AFM method for investigation of polymers irradiated with fission fragments

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Abstract

Tracks of fission fragments at the surface of polymer (PET) films were studied using AFM. Two types of defects, corresponding to two main types of incident fragments (according to average energy distribution) were found.

Irradiation of stack of ultra-thin PET films by fission fragments was carried out and some sheets were then investigated separately. The deep structure of track was studied and the ranges for two types of fragments were estimated. The increase of area of destruction was found at the deep 10-12 mcm, which may be associated with changing of mechanism of interaction of passing particle with polymer and dominant role of nuclear interaction. The obtained results are supported by a model calculations.

Introduction

Some types of polymers are known as excellent track detectors. These polymers can be used for detection of accelerated ions and fission fragments. Irradiation with these high-energetic particles produces tracks in polymers –the cylindrical areas of destruction. The structure of tracks (radial and depth) are of great interest.

The use of AFM method seems to be very perspective for investigation of surface changes after irradiation of polymer – due to high sensitivity to relief change. In some previous works the heavy ions tracks at the surface as well as their structure and thermal stability were investigated [1,2].

The mechanism of destruction by fission fragments has some specific features. The range and energy losses for this case were calculated for example in [3]. But up to now there are a few works where tracks of fission fragments are investigated experimentally by microscopic methods. Moreover, the irradiation with fission fragments often gave us additional possibilities – for example, investigation of many thin sheets of polymer, packed into one stack, and, therefore the dependence of changing of polymer on the deep.

So the aim of this work is both aspects of AFM study: the size of fission fragments tracks and their deep structure. Such approach gave us possibility to compare two types of irradiation as well as the "radial" structure of track, obtained before and its "deep" structure.

Experiment

Irradiation by U^{235} fission fragments was carried out at nuclear reactor BR-10 (Institute of Physics and Power Ingeneering, Obninsk). The packet of 15 ultra thin (2.5 μm) closed-packed polymer poly(ethylene terephthalate) (PET) sheets was used for fission-fragments irradiation. After the irradiation experiments each sheet can be investigated separately; in our mind it is one of the ways to study "deep structure" of track. Some of these irradiated polymers were then etched in alkali solution (5N KOH, 60 ^{o}C, 1 h – "soft etching").

The atomic-force microscope (AFM) Solver P-47 (NT-MDT, Russia) operated in tapping mode (frequencies 150-350 kHz , in air, at room temperature) was used for investigation of samples surface. The unit was completed with NT-MDT silicon cantilevers with conical tips with high aspect ratio (cone angle is less than $22^{O)}$, typical curvature radius of tip – 10 nm and tip height 10-20 μm.

Results and discussion

The irradiation chamber had the temperature approx. 100 ^{0}C, so, the process of annealing took place simultaneously with the irradiation. The irradiation of the "packet" of many thin polymer sheets gave us possibility to investigate "the deep" structure of track. It is known that U^{235} nuclei usually disintegrate into two unequal parts with different mass and energies. According to mass

distributions of fission fragments two probability peaks exists – mean light 95 u. (mean initial energy 100 MeV) and mean heavy –138 u. (initial energy-70 MeV). Calculations were made (see also [4] and calculation below) and initial energy losses for these two types of fragments (at the entrance into polymer) were found to be about 7 keV/nm, and 10 keV/nm, respectively.
According to this two types of radiation defects were found at the surface of outside sheet see - Fig.1. It must be mentioned, that in this case the damaged area is much larger than in the case of Xe-ions with the same energy- it is connected with different electrical charge and energy of particles.

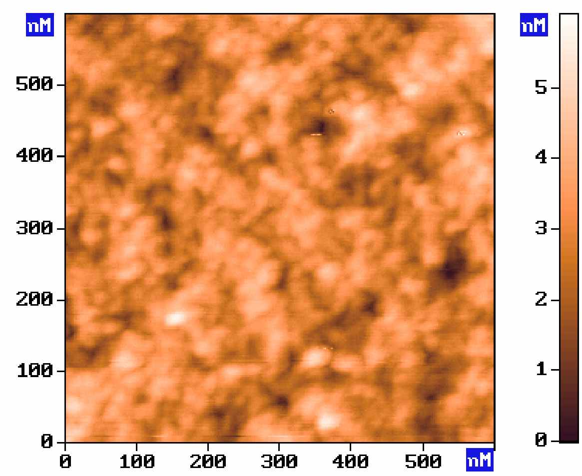

FIG.1 AFM image of upper sheet surface after fission fragment irradiation

Table . The average diameter of surface defects (tracks and pores), nm

Number of sheet	Initial, as-irradiated sample	Sample after chemical etching
1	60-80 and 20-30	120-140 and 70-80
2	20-30	60-80
3	20	100-120

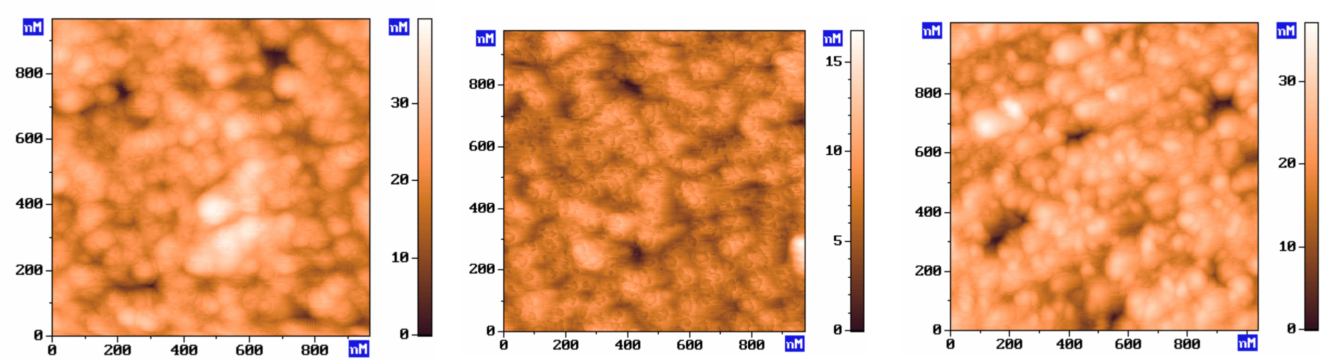

FIG.2 (a,b,c). Surface of sheets 1,3 and 5 (after “soft etching”)

The sheets from the 1st to 7th were tested. For better detection of the tracks "soft" etching was carried out then . The results for the sheets 1,3 and 5 are presented in Fig.2 (a, b and c – respectively) and in Table . It is easy to see that at the first sheet two types of defects, increased in size, are detected, while at the third and fifth –only one type. The size of defects is lower at third sheet than at the first, but the most interesting here is increasing of defect size at the fifth sheet. These results are supported by model calculations using Bethe-Bloch and Lindhard theories.

The Bethe formula used for quiet high velocities of an ion ($V >> V_0 Z$), has a form [5]:

$$-\frac{dE}{dx} = \frac{4\pi z^2 e^4}{m_e v^2} \ln\left(\frac{2 m_e v^2}{I}\right) \qquad (1)$$

For low ions speeds ($V < V_0 Z^{2/3}$) when a change of a charge of an ion and the electrons of an ion begin to interact with kernels of a target atoms the theory Lindhard has been used. The total losses of energy include electronic and nuclear [6] components.

$$-\frac{dE}{dx} = B\left[k_0 E^{1/2} + \frac{0.77\left(k_1^{-1} E\right)^{1/4}}{1.1 + k_1 E}\right] \qquad (2)$$

The calculation of a range of an ion in substance is carried out with use of classical dependence on energy losses, with allowance for conformities of relations to a Bethe-Bloch and Lindhard.

For ions range we used combination of (1) and (2) in order to take in account all velocities interval:

$$R = \left(\int_{E_{MAX}}^{E'} \left(dE/dx\right)_B^{-1} dE\right) + \left(\int_{E'}^{0} \left(dE/dx\right)_L^{-1} dE\right) \qquad (3)$$

Where E' is energy, at which Bethe-Bloch and Lindhard energy losses are equal.

As the results of calculations we obtain for the fission fragment with weight 95 u. -17 μm range and for the fission fragment with weight 140 u. -13 μm . These dada are in good correlation with AFM measurements.

The following explanation could be made – heavy fragments have the higher energy loss, shorter track length and therefore could be detected only in the first sheet. Light fragments, on the contrary, have smaller energy loss and longer track length and are detectable in "deeper" sheets. The increase of destructed area at the 5 th sheet is possibly connected with increasing of damage ability of fission fragment at the end of trajectory, due to changing of interaction mechanism - nucleon collision dominate here.

The electron microscopy of irradiated sheets in order to compare AFM and SEM data is now in progress.

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