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Defects in Heavy-Ion Bombarded Compound Semiconductors Due to the Elastic and Inelastic Energy Loss Regimes

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The irradiation of single crystalline compound semiconductors with energetic heavy ion beams produces disorder in the irradiated crystal lattices. Indium Phosphide (InP) is an important technological III-V compound semiconductor used in space solar arrays and variety of electronic devices. For InP crystals each bombarding single ion produces atomic disorder inside the lattice, this may lead to a nanoscale defect which could be observed by Transmission Electron Microscopy (TEM).

In this investigation, electron transparent InP single crystals as shown in figure 1(a) were bombarded by accelerated Au^+ ions at the low fluence ranges ($\leq 1 \times 10^{12}$ ion/cm^2) in order to avoid the possibility of accumulation of defects and their overlapping. Two energies of the Au ions were investigated; 100 keV Au ions (0.5 keV/amu) and 200 MeV Au ions (1 MeV/amu). TEM observations showed that we can in general assign two very broad types of defect arrangements in heavy-ion irradiated InP crystals.

Firstly, at low incident heavy ion energies, for the case of 100 keV Au, the energy transfer exceeds the displacement energy threshold E_d of both the constituent lattice atoms (In and P atoms). Then a recoil cascade (collision cascade) is initiated in which potentially many atoms are relocated from their equilibrium lattice positions by each single bombarding Au ion. Thus atomic cascades arising out of primary, secondary and higher order knocked-on atoms mean that a cascade produces disordered zones in three dimensions as shown in figure 1(b). In this case only elastic collisions (nuclear) with target atoms need to be considered, since interactions with the electron system are essentially negligible. The collision processes are then frequently referred to as being 'ballistic' similar to billiard balls collisions [1]. The inset in figure 1(b) shows the selected area diffraction pattern along the imaging (001) zone axis of the crystal, the absence of any diffused rings suggests that the material preserve its crystalline nature. Observations showed that the accumulation and overlap of these disordered zones lead to a complete amorphous state for high Au ion irradiation fluences in InP [2].

Secondly, we can consider the detailed path of the incident ion, particularly for the case of 200 MeV Au ions where the energy loss can reach to high levels of about several tens of keV/nm into the lattice, in this case a trail of damage along each ion path is created. The corresponding mechanism for producing that damage is the large energy deposition (inelastic) into the target electron systems both to individual atoms and to the overall crystal electronic band structure. This energy is subsequently transferred to the lattice atoms relocating them from their equilibrium lattice positions giving rise to the high aspect ratio aggregate of defects along the ion path generally referred to as an ion track [3, 4]. These tracks are shown in figure 2(a) and in figure 2(b) which shows a close-up view of two adjacent ion tracks in a very thin edge of the sample. High resolution TEM observations on such individual ion tracks revealed the continuation of lattice fringes along the width of the ion track cores (~ 5 nm in width) as revealed in figure 2(c). This strongly suggests that damage inside the track core is not amorphous in nature. Similar to the first case of low energy Au ion irradiation, the accumulation and overlap of these ion track cores leads to a complete amorphisation state for the high Au ion irradiation fluences in InP [2].

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[5] The authors acknowledge the contribution of Professor Lewis Taylor Chadderton (1938-2012) towards this work. To their deepest regrets, this outstanding scientist and colleague passed away two months before the closing date for manuscripts submission of the Microscopy and Microanalysis Conference 2013.

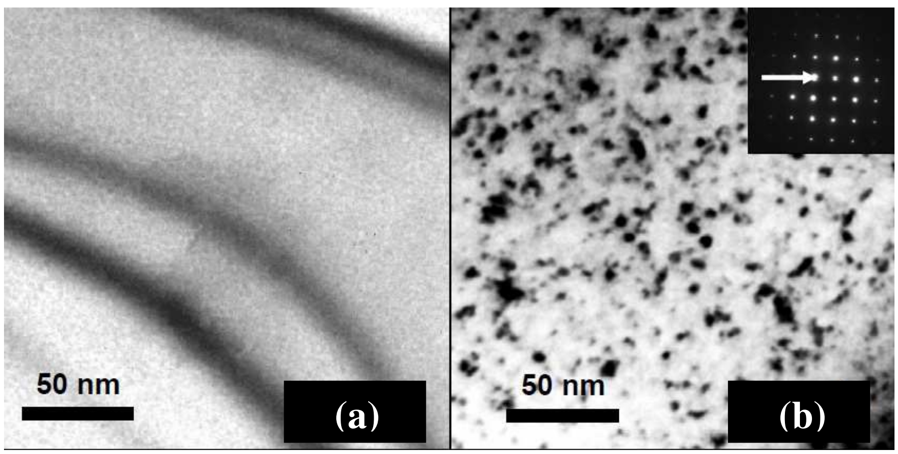

Figure 1. Bright Field TEM of **(a)** InP before irradiation and in **(b)** after irradiation by 100 keV Au ions which shows a field of created disordered zones, each might arise from a single ion impact.

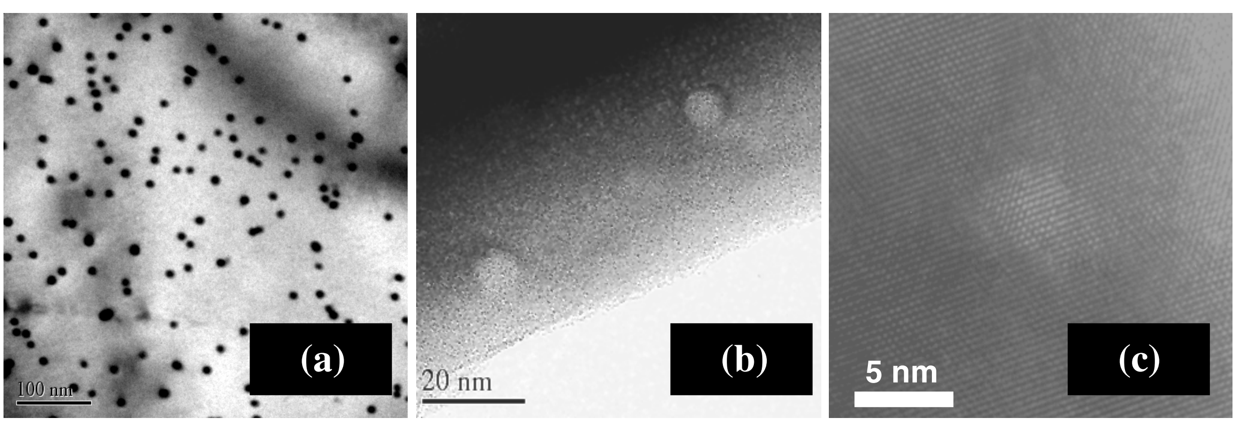

Figure 2. In **(a)** a field of ion tracks each one is due to a single ion impact and in **(b)** is a high magnification TEM close-up view of two such ion tracks resulting from two Au neighboring ion impacts. And in **(c)** is a high resolution image of a single ion track core.

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