Modification of Ge During High Energy Heavy Ion Irradiation ◊

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It has been shown that a moderate fluence (~10^{14} ions/cm^2) of heavy ions in the keV energy range can turn the lattice of covalently bound semiconductors amorphous. While amorphization has been thought to be the final state of lattice damage, a new damage structure which forms within the amorphous phase of germanium has been reported (see [1] and references therein).

In order to test for additional high energy effects we have exposed single crystalline Ge samples to heavy ion beams ranging from 90 MeV S to 266 MeV Au. The regions of the specimens show a step like elevation up to values of 2 μm which is due to the formation of a buried sponge-like structure. Fig. 1 shows the cross-section scanning electron microscopy (SEM) picture of a fractured Ge sample which has been irradiated with 185 MeV I ions at an incidence angle of 15° to the surface up to a total fluence of 4×10^{15} ions/cm^2. One can clearly see a porous layer in a depth of 3 μm, having a width of 2.2 μm. The average atomic density in this region was determined to be about 50% of the original value of crystalline Ge. Cross section TEM (XTEM) measurements have shown that the sample is completely amorphized in the depth interval between 3.5 μm and 7 μm.

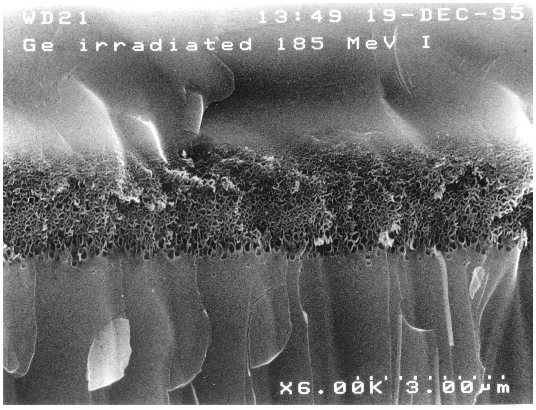

Fig. 1: Cross section SEM picture of Ge sample which has been fractured in the beam spot. The sample was irradiated with 185 MeV I ions up to a total fluence of 4×10^{15} ions/cm^2. The beam direction was in the plain of the picture at an angle of 15° to the sponge-like structure

It is interesting to note that Ge specimens irradiated with 90 MeV S and 165 MeV Ni show also a swelling of the bombarded region although no formation of a porous layer could be detected by XTEM and SEM measurements. The elevation of the irradiated part reaches only values up to 200 nm for a maximum fluence of 5.4×10^{15} Ni-ions/cm^2. To our knowledge the formation of such sponge-like structures in Ge has only been observed for projectiles heavier than Ga [2]. Therefore a critical cascade density seems to be necessary to initiate the morphological change of amorphous Ge.

To study the behavior of a prior formed porous layer in a second irradiation by ions with higher electronic energy loss, the beam spot of a 252 MeV Au irradiation at 15° (fluence 1.4×10^{15} ions/cm^2) was post-irradiated with 252 MeV Au ions at normal incidence up to a total fluence of 2.8×10^{14} ions/cm^2. The different incidence angles cause a more than twofold increase of the electronic energy loss at the buried layer. Fig. 2 shows the SEM picture of the twofold bombarded Ge which has been fractured in the beam spot. In the upper part of the porous region one can see the voids created by the first irradiation. Surprisingly the voids formed by the post-irradiation cannot be found in about 11 μm depth as it would be the case for normal incidence irradiation only, but just beneath the prior created damage layer. With increasing fluence the thickness of the horizontal bands is reduced, while its lateral dimensions are increased because of the Klaumünzer Effect on a microscopic scale [1].

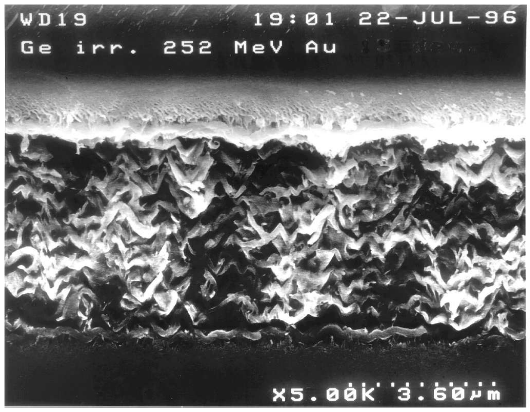

Fig. 2: Cross-section SEM picture of a Ge sample irradiated with 252 MeV Au-ions at 15° and additionally at 90° to the surface. The fluences have been 1.4×10^{15} and 2.8×10^{14} ions/cm^2, respectively.

The physical process of void formation in amorphous materials is not well understood. A possible driving force for vacancy clustering in covalent solids could be the minimization of dangling bond density. Therefore the elimination of dangling bonds at void surfaces may be the main reason for the formation and the stability of these big vacancy clusters in amorphous Ge.

References

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