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Submicroscopic analysis of damage structure in nuclear tracks

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Abstract

When some irradiated polymer detectors are analysed at submicroscopic level, four zones can be distinguished in the damaged region surrounding the ion trajectory: core, halo, cross-linking and bulk. The folding track replica technique has been used in previous works to study track profile characteristics. In the present work, starting from track profiles, a method is suggested to evaluate the shape and size of the different track zones. It is applied to 49.5 MeV ^{19}F and 2 MeV ^{16}O ion tracks in Makrofol E.

Keywords: Track profile; Damaged region

1. Introduction

The ion irradiation of non-conducting polymers produces alterations in the local molecular structure, in which the intensity of damage varies radially from the projectile incidence axis to the bulk region of pristine material.

The ion's energy deposition is followed by a series of complex chemical reactions, in which many chemical species are created (i.e. ionised and stable molecules, free radicals, radical ions, etc.). Then, a non-homogeneous spatial distribution of primary precursors in latent tracks could be expected. Moreover, in several polymer materials the effect of these events involves two competing mechanisms: molecular strand breaking and molecular cross-linking.

Therefore, to understand the ion projectiles effect in polymers, a detailed description of the internal track structure is of great importance. Some authors proposed that, in some polymeric targets, four different zones can be distinguished in the region surrounding the ion trajectory, as a result of the projectile nuclear and electronic collision cascades: core, halo, cross-linking and/or local density increase, and bulk (Apel, 1982,1991; Apel and Pretzsch, 1986; Enge, 1995; Petersen and Enge, 1995; Apel et al., 1998; Francisco et al., 2004).

The track core is associated to the high charge density of the ion cloud formed very close to the ion trajectory. Because of the high amount of stored electrostatic energy, the cloud expands explosively generating an atomic collision cascade (Gröeneveld et al., 1980). The track halo, the zone that spreads out between the track core and the pristine material, is associated in the literature with the radiation damage produced by the electronic collision cascade (Spohr, 1990).

In some polymers a more detailed description of the halo distinguishes its external part, adjacent to the bulk region, as a transient zone, associated to the preponderance of molecular cross-linking over strand breaking.

After ion irradiation, a chemical etching process can be applied to the detector, to enlarge the track-damaged region up to a microscopic scale allowing the observation of the revealed tracks. Nevertheless for a detailed study of the actual damaged region characteristics, the use of methods offering

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track parameters information at submicroscopic level is required. In a submicroscopic scale, it should be expected that the different zones could be evidenced by the evaluation of radial etch rate.

At present there are two useful techniques that can be used to analyse the track zones structure at submicroscopic level in single tracks:

1. Conductometric technique (Schnoor et al., 1981; Apel and Pretzsch, 1986; Petersen and Enge, 1995; Schulz et al., 1997; Apel et al., 1998).
2. Track profile analysis applying the folding track replica method (Bernaola and Mazzei, 1991; Francisco et al., 2004).

   In the present work, starting from track profile images, a method is suggested to evaluate the shape and size of the different track zones. It is applied to an irradiated and etched material, Makrofol E, in which projectiles at certain conditions can induce cross-linking of the polymer molecules (Apel et al., 1989).

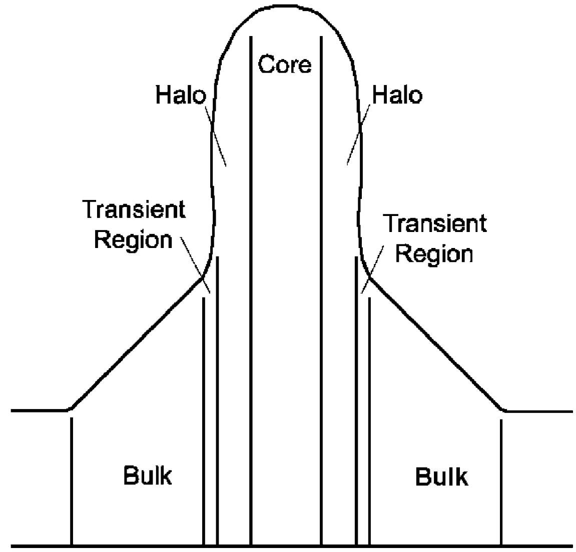

Fig. 1. Scheme of track profile zones.

2. Materials and methods

Makrofol E foils of 300 μm thickness were irradiated at normal incidence with beams of 49.5 MeV ^{19}F and 2 MeV ^{16}O in the Buenos Aires TANDAR accelerator. PEW solutions (30 g KOH + 80 g C_2H_3 OH + 90 g H_2O) at room temperature were used for the chemical etching. Relatively long etching times were applied in order to guarantee that the zone of bulk material is reached by the chemical attack.

Etched track replicas were produced through C–Pt vacuum deposition in a Balzers BAE 250 evaporator at a vacuum of 10^{-5} bar, and the folding track replica method (Mazzei et al., 1985; Bernaola and Mazzei, 1991) was applied to produce track profiles.

Then the replicas were observed at a Philips 300, transmission electron microscope and microphotographs of the desired profile images were obtained. The chosen image was then processed with a Scion Image computer program following the sequenced steps:

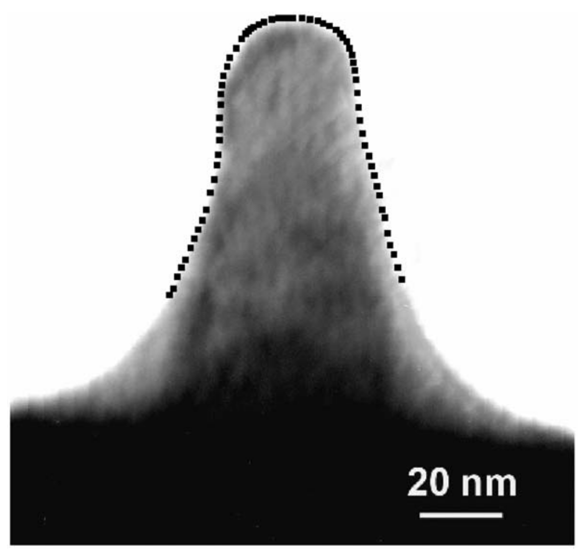

Fig. 2. Rotated image of a 49.5 MeV ^{19}F ion track profile with drawn pixel points. Etching time: 6 min at 20 °C.

(1) The TEM profile image is rotated to a position in which the flat zone corresponding to the core region is parallel to the x-axis,
(2) The external border of the profile is discretized with pixel size points and the numerical (x, y) coordinates of each pixel point are obtained. The resolution of the transmission electron microscope is about 1 nm but the processing technique resolution for the analysed profiles is of about 0.5 nm, which is assumed as the data error.
(3) To obtain the tangent value for each (x_i, y_i) point, Eq. (1) is used and a curve of this function at each marked point of the track profile is generated with a Spreadsheet Excel program

$$\left(\frac{\mathrm{d}y}{\mathrm{d}x}\right)_i = \frac{1}{2}\left[\frac{y_{i-1} - y_i}{x_{i-1} - x_i} + \frac{y_i - y_{i-1}}{x_i - x_{i-1}}\right]. \quad (1)$$

(4) A variation of 0.5 in the tangent values is assumed as a criterion to define the limits between the different track zones.