

## Effect of annealing and oxygenation on the DC conductivity of amorphous germanium

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**Abstract.** Thin films of amorphous germanium were deposited in an oxygen atmosphere. DC conductivity results are interpreted considering the possibility of the formation of Ge-O bonds. The density of states was determined. Results of conductivity are interpreted using the Davis-Mott model. Change in conductivity in annealed films of V-a-Ge and O-a-Ge is also reported.

**Keywords.** Amorphous germanium; oxygenation; annealing; density of states; DC conductivity.

### 1. Introduction

The electrical and optical properties of amorphous semiconductors are very sensitive to deposition techniques and the conditions during deposition (Spear 1973). This paper reports the studies on the effect of the preparation conditions and post-deposition heat treatment on the localised density of states and on the electrical properties of a-Ge thin film. To understand whether this is an inherent property of the deposition technique or whether it is connected with the effect of gas atoms incorporated into the structure during deposition, thin films of amorphous germanium were deposited in an oxygen atmosphere at a constant rate of evaporation. There is then the possibility of the formation of Ge-O bonds (Ma and Anderson 1974). It is well-known that one can find the density of states near the Fermi level from the relation (Ambegaonkar *et al* 1972).

$$T_0 = 16\alpha^3/kN(E_F)$$

where  $\alpha$  is the coefficient of exponential decay of localised state wave functions and  $N(E_F)$  is the density of states at the Fermi level.

### 2. Experimental

Amorphous germanium films (V-a-Ge) of thickness 2000 Å were deposited on a clean glass substrate at room temperature by evaporating 99.99% pure germanium

from a molybdenum boat, the evaporation rate being  $15 \text{ \AA} / \text{sec}$  and pressure in vacuum chamber being  $10^{-5}$  torr. O-a-Ge films were deposited on a clean glass substrate at room temperature with the partial pressure of oxygen being  $4 \times 10^{-5}$  torr. Pressure contacts were used while measuring the conductance by measuring voltage drop across a standard resistor.

V-a-Ge and O-a-Ge films were annealed at 100 to  $200^\circ\text{C}$  in a vacuum of  $2 \times 10^{-5}$  torr pressure; and the conductance was measured at room temperature. For low temperature measurements the sample was transferred to a cryostat. The sample conductance was measured at various stable temperatures between room temperature and  $130^\circ\text{K}$ . The current was measured by using an electrometer (ECIL model No. EA812) and the density of states near Fermi level estimated by measuring  $T_0$  from the plot  $\ln \sigma$  vs  $T^{-1/4}$ .

### 3. Results and discussion

The room temperature conductivity of V-a-Ge lies between  $10^{-2}$  to  $10^{-3} \Omega^{-1} \text{ cm}^{-1}$ . Films annealed at different temperatures show decrease in room temperature conductivity from  $0.4 \times 10^{-3}$  to  $1.98 \times 10^{-4} \Omega^{-1} \text{ cm}^{-1}$  (table 1). The room temperature conductivity of O-a-Ge films is  $0.27 \times 10^{-3} \Omega^{-1} \text{ cm}^{-1}$ . When such films were annealed from 100 to  $200^\circ\text{C}$  at different annealing times (table 1) it was found that conductivity decreases from  $0.27 \times 10^{-3}$  to  $1.13 \times 10^{-4} \Omega^{-1} \text{ cm}^{-1}$ . Increase in resistivity in both the films (V-a-Ge and O-a-Ge) after annealing is attributed to the fact that defects present originally in the films are minimised after annealing.

Low temperature measurement data is plotted as  $\ln \sigma$  vs  $T^{-1/4}$  for V-a-Ge and O-a-Ge (figure 1). A perfect straight line fit in the temperature range below  $300^\circ\text{K}$  is observed. According to Mott's theory, the conduction mechanism in this temperature range is by hopping into the localised states near the Fermi level.

Decrease in density of states (from  $2.58 \times 10^{18} \text{ eV}^{-1} \text{ cm}^{-3}$  to  $1.86 \times 10^{18} \text{ eV}^{-1} \text{ cm}^{-3}$ ) observed in O-a-Ge films is due to the compensation of dangling bonds and vacancies in the amorphous structure due to the presence of oxygen during deposition. There is a possibility of formation of Ge-O bonds in place of Ge-Ge bonds. In both films (table 1) annealing increases resistivity. It is found that even after annealing at high temperature ( $200^\circ\text{C}$ ) films contain a large number of localised states which are due to the presence of the dangling bonds. On annealing the density of defect states is reduced, perhaps due to some structural re-arrangement causing some of the dangling bonds to pair up (unpaired electrons). From table 2, it is

**Table 1.** Variation of conductivity at various annealing temperatures  $T_A$ .

	V-a-Ge	O-a-Ge
As deposited ( $\times 10^{-3}$ )	0.4	0.27
$T_A = 100^\circ\text{C} : 1 \text{ hr}$ ( $\times 10^{-3}$ )	0.291	0.20
$T_A = 150^\circ\text{C} : 2 \text{ hr}$ ( $\times 10^{-3}$ )	0.22	0.12
$T_A = 200^\circ\text{C} : 2 \text{ hr}$ ( $\times 10^{-4}$ )	1.98	1.13

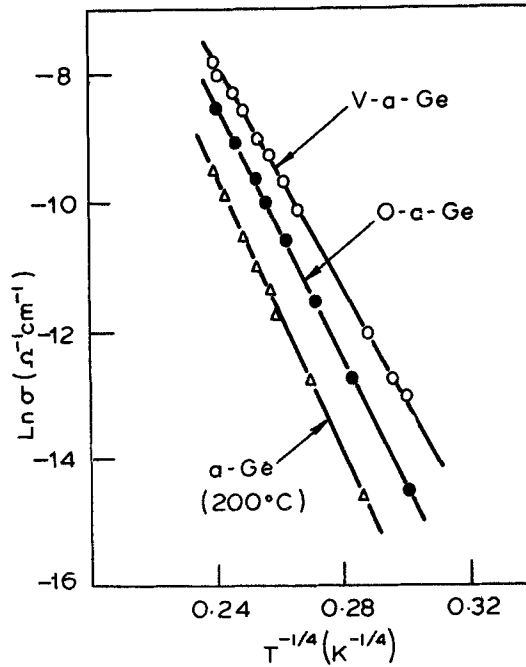


Figure 1. Low temperature measurement data is plotted for V-a-Ge and O-a-Ge.

Table 2.  $T_0$  and  $N(E_F)$  at room temperature.

Sample	RT $\Omega^{-1} \text{ cm}^{-1}$ ( $\times 10^{-3}$ )	$T_0$ (°K)	$N(E_F)$ $\text{eV}^{-1} \text{ cm}^{-3}$ ( $\times 10^{18}$ )
V-a-Ge	0.40	$7.2 \times 10^7$	2.58
O-a-Ge	0.27	$1 \times 10^8$	1.86
V-a-Ge	0.25	$1.41 \times 10^8$	1.32
$T_A = 200^\circ\text{C}$			

observed that the conductivity and hence the density of localised states is dependent on the deposition conditions *i.e.* whether deposited in vacuum or in the partial pressure of oxygen.

Similar work has been reported by Paul and Mitra (1973) on amorphous Germanium films prepared by RF sputtering. They have shown frequency independence of conductivity at lower frequencies of the order  $10^4$  Hz and is taken as RC conductivity. They reached the same conclusion that as annealing temperature increases density of states decreases.

#### 4. Conclusions

Our results also agree with the results reported by Chopra and Bahl (1970) and Agrawal *et al* (1975); who estimated density of states  $N(E_F)$  by AC conductivity data. They estimated density of states ranging from  $10^{19}$  to  $10^{20}$   $\text{cm}^{-3} \text{eV}^{-1}$ . The values of the density of states using  $T_0$  variation agree with the AC conductivity data mentioned above. We conclude that the effect of oxygenation and annealing is similar though the mechanisms are different.

#### References

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