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Analysis of Electrical Properties of Li^{3+} ion Beam Irradiated Lexan Polycarbonate

SANGEETA PRASHER[1], MUKESH KUMAR[2], and SURINDER SINGH[3]
[1]*Department of Physics, Kanya Maha Vidyalaya, Jalandhar-144004*
Tel: + 91 181 5071172, Fax:+ 91 181 2291741,
Email: sp105@rediffmail.com

The electrical properties of polymers are a subject which is inherently interdisciplinary in nature. The development of intrinsically conductive polymers has benefited immensely from the contributions of synthetic chemists. Electrical properties are closely allied with the mechanical properties of polymers studied by both physicists and engineers. A primary objective is, thus to produce semiconductive properties to the polymers. One of the best methods to increase the conductivity is to irradiate the polymers with swift heavy ions. In the present investigations the influence of 40MeV Li^{3+} ion beam in the range of $3x10^{11}$-$3x10^{13}$ ions/cm^2 on the electrical properties of lexan has been studied. The variations in dielectric constant and dielectric losses in the polymer have been investigated before and after irradiation. It has been observed that the ion beam irradiation enhances the degradation processes of lexan and helps in increasing the conductivity of the polymer.

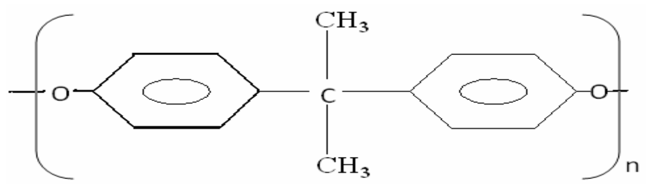
Key Words: 40MeV Li^{3+} ion beam, Dielectric dispersion, Tangent losses

INTRODUCTION

Swift heavy ion (SHI) irradiation of polymers provides a unique way to produce the specific modifications in the structural[1], optical[2-3], mechanical[4] and electrical[5] properties by depositing the energy of ions in the materials. The deposited energy of ion is sufficient to break all the bonds in the track core and leads to the production of new reactive species, defects and heat[6]. At larger distances secondary electrons cause the ionizations and excitations. In polymers which are radiolysis, the primary reactions may be the cross-linking or chain scission depending upon the properties such as composition and molecular weight of the polymeric unit[7-8], on the mass and energy of the impinging ion[9] and on the environmental conditions. Many years ago, Miller *et al*[10] reported that crosslinking will occur if each segment of polymer unit contains one α-hydrogen in its structure, i.e., if the polymeric unit contains $(-CH_2CH_2-)_n$ or $(-CH_2CHR-)_n$. But degradation will predominate, if the structure contains a quaternary carbon atom in its unit, due to the increased steric hindrance. However the presence of

[2]Department of Physics, LSTS, Lovely Professional University, Phagwara-144402
[3]Department of Physics, Guru Nanak Dev University, Amritsar-143005

an aromatic compound in the unit can lead to the decreased radiochemical yield[11]. Lexan a polycarbonate based upon bisphenol-A is one such polymer prepared by Schotten Baumann reaction of phosegene and an aromatic dial in an amine crystallized interfacial condensation reaction with three dimensional polymeric networks as



Hence has been chosen to describe the ion induced modifications in electrical properties of such a degrading polymer with Li^{3+} ion beam of energy 40Me

EXPERIMENTAL

Commercial lexan film pieces of thickness 75µm were irradiated with 40MeV Li^{3+} ion beam at a pressure of 10^{-6} torr under normal incidence using the 15UD pelletron facility at Nuclear Science Centre, New Delhi. The projected range of the 40MeV Li^{3+} ion beam for Lexan was calculated to be 270 µm using SRIM-2003 code[12]. During the sample irradiation, ion flux was maintained around 6.25×10^9 ions/cm^2/s at a current of 1pnA to attain fluence range of 3×10^{11}-3×10^{13} ions/cm^2. The capacitance and dielectric loss measurements have been made with the help of variable frequency LCR meter (Hewlett Packard 4284A) in the frequency range of 1-1000kHz at room temperature. The measured values of capacitance then have been converted into the dielectric constant by using the formula

$$\varepsilon' = Cd/\varepsilon_o A$$

AC conductivity σ_{ac} was obtained at a frequency of 300kHz fom the data using the relation

$$\sigma_{ac} = \varepsilon' \varepsilon_o \omega \tan\delta$$

where ω is the angular frequency.

RESULTS AND DISCUSSION

Irradiation to ion beams has caused color transformations to lexan at higher fluence. The polymer got brownish tinge with increasing ion fluence. It may be attributed to the trapping of free radicals and molecular fragments to the pre-existing defects. The presence of trace amounts of plasticizers and stabilizers etc. also act as catalyst to speed up the discoloration. The formation of conjugated double bonds may be the other cause of color transformations.

To ensure the changes produced in the polymer electrical properties of the pristine and irradiated polymers have been compared.The typical variation of dielectric constant (ε') with frequency at room temperature for pristine and Li^{3+} ion beam irradiated lexan have been shown in fig 1. The dielectric dispersion for all irradiation fluence has been observed and is found to decrease with increasing frequency. The slow migration of the active species may be the cause of decrease in the dispersion at higher frequencies. In general, the variation of dielectric constant with frequency suggests the presence of higher space charge polarizability of the material in low frequency region. The electronic exchange of the number of ions in the polymeric conformation gives local displacements of electrons in the direction of applied field, which produces the polarization. As the frequency increases, a point is reached where the space charge cannot sustain and comply with external field. Therefore, the polarization decreases and exhibits the reduction in the value of dielectric constant as the frequency increases[13]. Apart from this Gon[14] suggested that decrease in the values of dielectric constant with increasing frequency is due to the different domain sizes. The Debye formula giving the permittivity related to the free dipole oscillating in an alternating field is given by

$$\varepsilon' = \frac{\varepsilon_S - \varepsilon_\infty}{1 + \omega^2 \tau^2}$$

Where, ε_s and ε_∞ are the low and high frequency values of ε', τ is the relaxation time. At very low frequencies $\omega << 1/\tau$ dipole follow the field and $\varepsilon' = \varepsilon_s$. When the frequency reaches the characteristic frequency ($\omega = 1/\tau$) the dielectric constant drops and at very high frequencies $\omega >> 1/\tau$, dipoles can no longer follow the field and $\varepsilon' = \varepsilon_\infty$. The experimental results confirm the validity of the equation for lexan and it is to be noted that at higher frequencies (300-1000kHz) the values of ε' became constant.

The variation of the dielectric loss tangents (tanδ) for the polymers is shown in fig.2. it can be seen that tanδ shows a random behavior for lexan. It increases upto 80kHz, followed by a continuous decrease till 250kHz and sharply increases at 400kHz with a decrease thereafter. Thus no particular trend could be applied to the variation of tanδ with frequency. It seems that Li^{3+} ion irradiation of did not influence the dielectric losses in the polymer.

The results for the ac conductivity have been reported in table 1 and seem to follow the increasing trend with the increase in the ion fluence. The increase in the conductivity of the polymer can be attributed to the formation of molecular fragments containing π-electrons. These electrons are loosely bounded to the molecules and helps in conducting the polymer at lower electric fields.

TABLE 1
THE VARIATION IN THE CONDUCTIVITY OF LEXAN AT A FREQUENCY OF 300KHZ WITH LI^{3+} ION BEAM IRRADIATION FLUENCE

Ion Fluence ($ions/cm^2$)	**Conductivity (µS/cm)**
0	6.16
$3x10^{11}$	6.28
10^{12}	6.33
$3x10^{12}$	6.26
10^{13}	6.26
$3x10^{13}$	6.29

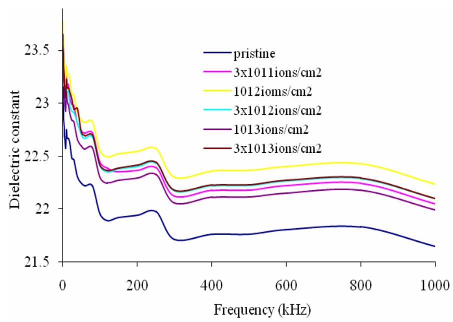


Fig. 1: Dielectric constant vs. Frequency for pristine and Li^{3+} ion beam exposed lexan

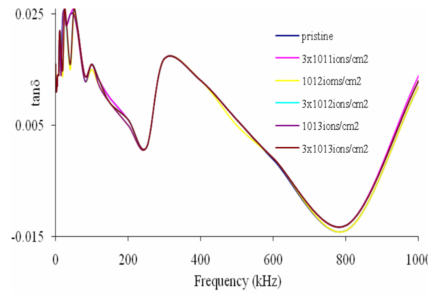


Fig. 2: Dielectric loss tangent vs. Frequency for pristine and Li^{3+} ion beam exposed lexan

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