

SPACE CHARGE LIMITED CURRENT IN FERRIC OXIDE

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The conductance of Al-Fe₂O₃-Al sandwich structure (0.136 cm. thick sample) is observed to be dependent on d.c. voltage bias and temperature. For $V < 350$ volt the current density increases linearly with voltage. For $V > 350$ volt, the current density has a nearly quadratic dependence on the voltage and the results are interpreted in terms of Rose theory of space charge limited currents in defect insulators. The capacitance of the sample remains constant for temperature $< 500^\circ\text{K}$ and increases above this value but it is found essentially to be voltage independent. The observed current is an exponential function of temperature and the thermal activation energy associated with this process is approximately 0.1 eV and is slightly voltage dependent.

INTRODUCTION

ALPHA-FERRIC OXIDE ($\alpha\text{-Fe}_2\text{O}_3$) is a semiconductor in the temperature range 20°C — 1350°C which crystallizes as a rhombohedral crystal (Smith 1916) with an axis of three fold symmetry, perpendicular to a plane of symmetry which is sometimes called the principal plane of the crystal. The density of iron oxide is 5.24 gm/cm^3 . The electrical properties of $\alpha\text{-Fe}_2\text{O}_3$ has been a subject of numerous investigations. Studies on the electrical conductivity was made by Morin (1954, 1959), Johnston (1957), Tannhauser (1962) and Gardner *et al.* (1963, 1964). Morin studied the temperature dependence of Seebeck effect between 200°C and 1600°C and assessed the conduction to occur in the d -levels of the ions. The energy of activation of $\alpha\text{-Fe}_2\text{O}_3$ was found to be 1.17 eV. The reported conductivities of the pure oxides at room temperature are in region of $10^{-13} \text{ ohm}^{-1} \text{ cm}^{-1}$ and attains higher values due to impurities.

In the present paper we report the current density of $\alpha\text{-Fe}_2\text{O}_3$ as a function of electric field and temperature.

MATERIALS AND METHODS

$\alpha\text{-Fe}_2\text{O}_3$ specimen in the pellet form has been obtained from puratronic (J.M.) grade-2 powder after pressing suitably at a pressure of 10^3 Kg/cm^2 and baking them at a temperature of 1250°C for 12 hrs in a platinum crucible. After lapping off the surface layer, aluminium electrodes were deposited by vacuum evaporation on the sample (0.136 cm. thick) so as to form the Al-Fe₂O₃-Al sandwiched system. The impurity content in the starting material is listed below ;

Impurity contents in the sample

Element	Ni	Mn	Si	Ca	Al
ppm	20	10	10	5	2

Note : A part of the work was presented in the 'Nuclear and Solid State Physics Symposium (Pune)' held in December 1977.

All the measurements were made in air. Current and voltage measurements were carried out by an electrometer amplifier (EA 810 A) and by a vernier potentiometer (Tinsley) of sensitivity $0.1 \mu\text{V}$. Voltage upto 250 volts was supplied from a power supply of range 0–250 volt and higher voltage (>250 volts) was supplied by a regulated power supply of range 250–2500 volt (Philips PW4022). The temperature of the sample was measured with a Cromel-Alumel thermocouple. The capacitance of the sample was measured with an LCR bridge having sensitivity better than 1 pf at audio frequencies.

RESULTS AND DISCUSSION

Fig. 1 shows current density-voltage (J - V) characteristics on a log-log scale for polycrystalline sintered pellets of $\alpha\text{-Fe}_2\text{O}_3$ at different temperatures. Each of the

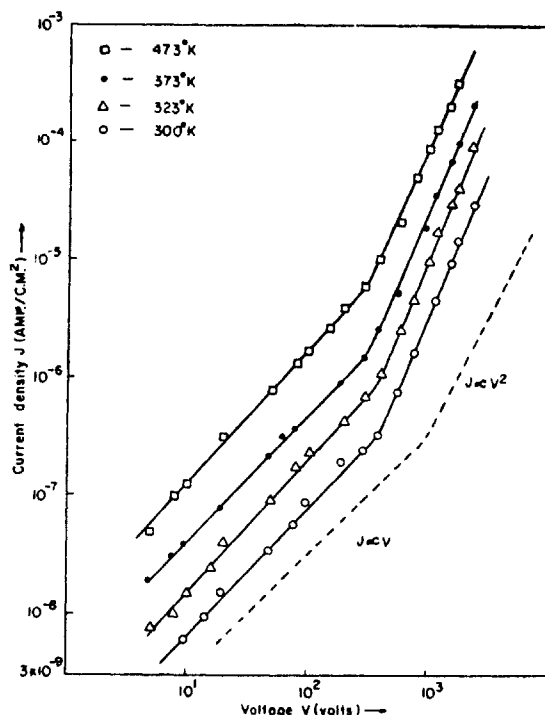


Fig. 1. Variation of current density (J) with voltage (V) at different temperature.

curves has an ohmic portion ($J \propto V$) which changes to the nearly square region. The transition voltage is about 350 volts for all curves. In the low field region the observed conductivity obeys ohm's law and is explained by the fact that in our sample, at low field, bulk limited current exceeds the space charge limited current. At high field the observed non ohmic behaviour is being explained on the model of SCL currents in defect insulators.

Mott and Gurnay (1948) proposed that in insulators at high fields SCL currents are formed whose density is given by

$$J = \frac{9}{8} \frac{\epsilon \mu V^2}{d^3}$$

where ϵ is the dielectric constant, μ is the mobility, V is the voltage applied and d is the distance between the contacts. As the plot given in Fig. 1 yields a characteristic $J \propto V^n$ where $n > 2$, the observed results are in contradiction with this theoretical approach.

To give a suitable explanation Rose (1955) introduced a uniform density of traps, which reduces the number of injected carriers, whose distribution is located in the band gap. With this trap distribution taken into account the current density is given by

$$J = \frac{9}{8} \mu N_0 \frac{eV}{d} \exp(tV),$$

where N_0 is the number of carriers removed by thermal agitation,

$$t = \frac{\epsilon A}{4\pi e N_i d^2 K_B T},$$

N_i is the trap density per unit energy, K_B the Boltzmann constant, e the electronic charge and A the cross-sectional area of the sample.

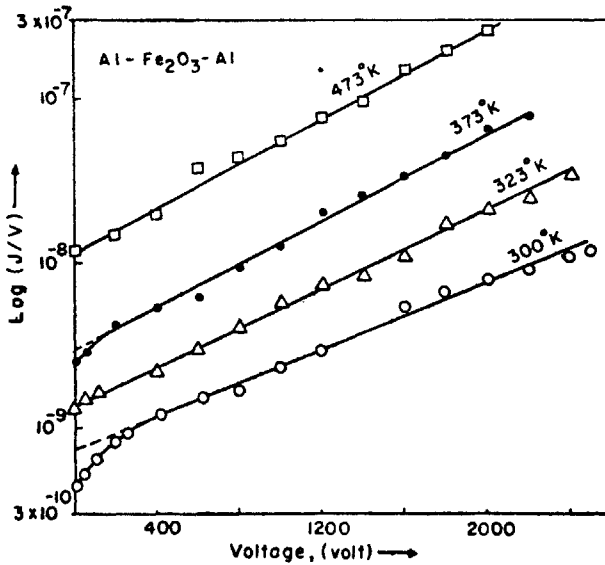


Fig. 2. Variation of $\log (J/V)$ with voltage (V) at different temperatures.

Fig. 2 shows the variation of $\log J/V$ vs V which comes out to be linear at high fields indicating the current to be space charge limited with traps uniformly distributed in energy. The slope t of the straight lines are reported into Table I. The values of N_i obtained from the relation

$$N_i = \frac{CV}{K_B T} \left(\frac{1}{ed} \right) \left[\frac{V}{J} \left(\frac{dJ}{dV} \right) - 1 \right]^{-1}$$

are also given in the Table I.

TABLE I

T °K	N_t $V^{-1}cm^{-3}$ $\times 10^{16}$	t eV^{-1} $\times 10^{-4}$	$tN_t \times 10^{23}$	
			Exptl.	Calc.*
(1)	(2)	(3)	(4)	(5)
300	2.31	5.00	11.55	11.97
323	1.70	5.91	11.11	11.10
373	1.38	6.58	9.08	9.93
473	1.06	6.69	7.09	7.08

* $A = 2.42 \text{ cm}^2$, $d = 0.136 \text{ cm}$.

It may be noted that the sample contained foreign cations (e.g., Mn) of variable valency which acts as an electron trap in iron oxide. The value of the trap density is $\approx 2.3 \times 10^{16} \text{ eV}^{-1} \text{ cm}^{-3}$ at room temperature and decreases with increasing temperature. To the suitability of above model in our sample, we make an attempt to compare the experimental values of tN_t , given in column 4 of the table with those obtained theoretically. The latter has been calculated using the relation

$$tN_t = \frac{\epsilon A}{4\pi e d^2 K_B T}$$

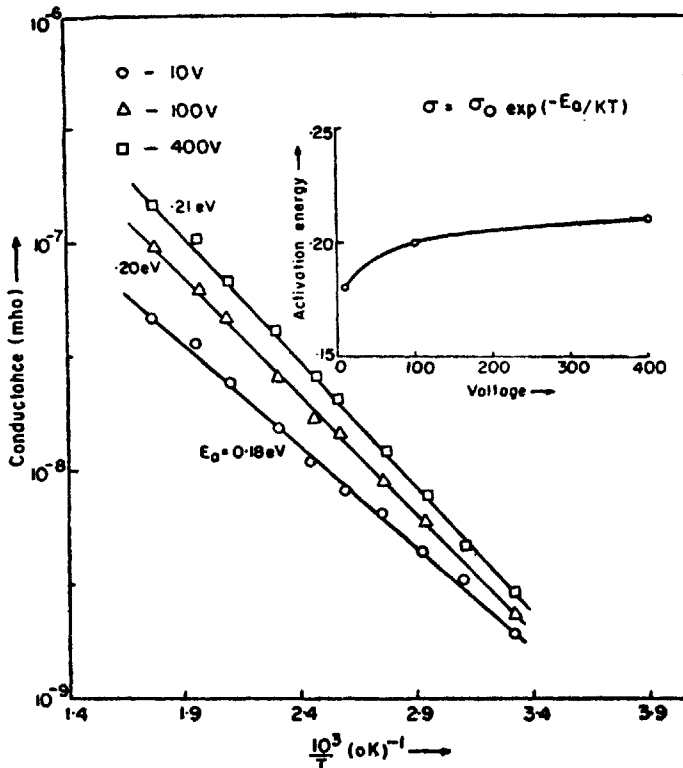


Fig. 3. Variation of conductance of Fe_2O_3 with temperature at different voltages.

and is presented at column 5 of the table. The dielectric constant involved in above relation is estimated considering the sample as a parallel plate condenser of capacity $e = \frac{\epsilon A}{4\pi d}$. It may be noted that experimental and calculated values of tN_i are in close agreement.

It has been noted that the variation of the capacitance of the sample with temperature remains almost constant for temperature $\leq 500^\circ\text{K}$, above which it increases significantly, but is voltage independent.

Fig. 3 shows the variation of log of conductance with reciprocal of temperature in the sample at 10, 100 and 400 volts. The activation energy E_a calculated from the conductivity formula $\sigma = \sigma_0 \exp\left(\frac{-E_a}{K_B T}\right)$ is found to be slightly voltage dependent and were determined to be 0.18 eV, 0.20 eV and 0.21 eV for 10, 100 and 400 volts respectively. The conductivity σ in the sample is found to be of the order of 10^{-9} ohms $^{-1}$ cm $^{-1}$ at room temperature. A comparison of our E_a and σ values with those obtained by Morin (1954) in iron oxide specimen indicates that the present E_a values are low and σ values are higher. The observed activation energy may possibly be interpreted in terms of the process involving the jumping of electrons to neighbouring cations. The activation energy associated with the process is ≈ 0.1 eV and is comparable with the observed value. The high conductivity in our specimen may be attributed to the known non-stoichiometry introduced during firing, the presence of foreign cations and the grain boundaries.

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