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ORIGINAL PAPER

Angular dependence of post-implantation damage recovery under 1 MeV electron irradiation in GaAs

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Abstract The angular dependence of post-implantation defects removal in GaAs irradiated with 1 MeV electrons from a Van de Graaff accelerator has been investigated. The possible way of enhancing defect annealing consists in ionization created by electron irradiation. In this paper new results of a damage level behaviour dependent on 1 MeV electron beam angle irradiation are presented. GaAs single crystals of <100> orientation were implanted with 150 keV As^+ ions at RT and then irradiated with a scanning beam of 1 MeV electrons at some selected angles. Rutheford Backscattering Spectroscopy (RBS) of 1.7 MeV $^4He^+$ ions were used to determine the depth distribution of defect concentration before and after electron irradiation. The results relate clearly the ionization intensity created by the electron beam with angle of incidence with respect to the GaAs <100> orientation.

Key words electron annealing • GaAs • implantation

Introduction

Electron beam irradiations are very often used to enhance post-implantation damage recovery in semiconductor crystals [1, 4, 6, 11]. The influence of ionization created by irradiating electrons on the stability and transformation processes of simple and complex defects has been the subject of extensive studies [2, 5, 8, 9, 10, 12].

Many papers reported on the crystallization of isolated clusters and continuous amorphous layers by using high and low energy (subthreshold) electron beams [7, 13]. In our last two papers [14, 15] we presented the results of the influence of 300 keV and 1 MeV electron irradiations on GaAs single crystals implanted with 150 keV As^+ ions at room temperature (RT). The results indicated a distinct instability of post-implantation damage level dependent on the electron fluence. The instability was revealed in the form of an "oscillatory" behaviour of a damage level versus an electron beam fluence.

The purpose of the present work was to check whether the intensity of ionization created by an electron beam depends upon the angle of incidence with respect to crystal orientation, which may influence the results of damage level measurements.

Experiments

The samples prepared from melt grown (Czochralski) single crystals of n-type GaAs with 10^{17} cm^{-3} Te were provided by the Institute of Electronic Materials, Warsaw. The GaAs wafers were 300–400 μm thick and were treated by

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mechanical lapping from one side and mechanical and chemical polishing from the other side which was exposed to ion implantation. The samples were implanted with 150 keV As^+ ions to a dose 2×10^{13} cm^{-2} which created a damage level well below amorphization. To assure uniformity of ion implantation the ion beam of 0.1 μA cm^{-2} was scanned electrostatically over the sample area. To avoid axial chanelling a 7° tilt angle between the surface normal and the ion beam was used.

The implanted samples of 5×5 mm^2 dimensions were then irradiated with a scanning beam of 1 MeV electrons from a Van de Graaff accelerator at the same 7° angle with a fluence of 1×10^{17} cm^{-2}, in a 3×10^{-6} Torr vacuum. Similar electron irradiations were performed at the angles of 0° and 3° between the surface normal and the electron beam. The samples were scanned at a distance of 1.4 m from the scanning system. The temperature of the samples was maintained constant at 320 K.

The post-implantation damage distributions, before and after electron irradiations, were measured by RBS/channeling spectra of 1.7 MeV $^4He^+$ ions using classical relation by Chu *et al.* [3]. The damage distributions related to both Ga and As peaks in the RBS spectra were calculated using the "Defect" computer program, (see Ref. [14]). All measurements were carried out at the Forschungszentrum Rossendorf, Germany.

Results and discussion

Fig. 1 shows the <100> aligned spectra for GaAs samples implanted with 150 keV As^+ ions to a dose 2×10^{13} cm^{-2}. The samples were then irradiated with 1 MeV electrons to a dose 1×10^{17} cm^{-2} at three selected angles 0°, 3° and 7° between the surface normal and the electron beam. The position of the spectra depends very clearly on the angle of incidence. This effect is better seen in Fig. 2 which presents the damage depth distributions as extracted from the channeling spectra in Fig. 1. Moreover, the damage profiles for these three angles run nonuniformly for the most part of the subsurface depth of a sample. We observe not only three various damage profiles for the same dose 1×10^{17} cm^{-2} of 1 MeV electrons but also nonuniform sequence of their position, i.e. the "amplitude" of 7° profile lies above the 3° profile. In other words the damage profiles run: as implanted – 0 deg – 7 deg – 3 deg. Fig. 3 presents the damage fluctuations in three selected depths of the damage distributions from Fig. 2, namely at 0, 20 and 50 nm from the surface of the sample.

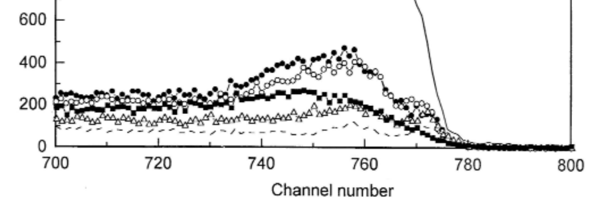

Fig. 1. Evolution of <100> aligned ion channeling spectra of GaAs implanted with 150 keV As^+ ions to a dose 2×10^{13} cm^{-2}: as implanted and after 1 MeV electron irradiations with a dose 1×10^{17} cm^{-2} at different angles of incidence.

In order to facilitate the comparison of our present results concerning damage level versus angle of incidence at the same dose 1×10^{17} cm^{-2} of 1 MeV electrons with our former results of damage level versus a fluence of 1 MeV electrons at a given 7° angle of incidence (see Ref. [15]), we put the inset presenting the dose dependent results. There is a dose similarity between the course of damage profiles, at 20 and 50 nm in both cases.

Based upon this similarity of damage level behaviour we may come to the conclusion that the same dose 1×10^{17} cm^{-2} of electrons applied to lower angles of incidence – 0° and 3° created lower level of ionization like in the runs of damage levels with increasing dose of electrons from 0 to 1×10^{17} cm^{-2} but at the same angle 7° of beam incidence. The final conclusion is that ionization created by high energy electrons of 1 MeV depends on the angle of beam incidence with respect to <100> crystal orientation, at least in the range 0°–7° tilt.

In our discussion we disregarded the damage level orientations at the surface of a sample marked as 0 nm. This curve runs in a different way compared to a similar curve 0 nm from the inset and does not fit to our explanations. A possible reason for this discrepancy is that the surface conditions of a sample are very hard to control.

Conclusions

GaAs <100> single crystals were implanted with 150 keV As^+ ions at RT and then irradiated with a scanned beam of 1 MeV electrons with a dose 1×10^{17} cm^{-2} at selected angles 0° – 3° – 7°. RBS – c spectroscopy of 1.7 MeV $^4He^+$ ions was used to measure defect concentrations before and after electron irradiations.

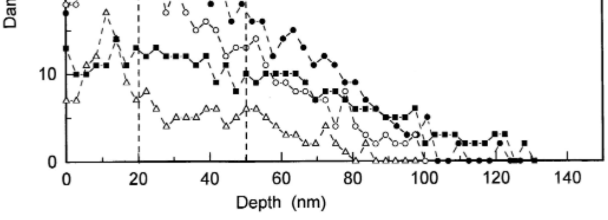

Fig. 2. Depth distributions of damage as extracted from the channeling spectra presented in Fig. 1 at three angles of 1 MeV electron beam incidence.

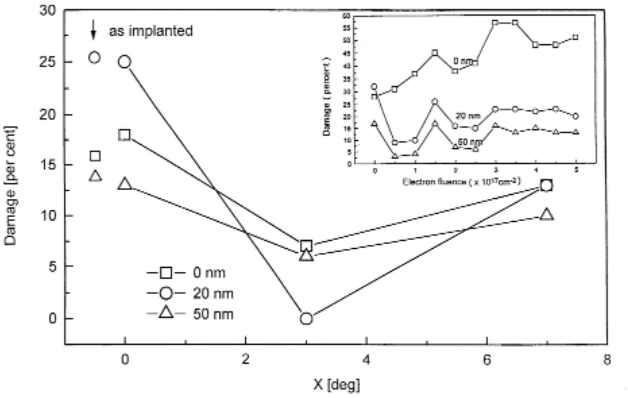

Fig. 3. Damage level fluctuations at 0, 20 and 50 nm from the surface of the sample as a function of 1 MeV electron beam angle of incidence. The inset shows damage level fluctuations as a function of 1 MeV electron fluences from Ref. [15].

From our study we conclude that the intensity of ionization created by 1 MeV electron dependens upon the electron beam angle of incidence with respect to GaAs <100> crystal orientation.

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