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Electrical conduction of erbium fluoride thin films

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Thin-film capacitors of erbium fluoride were fabricated by electron beam gun deposition. The current–voltage characteristics of the erbium fluoride films were studied in the temperature range 323 to 396 K. For sufficiently high electric fields ($> 10^4$ V cm^{-1}), the leakage current increases exponentially with the square root of the applied field. Analysis of the data suggests an electrode-limited mechanism such as that suggested by Schottky. It is seen that the conduction mechanism is an activated process with the activation energy decreasing with increasing field.

1. Introduction

In recent years, much interest has been stimulated in the study of electrical conduction [1–4] in thin dielectric layers because of their use in electronic and optical devices. Electrical conduction in rare earth oxide and fluoride films [5, 6] has been studied by various workers. Erbium fluoride films have been studied with regard to its electroluminescence [7] only. This paper reports an investigation of the transport mechanisms in erbium fluoride films as a function of temperature.

2. Experimental techniques

2.1. Sample preparation

The evaporation processes were carried out in a conventional 12 inch (305 mm) vacuum coating unit at a pressure of 3.99×10^{-3} Pa. Pure aluminium (99.999%) was evaporated from a tungsten filament onto carefully cleaned glass substrates through suitable masks to form the bottom electrode. Erbium fluoride powder of purity 99.9% (obtained from Leico Industries Inc., New York), air baked at 523 K for a few hours, was deposited as the dielectric layer using a molybdenum boat and an electron beam gun. Pure aluminium was again evaporated to form the top electrode and to complete the metal–insulator–metal (MIM) structure (Al–ErF_3–Al). The dielectric thickness was measured with a multiple beam interferometer (Fizeau fringes) [8]. All the capacitors were stabilized by prolonged ageing and repeated annealing cycles at about 373 K. The structure of the film was determined by X-ray diffractogram studies.

2.2. D.C. conduction measurements

The current across the capacitor was measured in vacuum of the order of 6.66×10^{-1} Pa as a function of the applied voltage at different temperatures using an electrometer amplifier (ECIL, model EA 815) and a FET nanommeter (APLAB, model 5006). The temperature of the sample was estimated using a previously calibrated copper–constantan thermocouple.

3. Results and discussion

3.1. Structure

The X-ray diffractogram obtained for the electron beam evaporated erbium fluoride film is shown in Fig. 1. The absence of peaks in the diffractogram indicates the amorphous nature of the deposited film. Several rare earth oxide and fluoride films [9, 10] exhibit amorphous structure.

3.2. D.C. conduction

The log I–log V characteristics of erbium fluoride film of thickness 176 nm are shown in Fig. 2. The current exhibits a voltage dependence of the form $I \propto V^n$ where n depends on the field region. The values of n are found to vary from 1.8 at moderate fields to above 4.7 at high fields. Electrical conduction by tunnelling has been ruled out in view of the film thickness. The current density in the

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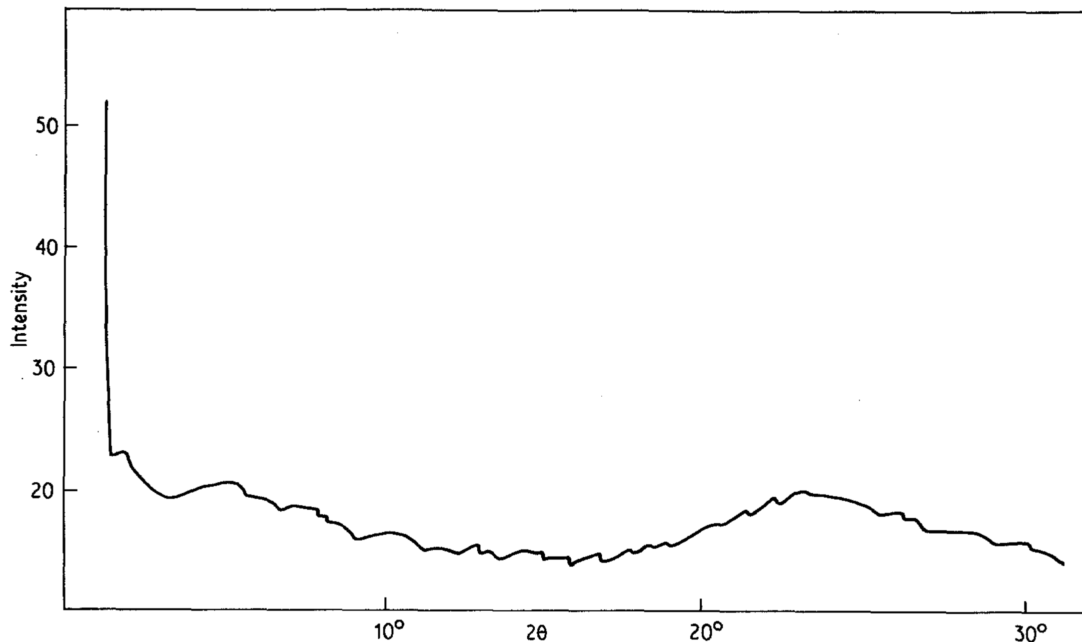

Figure 1 X-ray diffractogram indicating amorphous structure of erbium fluoride film (thickness = 176 nm).

space charge limited conduction (SCLC) region [11, 12] is not followed. Hence the possibility of SCLC is also ruled out for erbium fluoride films.

Fig. 3 represents the variation of $\log I$ with the square root of the field at different temperatures. The curves show slight deviation from straight-line characteristics at low fields and this has been attributed to contact potential effects [13]. The straight-line nature of the curves in Fig. 3 at high fields reveals that the conduction mechanism may be due to the presence of field assisted electrode emission of carriers (the Schottky effect) or internal field emission (the Poole–Frenkel effect). Many dielectric and semiconducting thin films [14–17] exhibit at high electric fields ($E > 10^6$ V cm^{-1}) a current–voltage characteristic of the form

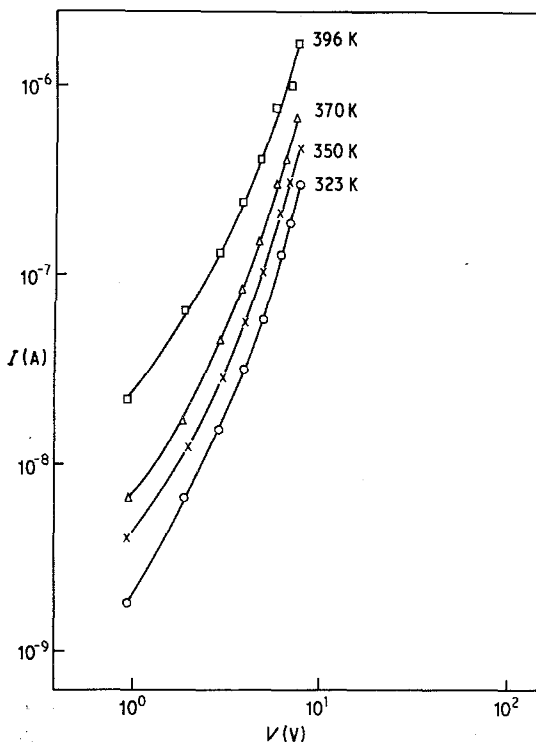

Figure 2 Log I–log V characteristics of erbium fluoride film at different temperatures.

$$I = I_0 \exp \frac{e\beta E^{1/2}}{kT} \tag{1}$$

where $E = V/d$ and β is a constant given by

$$\beta = \left(\frac{e}{\lambda \pi \epsilon_0 \epsilon'}\right)^{1/2} \tag{2}$$

where e is the electronic charge, ϵ_0 is the permittivity of free space and ϵ' is the high-frequency dielectric constant. The value of $\lambda = 1$ is assumed for Poole–Frenkel emission and the value of $\lambda = 4$ is assumed for Schottky emission. In the present investigation, the high-frequency dielectric constant of 10.3, calculated from the usual parallel-plate formula, has been used for the evaluation of β using Equation 2.

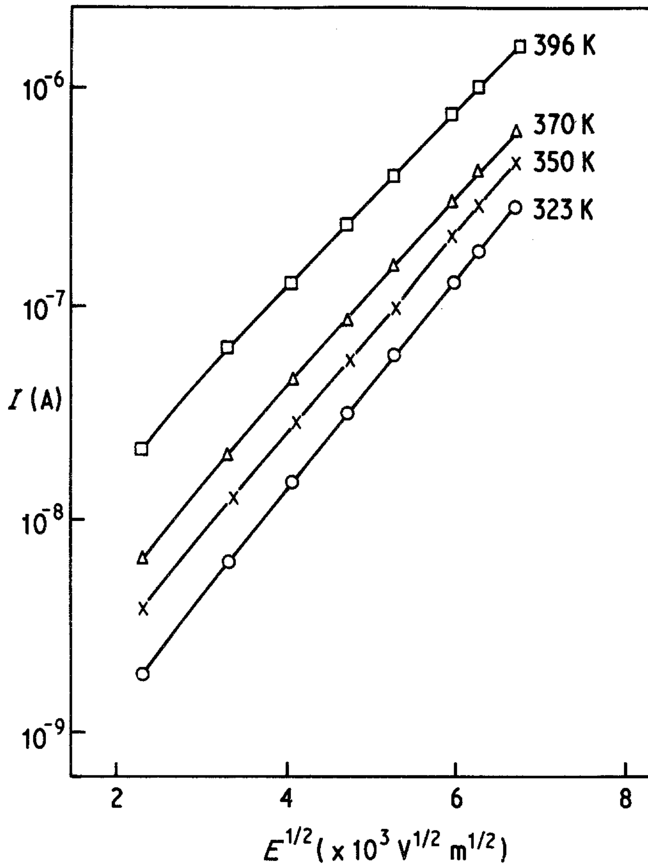

Figure 3 Plot of log current versus the square root of the applied field at different temperatures.

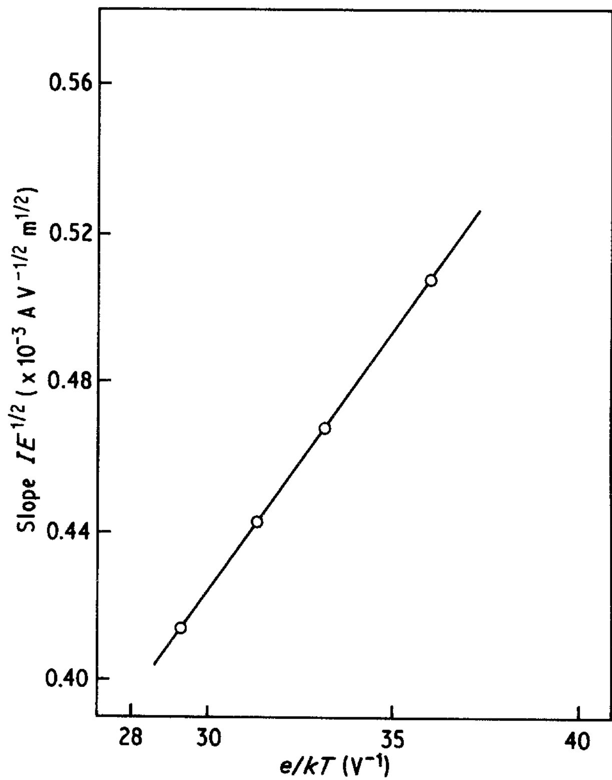

Figure 4 The slope of the curves $IE^{1/2}$ shown in Fig. 3 plotted against e/kT.

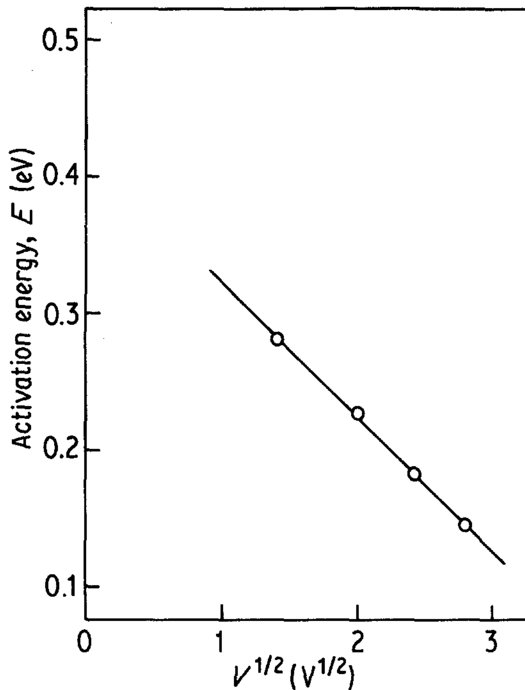

Figure 5 Activation energy E plotted against the square root of the applied voltage $V^{1/2}$.

The slopes of the straight lines obtained from log I against $E^{1/2}$ graphs are plotted against e/kT as shown in Fig. 4. The slope of the curve in Fig. 4 yields the experimental value of β [18]. The theoretical values of β obtained from Equation 2 are

$$\beta_S = 1.185 \times 10^{-5} \text{ mV}^{1/2}$$

$$\beta_{PF} = 2.370 \times 10^{-5} \text{ mV}^{1/2}$$

The experimental value of β derived from Equation 1 is

$$\beta_{expt} = 1.390 \times 10^{-5} \text{ mV}^{1/2}$$

The value of β_{expt} is closer to β_S, which indicates that the Schottky emission may be considered to be the more favourable conduction mechanism for the temperature range studied (323 to 396 K) in ErF_3 films.

The variation of activation energy with the square root of the field is shown in Fig. 5. It is evident that the conduction mechanism is an activated process with the activation energy decreasing with the increasing field. Similar results have been reported by several workers [19, 20] for different dielectric films.

4. Conclusions

The current–voltage characteristics of erbium fluoride thin films are suggestive of the Schottky conduction mechanism. The results indicate a definite lowering of the activation energy for the conduction process with the applied field.

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