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TEMPERATURE DEPENDENT DIELECTRIC AND ELECTRICAL PROPERTIES OF NIOBIUM (V) OXIDE

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The dielectric and electrical properties of Nb_2O_5 pellets (thickness 0.1679–0.5488cm) have been investigated at different temperatures. The relative permittivity first decreases upto 400 K, increases slowly upto $T < 673$ °K above which it increases sharply. *I-V* characteristics reveal that at low voltages, the conduction is ohmic, while at high voltages, the current has a quadratic dependence on voltage. The transition voltage (V_T), at which the conduction changes from ohmic to non-ohmic, decreases as temperature increases. The results are interpreted in terms of theory of space charge limited currents in defect insulators containing shallow traps. Electron trap levels exist at energy (0.715 ± 0.049) eV below the conduction band, with a density $\sim 10^{17}$ m^{-3}.

Key Words : Electrical Conductivity; Permittivity; Niobium V Oxide; Activation Energy

INTRODUCTION

NIOBIUM pentaoxide (band gap $\sim$ 3.9eV) belongs to the group of saturated transition metal oxides in which all *d*-electrons have been given off by the transition metal atoms to the oxygen atoms. Niobium pentaoxide finds many applications in industry, such as in corrosion resistant aluminium base material, ceramic capacitors, hardening constituents in cements and refractories, catalyst for chemical conversions and active devices such as MOST and FET etc. It has rhombic structure (*L* or θ Modification) at room temperature having unit cell dimensions $a_0 = 6.168$ Å; $b_0 = 29.312$ Å; $c_0 = 3.936$ Å; $Z = 8$ and density 4.965g/cc[1] and many modifications at higher temperatures have been reported. As there were confusions in the literature regarding different modifications, Schafer *et al.*[2] reviewed and grouped them and suggested uniform names as TT (low low); T (low), M(medium), B (plates), H (high), N (needles) and P (prisms). Aravindakshan *et al.*[3] have studied the various modifications of Nb_2O_5 while heating in vacuum and have shown that θ, φ and poorly crystalline forms exist at room temperature, 200 °C and 400 °C which further modify to the T and M forms at temperatures greater than 600 °C and 800 °C respectively.

Dielectric properties of Nb_2O_5 thin films have been extensively studied by Fuschillo *et al.*[4] and Goswami and Goswami.[5] Bovtun *et al.*[6] has studied the

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dielectric constant and loss of single crystal and ceramic samples, as a function of temperture and frequency. Electrical properties have been studied by Balachandran and Error,[7] Vezzoli,[8] Marucca,[9] Bogdan *et al.*[10] Fusschillo *et al.*[11] and Greener *et al.*[12] Space charge limited currents have been observed in Nb_2O_5 thin films by Bogdan *et al.*[10] and Lalevic and Slusark[13] Fuschillo *et al.*[11] observed evidences of hopping conduction at low fields and Poole Frankel effect at fields greater than 10^5V/cm. But no report of conduction at high fields in polycrystalline pressed samples is available. D'yakonov *et al.*[14] and Hickmott[15] have studied the optical properties of Nb_2O_5 thin films.

Results of our investigations on dielectric properties and electrical properties at low and high fields at different temperatures have been reported in this paper.

Materials and Methods

Nb_2O_5 specimens in the pellet form have been prepared from puratronic (J. M.) specpure grade powder at a pressure $5 \times 10^7 kg/m^2$ by a method already described in an earlier paper[16]. Capacity of the pellets at different temperatures has been measured with the help of a LCR bridge (Systronics 921) capable of measuring 10^{-12}F to 10^{-6}F with an accuracy of 2 per cent. Resistance of the samples at different temperatures (upto 800K) has been measured with the help of a Million Meg ohm meter (BPL make) by placing the pellets in a Muffel furnace. To obtain I-V characteristics, voltages upto 250V across the pellet have been applied by using an electronically regulated power supply (0-300V) and higher voltages by another regulated power supply (Aplab 7341P). Current passing through the pellet has been measured by using an Electrometer Amplifier (BARC EA810A). I-V characteristics at elevated temperatures have been obtained by placing the sample in a temperature controlled oven.

Results and Discussion

Fig. 1 shows variation of dielectric constant(ϵ_r) of the pellet (thickness 0.3761×10^{-2}m) with temperature, measured at 10KHz frequency. Our value of ϵ_r (41.56) at room temperature agrees well with the value ($\sim$ 45) in thin Nb_2O_5 films[4] at high frequency ($\sim 5 \times 10^6$ Hz). Hence, our measured values may be taken as high frequency dielectric constants. It can be seen (Fig. 1) that ϵ_r decreases upto $T \sim$ 400K, increases slowly upto $T <$ 673K above which it increases steeply and this type of variation may be due to θ, ϕ and poorly crystalline (Amorphous) modifications at room temperature, 200 °C and 400 °C.[3] Variation is not smooth as also observed in thin films by Goswami and Goswami.[5]

Fig. 2 shows *I-V* characteristics on log-log scale for samples having different thicknesses at 303K. Fig. 3 on the other hand, illustrates the *I-V* characteristics of one of the samples (thickness 0.3761×10^{-2}m) at different temperatures. All *I-V* characteristics (Figs. 2 and 3) starts with ohmic region ($I \alpha V$) at low voltages and changes to square region ($I \alpha V^2$) at higher voltages. The transition voltage V_T, at which conduction changes from ohmic to non-ohmic, decreases from 130V to 110V as temperature increases from 303K to 363K (Table I). The observed ohmic dependence

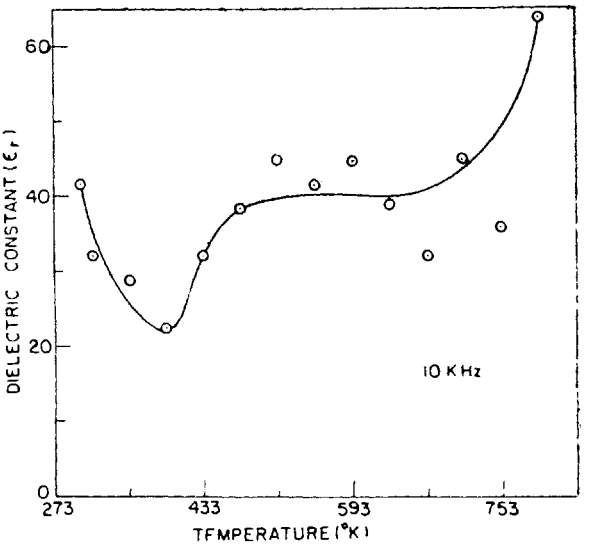

FIG 1 Variation of dielectric constant with temperature

TABLE I

The values of V_T, θ and n_e at different temperatures

S. No.	T °K	V_T Volts	$\theta \times 10^3$	$n_e \times 10^{-13}$m^{-3}
1.	303	130	1.0707 ± 0.0141	2.2597
2.	323	120	1.1293 ± 0.0036	2.2000
3.	343	115	2.8865 ± 0.0769	5.3889
4.	363	110	18.0693 ± 0.0471	32.2677

of current on voltage at low fields can be explained by the fact that in the studied samples bulk limited current exceeds the space charge limited current (SCLC). At high fields, the observed non-ohmic behaviour can be explained on the basis of Rose theory[17] for defect insulators containing shallow traps, according to which current through the specimen is given by

$$I = \frac{9\mu \epsilon_0 \epsilon_r A \theta}{8 s^3} V^2, \qquad \ldots(1)$$

where μ is the mobility, ϵ_0 the permittivity of free space, ϵ_r relative permittivity of the medium, A area of cross section of the pellet, s the thickness of the pellet, V the applied voltage and

$$\theta = \frac{N_c}{N_t} \exp\ (-E_t/k_B T) \qquad \ldots(2)$$

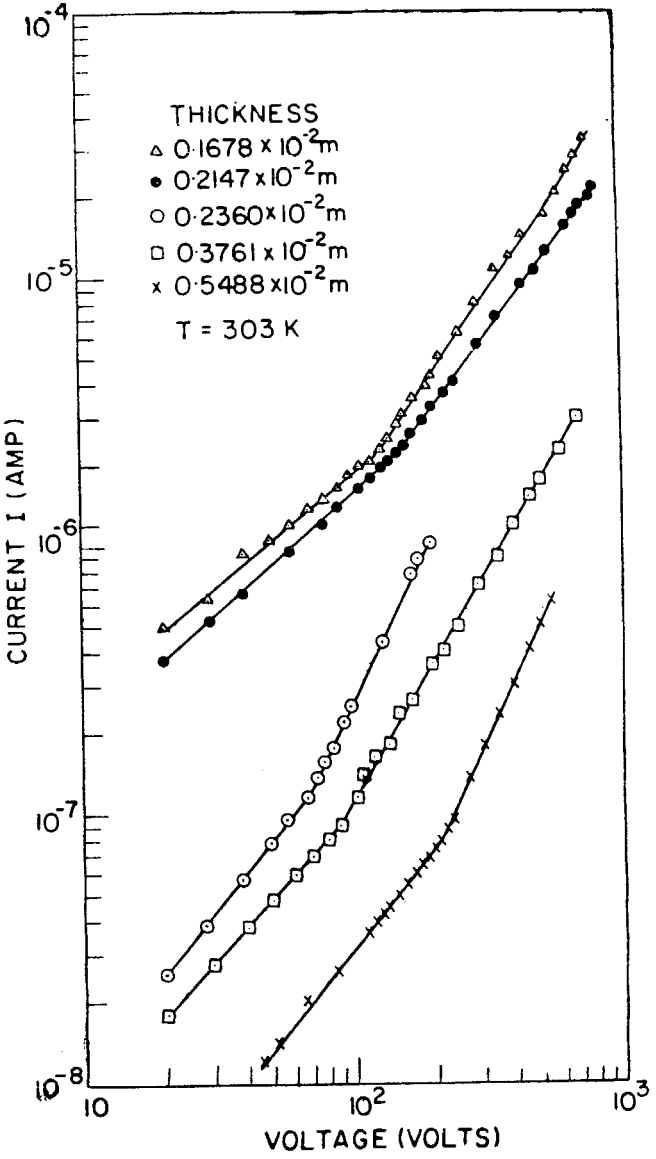

FIG 2 *I-V* characteristics for pellets of different thickness at 303K

in which N_c is the effective density of states in the conduction band, N_t is trap density of shallow traps at energy E_t below conduction band and it was assumed that free space charge density is negligible in comparison to the total trapped space charge density ($\theta \ll 1$).

Voltage (V_T) at which conduction changes from ohmic to non-ohmic is given by[18]

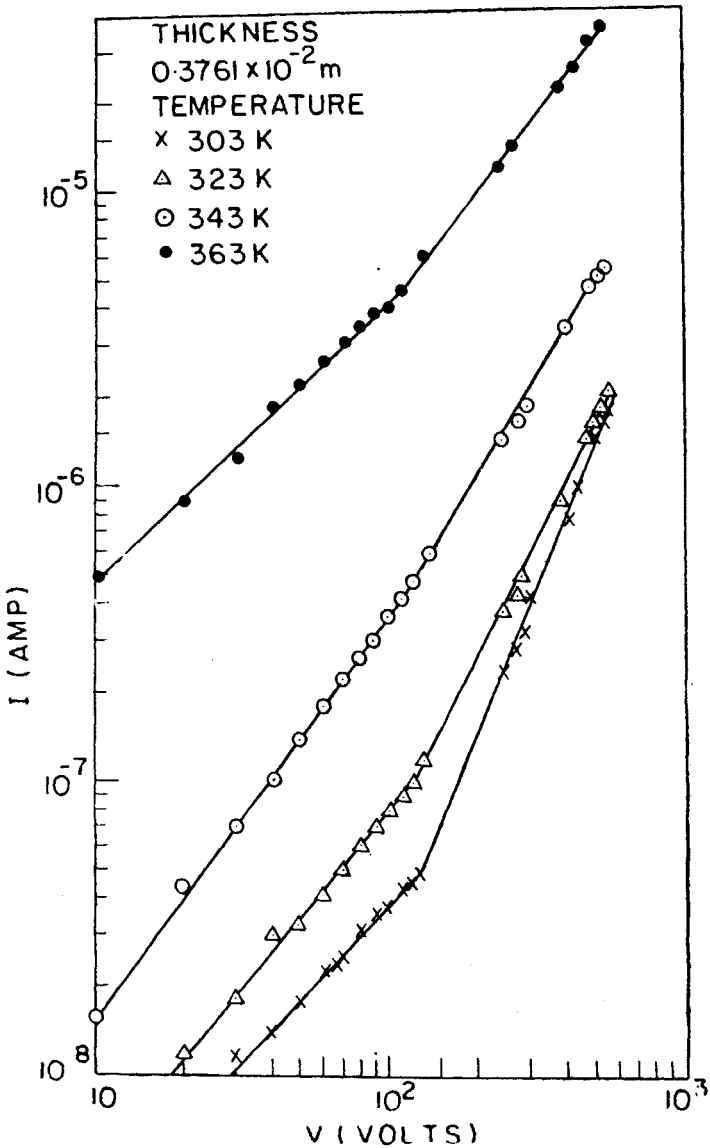

FIG 3 *I-V* characteristics at different temperatures

$$V_T = \frac{en_0 s^2}{\theta\, \epsilon_r \epsilon_0}, \qquad \ldots(3)$$

where e is electronic charge and n_0 is the volume generated free carriers.

The straight lines obtained in I vs. V^2 curves on log-log scale in the square law region, for pellets of different thickness at 303K (Fig. 4) and for a pellet (thickness 0.37×10^{-2}m) at different temperatures (Fig. 5) shows the validity of equation 1.

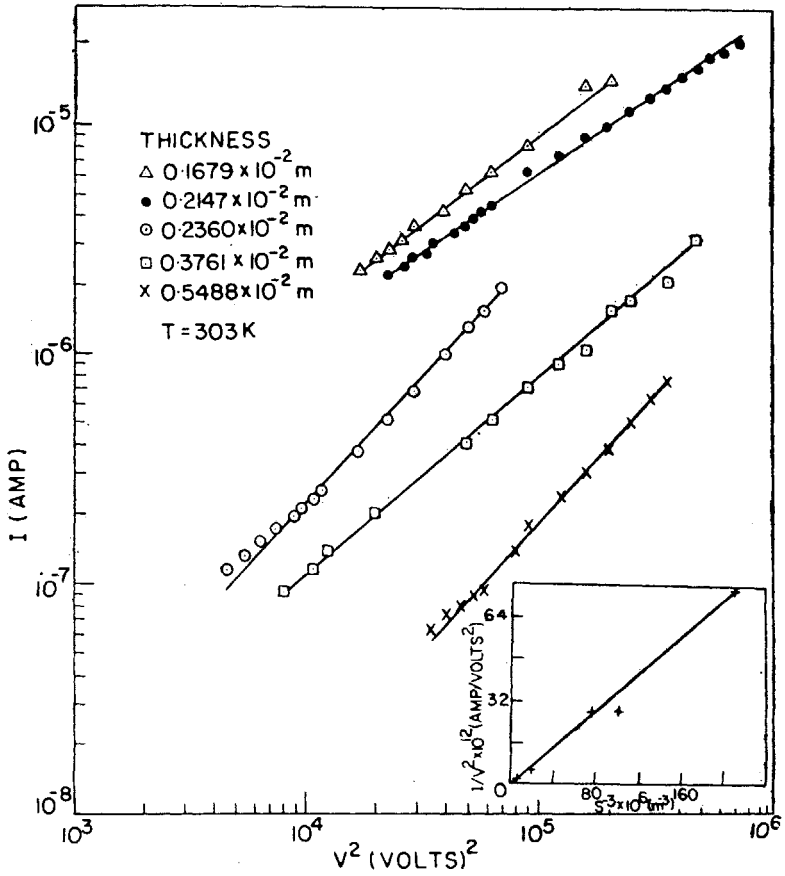

FIG 4 Variation of I with V^2 for pellets of different thickness at 303K (Inset) Plot of I/V^2 vs. S^{-3}

The straight line in I/V^2 *vs* s^{-3} graph (Inset Fig. 4) further supports the validity of the model. The horizontal and verticle bars in the graph represent the errors in the measurement of s and I/V^2.

Using the experimentally determined value of relative permittivity ϵ_r (41.56) and assuming $\mu = 10^{-2}\text{m}^2/\text{Vsec}$; the value of θ have been calculated by using eq. (1) and the least square fit method. Table I includes the values of θ, transition voltage (V_T) obtained from Fig. 3 and n_0 calculated from eq. 3.

Plot of ln θ *vs.* $10^3/T$ has been shown in the inset of Fig. 5, where horizontal bars represent the errors in the measurements of temperatures. Assuming that N_c and N_t are not strong functions of temperatures, the intercept of the straight line at $10^3/T$ being equal to zero yields a ratio $N_c/N_t = 1.267 \times 10.^8$ Assuming $N_c \sim 10^{25}\text{m}^{-3}$, N_t is of the order of $7.893 \times 10^{16}\text{m}^{-3}$ and a trap level (eq. 2) at a depth of (0.715 ± 0.049) eV below conduction band is obtained.

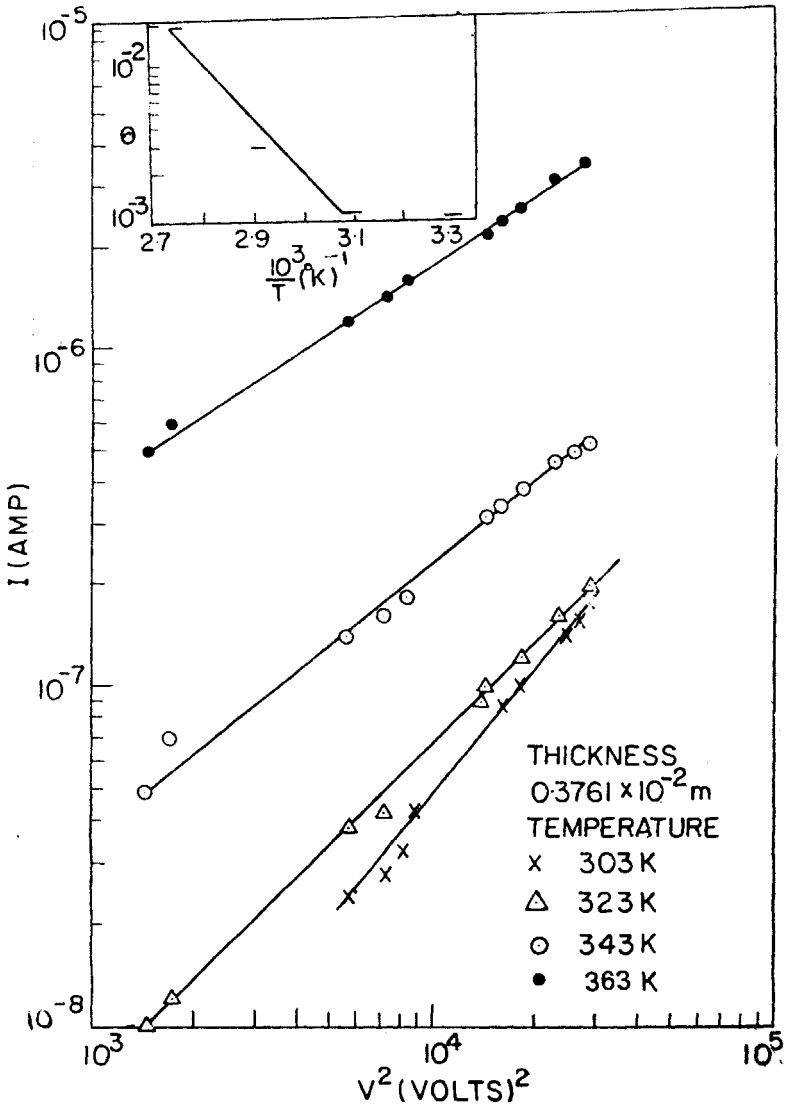

FIG 5 Variation of I with V^2 at different temperatures. (Inset) Plot of ln θ vs $10^3/T$

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