HREM investigation of latent tracks in GeS and mica induced by high energy ions

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Abstract

Observations of heavy ion latent tracks in layered materials were carried out with a 400 kV high resolution electron microscope as well as with conventional 100 and 200 kV microscopes. The materials were irradiated normal to the cleavage plane at the UNILAC-accelerator at GSI Darmstadt with ions up to several MeV/u. High-resolution images of latent tracks in muscovite mica and in GeS single crystals are presented in this paper. The micrographs show that the track core represents a disordered zone. Depending on the diffraction conditions in the surroundings of the tracks, strain contrast centres are visible. The boundary between the amorphous track core and the intact crystal lattice is well defined. The cross sections of the tracks in mica have a nearly circular shape. In contrast to that they are elliptical in GeS and are well oriented with respect to the crystal lattice. The sharp amorphous-crystalline transition allows the exact measurement of the track dimensions. The values resulting for the track diameters show a large variation in size depending on the ion sort. The tracks produced by heavy ions have more than twice the diameter of those produced by light ions. Relations between the track size and the energy loss for different ions are given. © 1998 Elsevier Science B.V. All rights reserved.

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1. Introduction

In insulating or semi-conducting materials an energetic heavy ion produces a considerable alteration of the original structure along its trajectory. At high velocity, the ion loses its energy mainly by interaction with the electrons of the solid. If the kinetic energy exceeds 10 MeV/u, the ion is successively transferring more than 10 keV per lattice plane in very short time intervals. Thus, the ion passage creates conditions initiating dramatic, rapidly developing primary processes which cannot be observed directly. However, the details of size, shape and internal structure of the ion track, though representing the final stage of the damage creation, contain indirect information about the
possible scenarios taking place in the medium after the passage of the ions.

The structural changes range from the occurrence of point defects via separate atomic clusters to continuous damage in regions called latent tracks, in which the crystal can be fully amorphized. Samples containing a large number of latent tracks have been investigated by a variety of methods: scattering of X-rays and neutrons or infrared spectroscopy. To provide also access to single tracks, transmission electron microscopy (TEM) was used. Scanning tunnelling (STM) and scanning force microscopy (SFM) were applied as well. The above microscopic techniques are capable of characterising the object under study with atomic resolution. At lower resolution TEM has been applied first to image fission fragment tracks in mica [1,2]. Later, high-resolution TEM of latent tracks was applied successfully to a variety of crystalline materials such as yttrium–iron-garnet [3–5], zircon [6,7], GeS [8–11] and high temperature superconductors [12]. In the present work, cross sections of latent tracks induced by heavy ions in GeS and mica were investigated by means of HREM as a function of different kinds of ions and their energy loss.

2. Experimental

Crystals with good cleavage properties are preferred for investigations of the cross sections of heavy ion tracks by HREM. GeS single crystals can be easily cleaved along their (0 1 0) crystallographic planes which are atomically flat over distances of several μm. The most characteristic property of muscovite mica KAl₂(SiAl)O₁₀(OH,F)₂. is also its perfect cleavage along the (0 0 1) basal plane into very thin sheets. Thin samples of these materials were irradiated at the UNILAC with different kinds of ions accelerated to energies between 5.6 and 13 MeV/u at fluences between 10¹⁰ and 5 × 10¹⁰ ions/cm². Utilising the easy cleavage of GeS and mica thin flakes were successively removed from the irradiated side by using an adhesive tape or a razor blade. They were placed between double-grids for conventional TEM observation. For high-resolution investigations some of the GeS flakes were subjected to additional short-time ion thinning. The samples were examined in JEOL100C and 4000EX microscopes and in a Philips CM20 microscope. These procedures allowed us to observe directly the cross sections of latent ion tracks.

3. Results and discussion

3.1. TEM of germanium monosulfide

In Fig. 1 (a) and (b) micrographs of cross sections of latent ion tracks are shown as they were induced in GeS by ¹²⁹xe and ¹⁹⁷Au ions with an energy of 11.4 MeV/u, i.e. without any additional chemical or physical treatment. The number of the tracks in the observed region corresponds to the ion fluence. The damaged volume of the tracks is more transparent for the electrons than the surrounding crystalline matrix under the diaphragm condition used. The cross sections have an almost elliptical shape and are always oriented with their long axis along the closest packed a₀ 0 0 1 crystal direction in the imaged plane. A tendency for faceting is noted. A comparison of the two images 1(a) and (b) taken with the same magnification shows that the cross sections are obviously of different size. The high-resolution EM image of a cross section shown in Fig. 2 reveals that the latent ion track is completely amorphized. In this case the track was created by a uranium ion.

Germanium monosulfide has an orthorhombic lattice. The (0 1 0) plane imaged in Fig. 2 is characterised by the lattice constants a = 0.429 nm and c = 0.3645 nm. They can be used for an exact determination of the real magnification of the microscope.

The boundary between amorphous and crystalline area is extremely sharp and therefore allowed an exact measurement of the size of the damaged area. In Fig. 3 averaged values for the cross section axes of latent tracks of different ion species
in GeS are plotted versus the energy loss. The TRIM code [13] was used to determine the energy distribution along the ion path and the penetration depths. This diagram shows significant differences in cross section sizes for various ions as was already illustrated in Fig. 1 for two ion species. The number of displaced atoms in the cross section plane can be calculated from the data shown in Fig. 3. In Fig. 4 the numbers of displaced atoms are plotted as a function of ion energy loss in GeS.
3.2. TEM of muscovite mica

High resolution images of track cross sections in muscovite mica have been acquired in the recent past for a series of heavy-ion species by SFM [14–16], providing the functional dependence of track diameter versus ion energy loss. In our study the latent tracks in mica were imaged by TEM. In accordance with the SFM measurements, it was found that their cross sections appeared almost circular.

Cross sections of Xe and U ions in mica are compared in Fig. 5. Pb ion tracks are shown with high magnification in Fig. 6. Similar to GeS the original structure of mica is completely destroyed within the ion track. The boundary of latent tracks in mica also appears sharp as in the case of GeS. However, no strain contrast regions have been observed in the neighbourhood of the tracks. The mean track diameters are shown as a function of the ion energy loss in Fig. 7.

4. Conclusion

Our ion bombardment experiments have shown for both GeS and mica that the crystal structure is completely amorphized in the latent track. The
boundary between amorphous areas and crystalline matrix is sharp without any smooth transition. In agreement with previous SFM results, we find that the average size of the track cross sections depends strongly on the ion energy loss. The form of the ion track cross section depends on the degree of crystal symmetry. In GeS, a crystal with a low symmetry, the cross sections are elongated with a tendency for faceting, the principal axes being directed along the crystallographic axes. The radial extension of the amorphisation reaches its maximum (minimum) along the symmetry axis with the lattice constant \( c = 0.3645 \text{ nm} \) (\( a = 0.429 \text{ nm} \)).

In the case of mica which possesses a hexagonal lattice and thus a higher symmetry than GeS, the observed cross sections are nearly circular. No strain contrast was found in mica, giving rise to the assumption that the strain contrast in GeS can also be attributed to the lower crystal symmetry.

HREM technique used in this investigation allowed us to obtain images of the ion track cross sections with high-quality contrast, that is essential for the exact measurement of the track sizes.

References