YU ISSN 0015-3206
FZKAAA 19 (1) 79 (1987)

SPACE CHARGE LIMITED CONDUCTION IN VACUUM DEPOSITED Sb_2S_3 FILMS

KHAIRY A. MADY, MAHMOUD M. EL-NAHAS* and ABD-EL-MONEM A. GABR**

Physics Department, National Research Centre, Dokki, Cairo, Egypt

* *Faculty of Education, Ain Shams University, Heliopolis, Cairo, Egypt*

** *Faculty of Science, Cairo University, Cairo, Egypt*

Received 7 January 1987

UDC 538.93

Original scientific paper

Antimony trisulphide films were prepared by conventional thermal evaporation technique. The temperature dependence of resistivity for films prepared at substrate temperatures $60°C < T_s < 100°C$ indicated stoichiometric uniformity. Dielectric and *I-V* characteristics studies were undertaken. The dielectric constant was evaluated to be 14.8 for thick films and remains invariant down to 90 nm thick films and is frequency-independent in the audiofrequency range. The *I-V* characteristics of Au-Sb_2S_3-Au systems showed a space charge limited conduction indicating that $I \sim V^2/L^3$, where L is the electrode spacing. The trap density and the trap energy level were found to be $3.52 \cdot 10^{16}$ cm^{-3} and 0.72 eV, respectively.

1. *Introduction*

Steady state one carrier injection currents have been observed in various types of nonmetallic solids[1)]. The decisive factor in determining the carrier type is the availability of suitable injecting contacts. The information that can be extracted from single injection measurements with solids is largely in the realm of defect structure although information concerning transport properties and electrical contacts is also furnished in a less direct manner. In materials with a high degree of structural disorder, even though chemically very pure, e. g. evaporated films or vitreous solids, we may expect to find traps smoothly distributed in energy.

In the course of photoconductive films for use as target materials in the vidicon, current — voltage characteristics were observed in the dark in antimony trisulphide[2] that were strongly suggestive of space charge limited (SCL) currents. At sufficiently large fields ohmic contacts can inject charge carriers to materials like CdS, Sb_2S_3, etc. to have a conduction which is limited by the space charge effects. The I-V characteristics of the Sb-Sb_2S_3-Sb systems showed a SCL conduction indicating that $I \sim V^2/d^3$ for film thickness d ranging from 95 to 525 nm[3].

In the present article SCL current conduction is Sb_2S_3 films, thickness 100 to 700 nm using gold electrodes is reported. This is compared with the temperature dependence of the dark conductivity of the corresponding films.

2. *Experimental techniques*

Metal-semiconductor-metal (MSM) sandwich structures for the I—V studies were prepared on microglass slides by using thick vacuum-deposited gold films as base and counterelectrodes. Deposition of Sb_2S_3 films of the desired thickness was made through appropriate masks by thermal evaporation of Sb_2S_3 powder from a molybdenum boat to that a sandwich structure of the type Au/Sb_2S_3/Au was obtained. The effective area of each MSM system was 0.25 cm^2. The measurements were carried out by keeping the film system in a light tight box at room temperature. The I—V characteristics were measured using a conventional circuit.

The capacitance of the film capacitors was measured using EI-411A bridge (Sanwa, Japan) using an external oscillator in the audiofrequency range. The effective area of the capacitor was measured accurately using a microscope. Tolansky's interferometry method was used to find the thickness of the film. Dielectric constant (ε) was evaluated from the knowledge of the capacitance, film thickness and the effective capacitor area.

The substrates were kept at temperatures ranging from room temperature to 100°C and the evaporation were carried out by keeping all other parameters unaltered. The resistance measurements were carried out for films by postdepositing aluminium films as electrodes using an electrometer (Keithley 610 C).

3. *Results and discussions*

The temperature dependence of the resistivity of Sb_2S_3 films prepared at different substrate temperatures are shown in Fig. 1. Films, prepared at substrate temperatures $T_s < 60°C$ showed values of the activation energy in the range 0.52—0.63 eV dependent on T_s. On the other hand, films, prepared at $60°C < T_s < 100°C$, have the same activation energy $\Delta E = 0.76$ eV. This uniform nature can be attributed to the stoichiometric uniformity in the films prepared at this range of substrate temperatures. In the case of films prepared below 60°C the condensation of excess sulphur is possible on the substrate as discussed by de Klerk and Kelly[4] which may also result in the nonstoichiometry in the films formed. Thus, the temperature dependence of the resistivity showed that films prepared at $60°C < T_s < 100°C$ have uniform composition. Hence, for current-

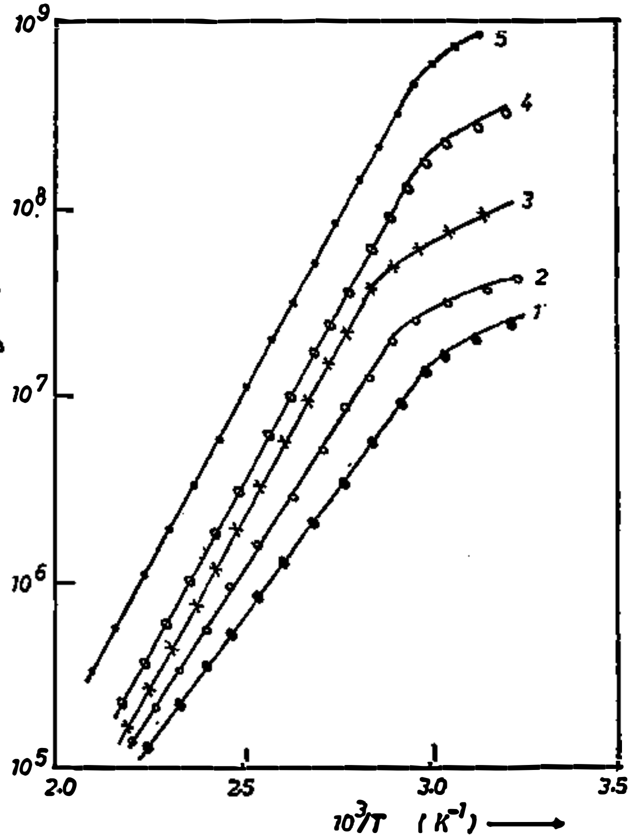

Fig. 1. Temperature-dependence of the electrical resistivity of Sb_2S_3 films deposited at different substrate temperatures; (1) 40°C, 300 nm thick (2) 60°C, 500 nm thick (3) 70°C, 300 nm thick; (4) 80°C, 500 nm thick (5) 90°C, 700 nm thick.

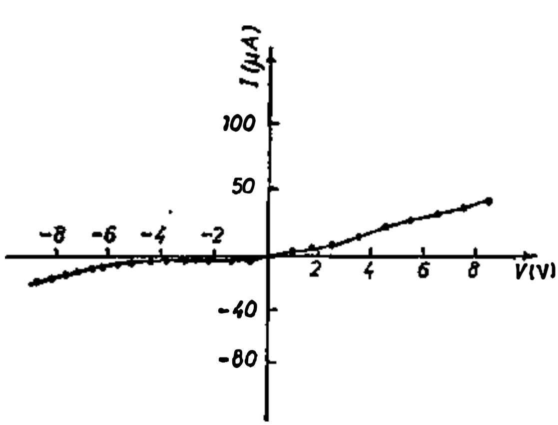

Fig. 2. Dark $I - V$ characteristics of $Al/Sb_2S_3/n - Si/Al$ junction.

voltage characteristics study such films of uniform composition were used. These films were found to be *p*-type, since on measuring the *I*—*V* characteristics of $Al/Sb_2S_3/n$-Si/Al junction in case of connecting the Si side of the junction to the positive electrode of the dc supply the inverse characteristics of the diode is observed (Fig. 2).

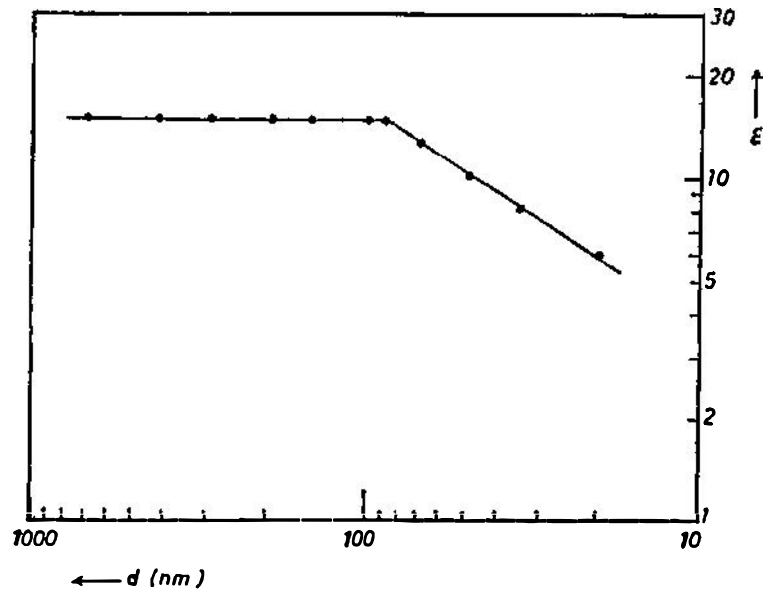

Fig. 3. Dependence of the dielectric constant (ε) of Sb_2S_3 on the film thickness (d) at 1 kHz.

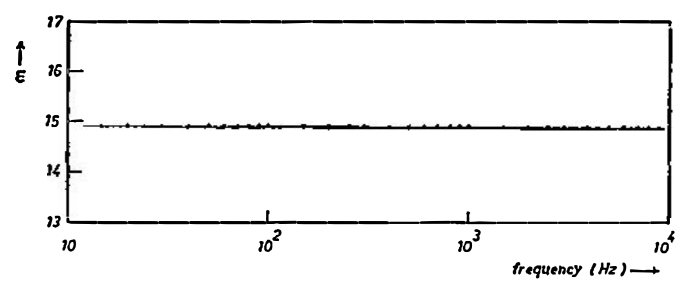

Fig. 4. Behaviour of the dielectric constant (ε) of Sb_2S_3 with frequency in the audiofrequency range at room temperature.

The variation of the dielectric constant with the film thickness measured at a frequency of 1 kHz is shown in Fig. 3. On increasing the film thickness the dielectric constant shows an instant rise and attains a constant value of 14.8 for 90 nm thick films, and thereafter remains invariant for thicker films. At room temperature, the dielectric constant of thick films is independent of frequency as shown in Fig. 4. The measured value of the dielectric constant $\varepsilon = 14.8$ for Sb_2S_3 films fairly agrees with the value of 15 for bulk material[5] and considerably compared to the values 13[6] and 14.5[7] obtained for thin films. The variation could be due to defects which are usually present in vacuum deposited films.

Fig. 5 shows the log-log plot of the I—V characteristics of a Au-Sb_2S_3-Au structure. It is characterized by an ohmic region at low fields followed by a square law region at high fields suggesting a space charge limited conduction. At the square law region the space charge limited current density, J, at a particular voltage, V, is given by[1]

$$J = \frac{9}{8} \Theta \varepsilon \mu \frac{V^2}{L^3}$$

where μ is the charge carrier mobility, ε is the relative static dielectric constant, L is the electrode spacing which is the thickness of the film and Θ is a constant independent of the injection level.

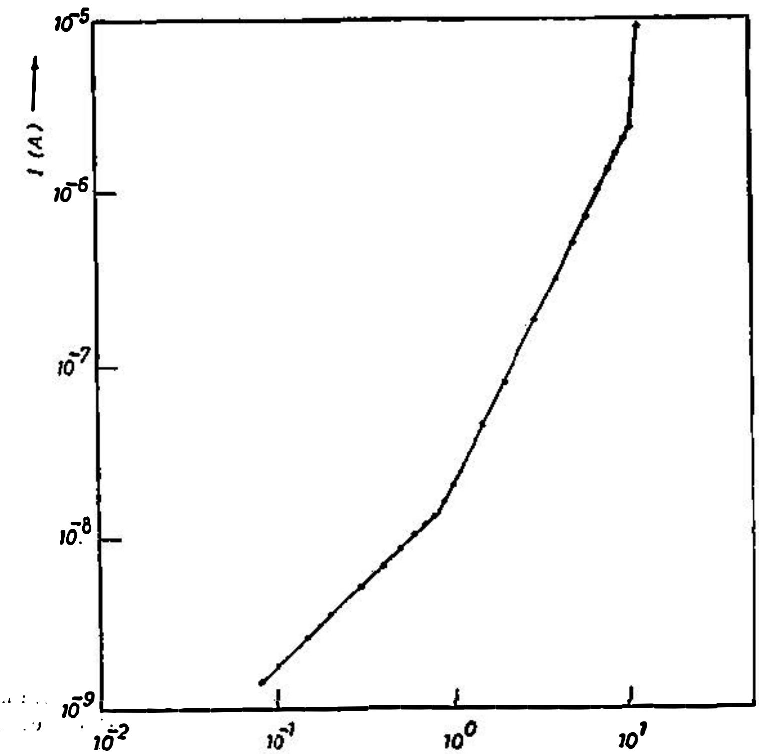

Fig. 5. I — V characteristics of Au-Sb_2S_3-Au sandwich structure where L equals 700 nm.

Plotting log I versus log L in the square law region for films of thickness ranging from 100 nm to 700 nm at the same voltage yields straight lines (Fig. 6) suggesting that $I \sim 1/L^3$ in accordance with Eq. (1). Such dependence establishes a

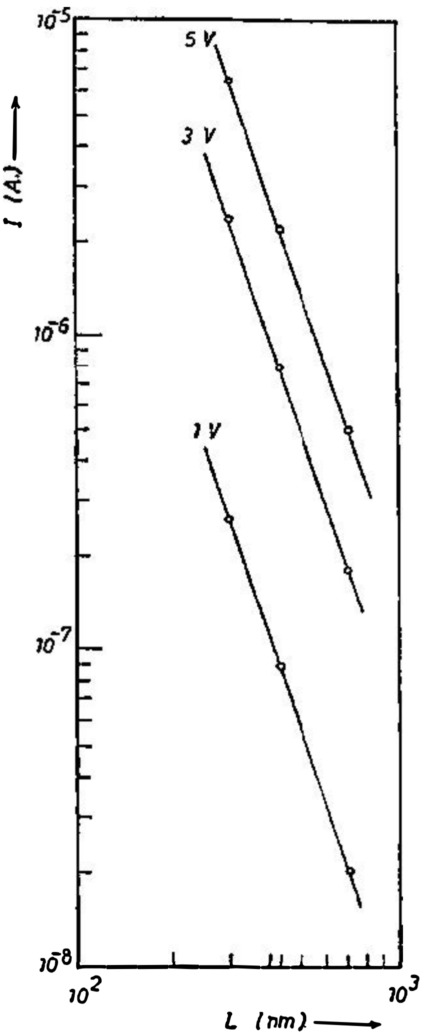

Fig. 6. log I-log L plot for constant voltage: a) 1 V, b) 3 V and c) 5 V.

one-carrier space charge limited current flow in the film system. The nearly vertical section of the characteristic followed directly the square law region section. Thus, the square law region is considered as a shallow trap square law region and the vertical section as the trap filled limit region. The trap density can be calculated using the formula:

$$N_t = \frac{1.1 \times 10^6 \, V_{TFL}}{L^2}$$

where V_{TFL} is the trap filled limit voltage at the trap filled limit region in V and L in cm. The mean value of the trap density calculated for films of different thickness was found to be $N_t = 3.52 \times 10^{16}$ cm^{-3}. The trap energy level E_t is determined using the relation[1]

$$E_t = kT \ln (N_v / \Theta g N_t)$$

where N_v is the effective density of states in the valence band ($N_v = 2.5 \times 10^{19}$ cm^{-3}), k the Boltzmann's constant, T the absolute temperature, $g = 2$ is the degeneracy factor of the traps and $\Theta = 3.05 \times 10^{-10}$ is the reduction factor calculated from the relation.

$$\Theta = 1.8 \times 10^{-6}\, p_0 L^2 / \varepsilon V_x$$

where $p_0 = 4.1 \times 10^5$ cm^{-3} (assuming $E_f = 0.82$ eV[8]) is the thermally generated free carrier concentration and V_x the cross-over voltage of the Ohm's law to square law region. The energy of the trap level was found to be $E_t = 0.72$ eV, which agrees with the value of the activation energy ($\Delta E = 0.76$ eV) deduced from the temperature dependence of resistivity.

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VODLJIVOST NAPARENIH SLOJEVA Sb_2S_3 OGRANIČENA PROSTORNIM NABOJEM

KHAIRY A. MADY, MAHMOUD M. EL-NAHAS* i ABD-EL-MONEM A. GABR**

Physics Department, National Research Centre, Dokki, Cairo, Egypt

* *Faculty of Education, Ain Shams University, Heliopolis, Cairo, Egypt*

** *Faculty of Science, Cairo University, Cairo, Egypt*

UDK 538.93

Originalni znanstveni rad

Slojevi antimon bisulfida dobiveni su standardnim postupkom naparavanja u vakuumu. Snimanje temperaturne ovisnosti otpora slojeva pokazalo je da su oni stehiometrijski jednoliki samo ako je temperatura podloge u intervalu 60°C $< T_s <$ 100°C. Mjerenja permitivnosti dala su za debele slojeve vrijednost 14,8. Ona ne ovisi o debljini sloja sve do 90 nm, a ne ovisi ni o frekvenciji u zvučnom području. I—V karakteristika trosloja Au-Sb_2S_3-Au ukazuje na vodljivost ograničenu prostornim nabojem kod koje vrijedi $I \sim V^2/L^3$, gdje je L razmak između elektroda. Koncentracija zamki je 3,52 $\times$ 10^{16} cm^{-3}, a njihova energija aktivacije iznosi 0,72 eV.