



Dielectric constant and loss factor measurement of polycarbonate, Makrofol KG using swift heavy ion O^{5+}

M. Mujahid^{a,*}, D.S. Srivastava^b, D.K. Avasthi^c

^a Physics Department, Faculty of Science Tabuk University, Kingdom of Saudi Arabia(KSA)

^b Physics Department, Mangalaytan University, Aligarh, India

^c Inter University Accelerator Centre, Aruna Asaf Ali Marg, P.O.Box 10502, New Delhi 110067, India

ARTICLE INFO

Article history:

Received 28 January 2010

Accepted 10 December 2010

Available online 21 December 2010

Keywords:

Polymers

Heavy ion irradiation

Chain scission

Crosslinking and dielectric loss

ABSTRACT

Swift heavy ion irradiation (SHI) induces modifications in the electrical properties of polycarbonate (PC), Makrofol KG. This enables us to study the dielectric response of pristine and irradiated polymers for a wide range of fluence, temperature and frequency. The results are related to structural changes of the polymer. Actually there exist two kinds of phenomena namely chain scission and endlinking in heavy ion irradiation of polycarbonate at different energy densities. Structural changes are co-related using UV and visible spectrophotometer by measuring the absorbance as a function of wavelength. A plot of dielectric loss versus temperature at 1 kHz reveals two relaxations in the temperature range of 30–140 °C, which may be associated with pre-glass transition (β), glass transition (α), and motion of the polymeric chain. Both the peaks show shifts to the low temperature side with increase of dose.

© 2010 Elsevier Ltd. All rights reserved.

1. Introduction

Dielectrics are insulating materials which have very tightly bound electrons to the nuclei in their atoms. Accordingly they have very few free electrons to carry current and their electrical conductivity is very low. Majority of polymers (or plastics) are typical dielectrics.

Irradiation of polymers with gamma rays, neutrons, protons or other heavy ions produces structural changes in the polymer matrix. Such changes have been studied in recent past by many workers (Singh et al., 2005; Surinder Singh, 2006; Martinez-Pardo et al., 1998; Phukan et al., 1999). We too have studied the modifications induced by swift heavy ion irradiation (SHI) using 85 MeV O^{5+} ions having fluences ranging from 1×10^{11} to 1×10^{13} ions/cm² by measuring real and imaginary parts of complex dielectric constant $\epsilon_{r(\omega)}^*$ and the loss tangent, $\tan \delta$, when subjected to alternating electric field having different frequencies.

The most important property of a dielectric is to get polarized under the action of applied electric field. As the relationship between electric displacement vector $\vec{D}$, electric field vector $\vec{E}$, polarization vector $\vec{P}$ and the dielectric constant (or relative permittivity) ϵ_r is given by

$$\vec{D} = \epsilon_0 \vec{E} + \vec{P} = \epsilon_r \epsilon_0 \vec{E} = \epsilon \vec{E}$$

where ϵ_0 is the permittivity of free space, a measurement of dielectric constant, ϵ_r gives significant insight to the modification of the bulk properties responsible for the dielectric response. Such studies will give

better understanding of track formation mechanism on the basis of microstructures so formed due to passage of heavy ions through polymers (or plastics).

The study of changes in dielectric response of solids also provides information about orientation and translational adjustment of mobile charges present in the dielectric medium in response to an applied electric field. The energy transferred to an alternating field is a function not only of the field but also depends on physical characteristic of the material. The dependence of contributions of different components of dielectric polarization (viz. the electric polarization, ionic polarization and orientational polarization) on frequency of applied ac field is responsible for the changes in the value of dielectric constant.

1.1. Dependence of dielectric constant ($\epsilon_{r(\omega)}^*$) on frequency

The dielectric constant (or relative permittivity) $\epsilon_{r(\omega)}^*$ of a dielectric solid, placed in an alternating electric field of angular frequency ω , is a complex quantity because the orientational polarization lags behind the polarizing electric field as the frequency of the applied field is increased. The complex dielectric constant can be written in the form

$$\epsilon_{r(\omega)}^* = \epsilon'_{r(\omega)} - i\epsilon''_{r(\omega)} \quad (1)$$

where $\epsilon'_{r(\omega)}$ is the real dielectric constant and characterizes the most important electrical property of the dielectric material. The imaginary part $\epsilon''_{r(\omega)}$ characterizes the dissipation of energy of electric oscillation in a dielectric subjected to the action of an

* Corresponding author. Cell: 09412731724.

E-mail address: mujahidm72@gmail.com (M. Mujahid).

alternating electric field. In this way there is a phase lag between the electric displacement vector $\vec{D}$ and the electric field vector $\vec{E}$ because at high frequencies the dipoles do not faithfully follow the rapidity of the applied alternating field. This phase lag is described by the so-called dielectric loss tangent or dissipation factor given by

$$\tan \delta = \frac{\epsilon''_{r(\omega)}}{\epsilon'_{r(\omega)}} \quad (2)$$

The magnitude of real dielectric constant $\epsilon'_{r(\omega)}$ of the polymer is determined by the chemical constitution, structure and composition. The parameters that characterize the dielectric loss (viz., $\epsilon''_{r(\omega)}$ and $\tan \delta$) depend upon the specific features of molecular motion in polymers; hence, on changes in their chemical constitution and structure.

Real polymeric dielectrics are commonly described by a spectrum of relaxation times. In their case relaxation spectra appear due to presence of long polymeric chains and specific inter-molecular interactions. However, the expression for $\epsilon''_{r(\omega)}$ assume the simplest form in the case of relaxation process characterized by a single relaxation time (Perpechko, 1997). If we introduce a relaxation time τ , for the process to go from one equilibrium state to another equilibrium state, i.e., from absorption to dissipation, then

$$\epsilon'_{r(\omega)} = A + \frac{B}{1 + \omega^2 \tau^2} \quad (3)$$

and

$$\epsilon''_{r(\omega)} = \frac{B\omega\tau}{1 + \omega^2 \tau^2} \quad (4)$$

where A and B are constants and ω is the angular frequency.

In our experiments the capacitance (C_p) and $\tan \delta$ measurements were carried out using a parallel plate configuration of electrodes on both sides of the polymer film using a Hewlett-Packard LCR meter (model number 4284A), a device to measure inductance, capacitance and resistance, over the frequency range 100 Hz–1 MHz. Dielectric constant was calculated from the measured capacitance using the relation

$$\epsilon_r = \frac{C_p}{C_0} \quad \text{where} \quad C_0 = \frac{\epsilon_0 A}{d} \quad (5)$$

Here, ϵ_0 is the permittivity of vacuum or free space, A is the cross-sectional area and d is the thickness of the sample film. C_p is the capacity of the condenser filled with the dielectric (plastic).

A Hitachi U3300 UV-vis spectrophotometer was used for the optical absorption measurements. In order to ensure that the oxidation and corrosion processes come to saturation, the samples were stored for two months after irradiation at lab temperature (28 °C). The UV absorption analysis was carried out thereafter.

1.2. Dependence of dielectric loss on frequency

As mentioned earlier, the expressions for $\epsilon'_{r(\omega)}$ and $\epsilon''_{r(\omega)}$ assume the simplest form in the case relaxation characterized by a single relaxation time τ in the case of polymer. In such case it can be shown (Perpechko, 1997) that

$$\epsilon'_{r(\omega)} = \epsilon'_{r(\infty)} + \frac{\Delta\epsilon}{1 + \omega^2 \tau^2} \quad (6)$$

where $\Delta\epsilon = \epsilon'_{r(0)} - \epsilon'_{r(\infty)}$, is the dielectric relaxation strength. Therefore,

$$\epsilon'_{r(\omega)} = \epsilon'_{r(\infty)} + \frac{\epsilon'_{r(0)} - \epsilon'_{r(\infty)}}{1 + \omega^2 \tau^2} \quad (7)$$

and

$$\epsilon''_{r(\omega)} = \frac{(\epsilon'_{r(0)} - \epsilon'_{r(\infty)})\omega\tau}{1 + \omega^2 \tau^2} \quad (8)$$

where $\epsilon'_{r(0)}$ is the static dielectric constant when $\omega\tau \rightarrow 0$ and $\epsilon'_{r(\infty)}$ is the dielectric constant at very high frequency, i.e., when $\omega\tau \rightarrow \infty$.

The expression for loss tangent has the form

$$\tan \delta = 2 \tan \delta_m \frac{\omega\tau_1}{1 + \omega^2 \tau_1^2} \quad (9)$$

where $2 \tan \delta_m = \frac{\epsilon'_{r(0)} - \epsilon'_{r(\infty)}}{\sqrt{\epsilon'_{r(0)}\epsilon'_{r(\infty)}}}$

In Eq. (9), the relaxation time τ_1 is different from the relaxation time τ of Eq. (8) and is given by

$$\tau_1 = \tau \sqrt{\frac{\epsilon'_{r(\infty)}}{\epsilon'_{r(0)}}}$$

1.3. Dependence of relaxation time τ on temperature

The temperature dependence of the dielectric relaxation can be found using the expression (Perpechko, 1997)

$$\tau = \tau_0 e^{U/RT_{\max}} \quad (10)$$

where τ_0 is a constant quantity, U the activation energy (kJ/mol), R is the universal gas constant and the absolute temperature $T_{\max}$ is the temperature that corresponds to the maximum value of $\tan \delta$ in $\tan \delta$ versus T plot at a given frequency ($f = 1/\tau$).

The magnitude of the activation energy is obtained by solving Eq. (10) for two frequencies $f_2 (= 1/\tau_2)$ and $f_1 (= 1/\tau_1)$. Thus,

$$U = 2.303 \times 8.31 \times \log_{10} \frac{(f_2/f_1)}{(1/T_{1\max} - 1/T_{2\max})} \quad (11)$$

In our experiments the frequency values are $f_1 = 1$ kHz and $f_2 = 5$ kHz.

1.4. Experimental details

Polycarbonate, $[-OC_6H_4-4-C(CH_3)_2-C_6H_4-4-OCO-]_n$ (PC) which exists in semi-crystalline form with a density of 1.2 g/cm³ was used in the form of 20 μ m thick films. The films were obtained from Goodfellow Corporation (UK).

The samples were irradiated using swift heavy ion beam from the 16 MV Van de Graff accelerator (Pelletron) facilities at the Inter University Accelerator Centre, New Delhi. During the irradiation the samples were kept inside a chamber with pressure maintained at 1×10^{-6} Torr. The ion beam used was 85 MeV O⁺⁵ having a current density of 1–5 pA/cm² (pA stands for particle nano ampere, 1 pA = 6.25×10^9 particles/s/cm²). The fluence range was from 10^{11} to 10^{13} ions/cm². The electronic stopping power of the O⁺⁵ beam in the film, i.e. $(dE/dx)_e$ is 50.38 eV/Å. The depth profile calculations of 85 MeV O⁺⁵ ions in 20 μ m thick polycarbonate using the TRIM code yielded $(dE/dx)_{0\mu m} = 49.88$ eV/Å and $(dE/dx)_{20\mu m} = 50.38$ eV/Å at the entrance and exit of the ion beam in the polymer film, respectively. Corresponding to the fluences used, the transferred energy densities (dose $\times$ stopping power) range from 50.3×10^{-4} to 25.15×10^{-3} eV/Å³ for O⁺⁵ irradiated sample at 1 kHz and 25.15×10^{-4} to 50.3×10^{-3} for the same sample at 5 kHz as given in Tables 1 and 2.

Table 1

Transition temperatures for the polycarbonate samples in the $\tan \delta - T$ plots at 1 kHz.

Sample	Fluence (ions/cm ²)	Energy density (eV/Å ³)	$T\alpha$ (K)	Peak area (arb. units)
Pristine PC	0	0	353 ± 0.5	0.05
¹⁶ O irr. PC	1×10^{12}	50.3×10^{-4}	328 ± 0.5	0.25
¹⁶ O irr. PC	5×10^{12}	2.51×10^{-3}	364 ± 0.5	0.27

Download English Version:

<https://daneshyari.com/en/article/10732082>

Download Persian Version:

<https://daneshyari.com/article/10732082>

[Daneshyari.com](https://daneshyari.com)