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Rezumat

S-a studiat influenţa iradierii cu electroni asupra spectrelor de fotoconductibilitate (FC) ale monocristalelor *n*- şi *p*-InP. S-a stabilit că iradierea cu electroni duce la formarea nivelului adânc $E_c=0{,}4$ eV, care se manifestă prin benzile FC cu limita roşie de 0,4—0,5 eV în *n*-InP şi 0,9 eV în *p*-InP.

Summary

The influence of electron irradiation on the photoconductivity spectra of *n*- and *p*-type InP single crystals was investigated. It was shown that electron irradiation leads to the E_c —0,4 eV deep level formation. This deep level was evidenced through photoconductivity bands with low energy cut-off at 0.4—0.5 eV in *n*-type InP and 0.9 eV in *p*-type InP.

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INFLUENCE OF P+-COIMPLANTATION ON ELECTRICAL PARAMETERS OF Zn+-IMPLANTED GaAS SINGLE CRYSTALS

Nowadays the ion implantation is widely used for the purpose of doping of semiconductor materials. However, *p*-type dopants (Be, Mg, Zn, Cd) have been established to exhibit a rather low electrical activation in GaAs and InP [1]. In order to promote a higher activation of ion-implanted dopants, the host-components ion coimplantation can be used [2—4]. Little attention has been paid until now to the study of the influence of isoelectronic-impurity coimplantation upon the behaviour of *p*-type dopants implanted in III—V compounds. In this letter, we report the results of electrical characterization of Zn^+/P^+ coimplanted GaAs single crystals. For the purpose of comparison, some data concerning Zn^+/As^+ coimplantation in GaAs are presented as well.

Liquid encapsulated Czochralski (LEC) grown semi-insulating GaAs single crystals were used. The resistivity of the as-grown crystals equaled 10^8 Ω·cm ($T=300$ K). The Zn^+, P^+ and As^+ ion implantation at doses $5\cdot10^{13}$ and $5\cdot10^{14}$ cm^{-2} was carried out at room temperature. The ion energies were chosen so that the profiles of as-implanted ions to overlap, namely, the energies were 143, 76 and 150 keV for Zn^+, P^+ and As^+ ions correspondingly. The post-implantation annealing was performed in H_2-atmosphere for 15 min at different temperatures for the interval 600—750°C. Carrier concentration and mobility were determined by Hall-effect measurements using the Van der Pauw method. The depth distribution of electrical parameters was obtained by step-by-step etching in a 2% Br-solution in C_2H_5OH, accompanied by Hall-effect measurements.

Fig. 1 illustrates the depth distribution of hole concentration and mobility for Zn^+ and Zn^+/P^+ implanted ($D=5\cdot10^{13}$ cm^{-2}) GaAs crystals with subsequent annealing at 700°C. The activation efficiency of impurity in Zn^+-implanted layers equaled 45—50%. After Zn^+/P^+ coimplan-

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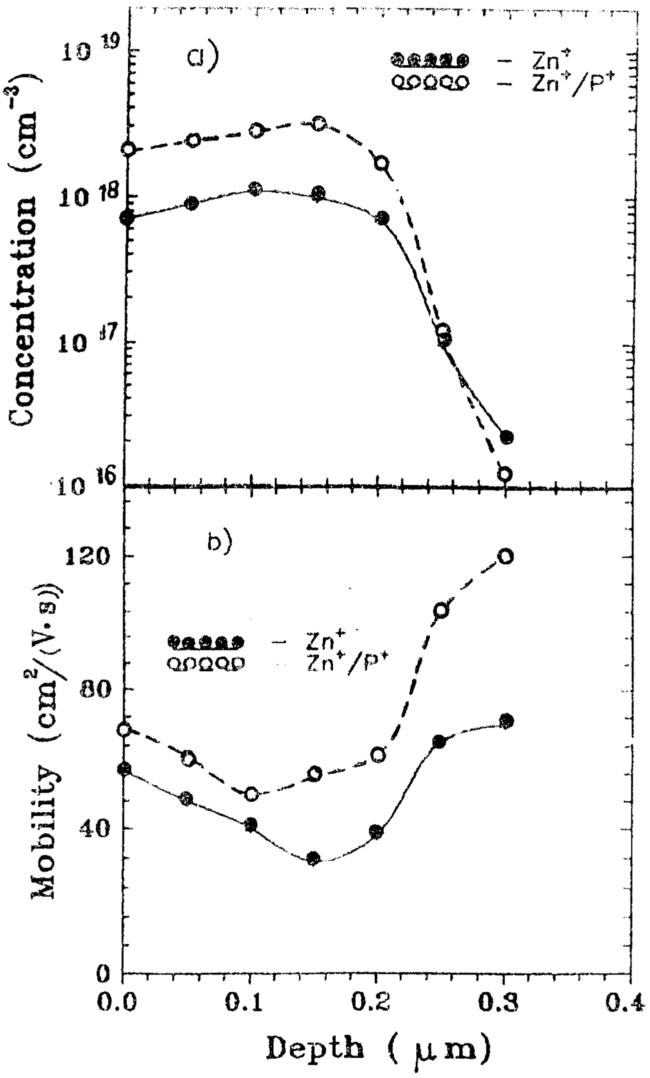

Fig. 1. The depth distribution of the free hole concentration (*a*) and mobility (*b*) in Zn^+ and Zn^+/P^+ implanted GaAs layers. $D=5\cdot10^{13}$ cm^{-3}, $T_{ann}=700$°C

tation at the dose $5\cdot10^{13}$ cm^{-2}, the activation efficiency was of about 80%, i.e., by 30—35% higher. It is of interest to note, that the hole mobility is also influenced by P^+-coimplantation (Fig. 1, *b*). In fact, the higher the dose of P^+-coimplantation the higher the hole mobility. The maximum value of hole mobility (220 cm$^2\cdot$V$^{-1}\cdot$s^{-1} at the depth of 0.45 μm) was found in GaAs samples coimplanted by Zn^+/P^+ ions at the dose $5\cdot10^{14}$ cm^{-2}.

Fig. 2 presents the hole concentration profiles for GaAs samples implanted by Zn^+, Zn^+/P^+ and Zn^+/As^+ ions at the dose $5\cdot10^{14}$ cm^{-2} followed by post-implantation annealing at 700°C. The analysis shows that both P^+ and As^+ coimplantations lead to an improvement by 20% of the Zn-impurity activation. Apart from that, the carrier concentration profile in Zn^+/P^+ coimplantation samples proves to be a little narrower in comparison with the one in Zn^+/As^+ coimplanted crystals. As concerns the free carrier mobility, it was found to show different dependences upon the type of coimplanted ions. In contrast to P^+-coimplantation which improves the hole mobility, As^+-coimplantation leads to a mobility diminution.

It is to be underlined, that good impurity activation in GaAs can be reached provided that the temperature of post-implantation annealing

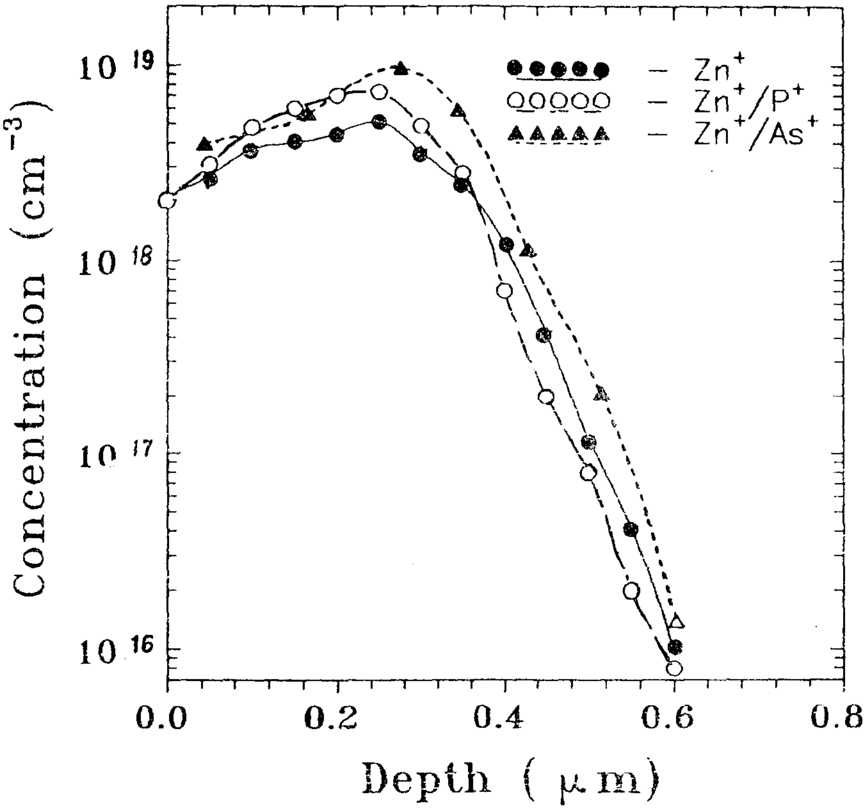

Fig. 2. The depth distribution of the free hole concentration in Zn$^+$, Zn$^+$/P$^+$ and Zn$^+$/As$^+$ implanted GaAs layers. $D=5\cdot10^{14}$ cm^{-3}, $T_{\text{ann}}=700$°C

$T_{\text{ann}}\geqslant700$°C. On the other hand, the increase of T_{ann} from 700 to 750°C gives rise to a pronounced broadening of carrier profiles caused evidently by fast in-diffusion of Zn-impurity. Taking this into account, the value $T_{\text{ann}}=700$°C may be considered as the optimum one in the case of Zn$^+$/P$^+$ coimplantation in GaAs single crystals.

The P$^+$-coimplantation induced improvement of GaAs properties may be attributed to the effect of the volume compensation. Indeed, since the radius of Zn atoms is larger than the one of Ga ions, P$^+$-coimplantation ($r_P>r_{As}$) may be expected to result in a lattice relaxation, e.g., in a diminution of lattice distortions.

Thus, the efficiency of Zn-impurity activation in GaAs and the hole mobility were found to be increased by the P$^+$-coimplantation.

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Rezumat

Sunt prezentate rezultatele investigării influenţei coimplantării ionilor P$^+$ asupra parametrilor electrici ai cristalelor *i*-GaAs implantate cu Zn$^+$. Se arată că coimplantarea P$^+$ duce la creşterea gradului de activare a zincului precum şi a mobilităţii golurilor.

Summary

The influence of P$^+$-coimplantation upon the electrical parameters of Zn$^+$-implanted *i*-GaAs crystals was investigated. The efficiency of Zn-impurity activation and the hole mobility in GaAs were found to be increased by the P$^+$-coimplantation.

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