Measurement of Strain in Silicon-on-Insulator Layers by using Synchrotron X-ray Microbeam

Semiconductor device characteristics are, more or less, influenced by crystalline defects such as dislocations. Therefore, from points of view of scientific and device performance improvement, the study of local strain distribution not only in starting bulk materials but also in some device-processed ones are of great importance. To analyze local minute strain in materials, we have provided an X-ray microbeam 7 µm × 6 µm in size with a narrow angular divergence of less than 2 arcsec in both the vertical and the horizontal polarization directions of synchrotron radiation by using successive asymmetric Bragg reflections [1] at an energy of 15 keV, on beamline **BL24XU**. By scanning the microbeam along a line on the sample surface, a series of X-ray rocking curves, which is referred to as rocking curve maps, RCMs, have been obtained. By putting an analyzer crystal behind the sample, reflection-intensity maps in a reciprocal lattice space (q_x, q_y), which is referred to as reciprocal space maps, RSMs, have been drawn for various local points on the surfaces.

Silicon-on-insulator (SOI) materials consisting of top-Si/buried-SiO_2 ("BOX" layer)/Si-substrate are expected to be some of the most promising silicon substrates for extending three-dimensional metal-oxide-silicon (MOS) devices. We have applied present X-ray microbeam diffraction techniques to analyze the strain fluctuation in bonded SOI crystals [2]. Since lattice plane of the SOI layer and that of the substrate are not completely parallel, the X-ray rocking curves usually reveal two peaks of the Bragg reflection, one coming from the SOI layer and the other from the substrate. Figure 1 shows one of the 004 reflection RCMs measured for a 5-µm-thick SOI sample. It is interesting to

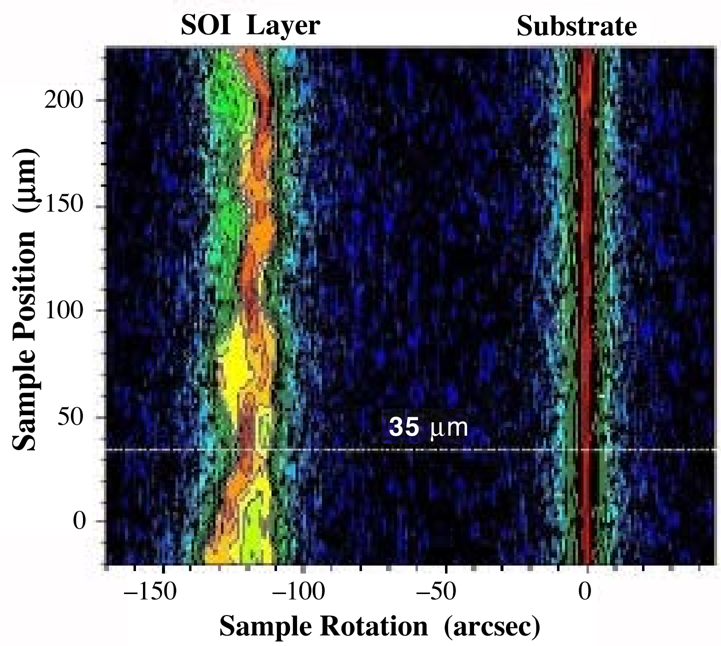

Fig. 1. RCM of 004 reflection taken from a 5-µm-thick SOI layer. The vertical axis indicates the positions of the sample irradiated by the scanning X-ray microbeam.

point out that the peak profiles and the half-widths corresponding to the SOI layer vary depending on the irradiated positions, while a vertical line of high intensity corresponding to the substrate on the right hand side of Fig. 1 is quite straight.

Then, RSMs were taken at some fixed positions of the SOI peaks in Fig. 1. Figure 2 shows an example of the RSM measured for the SOI layer at the dotted line (Z = 35 μm) in Fig. 1. It is clear from this figure that the lattice distortion in the SOI layer is mainly due to the lattice tilt variation because several high-intensity centers at different ω can be seen at $\Delta d/d = 0$. This fact suggests the existence of several crystal grains of an equivalent lattice tilt angle.

It is interesting to see how the equi-tilted lattice planes extend in the SOI layer. The sample was scanned against the microbeam and the reflection intensity was recorded at a fixed tilt angle of the crystal rotation (ω). Both images in Fig. 3 show the intensity distribution maps (so-called equi-tilt maps) for an area of about 300 × 300 μm² of the SOI layer, measured at two different rotation angles, (a) ω = –7.9 and (b) ω = +7.9 arcsec. Those images clearly show that magnitude of the lattice tilt varies in total more than 16 arcsec within the measured area. Typical spatial sizes of the equi-tilt grains range from 20 to 80 μm in this sample.

A similar feature of the lattice tilt was also observed in a SIMOX wafer, which is another type of SOI crystal. Analysis revealed that the SOI layers formed on the BOX layer are more or less strained and fluctuated, and magnitude of the lattice tilt depends on the SOI and the BOX thicknesses and the SOI layer processing conditions. At present, the major reason for such a large lattice tilt in the SOI layer has not yet been clarified. It can be safely said that the SOI surface polishing effects can be excluded, because there was no peak shift with a wide angular width observed for samples with a thicker (more than 60 μm) SOI layer.

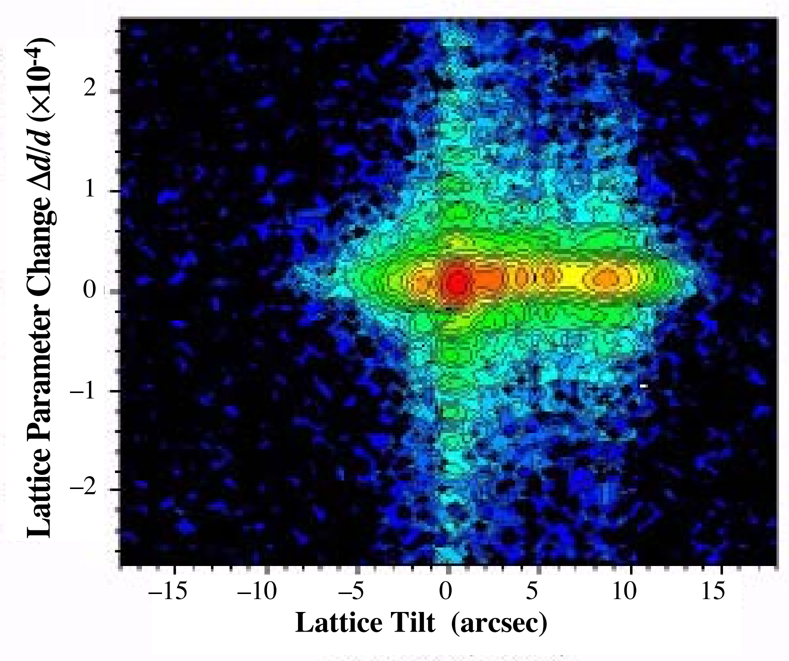

Fig. 2. RSM of a SOI layer measured at the dotted line position of the RCM shown in Fig. 1. Intensity spots in the horizontal direction at $\Delta d/d = 0$ show lattice tilt of the grains in the SOI layer. Additional spot arrays lying along the vertical direction are due to thickness fringes belonging to each small grain in the SOI layer.

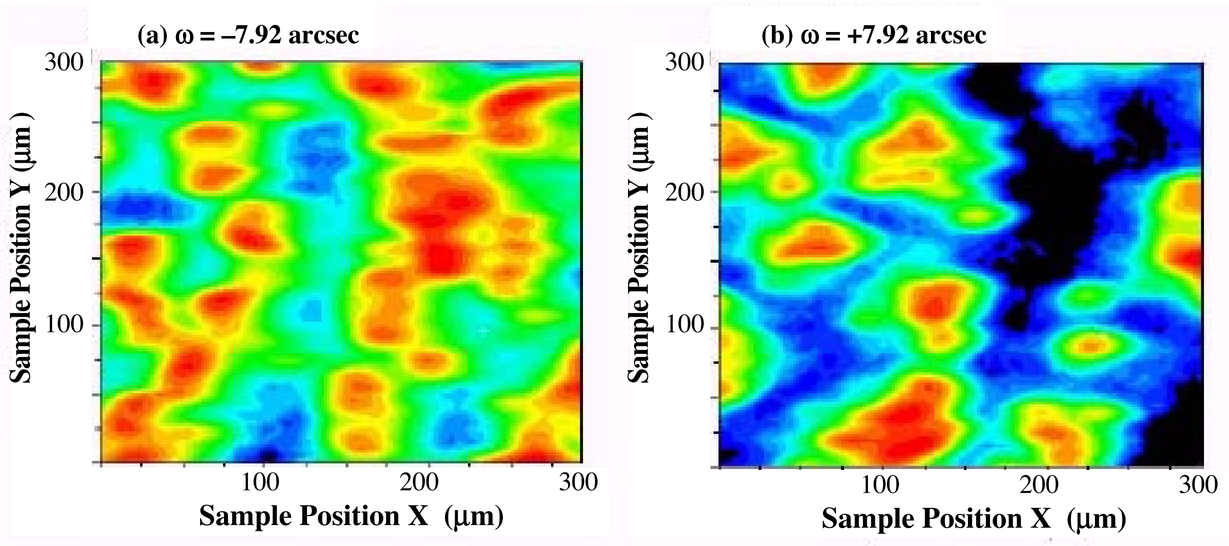

Fig. 3. Equi-tilt maps taken at two different angles around the Bragg peak. Contrasts seem to be complementary between (a) and (b).

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References

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