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SHORT COMMUNICATIONS

MODIFICATION OF PLASTIC AND BRITTLE PROPERTIES OF InP SINGLE CRYSTALS BY ION IMPLANTATION

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1. Introduction

The main purpose of the implantation of various ions into semiconducting materials is the modification of the electrical and optical parameters of these materials. During implantation occurs significant change in crystal properties (in particular, plastic and brittle properties). This change must be taken into account for the prediction of the quality and lifetime of the semiconducting materials used in devices. On the other hand, it is of interest to investigate the mechanical parameters of the semiconductors before and after ion implantation, in order to give more insight into the physics of the process. The electrical and optical properties of materials, as well as the mechanical ones, are structurally sensitive and their changes may be caused by the transformations occurring in the crystal structure.

In this paper has been investigated the influence of the implanted ions which belong to the third group of the Periodic Table (B^+, Al^+, Ga^+) on mechanical properties of undoped n-InP and Fe-doped InP single crystals.

2. Experimental procedure

The ion implantation was carried out onto (001) face of the chemically polished samples, at room temperature and beam energies from 300 keV to 1 MeV. Doses from 3×10^{13} cm^{-2} to 3×10^{15} cm^{-2} were used in the implantation experiments. After annealing for 15 minutes at 700 °C the hole concentration in both InP crystals was $p=3\times10^{15}$ cm^{-3}, and the depth of the ion implantation was $d \approx 0.6$ μm.

In the next stage, the implanted (001) plane of the crystals was deformed at room temperature by a concentrated load. The micromechanical properties (microhardness, H, microdurability, σ, and microbrittleness, γ) were investigated. For this purpose were performed several indentations by a diamond pyramid. The indentation diagonal (d) were parallel to the <100> directions. The measurements of microhardness were carried out in a microhardness tester PMT-3.

The mechanical parameters were calculated using the usual formulae [1,2]. The indentation loads were 0.2 N and 1N. The small load (0.2 N) leads to indentations with depth less than 0.6 μm, roughly the thickness of the implanted layer. By application of the large load (1N) the microhardness of the region situated under the implanted zone is also taken into account.

3. Results and discussion

The implantation ions (B^+, Al^+ and Ga^+) have been used in order to get In_p type structural defects. Such defects were found to be acceptors in the indium phosphide crystals, and their presence must lead to the change in the type of conductivity [3-5]. However, the measuring of the electrical parameters has shown that the implantation of these ions didn' t lead to the expected inversion. This result may point out that implanted ions do not occupy the phosphorus vacancies and another mechanism for the localization of the implanted ions should occur in this case. Three possibilities for the positioning of the ions into the indium phosphide crystal lattice are to be taken into account: In lattice sites, P lattice sites and interstitial positions. Only the first and the second possibility seem to be realistic, as long as acceptor centres of InP type have not been revealed by the electrical measurements.

The experimental results related to the change of the mechanical properties can decide between the suggested mechanisms. The values of microhardness, microdurability and microbrittleness for the n–InP crystals implanted by B^+, Al^+, and Ga^+ ions are presented in Table 1 (concentration of uncompensated donor centres in undoped n–InP crystals amounts to 2×10^{16} cm^{-3}).

Table 1 Modification of the mechanical parameters (H, σ and γ) by the implantation of the third group ions in n-InP crystals (indentation load: 0.2 N).

Crystal	Atomic radius of element r(Å)	$\Delta r_1=r_{In}-r_{i.e.}$ *	$\Delta r_2=r_P-r_{i.e}$	H (MPa)	σ (MPa)	γ
n- InP	In — 1.62 P — 1.18	—	—	3600	—	—
n-InP+Al^+	Al — 1.43	0.19	0.25	3290	330	4.4
n-InP+Ga^+	Ga — 1.39	0.23	– 0.21	3150	303	4.7
n-InP+B^+	B — 0.91	0.71	– 0.27	3060	235	6.05

*)$r_{i.e}$ — atomic radius of the implanted element.

Table 1 points out the change of the mechanical parameters, as a function of atomic radius of the implanted elements in the row Al–Ga–B. One can notice that H and σ values decrease, while γ values increases when passing from Al^+ to B^+. The difference in the microhardness value, $\Delta H=H_{n\text{-}InP}-H_{n\text{-}InP+M}$, becomes greater the larger the difference in the atomic radii, $\Delta r_1=r_{In}-r_{i.e}$, is.

The decrease of the microhardness values demonstrates the rise of plasticity during indium phosphide implantation. However, the pattern of the modification of the σ and γ values points to a different conclusion. Indeed, the material plastification, as it is well known, must be accompanied by microdurability increase (i.e. the rise of the resistance to crack formation) and by the decrease of the microbrittleness. Nevertheless, in our case one observes an opposite effect: σ decreases and γ increases when Δr_1 increases. Therefore, it may be concluded, that the decrease of hardness H is not caused by the improving of plastical properties of material, and it is related to the increasing tendency to the fragile destruction.

The failure that appears during penetration of the indenter brings about a supplementary indentation enhancement and, as a consequence, the decrease of the microhardness value.

An other effect is noticed by implantation of the InP: Fe crystals (Table 2).

Table 2 Modification of the mechanical parameters (H, σ and γ) by ion implantation of InP:Fe Crystals(indentation load:1 N).

Crystal	Atomic radius r(Å)	$\Delta r_1=r_{In}-r_{i.e.}$ *	$\Delta r_3=r_{Fe}-r_{i.e}$	H, (MPa)	σ, (MPa)	γ
InP :Fe	In — 1.62 Fe —1.24	—	—	3000	211	6.5
InP : Fe +Al^+	Al — 1.43	0.19	– 0.19	3140	278	5.05
InP : Fe +Ga^+	Ga — 1.39	0.23	– 0.15	2950	296	4.4
InP : Fe +B^+	B — 0.91	0.71	+ 0.33	3165	310	4.5

*) r = atomic radius of the implanted element.

Here, the hardness dependence versus the type of implanted atom is not very clear, but, as a whole, it may be a tendency toward a hardening occurring by implantation. This tendency is evidenced through the modification of other characteristics (σ and γ) too. The hardening is related to the microdurability increase and microbrittleness diminishing. The regularities, revealed by the use of small loads (0.2 N) are confirmed by the application of a higher load (P = 1 N) too (see Table 3 and 4). This result indicates that the structural transformations, occurring in the shallow implanted layer, also influence the deeper layers.

It is naturally to expect that the samples brittleness will be the less the smaller $r_{i.e.}$, if it is supposed that the implanted ions in n-InP crystals are located in the interstitial sites. The experiment shows the opposite effect. The possibility to have the occupancy of phosphorus and indium lattice sites should have to reveal the correlation of mechanical parameters modification with Δr_2, which is missing in the experiments too.

In the same time the relation between the change of mechanical characteristics and Δr_1 is seen in the Tables 1— 4. This result allows to assume that the ions of implanted elements preferentially occupy the In lattice sites. A larger Δr_1 leads to stronger lattice distortion that causes the modification of the mechanical properties.

A different situation seems to occur in the case of InP: Fe crystals subjected to implantation. The iron atoms, perhaps, exert a damping effect on the structural modifications, induced by implantation, and thereby diminish the tendency of crystals towards the fragile destruction.

Table 3 Modification of the mechanical parameters (H, σ and γ) by ion implantation of n–InP crystals (indentation load: 1 N).

.Crystal	H, MPa	σ, MPa	γ
n- InP	3800	—	—
n-InP+Al^+	3350	218	7.3
n-InP+Ga^+	3170	198	7.6
n-InP+B^+	3390	185	8.9

Table 4 Modification of the mechanical parameters (H, σ and γ) by ion implantation of InP:Fe crystals (indentation load: 1 N).

Crystal	H, MPa	σ, MPa	γ
InP :Fe	3270	—	—
InP : Fe +Al^+	3166	183	8.35
InP : Fe +Ga^+	3320	204	7.80
InP : Fe +B^+	3220	214	7.10

4. Conclusions

The electrical measurements show that the inversion of conductivity type does not take place by implantation of the n–InP and InP:Fe crystals with third group elements. This indicates that, very probably, the defect structure of the In_P type is not formed during implantation.

The ion implantation in n–InP and InP:Fe crystals is accompanied by the modification of mechanical characteristics of these crystals.

In the series of implanted ions (Al^+–Ga^+–B^+), the brittleness increases for the n–InP crystals and the plasticity rises for the InP implanted previously by Fe ions.

The modification of the mechanical parameters of InP crystals by ion implantation demonstrates that the implanted ions occupy the In sites for both n–InP and InP:Fe crystals.

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