Revista Brasileira de Física, Vol. 9, Nº 3, 1979

Poole Frenkel Effect in Thin Al-Al_2O_3-Dy Junctions

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Recebido em 20 de Janeiro de 1979

Al-Al_2O_3-Dy junctions were fabricated in which the oxide layers were thermally grown with a thickness of ~ 80 Å. A peak in the *I-T* characteristics is reported, being interpreted in terms of Poole-Frenkel effect.

Fabricaram-se junções Al-Al_2O_3-Dy, nas quais as camadas de óxido foram crescidas termicamente, com uma espessura de ~ 80 Å. Relata-se a presença de um pico nas características *I-T*, sendo interpretado em termos do efeito Poole-Frenkel.

1. INTRODUCTION

The Poole-Frenkel effect is one of the important mechanismc by which electrical conduction in *M-I-M* systems occur[1,2]. Recently L. Young[3] reported the Poole-Frenkel effect in thin Ta_2O_5 films in the thickness range 140-200 Å. The cause of this effect was attributed by Young to the flaws and defects present in the samples.

In this work the Poole-Frenkel effect has been reported for thin aluminium oxide films ~ 80 Å. The method of introducing defect centres into the oxide used by us was not the same as that of L.Young. In the present work a reactive element to aluminium oxide was chosen as a counterelectrode for a thermally grown aluminium oxide layer over an evaporated Al base electrode.

The main goal of this work was to study the bulk effect, and non steady state characteristics[4] by introducing chemical - reactivity between an oxide insulator and metal electrode which provide defect centers and localized states.

2. EXPERIMENTAL METHODS

Aluminium of purity 99.99% was evaporated with a high rate (200 Å/sec) on a precleaned glass slide so as to get a thickness of about 3000 Å. The vacuum was of the order of 10^{-7} torr using liquid Nitrogen trap. The aluminium strip was then oxidized in air in an oven at 250°C. The edges of the oxide were then covered with a thick layer of silicon monoxide[5,6]. In a similar manner Dysprosium was evaporated to act as counterelectrode. On each glass slide four junctions were fabricated, each with an area of 2 mm^2.

The temperature were measured using a calibrated copper--constantan thermocouple. The thickness of the oxide estimated from capacitance measured by a B642 Wyne-Kerr Atuobalance universal bridge employing 8.4 as the dielectric constant for the aluminium oxide[7,8]. The oxide thickness for the samples reported here was about 80 Å.

Immediately after fabrication the characteristics of the sample were found to be unstable. After about 24 hours, stable measurements could be taken. A solartron A 203 digital voltmeter and a keithly 616 digital electrometer was used.

3. RESULTS AND DISCUSSION

When the insulator thickness in the M-I-M systems is small enough, a tunneling current could predominate[7,12]. As the thickness of the oxide in the samples, used in this work, was about 80 Å, a tunneling current could be expected. It is well known[12,13] that a tunneling current has a T^2 dependence. Fig.1 is a plot of current I against the square of the temperature T at different bias voltages. The current has a T^2 dependence over the whole range of temperature (85°K - 270°K). It has, however, two slopes as is evident from Fig.1. Below about 150°K,

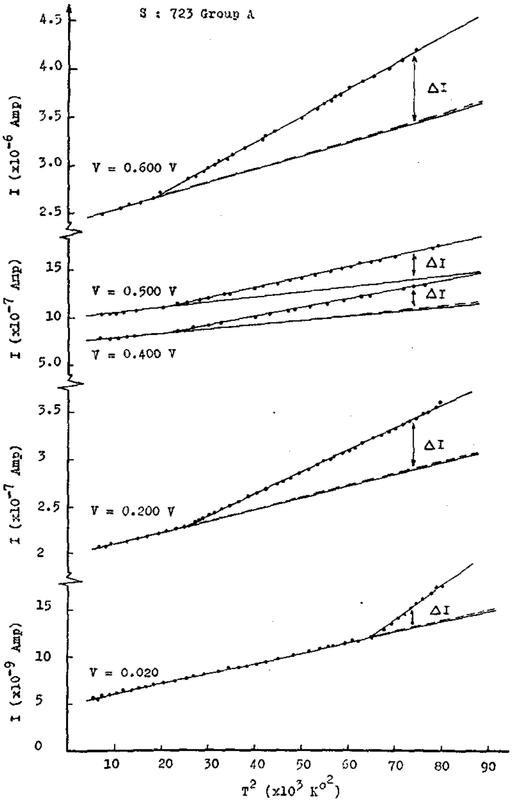

Fig.1 - I Vs. T^2 at different bias voltage, two regions of T^2 dependence are clear.

the conduction mechanism is entirely due to the quantum mechanical tunneling.

Further evidence for the existence of tunneling conduction at low temperature: The I-V characteristics at 85°K is plotted in a Foweler-Nordhiem plot. A minimum could be seen in Fig.2 which indicates tunneling nature of the current[21]. So that together with the T^2 dependence of Fig.1 we can be sure that below 150°K the conduction mechanism is due to quantum mechanical tunnelling. Above this temperature however, the main contribution is due to the tunneling, while the remaining portion is on account of some other processes which become apreciable above about 150^{o}K. These additional processes may be: the Schottky process or the Poole-Frenkel effect. In the Schottky process: schottky currents satisfy a relation of the type,

$$I = AA' T^2 \exp\left[-(\Phi - \beta_s V/S)/kT\right]$$

where $A' = 120$ Amp/cm^{2}K^{-2} is the Richardson constant, $\beta_s = (e^3/4\varepsilon)^{1/2}$, and A is the area of the junction. However, neither I, ΔI nor $(I - I_{85^oK})$ satisfy the temperature dependence of schottky emission, namely ln (IT^{-2}) versus T^{-1}. Thus we are left with the remaining mechanism, that is the Poole-Frenkel effect. ΔI which is indicated in Fig.1 is plotted in Fig.3 as ΔIT^{-3} exp$(0.122/kT)$ versus $V^{1/2}$ T^{-1} for three different temperatures: 200, 250 and 270^{o}K. This type of plot has been suggested by R.M. Hill[9] for Poole-Frenkel currents in amorphous solids. In Fig.3 the solid line superimposed on the experimental points gives the best visual fit for the plot α^{-1} (αcoshα - sinhα) against α, where $\alpha = \beta V^{1/2}/kT$, $\beta = (e^3/\varepsilon)^{1/2}$, ε the permitivity of the insulator, and k is the Boltzmann Constant. The experimental points are in good agreement with the theoretical curve, which suggests that the origin of ΔI is Poole-Frenkel effect, because Hill's plot is considered[2] as a satisfactory proof for the existence of Poole-Frenkel mechanism.

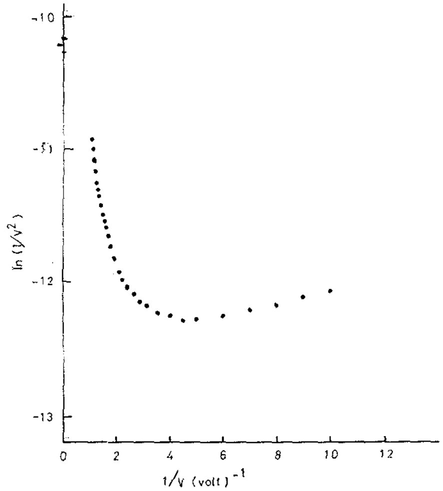

Fig.2 - Fowler-Nordheim plot (ln I/V^2 Vs. $1/V$) at 85K^{o}.

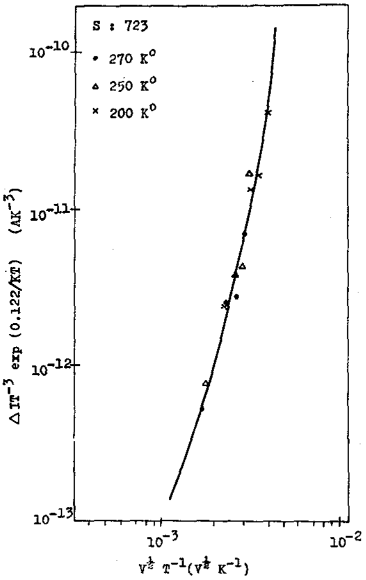

Fig.3 - Plot of $\Delta IT^{-3}\exp(0.122/kT)$ Vs. $V^{1/2}\ T^{-1}$ at three different temperatures 200, 250, and 270°K. The continuous curve is theoretical α^{-1} ($\alpha\cosh\alpha$ - $\sinh\alpha$) Vs. α.

The value (0.122) appeared in Hills plot which represent the ionization energy of the donor center, was deduced in the following way[17,22]: the Arrhenius plot (ln I versus $1/T$) is shown in Fig.4. The plot is not linear over the whole range of temperature, however we have taken the region prior to the appearance of the peak in the temperature range of about 240°K-270°K. A straight line was drawn through the region. The slopes of these lines were drawn against $V^{1/2}$. The plot is shown in Fig.5. The straight line is the least square fit to the experimental points. The intercept on the ordinate is the ionization energy Φ which is equal to 0.122 ev.

Further evidence for the Poole-Frenkel effect is that a small peak appears in the current temperature characteristics of the junction. Fig.6 shows the I-T characteristics at different bias voltage. The voltage range is so limited as to avoid breakdown of the junction which typically occurs at about (1 Volt). The peak in the I-T characteristics shifts towards higher temperatures if the rate of heating

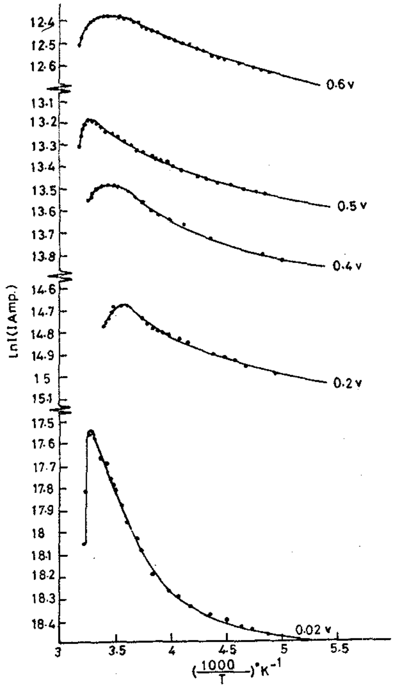

Fig.4 - ln I Vs. 1000/T $^{O}K^{-1}$ at different bias voltage.

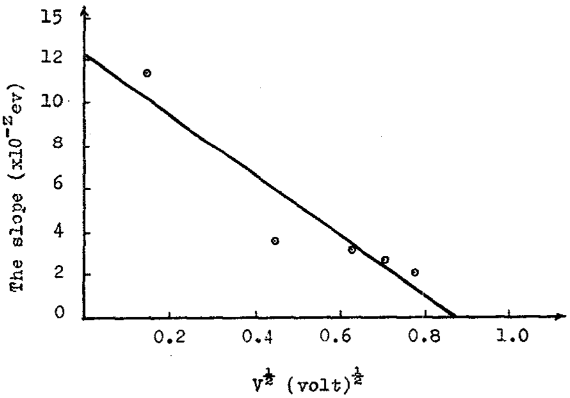

Fig.5 - Slopes of ln I Vs. 1/T curves (activation energy) Vs. square root of voltage ($V^{1/2}$), the line is least squares fit to the experimental points.

increased (compare the case of 0.02 *V* and 0.5 *V* with the rest of the curves in Fig.6) the peak appears no matter whether the sample cooled under short or under open-circuit condition. Such anomalous peaks in *I-T* characteristics of some materials have been reported in the literature[14-16]. Simmons *et al.*[16,18] interpret it in terms of Poole-Frenkel exhausation of donor centers in the insulators region. The peak appears even in a virgin sample, that is a sample which is not subjected to any bias voltage.

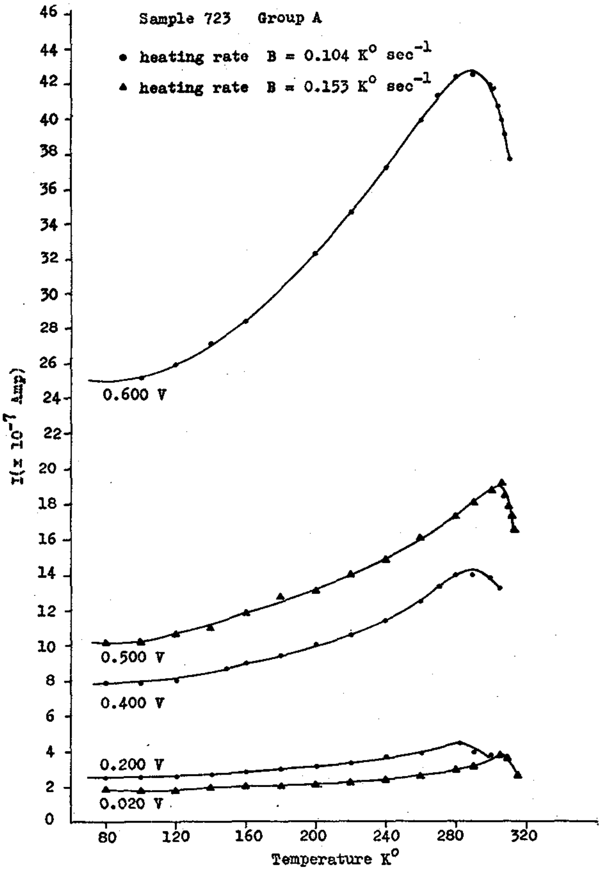

Fig.6 - *I-T* characteristics at constant bias (0.02-0.6 Volt), the rate of heating *B* is indicated in each curve, the triangle Δ = 0.153°Ksec^{-1} and the dot o = 0.104 °Ksec^{-1}. The appearance of a peak is very clear. The peak shifts towards higher temperatures when the rate of heating increased.

It may be recalled that during the measurement the sample was contained in a stainless steel container, so as to make sure that no optical excitation could occur.

Because thermally grown aluminium oxide is amorphous[19], it is expected that it contains a high density of localized states, traps and donors.[1,2,11] The existence of a Dy counterelectrode on such an oxide layer induces formation of further localized states because of the chemical reactivity of Dy with aluminium oxide as stated in the introduction [20]. Thus the Poole-Frenkel effect in such junction of $Al-Al_2O_3-Dy$ is not unacceptable although the oxide thickness is relatively thin.

CONCLUSION

Poole-Frenkel contribution to the conduction mechanism has been noticed in some temperature ranges (200-300°K) in case of $Al-Al_2O_3$ -Dy junction. In the junction the oxide was grown thermally, while the electrode was made by evaporation. Dy counterelectrode has a pronounced effect on the electrical properties of Aluminium oxide. It increases the donor centers in the oxide such that Poole-Frenkel effect reveals itself at some temperature range even in very thin oxide layers.

Above about 150°K, we have been able to establish the conduction on account of the Poole-Frenkel in addition to the tunneling process; the contribution being 17.7% ($\Delta I/I \simeq 17\%$) and 82.3% respectively.

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