Extended Abstracts of the 2006 International Conference on Solid State Devices and Materials, Yokohama, 2006, pp. 1090-1091

I-8-2

Dynamics of Defects in Strained Silicon, Strained SiGe and Strained Germanium

Alexander Reznicek, Stephen W. Bedell, Joel P. de Souza, Klaus W. Schwarz, Keith E. Fogel, John A. Ott, Harold J. Hovel, and Devendra K. Sadana

IBM Thomas J Watson Research Center
1101 Kitchawan Road, Yorktown Heights, NY 10598, USA
Phone: +1-914-945-2725, E-mail: alexrez@us.ibm.com

1. Introduction

Performance enhancement in successive technology generations in the past was driven by device scaling and lithography. With device scaling becoming more challenging new materials with improved charge carrier transport properties are needed. Compressively strained silicon does provide higher hole mobility and is currently in use to enhance the performance of pFETs in 90 and 65 nm CMOS [1-2]. Strain in conjunction with high mobility non-Si channels (Ge and strained Ge) are expected to be the key drivers for CMOS scaling beyond 32 nm [3-5]. Future use of s-Ge as a pFET channel will necessitate planar growth of Ge to achieve a biaxially strained channel.

Earlier work in the literature had been focused on understanding the origin of defects in strained silicon on relaxed SiGe. Four types of defect were found to be present in strain-Si grown on relaxed SiGe: (i) 60^o threading dislocations, (ii) long stacking faults, (iii) pile ups, and (iv) surface pitting [6-7]. We have shown that tensile strained Si has the propensity to form stacking faults (SFs). The density and length of SFs depends super linearly on thickness of the strained-Si. [8]. s-Si in previous investigation was grown on a high quality SiGe graded buffer layer (GBL) at different growth temperatures to obtain s-Si of varying thickness (200 – 4000Å). We established that thicker the s-Si layer the higher the stacking fault density [8]. An inverse relationship was observed between the SF and threading dislocation (TD) density. As the SF density increased, TD density decreased.

In this paper we will describe the following: (i) defectivity in tensile strain-Si, and changes in the defectivity as a function of anneal temperature, (ii) comparison of defect types in tensile Si and in compressive SiGe (grown on relaxed SiGe), and (iii) growth of compressive Ge on relaxed SiGe. Compressively strained SiGe was obtained by growing pseudomorphic SiGe (40%) on relaxed SiGe (20%). The strain values in both the Si and SiGe layers were matched to ~0.7%. Further study of defectivity in compressive SiGe with higher strain was performed by growing SiGe with higher Ge (50-100%) on relaxed SiGe (20%).

2. Experiments

Relaxed SiGe (20%) GBL were grown on bulk-Si substrates in a 300 mm Epsilon epitaxial reactor followed by in situ growth of 274 Å strain Si at 600^{o}C. This thickness is slightly above that corresponds to the critical thickness to form defects. SF density of < 10^4 cm^{-2} is observed under these growth conditions [8]. This material was subsequently annealed either in a furnace at 600^o - 700^{o}C, or in an RTA tool at 900^o - 1100^o C for different times. All samples were etched using modified Secco etch to highlight defects in the s-Si layer.

3. Results

Defects in s-Si vs Anneal Temperature

Figure 1 shows that a significant increase in the SF density occurs during annealing. For example, anneal at 600ºC for 10 minutes increased the SF density by a factor of 15 (Fig. 3) compared to that in the as-grown material (Fig. 2). Anneal at 700^o C for 5 minutes not only increased the SF density but also increased its length A (Fig. 4).

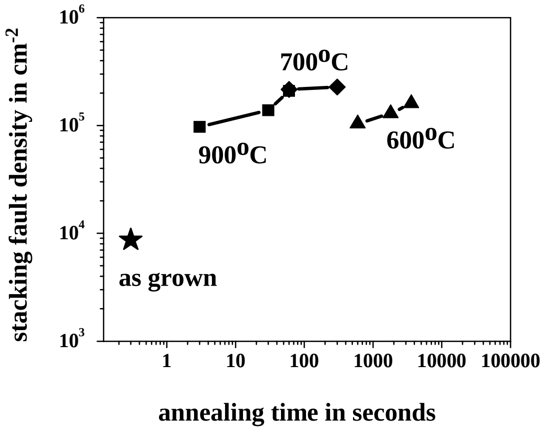

Fig. 1: Stacking fault density in a 274 Å thick strained silicon layer after annealing at different temperatures for various times.

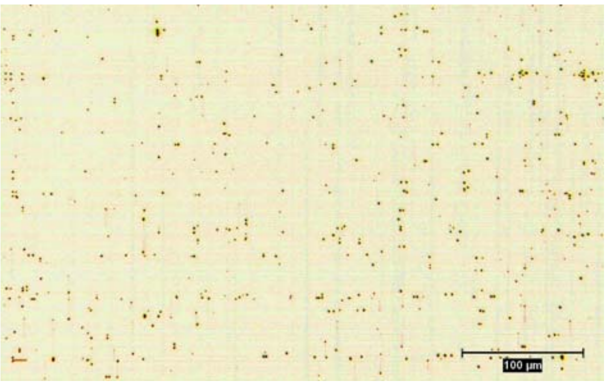

Fig. 2: Low stacking fault density in an as-grown 274 Å thick strained silicon layer grown on a 20% graded buffer layer. In the etch micrographs the dots are threading dislocations and the lines are stacking faults.

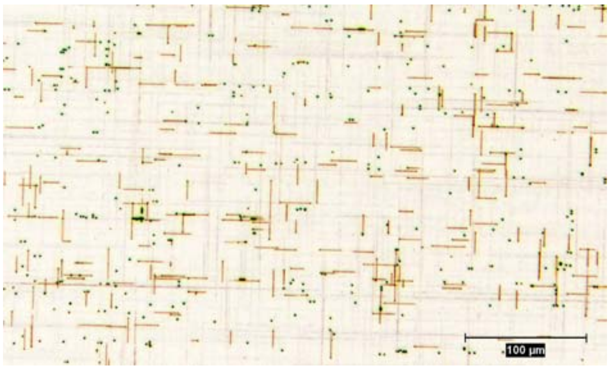

Fig. 3: Defects in a 274 Å thick strained silicon layer grown on a 20% graded buffer layer after annealing at 600^{o}C for 10 min.

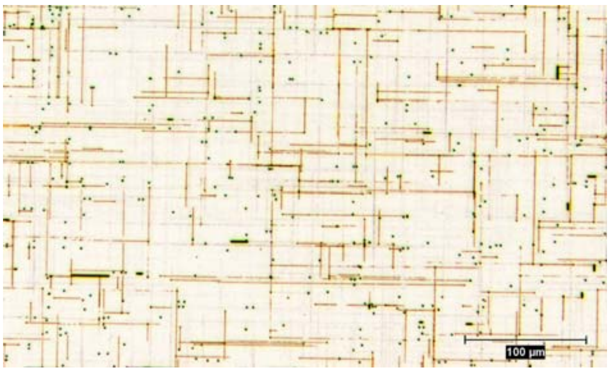

Fig. 4: Defect s in a 274 Å thick strained silicon layer grown on a 20% graded buffer layer after annealing at 700^o C for 5 min.

Defects in Compressive s-SiGe vs Tensile s-Si

Thicker s-Si (937 Å) and s-SiGe (40%, 1056 Å) were grown over relaxed 20% SiGe to obtain ~ 0.72% strain of opposite signs. This was done deliberately to ensure high density of SFs in s-Si to allowed for an accurate comparison of defects in s-SiGe and s-Si layers and obtain data in a statistically meaningful manner. It should be noted that SFs, TDs etc in s-Si can be highlighted by Secco etching whereas this is not the case for s-SiGe. Therefore the defect comparison will have to rely on TEM for s-SiGe and s-Si.. We believe that a SF in s-Si represents the SF bounded by two Shockley partials and it expands under the influence of tensile strain field. Therefore, opposite should occur (i.e., contraction of the SF) under the influence of compressive strain field. This will be discussed further at the conference.

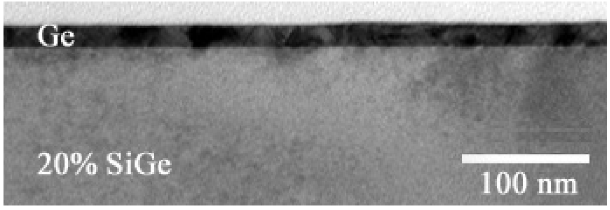

Fig. 5: Cross section TEM of a strained Germanium layer (1.75%) showing a high density of stacking faults.

Strained Ge Growth on SiGe GBL

Finally, thin (30 Å) and thick (180 Å) planar layers of s-Ge were grown on 20% relaxed SiGe to study strain-thickness, and defectivity-thickness relationships in s-Ge. Compressive strains of 2.7% and 1.75% were obtained for 30 Å and 180 Å Ge layers, respectively. Although s-Ge layers were highly strained, these were not pseudomorphic. Figure 5 shows an XTEM micrograph where s-Ge showed a SF density of > 10^9.

4. Conclusions

Annealing of s-Si creates a high density of stacking faults. It is believed that stacking faults originate from core of 60^o threading dislocations. Increased anneal time and/or anneal temperature accentuates the increase in stacking fault density. An attempt is made to compare defects in compressively strained SiGe with those in tensile s-Si. More studies are underway to determine the influence of tensile and compressive strain fields on SF evolution. Highly strained and planar growth of s-Ge is demonstrated on relaxed SiGe (20%).

References

[1] S. Yang et al., IEEE IEDM Conference Proceedings, 28.8, (2004) 1075.
[2] T. Ghani et al., Tech. Dig. International Electron Devices Meeting, Dec. (2003).
[3] H. Shang, et al., IEDM Technical Digest (2002) 441.
[4] A. Ritnour, et al., IEDM Technical Digest, (2003) 433.
[5] T. Krishnamohan, et al., Symp. VLSI Tech. Dig. (2005) 82.
[6] P. M. J. Marée et al., J. Appl. Phys., 62 (1987) 4413.
[7] S. W. Bedell et al., Appl. Phys. Lett. 85 (2004) 2493.
[8] S. W. Bedell et. al. IEEE SOI Technical Digest, (2005) 144