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ACTIVATION ENERGY OF TRACK ANNEALING IN MINERALS AS A FUNCTION OF INTERATOMIC SPACING

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Abstract - Experiments have been performed to study the annealing of nuclear tracks in some crystalline minerals viz. apatite, zircon and garnet. It is observed that the value of activation energy of track annealing (Ea) depends upon the interatomic spacing. Some new results on activation energy of track annealing in crystalline minerals are reported.

1. INTRODUCTION

Despite a large number of annealing studies in a variety of minerals and glasses, very little is known about the physical nature of the annealing process. The most successful approach to describing track annealing is based on the diffusion of elementrary point defects. According to this assumption, track fading occurs as interstitially displaced atoms thermally penetrate an activation barrier to recover their initial (lower energy) lattice positions[1]. Because a crystal has a regular atomic structural arrangement and since the atomic spacing is very variable along different crystallographic orientations, in an anisotropic mineral, the annealing properties of latent tracks will not be identical in every direction. It has been shown earlier[2,3] that in case of apatite the fission tracks lying parallel to the c-axis are more resistant to annealing than those lying perpendicular to this axis. The present study investigates the track annealing kinetics in apatite, zircon and garnet, in order to see the dependence of Ea on interatomic spacing.

2. EXPERIMENTAL PROCEDURE

Different samples from $10\bar{1}0$ and 0001 plane of apatite were prepared and polished. These polished samples were then irradiated with Cf-252 fission fragments at 15 ± 2^{o} angle of incidence. The irradiated samples were heated at 300, 325, 350, 400 and 425°C for 10 min in each case. These samples were etched for 3 min in 2 % HNO_3 at 25°C and the mean track length was measured at each heating event. The track annealing rate, V_a, is calculated as:

$$V_a = (L_o - L) / t \qquad (1)$$

where L_o and L are the mean lengths of unannealed and annealed tracks, respectively.

Similar experiments were carried out on different planes of zircon and garnet. The unannealed and annealed samples of zircon and garnet were etched in $HF:H_2SO_4$ (175°C, 14 hrs) and 5ON NaOH (150°C, 3 hrs), respectively. The track lengths were measured at each heating event. The plots of $\ln V_a$ vs $1/T$ for apatite, zircon and garnet are shown in Figs. 1, 2 and 3, respectively. The following empirical relation[4]:

$$V_a = At^{-n} e^{-Ea/kT} \qquad (2)$$

is used to determine the activation energy, Ea, for different planes of each mineral. The values of Ea are shown on the respective figures.

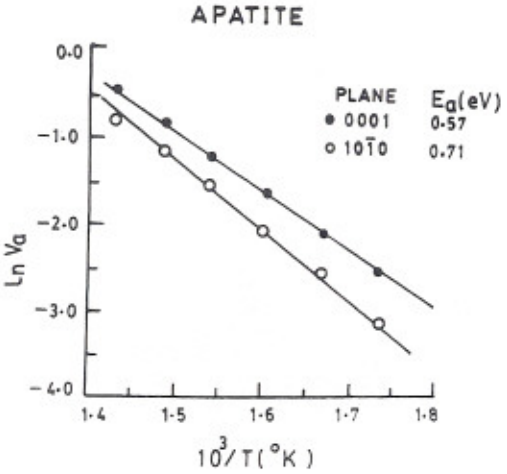

Fig.1. Plot of lnVa vs 1/T for different planes of apatite.

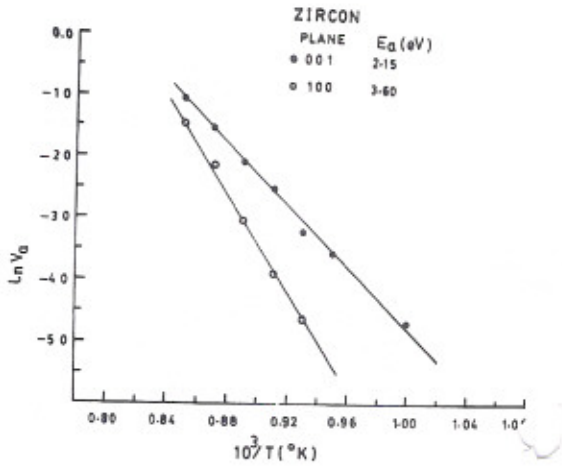

Fig.2. Plot of lnVa vs 1/T for different planes of zircon.

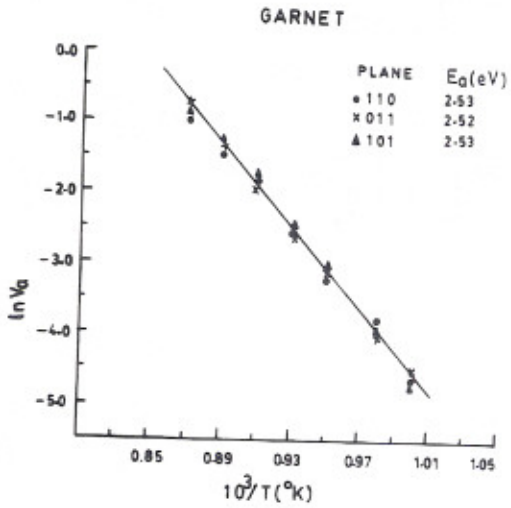

Fig.3. Plot of lnVa vs 1/T for different planes of garnet.

3. RESULTS AND DISCUSSION

The values of activation energies are found to be higher for the samples cut parallel to c-axis in apatite and zircon, whereas in garnet, all the planes yield identical values of E_a (Figs.1-3). During heating, the electrons on receiving very small amount of energy, become free and recombine with the ions at the interstitial positions, thus form neutral atoms, with this the coulomb stress is over and the only potential barrier for the interstitial atoms to migrate to their normal sites is the local stress presented by its neighbouring atoms. This potential barrier is a measure of the activation energy for annealing. Thus if the atom gets this much minimum energy it will be in a position to drift towards the core of the latent track, and the heating will start. The height of the potential barrier, which is a measure of E_a, is inversely related to the spacings between different atoms.

The interplaner spacing 'd' for the planes (h k l) is obtained for the fluoro-apatite crystal in terms of the indices of the plane and unit cell parameters a, b and c, as[5]:

$$1/d^2 = 4(h^2+hk+k^2)/3a^2+(l/c)^2 \qquad (3)$$

The values of a, b and c are taken from the Powder Diffraction File (Page No.1073, Card No.15-876) published by Joint Committee on Powder Diffraction Standards(1972), U.S.A. The interplaner distance for the planes parallel and perpendicular to c-axis of apatite are calculated (Fig.4). As the distance, d_1 is greater than d_2 (Fig.4), the potential barrier between atoms 3 and 4 will be less compared to that between atoms 1 and 3. This suggests that the diffusion of interstitial atoms is easier along the c-axis, in apatite. The fast diffusion along c-axis, will make the latent tracks, normal to this axis, to anneal more easily. In other words, the tracks normal to c-axis have less activation energy than those parallel to this axis. Similar treatment can be applied for zircon (Fig.5).

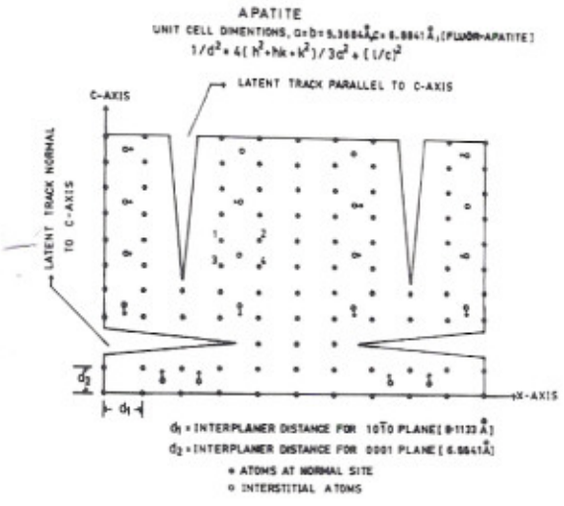

Fig.4. Annealing of latent damage trails through interstitial diffusion of atoms in apatite.

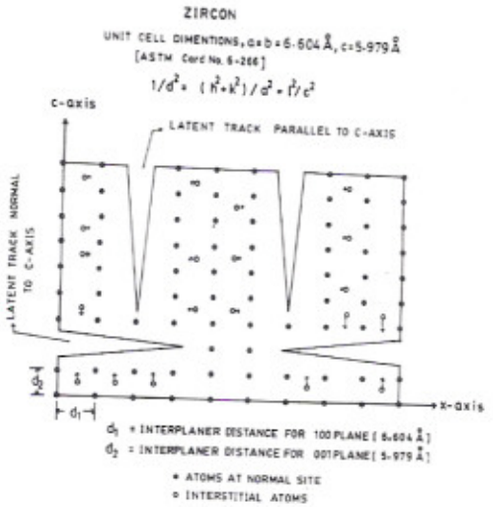

Fig.5. Annealing of latent damage trails through interstitial diffusion of atoms in zircon.

The interplaner distance for various natural planes is same (8.3573 A^{o}) in garnet (cubic sys., ASTM data Card No. 10-367, a=b=c=11.819 A^{o}). This leads to the identical value of potential barrier (activation energy) in different crystallographic planes of garnet(Fig.3).

4. CONCLUSION

The present study reveals that the activation energy is a function of interatomic spacing in crystalline minerals. The value of Ea is found to increase with the decrease of interatomic spacing and vice versa.

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