 2.46 | 81.45 | 1.04 |
| 323 | 3.35 | 42.52 | 1.06 |
| 333 | 3.60 | 36.60 | 1.10 |
| 343 | 3.71 | 33.12 | 1.13 |
| 353 | 3.79 | 29.20 | 1.18 |

## 3. CONCLUSION.

The current in all the samples increases with increase in temperature. The samples were also found to exhibit linear I – V relationship over specified range of voltage (10 – 60V). At higher voltage (>60) there was deviation from linear behaviour to rectifying characteristics. Hence, Antimony (Sb) metal forms ohmic contact with Silicon (Si) semiconductor within the voltage range 10 – 60V at temperatures 303k and above. This study agrees with previous work by Ormar [16] and Oberafo et al [2] for Ge and Te at temperatures above 330K for relatively high fields (>100V). The electrical surface conductance of the films increases with increasing temperatures of measurement, which is attributed to increase in carrier density with increasing temperature. On the other hand, the saturation current density decreases with increase in temperature. Nonetheless, the increase in barrier heights of the samples with temperature was found to be very small.

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