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Effects of Two-Step Deposition on Current Transport in Al-Ge-Au Sandwich Structures

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Abstract: Investigations have been carried out at temperatures between 123 and 300 K on as deposited, vacuum evaporated Al-Ge-Au sandwich structure samples fabricated on Al support discs. The sandwiched, evaporated Ge layers were vacuum-deposited in either one or two steps and of various thicknesses while the Al and Au contacts on either side were each vacuum-deposited in one step. Furthermore for the two-step Ge depositions, the first Ge layer was exposed to air at room temperature for an hour before the second layer was deposited. All the samples showed good ohmic behaviour. The specific resistance (R_s) of the Al-Ge-Au layers increased as the thickness of the sandwiched Ge layer increased but decreased as the temperature increased. The dependence of R_s on the temperature indicated semiconducting behaviour in the Ge layer. It was also found that for a given overall thickness, R_s increased as the number of steps increased while there was no significant change in R_s for samples of same overall Ge thickness deposited in the same number of steps.

Key words: Current transport, amorphous Ge, specific resistance, Al-Ge-Au structures, Ge thin film, Nigeria

INTRODUCTION

Considerable study has been carried out on amorphous Ge (a-Ge) and their contacts with other materials. Studies by Mott (1969), Donovan and Heinemann (1971), Morgan and Walley (1971), Connell and Pawlik (1976), Fajardo and Chambouleyron (1993) and Precker and da Silva (2002) were aimed at explaining the current conduction mechanisms of a-Ge over various temperature regimes. Grigorovici *et al*. (1967), Clark (1967), Walley (1968), Morgan and Jonscher (1972), Thanailakis and Northrop (1973), Hafiz *et al*. (1977), Magaritondo *et al*. (1980), Sinha and Misra (1983), Mathur and Kumar (1987), Oberafo *et al*. (1995), Nur *et al*. (1996), Mott and Davis (1979) and Oberafo *et al*. (1997) investigated the nature of some contacts to a-Ge and the role played by such contacts vis-a-vis the a-Ge films or layers.

Some of the conclusions are that vacuum evaporated Ge is amorphous in nature, Hafiz *et al*. (1977), exhibits p-type conduction, Grigorovici *et al*. (1967) and that carrier transport is by hopping between localized states at room temperature (Mott, 1969).

Non-ohmic conduction in a-Ge has been reported by Morgan and Walley (1971), Connell and Pawlik (1976) and Oberafo *et al*. (1997). It has also been shown by Mott and Davis (1979) and Oberafo *et al*. (1997) that the conductivity of a-Ge is independent of the field at sufficiently low field, thus exhibiting an ohmic behaviour. The present study is therefore, an attempt for a better understanding of evaporated a-Ge sandwich structure samples fabricated on Al support discs and to investigate the effect of thickness of a-Ge layer and temperature on the nature of the characteristics.

MATERIALS AND METHODS

The sample preparation commenced with the fabrication of 20 mm diameter aluminium discs which were used as support for the devices and of evaporation mask. The discs were first degreased by washing with soap solution and then rinsed in distilled, de-ionized water. Thereafter, they were etched in solution containing H_3PO_4, HNO_3 and H_2O in the ratio 17:1:2 for 1 min and subsequently rinsed with distilled, de-ionized water and then blow-dried with dry gaseous nitrogen. The clean discs were then transferred to the chamber of an Edwards, model 306 coater evacuated to a vacuum of about 10^{-5} Torr. For the coating process, first a gold layer 500Å thick was deposited by filament evaporation to cover the whole of one surface of each Al disc. Ge layers of 1.2 cm diameter with thicknesses varying between 500-2000Å were evaporated onto some of the gold-covered discs. After deliberate exposure of some of the Ge-covered disc to air for an hour, a second Ge layer of the same diameter and in the thickness range 500-2000Å was evaporated on

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top of the first Ge layer. Composite Ge layer samples were obtained either by one or two-step depositions. Finally, 500Å thick and 0.6 cm diameter Al layers were deposited on top of the final Ge layers. All the evaporants were of 5N9 purity (Ventron, Germany). Thicknesses of the various evaporated layers were determined with an Edwards, model FTM3 Digital Film Thickness Monitor. The deposition chamber of the coater was maintained at a vacuum of about 10^{-5} Torr for all the depositions mentioned earlier. The final sample configuration is shown in Fig. 1 while the sample nomenclature and Ge deposition steps are as shown in Table 1.

After fabrication, the samples were mounted, one at a time inside a liquid nitrogen cryostat with an ambient vacuum of about 10^{-4} Torr. Good electrical contacts to the samples were effected using in Hg. Current-voltage data were obtained at 123, 163, 213, 263 and 300 K, the temperature being regulated by a LakeShore Model 330 PID autotuning temperature controller. The current and voltage were measured with a digital electrometer (Keithley type 160 B) and a digital millivoltmeter (Hewlett-Packard type 3465 A), respectively. From the current density (J)-Voltage (V) plots, the specific resistance R_s was determined using the relation:

$$\left.\frac{dV}{dJ}\right|_{v=0} = R_s \tag{1}$$

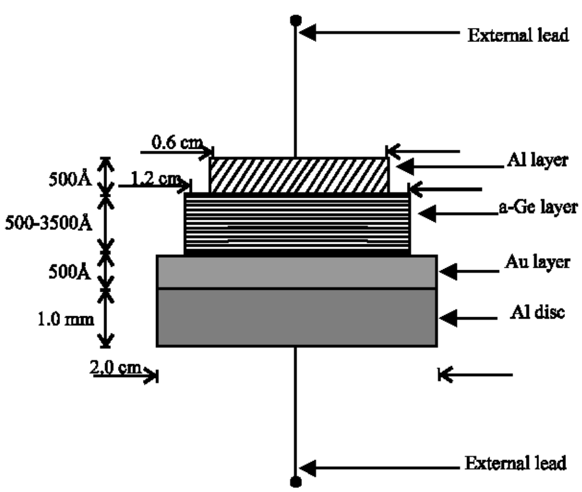

Fig. 1: Al-Ge-Au sandwich structure

Table 1: Device nomenclature and Ge layer thicknesses

	Ge layer thickness (Å)		
Device name	Step1 coating	Step2 coating	Ge overall thickness
D1	500	-	500
D2	1000	-	1000
D3	1500	-	1500
D4	2000	-	2000
D5	500	1500	2000
D6	500	2000	2500
D7	1000	1500	2500
D8	1000	2000	3000
D9	1500	2000	3500

RESULTS AND DISCUSSION

Figure 2 shows the J-V characteristics at various temperatures between 123 and 300 K for the device (D2) with Ge layer thickness of 1000Å deposited in one step. The plots display linear and asymmetrical J-V characteristics in the voltage range -70-70 mV covered in the measurements; the voltage is pegged to this range due to the high current (over 200 mA cm^{-2}) flowing through the samples. The characteristics for other samples are qualitatively similar. There has been report by Chen and Hile (1972) of depletion layer extending up to 0.33 μm from the metal junction into p-type Ge layer. We therefore, expect the depletion layers from both the Au and Al sides of the a-Ge layer to overlap and ensure that the a-Ge layer is fully depleted. Thus, the Ge layers (≤0.35 μm) in this research are thin enough for electrons from either metal to tunnel easily through, in either direction depending on the polarity of the applied bias and hence the observed ohmic behaviour. The high current values (up to a few 100 milliamperes cm^{-2}) recorded even for small-applied voltages (<70 mV) and which showed no polarity dependence, seem to indicate that the current carriers are uni-polar and are in fact electrons which originate from the metal contacts only.

Figure 3 shows the dependence of the specific resistance, R_s on the temperature. It can be seen that the device D6 obtained by depositing 2000Å Ge layer on top of 500Å layer and the device D7 obtained by depositing 1500Å Ge layer on top of 1000Å Ge layer have their specific resistances not significantly different.

On the other hand, the sample (D4) with 2000Å thick Ge layer deposited in a one-step process has a R_s curve well below that of the sample (D5) of 2000Å overall Ge layer, obtained by depositing 1500Å Ge layer on top of 500Å layer with one hour exposition to air at room temperature between the two steps. We believe that the additional resistance of the latter sample may be due to the natural growth of an oxide layer on the surface of the first Ge coating following the break in vacuum after the first coating and the subsequent exposure to air at room temperature. The development of the oxide layer is akin to the automatic oxidation of etched Si surfaces by the oxygen in the air as reported by Chen and Hile (1972) and with the oxide layer thickness not exceeding 20Å

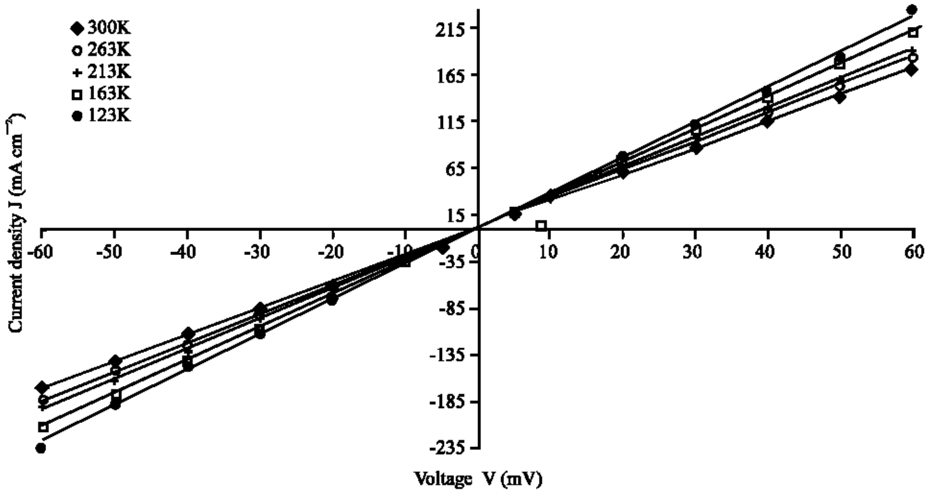

Fig. 2: Current density (J)-voltage (V) plots for device D2 at different temperatures

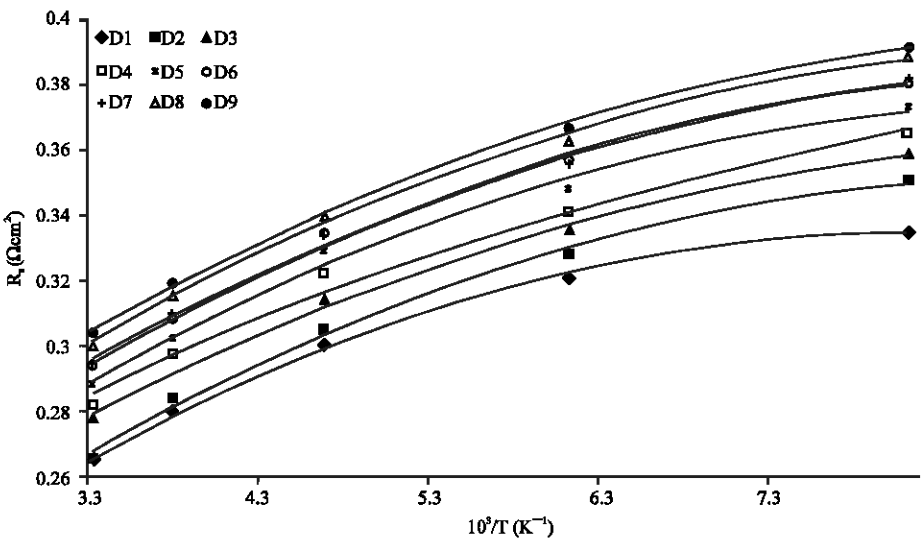

Fig. 3: R_s-10^3/ T plots

as estimated by Rhoderick (1978). Such oxide layers in the present case would sustain part of the applied voltage, thus reducing the voltage available.

The oxide layer would also increase the tunneling distance. The overall effect would be to lower the current slightly as has been observed in the present study (Fig. 3).

For the same reason, samples with Ge layers deposited in equal number of steps would be expected to behave alike since they would both develop equal thickness of intervening oxide layer between any two-component Ge layers and thereby experience equal voltage drop across each oxide layers. The variation of R_s with the temperature, T could be approximated by the equation:

$$R_s = A\left(\frac{1}{T^4}\right) + \frac{B}{T^2} + C \qquad (2)$$

Where A, B and C are constants. The above relationship is obtained with a determination coefficient R^2 >0.987 which is a proof of a good fitting.

The variation of the specific resistance, R_s with the thickness of the Ge layer is shown in Fig. 4. The observed linear increase in the value of R_s with the thickness of the sandwiched Ge layer is due to the resulting increase in the distance across which the electrons have to tunnel. Such increase in the tunneling distance as confirmed by Sze (1981) is known to lower the tunneling probability of the current carriers and hence the current. Moreover, it is observed

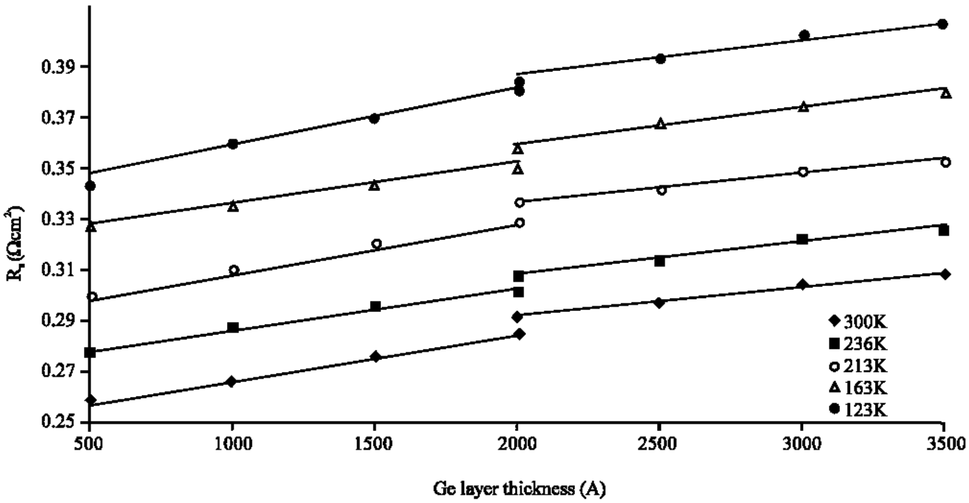

Fig. 4: R_s-Ge layer thickness plots

that samples in which the Ge layer is deposited in one step have their slope more pronounced than those in which the Ge layer is deposited in two steps. This is explained by the existence of the oxide layer between the two layers of Ge in the latter case.

CONCLUSION

We have shown that the current transport through sandwich structures of Al-Ge-Au samples with thin Ge layers is both ohmic and unipolar in the temperature range of 123-300 K. Furthermore, any break in vacuum with subsequent exposure to air at room temperature in-between deposition of successive layers of Ge results only in a slight increase in the specific resistance of the overall structure, probably due to oxide formation at such interfaces and the specific resistance depends on both the number of underlaying oxide layers of the component Ge layers and the overall thickness of the composite Ge layer but not on the thickness magnitude order of the component Ge layers.

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