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Effect of Gamma Radiation on Charge Storage in PTFE Exposed to Electron Beam

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Abstract- In this work, we focus our attention on data obtained from Pulse Electro Acoustic (PEA) measurements on PTFE films before and after irradiation with a ⁶⁰Co gamma radiation source. At first, samples are just polarized to determine the effect of the gamma irradiation on the charge transport in the bulk. In a second stage, these films have been exposed to a mono-energetic electron beam. The aim is to study the effect of gamma radiation on charge storage in the bulk.

Keywords- Gamma-irradiation, Polytetrafluoroethylene, Electron beam irradiation.

I. INTRODUCTION

Polytetrafluoroethylene (PTFE) is commonly used as electrical insulation in a variety of disciplines in aerospace engineering [1]. It may be exposed to different radiation sources, among them ionizing radiation such as Gamma rays and electron irradiation are considered. The polymer may be degraded by ionizing radiation, through mechanisms such as chain scission, cross-linking, and oxidation [2].

Several studies have indicated that the radiation-induced structural changes may dramatically affect the molecular structure [3-4], which may change its electrical properties over time. Irradiation of polymers may have an effect on the electrical behavior resulting in the trapped charges being stored inside the polymer [2, 5].

Much research has been conducted on PTFE under electron irradiation. This kind of polymer has been shown to be able to store charges for a prolonged period of time [6, 7]. In this study, we investigate the effect of gamma radiation on charge storage in PTFE exposed to the electron beam. Samples are exposed to gamma radiation in the presence of oxygen and then analyzed by PEA measurements. Then they were subjected to electron beam irradiation under vacuum. In this work, we have selected a single thickness of 200 μm PTFE of the polymeric film, which is better, suited for Pulsed Electro-Acoustic (PEA) measurements.

II. SAMPLES AND EXPERIMENTAL SET-UP

A. PTFE samples.

Commercially available PTFE films (provided by Good fellow) were chosen for this set of experiments.

B. Gamma and electron beam irradiation

The samples were irradiated in air and at room temperature with a ⁶⁰Co gamma radiation source at a dose rate of around

22 Gy/min. The gamma radiations are expected to cross the samples uniformly.

Since PTFE samples can store charges for long periods of time after electron beam irradiation [8], they were chosen for these measurements. In order to deposit charges in the bulk, all PTFE samples have been irradiated for 4 min to an electron beam with an energy of 100 keV and a flux of 1 nA/cm².

C. Space charge measurements.

PEA measurements were performed using the classic PEA set-up [9]. Experiments were carried out at room temperature and atmospheric pressure. Pulse voltages of 250 V amplitude, 8 ns duration, and pulse frequency of 2 kHz were applied. The space charge profiles were recorded every 60 s. Test samples were electrically stressed under 40 kV DC for 1 hour with increasing rates of 1 kV/mm/s, followed by 1 hour relaxation.

III. EXPERIMENTAL RESULTS AND DISCUSSION

A. Space charge distribution profiles of virgin sample:

To investigate the effect of irradiation on space charge formation in PTFE, the space charge profile was initially recorded on a non-irradiated sample every 1 min. Fig. 1 shows the charge distribution in the virgin sample after 1 hour of polarization at 40 kV/mm.

It can be seen that a small amount of negative charges are still detected close to the cathode when an electric field of 40 kV/mm is applied and we can consider them insignificant.

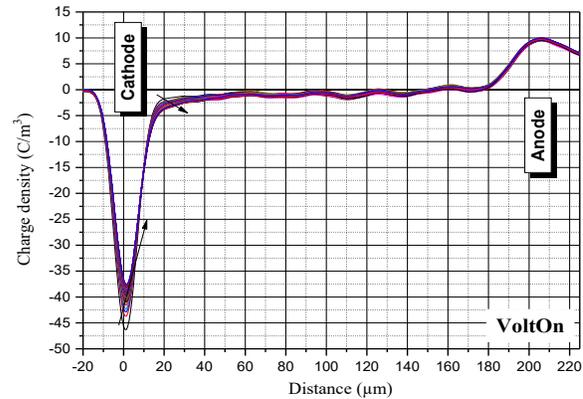


Fig. 1 Charge density recorded by the classic PEA set-up in a 200 μm -thick PTFE virgin sample, during 1 hour of polarization under 40 kV/mm, at room temperature.

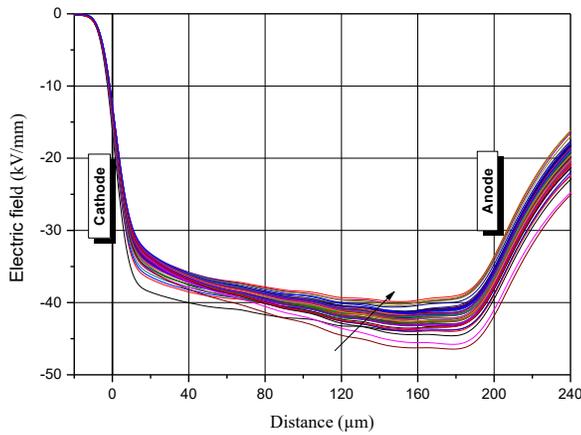


Fig. 2 Electric field distribution recorded by the classic PEA set-up in a 200 μm -thick PTFE virgin sample, during polarization under 40 kV/mm.

Despite the fact that an electric field is applied. However, there was no charge injection in the bulk of the sample.

The distribution of the electric field of the virgin sample in Fig. 2 shows that, as the charge time increases, the electric field decreases slightly in the bulk, during polarization. The local electric field appears to be evenly distributed throughout the depth of the sample. As expected, the value of the local electric field stabilizes within the limits of the applied electric field 40 kV/mm.

B. Space charge profiles of PTFE irradiated with an electron beam.

The PEA space charge profile (Fig. 3) was recorded after 4 minutes of electron beam irradiation with 100 keV energy and a flux of 1 nA/cm^2 . A negative peak due to the injected electrons is detected far from the irradiated surface. The maximum amount of negative charge is detected approximately 83 μm from the irradiated surface.

We can also notice the presence of some negative charges near the cathode that are still detected, as in Fig. 4 Also, at both boundaries, two positive charge peaks of induced charges can be seen (The abscissa 0 and 206 μm). The positive peak at 206 μm is relatively wide and weak as the majority of the positive charges are close to the opposite contact at 0 μm .

Another cluster of positive charges is detected at about 25 μm from the irradiated surface. The reason for the emergence of positive charges is probably due to the formation of electron-hole pairs during the electron beam irradiation in a vacuum.

It should be noted that the PEA space charge profile does not evolve over time and the positive and negative charges are likely to remain in traps for a long time within the PTFE sample.

The charge profile under polarization (40 kV/mm) on a PTFE sample submitted to a 100 keV electron beam is shown in Fig. 4. The approximate electron penetration depth in the PTFE is clearly observed at 83 μm where a negative peak of

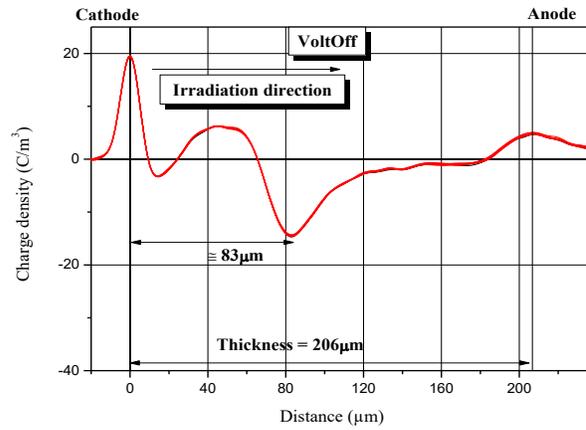


Fig. 3 Charge density in 200 μm -thick PTFE sample without polarization (Volt-Off) after irradiation, under 100 keV electron beam for 4 min with a flux of 1 nA/cm^2 . Always irradiated face to the left.

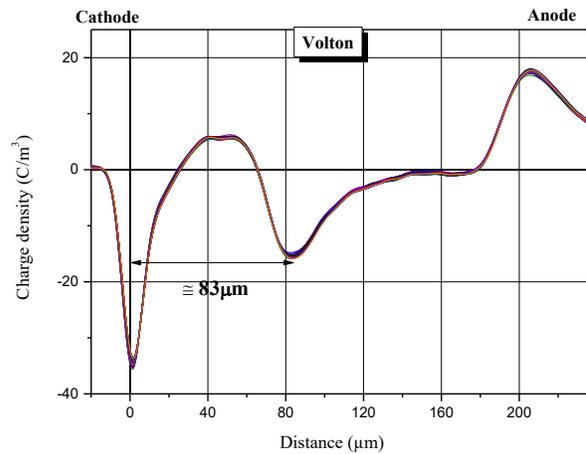


Fig. 4 Charge density in 200 μm -thick PTFE sample after irradiation, under 100 keV electron beam for 4 mins with a flux of 1 nA/cm^2 .during 1 hour of polarization (Volt-On) at 40 kV/mm.

charges is detected. The charges are not affected by the polarization and are still clearly detected during the relaxation. This could be explained by the strong electronegativity of the fluorine atoms, which traps the charges inside the PTFE. The behavior of space charge after removing the applied voltage remains identical.

C. Space charge profiles of PTFE irradiated with Gamma rays before the electron beam irradiation.

The charge density profile in a 30 kGy irradiated sample by gamma rays under polarization for 1 hour at 40 kV/mm is shown in Fig. 5. Space charge features on a gamma irradiated sample showed a significant amount of negative and positive heterocharges when an electric field is applied. It seems that charge injection starts instantaneously when an electric field of 40 kV/mm is applied. Negative charge injection is initially

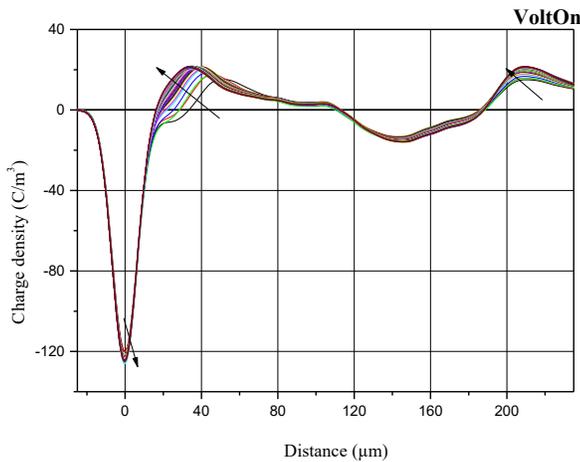


Fig. 5 Charge density profile recorded in 100 kGy irradiated sample during polarization for 1 hour at 40 kV/mm.

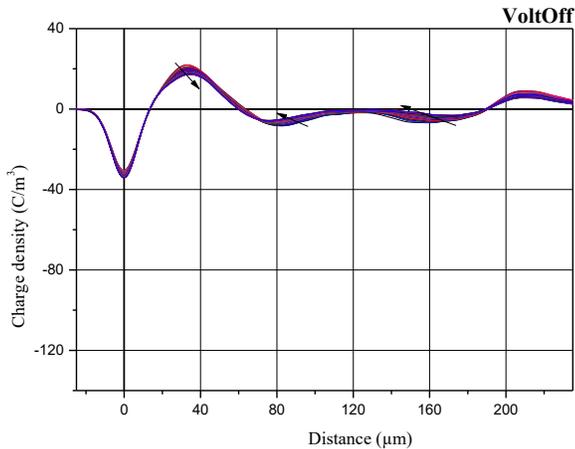


Fig. 6 Charge density profile recorded in 30 kGy irradiated sample during relaxation for 1 hour.

more powerful, where it is relatively stable towards the anode. Then the positive charges rapidly spread towards the cathode. As result, the electric field at the cathode increases dramatically, which leads to an increase in injection from the cathode [2, 10].

The appearance of heterocharges charges during polarization in gamma-irradiated PTFE and the accumulation of positive charges near the cathode in a short period (time of the electric field ramp = 40 s) is a completely new behavior compared to virgin PTFE. This significant change in space charge profiles is clearly associated with newly formed charge carriers, which is attributed to the effect of gamma-ray energy absorbed in the sample by increasing the electrical conductivity.

After removing the applied voltage for 1 hour, as shown in Fig. 6 Space charge distributions in Gamma irradiated PTFE obtained with the PEA method are significantly different from those in the polarized case. Negative charges decay rapidly at the first quantitative measurements of PEA, accompanied by a displacement towards the cathode, and the positive peak maintains the same maximum values of charge density. It is

worth noting that the positive charges are much narrower in the bulk of the sample than in the case of polarization. Besides, the space charge profile is slightly decreasing over time. Another feature is the change in the conductivity of the material. Resulting in the displacement of negative charges in the bulk of the sample under the influence of its own electric field, the charge could either move inside the sample or recombine [2]. It is possible to argue that 1 hour of relaxation is insufficient to dissipate all of the charges present in the bulk of the sample.

D. Charge profile of PTFE irradiated by gamma rays then by electron beam.

The same experiment was carried out on a sample that had previously been exposed to gamma rays with a dose of 30 kGy. Charge profiles were measured immediately after four minutes of electron beam irradiation with 100 keV energy (flux of 1 nA/cm^2), in this case as well. The difference in charge buildup between the virgin and gamma-irradiated samples is significant (Fig. 7). We notice that the electrons injected by the electron beam irradiation are not stored in the bulk as in a virgin sample (see fig. 3). This is mainly due to the presence of a small amount of negative charge at the tips of the electrodes rather than within the bulk as in the virgin sample. It is believed that the injected charges from the electron beam irradiation directly cross the depth of the sample. This is due to intrinsic modifications to the chemical structure of a sample due to gamma irradiation. It is clear that the space charge distribution under polarization of (electron beam +Gamma) irradiated sample shown in fig. 8 is similar to the Gamma irradiated sample under polarization (see Fig. 5).

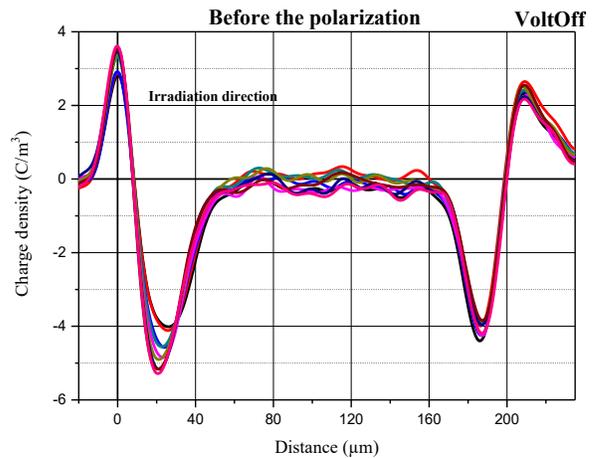


Fig. 7 Charge density profile recorded in a 100 kGy radiating sample on Volt-Off, under a 100 keV electron beam for 4 mins with a flux of 1 nA/cm^2 .

Heterocharges appear during polarization on both sides. Positive charges seem to accumulate and increase over time near the cathode. Negative charges are apparently more stable over time near the anode. The same behavior was observed in absence of electron irradiation. However, the peaks amplitude

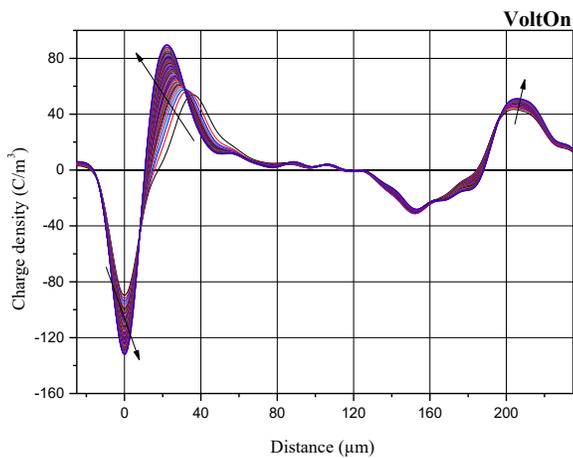


Fig. 8 Charge density profile recorded in (EB + Gamma) irradiated sample during polarization for 1 hour at 40 kV/mm.

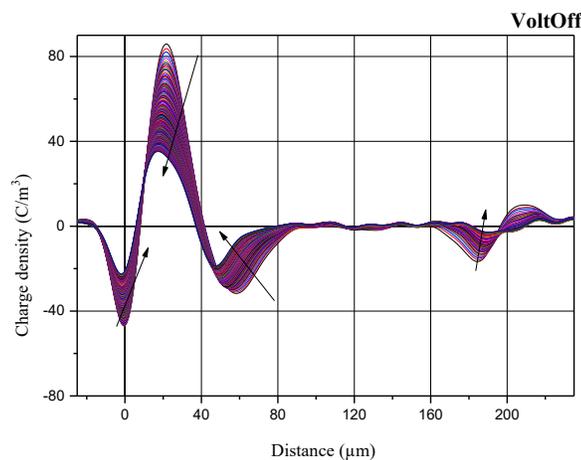


Fig. 9 Charge density profile recorded in (EB + Gamma) irradiated sample during relaxation for 1 hour.

are far more important after the electron injection in the irradiated area. The addition of electron beam irradiation to gamma irradiation results in more charge being injected into the bulk when an electric potential is applied. This observation shows that the electronic irradiation creates in the bulk of the sample some modifications in favor of charge mobility. As expected, the amount of the injected charge decreases immediately after the removal of the applied voltage and its decay with time is very fast, as shown in Fig 9.

One minute after removing the applied voltage, the majority of the charge in the bulk decreases due to recombination with the positive charge or conducting away from the sample. It can be seen that after an hour of relaxation, the charge decays rather quickly, resulting in a considerable drop in bulk charge. The difference in charge distribution among virgin and Gamma irradiated samples may indicate different chemical changes induced by Gamma irradiation. Especially in the presence of oxygen, which plays an important role in the degradation and change of the structure of the polymer [8]. As a result, the nature of the electrical conductivity changes or improves.

IV. CONCLUSION:

The space charge profiles of virgin material and PTFE treated with gamma rays in the presence of oxygen show significant variations. The irradiation by gamma rays is clearly required for a considerable quantity of space charge to develop under polarization. However, with adding the electron beam irradiation, there is no charge deposited in the bulk and the quantity of positive and negative charge rises during the polarization.

The structural changes occurring within the PTFE are obviously a result of how space charge distributions change with dosage and irradiation settings.

The increase in electrical conductivity of PTFE caused by gamma irradiation might be linked to the behavior seen after removing the applied voltage, which resulted in a decrease in the quantity of space charge due to recombination with positive charge or conducting away from the sample.

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