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Strain and stress tensor evaluation in global and local strained-Si by electron back scattering pattern

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1. Introduction

Strained-Si is one of the most important techniques in the post-scaling technology. The strain in devices is conventionally inhomogeneous and complicated. It is important to measure and control the strain value and distribution for device performance improvement. Various methods of the strain evaluation have been demonstrated, e.g., convergent beam electron diffraction, micro-Raman spectroscopy, and micro X-ray diffraction. In this study, the strains in global and local strained-Si were evaluated by electron back scattering pattern (EBSP), which allowed us to obtain the strain and stress as tensors nondestructively without complicated sample fabrication.

2. Experiments

Strained-Si on insulator (SSOI) was used as global strained-Si sample. SSOI has 70-nm thick strained-Si layer and 145-nm thick buried oxide on Si substrate. Isotropic biaxial tensile stress is expected to be induced in the strained-Si layer. Si substrates with patterned SiN films were used as local strained-Si samples. The stress in the SiN films was compressive of approximately -2 GPa. Figure 1 shows the structure of the global and local strained-Si samples.

The strain and stress tensors were evaluated by EBSP. The acceleration voltage was 20 kV. The diffraction pattern was detected in the depth of 30-50 nm. High-spatial resolution is expected because the EBSP detector is installed in a field-emission scanning electron microscope. Furthermore, UV-Raman spectroscopy was also performed for a comparison. Ar ion laser (λ = 364 nm) is used as an excitation source, the penetration depth of which is approximately 5 nm into Si. We applied a deconvolution method to the results of Raman measurements to improve the spatial resolution.

3. Results and Discussion

A. Global strained-Si

The stresses and strains in the strained-Si layer of SSOI measured by EBSP (averages of 130 points) and UV-Raman spectroscopy (averages of 5 points) are summarized in Table I. The biaxial stresses of 0.9 (S_{xx}) and 1.1 (S_{yy}) GPa were obtained by EBSP. The biaxial tensile strains and compressive strain perpendicular to the surface were obtained. On the other hand, the stress value of 1.3 GPa was obtained by UV-Raman spectroscopy with isotropic biaxial stress assumption. We believe the both measurements were relatively in good agreement.

Figure 2 shows the two-dimensional shear stress (S_{xy}) distribution in the strained-Si layer of SSOI for the area of 40×40 μm^2 obtained by EBSP. A clear cross-hatch pattern originating in dislocations was observed. The shear stress might be particularly sensitive to the dislocations.

B. Local strained-Si

Figure 3 shows the two-dimensional distributions of the stresses (a) S_{xx}, (b) S_{yy}, (c) S_{xy}, and (d) S_{xz} in the Si substrate with the SiN pattern (space shape is 5 x 10 μm^2 rectangular) obtained by EBSP. Both normal and shear stresses were obtained simultaneously. The stress concentrations at the SiN film edges were confirmed in the distribution of S_{yy} as well as S_{xx}. Figure 4 shows the one-dimensional profiles of the stress S_{xz}. The result of EBSP was consistent with analytical calculation by the edge force model [1, 2]. Therefore, it is possible to measure the shear stress in the EBSP measurements.

Next, we conducted a detailed evaluation in comparison between EBSP and UV-Raman spectroscopy. To improve the spatial resolution of UV-Raman spectroscopy comparable to that of EBSP, we performed deconvolution of stress distribution obtained by UV-Raman spectroscopy. The bilateral total variation method was used for the deconvolution [3], and the spatial resolution of 200 nm was achieved. Figure 5 shows the one-dimensional stress profiles in Si with the SiN film that has a 5-μm wide space obtained by UV-Raman spectroscopy before and after the deconvolution. As can be seen here, the stress enhancements at the SiN film edges were observed particularly after the deconvolution.

Figure 6 shows the one dimensional stress (S_{xx}) profiles obtained by EBSP, UV-Raman spectroscopy after deconvolution, and the edge force model calculation, respectively. In the edge force model calculation, the beam spot size and detectable depth were assumed as 100 nm and 50 nm, respectively. Good agreement is confirmed in each other.

4. Conclusion

EBSP was performed to evaluate strain and stress in global and local strained-Si. SSOI and Si substrates with patterned SiN films were used as the samples. Good agreements were obtained in the results of stress evaluation for both the global and local strained-Si between EBSP and UV-Raman spectroscopy. Shear stress was also measured by EBSP. We consider that the stress measurements as tensor by EBSP are useful for the evaluation of both the global and local strained-Si.

Acknowledgements

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Table I Stresses and strains in SSOI measured by EBSP and UV-Raman spectroscopy.

	Stress [GPa]	
	EBSP	Raman
Sxx	0.93	1.30
Syy	1.09	
Szz	0.00	---------
	Strain [%]	
	EBSP	Raman
Exx	0.48	0.72
Eyy	0.64	
Ezz	-0.43	-0.56

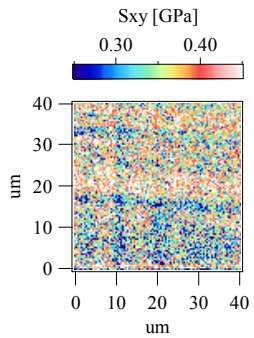

Figure 2 Shear stress (Sxy) distribution in strained-Si layer of SSOI obtained by EBSP.

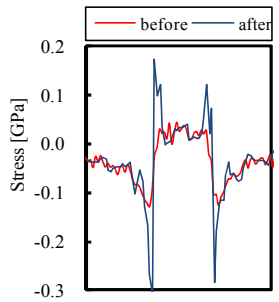

Figure 5 Raman analysis before and after deconvolution calculation.

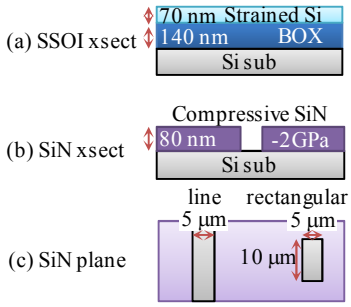

Figure 1 Structures of SSOI and Si with patterned SiN.

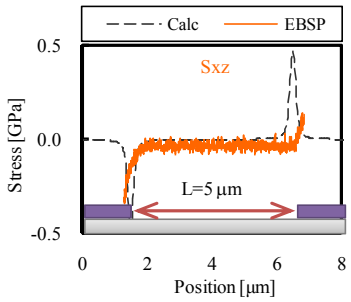

Figure 4 One-dimensional shear stress profiles in Si with patterned SiN obtained by EBSP and theoretical calculation.

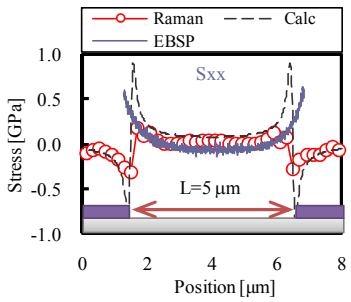

Figure 6 One-dimensional stress profiles in Si with patterned SiN obtained by EBSP, deconvolution Raman and theoretical calculation.

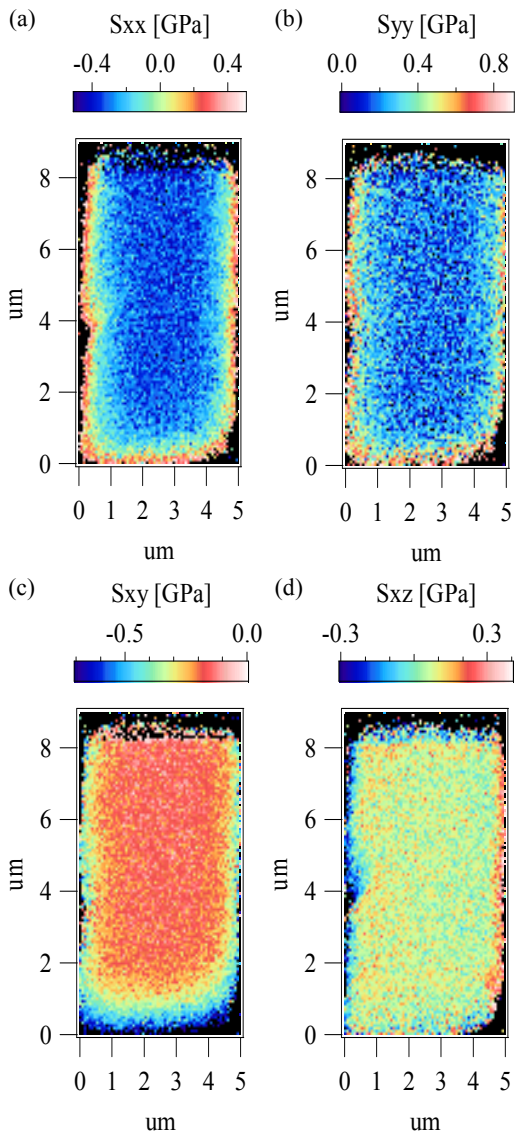

Figure 3 Two-dimensional stress distributions in Si with rectangular patterned SiN obtained by EBSP.