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DAMAGE PROFILING ON HIGH ENERGY ION IMPLANTED GaP

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Ion implantation with energies in the MeV region offers the possibility to produce three-dimensional monolithically integrated optoelectronic devices [1,2].

Depth and fluence dependences of damage production on GaP single crystals bombarded with $^{40}Ar^{++}$, $^{31}P^{++}$, $^{20}Ne^{+}$, $^{14}N^{+}$, $^{4}He^{+}$, and $^{1}H^{+}$ - ions were studied in the range of energies E_o=(0.3-1.0) MeV/amu. The monocrystalline targets were irradiated with heavy ions at the cyclotron U-300 of the Laboratory of Nuclear Reactions at the Joint Institute for Nuclear Research, Dubna. For the irradiations with light ions and for damage analyses we used the proton and He^{+}-beam from the Van de Graaff-accelerator at the Karl Marx University, Leipzig. The diameters of the cyclotron beams were in the range of 1 mm and the angular divergences about 0.5°. The bombardment was performed at angles of about 30° to the crystal surface under random conditions; fluences ranged from $2.5\times10^{13}cm^{-2}$ to 5×10^{18} cm^{-2}. A GaP single crystal of 0.6 mm thickness was fastened on a massive metallic plate in the vacuum chamber to provide effective heat removal. Target orientation, damaging and ion dose during the irradiation were controlled [3] using plastic or glass track detectors. After mechanochemical polishing and ion bombardment macrodamages of the crystal surface were not visible. On the other hand, in the spot region a blackening of GaP occurred which reached saturation at low ion doses. The distributions of the lattice damages were investigated by the Rutherford backscattering-channeling technique with 1 MeV protons, some months after the irradiations. With these data, the damage profiles were computed using a program modified for compounds, on the basis of the model of multiple scattering [4]. The lattice expansions were measured using the proton-induced Kossel effect [5].

The depth profiles of damage density determined in this way are presented for several fluences in Fig.1.

For all ions qualitatively similar profiles of damage density are produced at low fluences. These profiles are characterized by relatively low and homogeneous damage densities in the higher energy region near the surface and by a maximum near the penetration depth.

In the near-surface region the saturation behaviour of damage production occurs ($N_d^{sat}/N_o \approx 10\%$), similar to that observed in proton or electron bombardments since at energies $E_o >$ 100 keV/amu all atomic species investigated produce similar defect structures as the average energy transfer per binary encounter is sufficient to produce only

2-5 atomic displacements. In the surface region ($t \approx 0.5$ µm) the fluence dependences of damage density and of the damage-induced lattice strain scale with the energy deposited into nuclear processes /6/ (Fig.2).

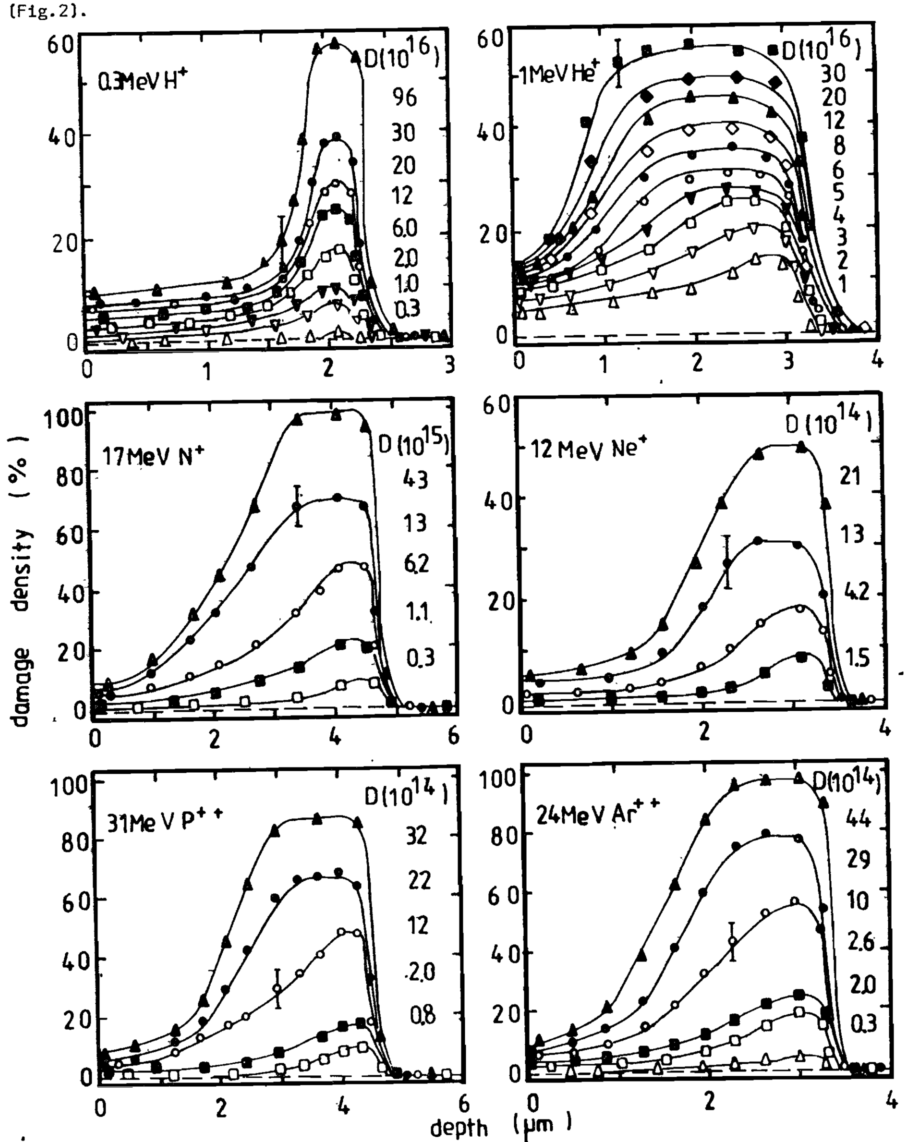

Fig.1. Depth profiles of damage density for (111) GaP implanted with different fluences (D,cm^{-2}).

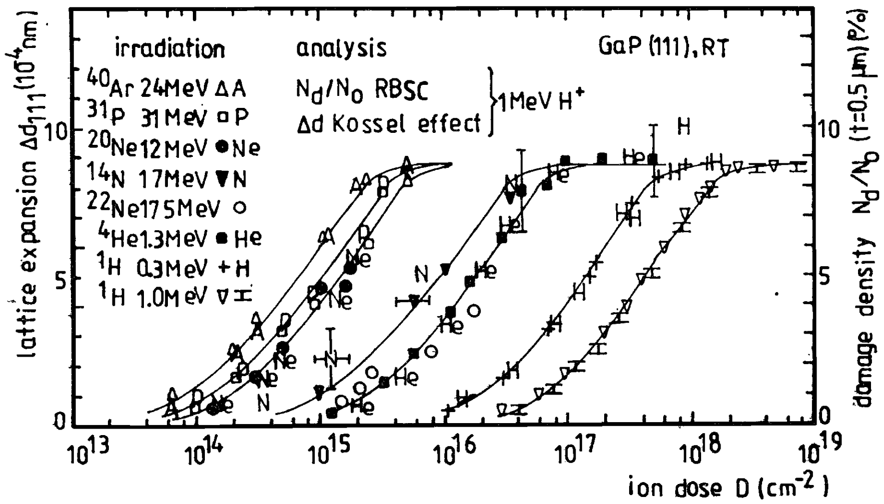

Fig.2. Fluence dependences of damage density (A, P, Ne, N, He, H, I) and of strain (Δ , ◻ , ● , ■ , ▼ , ○ , + , ∇) for ion-implanted (111) GaP.

The saturation behaviour of damage production by H^+ bombardment, which was studied up to very high fluences, indicates that amorphization cannot be reached. Electron microdiffraction patterns on highly implanted samples confirm the crystalline order within the damage peak region. In H^+ irradiated samples the highly damaged region is supersaturated with small, mainly vacancy-type, defects embedded in a crystalline matrix, which are too small to serve as centres for defect nucleation. Therefore, here the competing process of mutual annihilation of the Frenkel partners predominates over the defect growth.

For He^+ implanted GaP the higher nuclear energy loss is sufficient to produce bigger vacancy-type defects (voids), which seem to have the minimum size sufficient for nucleation.

If the critical concentration $N_d/N_0 \approx 15\%$ is exceeded, the interface between the highly damaged and the less damaged regions moves towards the surface due to the defect nucleation at this interface, thus producing a void layer with the remaining crystalline order.

In GaP implanted with heavier ions ($M > 4$), amorphization is reached by the overlapping of individual strongly disordered regions which represent centres for defect nucleation.

This process spreads towards the surface with increasing fluence since in the higher energy region individual disordered zones are also produced but in concentrations orders of magnitude lower. With rising fluence their concentration increases due to the point defect density. This observation of the coexistence of "hydrogen-type" and of "heavy ion-type" defects in the higher energy region is confirmed by similar results on N^+ implanted GaAs /7/ and Si /8/.

Summarizing one can state that bombardment of GaP with ions heavier than He can be used to produce buried amorphous layers beyond a slightly damaged surface layer with thickness $t \approx 1$ μm which is yet suitable for device applications.

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Ашерон К. и др. E14-86-448
Профиль повреждения GaP после имплантации высокоэнергетичными ионами

Характеристики решетки монокристалла GaP, поврежденной в результате облучения высокоэнергетичными ионами, исследованы с помощью техники резерфордовского обратного рассеяния каналированных частиц и эффекта Косселя на пучке протонов. Монокристаллы облучены различными ионами от ^1H до ^{40}Ar в диапазоне энергии (0,3-1,0) МэВ/нуклон. Для анализа использован пучок 1 МэВ протонов. Получена зависимость от дозы степени повреждения, профиля дефектов и параметра решетки GaP. Сделаны выводы о том, что наряду с генерацией дефектов пучком тяжелых частиц при комнатной температуре происходят процессы рекомбинации пар Френкеля, а также объединения точечных дефектов при большой плотности.

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Damage Profiling on High Energy Ion Implanted GaP

Characteristics of the GaP lattice damaged by high energy ion irradiations were studied using the Rutherford backscattering-channeling technique and the proton-induced Kossel effect. Single crystals were bombarded with different ions from ^1H to ^{40}Ar in the energy range 0.3-1.0 MeV/nucleon. An 1 MeV proton beam was used for analysis. The dose dependences of the damage density, damage profiles and of the GaP lattice parameters were extracted. Conclusions have been drawn that, along with defect generation during bombardment, recombinations of the Frenkel pairs even at room temperature, as well as nucleation of high density point defects are possible.

The investigation has been performed at the Laboratory of Nuclear Reactions, JINR.

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