Tensor Evaluation of Stress Relaxation Profile in Strained SiGe Nanostructures on Si Substrate

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Introduction

The strained SiGe is one of the next generation materials in post-scaling technology. It will be used in the transistors to improve device performance along with device scaling [1]. However, the stress relaxation of SiGe layer may be inevitable in nanodevices, because the SiGe layer is processed into nanostructure. In this study, we evaluated the precise stress relaxation profile in mesa-shaped strained SiGe layers on Si substrate by electron back scattering pattern (EBSP), super-resolution Raman spectroscopy (SRRS) and finite element method (FEM) simulation.

Experiments

The strained $Si_{0.7}Ge_{0.3}$ on Si substrate was used. The SiGe layer was formed by epitaxial growth on Si substrate. This layer has no defects and is lattice-matched to Si. Then, the SiGe layer was patterned into finite mesa shapes. Figure 1 shows the structure of the sample and the coordinate system (x: [110], y: [-110], and z: [001]). The stress tensors were evaluated by EBSP with the acceleration voltage of 20 kV. The diffraction pattern was detected from surface to the depth of 30-50 nm. The beam spot size was approximately 20 × 60 nm^2 with sample tilted by 70˚. Additionally, SRRS was also performed. Nd:YAG laser (λ = 532 nm) was used as an excitation source. An oil immersion lens (NA = 1.4) was used. The super-resolution algorithm of the bilateral total variation deconvolution method was applied in order to obtain extremely high spatial resolution and suppress the noise enhancement during the calculation [2]. Furthermore, FEM simulation was also performed for a comparison. In FEM, the plane strain model with approximately 6,600 tetragon quadratic elements was used.

Results and Discussion

Figure 2 shows the σ_{xx} stress profiles scanned from the pattern edge to x direction in SiGe layer of wide pattern, which is shown in Fig. 1(a), obtained by EBSP, SRRS, 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. It is confirmed by EBSP and SRRS, the relaxation of the σ_{xx} stress at the edge was approximately 65 and 78 percent. In the calculation of FEM, the σ_{xx} stress was perfectly relaxed. It is considered that a small difference between each method can be explained by the limitation of the spatial resolution. Thus, the consistent relationship between EBSP, SRRS, and FEM was confirmed. The significant σ_{xx} stress relaxation was concentrated in the range of distance from the edge to 100 nm. In FEM, the σ_{xx} stress relaxation was 24.6 percent at 100 nm from the edge. We estimated the spatial resolutions of EBSP and SRRS were less than 100 nm.

Figure 3 shows the (a) σ_{xx} and (b) σ_{xz} stress profiles for the fine structures of the SiGe layer, which is shown in Fig. 1(b), obtained by EBSP and FEM. It is clearly seen that the σ_{xx} stress was relaxed with decreasing nanostructure width from 1000 to 100 nm. The profiles of the σ_{xx} and the σ_{xz} stresses show consistent relationship between EBSP and FEM. Thus, EBSP is allowed us to evaluate the precise stress tensor, including shear stress, in the sub-100 nm order structures. Moreover, the stress relaxation of SiGe layer reproduced by perfect elastic deformation assumed in FEM. FEM simulation is important to complement EBSP and SRRS measurements.

Conclusion

The stress relaxation profiles in mesa-shaped strained SiGe layers were evaluated by EBSP, SRRS, and FEM simulation. The range of σ_{xx} stress relaxation is mostly 200 nm from edge. Thus, the stress relaxation is inevitable in nanostructure with less than 400 nm scale. Moreover, there is a good correlation between the results of EBSP, SRRS, and FEM. The spatial resolution of EBSP and SRRS were estimated less than 100 nm. Thus, it is expected to evaluate the precise stress relaxation profile the sub-100 nm order structures by EBSP and SRRS, respectively. The complement of FEM simulation is important to verify the results of EBSP and SRRS.

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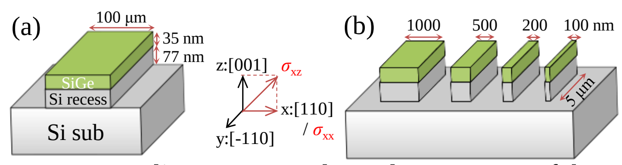

Fig. 1 Bird's-eye view and coordinate system of the strained SiGe on Si substrate sample.

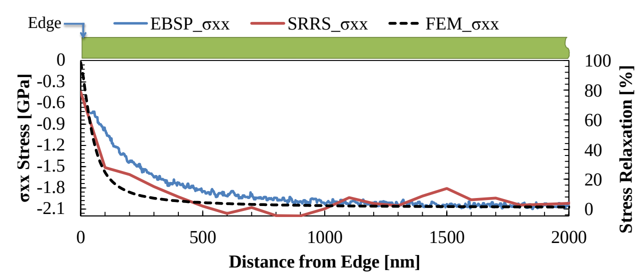

Fig. 2 σ_{xx} stress profiles scanned to x direction in SiGe layer of wide pattern obtained by EBSP, SRRS, and FEM.

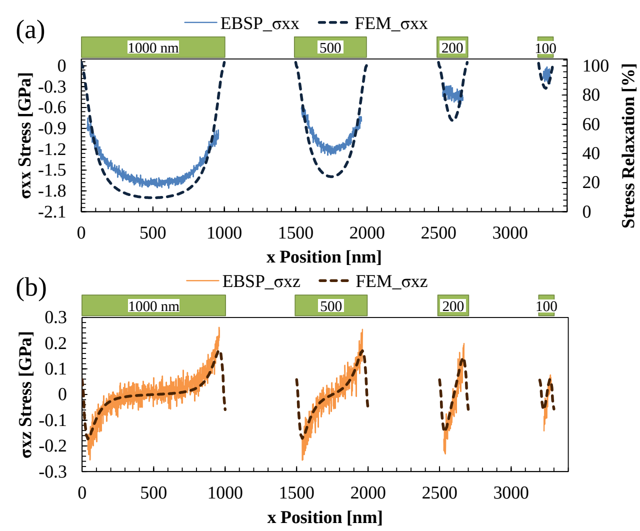

Fig. 3 (a) σ_{xx} and (b) σ_{xz} stress profiles for the fine structures of the SiGe layer obtained by EBSP and FEM.

References

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