Strain Distribution in Surface Region of Thin Silicon Overlayers on Insulator

High-quality thin silicon overlayers (SOLs) in silicon-on-insulator (SOI) wafers have attracted much interest in recent years [1]. This is because thin, nanometer-thick SOLs (SNOLs) are expected to exhibit a clear quantum confinement effect at low temperatures and because they have a great potential as advanced Si substrates. To obtain a SNOL less than 50 nm thick, thermal oxidation of a SOL with a thickness of several hundred namometers on SOI wafers is usually employed. During the thermal oxidation, the thickness of the SOL decreases as the oxide thickness increases. In this way, cyclically thinning by thermal oxidation of a thick (>100 nm) SOL and by HF etching of the top silicon oxide (TOX) layers, one can produce thin (<50 nm) SNOLs on top of a buried silicon oxide (BOX).

It is well known, however, that strain exist in SOI wafers, originating from the difference in specific volume and thermal expansion coefficients between the Si and SiO_2 at the SiO_2/Si interface. The strain usually induces defects at the interface and inside the SNOL. This degrades the electronic and optical properties of the final structures.

In this work, we characterized the lattice strain and strain distribution in a 47-nm-thick SNOL on a SIMOX wafer using grazing incidence X-ray diffraction (GIXD) near the critical angle of total reflection using synchrotron radiation.

GIXD experiments were performed using the z-axis goniometer at beamline **BL24XU** [2]. The 0.124 nm X-ray wavelength was used at incident angle α varying from 0.01 to 0.4º. This is schematically shown in the inset of Fig. 1. We used <001>-oriented SIMOX wafers with a diameter of 15 mm. After etching a wafer in HF dilute solution, the wafer was oxidized at 1200 ºC in a 0.2% O_2/Ar mixture to form a silicon oxide layer on top of the SOL and promote an internal thermal oxide layer on the bottom of the SNOL. Then, the thermal oxide on the SNOL was removed in a HF bath and X-ray diffraction was measured from the 47-nm thick SNOL on top of the SIMOX wafer.

Figure 1 shows the (220) Bragg diffraction curves collected from the 47-nm-thick SNOL at different grazing angles from 0.01 to 0.2º. The strong peak at the center (θ=0) comes from bulk Si(220). Additional oscillating subpeaks (denoted as 0th, 1st, 2nd in Fig. 1) appear at the lower and higher sides of the

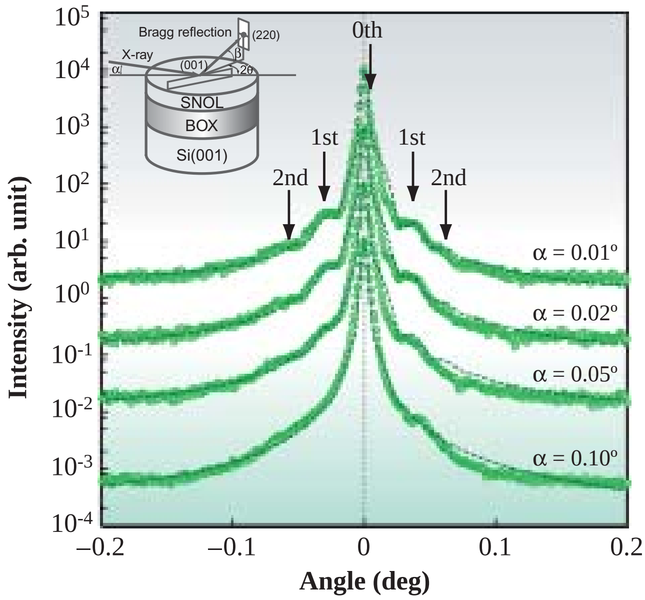

Fig. 1. Grazing incident X-ray diffraction curves of SIMOX wafer at different grazing angles. The broken lines are the kinematical calculations based on the structural model mentioned in the text. The inset shows a schematic diagram of grazing incident X-ray diffraction from the SIMOX wafer, where α, β, and 2θ represent the X-ray incident angle with respect to the sample surface, the angle between Bragg reflected beam and the sample surface, and the angle between the incident X-ray and the (220) plane.

Si(220) reflection, they are clearly observed for the grazing angles between 0.01º and 0.1º. However, for increasing grazing angle, the peaks merge and become unclear at the shoulder of the main peak. This suggests that they originate from the surface region of the sample. In addition, it can be seen that the oscillating peaks are asymmetric with respect to the center of the Si(220) peak. The asymmetric feature also becomes clear when decreasing the grazing angle from 0.1 to 0.01º. These findings indicate that the origin of the peak oscillation is independent of the strong peak related to the Si(220) reflection, suggesting the existence of finite domains at the SNOL surface.

The additional oscillating curves at the side of the main Si(220) peak can be explained in the framework of the kinematical scattering theory [3,4]. To reproduce the experimental curves, we constructed a structural model for the SNOL on the insulator, assuming that the SNOL is composed of two layers (surface region and underlying layers) with two different strain levels. Moreover, the surface region is composed of finite domains with less in-plane strain ε than the underlying SNOL. We also assume that the distribution of domain size is a Gaussian function, with average size D and standard deviation σ. The broken lines in Fig. 1 are the results of the kinematical calculations based on the two-layer model for different angles. The simulation reproduces well the experimental data. The GIXD shows that the difference in in-plane strain between the surface region of the SNOL and the remaining one is a few 10^{-4}. The size of the strain domain D on the surface region is about 500 nm with a deviation s of 70 nm.

To assess the thermal stability of the SNOL, we annealed the sample at 1000ºC and measured GIXD at the grazing angle of 0.01º. Figure 2 shows the GIXD curves obtained during the annealing at 1000ºC and at room temperature (RT) after the annealing. At 1000ºC, as seen in Fig. 2, the additional peaks completely disappear at the shoulder of the Si(220) (compare Fig. 1 and Fig. 2), which makes the peak symmetric with respect to $\theta = 0$. After the annealing, it is evident that the main peak becomes sharper while there are no additional peaks at the shoulder of the main peak. The broken lines in Fig. 2 are the simulation results obtained using the fitting parameters. These results clearly show that the post-annealing treatment is effective in improving the spatial inhomogeneous strain distribution in the SNOL.

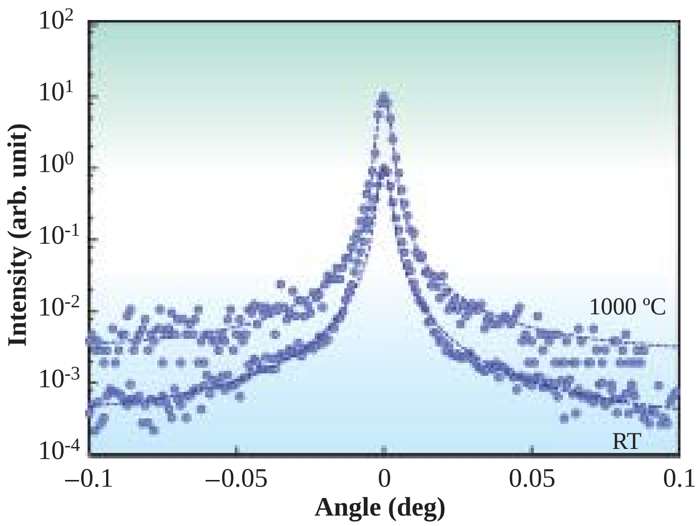

Fig. 2. Grazing incident X-ray diffraction curves of SIMOX wafer obtained at different temperatures. The broken lines are the kinematical calculations.

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