Threshold energy losses of ions for track formation in semiconductors and insulators

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For fast ions with kinetic energies $E \geq 1$ MeV a.m.u.$^{-1}$, the intensity with which energy is imparted to the electron subsystems, $(dE/dx)_e$, is 10^3-10^4 times higher than that of energy imparted to the nuclear subsystem of the solid. For instance, $(dE/dx)_e$ amounts to 20-30 keV nm^{-1} for heavy ions with a mass of about 100 a.m.u. and an energy $E \approx 1$ MeV a.m.u.$^{-1}$. The high rate of energy transfer to the electron subsystem enhances the role of electronic excitations in generating structural defects, causes intense inelastic sputtering of materials, and initiates a number of specific effects, such as track formation, local melting, amorphization, creation of extraordinary phases (high-pressure phases, fullerenes, and nanotubes), the generation of shock waves and destruction of materials. The most important and interesting result concerning the penetration of high-energy ions through solids is the formation of specific spatially distributed macrodefects, or tracks. Such defects are commonly known as latent tracks if they can be identified by chemical etching of the irradiated material. With some materials, most often with insulators, this technique is used to create various filters and microdiaphragms, as well as to fabricate nanochannel structures for electronics, photonics and optics.

We used the thermal spike approach adapted to semiconductors and dielectrics to simulate track formation in such materials as InP, GaAs, Si_xGe_{1-x}, SiO_2 and Si_3N_4. Theoretical results are discussed together with our experimental results for these crystals. The radius of molten region along the swift ion trajectory is used as a criterion for track «etchability» in amorphous SiO_2. On condition that the latent track density is equal to ion fluence and etched track radius ≥ 3.0 nm (that is larger than threshold latent track radii for homogeneous etching) it is possible to create SiO_2 layers with etched track density up to 10^{12} sm^{-2}. The low track etching efficiency and the considerable size spread of pores is observed in Si_3N_4 samples.