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ECULIARITIES OF DISTRIBUTION OF DEFECTS AND RODUCED IMPURITY IN P^+-IMPLANTED GaAs CRYSTALS

F. F. KOMAROV and I. S. TASHLYKOV

Institute of Applied Physics Problems, Byelorussian State University, Minsk, SSSR

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RODUCTION

concerned with the formation of damage ductor systems, like $A^{III}B^{V}$, during ion have been extensively studied for a[1,2] Electron microscopy, electron dif- techniques and electrophysical parameter have been used to study crystalline disorder in GaAs as well as the profiles of active impurity distribution, depth f the current carrier density and mobility implantation of IV and VI group-ions into The formation and range of the defects in Ca^+ ion implanted GaAs have been optical techniques.[3,4]

ly new means of studying solids have been through the channelling effect.[5,6] It was applied in physics of implantation pro- By means of the Rutherford backscattering used for studying compound semicon- crystals,[8] numerous experimental investiga- been performed. They were reviewed Picraux.[9]

is also of interest for studies from the point of radiation damage formation, appearance phases and structural transformations oc- during ion implantation (in particular, and Al^+ ions). From studies performed by techniques it is known that room-tempera- P^+ ion implantation into GaAs with a sub- high-temperature anneal or P^+ ion im- into warmed-up GaAs crystals results formation of ternary compounds, like P_x, which are capable of luminescence visible range of the spectrum.[10–12] At the our experimental studies have shown P^+ ion implantation into GaAs is char- by a number of peculiarities observed distribution and behaviour of the defects as well as in the profiles of the implanted component when varying fluence, ion current density and temperature of implantation. Some of these peculiarities are discussed below.

II EXPERIMENTAL PROCEDURE

(111)-oriented GaAs crystal wafers with mechanically and chemically polished surfaces were used for the present study. The samples were bombarded with $^{31}P^+$ ions at energies of 30, 40 and 60 keV. Integrated ion flux ranged from 3×10^{16} to 7×10^{17} ions/cm^2. The crystal temperature during the bombardment was close to T_{room} or 300, 350, 400 and 450 C. The ion current for different sets of samples was in the intervals from 5 to 7, 10 to 15 and 30 to 40 μA cm^2. Annealing was performed in dry-nitrogen atmosphere at temperatures 300 and 550 C for the crystals bombarded at room temperature and at 550 C for the rest. Some experiments were made with a multiple doping. In this case samples were successively bombarded with 60 and 30 keV P^+ ions. Ion fluences were 8×10^{16} cm^{-2} and 3×10^{16} cm^{-2} at T_{room} and 4×10^{17} cm^{-2} and $2,7 \times 10^{17}$ cm^{-2} at $T = 450$ C. To determine the influence of the crystal orientation upon the distribution of the defects and implanted ions experiments with tentatively disoriented crystals ($\alpha \geq 15$) were performed.

The implanted crystals were studied by 1.4 MeV He^+ ion backscattering technique. To determine the backscattering particle yield an Ortec surface berrier detector mounted at an angle of 160° to the direction of the $^4He^+$ ion beam was used. The system energy resolution was not worse than 15 keV. The (111)-axial and random spectra were taken. In turning to the depth scale the values of the stopping cross-sections from the tables in Ref. 13 were used. The calculation of the defect profiles was performed by an iterative technique. The distribution of the

III RESULTS AND DISCUSSION

Figure 1 shows typical spectra for backscattered $^4He^+$ ions from the original (curves 1 and 2) and implanted (curves 3 to 6) crystals. By treating the

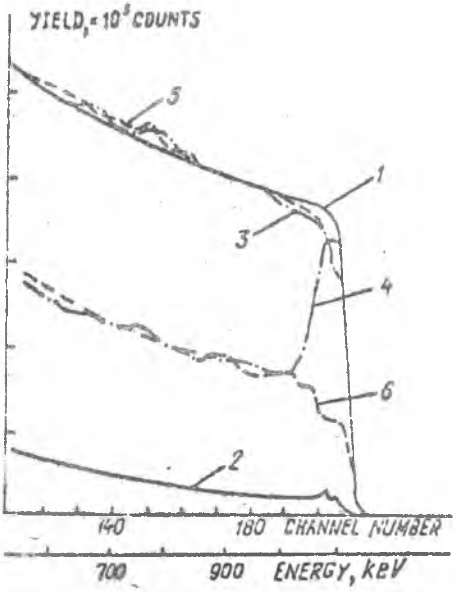


FIGURE 1 Backscattering spectra of GaAs using 1.4 MeV He^+ for random-(1) and (111) channeling-(2) before implantation and after 3, 2 × 10^{16} cm^{-2} (T_{impl} = 20°C)-(3; 4) and 1, 5 × 10^{17} cm^{-2} (T_{impl} = 300°C)-(5; 6) implants of 60 keV P^+-ions.

backscattering spectra the following parameters were analyzed: the defect profiles, the area under the defect peak in the axial spectra (S_d), the χ_{min}, χ_{max} values, the implanted phosphor profiles and the depth variation of the ratio of the yield for the random spectra of the bombarded crystals to the corresponding value of the yield for the original crystal (Y_{impl}/Y_{orig}).

Some of the results on the P^+ ion implantation into GaAs at current densities of $j \leq 15$ $\mu A/cm^2$ have been partially discussed.[15–17] Therefore we shall consider only the principal ones. Room-temperature implantation leads to the formation of a damaged layer whose magnitude exceeds (by 30 to 50%) a theoretically estimated projected range of P^+ ions in GaAs.[18] In this case the axial spectra exhibit defect "tails" extending up to depths of some thousands of Angströms. With rising fluence (in the interval of investigation) a slight increase in the defect concentration occurs due to a depth extension of the damaged layer.

The distribution of the phosphor implanted under such conditions is characterised by numerous peaks, its range being estimated by some thousands of Angströms.[17]

With rising implantation temperature (T_{im} 150°C) amorphisation of GaAs crystals during ion implantation to a fluence of ~7 × ions/cm² does not occur. The depth at which peak of the defect concentration is oberve some times higher than that for the room temp ature implantation. With rising fluence the num of the defects grows, due to both a slight incre in their concentration and to the defect p extension towards the surface.

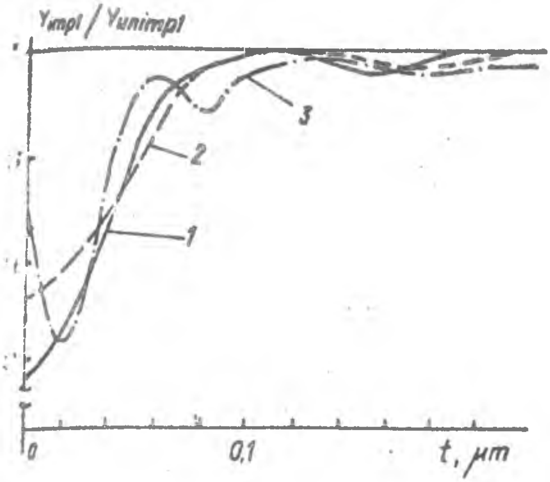
The axial spectra of the higher-temper bombarded crystals exhibit defect "tails," wh extension depth approaches some thousand Angströms (which is somewhat higher than for the room-temperature implantation).

The distribution profiles of the high-tempera implanted phosphor are also characterised numerous peaks, however, the range of the p phor is considerably higher than at T_{room}.[1] degree of the recovery of the damage in G crystals implanted with phosphor at T_{room} du thermal annealing is rather sensitive to the planted ion fluence. The analysis of the S_d and variations indicated that the defect anneal dur a thermal treatment is negligible and almost dependent of the integrated flux at fluences of ab 10^{16} ions/cm². At lower fluences due to the ann ing an intense recovery of the radiation defe occurs.

During a thermal treatment of GaAs bombar to a fluence of 3 × 10^{15} ions/cm² (E = 60 ke a near 90% anneal of the defects is observed χ_{min} becomes equal to 14%, while in GaAs planted with a fluence of 3, 2 × 10^{16} ions (E = 60 keV) less than ½ of defects are anneal and χ_{min} is altered only by 16%.

The difference in the property variation duri the implanted crystal annealing may be due that P^+ ion high-fluence implantation into Ga crystals and their thermal treatment may responsible for the structural transformati with the formation of compound defects. In th respect the composition variation in the nea surface layers of the matrix during implantati and thermal treatment should be analyzed. Figu 2 shows a relative depth variation of the rando spectra for the backscattered He^+ particles fro the implanted and subsequently annealed GaA crystal.

In the crystal implanted with 30 keV P^+ ion at a fluence of 7 × 10^{16} cm^{-2} a region with reduced concentration of the matrix atoms formed which extends to depths of t > 1000 Å



…URE 2 Depth dependence of the relative variation of …yield for the random spectra of GaAs crystals implanted …th phosphor ions at $E = 30$ keV, $\Phi = 7 \times 10^{16}$ cm^{-2}, T_{impl} = 20°C-1, after annealing at 300°C-2 and 550°C-3.

…r the near-surface layer 500 Å thick they make up …ss than 90% of the normal concentration. …ermal annealing at 300°C results in the profile …ation (curve 2). A reduction in the signal in the …ear-surface region is observed but the composition …iation extends to a larger depth (up to 2500 Å). …ith a further anneal temperature increase to …0°C the composition variation proceeds. The …ative yield variation is associated, in our opinion, …th the reduction of As content in the near-surface …ers of the implanted crystals which is in agree…ent with the results obtained in the cathodolumi…nescence studies[19] and in the microanalysis[20] of …aAs bombarded with ions at an energy of some …s of keV. The lack of As atoms is apparently …mpensated by P^+ atoms and perhaps partially …other light impurities. In this case we have an …ample of one more important aspect of the back…attering technique application, i.e. the pos…ility of determining the profiles (and in a number …cases the type) of light impurities implanted in …ge concentrations into heavy matrixes. We …nsidered this problem in more detail in Ref. 21.

Thus, variation of the matrix atoms concentra…n observed on implanting P^+ ions into GaAs …ay encourage structural transformations.

On increasing the current density in the ion beam …30 ÷ 40 μA/cm² the profiles for the defects …d the implanted phosphor acquire characteristics …ferent from those discussed above. For illustra…n Figures 3 and 4 present a spatial distribution of the defects and phosphor implanted into GaAs at different temperatures.

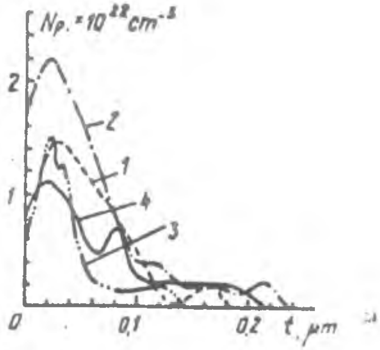


FIGURE 3 Distribution profiles of phosphor implanted into GaAs $E = 40$ keV, $\Phi = 4 \times 10^{17}$ cm^{-2}, $j \geq 40$ μA cm^{-2} T_{impl} = 20°C-1; 150°C-2; 450°C-3; $E = 30$ keV, $\Phi = 2 \times 10^{17}$ cm^{-2}; $j = 30 \div 40$ μA cm^2, T_{impl} = 450°C-4

The phosphor profiles at each implantation temperature exhibit a well defined peak which lies almost at the same depth as that predicted theoretically,[18] though straggling is somehow larger. These results correlate well with the profiles in Ref. 22, obtained in studying the distribution of radioactive phosphor when successively removing the thin layers. The profiles of the defects controlled by backscattering technique (Figure 4) are distributed in the depth corresponding to the range of the implanted phosphor.

Composition variation in GaAs crystals implanted with P_2^+ ions at high ($j > 15$ μA cm^{-2}) current densities differs not so remarkably as the phosphor or defect profiles (Figure 5, 2). Furthermore, variation in the curves is not always in agree-

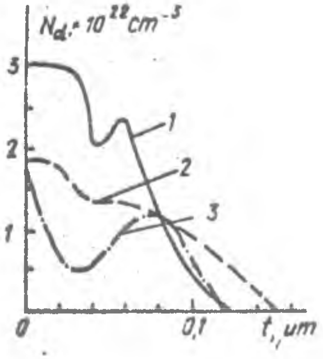


FIGURE 4 Defect distribution profiles in P^+ ion implanted GaAs. Notation is the same as for Figure 3.

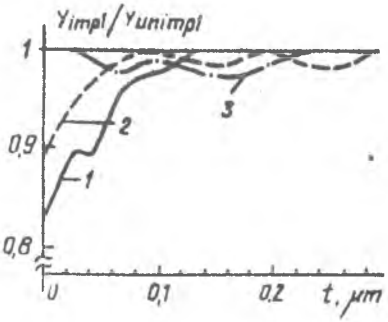


FIGURE 5 Depth dependence of the relative variation of the yield for the random spectra of P^+ ion-implanted GaAs crystals. Notation is the same as for Figure 3.

ment with the phosphor profiles even qualitatively. This is evidently due to the fact that the composition variation of the doped layers is associated not only with the range of P^+ ions, but also with the appearance of other light impurity atoms.

Thermal annealing of the room-temperature implanted crystals results in the redistribution of the implanted phosphor (Figure 6), its concentration and the range, however, are not changing monotonically with rising treatment temperature.

A complex character of the variation in the phosphor space distribution within GaAs indicates undoubtedly a competition between two counteracting processes: the synthesis reaction rate of a chemical compound like $GaAs_{1-x}P_x$ and the dissociation rate of the formed chemical bonds. The authors of Ref. 23 in studying the synthesis of silicon nitride and silicon carbide by means of N^+ and C^+ ion implantation into Si have shown the importance of accounting the basic processes, affecting the structural transformation in implanted crystals for better understanding experimental results.

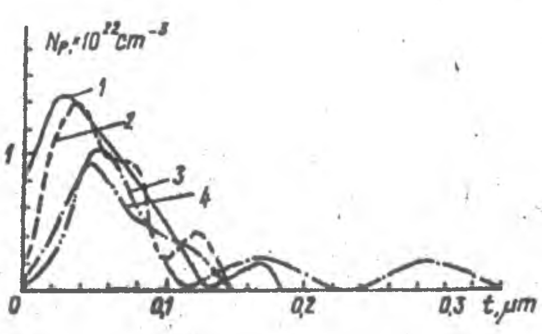


FIGURE 6 Phosphor distribution profiles in implanted GaAs. $E = 40$ keV, $\Phi = 4 \times 10^{17}$ cm^{-2}; $T_{impl} = 20$°C-1, after annealing at $T = 150$°C-2, 300°C-3, 500°C-4.

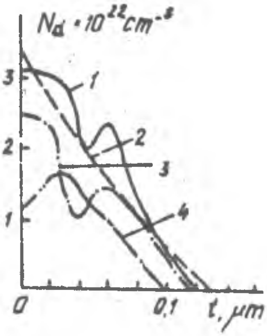


FIGURE 7 Defect profiles in P^+ ion implanted and ann GaAs. Notation is the same as for Figure 6

Figure 7 shows the defect profiles of the crystals subjected to a thermal treatment. recovery of the damage in the implanted cry occurs primarily due to the annealing of the de within the near-surface layer and only then higher-temperature annealing within the de layers. At the same time even after a 500 (nealing the level of the residual damage is fa high.

IV CONCLUSIONS

In studying phosphor-ion implanted GaAs it established that in the case of phosphor impla tion at low ion current densities in the beam (μA/cm^2) the implanted phosphor ion distribu has rather a complex form and is characterized the range some times larger than that calcula by the LSS theory.

In this case the defect profile distribution sensitive to the implantation temperature room temperature implantation the defect p is in the range by 30 to 50% exceeding the celerated phosphor ion projected range in oriented GaAs (R_p). calculated by the LSS the

With rising implantation temperature the de at which the defect peak maximum is observ increases approaching the value ~5 R_p at T 400°C. As a result of implantation of high phosp ion integrated fluxes composition variations in implanted GaAs layer take place.

In the case of P^+ ion implantation with h current densities ($j > 30$ μA/cm^2) the distribut profiles of the implanted phosphor and defects in agreement with the LSS theory.

Due to the annealing (up to $T = 550$°C) distribution of the implanted phosphor and t ation variation are considerably altered ing that intense migration processes of the and phosphor atoms take place.

rmal anneal of GaAs crystals implanted gh P⁺ ion fluences at room temperature n a small recovery of the radiation damage. gh-temperature implanted crystals have a rfect surface, though are characterized a high level of structure imperfections at epths.

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