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Degradation of nickel (86 MeV) ion irradiated polystyrene

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Abstract

Samples of polystyrene films were irradiated under vacuum at room temperature with $^{58}Ni^{7+}$ (86 MeV) ion with fluences ranging from 1×10^{11} to 1×10^{13} ions cm^{-2}. Ion induced structural modifications were studied by means of atomic force microscopy (AFM), X-ray diffraction (XRD), UV–visible absorption spectroscopy and Fourier transform infrared spectroscopy (FTIR) techniques. Atomic force microscopy shows that the root mean square (RMS) roughness of the irradiated polystyrene surface increases with the increment of ion fluence. XRD analysis reveals that in addition to the increase of amorphization of polymer with the increase of ion fluence there is also an increase of ordering (to a small extent) in some of the micro-domains. These results have further been supported by the study of optical and chemical analysis. The analysis of present study shows that the increase of full width at half maximum (FWHM) of first peak of XRD spectra, decrease of optical band gap and the formation of new alkyne group may be attributed to the increase of amorphization of polystyrene. Similarly, sharpening of second X-ray diffraction peak, decrease of Urbach's energy and increase in the absorbance ratio of I_{1222}/I_{1183} may be owed to the increase of ordering in some domains.

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1. Introduction

When swift heavy ions pass through polymers, a considerable amount of energy is transferred by the collisions with the electrons of the target material, resulting in transient high energy densities along the ion paths. The knocked out electrons, in turn, either dissipate their energy by collisions with other electrons or by electron–phonon coupling. High energy densities are known to be a prerequisite for phase transitions, which have occasionally been found to occur along swift heavy ion tracks. For example, heavy ions in the GeV range, impinging onto carbonaceous material (e.g. graphite, Kapton, etc.) give rise to formation of fullerenes [1]. In some cases there is ordering of the molecular alignment of polymeric chains after low-fluence ion irradiation [2] and vice versa i.e. transitions from crystalline to amorphous phase after high fluence ion impact have also been reported [3,4].

Pristine polymers often exhibit a grain structure or micro-domains. These micro-domains might be understood as dense zones (typically of 5–30 nm diameter) of aligned polymer chains (crystalline zones), embedded in low-density material with randomly arranged chains (amorphous zones). The micro-domains are gradually transformed during the heavy ion irradiation by degassing of volatile components, formation of radicals, double bonds and cross linking to dense carbon-enriched clusters, which become conducting and enable electron hopping between them [5].

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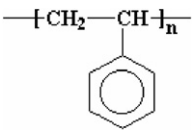
Polystyrene is one of the most stable organic polymers, which has made up a broad class of lightweight structural materials important in the automotive, aerospace and construction industries. The structure of the polymer-repeating unit can be represented as:



The presence of the phenyl (C_6H_5) groups is the key to the properties of polystyrene. These large, rings prevent the polymer chains from packing into close, crystalline arrangements, so that solid polystyrene is transparent. In addition, the phenyl rings restrict rotation of the chains around the carbon–carbon bonds, thus lending the polymer its noted rigidity.

In continuation to our earlier work [6] an attempt has been made to further investigate the micro-structural modifications in $^{58}Ni^{7+}$ (86 MeV) ion irradiated polystyrene, with emphasis on correlating the results obtained from the analysis of AFM, XRD, UV–vis and FTIR spectra.

2. Experimental procedures

The specimens of polystyrene in the form of flat polished thin films (~125 μm) were obtained from Good Fellow Ltd. (England). These were used as received form without any further treatment in the size of 1 cm × 1 cm. The samples were mounted on the sliding ladder and irradiated with $^{58}Ni^{7+}$ (86 MeV) ion beam using 15 UD pelletron facility in the general purpose scattering chamber (GPSC) under vacuum of $\sim 10^{-6}$ Torr at Inter University Accelerator Center, New Delhi. The electronic stopping power of $^{58}Ni^{7+}$ (86 MeV) ion in polystyrene is ~508.5 eV/Å [7]. The ion beam fluence was varied from 1×10^{11} to 1×10^{13} ions cm^{-2}. In order to expose the whole target area, the beam was scanned in the x–y plane. The beam current was kept low to suppress thermal decomposition and was monitored intermittently with a Faraday cup. The surface morphology of these samples was studied with a Veeco Digital Nanoscope IIIa Atomic Force Microscope. The polymers are soft materials; therefore the images were recorded in the tapping mode with a low force constant. Roughness RMS was determined as a mean from five scans over the same area. The X-ray diffraction patterns were recorded using the Cu K_α ($\lambda = 1.54056$ Å) radiation in θ–θ locked couple mode from the Brukar AXS D8 diffractometer with scan speed of 1°/min. The diffraction angle (2θ) has been varied from 5° to 45° with a step size of 0.02°. The measurements were done under ambient pressure conditions at room temperature. Each experiment was repeated at least twice and with both faces of the specimens alternatively exposed to the X-rays to check the reproducibility. The samples were analyzed with UV–vis

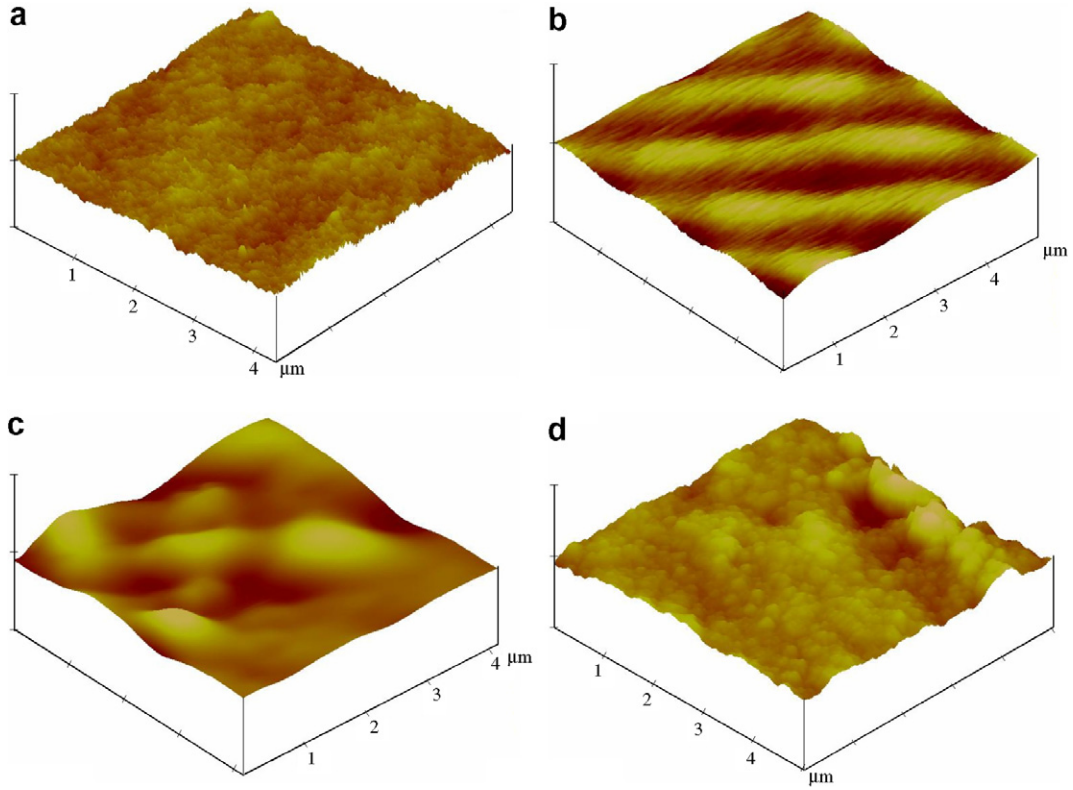


Fig. 1. AFM images (5 μm × 5 μm) of polystyrene irradiated with $^{58}Ni^{7+}$ (86 MeV) ion at (a) pristine, (b) with fluence 1×10^{11}, (c) with fluence 1×10^{12} and (d) with fluence 1×10^{13} ions cm^{-2}.