D-8-3
Extended Abstracts of the 2012 International Conference on Solid State Devices and Materials, Kyoto, 2012, pp769-770

Tensor Evaluation of Anisotropic Stress Relaxation in Mesa-shaped SiGe Layer on Si Substrate by EBSP

Motohiro Tomita[1, 2], Masaya Nagasaka[1], Daisuke Kosemura[1], Koji Usuda[3], Tsutomu Tezuka[3], and Atsushi Ogura[1]

[1]School of Science and Technology, Meiji University
1-1-1 Higashi-Mita, Tama-ku, Kawasaki 214-8571, Japan
E-mail: mot_tom@meiji.ac.jp
[2]Research Fellow of the Japan Society for the Promotion of Science
8 Ichibancho, Chiyoda, Tokyo 102-8472, Japan
[3]Green Nanoelectronics Collaborative Research Center, AIST
16-1 Onogawa, Tsukuba, Ibaraki 305-8569, Japan

1. Introduction

The strained SiGe is one of the most important techniques in post-scaling technology. It will be used in the next generation transistors to improve device performance, along with device scaling [1]. In nanodevices, the stress states in SiGe may be partially relaxed and become complicated, because the SiGe layer was processed into nanostructure. It was reported that electron back scattering pattern (EBSP) measurement is useful to evaluate the stress tensor in Si nanostructure with high spatial resolution [2]. Raman spectroscopy is also useful to evaluate anisotropic biaxial stress with high stress sensitivity [3]. In this study, we evaluated the anisotropic stress relaxation in mesa-shaped strained SiGe layers on Si substrate by EBSP. Moreover, the results were compared with those obtained by Raman spectroscopy, and finite element method (FEM).

2. Experiments

Strained SiGe on Si substrates were used as the samples with a 30-nm-thick $Si_{0.7}Ge_{0.3}$ layer. The SiGe layer was formed by epitaxial growth on Si substrate. It was confirmed that the SiGe layer has no defects and is lattice-matched to the Si substrate, that was confirmed by X-ray diffraction. The several structures were fabricated on the Si substrate by electron beam lithography and reactive ion etching. Figure 1 shows the schematic of the sample structure, transmission electron microscopy (TEM) image. The coordinate system is also shown in Fig. 1 (x: [110], y: [-110], and z: [001]). We evaluated the quarter area of the rectangular pattern with the size of 5000×1000 nm^2 and the wide pattern with the width X of 100 μm, as shown in Fig. 1(a) and (b), respectively. The evaluated area and line were also shown in Fig. 1.

The strain and stress tensors were evaluated by EBSP nondestructively. The acceleration voltage was 20 kV. The diffraction pattern was detected from surface to the depth of 30-50 nm. High-spatial resolution is expected because the EBSP detector is installed in a field-emission scanning electron microscope. Therefore, the beam spot size was approximately 20×60 nm^2 with sample tilted by 70°, and, the spatial resolution was estimated to be less than 100 nm [2]. Additionally, Oil-immersion Raman spectroscopy was also performed. Nd:YAG laser (λ = 532 nm) was used as an excitation source. NA of oil-immersion lens was 1.4. Furthermore, FEM simulation was performed for a comparison. In the FEM simulation, mechanical properties were drawn from refs. 4, 5. It was assumed that all materials have perfect elasticity, in other words, all materials do not have yielding point and plasticity.

3. Results and Discussion

Figure 2 shows the two-dimensional distributions of (a) σ_{xx} and (b) σ_{xz} stresses in the SiGe layer, obtained by EBSP. In Fig. 2, the position of $x = 0$ and $y = 0$ corresponds to the corner of the rectangular pattern. At the edge parallel to the y direction, the σ_{xx} stress was drastically relaxed, and the shear stress σ_{xz} was concentrated at the edge. On the other hand, at the edge parallel to the x direction, the σ_{xx} stress relaxation was rather week and the σ_{xz} shear stress concentration was not confirmed unlike the case of the edge parallel to the y direction. Figure 3 shows the two-dimensional distributions of (a) σ_{xx} and (b) σ_{xz} stresses in the SiGe layer, calculated by FEM. The results of EBSP were good agreement with FEM calculations. As a result, it can be concluded that EBSP is useful for the tensor evaluation of anisotropic stress relaxation in SiGe nanostructures.

Figure 4 shows the one-dimensional profiles of (a) σ_{xx}, (b) σ_{yy}, (c) σ_{zz}, and (d) σ_{xz} stresses in the SiGe layer of the wide pattern, obtained by EBSP, Raman, and FEM. In the Raman measurements, it is assumed that the σ_{yy} stress was not relaxed whole of the evaluated area (so-called the uniaxial relaxation model) because we think the wide pattern complies with plane strain model. Figure 5 shows the Raman shifts as a function of the distance from the edge. The examples of the Raman spectra were also shown in the inset of Fig. 5. It is confirmed by Raman, the relaxation of σ_{xx} at the edge was approximately 32 percent. In the result of by EBSP, the relaxations of σ_{xx} and σ_{yy} were approximately 65 and 35 percent, respectively. In the calculation of FEM, σ_{xx} stress was perfectly relaxed and σ_{yy} stress relaxation was very small. Although there is a difference between each method, which is caused by the spatial resolution, the consistent relationship between EBSP, Raman, and FEM was found. Moreover, the σ_{zz} and σ_{xz} stresses of approximately 0.1 and −0.2 GPa were concentrated at the edge, confirmed by EBSP. As a result, the profiles of σ_{zz} and σ_{xz} stress were good agreement between EBSP and FEM. The σ_{xx}, σ_{zz}, and σ_{xz} stress was drastically relaxed or concentrated in the range of distance from the edge to 200 nm. Thus, the stress relaxation is inevitable in less than 200 nm size nanostructure. Moreover, the stresses relaxation of mesa- shaped SiGe layer reproduced perfect elastic deformation assumed in FEM. EBSP is powerful method to evaluate stress tensor including shear stress components.

4. Conclusion

The anisotropic relaxation of stress tensors in mesa-shaped strained SiGe layers was evaluated by EBSP, Raman measurement, and FEM simulation. The σ_{xx} stress was drastically relaxed and the σ_{zz} and σ_{xz} stress were concentrated at the edge. The range of stress relaxation or concentration is mostly 200 nm from edge. Thus, the stress relaxation is inevitable in SiGe nanostructure with less than 200 nm scale. Moreover, there is a good correlation between the results of EBSP, Raman spectroscopy, and FEM. Therefore, the stress relaxation in SiGe nanostructure reproduced elastic deformation assumed in FEM. EBSP is useful for the evaluation of stress tensor, and complementary method to Raman measurement.

Acknowledgements

This study was partially supported by the Japan Society for the Promotion of Science through the “Funding Program for World-Leading Innovative R&D on Science and Technology.”

References

[1] K. Usuda *et al.*, Semicond. Sci. Technol. **22**, s227 (2007).
[2] M. Tomita *et al.*, Jpn. J. Appl. Phys. **50**, 010111 (2011).
[3] D. Kosemura, *et al.*, Jpn. J. Appl. Phys., **51** 02BA03 (2012).
[4] J. J. Wortman and R. A. Evans: J. Appl. Phys. **36**, 153 (1965).
[5] F. Schaffler: in “*Properties of Advanced Semiconductor Materials*” eds. M. E. Levinshtein *et al.*, Wiley, 149-188 (2001).

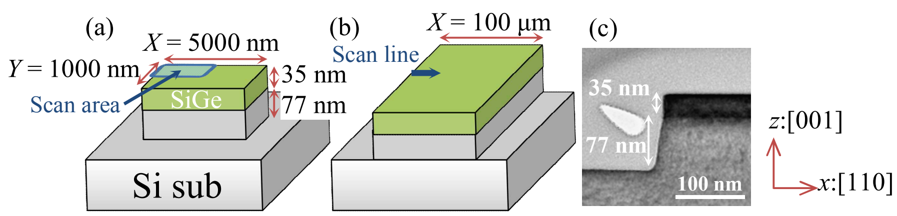

Figure 1 (a, b) Bird’s-eye view, (c) TEM image, and coordinate system of the sample.

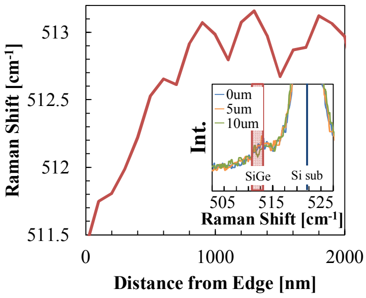

Figure 5 Raman shift profile and Raman spectra obtained at the edge.

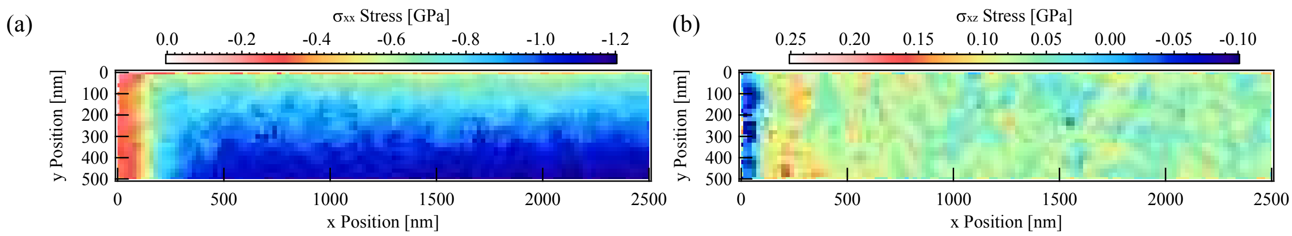

Figure 2 Two-dimensional distributions of (a) σ_{xx} and (b) σ_{xz} stress in the SiGe layer of the rectangular pattern, obtained by EBSP.

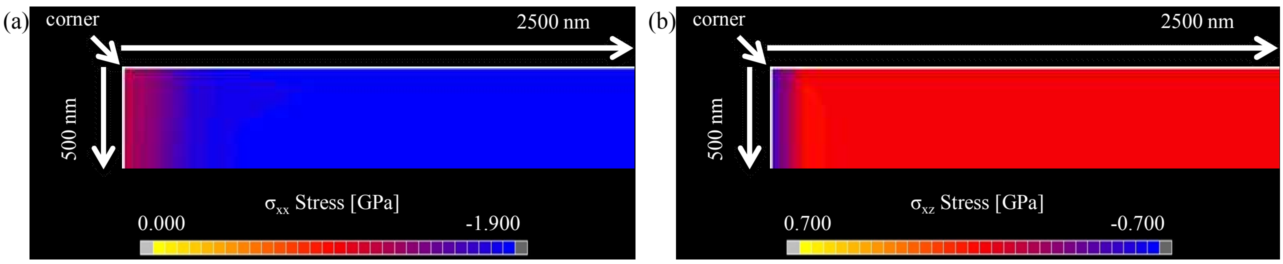

Figure 3 Two-dimensional distributions of (a) σ_{xx} and (b) σ_{xz} stress in the SiGe layer of the rectangular pattern, obtained by FEM.

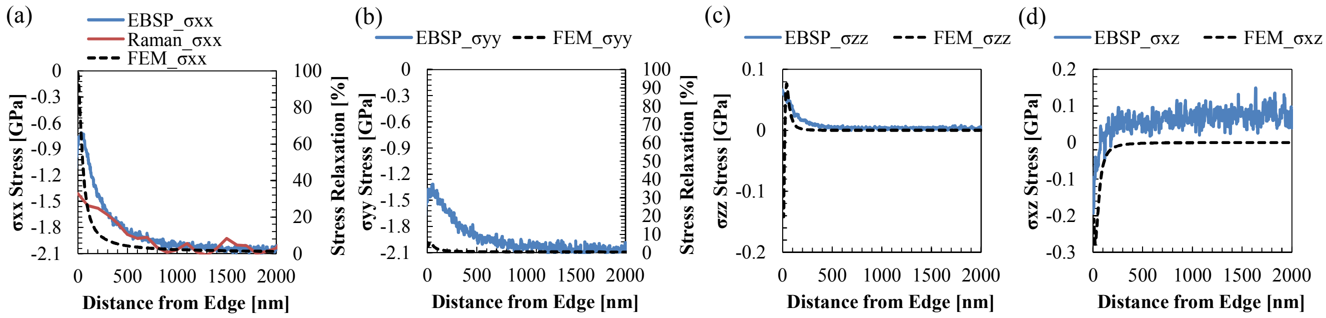

Figure 4 One-dimensional profiles of (a) σ_{xx}, (b) σ_{yy}, (c) σ_{zz}, and (d) σ_{xz} stress in SiGe layer on Si of the wide pattern, obtained by EBSP, σ_{xx} stress Raman measurement with uniaxial relaxation model, and FEM.