Electrical Conduction of Polypyromellitimide Films

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ABSTRACT

The electrical conduction of Kapton films of 50 μm thickness was measured under steady-state conditions in temperature range 40 - 200 ℃ and in electric fields of 20 - 100kV/cm. The field dependence of current was analysed by an electronic hopping conduction model. The apparent activation energies were obtained as U_h = 23.4 kcal/mol and U_l = 4.4 kcal/mol at higher and lower temperatures, respectively. Values of the jump distance of 35 – 55 Å show good agreement with those reported by other workers.

INTRODUCTION

Polyimide (PI) films are known to have high thermal stability, strong solvent resistivity and low dark currents. In recent years the photoconductivity of aromatic polyimides including Kapton polyimide, PI(PMDA/ODA), has been noted, arousing interest of electrographic and energy conversion applications[1~6]. In order to exploit this potential it is essential to understand the mechanism of electrical conduction in polyimide films.

Several workers have reported the results of their investigations in this field. But there is no reasonable agreement among them on the type of conduction in Kapton. Many published data claimed ionic conduction for steady-state current in the low field region[7~9]. On the other hand, the positive pressure dependence of conductivity of PI(PMDA/ODA) film was explained by Ye. B. Fainstein et al.[10] as an electronic process.

It was shown by S. Freilich et al.[2] that the mechanism of photocurrent in polyimide film involved excitation of a charge transfer complex, followed by comlete electron transfer.

In this study, the electrical conduction current of a 50 μm thick Kapton at temperatures of 40 - 200℃ is obtained as a function of electric field of 20 - 100kV/cm. An attempt is made to fit the experimental results to the theoretical values for the electronic hopping conduction.

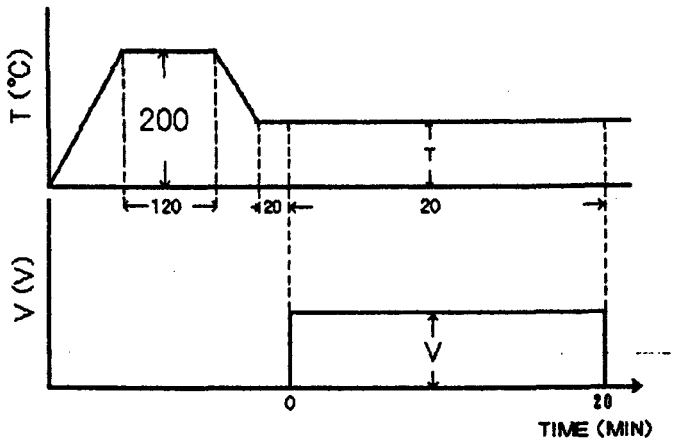


Fig.1. Experimental procedures.

EXPERIMENTAL

2 cm x 2 cm samles of Kapton- H film of 50 μm nominal thickness were used. Gold was evaporated on both surfaces of the film. The sample was heated for 2 hrs at 200℃ and cooled slowly to room temperature. The experimental procedure is shown in Fig. 1. A step voltage was applied to the film 20 min after the temperature T was attained and the electric current was measured using a Takeda Riken TR-84M vibrating reed electrometer. The temperature T was changed in 20 degree steps over the range of 40 - 200℃. All measurements were made in a vacuum of 10^{-2} Torr.

RESULTS AND DISCUSSION

The basic conduction process in the steady-state current of polymers is reflected more directly at an earlier time rather than that at a later stage, since the former suffers to a less extent from the space charges. Then the dependence of the current I on the electric field E was measured at times 40 s at each temperature.

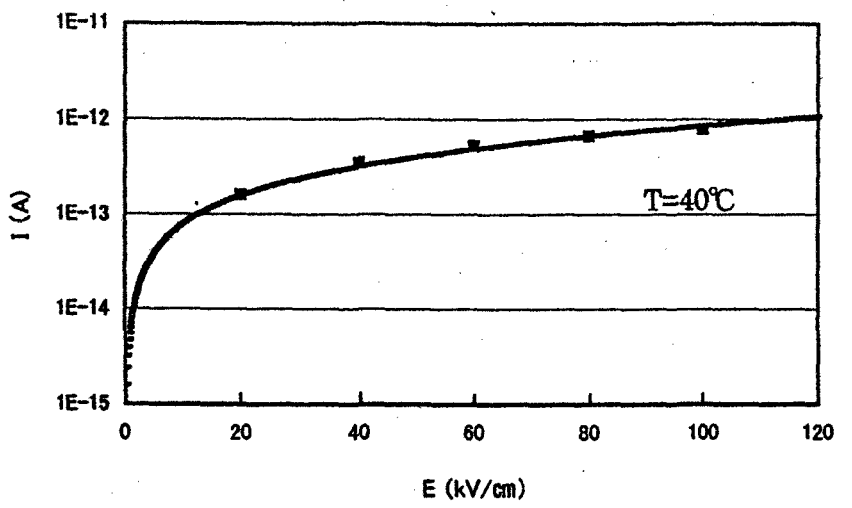
In case of hoping conduction the current I is given as

$$I = 2Sqna\nu e^{-U/kT}\sinh(qEa/2kT) \qquad (1)$$

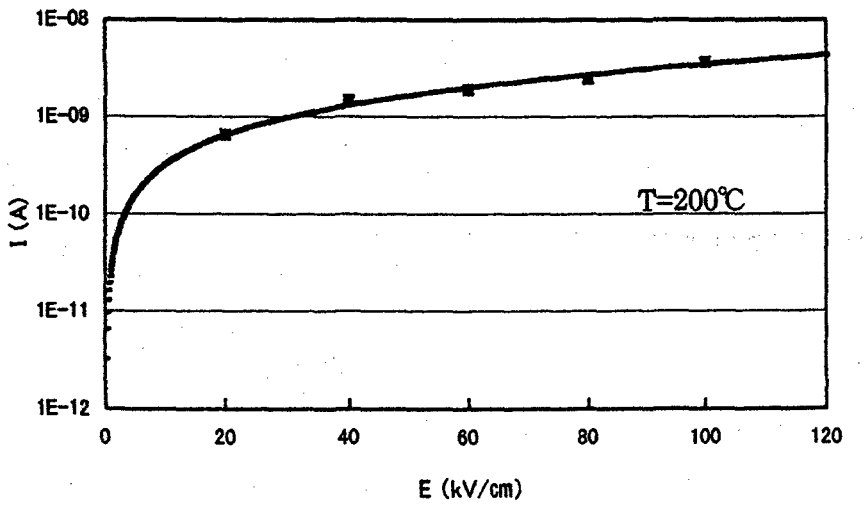
where S is the effective area of electrode, q the charge of carrier, a the carrier jump distance, U the barrier height, k the Boltzman's constant, ν the frequency factor, and T the absolute temperature.

In Fig.2 (a) and (b) are shown the dependence of the current I on the electric field E at times 10s at 40 ℃ and 200℃. The solid line is drawn so as to fit eq. (1) with adjustment of the parameters. The experimental points are in good agreement with the theoretical line.

Table 1 lists the jump distance, a, given by the fitting procedure of Fig. 2. The value of a slightly increases with temperature over a range of 36- 55Å. These values obtained by us agree with those of Sharma et al.[9]. However, the



(a)



(b)

Fig2. The logI-E curves : (a) 40℃ (b) 200℃

Table 1. Jump distance obtained from the logI-E plot of the data.

T(℃)	40	60	80	100	120	140	160	180	200
a(Å)	36	38	41	43	45	47	50	52	55

magnitude of these values seems too large to support ionic conduction, because an ion is a massive carrier which may not travel freely over distances greater than inter atomic ones in polymer. In fact the ionic jump distance computed from the hopping model was reported to be approximately 10 Å for PMMA at glassy region[11]. On the other hand an electron can travel over relatively large distances particularly in a crystal lattice.

Now, eq. (1) can be rearranged as follows:

$$I = I_0 \sinh(qEa/2kT) \qquad (2)$$

where

$$I_0 = 2Sqna\,\nu\, e^{-U/kT}$$

The value I_0 in eq. (2) can be obtained from the same fitting procedure as in Fig. (2).

The values of I_0 are shown as a function of reciprocal temperature in Fig. (3). It can be seen from Fig. (3) that the slope changes critically at about 120 ℃. The apparent activation energies are obtained from Fig. (3) at higher and lower temperatures as U_h = 23.4 kcal/mol and U_l = 4.4 kcal/mol, respectively. Our present data of U_h agree closely with one obtained by G. Sawa et al[8] in the corresponding temperature range.

Voishchef et al.[12] reported that the electrical conductivity of PI(PMDA/ODA) has an intrinsic character with an apparent activation energy of about 30 kcal/mol at high temperatures (T > 200℃) and is mainly contributed by contaminants at T ≦200℃. But the temperature dependences of the conductivity showed little change at T = 200℃ in their data. The results demonstrated in Fig. 3 may rather explained in terms of an intrinsic character in nature over all temperature ranges from 40℃ to 200℃.

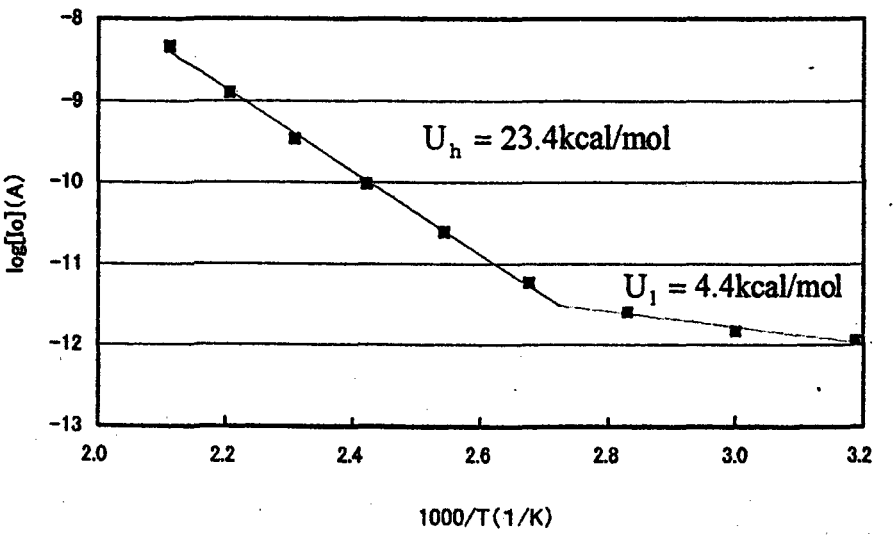


Fig3. Extrapolated zero-field current I_0 as a function of temperature.

Our experimental results for PI(PMDA/ODA) seem to favor the electron conductance which proceeds by intermolecular charge- transfer complexes. The exceedingly small mobility of PI polymer chains may, in general, hinder ionic mobility. Further, there is a need to study photoconduction phenomena in this material.

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