Ion tracks in relaxed $Si_{0.5}Ge_{0.5}$ alloy layers

P.I. Gaiduk[1,4], C. Trautmann[2], M. Toulemonde[3], A. Nylandsted Larsen[4] and J. Lundsgaard Hansen[4]

[1]BSU, Minsk, Belorussia; [2]GSI, Darmstadt, Germany; [3]CIRIL, Caen-Cedex, France; [4]IFA, Aarhus, Denmark

First evidence for discontinuous ion tracks in single-crystalline $Si_{0.5}Ge_{0.5}$ alloy layers has recently been found using 1.3 GeV U^{238} projectiles of electronic stopping power S_e = 33.8 keV/nm [1]. Here, we report observations concerning track formation and the velocity effect [2] in SiGe alloys. Near the S_e threshold for track formation, tracks are discontinuous and the morphology can be used as sensitive tool to demonstrate the velocity effect.

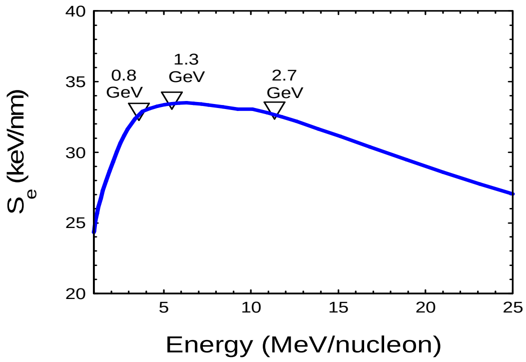

Fig. 1. Electronic energy loss S_e versus beam energy for U ions on $Si_{0.5}Ge_{0.5}$ alloy as calculated by TRIM 95 [3]. The ion velocities of different experiments (2.64 GeV ($4.27x10^7$ m/s), 1.36 GeV ($3.31x10^7$ m/s), and 0.8 GeV ($2.52x10^7$ m/s)) vary by a factor of two, whereas S_e is almost constant.

As samples, we used 2-µm thick strain-relaxed epitaxial $Si_{0.5}Ge_{0.5}$ layers grown by molecular-beam epitaxy on compositional graded buffers on (001) Si wafers [1]. The crystalline structure of such epitaxial layers has a high quality and contains only few threading dislocations (10^5–10^6 cm^{-2}). The irradiations were performed at room temperature with $5x10^{10}$ cm^{-2} ^{238}U ions of different velocities (energies) but almost equal electronic stopping powers (see Fig. 1). The beam flux was around 2×10^8 cm^{-2} s^{-1}. To decrease the initial beam energy from 2.64 GeV to 1.3 and 0.8 GeV, some of the samples were covered with Al foils of thickness 47 and 67 µm, respectively. The irradiated samples were investigated by transmission electron microscopy in plan-view (PVTEM) and in cross-section (XTEM) geometry with a Philips CM20 microscope operating at 200 kV.

Fig. 2 a-c shows the bright-field PVTEM images of samples irradiated at different beam energies. All samples exhibit black dot-like spots well resolved and of average size ~ 3-10 nm. They are invisible or have a weak contrast in most conditions of the two-beam bright-field imaging. Maximum image contrast is obtained at large deviation from the Bragg conditions. Both the density and the morphology of the dots strongly depend on the velocity of the projectiles as clearly seen when comparing the TEM images in Fig. 2 a–c. At highest ion energy (2.64 GeV, no degrader), less than $2x10^9$ dots per cm^2 are created (Fig. 2 a). The dots are randomly distributed within the surface layer. For lower beam energies, the dot density increases drastically to about $5x10^{10}$ cm^{-2} for 1.36 GeV U-ions (Fig. 2 b) and to about $7x10^{10}cm^{-2}$ for 0.8 GeV (Fig. 2 c). An even more important effect at reduced ion velocities is the clear tendency of the dots to form rows, which typically denotes the first stage of track creation [2].

The TEM image of the sample irradiated with 1.36 GeV U projectiles (Fig. 2 b), shows about $6.5x10^9$ dotted tracks per cm^2 containing approximately 40% of the total number of dots. The sample irradiated with 0.8 GeV U projectiles contains about $1.3x10^{10}$ dotted tracks per cm^2, thus comprising more than 70% of all dots (Fig. 2 c).

Fig. 2 d presents the dark-field image of an 0.8-GeV ion-irradiated sample (lowest-velocity) giving clear evidence that a large share of the dots in the tracks are dislocation loops (DLs) of size 5 - 10 nm. The density of DLs is about $(1\text{-}2)x10^{10}$ cm^{-2} in a ~0.5 µm thick layer. The fraction of the DLs is about 20-40% of the total number of dots. In agreement with our recent findings, the other dots are supposed to be clusters of point defects. The quality of the crystal lattice reconstructed during the melt solidification seems to be a critical parameter during track formation [1].

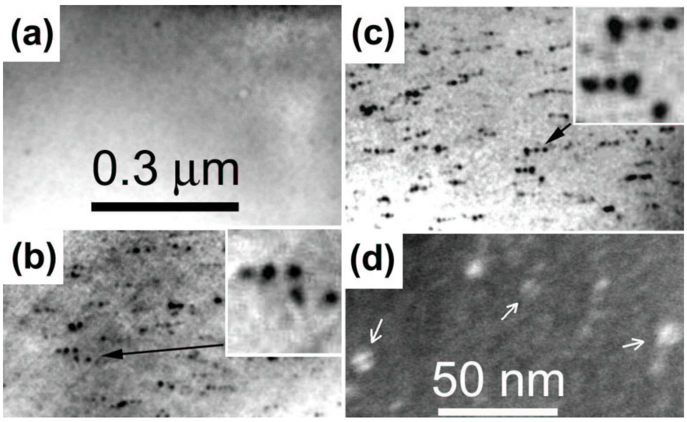

Fig. 2. (a-c) Bright-field PVTEM images of $Si_{0.5}Ge_{0.5}$ alloy layers irradiated with U ions of different energy (same magnification): (a) 2.64 GeV, (b) 1.36 GeV, (c) 0.8 GeV. Both insets exhibit magnified tracks. (d) Dark-field weak-beam TEM image of sample shown in (c) with double-arc features (see arrows) ascribed to dislocation loops.

The study was supported by the NATO CLG No. 976564 and the Danish Strategic Material Research Programme.

References

1 P.I. Gaiduk, A. Nylandsted Larsen, C. Trautmann, M. Toulemonde, Phys. Rev. B **66**, 045316 (2002).

2 A. Meftah, F. Brisard, J.M. Costantini, M. Hage-Ali, J.P. Stoquert, F. Studer, M. Toulemonde, Phys. Rev. B **48**, 920 (1993).

3 J.F. Ziegler, J.P. Biersack, U. Littmark, The stopping and ranges of ions in solids (Pergamon Press, New York, 1985).