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Diffusion of indium implanted in silicon: The effect of the pre-amorphisation treatment and of the presence of carbon

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Abstract

We investigate the effect of the pre-amorphisation damage on the structural properties, and dopant diffusion behaviour of indium and carbon co-implanted layers in silicon. Ion implantation of indium and carbon in silicon was used to produce co-implanted specimens. Rutherford Backscattering Spectroscopy and Secondary Ion Mass Spectroscopy have been performed on as-implanted and annealed samples to assess in detail the structural properties of the doped layers and the diffusion behaviour. The results have been compared with data obtained for similar implants performed into crystalline silicon to achieve a deeper understanding of the mechanisms driving the diffusion of the indium in silicon in presence of co-implanted species. In particular a reduction of the indium diffusion and a saturation level for the indium substitutional retained dose were observed.

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Keywords: Ion implantation; Diffusion; Indium; Carbon; Silicon

1. Introduction

As widely known, the improvements of the electronic device performance has been mainly associated with scaling the lateral size of the devices. The technology currently used to produce such ULSI technology is ion implantation, which allows the control of the amount and position of the dopant introduced, followed by thermal annealing, required to re-grow the damaged crystal and to activate the dopant. However this last process results in broadening the as-implanted distribution. Especially in the case of boron, the normally used *p*-type dopant, which suffers anomalous diffusion

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[1]. To overcome this problem the use of alternative species heavier than boron such as indium and gallium has attracted attention [2,3]. The authors have extensively studied the use of indium, especially combined with the use of carbon co-implantation, which resulted in a larger degree of incorporation of indium atoms within the silicon lattice [4] and in an enhanced electrical activation of the implanted layer [5]. We have also studied the electrical behaviour of gallium implanted silicon [6]. In this paper we report on the effect of the pre-amorphisation treatment and carbon presence on structural properties and diffusion behaviour of the layers implanted with indium.

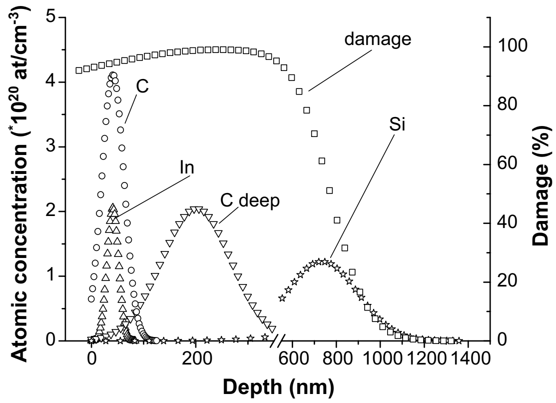

Fig. 1. Simulated (SRIM2003) positions of the implantation peaks and damage introduced by the Silicon pre-amorphizing implant. 100% of damage indicates full amorphization. The wafer represented is No. IV.

2. Experimental

Four (1 0 0) n-type silicon wafers, (resistivity 4–7 Ω/square), were used. They were previously implanted with silicon at an energy 500 keV and dose $5 \times 10^{15}\ \mathrm{cm}^{-2}$ in order to achieve an amorphous layer 1 μm thick according to SRIM simulations. Subsequently the four wafers were implanted with indium at an energy of 70 keV and dose $5.75 \times 10^{14}\ \mathrm{cm}^{-2}$, in order to produce an indium distribution with projected range at 40 nm. Once pre-amorphised and implanted with indium, three of the four wafers were co-implanted as follows: (II) Carbon with energy 13.5 keV and dose $2.22 \times 10^{15}\ \mathrm{cm}^{-2}$, (III) carbon with energy 70 keV and dose $3.42 \times 10^{15}\ \mathrm{cm}^{-2}$, (IV) Carbon with energy 13.5 keV and dose $2.22 \times 10^{15}\ \mathrm{cm}^{-2}$ and energy 70 keV and dose $3.42 \times 10^{15}\ \mathrm{cm}^{-2}$. Wafer (I) was not co-implanted with carbon. The implantation conditions were chosen in order to produce a carbon distribution matching the indium distribution with a concentration twice as large as the indium (implants at 13.5 keV) and to achieve a deeper carbon distribution spatially separated from the indium but lying between the indium distribution and the amorphous/crystalline interface (implants at 70 keV). Fig. 1 depicts the atomic distributions and the damage achieved, simulated using SRIM2003, in the case of wafer IV, which has all the implant conditions performed in it. Furthermore, another set of samples was produced into c-Si. Wafer V was implanted with indium at the same implantation specifications used for wafer I, wafer VI was a co-implant indium–carbon with the same implantation specifications indicated for wafer II. The implants were performed at RT with angles 7° tilt and 22° twist, using a 200 kV Danfysik 1090 implanter. The pre-amorphising silicon implants were carried out using a 2 MV Van der Graaff implanter.

The wafers were diced into squares of 1 cm^2 size and subsequently annealed using a matrix of conditions with temperatures of 650, 900 and 1000 ° C and time from 5 s to 1 h. Additionally, the implants performed in pre-amorphised wafers were annealed at 750 °C. Secondary Ion Mass Spectrometry (SIMS) was carried out to assess the as-implanted and after annealing atomic profile of the dopant within the layer and define its diffusion behaviour. The analyses have been performed by a Cameca Wf mass spectrometer. A 3.0 keV O_2^+ beam was used (incidence angle ∼60° with respect to the normal of the surface) and the positive secondary ions $^{115}In^+$ and $^{30}Si^+$ were collected. The rastered area was $200 \times 200\ \mu m^2$ and the primary beam intensity 30 nA: the ions were collected from an area of $60 \times 60\ \mu m^2$. Rutherford backscattering spectroscopy (RBS) with a 1.5 MeV He^+ beam in random and channelling mode was performed to evaluate the implanted and retained dose and the