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Electron Beam-Irradiation-Induced Annealing of Nanoscale Defects Created by Heavy Ion Beam Bombardment of Indium Phosphide

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The irradiation of single crystalline compound semiconductors with heavy ion beams produce damage inside the irradiated crystal lattices; this may be in the form of nanoscale defects observed by TEM. In this work *in-situ* TEM electron beam irradiation (from 100 to 300 keV) of defects created in indium phosphide (InP) were investigated. The defects were created in InP single crystals by gold ion (Au^+) beam bombardment.

The electron transparent InP single crystals were bombarded with accelerated Au^+ ions at low fluence ranges (< $1x10^{12}$ ion/cm^2) in order to avoid the possibility of the accumulation of created spatially isolated defects and their subsequent overlap. Two energies of the bombarding Au^+ ions were investigated; 100 keV Au^+ ions (0.5 keV/amu) and 200 MeV Au^+ ions (1 MeV/amu). The TEM observations show that we can in general assign two types of electron beam-sensitive defect arrangements in heavy ion irradiated InP single crystals [1].

Firstly, for the case of low energy 100 keV Au^+ ion bombardment of InP were the energy is transferred elastically from the bombarding Au^+ ions to the lattice atoms [2]; disordered isolated volumes (zones) were created due to Au^+ ion impacts. Shrinkage and disappearance of these disordered zones were observed under electron beam irradiation inside the TEM as shown in figure 1 for the case of 150 keV electron beam irradiation of InP pre-damaged by 100 keV Au^+ ion beam.

The total areal fraction of the disordered zones decreased as a function of irradiating electron fluence at the investigated electron energies as shown in the plot depicted in figure 2(I). The disappearance of the disordered zones proved that these nanoscale defects were susceptible to electron beam irradiation. And lattice recovery occurs (electron beam-induced annealing) even at electron energies not sufficient to elastically displace the constituent lattice atoms (both the In and P atoms). Direct electron beam heating effects were excluded. Calculations for temperature rise of thin foil InP samples which took into account the electron energy losses inside the lattice indicate that temperature rise were $\leq$ 3 ^{o}C [3]. This was supported by observations of areas adjacent to the post-electron bream irradiated areas (FWHM = 2 μm) which showed that disordered zones in these areas were intact; these observations preclude any heating effects due to electron beam irradiation on the annealing process.

Secondly, for the case of 200 MeV Au^+ ion irradiation of InP were the energy is transferred inelastically from the bombarding Au^+ ions to the lattice atoms [1]; trails of damage along the path of ions inside the lattice known as ion tracks were observed. High resolution TEM images (HRTEM) showed that similar to the disordered zones for the first case (100 keV Au^+), the ion tracks disappear and lattice recovery induced by irradiating electrons occurs as depicted in figure 2(II) for a single ion track core irradiated by 200 keV electron beam. The observed shrinkage and disappearance of the disordered zones and ion tracks under electron beam irradiation might proceed by mechanisms of electron beam-induced bond breaking and rearrangements at the interface between these nanoscale defects and the intact surrounding lattice [4, 5].

References:

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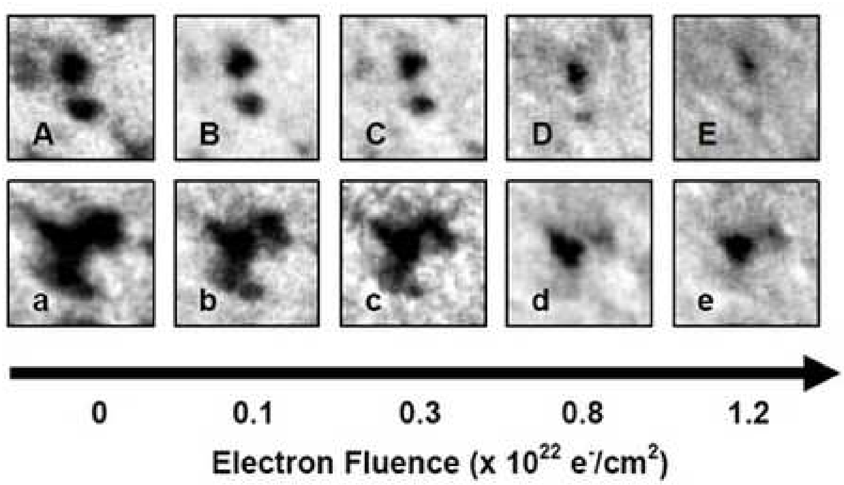
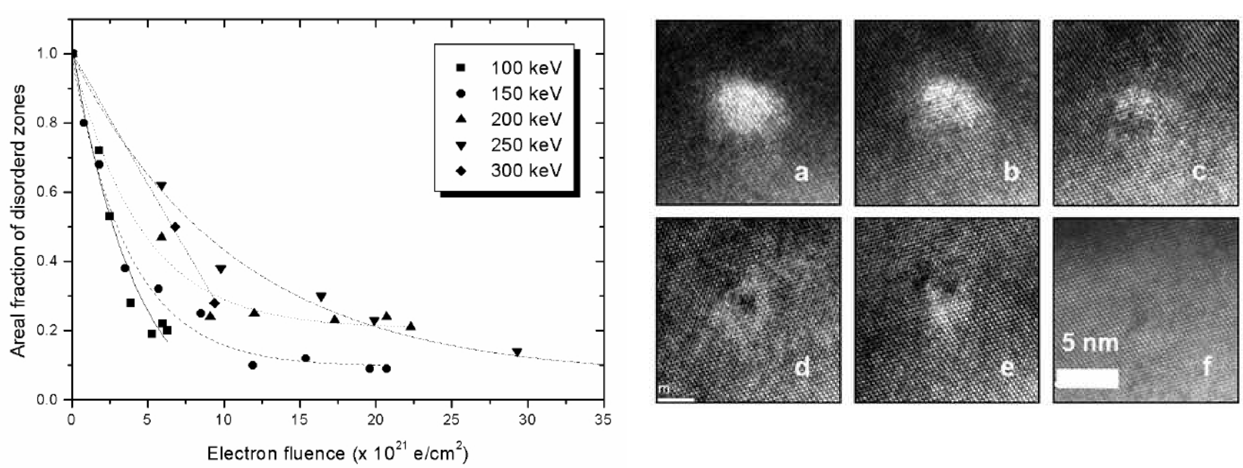


Figure 1. Two different TEM images time sequence (electron fluence of 150 keV electron beam) of electron-beam induced annealing of individual disordered zones in InP pre-damaged by 100 keV Au^+ ion irradiation. The side of each image is 40 nm.



(I) (II)

Figure 2. In **(I)** plot of total areal fraction of disordered zones (measured from TEM images sequences with many zones) as a function of irradiating electron beam fluence. In **(II)** HRTEM images time sequence of 200 keV electron beam-induced annealing of a single ion track core in InP pre-damaged by 200 MeV Au^+ ion irradiation. The electron fluence in (a) 0 e^-/cm^2, in (b) 8.4 x 10^{20} e^-/cm^2, in (c) 2.5 x 10^{21} e^-/cm^2, in (d) 7.6 x 10^{21} e^-/cm^2, in (e) 1 x 10^{22} e^-/cm^2 and in (f) 2.5 x 10^{22} e^-/cm^2.

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