Enhanced Relaxation of SiGe layers by He implantation supported by in-situ ultrasonic treatments

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1. Introduction

Strained silicon layers show enhanced mobility of holes and electrons and represent therefore an interesting channel material for advanced CMOS technologies [1]. One possibility to introduce biaxial strain in a way, compatible with existing Si technologies is the pseudomorphic hetero-epitaxial growth of Si layers on strain relaxed SiGe layers. It was demonstrated that thin SiGe layers grown on Si substrates with thickness of 80 – 150 nm can be strain relaxed by H or He ion implantation and thermal annealing [2,3]. An implantation induced defect band about 100 - 200 nm below the SiGe/Si substrate interface promotes strain relaxation of the SiGe layer, maintaining a high surface quality (rms roughness below 1 nm) and reaching low threading dislocation densities.

However, the degree of relaxation depends strongly on technology treatment and still needs improvement.

Ultrasonic treatment (UST) during ion implantation changes the point defect distribution and influences the behaviour of defects during post-implantation annealing. It was shown [4] that UST allows to lower the amorphization threshold and stimulates diffusion of Si interstitials and vacancies. Changing intensity and frequency of the ultrasonic waves influences the kinetics of defect redistribution during ion implantation

In this contribution we show that ultrasonic treatment applied during He implantation can improve relaxation of strained SiGe layers on Si. This widens the processing window, improves layer quality and simplifies optional overgrowth.

2. Experimental

We used rapid thermal chemical vapor deposition (RPCVD) to grow metastable 300 nm $Si_{0.8}Ge_{0.2}$ buffers layers on 200 mm Si(100) wafers. Parts of the wafers were implanted with He ions (50 keV) with doses of 1 - $8x10^{15}$ cm^{-2}. During implantation several samples were supposed to ultrasonic waves with a frequency of 5.6 MHz and a power of 0.01 – 1 W/cm^2. Subsequently the samples were annealed in Ar at temperatures between 650°C and 850°C for 60s.

The strain and strain relaxation in the layers were measured with Raman spectroscopy, using excitation at a wave length of 488 nm, and double-crystal X-ray diffraction in symmetric and asymmetric geometries .

2. Results and Discussion

Figure 1 shows Raman spectra of annealed samples without He implantation (1), with He implantation (2) and with additional in-situ UST during implantation (3). We observe a shift of the Si-Si band in the SiGe layer towards lower frequencies by 0.8 cm^{-1} for the He implanted samples, indicating additional relaxation. The UST enhances this shift (1.4 cm^{-1}) showing increased relaxation in the corresponding samples.

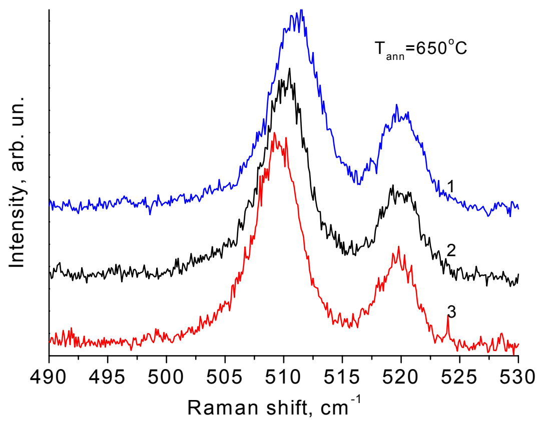

Fig. 1. Raman spectra for samples after annealing at 650°C: without He implantation(1), with He implantation (2) (D = 5 x $10^{17}cm^{-2}$), with additional UST (3).

Figure 2 shows the X-ray spectra of typical samples in different stages: as-grown (1), as-implanted (2) without UST, as-implanted (3) with UST, annealed after implantation without UST (4), and with UST (5). By the arrows in Fig.1 the theoretical position of completely relaxed (R) and coherently strained (S) layers are indicated.

The degree of relaxation R is defined as

$$R = (a^{T}_{SiGe} - a_{Si}) / (a^{II}_{SiGe} - a_{Si}) \times 100\%,$$

with a^{T}_{SiGe}, a^{II}_{SiGe} – the lattice parameter of the SiGe layer perpendicular and parallel to the substrate, respectively, and a_{Si} the lattice parameter of Si.

Due to the large, supercritical thickness of the as-deposited SiGe layers we observe relaxation already in the as-deposited layers. Values up to 48% were measured by X-Ray diffractometry, obviously relaxation takes place during layer growth at temperatures of about 600°C.

Annealing of the unimplanted layer at temperatures up to 650°C does not increase the degree of relaxation, significantly. At temperatures above 800°C additional relaxation processes take place.

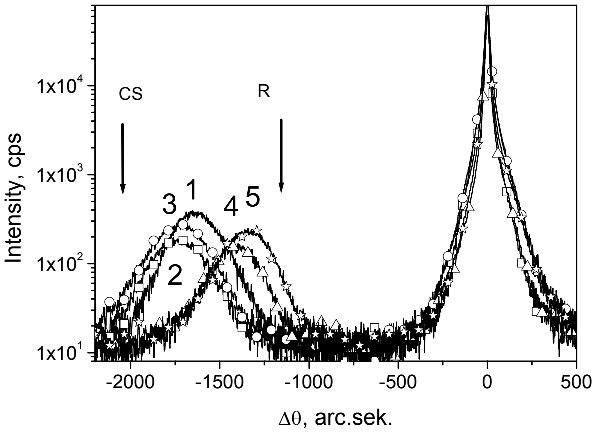

Fig. 2. X-Diffraction curves for samples with different treatment: as-grown (1), as-implanted (2) without UST, as-implanted (3) with UST, annealed after implantation without UST (4), and with UST (5). By the arrows in Fig.1 the theoretical position of completely relaxed (R) and coherently strained (CS) layers are indicated.

It is well known that the implantation of He atoms increases the stress in the layered structure dependent on the implanted dose. This is one reason for increased relaxation in these structures. Moreover, due to precipitate and bubble formation additional relaxation mechanisms are activated for the implanted samples [3] compared to relaxation during growth of thick buffer layers. We found after annealing of the He implanted samples a degree of relaxation up to values of 72%.

Ultrasonic waves during implantation stimulate the diffusion of Si interstitials into the bulk of the substrate [4]. They might also stimulate the diffusion of He atoms and influence the kinetics of bubble and precipitate formation during implantation and subsequent heat treatments, e.g. by clustering. This will influence the generation of misfit dislocations in the layered structure.

As visible from Fig.2, the use of UST allows to increase the relaxation (see Fig.2, curve(5)) under identical implantation doses and annealing conditions. Values up to R = 82% were determined. It is interesting to mention that the level of stress in the as-implanted structure is comparable (or even slightly less) than without UST. Work is in progress to investigate differences in the relaxation mechanism under the influence of UST.

It is expected that the effect will depend on the amplitude of the ultrasonic waves. Figure 3 shows differences in relaxation as a function of the intensity of the ultrasonic waves.

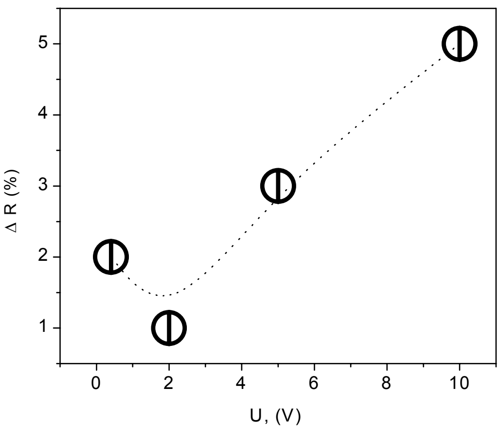

Fig. 3. Differences in the degree of relaxation as a function of the power of the applied UST.

3. Summary

We show increased relaxation of SiGe layers by adding in-situ ultrasonic treatments during the process of He implantation. It is expected that increased relaxation will improve the properties of pseudomophic Si on top of the relaxed SiGe layer and allow better application of these layers in advanced CMOS technologies.

References

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