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High temperature antimony ion implantation in strained silicon-on-insulator

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ABSTRACT

We present experimental results on shallow junction formation in strained silicon-on-insulator by antimony ion implantation and standard rapid thermal processing. An attempt is made to obtain Sb activation without layer amorphization by implanting Sb at elevated temperature. The focus is on studying the Sb activation during implantation at high temperature. Rutherford backscattering spectrometry and secondary ion mass spectroscopy are employed for characterization of Sb diffusion in amorphous and crystalline Si. The results are discussed in terms of the defect reaction kinetics involved.

1. Introduction

The continuous trend in scaling down semiconductor devices makes it important to create ultra-shallow contacts and sharply limited highly doped junctions. Ion implantation can provide very high concentrations of dopants in shallow layers but it has become increasingly difficult to activate the dopants electrically without significant diffusion during annealing. Moreover, the use of new channel materials such as strained silicon complicates the formation of precise and reproducible ultra shallow junctions. In order to meet these challenges and to control doping properties, understanding of the diffusion and activation processes in strained silicon during annealing is necessary. Up to now one of the favored dopants for n-type contacts is arsenic. However, previous studies concerning the activation behavior of implanted dopants show that antimony is easier to activate than arsenic [1,2]. In addition, the creation of shallow junctions with higher abruptness is facilitated due the possibility of diffusion-less Sb activation. In the case of Sb, the use of tensely strained Si as channel material is not only advantageous because of the enhanced carrier mobility but also since tensile strain increases the solubility of Sb in Si [3,4]. The disadvantage of Sb is layer amorphization during implantation due to its high mass. To maintain the high Sb solubility it is important to avoid complete layer amorphization and defect induced plastic strain relaxation during the subsequent annealing/recrystallization processes.

In the present work we examine the shallow junction formation in strained silicon-on-insulator by Sb implantation as a function of the implantation temperature. Elevated temperature implantation avoids the amorphization of the Si top layer and eliminates the risk of strain relaxation. Favorable results were previously reported, although an enhancement in dopant diffusion over the intrinsic value has been observed during subsequent rapid thermal processing (RTP) for certain species [5,6]. Moreover, a certain fraction of the implanted dopant is expected to activate during the implantation process. We characterize the electrical properties of these implanted layers and make an attempt to explain the results in terms of defect kinetics.

2. Experimental setup

The implanted material is strained silicon-on-insulator (sSOI) [7,8] under a biaxial tensile strain of $\varepsilon = 0.8\%$ which corresponds to an in-plane stress of about $\sigma = 1.3$ GPa. We have chosen for the present study Sb implantation energy of 20 keV and a dose of 1×10^{14} Sb/cm^2. The chosen implantation temperatures are: 23, 100, 200, 300 and 375 °C. Several RTP temperatures ranging from 500 °C up to 950 °C and annealing times of 1 and 5 min were applied. The high annealing temperatures were reached with a ramp-up slope of 25 °C/s. For the chosen implantation energy

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amorphization occurs inside the strained-Si layer but far away from the Si/SiO_2 interface. The thickness of the amorphized layer was determined using Rutherford backscattering spectrometry. The analysis in the channeling mode allowed us to study the crystalline quality of the epitaxial Si layer.

Sheet resistance and Hall-effect measurements were made using the van der Pauw technique. Measurements were carried out using a Biorad tool to extract the sheet carrier concentration, Hall mobility and sheet resistance in the as implanted samples and after annealing. The layer morphology was study by cross-sectional transmission electron microscopy (XTEM). The dopant distributions in the as-implanted and annealed samples were measured by time of flight-secondary ion mass spectroscopy (TOF SIMS).

3. Results and discussion

In order to establish a systematic presentation of the experiments three different cases are discussed: (i) Sb activation by in situ dynamic annealing during high temperature implantation, (ii) solid phase epitaxial regrowth (SPER) at low annealing temperature, and (iii) high temperature rapid thermal annealing. For every case the discussion of the results follows the presentation of the experimental data.

3.1. Dynamic annealing during implantation

The emphasis in this case is on the Sb activation without amorphization of the sSOI layer during implantation. Rutherford backscattering spectrometry/channeling (RBS/C) was used to study the layer crystallinity as a function of the implantation temperature. As expected, the channeling spectra indicate that the degree of amorphization is reduced with increasing implantation temperature. Above an implantation temperature of 300 °C, amorphization of the top Si layer is completely avoided. Fig. 1 shows the channeling spectra of the unimplanted sSOI sample, and of the samples implanted at room temperature and at 375 °C, respectively. The coincidence of the channeling yield of sample implanted at the 375 °C with the channeling yield of the unimplanted sample indicates the conservation of the crystalline quality of the Si layer during implantation. The increased channeling yield of the sample implanted at room temperature to the value of the random spectra reveals a partial amorphization of the top Si layer. A 22 nm amorphous Si layer is formed during the room temperature implantation. The RBS/C results are confirmed by the cross-section transmission electron micrograph images presented in Fig. 2a and b.

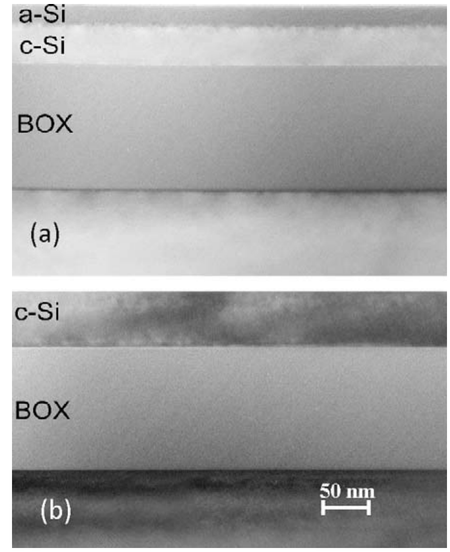

Fig. 2. Bright field XTEM image of a 70 nm strained-SOI layer: (a) implanted at room temperature with 20 keV, 1×10^{14} cm^{-2} Sb. A 20 nm amorphous layer can be observed. (b) Implanted at 375 °C with 20 keV, 1×10^{14} cm^{-2} Sb. No amorphous layer can be observed.

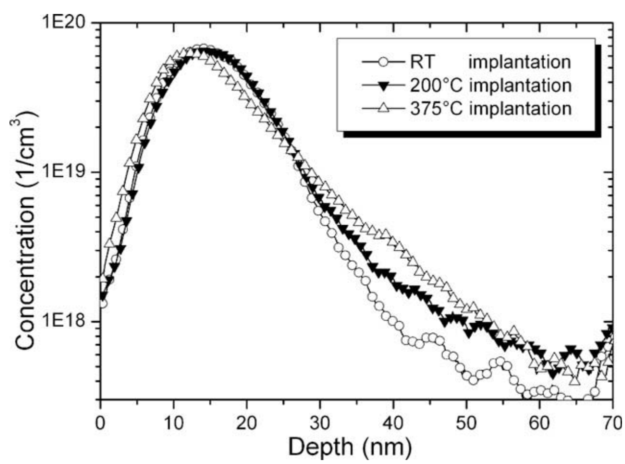

Fig. 3. SIMS profile of Sb implanted at room temperature and implantation temperatures of 100, 200, 300 and 375 °C.

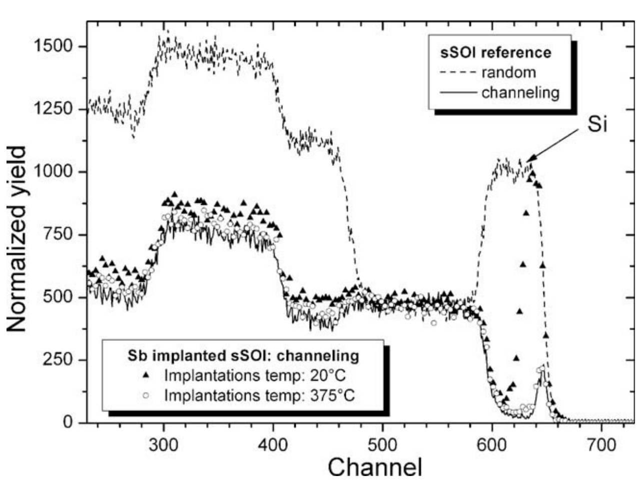

Fig. 1. Random and [1 0 0] channeling RBS spectra of an unimplanted sSOI structure in comparison to corresponding channeling spectra after 20 keV, 1×10^{14} cm^{-2} Sb implantation at room temperature and at 375 °C, respectively.

From the low channeling yield of the samples implanted at elevated temperature we conclude that dynamic annealing during implantation results in substitutional incorporation of Sb atoms in the strained Si lattice. Indeed, electrical characterization indicates a Si sheet resistance of 8 $k\Omega/\square$ for the case of Sb implantation at 300 °C and 6 $k\Omega/\square$ at 375 °C. However, the estimated Sb activation is, in these cases, only about 15% and 20%, respectively. For implantation temperatures below 200 °C the sheet resistance could not be measured, since it is beyond the resolution limit of our measurement system.

For more detailed information about the dynamic annealing process the antimony distribution profiles were measured by SIMS. Fig. 3 reveals profile broadening with increasing implantation temperature: a significant tail is formed, decreasing the profile steepness, and for implantation at 375 °C the peak of the distributions shifts somewhat towards the surface. Fig. 3 shows that the Sb distribution significantly changes with increasing implantation tem-