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Modifications induced by gamma irradiation to Makrofol polymer nuclear track detector

A. Tayel [a], M.F. Zaki [b,*], A.B. El Basaty [a], Tarek M. Hegazy [c]

[a] *Physics Department, Faculty of Industrial Education, Helwan University, Cairo, Egypt*
[b] *Experimental Nuclear Physics Department, Nuclear Research Center, Atomic Energy Authority, P.O. 13759, Abu Zaabal, Cairo, Egypt*
[c] *Physics Department, University College for Girls, Ain Shams University, Cairo, Egypt*

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ABSTRACT

The aim of the present study was extended from obtaining information about the interaction of gamma rays with Makrofol DE 7-2 track detector to introduce the basis that can be used in concerning simple sensor for gamma irradiation and bio-engineering applications. Makrofol polymer samples were irradiated with 1.25 MeV ^{60}Co gamma radiations at doses ranging from 20 to 1000 kG y. The modifications of irradiated samples so induced were analyzed using UV–vis spectrometry, photoluminescence spectroscopy, and the measurements of Vickers' hardness. Moreover, the change in wettability of irradiated Makrofol was investigated by the contact angle determination of the distilled water. UV–vis spectroscopy shows a noticeable decrease in the energy band gap due to gamma irradiation. This decrease could be attributed to the appearance of a shift to UV spectra toward higher wavelength region after irradiation. Photoluminescence spectra reveal a remarkable change in the integrated photoluminescence intensity with increasing gamma doses, which may be resulted from some matrix disorder through the creation of some defected states in the irradiated polymer. The hardness was found to increase from 4.78 MPa for the unirradiated sample to 23.67 MPa for the highest gamma dose. The contact angle investigations show that the wettability of the modified samples increases with increasing the gamma doses. The result obtained from present investigation furnishes evidence that the gamma irradiations are a successful technique to modify the Makrofol DE 7-2 polymer properties to use it in suitable applications.

Introduction

Polymers are a popular part of everyday life that are included in various applications among several domains. Solid State Nuclear Track Detectors (SSNTDs) have been modified for many applications, such as detection of ion beam, biological filters, sensors and dosimetry [1,2]. Makrofol DE (a bisphenol-A polycarbonate) is a well-known polymer widely used as SSNTDs. Makrofol DE is transparent material which has high compact

* Corresponding author. Tel.: +20 1002718565.
E-mail address: moha1016@yahoo.com (M.F. Zaki).
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strength. This makes it an advantageous material for several applications such as microelectronics and biosensor production technologies [3]. Nowadays, irradiation of polymers by high (i.e., ion beam) and low (gamma-ray and electron beam irradiations) linear energy transfer radiation is widely used in improving the physical and chemical properties of the polymeric material for high technology applications [4,5]. Ionizing radiation by way of matter, deposits energy inside the target material that causes irreversible modifications in its structure at the macromolecular scale. The gamma-ray loses their energy in several ways, but each type includes electronic liberating which deposit its energy during the interaction with other atomic electrons [6,7]. Moreover, the gamma ray interaction with polymers leads to complex phenomena such as chain scission, radical composition, bond breaking, creation of unsaturated bonds, intermolecular cross-linking, free radicals formation, hydrogen release and some oxidation reactions. The gamma irradiations of polymer may lead to irreversible changes in their physical properties. Part of these changes are attributed to the chain scission of polymers due to irradiation, cross-linking, breaking of some covalent bonds, and formation of carbon clusters or even libration of free radicals that may also induced the formation of new chemical bonds [8–14]. During the gamma-irradiated polymers, the release of volatile species almost takes place [15–17]. However, to be best of our knowledge a few published papers have been carried out in investigating the optical, photoluminescence, as well as the Vicker's hardness and wettability properties of Makrofol DE 7-2 SSNTDs for the unirradiated and gamma irradiated samples. The obtained results, in this work, shed light on the effect of gamma irradiations of Makrofol DE 7-2 SSNTDs to suitable industrial applications and to modify the optical, photoluminescence, hardness properties and surface wettability through gamma-induced modifications of the polymer structure.

Material and methods

Makrofol DE 7-2 introduced by Farbenfabriken Bayer A.G., Leverkusen (Germany), is a bisphenol-A polycarbonate where its chemical composition is $C_{16}H_{14}O_3$ with thickness of 300 μm and its density of 1.2 g cm^{-3}. The irradiations were obtained at room temperature with 1.25 MeV ^{60}Co gamma source up to 1000 kG y, which is available in NCRRT, Atomic Energy Authority, Cairo, Egypt. UV–vis measurements of pristine and irradiated Makrofol DE 7-2 samples were performed with Jasco V-576 (Japan) model double-beam spectrophotometer where its wavelength range is from 190 to 1000 nm. The induced defects in the irradiated Makrofol samples were determined with photoluminescence measurements at Nuclear Research Center (NRC), Atomic Energy Authority, Cairo, Egypt. The instrument has an RF-1501 SHIMADZU double monochromator spectrometer. The excitation wavelength for the pristine and that irradiated with gamma rays was 346 nm. The hardness was measured using a Shimadzu HMV-2000 micro-hardness tester at NRC. Vicker's diamond pyramid indenter was used with a square base and 360° pyramid angle to determine the Vicker's hardness, *Hv*. The measurements of the hardness were performed on the surfaces of all Makrofol samples at room temperature at load 100 mN and for duration time 40 s. The wettability of both pristine and irradiated samples was performed by the contact angle measurements using drop-distilled water on the surface of the samples. The surface roughness R_a was measured with TR110 Surface Roughness Tester. Three measurements were made for all samples and the roughness R_a values were calculated as the average of the three values.

Results and discussion

UV–vis analysis

The nature changes in the UV–vis absorption spectra of unirradiated and gamma irradiated Makrofol DE 7-2 samples are shown in Fig. 1. A remarkable increase can be observed in the optical absorption for irradiated samples compared with unirradiated one. These increases may be due to the formation of some electronic levels inside the forbidden gap after irradiation with gamma rays [18,19]. One can notice the existence of a shift in the spectra toward the higher wavelength for irradiated samples. This shift may be attributed to irradiation-induced defects in the polymeric materials [5,20–22]. In addition, the changes observed are attributed to unsaturation and the presence of hydroxyl and carbonyl groups [23]. Furthermore, after irradiation with gamma rays, a broadening of the absorption edge is observed. This broadening may be due to the formation of some defects due to gamma irradiation, i.e. the formation of conjugated bonds [19]. From the absorption spectra, the optical energy gap of the modified and unmodified polymers can be determined using the inter-band absorption theory using the relation [24]:

$$\alpha h\nu = B(h\nu - E_g)^n \qquad (1)$$

where α is the absorption coefficient and $h\nu$ is the incident photon energy. B is a constant, E_g is the optical band gap and n is an empirical exponent index that characterizes the transition mode. The exponent n has value of 1/2 for allowed direct transition, while it takes the value 3/2 for the direct forbidden transition. However, it has the values 2 and 3 for the indirect allowed and forbidden transitions, respectively [25]. In our case, the transition is allowed direct transition, where the electron transition is vertical from the top of the valence band to the bottom of the conduction band. The non-vertical transi-

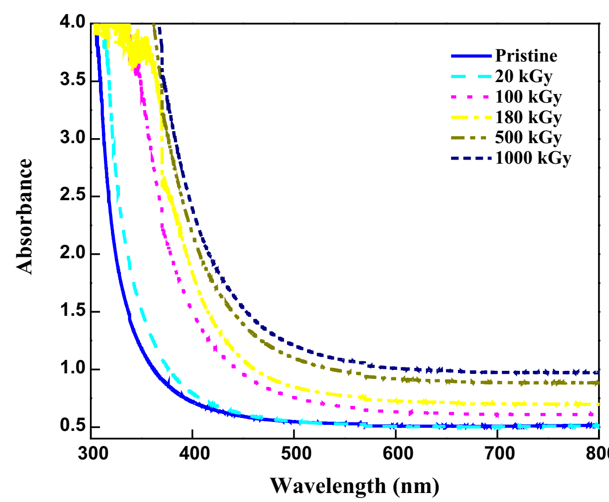

Fig. 1 Variation in UV–vis spectra of gamma irradiated Makrofol at different doses.