RESEARCH INSTITUTE FOR ELECTRONIC COMPONENTS (ICCE)
ROMANIAN ACADEMY MINISTRY OF RESEARCH AND TECHNOLOGY
IEEE-ROMANIA SECTION

16th ANNUAL SEMICONDUCTOR CONFERENCE

OCTOBER 12-17,1993,SINAIA,ROMANIA

CAS'93

PROCEEDINGS

16-th ANNUAL SEMICONDUCTOR CONFERENCE

CAS 1993

PROCEEDINGS

Tuesday 12-th to Saturday 17-th October 1993
Sinaia Hotel, Sinaia, Romania

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
Державний вищий навчальний заклад Прикарпатський національний університет імені Василя Стефаника
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UNDER THE
AUSPICES OF : ROMANIAN ACADEMY
MINISTRY OF RESEARCH AND TECHNOLOGY
IEEE - Romania Section

Zn^+/As^+ AND Zn^+/Ar^+ CO-IMPLANTATIONS IN GaAs SINGLE CRYSTALS

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GaAs is an important material for microwave and optoelectronic device applications. Since ion implantation affords precise dopant control and selective p- or n-type doping area, it has emerged as a reliable fabrication techique for realizing GaAs based integrated circuits and field-effect transistors. However, the low electrical activation of the dopants (especially p-type dopants such as Be, Mg, Zn, Cd) and their diffusion during post-implantation annealing proves to be one of the major problem in this direction. The co-implantation of host components and dopants in semiconductor compounds was firstly proposed by Heckingbotton and Ambidje [1] to control the stoichiometry of the implanted layers and thus to promote higher activation. The influence of co-implantation upon the behaviour of amphoteric Si-dopant in GaAs has been investigated in detail [2,3]. On the other hand the degree of understanding of the acceptor dopant activation enhancement mechanism by co-implantation in GaAs remains relatively poor.

The purpose of the present report is to analyse the influence of co-implantation on the Zn-acceptor dopant activation in GaAs single crystals. Zn^+/As^+ and Zn^+/Ar^+ co-impantations have been used to separate chemical effects from radiation-damage ones.

Liquied encapsulation Czochralski (LEC) grown semi-insulating GaAs single crystals have been employed. The ion implantation at doses $5 \cdot 10^{13}$ and $5 \cdot 10^{14}$ cm^{-2} was performed at room temperature. The ion energies were chosen so that the profiles of as implanted ions to overlap, i.e. the energies were 143; 150 and 90 keV for Zn^+, As^+ and Ar^+ respectively. The post-implantation annealing was performed in H_2-atmosphere for 15 min at different temperatures in the interval 600-750 °C. Sheet carrier concentration, hole mobility and resistivity were determined by the Hall-effect measurements using Van der Pauw method. The depth distribution of free carrier concentration was obtained by step-stripping technique and Hall effect measurements. A solution of 2% Br in C_2H_5OH was employed for layer removal in steps of $\simeq 0.05\ \mu m$.

Fig.1 illustrates the dependence of the zinc impurity activation upon the annealing temperature for Zn^+, Zn^+/As^+ and Zn^+/Ar^+ implanted GaAs layers. The parameters of the layers involved are summarized in Table 1. It is seen, that the co-implantation of As^+ in GaAs single crystals considerably increases the Zn-impurity activation. At the same time a diminution of the impurity activation degree is observed after

Table 1.

Implantation schedule	Anneal. temperature, $^{\circ}C$	Resistivity, Ohm·cm	Sheet concentration cm^{-2}	Mobility, $cm^2/V\cdot s$	Activation, %
Zn^+/143 keV/ $5\times10^{13}\ cm^{-2}$	600	3.2×10^4	1.1×10^{13}	1.9×10^1	21
	700	7.3×10^3	4.1×10^{13}	2.1×10^1	82
	750	5.8×10^3	4.5×10^{13}	2.2×10^1	89
Zn^+/143 keV/ $5\times10^{14}\ cm^{-2}$	600	7.6×10^2	1.7×10^{14}	4.8×10^1	34
	700	6.8×10^2	1.6×10^{14}	5.6×10^1	33
	750	8.5×10^2	1.4×10^{14}	5.3×10^1	28
As^+/150 keV/ $5\times10^{13}\ cm^{-2}$, Zn^+/143 keV/ $5\times10^{13}\ cm^{-2}$	600	7.0×10^4	2.6×10^{13}	3.5×10^0	52
	700	2.1×10^3	4.4×10^{13}	5.8×10^1	87
	750	1.7×10^3	4.6×10^{13}	1.1×10^2	92
As^+/150 keV/ $5\times10^{14}\ cm^{-2}$, Zn^+/143 keV/ $5\times10^{14}\ cm^{-2}$	600	6.0×10^2	3.0×10^{14}	3.4×10^1	61
	700	4.3×10^2	2.4×10^{14}	6.1×10^1	47
	750	3.9×10^2	2.6×10^{14}	6.2×10^1	52
Ar^+/ 90 keV/ $5\times10^{13}\ cm^{-2}$, Zn^+/143 keV/ $5\times10^{13}\ cm^{-2}$	600	3.3×10^4	3.3×10^{12}	5.7×10^1	6.5
	700	2.2×10^3	2.5×10^{13}	1.2×10^2	49
	750	2.9×10^3	2.7×10^{13}	7.8×10^1	54
Ar^+/ 90 keV/ $5\times10^{14}\ cm^{-2}$, Zn^+/150 keV/ 5×10^{14} cm	600	6.2×10^3	5.3×10^{13}	1.9×10^1	11
	700	1.2×10^3	6.9×10^{13}	7.3×10^1	14
	750	1.0×10^3	7.4×10^{13}	8.1×10^1	15

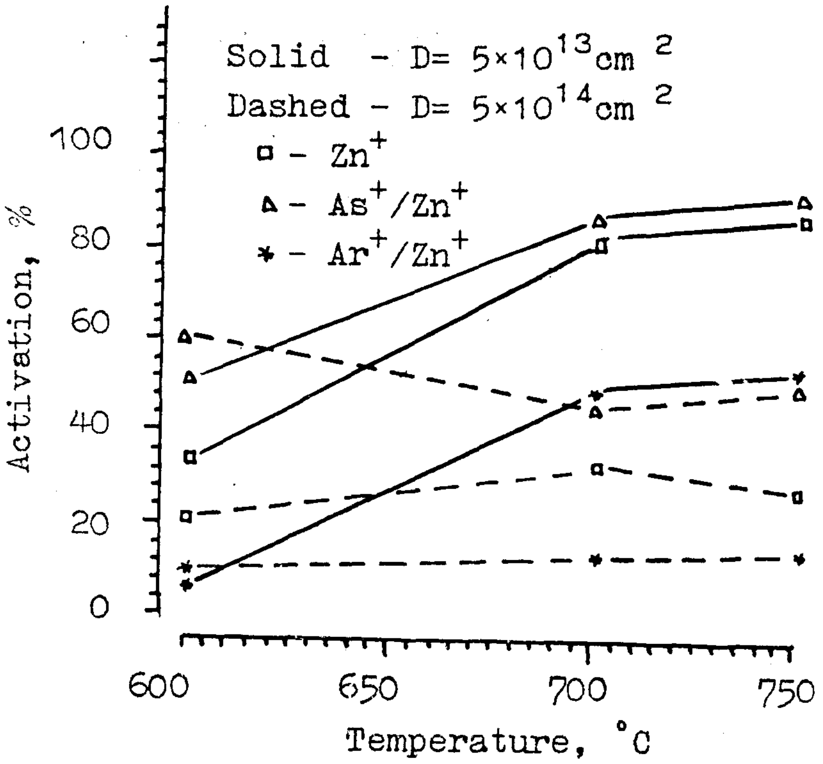

Fig.1.Zinc impurity activation efficiency versus annealing temperature for Zn$^+$, Zn$^+$/As$^+$ and Zn$^+$/Ar$^+$ implanted GaAs layers.

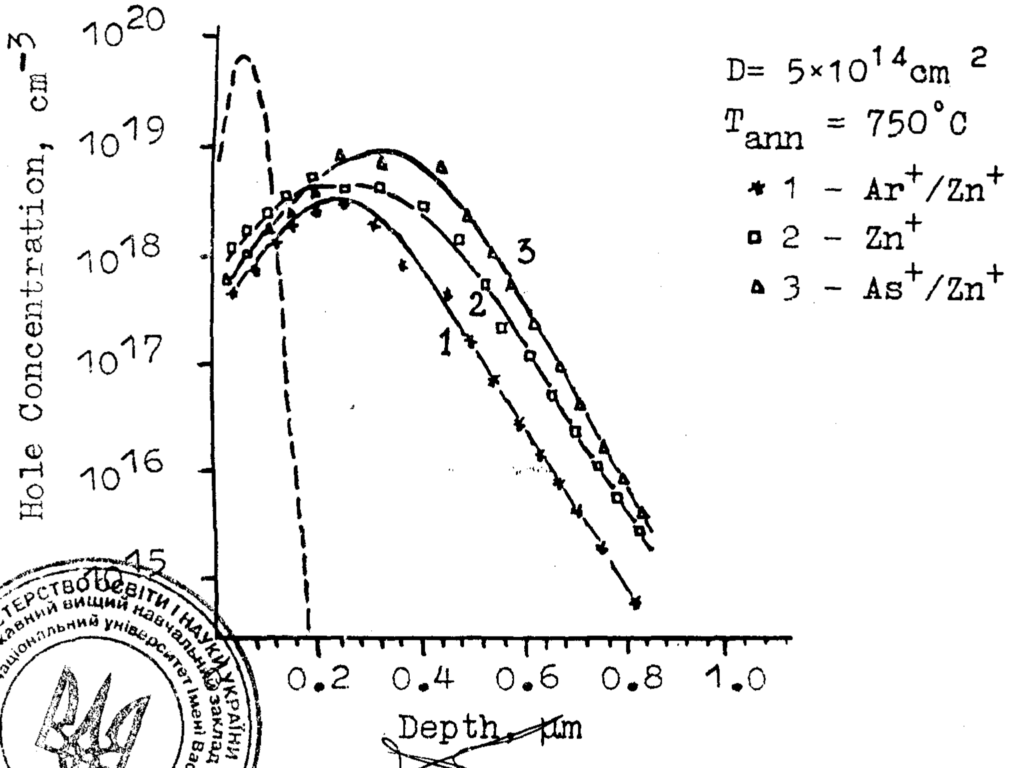

Fig.2.The depth distribution of the free hole concentration in Zn$^+$, Zn$^+$/As$^+$ and Zn$^+$/Ar$^+$ implanted GaAs layers. The dashed line represents the theoretical profile for 143 keV Zn-implantation.

Ar^+ co-implantation. For example, the co-implantation of As^+ at the dose $5 \cdot 10^{13}$ cm^{-2} leads to an enhancement of the Zn^+ activation efficiency up to 92% at the annealing temperature 750 °C. At the same time after co-implantation of both As^+ and Ar^+ the hole mobility increases. In our opinion these results indicate the activation efficiency enhancement to be primarily connected to stoichiometric disturbances caused by As^+ implantation. The disturbances involved probably provide a high concentration of gallium vacancies V_{Ga} resulting in the Zn-impurity activation efficiency increasing. As to the Ar^+ co-implantation, it only produces the radiation damages which compensate the activated dopant and decreases the zinc activation efficiency.

Fig.2 presents the depth distribution of the free hole concentration in GaAs after Zn^+-implantation as well as after Zn^+/As^+ and Zn^+/Ar^+ co-implantations at the dose of $5 \cdot 10^{14}$ cm^{-2} (the post-implantation annealing was performed at 750 °C). The dashed line represents the theoretical LSS profile for 143 keV zinc ions implanted in GaAs. The results presented in Fig.2 indicate that the dual implantation changes only the zinc activation while the depth distribution of implanted impurity remains practically unchangable. To obtain more narrow impurity profiles and higher peak hole concentration rapid thermal annealing appears to be required [4].

Thus, the activation efficiency of Zn-impurity implanted in GaAs single crystals was established to be considerably increased by As^+ co-implantation.

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