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LATTICE DEFORMATION IN $Al_xGa_{1-x}As$ EPITAXIAL LAYERS CAUSED BY IMPLANTATION WITH HIGH DOSES OF 1 MeV Si IONS

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A series of highly perfect $Al_{0.45}Ga_{0.55}As$ epitaxial layers implanted with 1 MeV Si ions to the doses in a range $7\times10^{13}-2\times10^{15}$ ions/cm^2 were studied with various conventional and synchrotron X-ray diffraction methods. The presently used methods allowed both the measurement of lattice parameter changes and strain induced deformation. The evaluation of complete strain profiles was also performed by numerical simulation of diffraction curves. It was found that the implantation induced considerable change of lattice parameter reached the maximum at the dose 3×10^{14} ions/cm^2. The recorded curves proved also that the lattice parameter is almost constant in the near surface region of the implanted layers. The applied doses did not cause lattice amorphisation at room temperature.

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1. Introduction

In recent years ion implantation became a widely used technique in manufacturing of different semiconductor devices, in particular new optoelectronic elements manufactured using new types of $A^{III}B^{V}$ compounds. The effective use of implantation technique requires systematic studies of implantation induced defects, especially the evaluation of amorphisation doses.

In the present paper the effects caused by implantation with 1.0 MeV silicon ions in metalorganic chemical vapour deposition (MOCVD) grown $Al_{0.45}Ga_{0.55}As$ are studied for a wide range of doses. The effects of other types of implantation were studied in AlGaAs by a number of authors [1–3]. The present type of implantation was realised for comparative studies with the implantation with 1.5 MeV selenium performed by present authors in analogous epitaxial layers [4–6]. For effective use of X-ray diffraction methods a high perfection of epitaxial layers was provided by using a substrate with low dislocation density.

2. Experimental

The effects of implantation were studied in (100) oriented epitaxial layers deposited with MOCVD method on indium doped GaAs substrates with low dislocation density. As it was proved by X-ray topographic studies the epitaxial layers were also of good perfection enabling a good visibility of interference effects.

The implantation with 1.0 MeV silicon ions was performed at room temperature in the Rossendorf Research Centre. This energy should provide the same penetration range of ions as the 1.5 MeV selenium ions used in our other experiment [4–6]. The ion doses were in the range 7×10^{13}–1×10^{15} and the maximal dose was more than twice larger than the amorphising dose for pure GaAs.

The implanted layers were studied with the white beam synchrotron topography using both wide and strongly limited front of the wave beam. The first case corresponds to the so-called projection topography revealing dislocations and other defects. In the second case we used either section topographic method with a 5 μm narrow linear beam or micro-Laue method using pinholes of diameter 10–30 μm. The last two methods reveal the effects connected with tetragonal deformation present in the implanted and non-implanted part of epitaxial layer and the effects of depth location. The separation of this two effects is easily achieved comparing the topographs taken at different film-to-crystal distances. The synchrotron micro-Laue patterns allowed also the evaluation of the diffraction vector changes and monitoring of the diffuse scattering effects caused by the development of dislocation loops.

The present investigation included the complementary recording of conventional double-crystal rocking curves for two different asymmetries of 511 reflection in the investigated samples. The methods allowed to evaluate both the lattice parameter difference and the tetragonal deformation caused by lattice misfit. The obtained rocking curves were also used for determination of the strain profiles by the fitting of the theoretical rocking curves obtained by the numerical integration of the Takagi–Taupin equations.

3. Results and discussion

The performed implantation causes a significant increase in the lattice parameter manifesting either as additional stripe at the section topographs or maximum in the double-crystal rocking curves — Figs. 1, 2. These both methods also revealed a set of two stripes or equivalent maxima connected with the non-implanted part of epitaxial layer and the substrate. The separation between the two last stripes or maxima is much smaller than between them and the first. The curve shown in Fig. 2 exhibits also high distinct interference maxima connected with the implanted layer.

It was found that the dependence of implantation induced lattice parameter change on the dose was analogous to observed previously by us in the case of Se implantation (presented at SIMC-X Conf. Berkeley, USA, June 1–5, 1998 [4]). As may be observed in Fig. 3 the implantation induced lattice parameter change increased with the dose apparently reaching the maximum at 7×10^{14} ions/cm^2.

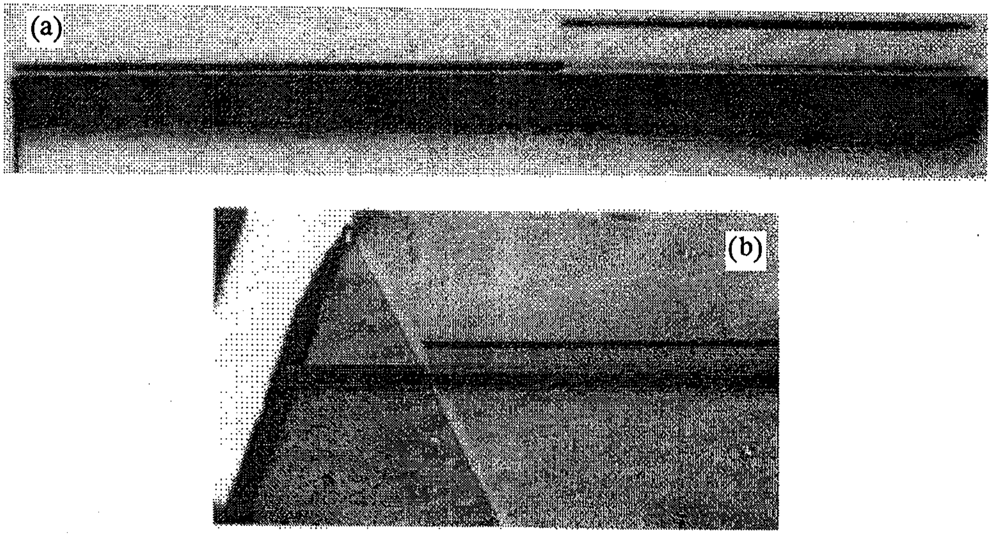

Fig. 1. White beam Bragg-case section topograph of AlGaAs/GaAs implanted with Si ions to the dose 1×10^{14} ions/cm^2 taken at film to crystal distance 28 cm (a) and the representative double exposure of section and projection Bragg-case topographs of $Al_xGa_{1-x}As$ epitaxial layer implanted with 1.5 MeV Se to the dose 6×10^{12} cm^{-2} in a skew 531 reflection selecting 1.2 Å radiation (b).

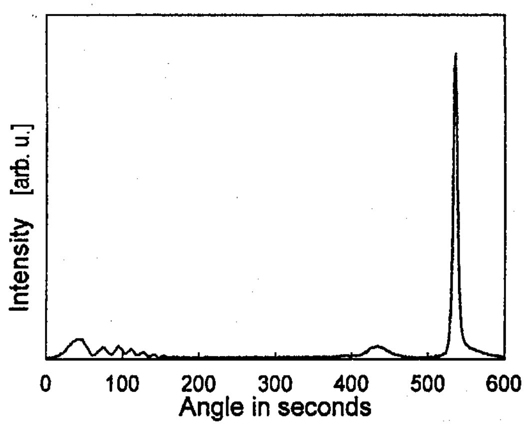

Fig. 2. The experimental rocking curve for the sample implanted with 1.0 MeV Si ions to the dose 1.4×10^{14} ions/cm^2 in 511 reflection of Cu K_{α_1} radiation.

The other similar effect proved by computer simulation of rocking curve, shown in Fig. 4, was that the range of the lattice parameter changes was greater than predicted by TRIM-95 calculation and that the implantation forms a relatively thick layer with almost constant lattice parameter close to the surface. It may be expected that these phenomena are due to the creation of point defects and their diffusion during the implantation. In particular the reasonable lattice

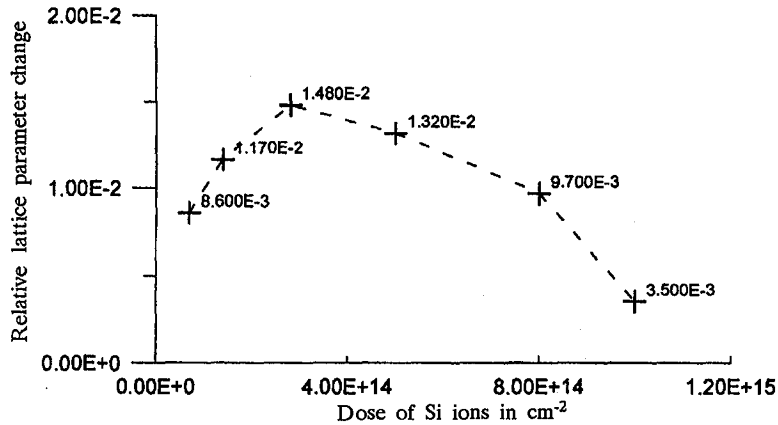

Fig. 3. The dependence of the implantation induced lattice parameter change on the dose in $Al_xGa_{1-x}As$ with $x = 0.45$ for implantation with 1 MeV Si ions.

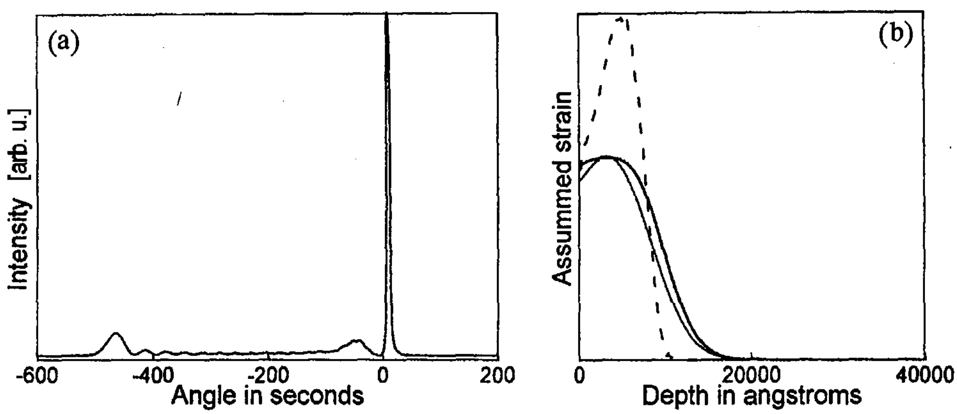

Fig. 4. The theoretical rocking curve (a) obtained by numerical integration of the Takagi–Taupin equations corresponding to the experimental one shown in Fig. 2 and the assumed strain profile (b). The dashed line in (b) denotes the vacancy distribution profile calculated with TRIM-95 program. The thin line is the intermediate profile obtained assuming the diffusion of the point defects.

parameter depth distribution profiles were obtained from TRIM-95 calculated vacancy profiles, simulating concentration dependent diffusion and the saturation effect described by sine function.

The present investigation did not reveal any signs of lattice amorphisation for all used doses. Also the measurements of rocking curves with different asymmetrical reflections did not point any strain relaxation. The lack of amorphisation for various room temperature implantation in Al-rich $Al_xGa_{1-x}As$ was signalised by previous authors [1] and was interpreted as due to the free diffusion of vacancies.

Acknowledgments

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