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Amorphous phase formation in ion implanted $In_xGa_{1-x}As$

Z.S. Hussain [a,*], W. Wesch [b], E. Wendler [b], M.C. Ridgway [a]

[a] *Department of Electronic Materials Engineering, Research School of Physical Sciences and Engineering, Australian National University, Canberra, Australia*

[b] *Friedrich-Schiller-Universität Jena, Institut für Festkörperphysik, Jena, Germany*

Abstract

The amorphisation kinetics of $In_xGa_{1-x}As$ alloys were investigated using Rutherford backscattering spectrometry in channelling configuration. Using metal organic chemical vapour deposition, epitaxial $In_xGa_{1-x}As$ layers were grown on either GaAs, InP or InAs over a wide range of stoichiometries. Ion implantation was then performed using 60 keV Ge ions at room temperature. In contrast with $Al_xGa_{1-x}As$ alloys, $In_xGa_{1-x}As$ does not exhibit amorphisation kinetics intermediate between the two binary extremes. The amorphisation behaviour was fit using the Hecking model yielding a determination of the relative probabilities of direct impact amorphisation (P_a) and stimulated amorphisation (A_s). For $In_xGa_{1-x}As$, P_a is effectively independent of the stoichiometry whilst A_s exhibits a quadratic dependence on x with a maximum at $x \approx 0.31$ (where the critical ion fluence for amorphisation is at a minimum). We attribute the rapid $In_xGa_{1-x}As$ amorphisation to the local strain induced by a bimodal bond length distribution, the latter demonstrated by previous EXAFS studies.

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1. Introduction

Ternary semiconductor alloys such as $Al_xGa_{1-x}As$, $In_xGa_{1-x}As$ and $In_xGa_{1-x}P$ have a growing number of applications in the electronic and photonic device industry. This is due to the ability to tailor the properties of the ternary semiconductor by varying the stoichiometry. The resulting properties are generally intermediate between those of the binary extremes [1,2]. For example, the critical ion fluences for amorphisation of AlAs and GaAs differ by approximately two orders of magnitude and the critical ion fluence for the ternary alloy $Al_xGa_{1-x}As$ is composition-dependent with values intermediate to those of the two binary extremes [3]. The critical ion fluences for amorphisation of InAs and GaAs also differ by approximately two orders of magnitude. However, recent studies have shown that $In_{0.53}Ga_{0.47}As$ [4] and $In_{0.20}Ga_{0.80}As$ [5] both amorphise at an ion fluence lower than that observed for either InAs or GaAs.

In the present paper, we report on the amorphisation kinetics of $In_xGa_{1-x}As$ over a wide range of stoichiometries x, studied at room temperature and show that the critical ion fluence for $In_xGa_{1-x}As$ amorphisation exhibits a quadratic behaviour with respect to stoichiometry, with the minimum critical ion fluence occurring at $x \approx 0.31$.

2. Experimental

Using metal organic chemical vapour deposition (MOCVD), samples of epitaxial $In_xGa_{1-x}As$ were grown with $x = 0.06$, 0.28, 0.37, 0.53, 0.75 and 0.9. The thickness of the epitaxial layers was 0.1 ± 0.01 μm in all cases except $In_{0.53}Ga_{0.47}As$ where the layer thickness was 0.6 μm. $In_{0.06}Ga_{0.94}As$, $In_{0.28}Ga_{0.72}As$ and $In_{0.37}Ga_{0.63}As$ layers were grown on (1 0 0) oriented GaAs whereas $In_{0.53}Ga_{0.47}As$

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[*] Corresponding author. Tel.: +61 2 6125 0520; fax: +61 2 6125 0511.
E-mail address: zsh109@rsphysse.anu.edu.au (Z.S. Hussain).

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and $In_{0.75}Ga_{0.25}As$ were grown on (1 0 0) oriented InP and $In_{0.90}Ga_{0.10}As$ was grown on (1 0 0) oriented InAs. These substrates were chosen to minimise the lattice mismatch with the epitaxial layer. Nominally undoped InAs, GaAs and the $In_xGa_{1-x}As$ samples were irradiated with 60 keV Ge ions at room temperature. Rutherford backscattering spectrometry in channelling configuration (RBS-C) was used to measure the irradiation-induced disorder on the In sub-lattice for the ternary alloys and the InAs samples and on the Ga/As sub-lattices for the GaAs samples. RBS-C measurements were performed along the ⟨1 0 0⟩ direction with 2.0 MeV He ions and a scattering angle of 168°.

From the RBS-C spectra, the quantity $\Delta\chi_{\mathrm{min}}$ was calculated using $\Delta\chi_{\mathrm{min}} = (Y_{\mathrm{implanted}} - Y_{\mathrm{unimplanted}})/(Y_{\mathrm{random}} - Y_{\mathrm{unimplanted}})$, with $Y_{\mathrm{implanted}}$ and $Y_{\mathrm{unimplanted}}$ being the yield of backscattered ions in channelling direction of the implanted and unimplanted sample, respectively and Y_{random} being the random yield. $\Delta\chi_{\mathrm{min}}$ is an approximate measure of the amount of damage produced, here called relative amorphous fraction. A $\Delta\chi_{\mathrm{min}}$ value of zero corresponds to unimplanted material whereas a $\Delta\chi_{\mathrm{min}}$ value of one represents no epitaxial alignment, consistent with amorphous material. For consistency the yield was determined by integrating over a depth range (typically 50–350 Å) where the implantation-induced vacancy concentration (determined from SRIM 2003 [6]) dropped to two-thirds of its maximum value.

To compare the results for the various compounds, the ion fluence N_{I} was converted into the number of displacements per lattice atom n_{dpa}, which is given by $n_{\mathrm{dpa}} = N_{\mathrm{displ}}N_{\mathrm{I}}/N_0$. N_{displ} is the number of displacements per ion and unit depth calculated with SRIM 2003 and N_0 is the atomic density of the corresponding material. Furthermore this enables us to compare our results to those previously reported [4,5,7,8].

The measured data ($\Delta\chi_{\mathrm{min}}$ versus n_{dpa}) were modelled using the defect interaction and amorphisation model of Hecking et al. [9,10]. In the present paper, only the process of amorphisation is considered. This is characterised by the two parameters P_{a} and A_{s}. P_{a} represents the production of amorphous material within a single ion impact and A_{s} describes the growth of pre-existing amorphous zones (stimulated amorphisation).

3. Results and discussion

Fig. 1 shows the RBS-C spectra of $In_{0.53}Ga_{0.47}As$ irradiated with 60 keV Ge ions at room temperature. With increasing ion fluence there is an increase in the backscattered yield, thus indicating an increase in damage in the ternary layer [11].

Fig. 2 is a plot of the relative amorphous fraction $\Delta\chi_{\mathrm{min}}$ versus n_{dpa} for the entire stoichiometry range. The plotted curves are fits to the $\Delta\chi_{\mathrm{min}}$ values obtained from the RBS-C measurements. The experimental data themselves are not shown, to enable one to distinguish between the curves for the various x values. In previous papers, it was shown that a good fit of the experimental data is obtained in the framework of the Hecking model [4,5]. From Fig. 2 one can see that for selected stoichiometries $In_xGa_{1-x}As$ amorphises at ion fluences lower than that required to amorphise either InAs or GaAs.

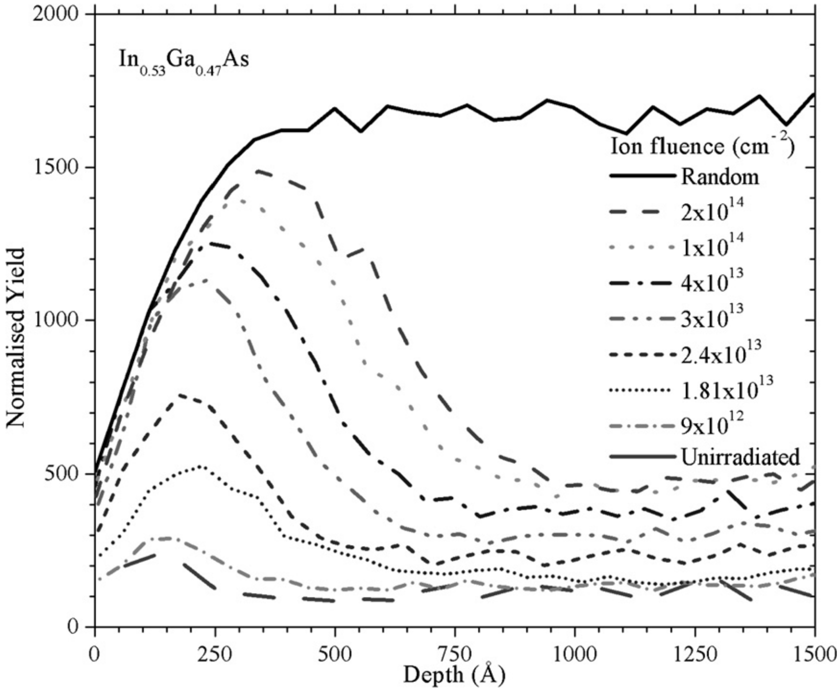

Fig. 1. RBS-C spectra of $In_{0.53}Ga_{0.47}As$ irradiated at room temperature as a function of the Ge ion fluence.