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전자빔 조사 폴리머의 전자 분포의 축퇴 과정

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Decay Process of Charge Distribution in E-beam Irradiated Polymers

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Abstract : Decay processes of accumulated charge in e-beam irradiated polymers during elevating temperature are observed using pulsed electro-acoustic measurement system. Since the polymeric materials have many superior properties such as light-weight, good mechanical strength, high flexibility and low cost, they are inevitable materials for spacecrafts. In space environment, however, the polymers sometimes have serious damage by irradiation of high energy charged particles. When the polymers of the spacecraft 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 the decay processes in polymeric materials under change of temperature is important to decide an adequate material for the spacecrafts. By measuring the charge behavior in e-beam irradiated polymer, such as polyimide or polystyrene, it is found that the various accumulation and decay patterns are observed in each material. The results seem to be useful and be helpful to progress in the reliability of the polymers for the spacecraft.

Key Words : Decay processes, E-beam irradiated polymer, Eelevating temperature, Electro-acoustic measurement system

1. Introduction

The polymeric materials used for the spacecraft are demanded a stable performance in the environment of temperature change from -120 to 150 oC under irradiation of high energy charged particles. 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". 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 the 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 temperature change have not been clear yet. Fortunately, we have an experience to measure the charge distribution at high temperature using an originally developed system [2], we have 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 accumulated charge in e-beam irradiated polyimide and polystyrene. The polystyrene is said that its performance against the irradiation is superior to the polyimide [4].

2. Experimentals

Measurement system Figure 1 shows the PEA system for measurement of the space charge distribution in polymeric materials. Since the space 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 ℃ using the electric band heater put on upper electrode unit.

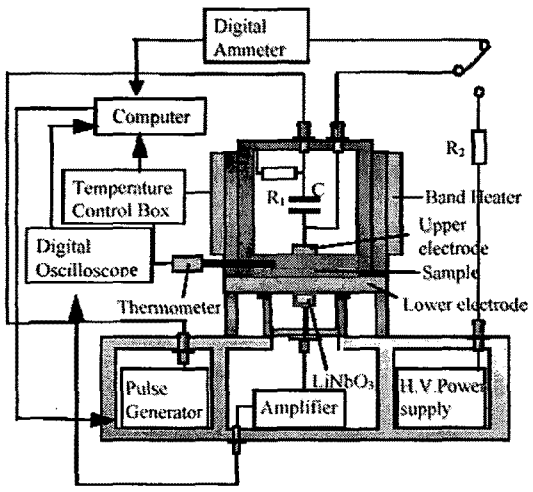

Fig. 1. Measurement system for space charge distribution during elevating temperature.

Since the space 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 ℃ using the electric band heater put on 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 space charge distribution in the sample at the high temperature, the 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 the 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 measurement principle are described elsewhere [1-2].

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 the 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 e-beam irradiated sample was measured in air atmosphere by increasing the temperature under short circuit condition from room temperature to 120 ℃ at a rate of one ℃/min.

3. Results and Discussion

Figures 2 shows the space charge and the electric field distributions in e-beam irradiated polyimide and polystyrene films, respectively. We observed the charge decay processes for 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 with (a) and (b), respectively. The samples were irradiated by e-beam from right side in each figure. As show in Fig. 2 (1-a), the injected electron (peak A) accumulates in the middle of the sample. When the irradiation period becomes longer, we can observe the charge distribution changed obviously. As shown in Fig. 2 (1-b), it is not found only the negative charge (peak B), but it is also found the positive charge (peak C). It is assumed that when the irradiation period is longer, the positive charge come appear in the bulk of the polyimide film. The reason why the positive charge appears with longer e-beam irradiation has not been clear yet. It maybe, however, thought that the longer irradiation period makes the possibility of the ionization higher.

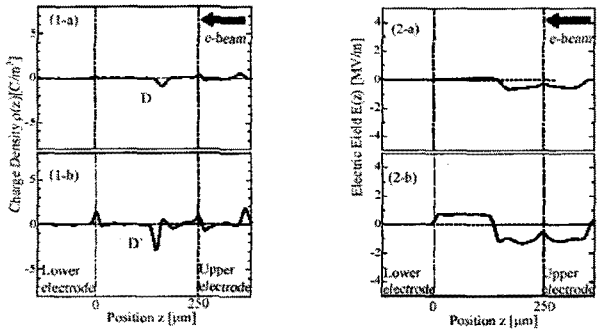

Fig. 2. Charge (1) and electric field (2) distributions in e-beam irradiated polyimide film for (a) 10, (b) 600s, respectively.

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 near irradiated surface of the sample as shown in Fig. 2 (1-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. The charge and the electric field distribution patterns in this sample are similar to those observed in polyimide as shown in Fig. 2 (1-a) and (1-a).

Fig. 3 shows 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. Fig. 4 also shows 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 Fig. 3 (b), the positive current stands for the current flow from left to right side in 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.

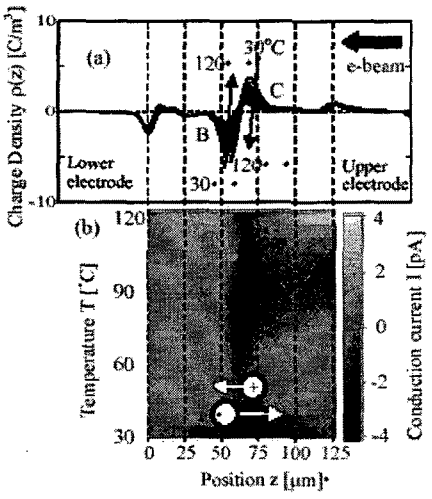

Fig. 3. Temperature dependent (a) the charge and (b) the conduction current distributions in polyimide film irradiated by e-beam for 10s.

For example, as shown in Fig. 3 (b) it is found that the large negative conduction current was observed 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 as show in Fig. 3 (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 negative and positive charges drifting the right and left side, respectively. It seems to be reasonable that the released negative and positive charges by increase of the temperature should move along the electric field shown in Fig. 2 (1-b). On the other hand, the carriers of the space 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 Fig. 4 (b), the conduction current is not conspicuous in temperature between 30 and 60 ℃. It means accumulated charge hardly move between 30 and 60 ℃. When the temperature exceeded 60 ℃, the negative and the positive conduction currents were observed at right and left hand sides, respectively.

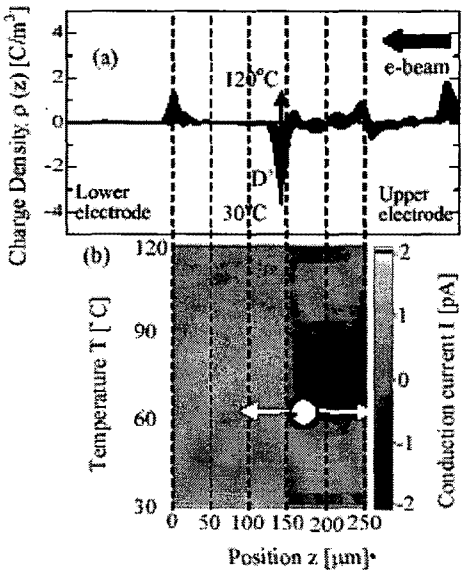

Fig. 4. Temperature dependent (a) the charge and (b) the conduction current distributions in polystyrene film irradiated by e-beam for 10s.

4. Conclusion

From the results, it is found any remarkable positive charge was not 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 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 are observable using this technique. Further details of analysis about the movement of charges would be shown in future.

감사의 글

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(References)

[1] Y.Li and T.Takada, "Progress in Space Charge Measurement of Solid Insulating Materials in Japan", IEEE EI Magazine, Vol.10, No.5, pp.16-28, 1994.

[2] H.Kitajima, Y.Tanaka, M. Kodaka, T. Takada "Dielectrics and Electrical Insulation", IEEE Transactions on, Vol.5, Issue:6, pp952-956, Dec. 1998.

[3] S. Sato, S. Yanagisawa, Y. Tanaka, T. Takada "Investigation of Space Charge Behavior in Polyimide film during Elevating Temperature" Annual report of CEIDP, pp.57-60, Oct, 17-20, 2004.

[4] A.C Trribble "The space environment", Princeton Univ. Pr,1995.