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TRANSIENT ANNEALING OF GaAs BY ELECTRON AND LASER BEAMS

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Transient Annealing of GaAs By Electron and Laser Beams

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Satisfactory electrical activation of heavy implanted species in GaAs usually requires (a) that the sample be kept at a temperature higher than ~200°C during implantation[1], and (b) that subsequent annealing be carried out at temperatures above 800°C. During the post-implantation annealing stage, the GaAs surface must be protected from dissociation. This is done either by using an inert encapsulant, such as Si_3N_4 or SiO_2[2], or by providing a suitable ambient pressure of As and Ga[3]. The hot implantation and the surface dissociation problem complicate GaAs device fabrication considerably, as compared to Si technology. The recent advent of annealing semiconductors by means of short electron beam or laser pulses[4] promises a much simpler alternative for GaAs processing, in the form of room-temperature implantation followed by capless transient annealing. Several recent studies[4-6], using pulsed or cw laser sources, or a pulsed electron beam, have demonstrated that transient annealing can indeed be used to restore crystallinity in implanted amorphous GaAs layers, and place the implanted species on substitutional lattice sites. In this work we compare the results of pulsed electron beam and ruby laser irradiations of high-dose and low-dose implanted layers in GaAs.

Semi-insulating, Cr-doped GaAs crystals were implanted at room temperatures with 300 keV Se or Kr ions to doses in the range $3x10^{12}$ -

10^{15} cm^{-2}. The <100> axis of the samples was offset by 10° with respect to the beam during implantation. The samples were irradiated with a pulsed, 100 ns electron beam in vacuum (mean electron energy 20 keV), or with a Q-switched ruby laser (15 ns) in air, and characterized by MeV He^+ channeling, TEM, optical microscopy, electrical measurements in depth, and SIMS.

Results of 2 4 MeV He^+ channeling analysis of electron-beam irradiated samples are given in Figures 1 and 2, and summarized, together with observations from TEM in Table 1. These data show the existence of a threshold (>0.4 J/cm²) and a narrow window in the fluence (between 0.4 and 0.7 J/cm²) for successful recrystallization of an amorphous layer in GaAs by means of a pusled electron beam. A similar situation exists for pulsed laser irradiation, with a threshold at ∿1 J/cm² for ruby laser[7] or ∿0.2 J/cm² for frequency-doubled Nd-YAG laser[8], and a surface channeling yield of 0.04 for irradiation slightly above threshold in both cases. We believe that the annealing takes place in the liquid phase. The channeling spectra indicate that electron beam pulsing at 0.7 J.cm² produces more damage in the high-dose, amorphous implanted layer, than in the low dose case.

A similar effect occurs in Si[9], and can be rationalized in terms of a lower latent heat of fusion or melting temperature for amorphous as compared to crystalline material. Ruby laser irradiation gives results similar to electron beam irradiation; ruby laser photons have an energy (1.8 eV) which is larger than the bandgap of GaAs (1.4 eV). Their absorption is similar in crystalline and amorphous GaAs. However, spatial non-uniformities in the ruby laser beam produce a rougher surface topography on the irradiated samples than for electron beam irradiations.

Measurements of the electron concentration for Se implantations show that for implantation doses above a few times 10^{14} cm^{-2}, ruby laser and

and even more so electron beam irradiations result in peak concentrations significantly higher than can be obtained in furnance annealing. However, the mobilities after transient annealing are ususally lower, as compared to conventional annealing. Implantations at doses at or below the 10^{13} cm^{-2} level show poor or no electrical activity after transient annealing. These effects will be correlated with the corresponding microstructure and atomic profiles of implanted and dopant species in GaAs.

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FIGURE CAPTIONS

Fig. 1 Energy spectra of 2.4 MeV $^{4}He^{+}$ ions backscattered at 170° from <100> GaAs implanted at room temperature with 300 keV, $10^{15}Kr^{+}/cm^{2}$ before and after single-pulse electron beam irradiation at the indicated fluences. The aligned and random spectra from a virgin sample (unimplanted and unirradiated) are included in the figure for comparsion.

Fig. 2 Energy spectra of 2.4 MeV $^{4}He^{+}$ ions backscattered at 170° from <100> GaAs implanted at room temperature with 300 keV, $3x10^{12}$ Se^{+}/cm^{2} before and after single pulse electron beam irradiation at the indicated fluences. The aligned and random spectra from a virgin sample (unimplanted and unirradiated) are included in the figure for comparsion.

TABLE I

Implant conditions	Characterization	As-implanted	Electron beam influence (J/cm^2)		
			0.4	0.7	1.1
300 keV 10^{15}	Crystallinity	2200A amorphous layer	no change from as-implanted	$\chi_0=0.11$	$\chi_0=0.17$
Kr/cm^2	$(As/Ga)_0$	1	1	0.8	0.8
R.T.	TEM	amorphous layer	polycrystalline and heavily damaged layer	dislocation lines and disordered zones	dense dislocation network
300 keV 3×10^{12}	Crystallinity	good crystal $\chi_0=0.05$	no change from as-implanted	$\chi_0=0.07$	$\chi_0=0.31$
Se/cm^2	$(As/Ga)_0$	1	1	0.75	0.7
R.T.	TEM	some damage	disordered zones	dislocations stack.faults	dense disloc.network

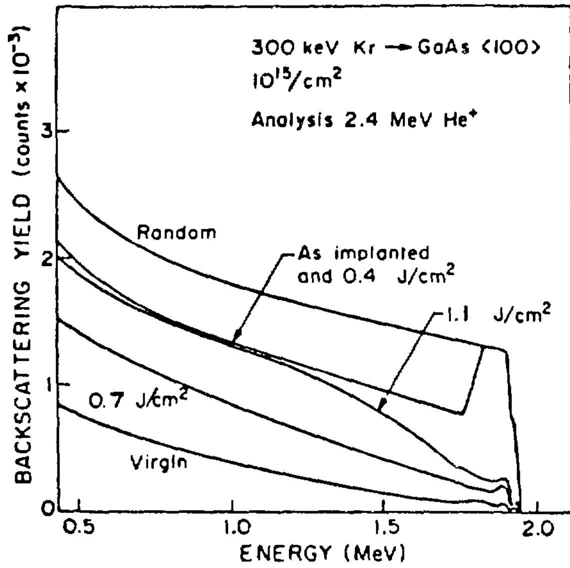

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Fig. 1

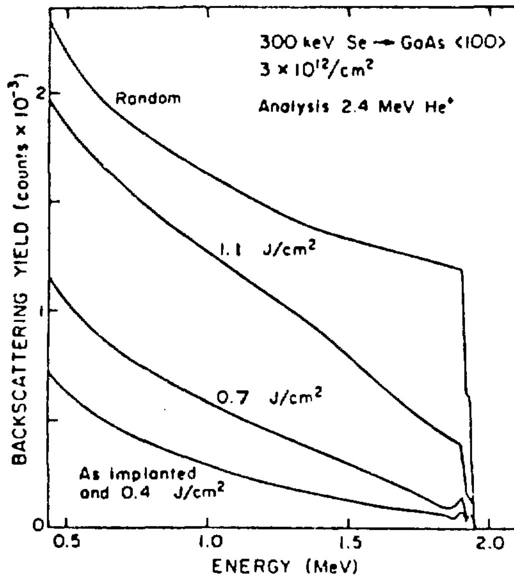

Fig. 2

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