SHALLOW p^+n-JUNCTION FORMATION IN Si BY PRE-AMORPHIZATION WITH Sn

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ABSTRACT

Ion implantation has been a key process of microelectronics for the last 20 years. The production of ultra-shallow junctions, even shallower than 50 nm, which is necessary for future silicon devices, requires extreme performances from ion implantation and thermal processing [1]. Shallow implanted profiles can easily be achieved for As doped n^+ layers. However, shallow B doped p-type profiles can only be realized if the channeling of B ions is prevented. Complete elimination of channeling is possible by preamorphization prior to B or BF_2 implantation [2]. In this work we studied the regrowth of Si after preamorphization by Sn implantation. We also look for the minimum dose for amorphization and maximum solid solubility of Sn into crystalline Si. Based on these results, we proceeded with BF_2 implantation into single crystal and preamorphized samples to compare the boron redistribution after annealing.

1. INTRODUCTION

In the last few years, new ion implanters have been fabricated in order to provide ultra-low energy ion beams for shallow junction formation in silicon. Through the use of such beams, the achievement of ultra shallow junctions with the required specifications appears to be close. However, the lattice defects in excess of the equilibrium concentration, created by the implantation, interact with the implanted doping impurities during annealing, inducing non-equilibrium diffusion phenomena [3]. The transient enhanced diffusion (TED) of B during annealing arises from the interaction between self-interstitials and boron that causes major redistribution of the implanted profile, resulting in junction depths much deeper than expected.

In order to prevent channeling and also TED, we have implanted Sn into Si prior to the implantation of B. We used Sn ion to create the amorphous layer by the fact that being a group IV element, we can eliminate any chemical influence, as well as any impurity diffusion, since the diffusivity of Sn in Si is very low [4].

The choice of Sn is also made in order to access the study of the local microstructure around the implanted impurity by means of conversion electron Mössbauer spectrometry (CEMS) [5].

Furthermore, being a much heavier ion than Si, the amorphous layer created by implantation of Sn has an abrupt amorphous/crystalline interface improving the solid phase epitaxial (SPE) regrowth.

In the first part of this work we have studied the SPE regrowth and the substitutional solid solubility of (100) silicon implanted with $^{119}Sn^+$.

Next, we determined the minimum dose to create a continuous amorphous layer in silicon. Using the minimum dose for amorphization, we have proceeded with BF_2^+ implantation for shallow p^+n junction formation.

2. EXPERIMENTAL PROCEDURE

Samples of p-type (100) silicon with a nominal resistivity of 1-2 Ωcm were used in the first part of the work. They were implanted to a dose of $1x10^{16}$ cm^{-2} at 250keV, and were annealed using three different procedures, namely furnace annealing (600°C, 1 h), rapid thermal annealing, RTA (1200°C, 5 s) and two-step annealing comprising a combination of both.

The samples were analyzed, prior to and after annealing, by random and aligned Rutherford Backscattering (RBS) of 760keV $^4He^{2+}$. All the implantation and RBS analyses were performed using the Porto Alegre HVEE-400 ion implanter. The resolution of the RBS detector was 14keV.

The CEMS spectra were obtained in a back-scattering geometry by mounting samples on the back-plate of a proportional counter through which He + 5% CH_4 was allowed to flow. Measurements were made with the sample and source at room temperature.

In the second part of the work, samples of n-type (100) silicon, with resistivity of 1-2 Ωcm undergo implantations varying from $1x10^{12}cm^{-2}$ to $3x10^{14}$ cm^{-2} with energy of 240keV. These samples were analyzed by RBS and Channeling, prior and after being annealed by RTA.

The next step was a dual implantation, first with Sn at a dose of $3x10^{14}$ cm^{-2} with energies of 240keV and 120keV, and after with BF_2^+ at a dose of $5x10^{14}$ cm^{-2} and energy of 50keV, which provides about 11kev for the boron ions. We included a single crystal silicon without pre-amorphization like a reference sample.

We investigate the implanted profile redistribution of boron in amorphous and crystalline samples by anodic oxidation and four point sheet resistance measurements.

3. RESULTS

In figure 1(a) we can see the aligned RBS spectrum of the as implanted sample, showing an amorphous layer

that extends from the surface down to approximately 200nm.

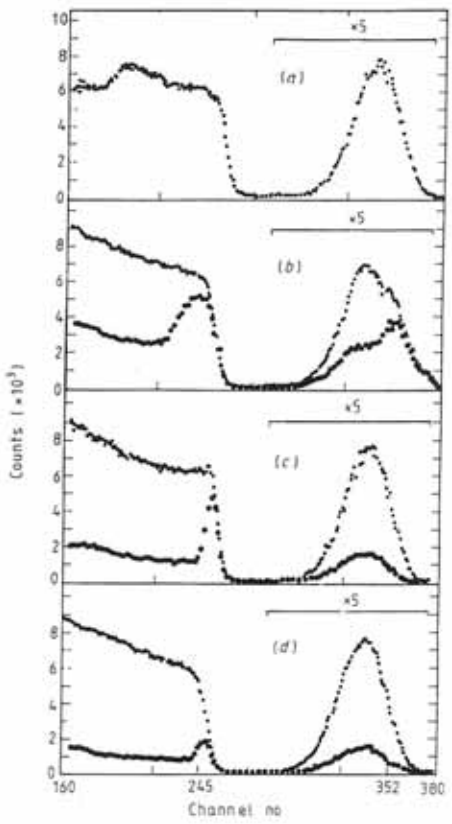

Figure 1 – Random and channeled RBS spectra for Si implanted with $1x10^{16}$ cm^{-2} Sn at 250 keV, (a) as implanted, (b) RTA, (c) furnace annealing, (d) RTA + furnace annealing.

Figure 1(b) shows the random and <100> aligned spectra for the sample after RTA (1200°C, 5s). The region of the aligned RBS spectrum corresponding to scattering of α-particles from silicon atoms shows clearly a partial recristalization of the amorphous layer, with a highly damaged layer remaining close to the surface. The tin part of the RBS spectra reveals that a large proportion of the implanted profile has out-diffused, in the direction of the surface, and the rest remains within a depth distribution comparable to the implanted profile. In figure 1(c) we show the random and <100> aligned RBS spectra after furnace annealing at 600°C during 1 h. We note an appreciable improvement on the quality of SPE regrown layer (χ_{min}=9%), but we can still observe a surface peak in the Si part of the spectrum much higher than what is observed for virgin silicon. The tin part of spectrum shows no redistribution of the implanted profile, and the substitutionality of Sn in Si host is around 93%, exceeding by almost two orders of magnitude the maximum solid solubility of Sn in silicon (approximately $5x10^{19}$ cm^{-3} at room temperature). In figure 1(d) we show the random and aligned RBS spectra after two-steps annealing (600°C, 1 h and 1200°C, 5 s). The surface peak in silicon is reduced to be closer to the virgin silicon height, and the cristallinity of the regrown silicon layer and the substitutionality of the implanted Sn are slightly improved with respect to those shown in figure 1(c). There is no noticeable redistribution of the implanted profile.

Figure 2 shows the RBS Channeled spectra for Sn implantation in Si with different doses at 240 keV. It is seen that the dose of $3x10^{13}$ cm^{-2} is not enough to reach full amorphization, but it creates about 50% of disordering in the defect depth profile maximum. The doses of $1x10^{14}$ cm^{-2} and $3x10^{14}$ cm^{-2} create continuous amorphous layers of 167 nm and 193 nm respectively.

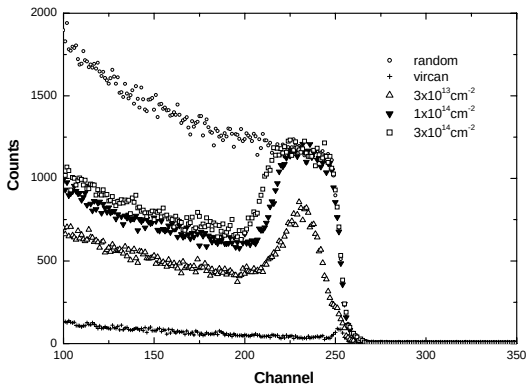

Figure 2 – Random and aligned RBS spectra for Si implanted with different doses of Sn at 240 keV.

4. CONCLUSIONS

It was shown that by means of two-step annealing we can reach a complete epitaxial regrowth of the amorphous layer, as well as a complete substitutional solid solution of the Sn impurity, to a concentration two orders of magnitude higher than the solid solubility limit, without any observable redistribution of the implanted concentration profile. The minimum dose for amorphization of Si by Sn implantation is approximately $1x10^{14}$ cm^{-2}.

5. REFERENCES

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