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Poole-Frenkel Conduction Mechanism in Amorphous GeSe Films

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It will be shown that the current-voltage (I-U) characteristics of amorphous GeSe films can be described by a Poole-Frenkel conduction mechanism with a field dependence deviating from known ones (1, 2).

The I-U characteristics were measured on samples with sandwich elements M1-$Ge_{50}Se_{50}$-M2 (M: metal) of different thickness in the temperature range from 240 to 360 K. Al, Cr, and Ni were used as contact materials.

The measured characteristics are independent of the used combinations of contact materials and exhibit a significant dependence on the thickness of the films. This behaviour can only be interpreted by a bulk-controlled conduction process.

It was found that a plot of lg(I/U) against U^m gives straight lines in a range of two decades of voltage. The constant m is lying in the range of $0.5 \leqq m \leqq 1$ and varies from sample to sample.

Hill (1) gives the following equation for the current density J in the case of thermal emission of electrons over the potential barriers of Coulomb centres:

$$J = eN_t(kT)^2 \mu F \exp \left([\Delta E(F) - E_t]/kT \right) . \tag{1}$$

Here N_t is the density of the Coulombic centres at an energy level which lies E_t below the conduction band edge, μ is the mobility, k the Boltzmann constant, T the temperature, and e the electron charge. The term $\Delta E(F)$ describes the lowering of the potential barrier under the influence of an electric field strength F.

From the experimental results at constant temperatures (a characteristic example is shown in Fig. 1) the relation

$$\Delta E(F) = \alpha F^m \tag{2}$$

was found to be valid in a great range of F, where α is a constant and m the exponent mentioned above. The real proportions of the film thicknesses (measured by optical methods) between various elements were obtained, too, from the slope of a

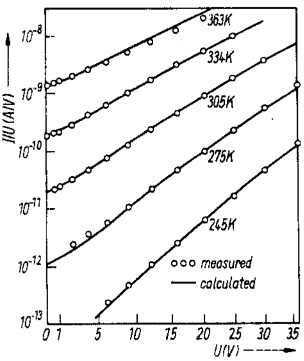

Fig. 1. Plot of lg(I/U) vs. $U^{0.8}$. The solid lines are calculated with $\varepsilon_r = 8$ from reference (3) and with $d = 2\text{x}10^{-7}$ m and $s = 3.5\text{x}10^{-9}$ m

plot of lg(I/U) versus U^m corresponding to equation (1) with $\Delta E(F)$ according to equation (2) and assuming a homogeneous field $F = U/d$, where d is the film thickness.

As far as we known there is no reference in the literature to a field dependence of the barrier lowering according to equation (2) in the case of the Poole-Frenkel conduction mechanism, except the following two limiting cases. Assuming a single centre model Yeargan and Taylor (2) give

$$\Delta E(F) = \beta F^{1/2} , \tag{3}$$

with

$$\beta = e^{3/2}/r(\pi \varepsilon_o \varepsilon_r)^{1/2}$$

and ε_r is the relative dielectric constant at high frequencies, the factor r depending on the degree of compensation ($1 \leqq r \leqq 2$).

Hill (1) considers a two-centre model (Fig. 2) and finds for low field strengths

$$\Delta E(F) = \frac{1}{2} e\, Fs , \tag{4}$$

where s is the distance of the two centres.

It will now be shown that the field dependence of the current in our experimental results (Fig. 1) can be understood by the barrier lowering due to an electric field

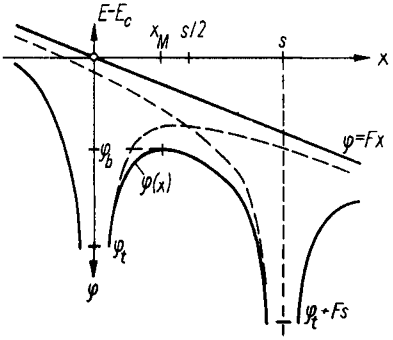

Fig. 2. Two-centre model of the Poole-Frenkel effect; $\varphi_{bo} = \varphi_b(F = 0)$

in the two-centre model. In this model the potential $\varphi(x)$ is given by

$$\varphi(x) = \frac{e}{4\pi\varepsilon_o\varepsilon_r}\left(\frac{1}{x} + \frac{1}{s-x}\right) + xF \ . \tag{5}$$

To obtain the barrier lowering ΔE (see Fig. 2)

$$\Delta E = e(\varphi_b - \varphi_{bo}) \tag{6}$$

as a function of the electric field strength F the equation was solved numerically, because a simple analytical solution cannot be found. The calculated field dependence of the barrier lowering is given in Fig. 3.

Fig. 3 shows that equation (2) is valid only approximately. The slope m of the curves of Fig. 3 is plotted against the distance s with ε_r and F as parameters (Fig. 4) and it can be seen that equation (3) and (4) are limiting cases for $s \rightarrow \infty$ and $s \rightarrow 0$ respectively.

In the general case the barrier lowering must be expressed as

$$\Delta E(F) = \alpha(\varepsilon_r, s) F^{m(F, \varepsilon_r, s)} \tag{7}$$

The experimental curves can well be fitted with the computer results of $\Delta E(F)$ if the parameters ε_r and s are chosen suitably (Fig. 1).

The considered model only describes the field dependence of the height of the potential barrier between two centres. The temperature dependence of the I-U characteristic is determined by the emission process. The experimental curves (Fig. 1) do not obey equation (1), but a good approximation to the experimental results can be obtained by assuming a temperature dependence of the exponential term as follows:

$$J \sim \exp\left(\left[\Delta E(F) - E_t\right]/aT^{3/2}\right), \tag{8}$$

where a is a constant.

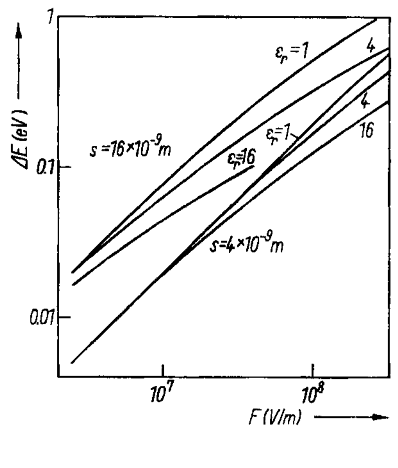

Fig. 3. Field dependence of the barrier lowering (calculated)

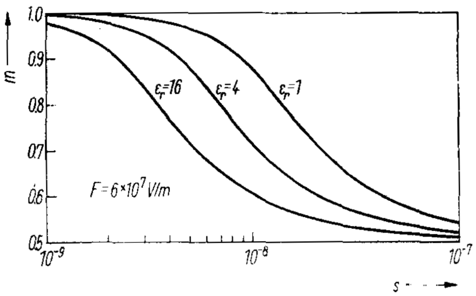

Fig. 4. Dependence of the exponent m (equation (7)) on the distance s of the two Coulomb centres

It seems that this temperature dependence cannot be interpreted by ordinary thermal emission models. Possibly completely other effects are responsible for this curious $T^{3/2}$ behaviour.

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