Highly porous tracks in fluorapatite*

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In volatile-rich fluorapatite, which represents 70 % of all fission track age-determinations, tracks produced along the trajectories of fission fragments have been considered to be cylinders of radiation-damaged amorphous material, similar to tracks in other minerals, such as zircon [1]. The atomic-scale structure of unetched fission tracks controls temperature-induced "fading" and finally leads to shortening of the etchable length of a track. Here, we demonstrate that tracks in apatite are actually highly porous tubes instead of amorphous cores [2]. The atomic-scale studies of the highly-porous tracks in apatite are essential not only for geophysics community to unravel mechanisms of track annealing but also for the ion-matter community to understand the track formation mechanism.

Two types of tracks were investigated in fluorapatite ($Ca_{10}(PO_4)_6F_2$), from Durango, Mexico: (1) randomly oriented thermal-neutron induced tracks from fission of ^{235}U; (2) parallel tracks produced along the *c*-axis of the material by exposing 50-µm thick single crystals to 2.2-GeV Au ions from the UNILAC accelerator of GSI. For transmission electron microscopy (TEM) observations the samples were crushed and suspended on a carbon film supported Cu grid. *In situ* heating of fission tracks was performed by using a hot-stage TEM specimen holder.

A high resolution TEM (HRTEM) image of highly porous tracks produced with 2.2-GeV Au ions is shown in Fig. 1. During this TEM analysis the electron current density (~ 0.5 A/cm^2) was low to minimize electron-beam induced damage. The central core region of the track has the same bright contrast as the free space outside the sample grain, suggesting that no solid components remain in the track core. The Airy pattern in the fast Fourier transform (FFT) image (inset) from a region centred in a track confirms that the track is highly porous. During the *in situ* heating of fission tracks (Fig. 2), Cu atoms obviously diffuse through the track opening into some of the highly porous fission tracks, forming cylindrical Cu nanorods through capillary action.

The formation of the porous track in apatite is ascribed to the highly ionizing energy deposition of fission fragments inducing radiolytic decomposition of fluorapatite accompanied by the loss of volatile elements [2]. As a result of the significant mass loss and "density jump" between the tracks and the surrounding crystalline matrix, the Fresnel contrast (contrast change at different TEM focus conditions) can be seen for tracks in apatite (see Ref. 2 for details). This is in contrast to amorphous tracks, where the interface to the matrix remains dark when changing the focus, because the track density change is insignificant as compared to that of the porous track [2].

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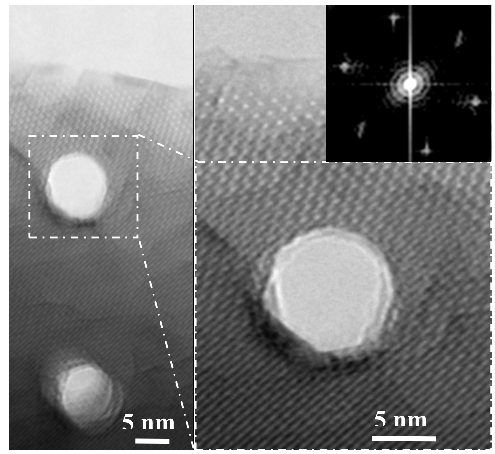

Figure 1: Plan-view HRTEM images of tracks in apatite induced by 2.2-GeV Au ions showing a highly porous core. Airy pattern shown in the FFT image (inset) is caused by the electron diffraction from the highly porous track, acting as an aperture.

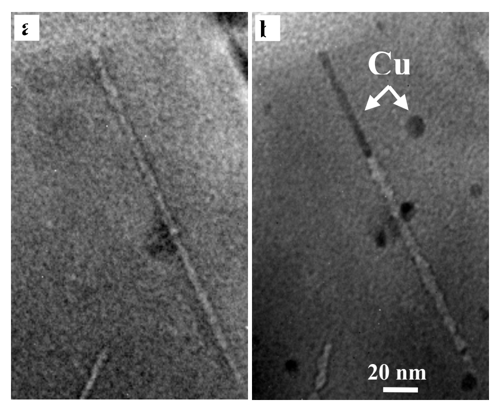

Figure 2: *In situ* heating of fission tracks in apatite. TEM images (a) before heating and (b) after the temperature is stabilized at 700 °C for 1 min. Cu atoms from the supporting copper grid (dark features in (b)) diffuse into a fission track through the open end and form a nanorod inside the track.

References

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