

ELECTRICAL TRANSPORT PROPERTIES OF PRISTINE AND IODINE DOPED POLYETHERIMIDES*

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Abstract Electrical conduction behavior of pristine and iodine doped polyetherimides (PEI) has been investigated under both transient and steady state conditions in the operating temperature range 50–200°C at various electric fields of 12–60 kV/cm. The transient currents show the hyperbolic decay character, and the decay exponent p (a measure of current decay rate) decreases with temperature (T) and doping concentration. The origin of transient currents has been attributed to the dipolar nature of carbonyl ($>C=O$) groups and the ether linkages present in the main chain of PEI. The low field steady state conduction is ohmic in nature. The magnitudes of ionic jump distance (a) values do not favor an ionic type of conduction as a possible conduction mechanism in pristine as well as iodine doped PEI. The Schottky coefficients estimations do not show the possibility of Schottky type or Poole-Frenkel type conduction mechanisms in the low temperature region ($< 120^\circ\text{C}$), however, in the high temperature region ($> 120^\circ\text{C}$) there is a certain possibility of Poole-Frenkel type conduction mechanism in both pristine and iodine doped samples. The dual slope in the $\lg I$ versus $1/T$ curves for iodine doped samples indicates the presence of more than one type of trapping levels.

Keywords: Transient currents; Electrical conduction; Polyetherimide.

INTRODUCTION

Polyetherimide (PEI) is a well known high performance polymeric material available under the commercial name ULTEM. It is an amorphous thermoplastic material derived from the combination of ether and aromatic imide units^[1, 2]. The high proportion of aromatic units provides excellent thermal stability to the polymer and it does not show appreciable degradation up to 400°C. The ether units provide flexibility and good melt flow characteristics to this polymer. PEI exhibits outstanding mechanical and electrical properties which remain stable over wide range of temperatures and frequencies^[3–5]. In view of its wide ranging applications a detailed understanding of its electrical properties becomes highly imperative. Though few reports are available on the dielectric and electrical conduction behavior on PEI, the conduction mechanism is still not well understood for this polymer^[6]. In the present paper, we report the transient and steady state current behavior of PEI in the temperature region 50–200°C under the biasing fields varying in the range of 12–60 kV/cm. The effect of iodine doping on the electrical conduction behavior of PEI has also been investigated.

EXPERIMENTAL

Polyetherimide used in the present investigation was procured from Good Fellow (U.K.) in thin film form of thickness 85 μm . The electrical contacts (0.45 cm in diameter) were made by vacuum evaporation of aluminium onto both surfaces of the samples. The sample holder was kept inside a properly grounded metallic chamber.

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The temperature of this assembly was regulated and recorded with the help of a precision temperature controller-cum programmer. A voltage source (3 kV dc, Aplab) and a Keithley electrometer (610 C) form the salient components of the equipment.

The PEI samples were doped with iodine by exposing them to iodine vapors at 100°C for different durations (24, 48 and 72 h). The doped samples were cooled, washed with alcohol and distilled water in order to remove the excess iodine from the surface, subsequently dried and stored in a desiccator. The concentration of iodine doping in PEI was estimated by taking the difference of weights of the samples before and after the doping.

RESULTS AND DISCUSSION

Pristine PEI

Transient current behavior

Figure 1 illustrates the transient current behavior of PEI at various temperatures for an electric field 36 kV/cm. The current response comprises of two components: a rapid decay of current is observed in the first part, lasting nearly for 40 s and thereafter the current decays with slower rate and attains a steady state within 3 min of the application of electric field. Unlike in case of Kapton-H polyimide, the temperature dependence of transient currents is not very strong^[7]. However the transient currents do show the hyperbolic decay character following the relation $I = At^{-p}$. The decay exponent p shows a decrease with temperature (Table 1). In the present case, the variation in the values of p lies in the range 1.03–0.54 for the temperatures varying from 50–200°C. These values are somewhat higher than those reported for Kapton-H polyimide (0.4–0.6) by Hanscomb *et al.* in the same temperature region^[8]. This accounts for the significant component of the transient currents in PEI even at higher operating temperatures which is usually not observed in other polymers. The field dependence in the form of $\lg I$ versus $V^{1/2}$ of transient current magnitude at 1 s over the temperature range 50–200°C has been shown in Fig. 2. We have estimated the zero-field transient currents (I_{0t}) by extrapolating these characteristics on Y-axis for different temperatures. The activation energy (ϕ_T) for transient currents has been estimated by plotting the extrapolated zero-field transient currents (I_{0t}) against $1/T$. The extrapolated zero-field transient current (I_{0t}) shows a linear variation with $1/T$ (Fig. 3). The activation energy (ϕ_T) calculated from the slope of $\lg I_{0t}$ versus $1/T$ is 0.04 eV, which is nearly 10 times less than that for Kapton-H polyimide^[8]. With such small activation energy it seems unlikely that the electron excitation could take place between the donor states at the Fermi level and the tail states. One of the possible mechanisms for the transient currents has been discussed by Hanscomb *et al.*

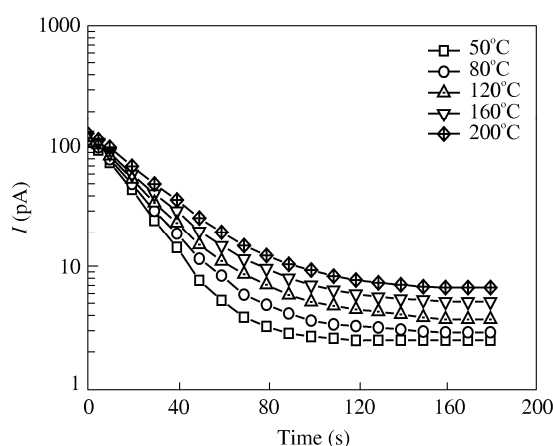
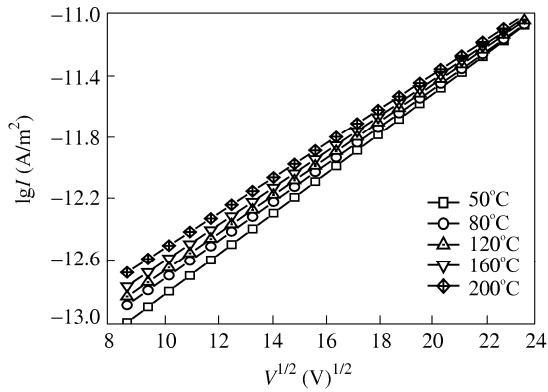
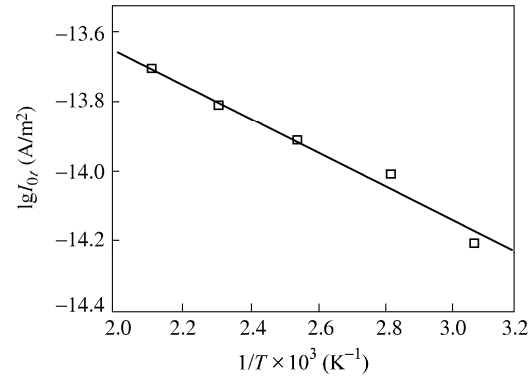


Fig. 1 Temporal behavior of transient current at different temperatures for a biasing field 36 kV/cm for pristine sample

Table 1. Decay exponent p for pristine and iodine doped samples

T (°C)	E (kV/cm)	Exponent p			
		Pristine	Iodine doped		
			1%	4%	6%
50	12	0.93	1.03	1.01	1.21
	24	0.95	1.04	1.11	0.97
	36	1.03	1.02	1.20	0.95
	48	0.92	1.02	1.11	0.97
	60	0.94	1.04	1.03	1.04
80	12	0.84	0.96	1.20	1.05
	24	0.87	0.95	0.97	0.98
	36	0.85	0.98	0.94	0.98
	48	0.85	0.95	0.98	0.94
	60	0.87	0.92	0.99	0.93
120	12	0.81	0.64	0.80	0.93
	24	0.89	0.64	0.78	0.77
	36	0.84	0.58	0.74	0.85
	48	0.80	0.67	0.73	0.80
	60	0.80	0.65	0.77	0.78
160	12	0.76	0.26	0.50	0.45
	24	0.83	0.26	0.41	0.51
	36	0.72	0.37	0.43	0.49
	48	0.71	0.40	0.43	0.50
	60	0.73	0.44	0.46	0.53
200	12	0.89	0.10	0.12	—
	24	0.73	0.11	0.10	—
	36	0.62	0.11	0.06	—
	48	0.54	0.12	0.08	—
	60	0.64	0.11	0.10	—

**Fig. 2** Dependence of 1 s transient current density on voltage for pristine PEI samples at different temperatures**Fig. 3** Extrapolated zero-field transient current density I_0 as a function of temperature for pristine PEI samples

following the model of Mott for amorphous solids^[8, 9]. The model suggests the existence of localized states extending as tails from the conduction and valence bands into the band gap with a possibility of overlapping near the Fermi level. This results in the formation of donor and acceptor states in this energy region. In the presence of an electric field, electrons are excited into the tail states through the process of hopping and generating a current of low mobility between these states. We have also examined the tunneling as a possible mechanism for the transient current behavior in PEI. The following expression derived by Simmons for the

tunneling current density^[10]

$$I \propto E^2 \exp \left[\frac{8\pi(2m)^{\frac{1}{2}} \phi^{\frac{3}{2}}}{2.96heE} \right]$$

where, m , ϕ , h and e are the electronic mass, the barrier height, Planck's constant and electronic charge respectively, may be used for obtaining the barrier height ϕ and the tunneling distance R ($= \phi/eE$)^[8]. In the present case we have estimated the value of ϕ from the slope of $\lg I/E^2$ versus $1/E$ characteristics at different temperatures (not shown). In the field region of 24–60 kV/cm, the value of ϕ comes out to be 0.01 eV and the value of tunneling distance R (for $E = 2 \times 10^7$ V/m) comes out to be 0.5 nm. This value of R reasonably agrees with that obtained for Kapton-H polyimide and also favors the tunneling as a possible mechanism for transient currents^[8].

The dependence of the ratio I_0/I_s (where I_0 represents the current observed immediately after applying the voltage and is the steady state current) on temperature (Table 2) is not as strong as observed in case of other polymers^[7, 11]. However, there is a certain decrease in I_0/I_s with increasing temperature which may be attributed to the cumulative effect of rapid decrease in relaxation time, a characteristic of transient phenomenon and progressive increase of steady state conduction.

Table 2. I_0/I_s ratio for pristine and iodine doped samples

T (°C)	I_0/I_s at different temperatures for 36 kV/cm			
	Pristine	Iodine doped		
		1%	4%	6%
50	44.00	85.61	115.00	76.66
80	38.33	52.27	50.00	54.54
120	34.00	8.57	16.00	25.00
160	25.00	3.13	3.94	5.29
200	19.00	1.45	—	—

One of the major molecular processes held responsible for the origin of transient currents in polymers is dipolar relaxation process. In PEI, the dipolar relaxation process mainly arises due to the presence of large number of carbonyl ($>C=O$) groups in the main chain. We have estimated the density of carbonyl ($>C=O$) groups as $3 \times 10^{20}/\text{cm}^3$ following the method of Shirnet *et al*^[12]. In addition to the contribution from $>C=O$ groups towards dipolar relaxation process, the ether linkages have also been shown to contribute towards this relaxation process. Hence the dipolar relaxation process may play a major role in determining the current transient nature in PEI.

Steady state conduction

Figure 4 illustrates the dependence of steady state dc conduction on electric field for PEI samples at different temperatures plotted in the form of $\lg I$ versus $\lg V$ curves. The curves show usual ohmic behavior below 24 kV/cm and above this field it deviates from ohmic behavior. However, the non-linear nature of I - V characteristics appears to be influenced by operating temperature. In addition to the ohmic conduction, the I - V curves can be examined considering many other processes *e.g.* ionic-hopping, tunneling, Schottky and Poole-Frenkel mechanisms *etc*^[13–16]. In case of ionic hopping conduction, the current I is given as^[17]

$$I = 2sqna v \exp \left(\frac{-U}{kT} \right) \sinh \left(\frac{qEa}{2kT} \right) \quad (1)$$

where, q , n , a , U , k , v , T and s respectively are the charge of ion, ionic concentration, ionic jump distance, the barrier height, Boltzmann's constant, the attempt to escape frequency, the absolute temperature and the effective electrode area.

In the high electric field region, where the non-linearity occurs ($qEa/2kT \gg 1$), Eq. (1) can be written as

$$I = I_0 \exp\left(\frac{qEa}{2kT}\right) \quad (2)$$

where, $I_0 = 2sqma v \exp\left(\frac{-U}{kT}\right)$.

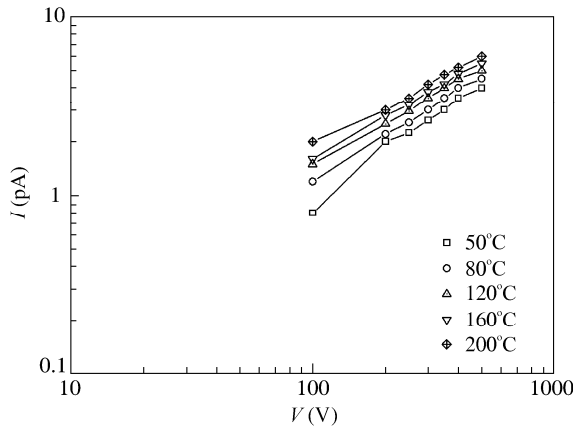


Fig. 4 Field dependence of steady state current ($\lg I$ - $\lg V$) for pristine PEI sample at different temperatures

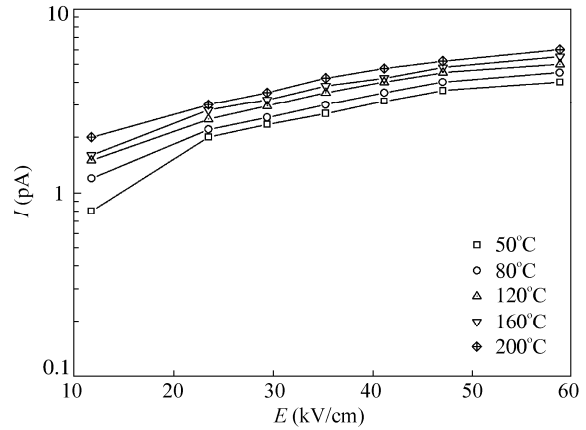


Fig. 5 Ionic-hopping plots ($\lg I$ - E) for pristine PEI sample at different temperatures

The slope of the straight line of the plot of $\lg I$ versus E at constant T gives the ionic jump distance a . Figure 5 illustrates I - V characteristics in the form of $\lg I$ versus E for PEI samples at different operating temperatures ranging from 50°C to 200°C. The plots can be regarded as straight lines above 24 kV/cm electric field. The ionic jump distance a estimated from the slope of these curves is given in Table 3. The value of a varies with temperature over a range of 11.1–16.3 nm. The temperature variation of a in some other organic polymers has also been reported but no one has offered any reason for this variation^[7, 11, 17]. The order of magnitude of a is somewhat more than those obtained for Kapton-H polyimide^[17]. This may be due to the additional ether linkages available in polyetherimide structure, resulting in modification in the intermediate energy-states (electrons excited into the tail states as discussed earlier). However, the magnitude of a values does not favor ionic type of conduction as a possible conduction mechanism in polyetherimide. Thus it will be worth to examine the fitness of present results in relation to other electronic processes mainly Schottky or Poole-Frenkel type conduction. The current densities for these processes are expressed respectively as^[14]

$$I = AT^2 \exp\left(\frac{\beta_s E^{\frac{1}{2}} - \phi}{kT}\right) \quad (3)$$

and

$$I = BE^{\frac{1}{2}} \exp\left(\frac{\beta_f E^{\frac{1}{2}} - \phi}{kT}\right) \quad (4)$$

where, A and B are constants, E the applied electric field, ϕ the effective work function, β_s and β_f are the Schottky and Poole-Frenkel coefficients respectively given as

$$\beta_s = \left(\frac{e^3}{4\pi K \epsilon_0}\right)^{\frac{1}{2}} \text{ and } \beta_f = 2\beta_s \quad (5)$$

where, e , ϵ_0 and K are the electronic charge, vacuum permittivity and high frequency dielectric constant respectively. The Schottky mechanism involves the field assisted thermionic emission of charges from electrodes into the sample (resulting in a field dependent lowering of barrier potential) whereas in the Poole-Frenkel effect, the current is considered to be due to field assisted thermal excitation of electrons from traps into the conduction band.

Table 3. Ionic jump distance a obtained from $\lg I$ versus E plots for pristine and iodine doped samples

T (°C)	Ionic jump distance a (nm)			
	Pristine	Iodine doped		
		1%	4%	6%
50	11.1	22.2	38.9	33.3
80	12.1	36.4	42.5	30.3
120	13.5	27.0	27.0	40.5
160	14.9	14.9	22.3	22.3
200	16.3	24.4	24.4	—

In Fig. 6, the data of Fig. 5 have been replotted in the form of $\lg I$ versus $E^{1/2}$ usually known as Schottky plots. The slopes of the Schottky plots give the experimental value of β (β_{exp}). The theoretical values of β (β_{th}) can be obtained from Eq. (5). Table 4 gives the β_{exp} and β_{th} values for pristine PEI samples. The β_{th} values have been estimated by taking the dielectric constant (K) for PEI measured using a precision LCR meter. In the temperature region up to 120°C we cannot make any definite comment on the possibility of a Schottky type or Poole-Frenkel type conduction mechanism in PEI since β_{exp} values are neither very close to β_{th} values (Schottky type conduction) nor β_{exp} values are twice the β_{th} values (Poole-Frenkel type conduction). However, at higher temperatures (above 120°C) the β_{exp} values are in close agreement with twice the β_{th} values suggesting a definite possibility of a Poole-Frenkel type conduction mechanism.

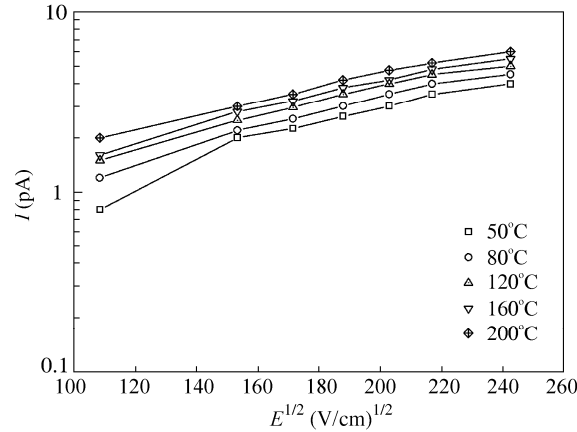


Fig. 6 Schottky plots ($\lg I$ - $E^{1/2}$) for pristine PEI sample at different temperatures

Table 4. The values of β_{exp} and β_{th} for pristine and iodine doped samples

T (°C)	$\beta_{\text{exp}} \times 10^{24}$ & $\beta_{\text{th}} \times 10^{24}$ ($\text{Jm}^{1/2}\text{V}^{-1/2}$)							
	Pristine		Iodine doped					
			1%		4%		6%	
	β_{exp}	β_{th}	β_{exp}	β_{th}	β_{exp}	β_{th}	β_{exp}	β_{th}
50	3.56	2.67	7.13	2.84	12.03	2.86	9.80	2.82
80	3.90	2.70	7.79	2.88	12.67	2.88	9.74	2.84
120	4.34	2.73	7.05	2.90	8.13	2.90	12.47	2.86
160	4.78	2.73	4.18	2.92	6.57	2.90	7.17	2.86
200	5.22	2.73	7.83	2.92	7.18	2.88	—	2.84

Deviation between the β_{th} and β_{exp} values can be attributed to the build-up of space-charge layers in the vicinity of electrodes modifying the effective field at the dielectric-metal interface. Hence, we can also examine the $\lg I$ versus $E^{1/2}$ data using the modified Schottky equation particularly in the temperature region up to 120°C where the possibility of Schottky type conduction may exist. The current density for the modified Schottky equation due to the presence of space-charge layers in the vicinity of injecting electrodes is given as^[14]

$$I = AT^2 \exp \left[- \left\{ \frac{\phi - \beta(\gamma E)^{1/2}}{kT} \right\} \right] \quad (6)$$

where γ is a factor which expresses the change in the field at the injecting electrode due to space charge. From the above expression the value of γ can be determined if we know the Schottky coefficient β_s . The value of β_s has been estimated using Eq. (5) by taking $K = 4.5$. The value of γ comes out to be 3.5. To our knowledge, no value of γ in PEI has been reported previously. However, this is comparable to the value of γ (2.9) reported by Sessler for Kapton-H polyimide^[14]. This is a reasonable value for the field enhancement in the vicinity of electrodes due to migration of intrinsic charges during the initial current period. This may also account for the deviation between β_{th} and β_{exp} values at low temperatures.

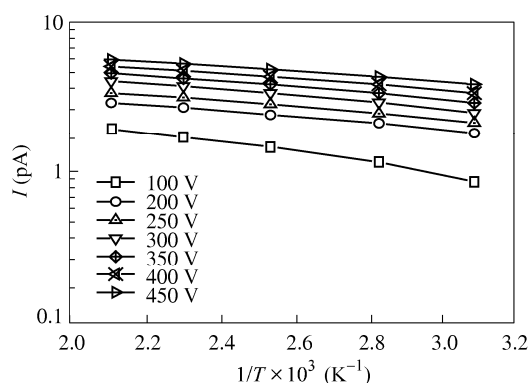


Fig. 7 Temperature dependence of steady state current ($\lg I$ - $1/T$) for pristine PEI sample at different biasing voltages

Table 5. The values of steady state activation energies for pristine and iodine doped samples

Activation energy (eV)							
Voltage (V)	Pristine	Iodine doped					
		1%		4%		6%	
		Below 90°C	Above 90°C	Below 90°C	Above 90°C	Below 90°C	Above 90°C
100	0.07	0.55	0.19	0.74	0.23	1.01	0.17
200	0.04	0.49	0.19	0.56	0.12	0.76	0.12
250	0.04	0.48	0.20	0.52	0.23	0.67	0.17
300	0.04	0.47	0.18	0.49	0.27	0.60	0.19
350	0.04	0.47	0.20	0.49	0.18	0.60	0.17
400	0.04	0.50	0.21	0.49	0.13	0.64	0.17
500	0.03	0.50	0.25	0.50	0.18	0.65	0.16

The dependence of steady state current on temperature has been shown in Fig. 7 in the form of $\lg I$ versus $1/T$ characteristics for different electric fields. Usually the $\lg I$ versus $1/T$ characteristics in most of the aromatic polymeric materials consist of two straight lines with different slopes and the steady state current shows a strong dependence on temperature^[7, 11]. However, in the present case, we do not observe a very strong dependence of

steady state current on temperature and also the $\lg I$ versus $1/T$ characteristics show single slope and the steady state current varying in several orders of magnitude. But in the present case, we do not observe a single slope in $\lg I$ versus $1/T$ curves. Also the dependence of current I on temperature is not very strong. Not surprisingly, the activation energy estimated is much less (0.03–0.07 eV) as compared to those reported for Kapton-H polyimide (Table 5)^[7].

Iodine Doping Effect

Transient current behavior

Few representative I - t characteristics at different operating temperatures depicting the transient current behavior of iodine doped PEI samples (biasing field 36 kV/cm) have been illustrated in Fig. 8. The nature of I - t characteristics at low operating temperatures is almost similar to that of pristine samples with an enhancement in I_0/I_s ratio (Table 2). However, at higher operating temperatures the I_0/I_s ratio for doped PEI samples is significantly less as compared to pristine samples suggesting the dominance of steady state component at higher operating temperatures. This is also confirmed by the fact that the decay component p considerably decreases at higher operating temperatures (Table 1). Except in few cases, the I_0/I_s ratio increases with increasing doping concentration (Table 2). It is very difficult to assign any definite mechanism for the transient current behavior in doped samples. The complexities arise due to the various possible doping mechanisms.

It is established that iodine diffuses preferentially in the less dense volume region of the polymer and is present either interstitially or is trapped between the chain configurations and forms a charge-transfer complex within the structure. As a result of the electrostatic interaction between the chain and iodine, the intermolecular interactions are reduced and this facilitates the motion of the molecules resulting in an increase in their mobility^[18]. Iodine is incorporated as chains of ions in channels between the polymer molecules^[19, 20]. Clarke *et al.* have suggested the possibility of intermolecular cross-linking of iodine molecules between phenyl-rings^[21]. Hulten and Hadziioanou have shown that the doping facilitates the rotation of the phenyl rings into a more coplanar conformation^[22]. In PEI, iodine may get attached at the aromatic imide rings with a stereo-specific arrangement converting the double bonds into single bonds.

Mizutani *et al.* have shown a significant enhancement in conductivity of polyethylene due to iodine doping which is found to be dominated by electron injection from the cathode^[23]. They attributed this enhancement to the increase in electron injection by the localized states due to iodine doping. It is obvious from the I - t characteristics (Figs. 8 and 9) that the mechanisms responsible for the transient behavior in doped PEI are not only dependent on the doping concentration but also very sensitive to the operating temperature. In addition to the ketonic groups in PEI structure, which play the role of active trapping centers the iodine molecules attached

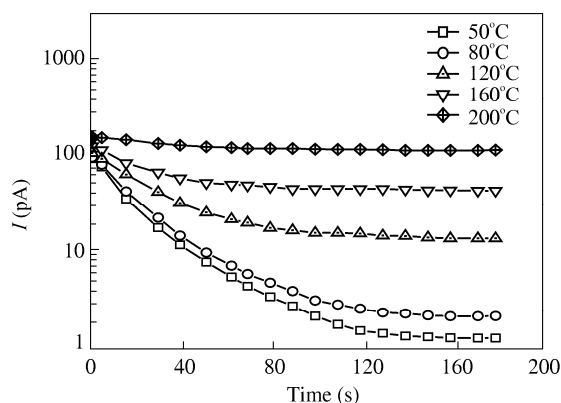


Fig. 8 Temporal behavior of transient current for iodine doped (1% by weight) PEI sample at different temperatures for a biasing field of 36 kV/cm

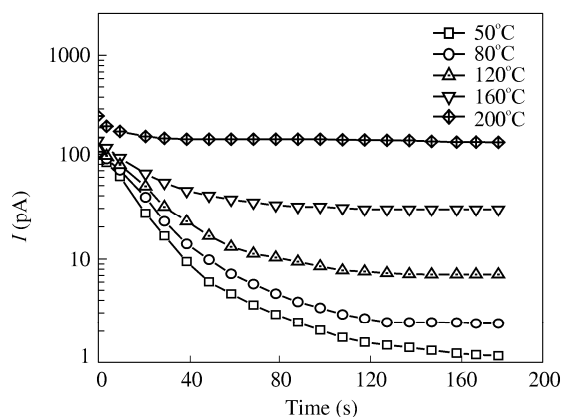


Fig. 9 Temporal behavior of transient current for iodine doped (4% by weight) PEI sample at different temperatures for a biasing field of 36 kV/cm

at the aromatic imide rings will also become the source of deep energy centers. Since the charge due to the guest molecules (dopant molecules) depends upon the electronic affinity and the ionizing potential and both processes being temperature dependent, it is not surprising that the transient current mechanism should also be temperature dependent which also discards the tunneling as a possible mechanism in doped PEI. The charge carrier depletion processes and the trapped space charge effect resulting from the charge injection appear to be the possible mechanism for transient behavior in doped PEI.

Steady state conduction

The steady state conduction behavior of iodine doped PEI samples in the form of $\lg I$ versus $\lg V$ characteristics at various operating temperatures ranging from 50°C to 200°C is illustrated in Fig. 10. The ohmic conduction is almost missing, and the non-linearity in I - V characteristics dominates almost at all the operating temperatures. We also observe a significant enhancement in the steady state conduction currents (I_s) as compared to pristine samples. This is not surprising owing to the fact that carrier mobility in polymeric materials increases by the introduction of a small molecule such as iodine^[24]. As we have discussed earlier that the aromatic imide rings are the active traps for the iodine molecules in PEI. This results in a charge-exchange complex formation better known as C-T complex. The formation of C-T complexes helps in the increment in electron-hole pair concentration. This gives an overall enhancement to the conduction currents^[23].

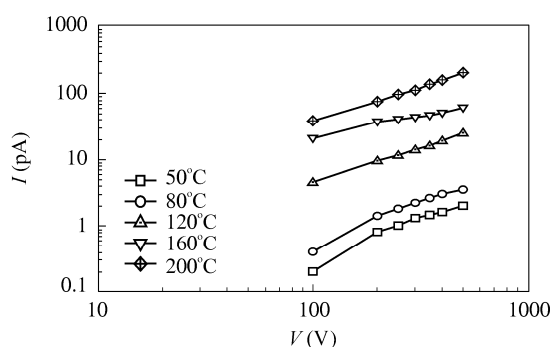


Fig. 10 Field dependence of steady state current ($\lg I$ - $\lg V$) for iodine doped (1% by weight) PEI sample at different temperatures

Surprisingly, the values of ionic jump distance a (estimated using Eq. (2), Table 3) are significantly higher as compared to those of the pristine PEI. This discards the possibility of ionic conduction in doped PEI. The conduction mechanism in doped PEI has also been examined in the light of Schottky or Poole-Frenkel type conduction. The experimental (β_{exp}) and theoretical (β_{th}) values of Schottky coefficients for iodine doped PEI samples have been shown in Table 4. We do not observe $\beta_{\text{exp}} = \beta_{\text{th}}$ at any operating temperature and for any doping concentration. However, in certain cases particularly at high operating temperatures and lower doping concentration we observe that β_{exp} values are nearly twice the β_{th} values. This shows that in doped PEI, though there is no possibility of a Schottky type conduction mechanism but there exists a certain evidence for the occurrence of a Poole-Frenkel type conduction mechanism particularly at high operating temperatures. Interestingly Quamara *et al.* and Garg & Quamara have shown the existence of a Poole-Frenkel type conduction mechanism at high operating temperatures in energetic ion irradiated Kapton-H polyimide^[7, 11]. Radiation-induced defects act as dopants in the polymer matrix. Our results are in conformity with these observations. Either there is a direct doping of foreign molecules (as in present case) or there is an indirect doping of foreign molecules (in case of ion irradiated samples) both of them lead to a Poole-Frenkel type conduction mechanism particularly at higher operating temperatures.

The temperature dependence of steady state conduction behavior of iodine doped PEI samples for different electric fields has been illustrated through representative curves in the form of $\lg I$ versus $1/T$ characteristics.

Unlike in pristine PEI, the $\lg I$ versus $1/T$ plots consist of two straight lines with a break point around 90°C. The activation energy computed from the slopes of these straight lines in the low temperature region (< 90°C) is 0.21 eV whereas in the high temperature region (> 90°C) it is 0.5 eV. The activation energy for 4% and 6% doping concentrations has been given in Table 5. A significant increase in the activation energy in iodine doped samples indicates a strong dependence of conduction currents on temperature. Interestingly the high temperature activation energy shows an increase with increase in doping concentration confirming our observation that iodine is attached to aromatic imide rings with a stereo-specific arrangement.

CONCLUSIONS

The transient and steady state conduction behavior of pristine and iodine doped PEI samples has been studied. The activation energy associated with the zero-field transient currents for pristine samples (0.04 eV) is nearly 10 times less than that for Kapton-H polyimide. The low value of tunneling distance (around 0.5 nm) favors tunneling as a possible mechanism for transient currents in pristine PEI. But in iodine doped samples, the temperature dependence of transient currents discards the tunneling as a possible mechanism. The ionic jump distance estimations do not favor ionic hopping as a steady state conduction mechanism in pristine as well as in doped samples. However, in the higher temperature region (> 120°C) there is a possibility of Poole-Frenkel type conduction mechanism. The dual slope in the $\lg I$ versus $1/T$ curves for iodine doped samples indicates the presence of more than one type of trapping levels. A significant enhancement in the steady state conduction currents in iodine doped samples is due to the formation of charge-exchange complexes. An increase in the activation energy with doping concentration confirms the attachment of iodine to the aromatic imide rings with a stereo-specific arrangement.

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