Effect of high frequencies on losses and other defects in dielectrics of $\alpha - $PADC polymer $(C_{12}H_{18}O_7)$

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Abstract: $C_{12}H_{18}O_7$ Polyallyl diglycol carbonate (PADC) is a $CR-39$ polymer. Losses and other defects in dielectrics of $CR-39$ polymer before and after α-irradiation have been investigated at room temperature under various constant frequencies ranging from $100\ kHz$ to $100\ MHz$. The results show a large change of the dielectric properties in the frequency range from $3\ MHz$ to $10\ MHz$. Peak values of dielectric properties are obtained at $10\ MHz$. The dependence of dielectric characteristics on the total number of α –particles at room temperature for irradiated $CR-39$ samples have been studied at constant higher frequency $(10\ MHz)$. This method may give a novel technique to measure the effect of α –irradiation on $CR-39$ polymer by the direct measurements for the dielectric parameters without using an optical microscope technique.

Keywords: $CR-39$ polycarbonate; α-irradiation; Losses and defects in dielectrics.

1. Introduction

Polyallyl diglycol carbonate ($C_{12}H_{18}O_7$, $\rho = 1310\ Kg/m^3$) is a thermo set polymer [1]. $CR-39$ is a polymer of Polyallyl diglycol carbonate(PADC) has been used in heavy ion research such as composition of cosmic rays, heavy ion nuclear reactions, radiation dose due to heavy ions, exploration of extra heavy elements etc. Its availability in excellent quality from different manufactures is also an advantage for further applications. Some applications [2,3] include studies of exhalation rates of radon from soil and building materials and neutron radiology. When a charged particle passes through $CR-39$ polycarbonate a damage zone are created, this zone is called latent track. The latent track of the particle after chemical etching is called “etch pit” [4].

Radiation effects induced by ionizing particles like electrons; ions and photons have been largely used to modify the chemical and physical properties of the polymers [5,6]. Most plastics are dielectric and resist the flow of a current. This is one of the most useful properties of plastics and makes much of modern society possible through the use of plastics as wire coatings, switches, and other electrical and electronic products [7].

In the present work we have chosen an important plastic $CR-39$, which is an amorphous polymer consisting of short polyallyl chains joined by links containing carbonates and diethylene glycol groups into a dense three dimensional network with an initiating monomer unit as given below:

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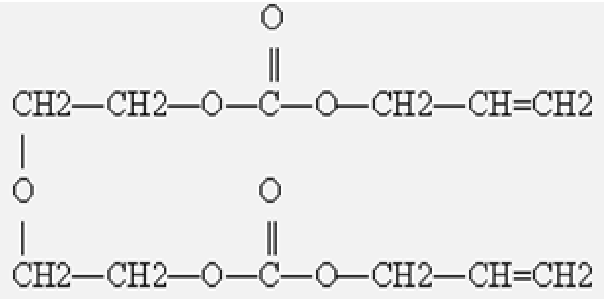

The branching point in this net is the tertiary carbon in the polyallyl chain [8,9]. Out of three links originating from this point two form the polyallyl chain and one consists of diethylene glycol dicarbonate.

The irradiation in polymer destroys the initial structure by cross-linking, scission and emission of atoms, molecules and molecular fragments [6]. This leads to the changes in their properties like density, conductivity, optical absorption and molecular weight distribution. The effectiveness of these changes produced depends upon the structure of the polymer and the experimental conditions of irradiation like energy and fluxes. The incident flux Φ ($= A/4\pi r^2$, where A is the activity of the used source in Bq and r is the source-detector distance in centimeters) was calculated.

The dielectric loss, ϵ'', was calculated from the measurements of loss factor ($\tan\delta$) using the following relationship:

$$\epsilon'' = \epsilon' \tan\delta \quad \ldots\ldots\ldots\ldots..(1)$$

ϵ' is the dielectric constant ($= Cd/\epsilon_0 S$, where ϵ_o is the permittivity of vacuum, S is the area of the sample, C is the capacitance of the given sample and d is the sample thickness). The fitting equation for the dielectric constant ϵ' for the irradiation times $\cong 2-6$ min is given:

$$\epsilon' = -57.69 + 0.0016\,\Phi - 1.11\times10^{-8}\,\Phi^2 + 2.31\times10^{-14}\,\Phi^3 \quad \ldots\ldots(2)$$

Also, the conductivity (σ) was calculated using the relationship:

$$\sigma = \epsilon''\,\omega\,\epsilon_0 \quad \ldots\ldots\ldots\ldots\ldots(3)$$

where $\omega = 2\pi f$, and f is the applied frequency.

In this work a novel method to measure the effect of ^{241}Am(**4.84 MeV**) $\alpha -$ **particle**s irradiation on **CR − 39** polymer samples by the direct measurements for the dielectric properties at higher frequency $\cong$**10 MHz** without using an optical microscope method for investigation.

2. Experimental procedures

Several circular discs of diameter 10 mm were punched from a 500 μm thick sheet of polished CR − 39 polycarbonate sheets, were commercially obtained from Pershore Moulding Ltd. (UK). Track detectors, CR − 39 polymers, were normally irradiated in air by different fluxes of α −particles at energy 4.84 MeV emitted from coin-sized metal 0.1 μCi ^{241}Am-source that is about the size of a pencil erasure through a holder collimator of approximately 1 mm in a diameter. The height of the holder is 7.25 mm. The total number of $\alpha -$particles (Φ) emitted from ^{241}Am-source and incident on CR − 39 samples per unit area in a certain irradiation time (t) is equal ϕ t. To measure the dielectric properties of the CR − 39 polymer after irradiation for different times from 2.0 to 6.0 min, an electric cylindrical cell 19 mm in diameter and 100 mm the length is used. The cell consists of two silver electrodes. The sample exists between the electrodes. The temperature is controlled by the use of a double wound electric oven.

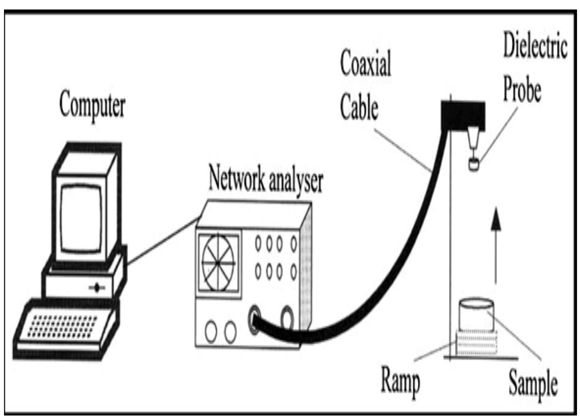

Fig. 1. Schematic diagram of the dielectric probe measurement system.

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Dielectric measurements were made using an Agilent Technologies open-ended co-axial probe (Outer diameter 19 mm) (Model No. 85070C) connected to a Hewlett Packard network analyzer (Model No. 8714ET, Agilent Technologies, California, USA), with the aid of the 85070C software package (Version C1-02, Agilent Technologies) (Fig. 1). The network analyzer was used to automatically obtain dielectric spectra for each of the samples under different constant frequencies between 100 kHz and 100 MHz at room temperature.

3. Results and Discussion

The losses and the other defects in dielectrics results of $\mathrm{CR}-39$ polymer track detector due to $\alpha-$irradiations at different constant frequencies ranging from 100 kHz to 100 MHz in the room temperature have been investigated (Fig. 2).

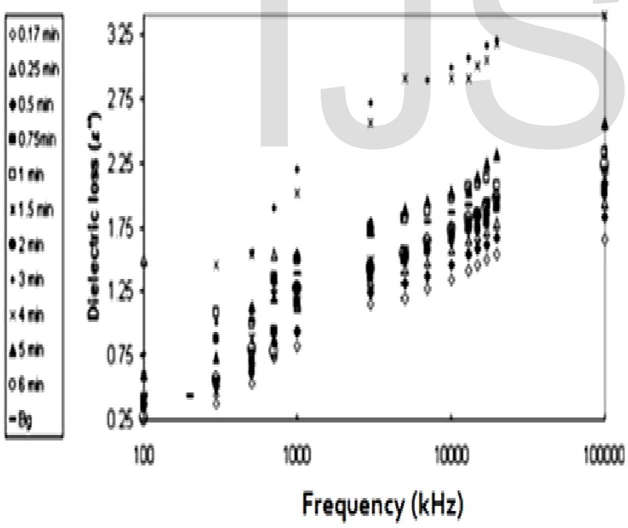

Fig. 2. The frequency dependence of dielectric loss ϵ'' at room temperature for unirradiated and irradiated CR-39 polymer samples.

A large change in the dielectric properties was only observed in the frequency range from 3 MHz to 10 MHz. The results show that the megahertz and gigahertz frequencies tend to reveal losses and other defects in dielectrics much better than audio [10].

The dependences of the dielectric constant, dielectric loss, and conductivity for $\mathrm{CR}-39$ irradiated samples under constant frequency ≅10 MHz in the room temperature (20 ℃) on the total number of α −particles (Φ) are represented in Figs. (3, 4, 5). It is observed from the three figures that the dielectric parameters studied sharply increased and then sharply decreased with increasing the Φ -value, for irradiation times $\cong 2-6$ min.

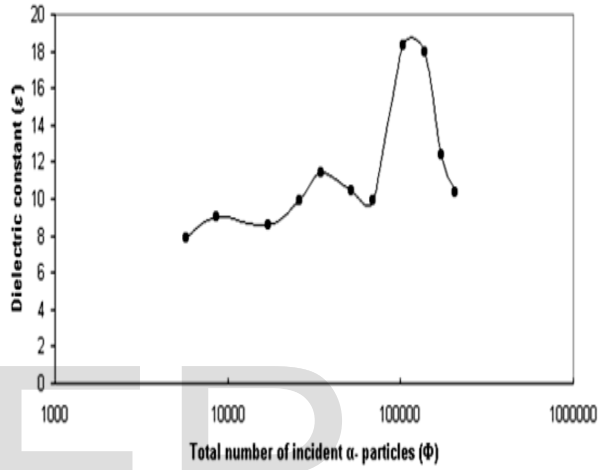

Fig. 3. The variations of dielectric constant ϵ' with the total number of α-particles (Φ) incident on CR-39 samples.

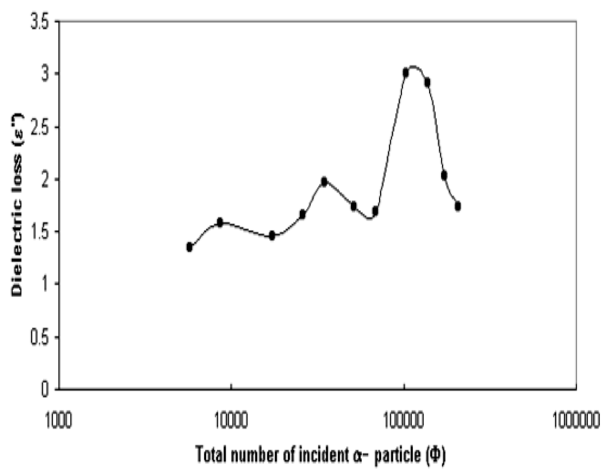

Fig. 4. The variations of dielectric loss ϵ'' with the total number of α-particles (Φ) incident on CR-39 samples.

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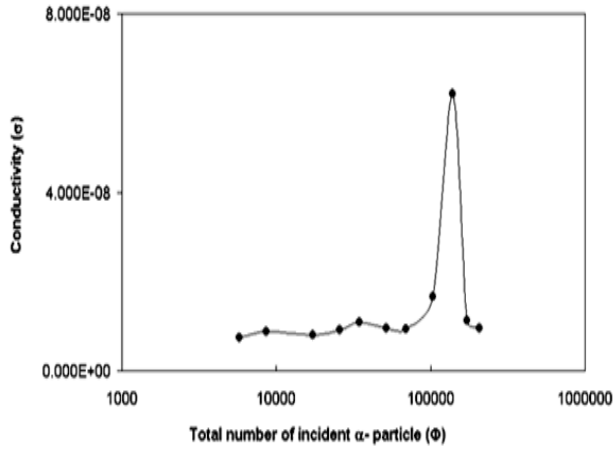

Fig. 5. The variations of conductivity (σ) with the total number of α-particles (Φ) incident on CR-39 samples.

The behavior of dielectric parameters reveal an abrupt change and a new peak that start to appear at the position of the transition. The one prominent peak is located and it grows up with increasing the Φ-value (Figs. 3, 4, 5). The appearance of this peak might be related to phase transition. The change in the peak intensity and position of the transition can be explained by a change in lattice spacing and torsional oscillations in the polymer chain [8,9]. This behavior can be related to the different phases. Srivastana et. al. [11] have investigated polymorphic transitions. The phase transition in the $CR - 39$ polycarbonate remains complex.

Also, in the presence of an electric field the dipoles will attempt to move to align with the field (Fig. 5). This will create ''dipole polarization'' of the material and, because a movement of the dipoles is involved, there is a time element to the movement. The alternating current frequency is an important factor because of the time taken to align the polar dipoles [7]. For the fitting Eq. (2) the correlation factor (r^2) is 0.99. This equation makes it possible to use $CR - 39$ as a good sensor (dosimeter) for counting α −particles [5]. This sensor does not need etching operation and scanning with an optical microscope as usual in dealing with $CR - 39$ as a detector. Also, it is impossible to differentiate the tracks in $CR - 39$ by the microscope at irradiation times 5 and 6 min.

4. Conclusion

A novel technique of the dielectric properties measurements may be fast and accurate for the assessment of α − particles radiations in $CR - 39$ polymer at irradiation times higher than 4 min without using an optical microscope technique. This study shows that the peak values of dielectric losses and other defects are obtained at 10 MHz. It is a possibility to use $CR - 39$ as a good detector for counting high α −particles fluxes.

In optical microscope techniques, it's difficult counting the real number of α − particles etched tracks in $CR - 39$ at irradiation times higher than 4 min due to the overlapping of tracks.

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