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Influence of UV light illumination on latent track structure in PET ☆

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Abstract

Xe-ion irradiated PET films were chemically etched and the pore growth process was monitored by the conductometric method. By assuming that the break-through probability of pores is a single Gaussian function of etching time and the conductivity of the etchant inside pores is an exponential function of etching time after pore opening, the experimental measurements were numerically analyzed and information related to track structure and its variation with UV-light illumination were acquired. It is found that with increase of UV-light illumination time, in addition to an increasing in track etching rate, distribution of track break-through time narrows significantly which indicates a great improvement in etched-through pore size distribution. The conductivity of etchant inside pores is found to be about half that of the bulk etchant just after pore opening. After etching proceeding in the track halo range, the reduced etching products inside pores enables an increase in conductivity with increase of pore size.

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Keywords: Polyethyleneterephthalate (PET); Ion track; UV light sensitization; Etching rate

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1. Introduction

Swift heavy ion in solids loses energy mainly through electronic energy loss processes and the energy deposition is centered in a very small region around the ion path. Cylindrical damaged zones, which are referred to as latent tracks, are produced along the ion path with structure and cross-section depending on ion energy, ion velocity and material

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properties, etc. Due to its great importance in basic science researches as well as in technological applications, latent track has been intensively studied in the past, especially in the last 20 years.

In inorganic crystalline materials, track morphology can be visualized through high-resolution electron microscope, scanning tunneling microscope as well as atomic force microscope. In organic materials such as polymers the application of these techniques is limited by the fact that these materials are highly sensitive to radiolysis [1,2]. Conductance measurements in combination with chemical etching have been found to be suitable for the studies in organic materials. This technique is originally designed for studying of the preferred etching of ion tracks [3–5], which was at that time a key point in ion registration by using plastic detectors. It was later realized that the technique could be utilized to reveal track structures in polymeric materials [6,7]. Since then valuable information on track structure in polymers has been provided. It is now generally accepted that tracks in most polymers possess a core and a halo [8–10]. In the track core the strong energy deposition of heavy ion destroys completely the original molecular structure whereas in the track halo cross-linking of molecular is dominant over chain scission.

UV light illumination technique has been commonly used in track membrane production [11] as UV light can sensitize track etching process [4,5]. In previous works we have studied the high energy heavy ion induced effects in polymers [12,13] and the influence of UV light illumination on track- and bulk-etching rates of PET films [14,15]. In this work we will concentrate on how track etching processes varying with UV light illumination by numerically analyzing the conductometric measurements.

2. Experimental details

The samples used were commercial available 12 μm thick poly-ethyleneterephthalate (PET) films (Hoechst Diafoil Company) which have a crystallinity of about 40% and a density of about 1.4 g/cm^3. Irradiations with 450 MeV Xe ions were performed at Takasaki Ion Accelerators for Advanced Radiation Applications (TIARA) of JAERI in vacuum and at room temperature. A total amount of about 3×10^5 ions/cm^2 were irradiated to an area of about 2×2 cm^2 with a beam flux of about 1.5×10^4 ions/cm^2/s. During irradiation ion beam was defocused to ensure homogeneity across the sample surface. As the projected range of the ion is around 44 μm in PET (TRIM calculation [16]), the electronic energy loss is almost constant ($\sim$11.66 keV/nm) across the sample thickness. After irradiation the samples were stored in air condition for 6–7 months.

The samples were exposed to UV light from one surface for various times in air before etching. The illuminations were conducted on a USHIO optical system which has a high pressure mercury lamp (SH-UI500XQ) as the light source with strong light emissions at 254, 313, 365, 405 and 435 nm. The light was filtered before injecting perpendicularly on the sample surface, first through a 10 cm long water cylindrical glass container and then through a glass filter, in order to reduce the light intensity (avoid heating of the sample) as well as to define the illumination wavelength. The glass filter (UV-31, Asahi Techno Glass) can cut UV light below 290 nm with a light transmission at 313 nm wavelength around 38%. Light flux density on the sample surface at the wavelength of 365 nm is around 35.3 mW/cm^2.

Chemical etching of the samples were conducted with 0.74 mol/L sodium hydroxide solution at a controlled temperature (40 ± 0.5 °C). Growth of the etched-through pores was monitored by the conductometric method [3,6]. During etching the sample was clamped between two Teflon cells and served as a barrier to the flow of etchant between the cells. Electrical resistance caused by the barrier is monitored continuously with etching time, from which the electrical conductance (G) through pores is evaluated by $G = 1/(R_\mathrm{m} - R_\mathrm{o})$ where R_m and R_o are the resistances of the etching system with and without the sample between the cells, respectively. The electrical conductance is related to pore radius (r) as follows:

$$G = \frac{\pi r^2 k \Phi S}{l}. \tag{1}$$