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AC and DC conduction properties of vacuum evaporated V_2O_5 thin films

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Thin films of vanadium pentoxide (V_2O_5) was deposited on to well cleaned glass substrate in between aluminum electrodes form the MIM structure under the pressure of 10^{-5}Torr. The transport mechanism in these films under A.C fields was studied by employing LCR meter in the frequency range 12 Hz to 100 kHz at various temperatures. The temperature co-efficient permitivity (TCP), temperature co-efficient of capacitance (TCC) and dielectric constant (ἐ) for the material of the film were calculated. The dependencies of activation energy on frequency and thickness also calculated. DC conduction studies indicate that the transport phenomenon may be of Schottky emission type. The zero field activation energy has a tendency to decrease with increase in thickness.

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Keywords: Thin films; Temperature co-efficient; Dielectric constant; Schottky

1. Introduction

Vanadium Pentoxide (V_2O_5) has been extensively studied since it tends to form a layered structure which allows the insertion / extraction of different ions between its layers. The use of V_2O_5 is closely connected with a way of preparing material for its final usage. It can be used as a catalyst in electro chromic devices, electronic devices and advanced electrochemical cells, especially in lithium batteries. The application of V_2O_5 thin films in the fabrication of micro electronic devices is well known.

A recent study shows that V_2O_5 undergoes a semiconductor-to-metal phase transition at 257± 5ºc. A large change in electrical behaviour accompanies the phase change and thermally activated electrical switches have been fabricated from this material. Since optical and electrical behaviors are coupled, V_2O_5 may have potential use in optical switches and write-erase media as well (1).

V_2O_5 is especially interesting in thin films because of the possibility of integration into microelectronics circuitry (1). Alternatively V_2O_5 films can be employed in conjunction with electrochromic tungsten oxide films in charge- balanced devices (2-4) for display purposes in informatics, for variable- reflectance mirrors, for Variable-transmittance (smart) windows in energy- efficient buildings, and for variable emittance surfaces for temperature control of space vehicles. The present paper deals with the AC and DC conduction studies on vacuum evaporated V_2O_5 thin films.

2. Experimental

V_2O_5 thin films were prepared by thermal evaporation method using Hind High Vacuum unit at 10^{-5}Torr pressure. First the aluminum was evaporated from a tungsten filament onto well- cleaned glass substrate (dimension 3.75×2.5cm) through suitable masks to form the base electrode. V_2O_5 was then evaporated from molybdenum boat to form the dielectric layer and the suitable masks were used to form the top electrode, so as to complete the aluminum- V_2O_5- aluminum (MIM) capacitor structure. The rectangular samples of (dimensions 3.75X2.5cm) vacuum evaporated V_2O_5 films were used for structural studies and surface analysis. A constant rate of evaporation (1Å/sec) was maintained to prepare all the V_2O_5 thin film samples. Rotary drive was also employed to maintain uniform thickness through the samples prepared.

2.1Measurements

The thickness of the samples was measured by multiple beam interferometry (MBI) technique. The dielectric and a.c measurements for the V_2O_5 film were made using a digital LCR meter (LCR-819, GW instek, Good will Instrument company Ltd., Taiwan). A dc regulated power supply was employed in d.c studies keeping the MSM structure in ‘vacuo’ at different temperatures. The current was studied by digital Pico ammeter (DPM – 111). In both dielectric and conduction studies the temperature was measured by multimeter (Dot-705).

3. Results and discussion

3.1 Dielectric properties

The capacitance and loss factor (tanδ) are important scale factors to analyze the dielectric properties. In the present study the equivalent series capacitance (C) was measured and whenever necessary a series – parallel conversion was made. The dielectric constant of V_2O_5 film were calculated using the formula $\varepsilon' = Cd / \varepsilon_0 A$ and it was found to be 0.07410 for 1 kHz at room temperature.

3.2 Frequency and temperature effect

The changes in capacitance with frequency at different temperature for V_2O_5 film capacitor formed by vacuum evaporation are represented in Fig. 1. From the figure it is seen that the capacitance decreases with increase in frequency for all temperatures.

Fig. 1. Change of capacitance with log frequency at different temperature (d = 1100Å)

The large increase in capacitance towards the low frequency region may be attributed to the blocking of charge carriers at the electrodes. Actually, the charge carriers present in the film migrate upon the application of the field and because of the impedance to their motion at electrodes there is a large increase in the capacitance at low frequencies. The trend observed is in good agreed with earlier workers on semiconductors.

The variations of tanδ with frequency at different temperature for V_2O_5 film are represented in the fig. 2. It is observed that the value of tanδ increase in frequency for all temperatures. It is found that the presence of loss peaks in the lower frequency region (12-800Hz) shifts to higher frequency region with increasing temperature.

Fig. 2. Variation of dielectric loss with log frequency at different temperatures (d = 1100Å)

Generally the deficiency or the imperfection in the solid state materials pave way to form dipoles which leads to occurrence of Debye type dispersion [10] such a dispersion could be expected in vacuum evaporated V_2O_5 thin films.

Fig. 3 shows the variation of dielectric constant with frequency at various temperatures. It is seen that dielectric constant with frequency curve closely resemble those predicted by the Debye relaxation model for orientation polarization [10].

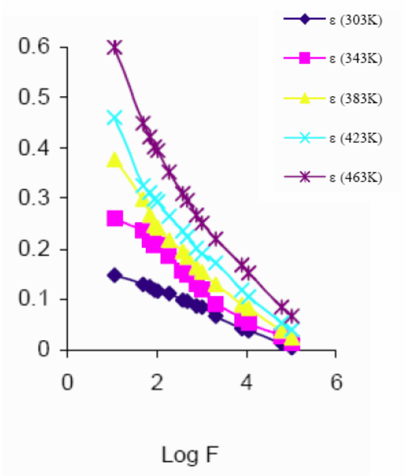

Fig. 3. Variation of dielectric constant with log frequency at different temperatures (d = 1100Å)

3.3 Temperature co-efficient of capacitance

Fig. 4 illustrates the temperature dependence of capacitance at different frequencies. It has been observed that the capacitance increases with temperature at all frequencies.

The temperature co-efficient of capacitance has been evaluated using the equation TCC = γ_c=1/C(dC/dT) the estimated TCC for V_2O_5 films has been found to be 15620 ppm/K for1 kHz. Fig. 5 represents the temperature dependence of dielectric constant at different frequencies. The temperature co-efficient of permittivity TCP have been evaluated using the equation TCP= γ_p=1/ ε'(dε'/dT) and it is found to be10600 ppm/K for 1 kHz.

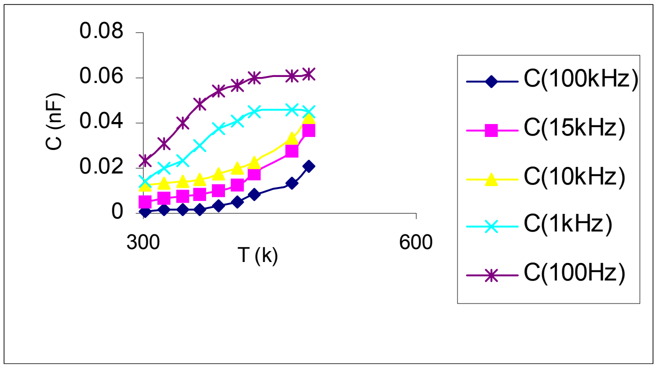

Fig. 4. Variation of capacitance with temperature at different frequencies (d = 1100Å)

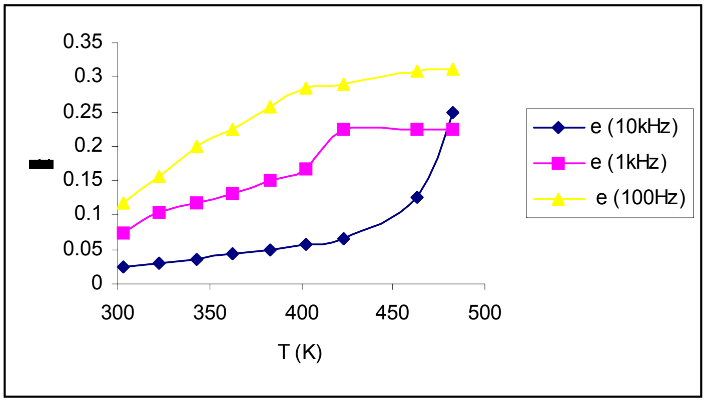

Fig. 5. Variation of dielectric constant with temperatures at different frequencies (d = 1100Å)

3.4 Ac conduction

Fig. 6 represents the dependence of a.c conductance on frequency at different temperatures for vacuum evaporated V_2O_5 thin film of thickness 1100Å.

The conductance is found to increase linearly with increase of frequency in all the films in accordance with the relation, $G_p \alpha f^n$.

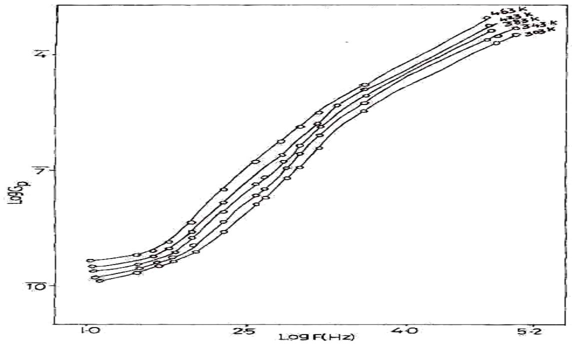

Fig. 6 Dependence of conductance on frequency at different temperatures (d = 1100Å)

The values of exponent n have been estimated and found is lie between 0.88 and1.38. This behaviour is exhibited by many hopping system mostly disordered or amorphous materials exhibit this behaviour. The frequency dependence of conductivity is a general feature of hopping systems [11,12]. The value of n in general decreases with increase of temperature. Fig. 7 displays the temperature dependence of conductance of the V_2O_5 film (d =1100Å) at different frequencies and their corresponding activation energy was calculated. In similar way, the activation energy for films of thicknesses 1950 Å and 3650 Å were also estimated and presented in the Table 3.4. The action energy decreases with increase in thickness and increases with increase in frequency. The low value of activation energy suggests that the hopping conduction may be due to electrons rather than ions [13, 14].

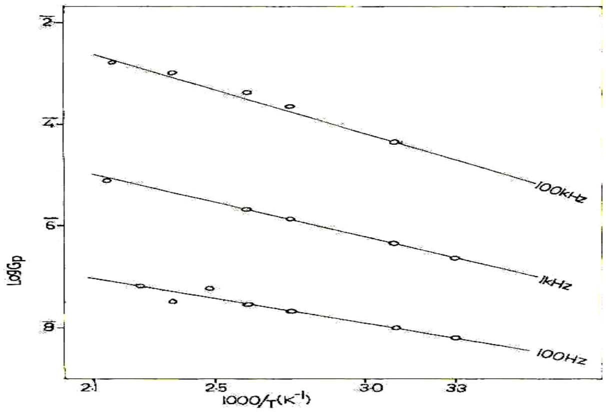

Fig. 7 Temperature dependence on conductance at different frequencies (d = 1100Å).

Table .3.4 Activation energy dependence on thickness

Frequency KHz	Activation energy eV		
	Thickness 1100 Å	Thickness 1950 Å	Thickness 3650 Å
0.1	0.2102	0.1651	0.1402
1	0.2703	0.2102	0.1652
100	0.3148	0.2720	0.2202

3.5 D.C conduction

Information about the conduction mechanism can be obtained from I-V characteristics at different temperature. LogI Vs LogV characteristics of V_2O_5 films of thickness 1100Å for different temperature are represented in fig. 3.5.1. It is seen that the curve for each temperature exhibits two regions namely AB and BC. In the region AB at low voltage the conduction is ohmic ($I\alpha$ V), indicating that the current is controlled by thermally generated carriers. In the region BC corresponding to approximately 4Vto10V, a traps square law region($I\alpha V^2$) obtained. The similar behaviour has been reported by G.N.Nadakarni and V.S. Shirodkr (15). Fig. 3.5.2 represents the variation of log current with the square root of applied filed. It is observed that in the high filed region the V_2O_5 films exhibit linear current filed characteristics for all temperatures that the conduction mechanism may be either Schottky or Poole-Frenkel type.The high field which exists in a film, causes a lowering of potential barrier height or the Schottky conduction relation is give by ‚$J = AT^2 \exp (e\beta_s F^{1/2} - \varphi_0 / KT)$

Where

$\beta_s = (e / 4\pi\varepsilon_0\, \varepsilon')^{1/2}$

A= Richardson's constant

Φ_0= Barrier height (in eV)

The barrier height at the metal insulator increases in the absence of a field and β_s is the Schottky co-efficient.

In the Poole-Frenkel type of conduction the expression for the current density takes the form, $J=\sigma_0 F \exp (e\beta_{pf}F^{1/2} - \varphi_0) / KT$

Where σ_0 is the low field conductivity and the Poole-Frenkel co-efficient is

$$\beta_{pf} = 2(e)^{1/2} / (4\pi\varepsilon_0\varepsilon')^{1/2} = 2\beta s$$

By taking the dielectric constant έ to be0.0741, the theoretical values of β_{pf} and β_s were calculated give in the Table.3.5

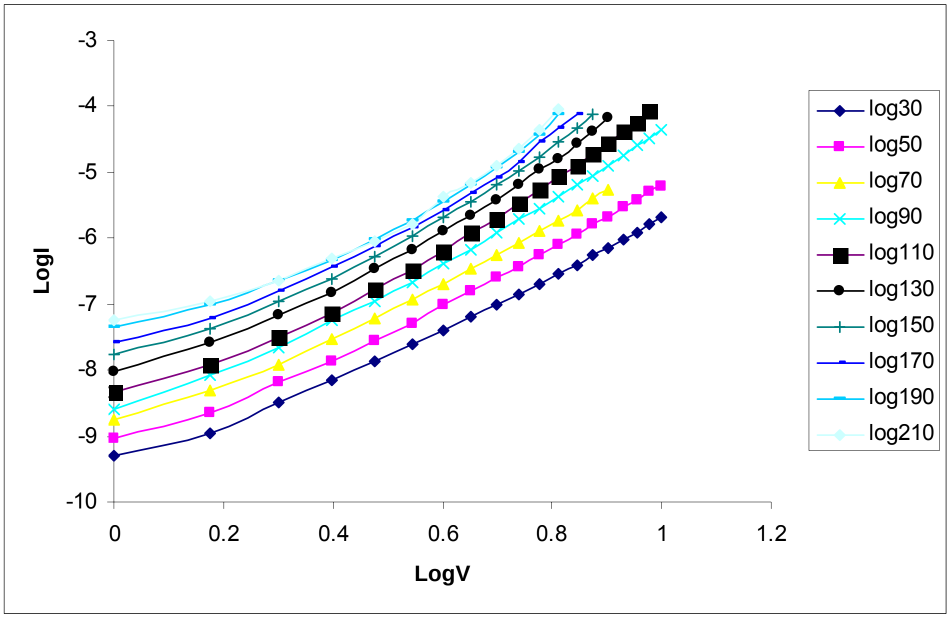

Fig.3.5.1 LogI Vs LogV characteristics of V_2O_5 films of thickness 1100Å for different Temperatures

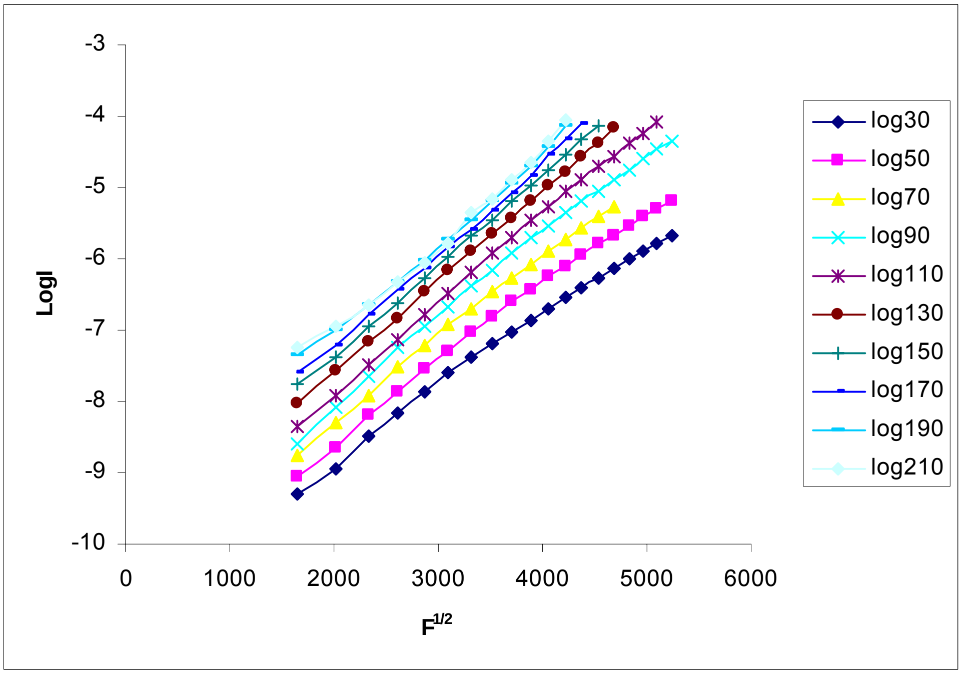

Fig. 3.5.2 The variation of log current with the square root of applied field for different temperatures

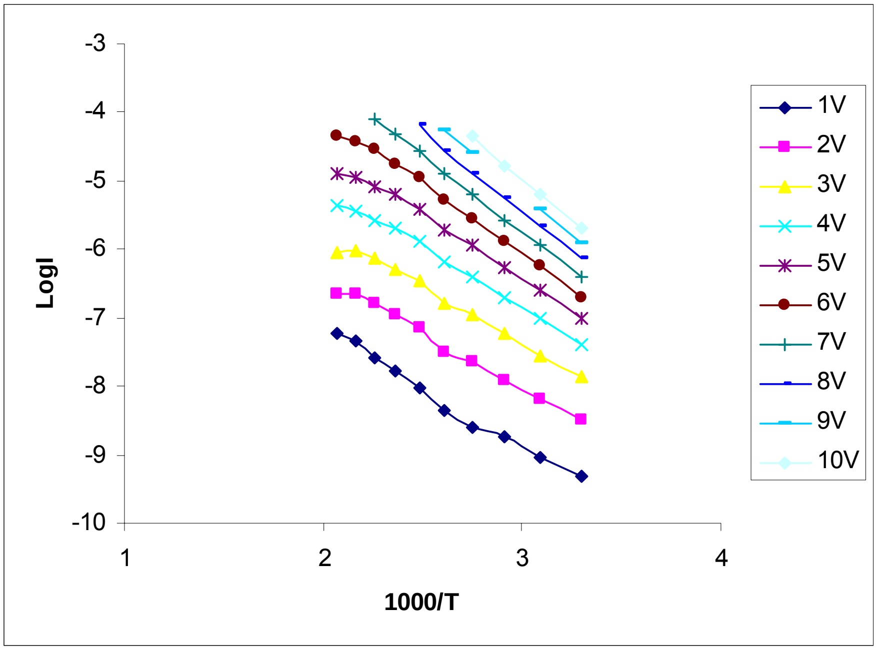

Fig. 3.5.3 The logI Vs 1000/T for different applied voltages

Table.3.5 Experimental and theoretical values of β for V_2O_5 film.

Temp in K	βExperimental $x10^{-4}$ $(mv)^{1/2}$	β Theoretical x 10^{-4} $(mv)^{1/2}$ Schottky	Poole-Frenkel
303	0.53122	1.3946	2.7827
323	0.59917		
343	0.6336		
363	0.7527		

From the evaluated values indicated in the table it has been found that the experimental value of β coincides with the theoretical value of Schottky-emission (15) and hence the conduction is Schottky-emission type. Graph drawn between logI Vs 1000/T for different applied voltages are shown in Fig. 2.3. The activation energy was determined at different applied voltages using the relation, $I= I_0 \exp(-E/KT)$.Fig. 2.4 displays the variation of the applied field and activation energy at various thicknesses. It is found that activation energy decreases as the voltage increases and corresponding zero field energies were found to be 0.514, 0.465 and 0.367 eV for films of thickness 1100, 1950, and 3650Å respectively.

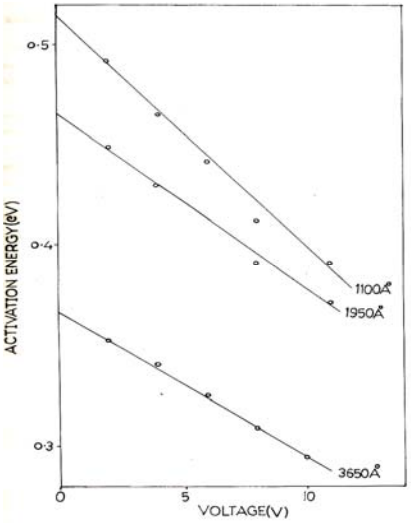

Fig. 2.4 The variation of the applied field and activation energy at various thicknesses

4. Conclusion

In the present study, V_2O_5 thin films were obtained by vacuum evaporation method. The dielectric study reveals that a polarization mechanism prevails in the film. The observed loss-peaks in the lower frequency region (12-800 Hz) shift to higher frequency region with increasing temperature confirm that Debye type polarization predominates in the thermally evaporated films. For a.c conduction it has been attributed to electronic hopping conduction mechanism. The dependence of activation energy on thickness exhibits a decreasing behaviour with increase of thickness. DC conduction studies indicate that the transport phenomenon may be of Schottky emission type. The zero field activation energy has a tendency to decrease with increase in thickness.

References

[1] Carolyn Rubin, Ying-Li Liu, Mei Lee Kao, Steven D. Hansen, J.Appl. Phys., **60**(2), 749 (1986)

[2] K. Kuwabara, S. Ichikawa, K. Sugiyama, J. Electrochem. Soc. **135**, 2432 (1988).

[3] K. Kuwabara, M. Ohno, and K. Sugiyama, Solid state Ion. **44**, 319 (1991).

[4] S.F. Cogan, R. D. Rauh, N. M. Nguyen, T .D. Plante, J .D. Westwood; J. Electrochem. Soc. **140**, 112 (1993).

[5] C. J. Ridge, P.J. Harrop and D.S. Campbell, Thin Solid Films, **2**, 413 (1968).

[6] F. Argall and A.K. Jonscher, Thin Solid Films, **2**, 185 (1968).

[7] A. Subbarayan, C. Balasubramanian, Sa. K. Narayandass, Indian Journal of Pure and Applied Physics, **26**, 410 (1988).

[8] R. Sathyamoorthy, Ph.D. Thesis (1991), Bharathiar University, Coimbatore.

[9] D. Natarajan, Ph.D. Thesis (2000), Bharathiar University, Coimbatore

[10] P. Debye, Polar Molecules, Dover, New York, 1929

[11] M.H. Nathoo, A.K. Jonscher, J. Phys. C: Solid State Physics, **4**, L301 (1971).

[12] A.K. Jonscher and M.H. Nathoo, Thin Solid Films, **12**, 515 (1972).

[13] S. Chan, A.K. Jonscher, Phys. Stat. Sol., **32**, 749 (1969).

[14] J. Chutia, K.Barua, J. Phys. D: Appl. Phys. **13**, L9 (1980).

[15] G. S. Nadkarni, V. S. Shirodkar, Thin Solid films; **105**, 115 (1993).