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ATOMIC FORCE MICROSCOPY OF HEAVY ION LATENT TRACKS IN SOME TRACK RECORDING MATERIALS

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ABSTRACT

The morphology, size and shape of different heavy ion latent tracks in different track recording insulators, viz. soda-glass, barium phosphate (BP-1) glass and SR-86 plastic are analysed under atomic force microscope (AFM). The heavy ion irradiations were made from UNILAC, GSI, Darmstadt and Heavy Ion Pelletron at Nuclear Science Center, New Delhi. The irradiated samples were etched for a very short interval (in seconds) in suitable etchants. The AFM was operated in lateral force mode. The average track diameter and depth is determined from the lateral force profile.

1. INTRODUCTION

The irradiation of solid materials by heavy ion beams has become a wide field of basic research, especially related to the underlying processes of damage creation and motivated a lot of interest in science and technology ranging from basic research on ion track creation (Fleischer et al., 1975; Durrani and Bull, 1987) to applied fields like microtechnology (Spohr, 1990) and material modifications (Mazzoldi and Arnold, 1987; Calcagno et al., 1992; Stoneham, 1994; Balanzet et al., 1995). The damaged zones created along the path of the heavy ions moving in solids are called heavy ion latent ion tracks. The size, shape and internal structure of these latent tracks resulted from many primary processes which are not directly observable. Although a lot of simple and more complicated models are proposed, we do not yet have a satisfactory explanation for the production of latent tracks in solids created by energetic by ionizing charged particles. Their detailed study is necessary to achieve a better understanding of primary processes of energy loss, bond breaking and dislocation of atoms, eventually leading to amorphization or increased chemical reactivity. A clear understanding of the structure and dimensions of these latent tracks has also vital importance for achieving an understanding of the mechanism behind track formation. The property of enhanced chemical reactivity in the regime of proximity to the ion track has made it possible to enlarge the tracks by chemical etching so that they can be visualised under the optical microscope. The etching approach does not provide exact information about the initial structure and nature of the ion tracks since a large amount of material is removed in the etching process and many other physical and chemical properties altered.

In the recent past, various techniques have been used for the investigation of morphology and structure of latent tracks in solids such as neutron and x-ray scattering (Albrecht et al., 1985), transmission electron microscopy (Scholz et al., 1993; Studer et al., 1986) and scanning tunneling microscopy (Coreger et al., 1990; Kemmer et al., 1992) In the past few years, several scanning probe microscopes [SPM] have been developed such as photon scanning tunneling microscope (Ferell et al., 1991), scanning ion microscope (Hansma et al., 1989), magnetic force microscope (Martin and Wickermasinghe, 1987 and atomic force microscope (AFM) (Binning et al., 1986). Atomic force microscope has an important advantage over other microscopes that images can be obtained for conducting as well as insulating surfaces on a nanometer scale. A sharp tip attached to a flexible microlever interacts with the surface underlying via contact forces. In the so called topographical mode, the AFM is sensible to the forces causing cantilever move up and downward while the tip follows the surface corrugation. In addition, lateral forces caused by friction result in a torsion of the lever around its long axis. The direct image of the surface morphology of the latent tracks made by AFM gives new information on track formation and its structure. With this technique it is possible to reach upto atomic resolution and to produce 3-D images of heavy ion impacts on the surface of material. Atomic force microscopy of heavy ion latent tracks in different track recording insulators, viz., polycarbonates, glasses, mica, etc., has been reported by different groups in literature (Thibadau et al., 1991; Ackermann et al., 1993; Rozlosnik et al., 1997; Vetter et al., 1998; Hagen et al., 1994).

In the present investigation, the samples of SR-86 plastic, BP-1 phosphate and sodalime glasses were irradiated from Heavy Ion Pelletron at Nuclear Science Centre, New Delhi and UNILAC, GSI, Darmstdt, Germany. The irradiated samples were etched for a very short time interval (in seconds) in suitable etchants. All these samples were scanned under atomic force microscope (AFM) being developed at CSIO, Chandigarh. The measured diameters and depths of heavy ion tracks are reported in this investigation. Track morphology is also revealed in all these samples.

2. EXPERIMENTAL DETAILS

The samples of soda glass were irradiated by ^{40}Ar (15.5 MeV/u) and ^{12}C (5.0 MeV/u) from UNILAC, GSI Darmstadt, Germany and Heavy Ion Pelletron at Nuclear Science Centre, New Delhi, respectively. Similarly, samplers of SR-86 plastic and BP-1 phosphate glass track detectors have been irradiated by ^{12}C (5.0 MeV/u) from the same source. The irradiated samples of soda glass by Ar(15.5 MeV/u) were etched in 5% HF for 10 seconds at room temperature. The surface of the etched samples of soda glass has been investigated under atomic force microscope at Central Scientific Instruments Organization at Chandigarh. Similar investigation was made on soda-glass material irradiated by ^{12}C (5.0 MeV/u) and etched for 30 seconds in vol. 5% HF at room temperature. The details of irradiations and etching conditions are given in Table 1. All the irradiations were made at an angle of 90° w.r.t. the surface of the detector.

Table 1. Irradiation and etching parameters.

Sample	Ion	Energy MeV/u	Fluence Ions/cm²	Etchant	Etching time
Soda glass	Ar	15.5	10^{12}	vol.5%HF	10 sec
Soda glass	C	5.	10^{12}	vol. 5% HF	30 sec
SR-86 plastic	C	5.0	10^{14}	6.0NaOH	8min.

3. RESULTS AND DISCUSSION

The scanned surface of the soda glass detector irradiated by Ar (15.5 MeV/u) heavy ions and etched for only 10 seconds in vol 5% HF at room temperature is shown in figure 1. Each dark spot represents an impact of a single ion with the soda-glass detector. The scanned area of the sample was 1299x1299 nm². AFM images were taken in lateral force and topographical mode. The topographical mode is sensitive to change of height of surface stucture. In lateral force mode force sensing cantilever records torsion around its long cylindrical axis and is particularly sensitive to friction. Hagen et al. (1994) have reported that the ion track having damaged zone exhibits a significantly

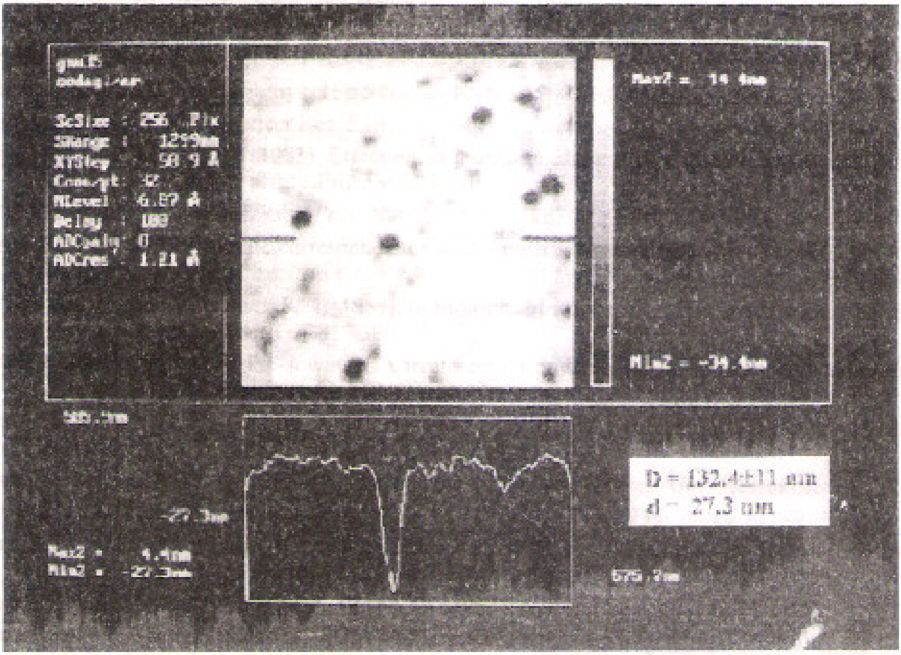

Figure 1. AFM image of ^{40}Ar (15.5 MeV/u) heavy ion tracks in soda-glass.

higher friction coefficient than the surrounding undamaged region. A lateral force image showing ion induced damaged zone is depicted in figure 1. The diameter of an individual track can be estimated from lateral force profile perpendicular to the scanning surface by marking a left and right position to the damaged zone. Track diameter is measured in between these marks distinguishing between damaged and undamaged region. The observed track diameter is 132.4 nm and depth 27.3 nm. A single impact of Ar ion in soda-glass is shown in figure 2, where scanned area is 520x520 nm^2 observed track diameter is 130.2 nm and depth 24.4 nm. The scanned surface of soda-giass irradiated by ^{12}C (5.0 MeV/u) and etched in vol. 5% HF at room temperature is shown in figure 3. A large number of tracks can be seen in this microphotograph due to a large scanned area of 7779x7779nm^2. The average diameter of the track is 374.2±24nm and the depth of tracks varies between 140 to 200nm in the scanned area. Figure 4 shows tracks of carbon ion in soda-glass where scanned area was small 2874x2874 nm^2.

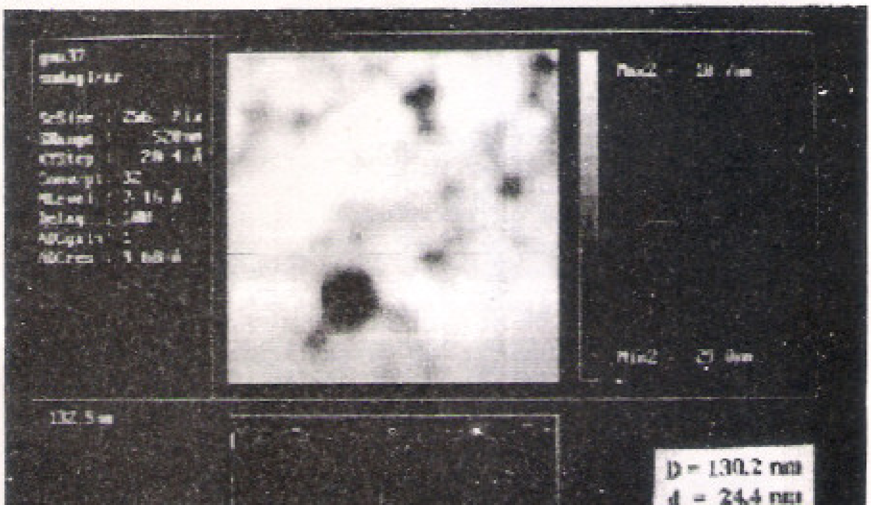

Figure 2. AFM image of single impact of ^{40}Ar(15.5 MeV/u heavy ion tracks in soda-glass.

From the class of plastic track recorders, CR-39 is used in many applications because of its high detection sensitivity and charge resolution. Fujii et al. (1991) have studied the relationship between the molecular structures and sensitivity to charged particles by using commercially available themosetting resins. They have shown that the introduction of sulphonate groups into themosetting resins with three dimensional network structures increases both bulk and track etch rates. This new track detector known as SR-86 is a co-polymer of CR-39 with DEAS, diethylene allyl sulphonate and shows higher sensitivity than CR-39 and CR-39 (DOP) to -particles from^{241} Am and ^{252}Cf (Randhawa et al., 1997). Figure 5 shows the morphology of SR-86 plastic detector irradiated by

^{12}C(5.0 MeV/u) heavy ions with a fluence of 10^{14} ions/cm^2 and etched in 6.0 N NaOH solution for 8 minutes at room temperature. Due to a high fluence of carbon beam no

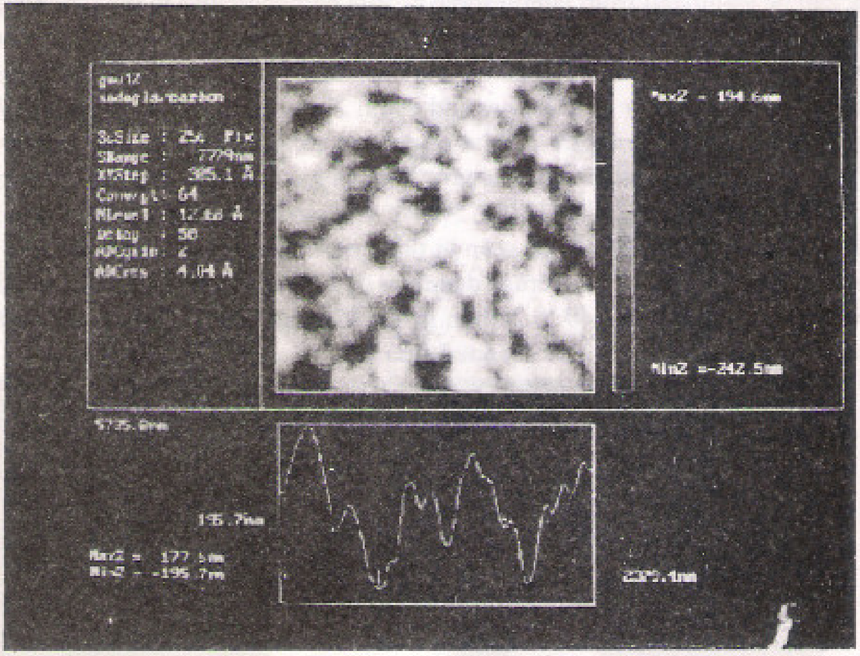

Figure 3. AFM scanned surface of soda-glass irradiated by ^{12}C(5.0 MeV/u).

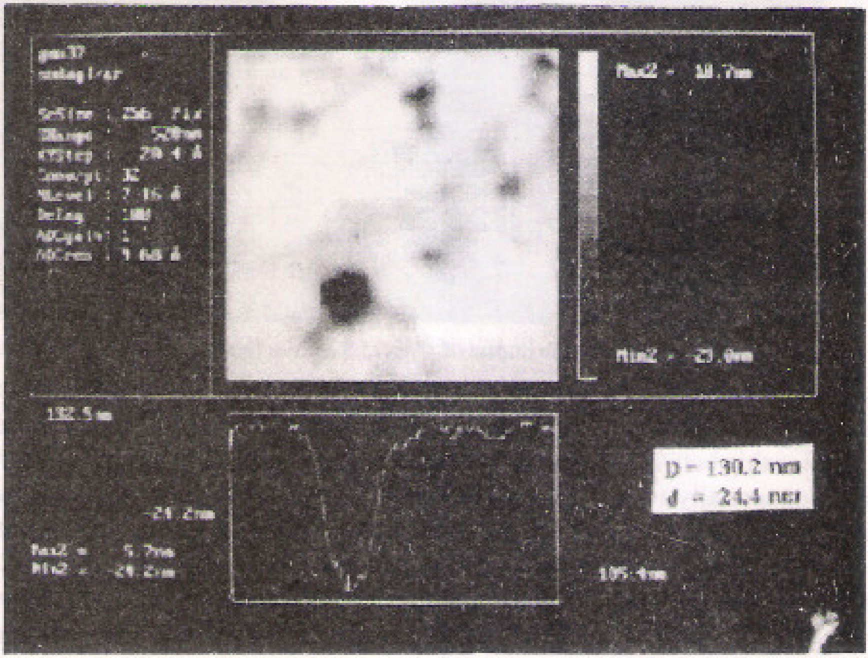

Figure 4. AFM image of ^{12}C(5.0 MeV/u) heavy ion tracks in soda-glass.

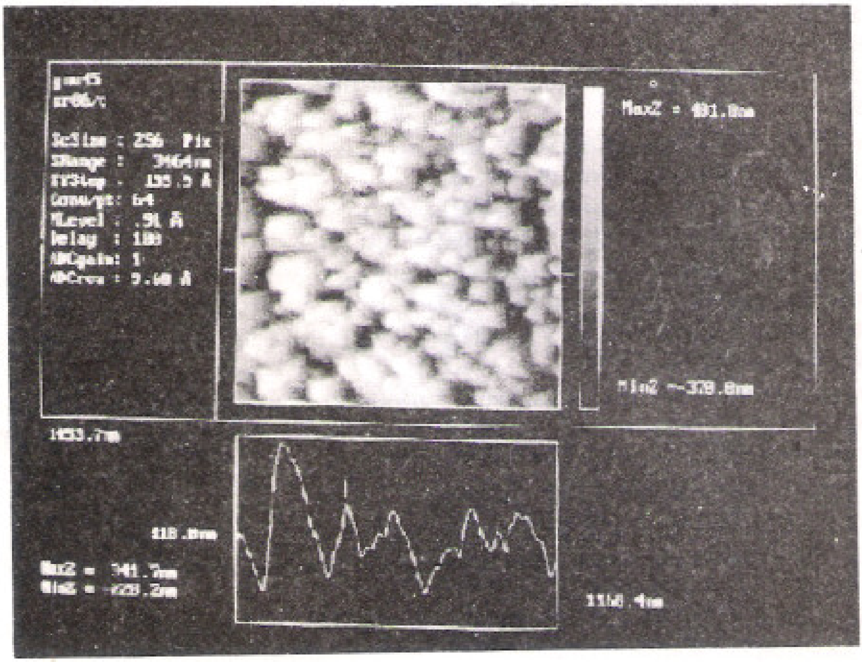

Figure 5.AFM scanned surface morphology of SR-86 track recording insulator irradiated by ^{12}C (5.0 MeV/u).

single ion track is resolved in this figure. A large damage is visible in this micro-photograph. The material modification results in SR-86 are reported elsewhere (Virk et al., 1998).

4. CONCLUSIONS

1. The morphology, size and shape of heavy ion tracks in glasses and plastics is analysed successfully under AFM after a slight etching in a suitable etchant.
2. Track diameter and depth are determined in the nanometer range.
3. The profile of damaged and undamaged surface of a material can be sucessfully resolved.

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