Volume 6, Number 10
1004-423X/97/06100746-06

ACTA PHYSICA SINICA
(Overseas Edition)

October, 1997
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HEAVY ION TRACK DIAMETERS IN MICA STUDIED WITH SCANNING FORCE MICROSCOPE

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(Received 25 February 1997)

In the present study, the scanning force microscope (SFM) was employed to measure the heavy ion track diameters in mica and was operated in the lateral-force mode with different loading forces. The mica samples were irradiated with Se, Au, Pb and Zn ions with a kinetic energy of 11.4 MeV/u at the UNILAC of GSI. The measured average track diameter increased slowly with increasing loading force between the SFM tip and sample. The experimental data pointed out that the track diameter versus loading force could be fitted by a linear function both for Se and Au ion species and the slopes of the fitted lines were nearly the same. By extrapolating to zero loading force, the intrinsic diameters of the ion tracks were obtained. A possible mechanism for the observations was discussed.

PACC: 6180; 6820

I. INTRODUCTION

In the recent decade, after its invention in 1985, atomic force microscope (AFM), or scanning force microscope (SFM) has been used to investigate the latent ion track, especially in mica.[1-3] All the published results have a common conclusion that the average diameters of the ion track increases with the increase of electronic energy loss of heavy ions in solids. However, there is a systematic deviation in the measured track diameters from one group to another. The problem may come from the difference in mica samples and may result from the different methods of evaluating the track diameter. More importantly, it may also result from some physical effects. The calculated results by Heuberger *et al*.[1)] showed that there was an elastic deformation both on Si_3N_4 SFM tip and mica sample when an external force in the range from 10^{-12} to 10^{-7} N was applied on the tip. These results have a hint that when SFM is used to investigate the latent heavy-ion track in mica, the elastic deformation both on the tip and the sample should be considered.

In this study, the SFM loading forces from about 20 to 100 nN were applied on the SFM tip to investigate their effect on the measurment of track diameter.

II. EXPERIMENTAL PROCEDURE

Muscovite mica samples were irradiated under normal incidence (perpendicular to

[1)] Private communication.

the (001) cleaved plane of mica) with 11.4MeV/u Se, Au, Pb and Zn ions at the universal linear accelerator (UNILAC) of GSI-Darmstadt. The ion species, their total energy, electronic energy loss and penetration depth in mica are given in Table 1. The values of energy loss and the range in mica were calculated with TRIM code.[4] The ion dose used in this study was chosen to be 5×10^{10} cm^{-2} to induce nonoverlaped ion tracks.

Table 1. The ion species, energies, energy losses and ranges in mica.

Ion species	Total energy /GeV	Energy loss/keV·nm^{-1} at mica surface	Range/μm
Au	2.67	23.7	110
Se	0.912	7.53	100
Pb	2.37	25.9	95
Zn	0.729	6.15	95

After irradiating with heavy ions, the mica samples were cleaved by using an adhesive tape to obtain a fresh surface without absorbates and were investigated with a home-made SFM in air. The commercial SFM cantilever and tip are made of Si_3N_4 and the cantilevers used in this work are bar-shaped and V-shaped. All the SFM images were acquired in a constant force mode. During one time of tip scanning, four images were registered simultaneously and were named "topographical images" and "lateral force images", respectively. In the previous publications, it has been shown that in Ref [3]. the contrast of the latent tracks in these images were originated from the difference of local friction on the surface and there was no evident difference in determining the track diameters based on these two kinds of images. In this paper, all the images used to evaluate the track diameter are the "lateral force images".

III. RESULTS

Even as the SFM loading force was increased up to 100 nN, there was no track

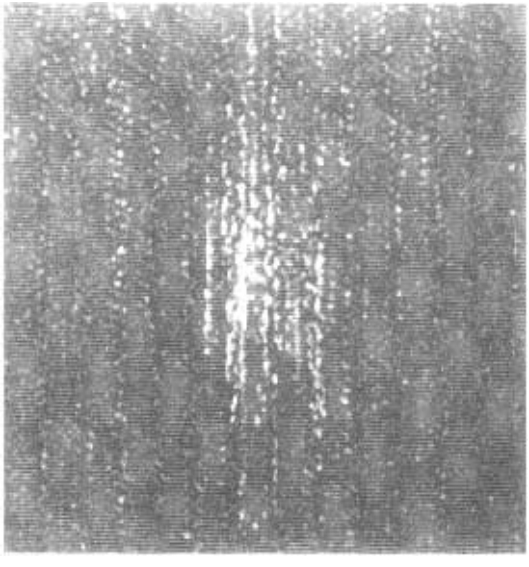
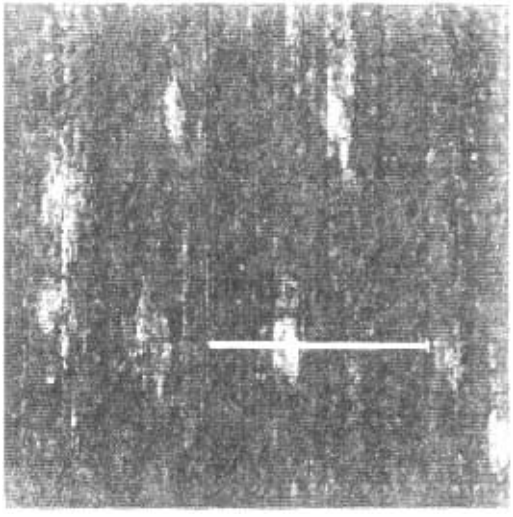


Fig.1. The Se ion-track in SFM image with high resolution. The ion energy is 11.4 MeV/u, and the SFM scanning area is 29.1 nm × 27.5 nm.

could be seen on the surface of the un-cleaved mica sample because of the absorbates. For the freshly cleaved samples, the latent tracks could be seen when the SFM loading force exceeded 10nN. Figure 1 is a high-resolution image of ion track surrounded by the crystalline mica lattice. Figure 2 (a) is a typical latent ion-track SFM image of 100 nm × 100 nm. From the above images one could see that the track zone is damaged into amorphous material and the image contrast comes from the difference in local friction between the amorphous track zone and the perfect mica lattice.



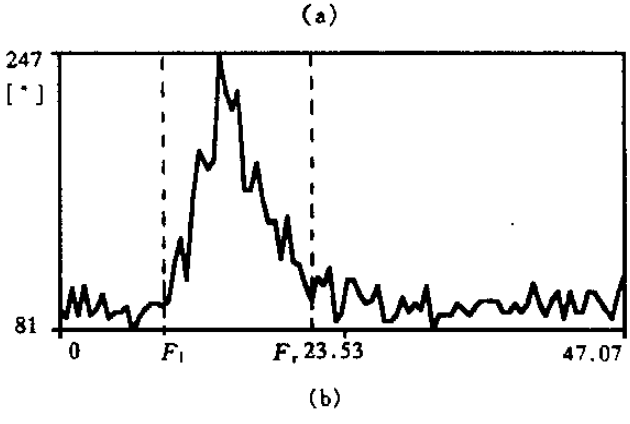


Fig.2. (a) SFM image of Se ions track in mica. The scanning area is 100 nm × 100 nm; (b) the profile of the ion-track shown in Fig.2(a).

From the track profile obtained by SFM, as shown in Fig.2 (b), the track diameter F_lF_r was evaluated by determining a left and a right feet. The detailed procedure of determining the diameter could be found elsewhere.[2] Normally, about one hundred or more ion-tracks were evaluated for each ion species and at each SFM loading force. Figures 3(a) and 3(b) show the typical distributions of Se ion-track diameters,

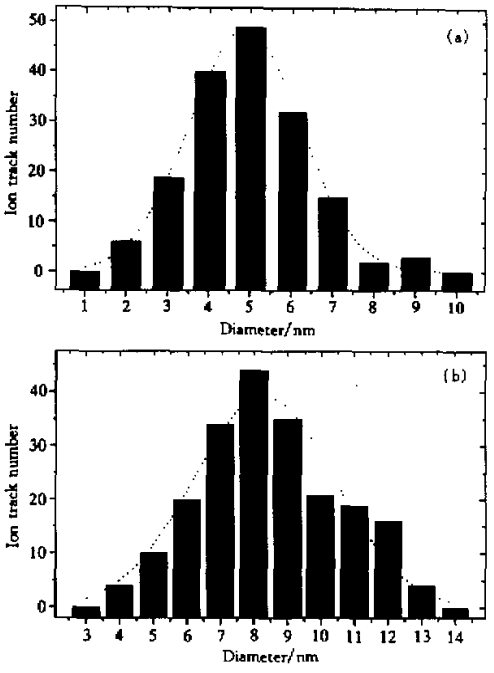


Fig.3. The histrogram of track diameter measured with SFM. The Se ion energy is 11.4 MeV/u. The SFM loading force is (a) 21.8 nN; (b) 94.7 nN.

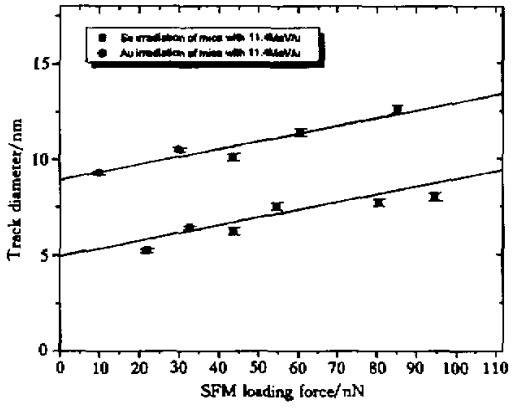


Fig.4. The relationship of SFM loading force with track diameter.

and the average diameter of the track could be determined from a Gauss fitting of the

histogram of the track diameter. The relationship of the average diameter of ion track with the SFM loading force is shown in Fig.4 for Se and Au irradiation, and one could find that the track diameter increases slowly with the increase of the SFM loading force. With the same procedure, the average track diameter of 7.2 nm at the loading force of 76.2 nN and 11.1 nm at 10.9 nN for Zn and Pb irradiation of mica were obtained, respectively.

Approximately the data points of track diameter were fitted with a linear function. The most interesting thing is that the two fitting lines nearly have the same values of slope 0.04.

IV. DISCUSSIONS

When the heavy ions penetrate the mica samples, they deposit their kinetic energy in the lattice and damage the crystalline mica into amorphous zones. As the formation of the ion tracks is mainly due to the energy deposition, the track diameter should only depend on the amount of energy loss of heavy ions in mica. From Fig. 4, one could find that the average track diameters measured in our experiments also depend on the SFM loading force applied on the tip. It is believed that the above relationship of the track diameter with loading force comes from the deformation of the SFM tip and the mica sample when an external force is applied.

For a first-order approximation, i.e., linear approximation, the following model was constructed. Assuming that the original contact width between the tip and surface is t and that it would increase to $t+\Delta t$ when a loading force of F is applied, the increment Δt may equal to

$$\Delta t = k_1 F, \tag{1}$$

where the constant k_1 is determined only by the mechanical properties of the tip and the sample.

The intrinsic diameter of an ion track is assumed to be d_0, which is resulted from the irradiation of heavy ions, and the measured diameter of the ion track by SFM is d (see Fig.2). If t is much smaller than Δt, then the intrinsic diameter of the ion track would be

$$d_0 \approx d - 2k_1 F. \tag{2}$$

Comparing with the track measurements of mica sample irradiated by Se and Au at an energy of 11.4 MeV/u (see Fig.4), i.e., the slope of the fitting line 0.04, one could obtain the constant k_1 from the linear fitting for Si_3N_4 tip and mica sample as

$$k_1 \approx 0.02 \text{ m/N}.$$

By using this constant of k_1 with Eq.(2), one could convert the experimental diameter d measured from SFM to an intrinsic one d_0, which are 8.9 and 4.9 nm for Au and Se ion irradiation of mica, respectively. And also the values of track diameter for Zn and Pb ion irradiation of mica were converted from 7.2 to 4.2 nm and from 11.1 to 10.6 nm, respectively.

All the above extrapolated values of track diameter are plotted in Fig. 5 with the electronic energy losses near the surface. The error bars of ±2 nm come from the difficulty in determining the feet-points in track profiles. It is clear from Fig. 5 that the intrinsic track diameter increases with the energy loss. The data of track diameters from other measurements and methods are also shown in Fig. 5. One could find that our new extrapolated data are quite close to the Ackermann's early values of track diameters measured by SFM and they are also in good agreement with the small angle X-rays scattering experiment.

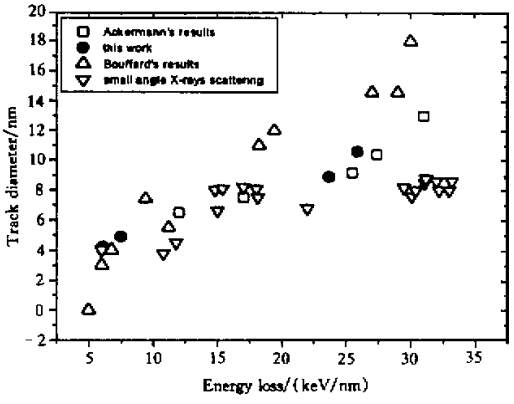


Fig. 5. Track diameter in mica as a function of electronic energy loss.

V. CONCLUSIONS

In this paper, the diameter of latent ion track induced by Au, Se Pb and Zn ions with an energy of 11.4 MeV/u were measured with SFM at different loading force. The experimental results showed that the average track diameter increases slowly with the increase of the SFM loading force. By extrapolating the linear fitting lines, the intrinsic track diameters could be obtained at zero loading force. The slopes of the fitting lines for Au and Se ions irradiation of mica are nearly the same and may also be applied for Zn and Pb ions. The results also showed that the higher the ion energy loss, the larger the intrinsic track diameters.

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