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A. I. MUKOLU

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Space Charge Limited Current at High Fields in Al-Ge-Al Surface Barrier Devices

A. I. MUKOLU
Department of Physics, University of Ado Ekiti,
Ado-Ekiti - NIGERIA

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Abstract

The current-voltage (I-V) characteristics of Aluminium-Germanium-Aluminium (Al-Ge-Al) surface barrier devices at different fields (<1,000V/cm) have been investigated. The results reveal that in the low field region (<300 V/cm), the conduction is ohmic while in the high field region (>300 V/cm), the current is proportional to the square of the applied voltage and is interpreted in terms of space charge-limited current. Also, the overall analysis of the results shows that the surface conductance (δ_s) of the samples increases with film thickness. The empirically determined values ofδ_s vary from 0.40 to 0.93 $\Omega^{-1}\text{m}^{-2}$ as the thickness of the films increased from 500 to 2000 $\AA$.

1. Introduction

Space charge-limited current in insulators and semiconductors is of interest because of its technological potentials. Space charge is of importance in thermionic tubes, photoelectric cells and particle accelerators owing to its effect on the flow of current and also plays a part in electrical conduction in solids.

By operating under space charge-limited conditions one intuitively anticipates short carrier transit times and thus good high frequency performance [1], relative insensitivity to temperature changes [2] and low noise [3]. Many amorphous insulating and semiconducting materials are known which, when a high electric field is applied to thin samples of the substance, exhibit current flow increasing roughly exponentially with applied voltage [4]. Mechanisms which might explain one or more of the observed characteristics are: ionic flow, space charge limited flow [5,6] Schottky emission [7] or Poole-Frenkel effect [8].

One of the most widely studied materials is Germanium (Ge). It is well known that while there is agreement on most properties of crystalline Ge, the situation is different for amorpous germanium (a-Ge). For example, over the years, there has been controversy

on the role of the junctions formed between a-Ge and metal contacts on the one hand and the a-Ge bulk (film) itself in determining the electrical transport characteristics [9-11]. Clark [9] and Morgan and Jonscher [10] regarded such junctions as the dominant contributors, while Hafiz et al [11] proposed that the junction and the bulk were joint contributors. Most properties of intrinsic and extrinsic crystalline germanium are now pretty well established. By comparison, however, more work still needs to be carried out on a-Ge.

Amorphous semiconductors including amorphous germanium films have received considerable interest [12-18] because of the intriguing properties of switching and memory exhibited by some of the compound amorphous semiconductors [19, 20] which show technological promise. Also, their ease of fabrication and relatively low cost make them indispensable and adequate materials for the fabrication of cheap and efficient space charge limited solid state devices. However, the technology of amorphous semiconductors cannot be properly utilized because basic understanding is far from complete. Hence the need for the present investigation on amorphous germanium.

It is now well established [21-25] that the electrical properties of thin films are strongly influenced by film structure. The factors that are found to affect the film structures are film thickness, the method and rate of deposition, substrate temperature during deposition, degree of annealing and vacuum conditions. It is with this in mind that the present investigation was under-taken in order to find the effect of varying thickness on the surface conductance of Al-Ge-Al surface barrier devices.

2. Experimental Work

The polished microscope glass slides which were used as substrates, were cleaned by first boiling in chromic acid and then ultrasonically in distilled, deionized water, trichloroethylene, acetone and ethanol. Also, the mica masks which were used to generate the desired patterns were cleaned thoroughly first with soap, rinsed in distilled, deionized water and then by utrasonic agitation for 10 minutes in successive baths of trichloroethylene, acetone and ethanol, in that order. After the cleaning, the slides and masks were transferred to the chamber of an Edwards, model 306 coater, where germanium films of thicknesses 500, 1000, 15000 and 2000 $\AA$ were deposited on them by thermal evaporation from tungsten filament in the chamber, maintained at a vacuum of about 10^{-5} torr. Thereafter, aluminium contact electrodes about 500 $\AA$ thick, were deposited on the Ge films in the form of a two point probe configuration of Al-Ge-Al. The samples were prepared from appropriate quantities of elemental germanium and aluminium, each of 99.999% purity (Ventron, Germany). The deposition rate which was about 500 $\AA$ min^{-1}, was determined with an Edwards, model FTM3 Film Thickness Monitor.

For the actual measurement, the chamber containing the test sample was initually evacuated. Thereafter, current-voltage (I-V) measurements were taken at room temperature with Keithley 160B electrometer and Hewlett-Packard 3465A millivoltmeter. From the I-V data, the surface conductance values of Al-Ge-Al samples were determined. The configuration and dimensions of a typical sample used for the measurements are shown

in Figure 1.

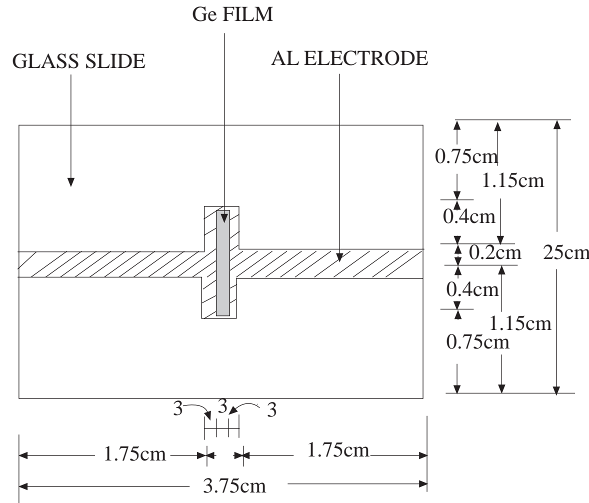

Figure 1. Dimensions and configurations of a typical sample used for the measurements.

3. Results and Discussion

A typical result of the I-V characteristics of Al-Ge-Al samples with different thicknesses (plotted on a log-log scale) is shown in Figure 2. These plots are linear at low voltage (<30V). The ohmic behaviour at low voltage (<30V) can be explained by the fact that there is negligible injection of carriers from the aluminium electrode to the Ge film and the initial current is governed by the intrinsic free carriers in the materials.

The increase in current at high fields (>300V/cm) is due to space charge limited current. At high fields (>300V/cm), the non-ohmic behaviour can be explained with the model of space charge limited current. Under conditions of thermodynamic equilibrium the conduction levels of the Ge samples are essentially empty and the valence levels are filled. With Al source contact, however, electrons can be injected into the conduction levels. The injected charge is a space charge and the mutual repulsion between the individual carriers limits the total space charge density which can be injected into the semiconductor. The charge carriers are electrons. At a sufficiently large applied voltage, the injected space charge density is sufficient to saturate the trapping centres and current increases in accordance with Mott-Gurney law.

Mott and Gurney [26] proposed that, in insulators and semiconductors at high fields, space charge limited currents are formed, and they arrived at the following relation:

$$\frac{J = 9\varepsilon\mu V^2}{8d^2}, \tag{1}$$

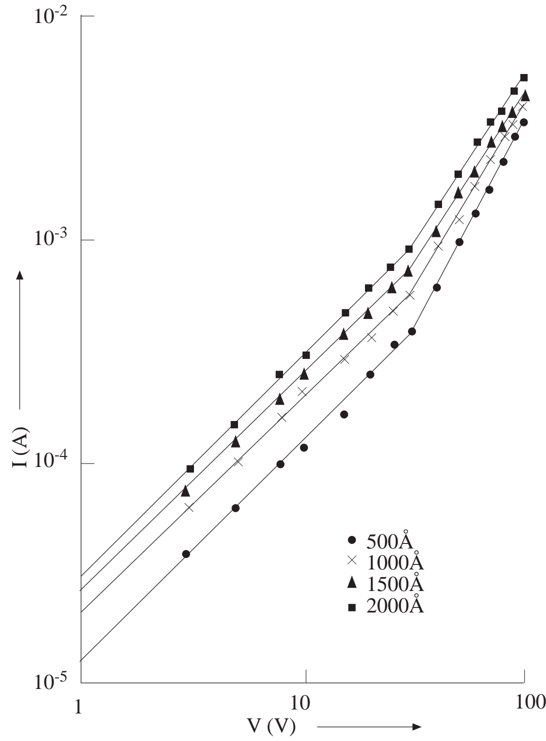

Figure 2. I-V characteristics of Al-Ge-Al samples with different thicknesses.

where J is the current density, V the voltage applied, ε the dielectric constant and d is the distance between the contacts. Mott-Gurney law seems to be operative in this investigation since current is proportional to the square of the applied voltage at high fields (>300 V/cm) as shown in Figure 3. The fact that current is proportional to the square of the applied voltage in the high voltage range (>30 V) suggests that in this range the current may be limited by space charges [2, 5, 6, 26-31]. Assuming that the surface layer with a width w, a thickness t, inter-electrode distance d, is considered as a volume, the space charge limtied current 1_s as given by Sawa and Calderwood [32] is

$$I_s = \frac{9}{8}\mu\varepsilon\frac{V^2}{d^3}tw\frac{I}{\theta}(\theta < 1), \tag{2}$$

where ε is the dielectric constant, μ the mobility, V the applied voltage and Θ is a geometrical factor indicating the direction of the electric field. Since ε and t are unlikely to change so rapidly as the measured current, the increase in current is suggested to be mainly due to the increase in the mobility of current carriers [33].

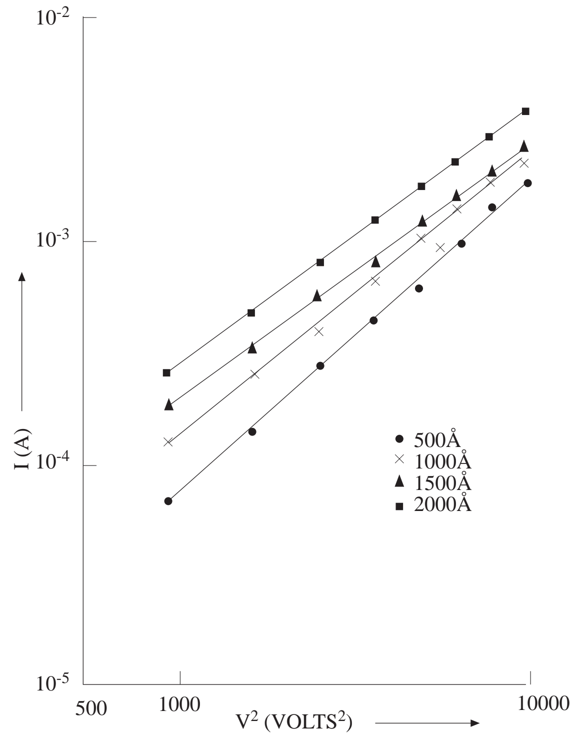

Figure 3. I versus V^2 characteristics of Al-Ge-Al structures of various thicknesses.

The values of surface conductance δ_s of the samples at zero bias are presented in Table 1, and were deduced from the slopes of the I-V curves using the following relation:

$$\delta_s = \frac{I}{RA} = \left.\frac{dI}{AdV}\right|_{V=0} \tag{3}$$

where A is the area of the samples and the other symbols have their usual meanings. Also, the resistances and resistivities of the different samples were evaluated and are presented in Table 1.

These results reveal that the surface conductance of amorphous germanium increases with film thickness while its resistance decreases with film thickness. It is reasonable that, as the film thickness increases, the size of crystallites also increases resulting in a reduction in the number of intercrystallite boundaries which offer less resistance and, hence, the conductance of the film should increase as observed in the present measurement. Similar obervation has been made by Chaudhuri [34] for Tellurium films, Sharma and singh [35] for Selenium films and Patel and Biradar [36] for Aluminium Antimonide films.

Table 1. The Values of Surface Conductance, Resistance and Resistivity of Al-Ge-Al Samples of Various Thicknesses.

Samples Thickness (A)	Surface Conductance ($\Omega^{-1}m^{-2}$)	Resistance (Ω)	Resistivity (Ω m)
500	0.40	$8.3x10^4$	2490
1000	0.58	$5.7x10^4$	1710
1500	0.76	$4.4x10^4$	1320
2000	0.93	$3.6x10^4$	1080

4. Conclusion

The present study shows that the variation of current with electric fields for the various samples follows Ohm's law at low fields (<300 V/cm) but deviates from Ohm's law at high fields (>300 V/cm). Also, from the experimental results presented above, it can be seen that in the high field region (>300 V/cm), the current is proportional to the square of the applied voltage, indicating that in this range the current may be limited by space charges. In addition, the surface onductance of Al-Ge-Al samples increases with thickness. The dependence of surface conductance on thickness confirms that the space charge limited current mechanism of conduction is operative in the high field region ($>300 \leq 1000$ V/cm) under investigation.

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