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Dielectric response of makrofol-KG polycarbonate irradiated with 145 MeV Ne⁶⁺ and 100 MeV Si⁸⁺ ions

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Abstract : The passage of heavy ions in a track detector polymeric material produces lattice deformations. These deformations may be in the form of latent tracks or may vanish by self annealing in time. Heavy ion irradiation produces modifications in polymers in their relevant electrical, chemical and optical properties in the form of rearrangement of bonding, cross-linking, chain scission, formation of carbon rich clusters and changes in dielectric properties *etc.* Modification depends on the ion, its energy and fluence and the polymeric material. In the present work, a study of the dielectric response of pristine and heavy ion irradiated Makrofol-KG polycarbonate is carried out. 40 μm thick Makrofol-KG polycarbonate films were irradiated to various fluences with Si⁸⁺ ions of 100 MeV energy from Pelletron at Inter University Accelerator Centre (IUAC), New Delhi and Ne⁶⁺ ions of 145 MeV from Variable Energy Cyclotron Centre, Kolkata. On irradiation with heavy ions dielectric constant (ϵ') decreases with frequency where ϵ'' increases with fluence for both the ions. Variation of loss factor ($\tan \delta$) with frequency for pristine and irradiated with Si ions reveals that $\tan \delta$ increases as the frequency increases. $\tan \delta$ also increases with fluence. While Ne irradiated samples $\tan \delta$ shows slight variation with frequency as well as with fluence. $\tan \delta$ has positive values indicating the dominance of inductive behavior.

Keywords : Makrofol-KG polycarbonate, silicon and neon ions, ion beam modification, dielectric constant, dielectric loss.

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1. Introduction

Various modifications in polymeric materials such as radical formation, main chain scission, intermolecular cross-linking, creation of triple bond and unsaturated bond and loss of volatile fragments [1] have been observed due to irradiation of polymers with swift heavy ions (SHI).

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When an energy rich ion penetrates a solid, the material along the trajectory of the ion beam is modified. Atoms are pushed out of their normal positions; many split into pieces and ordered structures such as that of the crystal are destroyed. In this process a so-called, latent track is created by the ion. The diameter and length of this track depends on the type of the ion and its energy as well as on the structure and chemical composition of the irradiated material. If the radiation dose be so high that ion tracks overlap, the physical and chemical properties of the material can also be altered on a macroscopic scale to such an extent that it can be considered a new material with new properties. Various modifications in polymeric materials have been observed due to irradiation of polymers with energetic heavy ions [2,3]. This happens due to high value of the electronic stopping power or high linear energy transfer (LET) of the ions which induces an unusual density of the electron hole pairs close to ion path. Energetic heavy ions create cylindrical tracks with complex damage structures such as radical formation, main chain scission, intermolecular cross-linking, creation of triple bond and unsaturated bond and loss of volatile fragments [4,5]. The effects of ion irradiations are mostly due to electronic excitations and ionization. The effect of ion irradiation on the dielectric properties of polymers has been studied earlier [6–9].

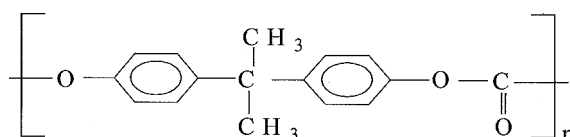
Makrofol-KG, a bisphenol A polycarbonate (PC) is widely used for ion track recording and to prepare track etched membrane as micro filters. Now PC particle track-etched membranes (nano-PTM) with pore shape and size very well controlled within diameters from 10 to 100 nm [10,11] have been produced. These membranes are used for the manufacturing of nano tube and nano wires [12,13]. Swift Heavy Ion degradation of polymers have been analyzed by various researchers [14–17] in a wide range of energies. The sensitivity of a polymer [18] to the registration of particle tracks is closely related to its sensitivity to the formation of chain scission under irradiation. It provides strong evidence that chain scission is of primary importance in the track formation process in track storing materials.

The energy of projectile is to be so chosen so that the ions not only pass through the PC sample, but the ion range is as large, with respect to the sample thickness, as practically possible. Latter condition ensures less difference in entry and exit energies of the ions, and hence a more uniform damage. Table 1 firstly shows that the modifications in Makrofol PC will be mostly due to electronic energy loss, given by $(dE/dx)_{elec}$, contribution of $(dE/dx)_{nucl}$ being low. Range of 145 MeV Ne^{6+} as per SRIM calculation is 152.72 μm . It is comfortably large with respect to sample thickness of 40 μm . For Ne^{6+} beam from Variable Energy Cyclotron Centre (VECC), Kolkata, high energy of 145 MeV was chosen to get optimal beam. However, for Si^{8+} ion beam from IUAC, 100 MeV is about the highest energy possible in IUAC pelletron and its range is 48.54 μm . So, we used this beam with the satisfaction that its range in our polycarbonate is larger than the sample thickness. From the table it is clear that 100 MeV Si^{8+} turn out to be more damaging than 145 MeV Ne^{6+} . In the present work, modifications in electrical properties of Makrofol-

KG PC induced by 145 MeV Ne^{6+} and 100 MeV Si^{8+} ions have been investigated by dielectric constant measurements.

2. Experimental details

40 μm thick Makrofol-KG bisphenol A PC films, manufactured by a casting process were obtained from Bayer AG, Lever Kussen, Germany. The chemical structure of Makrofol-KG polycarbonate is given as :



The Makrofol-KG PC films ($1.5 \times 1.5 \text{ cm}^2$) were mounted on a vertical vacuum shield ladder and irradiated in General Purpose Scattering Chamber (GPSC) by 100 MeV Si^{8+} ion beam from 15 UD Pelletron accelerator at Inter University Accelerator Centre (IUAC), New Delhi to the fluences of 1×10^{10} , 3×10^{10} , 1×10^{11} , 6×10^{11} and 1×10^{12} ions/ cm^2 . 145 MeV Ne^{6+} ion beam irradiation was carried out at Variable Energy Cyclotron Centre (VECC), Kolkata to the fluence of 10^{10} , 10^{11} , 10^{12} and 10^{13} ions/ cm^2 . The ion beam was defocused using a magnetic scanning system so that the film may be uniformly irradiated. The beam current was kept below (10 nA) to suppress thermal decomposition. To expose the whole target area uniformly the beam was scanned in the X-Y plane.

Table 1. Electronic and nuclear energy loss and range for Si and Ne ions in Makrofol-KG polycarbonate

Target	Ion	E in MeV	$(dE/dX)_{\text{elc}}^{\#}$	$(dE/dX)_{\text{nucl}}^{\#}$	Range in μm
Makrofol-KG polycarbonate	Ne^{6+}	145	5.487	2.889E-3	147.07
Makrofol-KG polycarbonate	Si^{8+}	100	13.91	1.024E-2	48.54

Above values of (dE/dX) are the MeV/ (mg/cm^2) units, multiplication by 0.12000 gives in MeV/ μm .

The dielectric constant of the samples was determined by measuring the capacitance of the samples. Simultaneously the loss factor was also measured. Capacitance (C_p) and dielectric loss ($\tan \delta$) measurements were carried out using a parallel plate configuration of electrodes on both sides of PC film using a Hewlett-Packard LCR meter at Inter University Accelerator Centre, New Delhi.

3. Results and discussion

Figures 1 and 2 illustrates the dielectric response of 100 MeV Si^{8+} ions and 145 MeV Ne^{6+} ions irradiated Makrofol-KG PC samples respectively along with that of pristine samples.

Significant changes have been observed in dielectric response of Makrofol-KG PC after irradiation. It is evident from the Figures 1 and 2 that dielectric constant increases with

the fluence and at a particular fluence does not show any change in the frequency range of 300–1000 kHz at all the ion fluences studied for Si ion and in the range of 200–1000 kHz for Ne ion irradiated sample. The motion of free charge carrier may be assumed

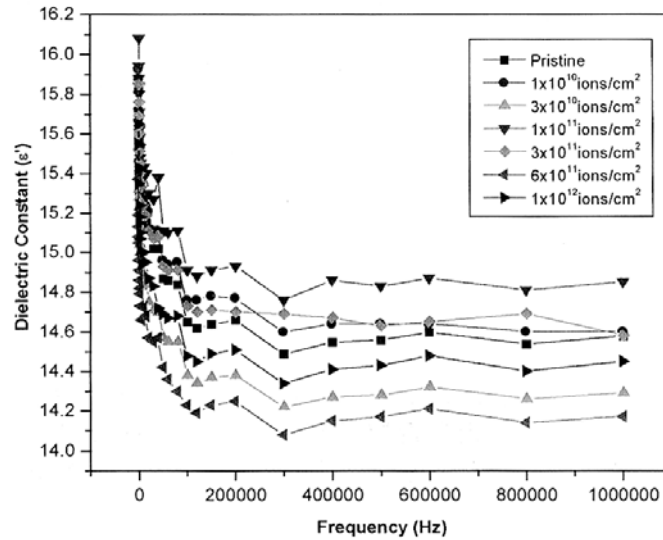


Figure 1. Frequency variation of dielectric constant for Si^{3+} (100 MeV) ion beam irradiated Makrofol-KG polycarbonate.

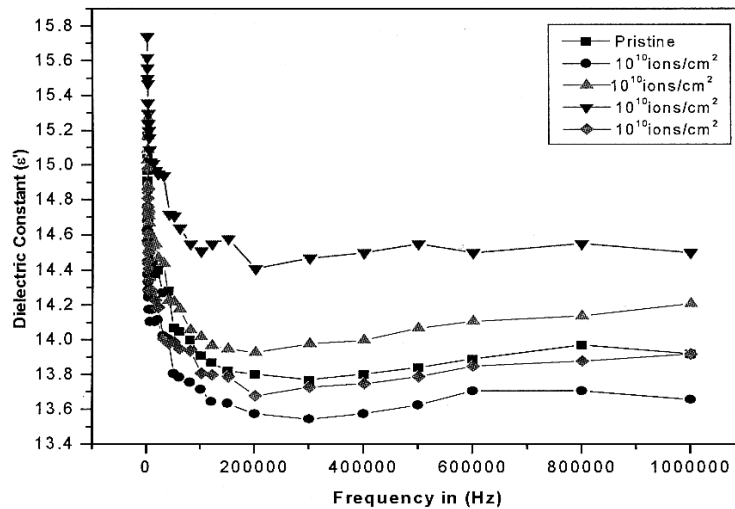


Figure 2. Frequency variation of dielectric constant for Ne^{6+} (145 MeV) ion beam irradiated Makrofol-KG polycarbonate.

constant at these frequencies, which indicate the uniform motion of defects responsible for ion migration through the polymer. Ion migration in solids is assumed to be dependent on the hopping rate *i.e.* the jumping frequency of the ions, which has a unique value for an ion. Therefore, the nearly constant value of dielectric constant may be due to the presence

of some ionic species in excess amount. At lower frequencies a rapidly decreasing trend is observed. In this region the slow migration of charge carriers may be assumed to be the cause of the observed decrease in dielectric constant. With increase in frequency the charge carriers migrating through the dielectric get entrapped in the defect site and induce opposite change in its vicinity.

The variation of dielectric loss presented in Figures 3 and 4 shows random behavior. It increases up to about 70 kHz for both the ions follow by a decrease up to 200 kHz.

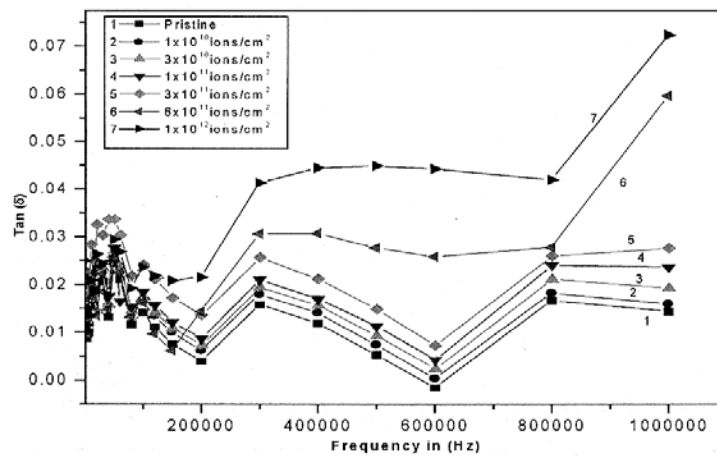


Figure 3. Frequency variation of dielectric loss for Si⁸⁺ (100 MeV) ion beam irradiated and Pristine Makrofol-KG polycarbonate.

The variations with ion fluences are visible only at higher frequencies in the range 600–1000 kHz for Si⁸⁺ ion and 200–1000 kHz for Ne⁶⁺ ions. This indicates a small change in the dissipation factor of the polymer with ion irradiation although the change depends on

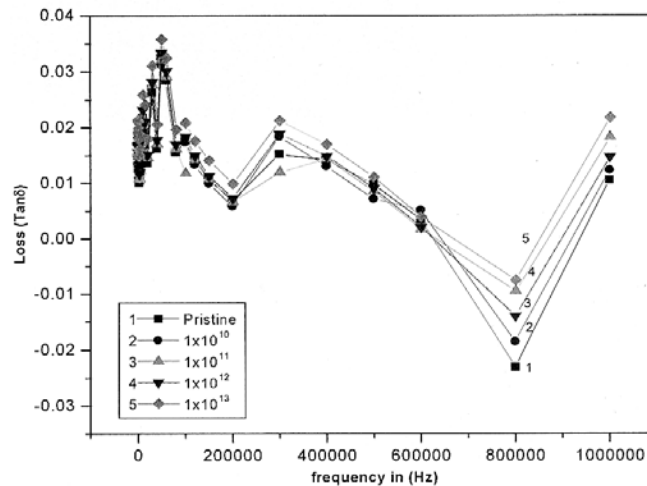


Figure 4. Frequency variation of dielectric loss for Ne⁶⁺ (145 MeV) ion beam irradiated and Pristine Makrofol-KG polycarbonate.

the ion. It may thus be concluded that irradiation has changed the dielectric constant without affecting the dielectric losses only slightly in the polymer. The change in dielectric loss tangents in Makrofol-KG are found to be higher for Ne⁶⁺ as compared with Si⁸⁺ ion.

4. Conclusion

Makrofol-KG polycarbonate films were irradiated with 100 MeV Si ions and 145 MeV Ne ions to study the modification in dielectric properties induced by ion irradiation. It has been observed that on ion irradiation dielectric constant decreases with frequency whereas dielectric loss shows random behavior. It increases up to 70 kHz for both the ions followed by a decrease up to 200 kHz. Irradiation changes the dielectric constant without affecting the dielectric losses, only slightly in the polymer. The effect of Ne⁶⁺ ion beam irradiation on Makrofol-KG is more compared with the Si⁸⁺ ion.

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