17th ANNUAL SEMICONDUCTOR CONFERENCE

CAS 1994

Tuesday 11 to Saturday 16, October 1994
Sinaia Hotel, Sinaia, Romania

PROCEEDINGS

VOLUME 2

organized by

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under the auspices of

ROMANIAN ACADEMY
MINISTRY OF RESEARCH AND TECHNOLOGY
IEEE - Romania Section
Electron Devices Chapter

RAMAN CHARACTERIZATION OF Zn^+ IMPLANTED GaAs SINGLE CRYSTALS COIMPLANTED WITH As^+ AND Ar^+ IONS

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1. Introduction.

GaAs is an important material for microwave and optoelectronic device applications. Dopant implantation in GaAs substrates is a widely used technique for preparing electrically active layers. However, p-type dopants are usually characterized by a low electrical activation efficiency. The dual implantation technique proves to promote the higher activation degree of the dopants [1]. The influence of coimplantation upon the behaviour of p-type dopants in GaAs has been investigated earlier using the Hall-effect measurements [1,2]. Another nondestructive method aimed to determine the doping level of the material is Raman scattering (RS) by phonon-plasmon coupled modes (LOPC) [3,4]. This report illustrates the use of RS for simultaneous monitoring the lattice recovery and evaluating the electrical characteristics after thermal annealing of Zn^+-implanted GaAs coimplanted with As^+ and Ar^+ ions.

2. Experimental.

LEC-grown semiinsulating (100)-oriented GaAs single crystals have been employed. The crystal parameters, ion implantation, annealing and layer removing procedures have been described earlier [2]. The RS spectra have been measured at 300 K by an automatic set-up based on the DFS-52 spectrometer using 488 nm line of an Ar^+ laser. The penetration depth of the incident light is $\alpha_1^{-1} \approx 100$ nm in the bulk of GaAs at 300 K.

3. Results and Discussion.

Fig.1 compares the Raman spectrum of an unimplanted GaAs sample with the spectra of $5\cdot10^{13}$ cm^{-2} and $5\cdot10^{14}$ cm^{-2} Zn^{+} implanted crystals. The spectra of samples annealed at T_{ann} = 500 °C practically coincide with the spectrum of unimplanted crystals. This indicates that for the annealing temperature higher than 500 °C the recovery of the crystal lattice occurs. In the unimplanted sample (Fig.1), only a sharp longitudinal optical (LO) phonon line at 292 cm^{-1} is present. In the Zn^{+} implanted samples, the LO peak is broadened and shifted towards lower frequencies. In addition to the LO peak, the forbidden in this geometry TO peak as well as three broad bands located around 70, 180 and 250 cm^{-1} emerge. The latter bands are known to originate from amorphous GaAs.

Now we will present the results of the RS investigation of dual implanted GaAs crystals for T_{ann} = 700 °C. It is to be noted that the RS spectra of all Zn^{+} implanted as well as As^{+} or Ar^{+} coimplanted samples (with the only exception for $5\cdot10^{13}$ cm^{-2} As^{+}/Zn^{+} implanted crystals after 0.1 μm layer removing) are similar to the unimplanted reference one. In our opinion these data indicate the activation efficiency of the dopant and the carrier mobility to be low near the surface of the crystal layers, explored by the Raman probe.

The RS spectrum for the As^{+}/Zn^{+} implanted crystals at the $5\cdot10^{13}$ cm^{-2} dose after 0.1 μm layer removing is presented in Fig.2. One can observe that the LO band undergoes a sudden modification with a pronounced asymmetrical broadening. Light scattering by LO phonon-plasmon coupled modes seems to be the reason for such a behaviour. The peculiarities of coupling between the LO phonon and plasmon modes are now well understood in the light of earlier studies (see, for example, [3]). On the basis of the LOPC analysis, one can conclude that the band width increase of the LO peak observed in Fig.2 is due to the presence of an overdamped single coupled mode located in the vicinity of pure LO frequency. We also have to take into account surface space-charge effects. In the surface region the free carriers are forced to move towards the bulk leaving depleted zone where the LO vibrations are now decoupled from the plasmon and contribute to a pure "unscreened" LO signal.

Analytical adjustments using a standard fitting procedure

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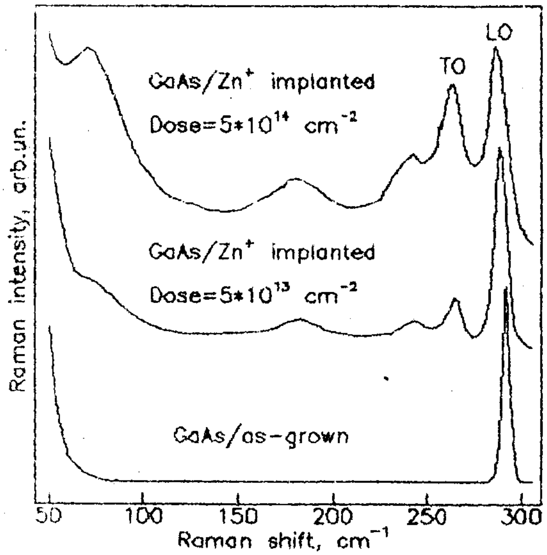

Fig. 1. RS spectra of GaAs before and after ion implantation.

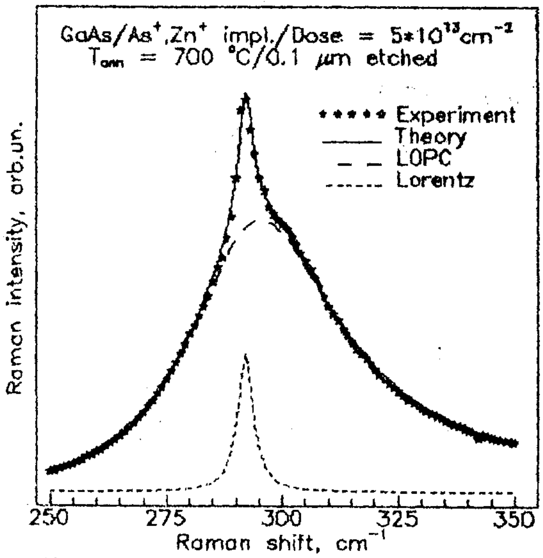

Fig. 2. Typical example of the RS with fitting curves.

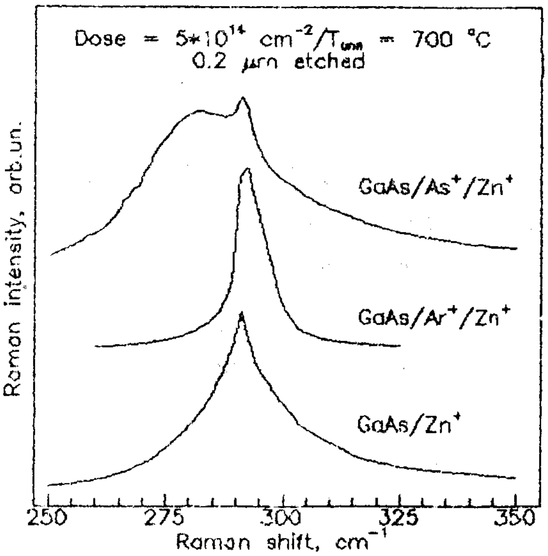

Fig. 3. RS spectra of implanted GaAs after 0.2 μm layer removing.

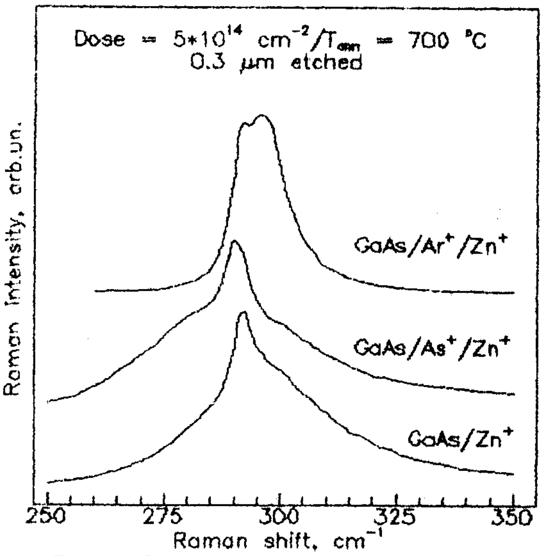

Fig. 4. RS spectra of implanted GaAs after 0.3 μm layer removing.

Table 1. "Best-fit" parameters obtained for the LOPC.

Processing schedule	ω_p, cm^{-1}	Γ_p, cm^{-1}	N_h, cm^{-3}	μ_h, $cm^2/(V\cdot s)$
Zn^+ impl.;0.2 μm etch.	350	680	$4.3\cdot10^{18}$	36
As^+/Zn^+ impl.;0.2 μm etch.	530	880	$1.0\cdot10^{19}$	28
Ar^+/Zn^+ impl.;0.2 μm etch.	220	850	$1.7\cdot10^{18}$	29
Zn^+ impl.;0.3 μm etch.	290	420	$3.0\cdot10^{18}$	58
As^+/Zn^+ impl.;0.3 μm etch.	390	510	$5.4\cdot10^{18}$	48
Ar^+/Zn^+ impl.;0.3 μm etch.	170	240	$1.0\cdot10^{18}$	100

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[3] were performed for the LOPC contribution and Lorentzian forms for unscreened LO signal. The result for such an analysis is given in Fig.2. The best fit results are the following: $\omega_{LO}=292$ cm^{-1}, $\gamma_{LO}=4$ cm^{-1} for the LO mode and $\omega_p=305$ cm^{-1}, $\Gamma_p=415$ cm^{-1} for the plasmon parameters. Using this ω_p value and the effective mass of holes $m^* = 0.378 \cdot m_o$ [4], the free carrier density is deduced $N_h = 3.3 \cdot 10^{18}$ cm^{-3}. The evaluation of carrier mobility can be performed if one assumes that the average scattering relaxation time τ of the carrier may be taken equal to $(\Gamma_p)^{-1}$. The mobility is then given by $\mu=e/(m^* \cdot \Gamma_p)$. In our case from the Γ_p value of 415 cm^{-1} the carrier mobility is deduced $\mu = 59$ cm^2/(V·s).

The RS spectra for the $5 \cdot 10^{14}$ cm^{-2} implanted dose are presented in Fig.3 and Fig.4 for the 0.2 µm and 0.3 µm layer removing respectively. The best fit results obtained using the above mentioned fitting procedure are presented in Table 1. As it is seen from this table the activation efficiency of Zn-impurity implanted in GaAs single crystals is considerably increased by As$^+$ co-implantation. The maximal activation efficiency has been registered for the 0.2 µm depth. To obtain more narrow impurity profiles, rapid thermal annealing appears to be required.

Thus, RS proves to be a very valuable nondestructive and contactless technique for monitoring the lattice perfection recovery and evaluating the electrical characteristics of ion implanted GaAs layers.

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