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Electrical conduction mechanism of polyvinyl chloride (PVC)–polymethyl methacrylate (PMMA) blend film

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Abstract. The electrical conduction mechanism in polyvinyl chloride (PVC)–polymethyl methacrylate (PMMA) blend film has been studied at various temperatures in the range 313 K to 353 K. The results are presented in the form of I–V characteristics. Analysis has been made in the light of Poole–Frenkel, Fowler–Nordheim, Schottky, log(J) vs. T plots and Arrhenius plots. It is observed that, Schottky–Richardson mechanism is primarily responsible for the observed conduction.

Keywords. Polyvinyl chloride (PVC); polymethyl methacrylate (PMMA); blend film; conductivity.

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1. Introduction

The electrical conduction in iodine-doped polystyrene (PS) and polymethyl methacrylate (PMMA) has already been reported [1]. Belsare and Deogaonkar [2] have reported the increase in electrical conductivity of polystyrene (PS) and polymethyl methacrylate (PMMA) with the increase in iodine doping concentration.

In the case of organic solids, whose conductivity due to electrons excited from valence band to conduction band [3] is negligible, a complex conduction behaviour [3,4] has been explained usually in terms of electron emission from cathode, i.e. Schottky–Richardson mechanism [5] or by electron liberation from the traps in the bulk of the material, i.e. Poole–Frenkel mechanism [6]. The possibility of tunneling or Fowler–Nordheim mechanism [7], space charge limited conduction [8] etc. have also been investigated in the literature. The possibility of formation of link between two or more molecules can be realised through the choice of proton donor PVC and proton acceptor PMMA polymers [9]. In the present study, DC-conduction through blend film was studied to identify the mechanism of electrical conduction. It is shown how the I–V data of the sample can be used to arrive at possible conclusions. Results have been discussed in the light of different mechanism.

2. Experimental details

2.1 *Preparation of sample*

The film was prepared by isothermal evaporation technique [10]. The thickness of the film was measured by a compound microscope in conjunction with an occulometer having least count 13 μm and 3.3 μm at the magnification of 1:10 and 1:100 respectively. The film used for the present study is of thickness 70 μm. The electrode coating on the film by using the quick drying silver paste [11] and a mask of circular aperture of a diameter 2.4 cm.

2.2 *Measurements*

The sample film coated with silver electrodes was sandwiched between two brass-electrodes of the sample holder specially fabricated in the laboratory having electrode diameter of 2.4 cm each. This formed the metal-insulator-metal (M-I-M) system, which was placed in a thermostatically controlled furnace. The current I (measured with picoammeter of accuracy ±0.2%) and voltage (V) measurements have been recorded at various constant temperatures.

3. Results and discussion

The log I–log V plots of the sample at various temperatures 313, 323, 333, 343 and 353 K are shown in figure 1. The current increases non-linearly with the applied voltage and does not follow a power law, $I = kV^m$, where k and m are constants.

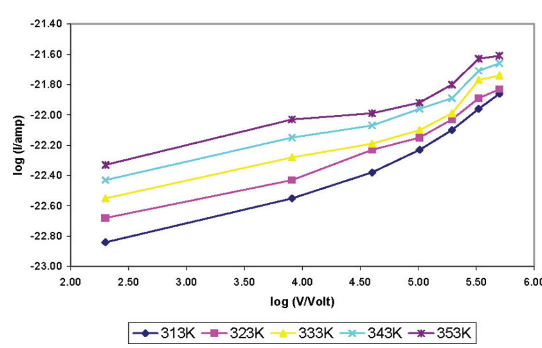

Figure 1. Current–voltage characteristics.

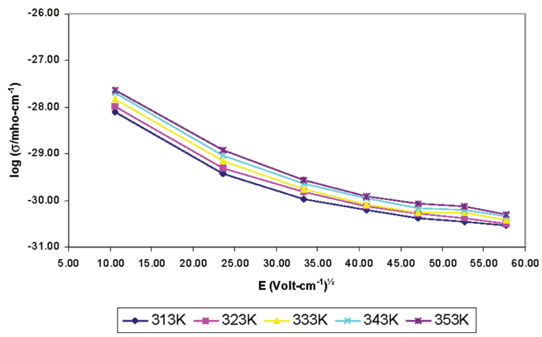

Figure 2. Poole–Frenkel plots.

The increase of current with voltage is rather weaker at low values of voltages and gets improved at higher voltages. Figure 1 indicates that (i) the current at a constant temperature increases with applied voltage, (ii) the current at constant applied voltage increases with temperature. The mechanism operative in the present case is discussed in the light of the following mechanisms.

3.1 *Poole–Frenkel mechanism*

The Poole–Frenkel relation [6] for current density is

$$J = B \exp\left(\frac{-\varphi}{kT} + \beta_{\mathrm{PF}} E^{1/2}\right), \tag{1}$$

where $\beta_{\mathrm{PF}} = \frac{e}{kT}\left(\frac{e}{\pi\varepsilon\varepsilon_0 d}\right)^{1/2}$ = constant and e = electronic charge which predicts a field-dependent conductivity as

$$\log\sigma = \log\sigma_0 + \frac{\beta_{\mathrm{PF}}}{2kT}E^{1/2} \tag{2}$$

so that the Poole–Frenkel mechanism is characterized by the linearity of log σ vs. $E^{1/2}$ plots with a positive slope.

In the present case of PVC and PMMA blend film the log σ vs. $E^{1/2}$ plots are linear but with a negative slope (figure 2) indicating the absence of PF mechanism.

3.2 *Fowler–Nordheim mechanism*

The Fowler–Nordheim relation [7] for current density J can be expressed as

$$\log\frac{J}{V^2} = \log A - \left(\frac{\varphi}{V}\right) \tag{3}$$

and the log J/V^2 vs. $1/V$ plot is expected to be a linear relation with a negative slope.

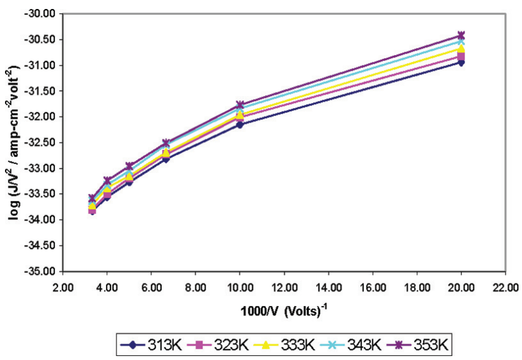

Figure 3. Fowler–Nordheim plots.

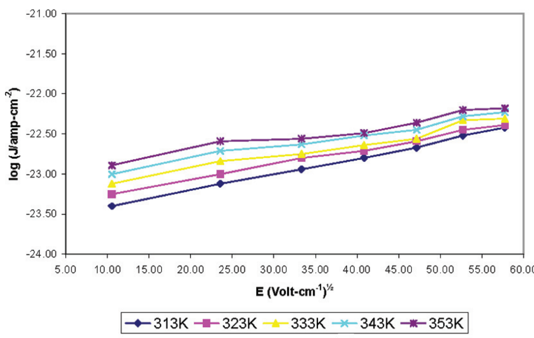

Figure 4. Schottky plots.

In this case the log J/V^2 vs. $1/V$ plot for the sample is presented in figure 3. Excepting few points, which have strayed away, the graphs are nearly straight lines with a positive slope, indicative of the absence of tunneling current as is suggested by F–N mechanism.

3.3 *Schottky plots*

Thermal activation of electron, may occur over the metal–insulator interface barrier, which is further helped by the applied electric field effect, which reduces the height of the barrier. The Schottky–Richardson current voltage relationship is expressed as

$$\log J = \log AT^2 - \frac{\varphi_s}{kT} + \beta_{\rm SR}E^{1/2} \tag{4}$$

and that log J vs. $\sqrt{E}$ plot referred to as Schottky plots should be a straight line with a positive slope.

For the present case, these are shown in figure 4. The linear positive slope indicates that the Schottky–Richardson mechanism is applicable to the conduction

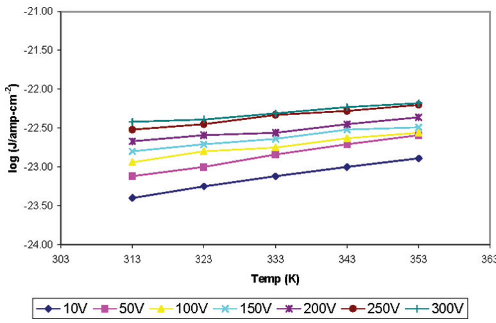

Figure 5. Current density vs. temperature plots.

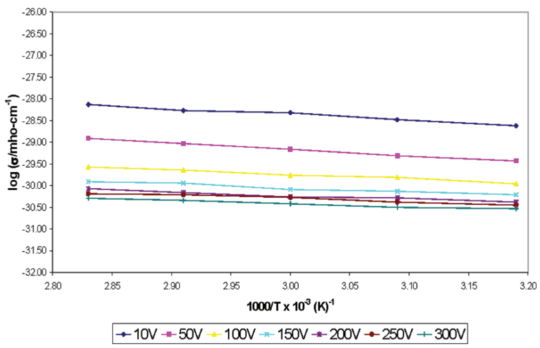

Figure 6. Arrhenius plots.

process in PVC–PMMA blend film. Further, in the case of Schottky–Richardson mechanism the current shows strong temperature dependence but not in the case of Poole–Frenkel mechanism. The temperature dependence of current density is presented in the form of log J vs. T plots in figure 5, which shows that log J increases almost linearly with temperature. The temperature dependence is in agreement with the Schottky–Richardson mechanism. Further that the slopes of all the lines are nearly same for all the fields, shows that no thermodynamic transition occurs in the temperature range studied.

3.4 *Arrhenius plots*

The log σ vs. $1/T$ plots (figure 6) at all values of applied voltages show parallel straight line with negative slope. From the slope of straight line, the activation energy is calculated and is found to be in the neighbourhood of 0.11 eV. This is in good agreement with the reported order of magnitudes.

4. Conclusion

The conduction mechanism applicable in the case of PVC–PMMA blend film is the Schottky–Richardson mechanism. Current density–temperature plots indicate the absence of thermodynamic transition in the temperature range studied. The activation energy is found to agree with the reported order of magnitude.

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