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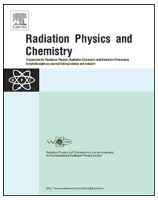

Structure, thermal, optical and electrical investigation of the effect of heavy highly energetic ions irradiations in Bayfol DPF 5023 nuclear track detector

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HIGHLIGHTS

- Fe ion irradiation led to a more compact structure of Bayfol with enhanced thermal stability.
- Both average molecular mass and isotropic nature of Bayfol increased with irradiation.
- The Bayfol samples showed significant color sensitivity toward Fe ion irradiation.
- Fe ion irradiation provides mobile-free charge carriers that increase DC conductivity.

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ABSTRACT

The effects of 28 GeV ^{56}Fe ion irradiation on the structural, thermal, optical and electrical properties of Bayfol DPF 5023 have been investigated. Samples from Bayfol sheets have been irradiated using different Fe fluences in the range 1×10^{12} to 5×10^{15} ion/cm^2. The total energy deposited is between (28×10^{21} eV and 14×10^{25} eV). The resultant effect of Fe ion irradiation on the properties of Bayfol has been investigated using FTIR spectroscopy, intrinsic viscosity, Thermogravimetric Analysis TGA, refractive index, color changes, and DC conductivity. The results indicate that the Fe ion irradiation in the fluence range 10^{12}–10^{15} ion/cm^2 led to a more compact structure of Bayfol polymer, which resulted in an improvement in its thermal stability with an increase in activation energy of thermal decomposition and crosslinking. This crosslinking enhanced the intrinsic viscosity of Bayfol from 0.58 to 0.89 at 35 °C, indicating an increase in the average molecular mass. This was accompanied with an increase in refractive index. Further, the transmission of Bayfol samples in the wavelength range of 370–780 nm, as well as any color changes, was studied. The color intensity ΔE was increased with increasing the Fe fluence, and was accompanied by a significant increase in the blue color component.

1. Introduction

Experimental studies of energetic iron ions are rapidly increasing. Iron is indeed of great interest for space radiation research, especially to quantify the risk related to the exposure to galactic cosmic radiation (Scampoli et al., 2005). In fact, although iron is over 1000 times less abundant than protons in the galactic cosmic radiation, it is the major contributor in terms of dose equivalent among all nuclei in space, because it is the heaviest element present in significant numbers in space, and it has a high relative biological effectiveness (Scampoli et al., 2005). Heavy ion irradiation is a useful technology to induce suitable modifications of polymers. In particular, it is an important way to achieve some desired improvements that promise many applications in a wide range of industrial fields (Abdel-Salam et al., 2011). There are several applications of ion irradiated polymer such as microelectronics, biosensors production technologies. Dramatic changes in the radiation-induced damage processes may occur if ion irradiations are performed, instead of classical-condition

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irradiations such as electron beams or gamma rays (Singh and Samra, 2008; Calcagno et al., 1992). The reason is the very high value of the electronic stopping power of the ions which induces an unusual density of electron–hole pairs close to the ion path (Singh and Samra, 2008). Also, heavy ion irradiation may lead to many processes, such as the production of primary and secondary radicals, formation of double bonds and transformation of C–C bonds. These reactions depend on the dose as well as on the environmental conditions during and after irradiations (Tripathy et al., 2001). These are accompanied by changes in chemical, structural, geometrical, optical and electrical properties of the polymer (Fink et al., 1996; Steckenreiter et al., 1997; Biswas et al., 1999). The obtained chemical system is characterized by new functional groups, a different backbone with different electronic structure and different physical properties (Lounis-Mokrani et al., 2003). The modification induced in some SSNTDs due to heavy ion irradiation have already been widely reported (Murat et al., 2011; Szydlowski et al., 2009; Kalsi, 2011; Sihver et al., 2013). Ramola et al. (2011) studied the effect of 120 MeV Ni^{+9} ions with fluences 1×10^{10}–1×10^{12} ion/cm^2 on the optical, structural and morphological properties of Makrofol-KG polycarbonate. They found that the roughness of the polymer surface increased with increasing fluence.

The present study deals with the modifications induced in Bayfol DPF 5023 upon Fe ion irradiation with very high energy (28 GeV). The study may be considered as the first ones dealing with that topic of materials changes in this high energy range. It aims, not only to obtain information concerning the interaction of ^{56}Fe ions with Bayfol, but also to study the feasibility of enhancing its properties, improving its performance in different applications.

2. Experimental

2.1. Samples

Bayfol DPF 5023 is a polycarbonate based film with a gloss first surface and a micromatte second surface. It has advantages over standard polycarbonate films in terms of dynamic strength, chemical resistance, dimensional stability, and cold formability. It is manufactured by Farbenfabriken Bayer A.G., Leverkusen (Germany), with an average thickness of 380 μm and density 1.23 g/cm^3.

2.2. Irradiation facilities

In the present work, Bayfol samples were irradiated using different fluences 1×10^{12}–5×10^{15} ion/cm^2 of 500 MeV/n (28 GeV) ^{56}Fe ions at the Heavy Ion Medical Accelerator of Chiba (HIMAC), National Institute for Radiobiological Sciences (NIRS)-Japan. The ion beam was defocused using a magnetic scanning system, so that the area of the sample 1.5×1.5 cm^2 be uniformly irradiated.

2.3. Analysis of the irradiated samples

Fourier Transform Infrared spectra were recorded using model Shimadzu 8201 PC. All the measurements were done in the range of 4000 to 400 cm^{-1}. The spectra were obtained for the absorbance of the polymer as a function of wavenumber with resolution 1 cm^{-1} and accuracy better than ±4 cm^{-1}.

Solutions of different concentrations (0.2%, 0.4%, 0.6% and 0.8%) were prepared from the irradiated and non irradiated samples using pure chloroform as a solvent. The viscosity measurements were carried out in Oswald viscometer of the type pinkevitch Size 0 No. 2106, manufactured by Poulten, self and LEE, LTD, England. This viscometer was calibrated in accordance with the standard method of test for kinematic viscosity specified in ASTM D 445-IP 71.

Thermogravimetric analysis (TGA) was performed on irradiated and non-irradiated Bayfol samples using the TGA apparatus model Shimadzu-50 with platinum cells. Thermal experiments were carried out on all samples at a heating rate of 10 °C/min with nitrogen as a carrier gas at a flow rate of 30 ml/min.

The refractive index measurements were carried out using an Abbe refractometer (Type Reichert; mark II, Model-10480, New York). The wavelength of the light used is 5893 Å. The accuracy of measuring the values of refractive indices and surface temperature of the prism were ±0.0001 and 24–26 °C, respectively. Several values were measured on the same sample and the average value was considered.

The transmission measurements were carried out using a Shimadzu UV–Vis–Nir scanning spectrophotometer, type 3101 PC. This unit measures in the wavelength range from 200 to 3000 nm. The Commission International de E'Claire (CIE units x, y and z) methodology was used in this work for the description of colored samples (Abdel-Salam et al., 2011).

The samples used in electrical conductivity measurements have the form of squares of length, width and thickness 1 cm, 1 cm and 3.84×10^{-2} cm, respectively. The electrodes were made of silver paste covering the two major surfaces of the samples. A specially designed cell in which the sample is fixed between two parallel plates of brass, isolated from each other by Teflon, was used. The current was measured using a digital electrometer (Type Keithley 616). This electrometer is essentially used for measuring weak currents in high resistivity samples.

The DC electrical conductivity, σ, is determined from the relation:

$$\sigma = Id/VA, \qquad (1)$$

where d is the thickness of the examined sample in cm, A is the cross-sectional area of the sample in cm^2, V is the applied voltage in volts and I is the current in ampere.

The DC conductivity σ varies exponentially with the absolute temperature (T) according to the well-known relation:

$$\sigma = \sigma_0 \exp(-\Delta E/KT); \qquad (2)$$

where σ is the electrical conductivity at a given absolute temperature T; σ_0 is the initial conductivity, K is the Boltzmann constant and ΔE is the activation energy of the sample under test. From this relationship the activation energy of conduction can be calculated.

3. Results and discussion

The electronic stopping power, nuclear stopping power, projected range of the ion inside the sample, longitudinal straggling and lateral straggling were calculated, for Fe ions in Bayfol, using SRIM 2008 by J.P. Biersack and J.F. Ziegler. The obtained values are given in Table 1.

3.1. FTIR spectroscopy

The effect of Fe ion irradiation on the optical absorption of Bayfol detector was investigated. The infrared absorption spectra were obtained in the wave number range 400–4000 cm^{-1}, for non-irradiated and irradiated samples (Fig. 1). The changes have been estimated from the relative increase or decrease in the intensity of the peak associated to the functional groups present in the polymer. The vibration modes of chemical bonds are characterized by the absorption bands in the FTIR spectra (Noda et al., 1996). Fig. 2 shows the variation of the absorbance measured at the characteristic function groups of Bayfol with the Fe fluence. From the figure it is clear that the absorbance measured at the wavenumbers 1778 cm^{-1} and 1176 cm^{-1} decreases with increasing the Fe fluence up to