TEM investigation of the velocity effect in materials with continuous and discontinuous latent tracks

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It has been reported that the ionization which occurs when an energetic particle passes through a crystal may cause significant structural modification along the ion path inside the irradiated material. These structural changes are widely known as latent tracks. Theoretical models [1 - 4] have been proposed to explain the track formation mechanism but these remain a work in progress as they fail to fully describe certain observations. One such observation is the so-called velocity effect (VE). At a fixed value of electronic energy loss in the target material, low-velocity ions produce latent tracks of larger diameter than high-velocity ions. This idea is schematically reflected in figure 1. Currently, the explanation for this effect is based on the fact that a narrower excited electron distribution for low-velocity ionization leads to more efficient energy transfer from the electronic to atomic subsystem and as a result, a larger defect structure. The VE was observed for the first time in yttrium iron garnet ($Y_3Fe_5O_{12}$, YIG) [5]. In this work, most of the experimental track size data was determined indirectly from damage cross-section values measured by CEMS and RBS/C. To date, most of the available data on track diameters used to support the idea of VE was obtained indirectly by measuring bulk disorder in materials and inferring an effective averaged track diameters based on the total ion fluence. These experiments were mostly performed in the track overlapping regime and synergistic effects due to track overlap were not considered.

In this work we exposed single crystal YIG, YAG, Al_2O_3 and TiO_2 specimens to high energy Kr and Xe using Al foil degraders to achieve a number of different ion velocities and stopping powers. Ion fluences were kept low ($\sim 2^{10}/cm^2$) in order to avoid track overlap and the resulting track diameters were measured using high resolution scanning transmission electron microscopy (HRSTEM) in a Cs corrected JEOL ARM200F. TEM lamellae were prepared using an FEI Helios 650 FIB.

It was found that YIG and YAG which produce continuous amorphous tracks, as shown in figure 2, do in fact exhibit a VE although less pronounced than that suggested by indirect measurements. In the case of TiO_2 and Al_2O_3 where tracks are discontinuous and much smaller, some uncertainty remains due to the difficulty in defining the extent of a single track.

References

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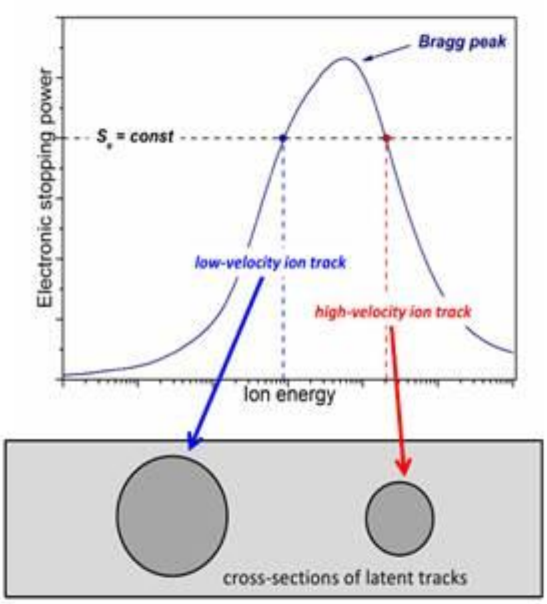 	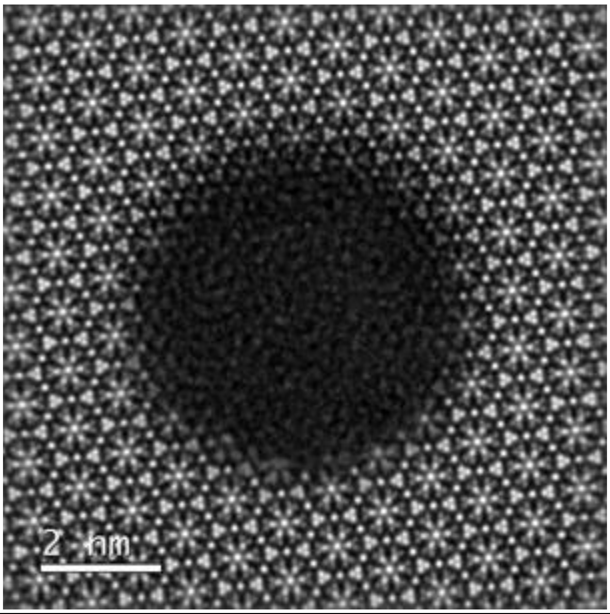
Fig. 1. Due to the Bragg peak, ions with low and high velocities may have the same electronic stopping power. In this case low-velocity ions produce larger tracks compared to high-velocity ions.	Fig. 2. High energy Kr ion track in YIG