OBSERVATION OF INTERNAL CHARGE BEHAVIOR OF E-BEAM IRRADIATED POLYMERS USED ON SPACECRAFTS DURING ELEVATING TEMPERATURE

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Abstract

Since polymeric materials have many superior properties, they are inevitable materials for the spacecrafts. The space environment, however, is so severe for the spacecrafts because the temperature changes drastically from -150 to 120 °C and the high energy charged particles are scattered. The polymers sometimes have serious damage by irradiation of high energy charged particles. When the polymers of the spacecrafts are irradiated by high energy charged particles, some of injected charges accumulate and remain for long time in the bulk of the polymers. Since the bulk charges sometimes cause the degradation or breakdown of the materials, the investigation of the charging and decay processes in the polymeric materials at various temperatures are important to decide an adequate material for the spacecrafts. In this report, we observed the decay processes of accumulated charge in e-beam irradiated polymers, such as Polyimide or Polystyrene, during elevating temperature using pulsed electro-acoustic method.

Introduction

The polymeric materials used for the spacecraft are demanded a stable performance in a severe environment, such as temperature change from -150 to 120 °C under irradiation of high energy charged particles with energy of a few keV-MeV. Since there were few methods to observe the charge distributions in the irradiated polymeric materials by charged particle, it had been difficult to analysis about, so-called "internal charge" phenomena. Therefore, we have been developing the measurement system using pulse electro-acoustic (PEA) method [1] to observe the charge distributions in dielectric materials under charged particle irradiation. Consequently, we have some significant results about the "internal charge" accumulated in polymeric materials by an irradiation of the high energy electron beam (e-beam). Since, the measurement, however, have been carried out at room temperature, the dependence of the internal charging on a change of temperature have not been clear yet. Fortunately, we had an experience to measure the charge distribution at high temperature using an originally developed system [2], so that we could applied the system to observe the decay processes of accumulated charge in the e-beam irradiated polyimide during elevating temperature [3]. Using the system, we can not measure only charge distribution in polymeric materials during elevating temperature, but we can also measure the external current, which is, so-called, thermally stimulated current (TSC), simultaneously. Since the simultaneous measurement of PEA and TSC makes it possible to calculate the conduction current during the decay process, we can analyze the details of the decay processes [2]. In this report, we have observed the decay processes of the accumulated charge in the e-beam irradiated polyimide and polystyrene. The polystyrene is said that its performance against the irradiation is superior to the polyimide [4].

Principle of PEA Method and TSC

Figure1 shows the principle of the PEA method. The PEA is one of convenient methods to measure the internal charge

in polymers. A schematic diagram for the principle of the PEA is shown in Fig.1. In this figure, the sample including the internal negative charge is put between a lower and an upper electrode. The electrodes are grounded, so that the positive charge are induced at the interfaces between the sample and the electrodes. When an external pulsed electric field $e_p(t)$ is applied to the sample, a perturbation force is induced on each charge. Then, this force generates an acoustic pressure wave which is proportional to the charge density. The acoustic wave propagates and it is detected by a piezoelectric transducer. By measuring the transformed electric signal continuously, we can observe the charge distribution.
Figure2 shows a diagram for the principle of the thermally stimulated current (TSC). When we elevate the temperature of the sample including trapped charges, the movements of the activated charges by thermal energy make a current of external circuit. The external current, which is so called TSC, is composed of a displacement and conduction currents. Since the displacement current in the sample is due to the time differential of the electric field, we can calculate it from the time dependent charge distribution measured using the PEA system. The details of the principle are described elsewhere [2].

Measurement system

Figure 3 shows the developed PEA system for simultaneous measurement of the TSC and the internal charge distribution in polymeric material. Since the internal charge distribution is measured by applying the high voltage narrow pulse to the sample, the electrode is connected with a pulse generator. The temperature of the sample is controlled from room temperature to 150 °C using an electric band heater put on the upper electrode unit. The temperature of the sample is measured by a thermocouple inserted into silicon oil in which the sample is immersed. To obtain the internal charge distribution in the sample at the high temperature, a piezoelectric transducer of $LiNbO_3$ crystal, which has a stable sensitivity at high temperature [3], is used in the PEA system as a signal detector. In this system, an external circuit current is also measured using a digital electrometer to calculate the conduction current. To obtain all data automatically, the pulse generator, the temperature controller and a digitizing oscilloscope are controlled using a personal computer. Details of the measurement principle are described elsewhere [3].

Experimental Condition

The samples used in the experiments are commercially available Polyimide and Polystyrene films with thicknesses of 125 and 250 μm, respectively. The e-beam irradiation was carried out with an acceleration energy of 70 keV for 10 or 600 seconds in vacuum at room temperature. Table 1 shows the condition of the e-beam irradiation. The TSC of the e-beam irradiated sample was measured in air atmosphere by increasing the temperature under short circuit condition from room temperature to 120 °C with a rate of one °C/min.

Table 1: conditions of electron beam

Irradiation conditions	Unit	
Acceleration voltage	keV	70
Electron current	mA	0.06
Irradiated time	sec	10
		600

Results and Discussion

Charge distributions

Figures 4 and 5 show the internal charge and the electric field distributions in the e-beam irradiated polyimide and polystyrene films, respectively. We observed the charge decay processes for the sample which are irradiated by e-beam for 10 and 600 seconds. So, in those figures, the results obtained from the samples irradiated by e-beam for 10 and 600 seconds are shown in (a) and (b), respectively. The samples were irradiated by the e-beam from right side in each figure. As show in Fig.4 (1-a), the injected electron accumulates in the middle of the sample (peak A). When the irradiation period becomes longer, we can observe the obvious change of the charge distribution. As shown in Fig.4 (1-b), it is not only found the negative charge (peak B), but it is also found the positive charge (peak C). It seems when the irradiation period is longer, the positive charge appear in the bulk of the polyimide film. The reason why the positive charge

appears with longer e-beam irradiation time has not been clear yet. It maybe, however, thought that the longer irradiation period makes the possibility of the ionization higher. The electric field distributions are also different between samples irradiated for 10 and 600 s. In polyimide irradiated for 10 s, the maximum electric field in the sample is shown near the irradiated surface of the sample as shown in Fig.4 (2-a). On the other hand, that in the sample irradiated for 600 s, the maximum electric field is located at the middle of the sample. In the case of polystyrene, only negative charge accumulation was observed in the sample irradiated for both 10 and 600 s. Besides, there are smaller amount of negative charge in polystyrene than that in polyimide.

Decay processes of the injected charges

Fig.6 shows the TSC curves obtained by measuring the external current during elevating temperature of e-beam irradiated samples. We calculated the conduction currents from those results. Details of the calculation of the conduction current are described elsewhere [3]. Figures 7 and 8 show the (a) decay processes of the charge distribution and the (b) temperature dependent conduction current distributions during elevating temperature in the polyimide films irradiated by e-beam for 10 and 600 s, respectively. Figures 9 and 10 also show them in polystyrene films irradiated by e-beam for 10 and 600 s, respectively. The temperature dependent conduction current distributions are displayed using gray scales. In those figures of (b), the positive current stands for the current flow from left to right side in the figures. Therefore, when the conduction current is positive, the negative charge moves from right to left side in the figure if the carrier of the conduction current is negative charge. In the gray scale mapping, the vertical and the horizontal axes show the temperature and the position in the sample, respectively. For example, as shown in Fig.8 (b) it is found that the large negative conduction current at the middle of the sample during elevating temperature. The position of the large current observed in the figure is corresponding to the position of both negative and positive charges are observed closely each other as show in Fig.8 (a). Therefore, the carriers of the conduction current are assumed as both negative and positive charges. In other words, the conduction currents should be composed of the movements of the negative and the positive charges drifting the right and left side, respectively. It seems to be reasonable that the released negative and/or positive charges by increase of the temperature should move along the electric field shown in Fig.4 (2-b). On the other hand, the carriers of the internal charge distributions in other samples should be only the negative charge. With increase of the temperature, the negative charges moved towards both side. In the case of polystyrene irradiated for 10 and 600 s, as shown in Figs.9 (b) and 10 (b), the conduction current is not conspicuous in temperature between 30 and 60 °C. It means the accumulated charge hardly moves between 30 and 60 °C. When the temperature exceeded 60 °C, the negative and the positive conduction currents were observed at right and left hand sides, respectively. It means that the released negative charges by increase of temperature moves towards the both electrodes. From the results, it is found that no remarkable positive charge was observed even when the polystyrene was irradiated by e-beam for long period. It is said that the benzene ring included in polystyrene absorbs the energy of the scattered electrons. That may be the reason why the positive charge is not generated in polystyrene. As shown in above, the details of the movement of each carrier is observable using this technique. Further details of analysis about the movement of charges would be shown in the future.

References

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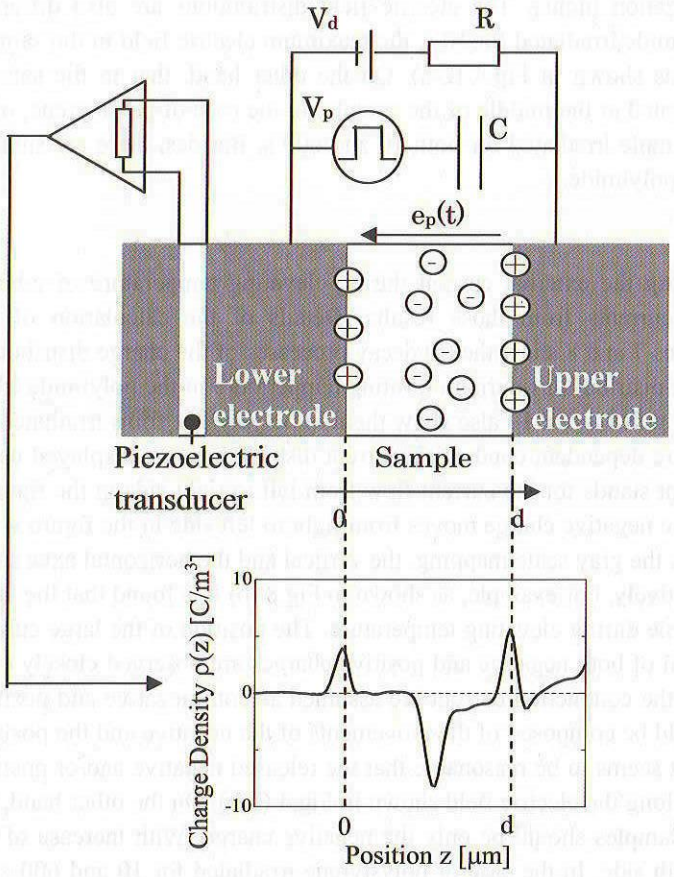

Fig.1 Principle of the PEA method

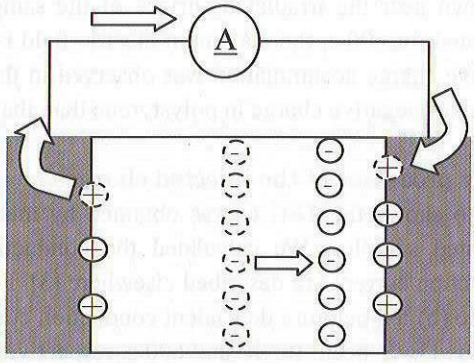

Fig.2 Principle of thermally stimulated current (TSC)

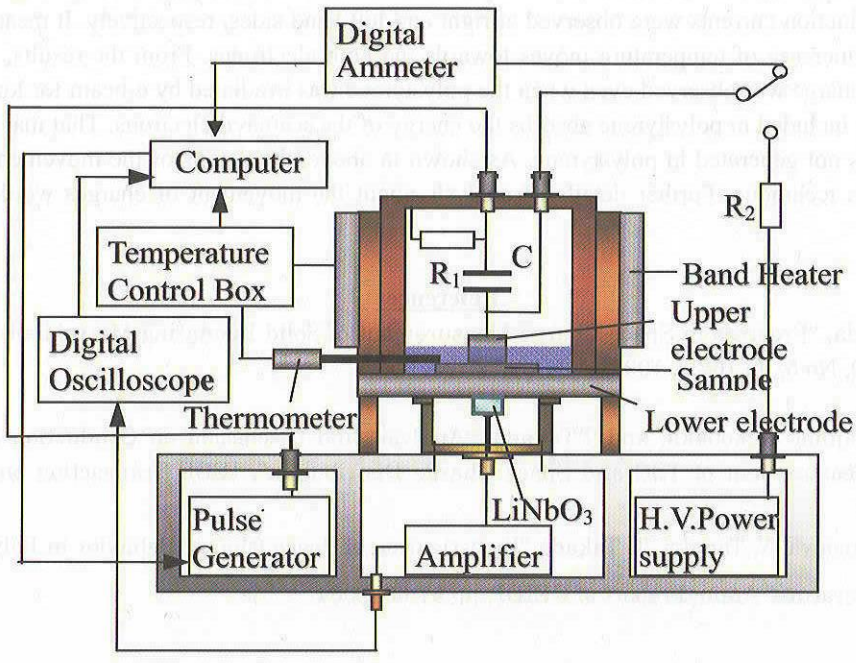

Fig.3 Measurement system for internal charge distribution during elevating temperature

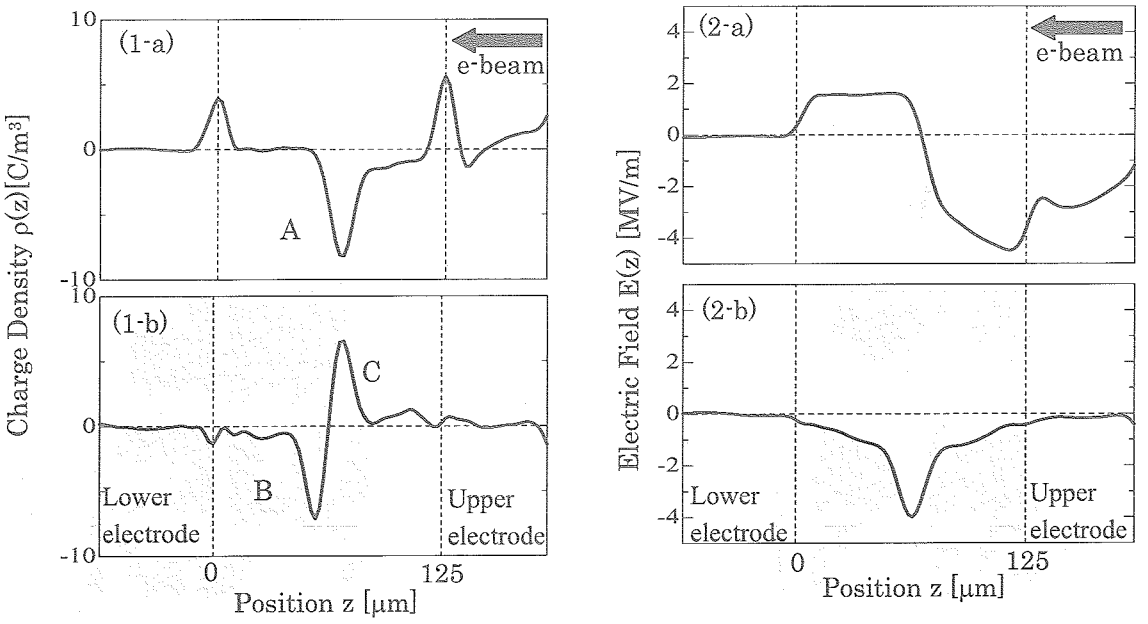

Fig. 4 Charge (1) and electric field (2) distributions in e-beam irradiated polyimide film for (a) 10, and (b) 600s, respectively.

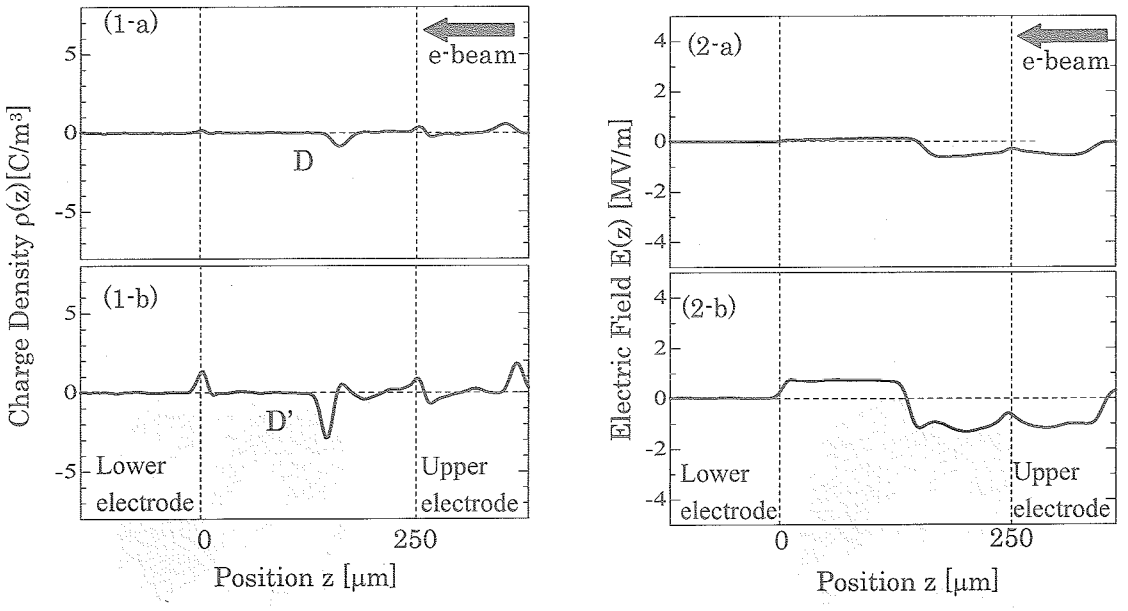

Fig.5 Charge (1) and electric field (2) distributions in e-beam irradiated polystyrene film for (a) 10, and (b) 600s, respectively.

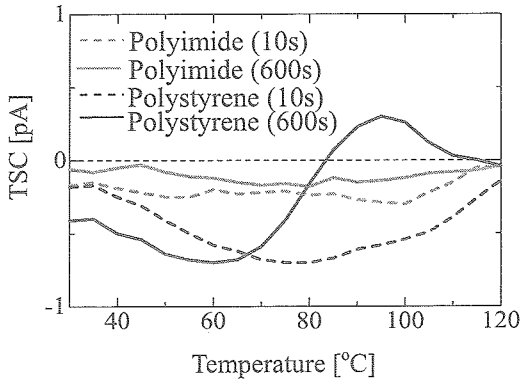

Fig 6. TSC curves obtained by measuring the external current during elevating temperature of e-beam irradiated samples.

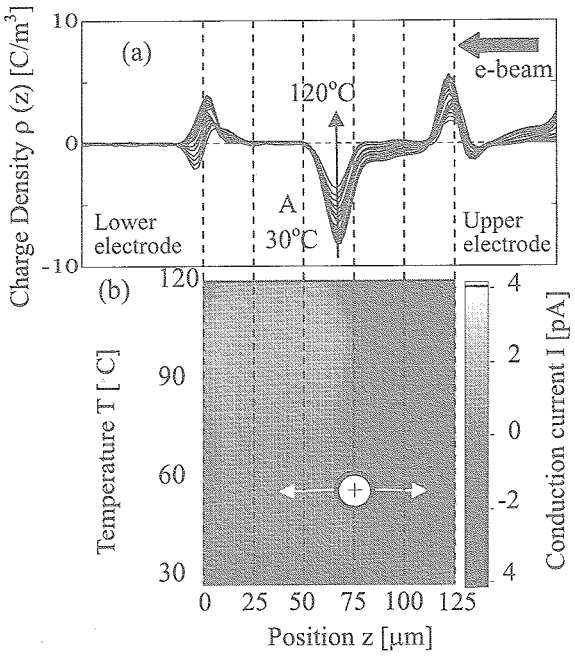

Fig.7 Temperature dependent (a) the charge and (b) the conduction current distributions in polyimide film irradiated by e-beam for 10s.

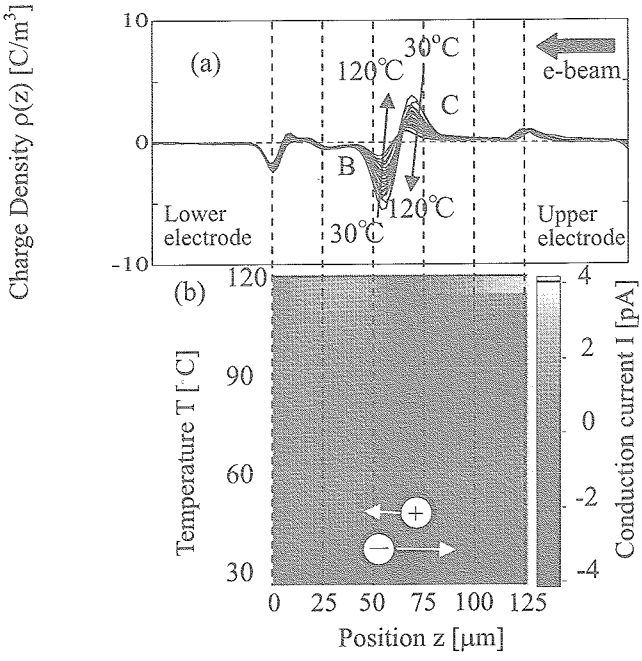

Fig.8 Temperature dependent (a) the charge and (b) the conduction current distributions in polyimide film irradiated by e-beam for 600s.

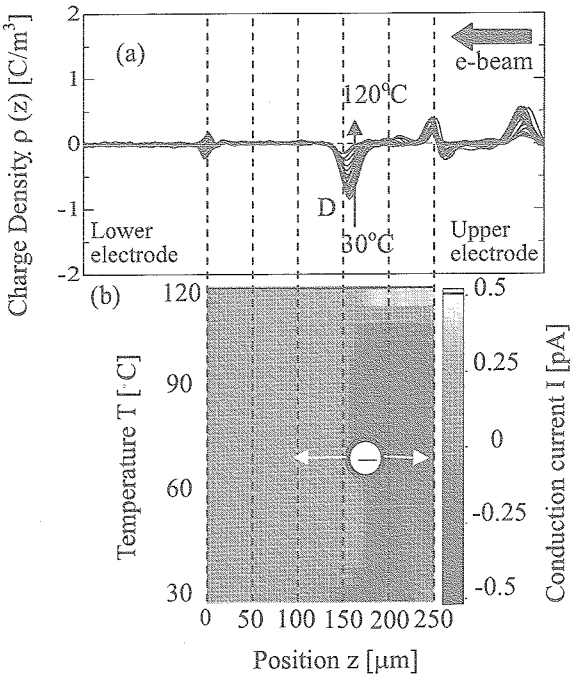

Fig.9 Temperature dependent (a) the charge and (b) the conduction current distributions in polystyrene film irradiated by e-beam for 10s.

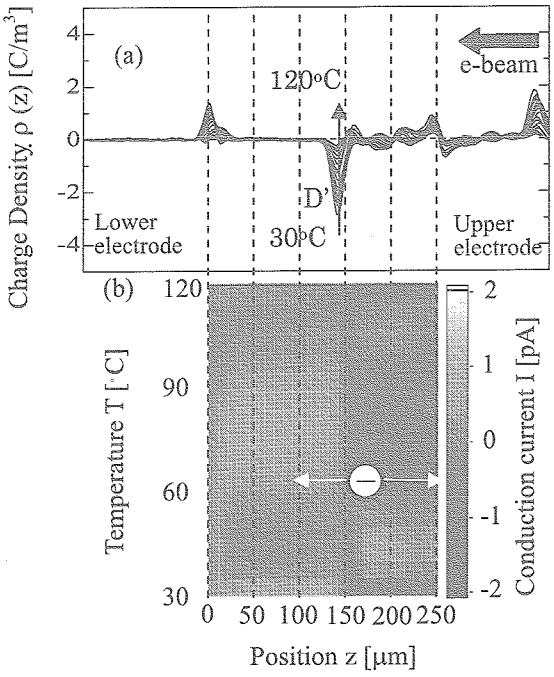

Fig.10 Temperature dependent (a) the charge and (b) the conduction current distributions in polystyrene film irradiated by e-beam for 600s.