ADVANCED X-RAY DIFFRACTION IMAGING TECHNIQUES FOR SEMICONDUCTOR WAFER CHARACTERISATION

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Abstract

Wafer quality inspection and defect analysis are crucial for improvements of the wafer fabrication technology as well as for the correlation of device properties with the processes of wafer treating. This work demonstrates trends of high-resolution X-ray diffraction imaging techniques with synchrotron radiation sources and their capability for detailed quality inspection of wafers concerning their structural perfection. We apply these methods to visualise and to characterise the defects and deformations induced by growing, cutting, grinding, etching and gluing in the production of semiconductor wafers (in particular Si and GaAs wafers) and in ultra-thin wafers. We present synchrotron topography and synchrotron area diffractometry methods to analyse qualitatively and quantitatively: dislocations and lineages, micro-defects and micro-cracks, wafer tilts and warpages, tensors of local lattice rotations.

1. Defects and deformations induced by grinding and gluing of ultra-thin silicon wafers

Thin semiconductors are used for power devices, chip card applications, high frequency integrated circuits (ICs) and opto-electronic components. Current trends in thin chip technology are targeting to extremely low packaging heights and thin and flexible ICs for smart labels and highly integrated chip systems for multifunctional devices. Until today the chip thickness of the ICs is limited to the range of 100 to 200 μm. Completely new applications appear when wafer thinning, dicing and die mounting technology are extended to ultra thin chips with a remaining thickness of 10–30 μm [1]. In this range silicon substrates become mechanically flexible and new products like laminate mounted "Smart Labels" become reality, see Figure 1.

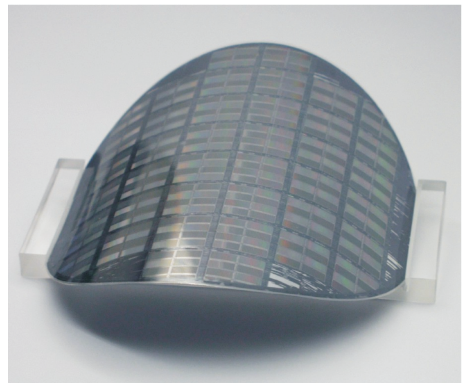

Fig. 1. Ultra-thin silicon wafers become mechanically flexible.

Wafer thinning approaches rely on a coarse grinding process to remove off the wafer about 300 μm silicon bulk. Further micro-thinning (grinding, spin and plasma etching) removes the additional material and eliminates the stress resulting from micro-defects. Damaged subsurface zones extending 5–15 μm into the substrate have to be removed by chemical etching. Finally, the chemical-mechanical polishing step reduces the roughness and cleans the surface.

Synchrotron X-ray diffraction imaging techniques prove their value for research and industry in characterisation of grown-in and process-induced defects as well as stresses. Here we study the surface and volume damage introduced by the grinding and the damage removal by subsequent surface treatment mentioned above, as well as the detection of lattice distortion fields generated by the gluing of the ultra-thin wafer on a target wafer. The main results have been obtained by:

a) X-ray monochromatic section topography in Bragg case with a high sensitivity, specially to (sub-micrometer), defects exploiting the visibility of Pendellösung fringes,
b) high resolution monochromatic double crystal topography with a high sensitivity in particular to strain and to diffuse scattering at the tails of rocking curves,
c) the quantitative imaging of lattice deformations and macroscopic defects by micrometer resolved tilt maps.

The main results concerning the grinding damage and its removal by spin etching are:

1. Etching-off or polishing-off (CMP) only 5 μm thick surface layer after grinding are sufficient to remove the surface damage significantly so that the Pendellösung fringes are restored to a high degree. However, full restoration of the visibility of fringes was not observed even after etching and polishing removal of 50 μm, see Figure 2.
2. Low density (<1000 cm^{-2}) of larger (<20–80 μm) low contrast defects (LCD) remains also after etching-off 20 μm of surface layer, see Figure 3.

The qualitative and quantitative imaging of lattice tilt induced by the glue attaching the thin wafer to the carrier wafer has been performed by white beam section topography and by lattice tilt mapping by the area diffractometry method discussed in more details in the following section.

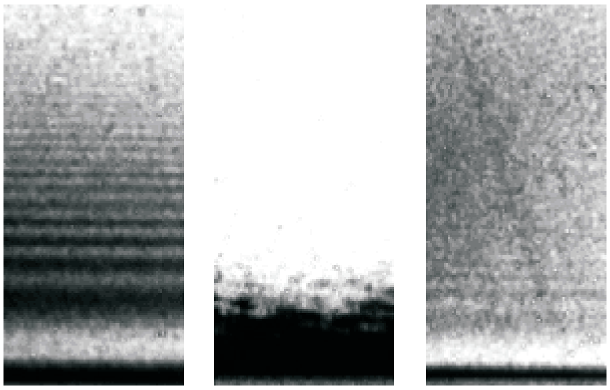

Fig. 2. Sub-surface damage characterisation by Pendellösung fringes visibility: reference Si wafer (left), ground wafer (middle), ground and 46 m etched wafer (right).

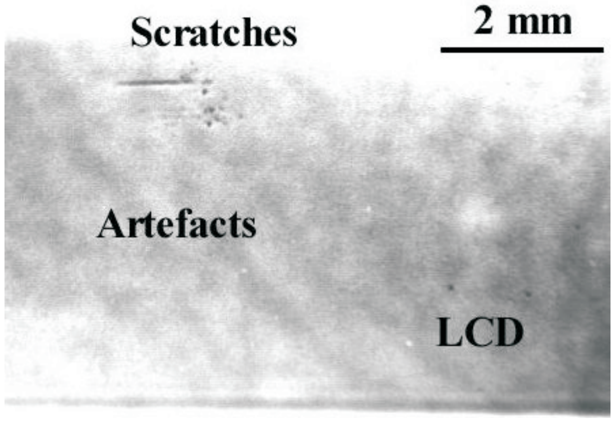

Fig. 3. Monochromatic projection topography of a 80 m thick Si wafer (grounded and etched).

2. μm-resolved determination of the three-dimensional lattice misorientation for the semiconductor wafers inspection by synchrotron radiation area diffractometry

Wafer fabrication technology of compound materials such as GaAs, InP, SiC, CdZnTe requires up-to-date structure characterisation methods and defect analysis methods in order to achieve high-quality wafers for micro-electronic applications. GaAs, for example grown by LEC method, can form columnar structures with highly perfect crystalline structure inside the crystallites. This can be observed optically on etched wafers as a presence of lineages, dislocations, and other defects at the boundaries. Furthermore, a growth inhomogeneity can lead to nucleation of specific misoriented crystallite-like defects with lattice planes tilted with respect to the main substrate lattice, which cause problems during subsequent epitaxy steps.

In an earlier work [2] we developed a method of μm-resolved synchrotron X-ray area diffractometry as a tool for wafer quality characterisation by combining digital topography and conventional wafer Bragg-diffraction rocking curves. Recently we have extended this method to reveal the complete three-dimensional tensor of local lattice misorientation in wafers, including so-called macrodefects of large rotation angles with respect to the undisturbed region [3].

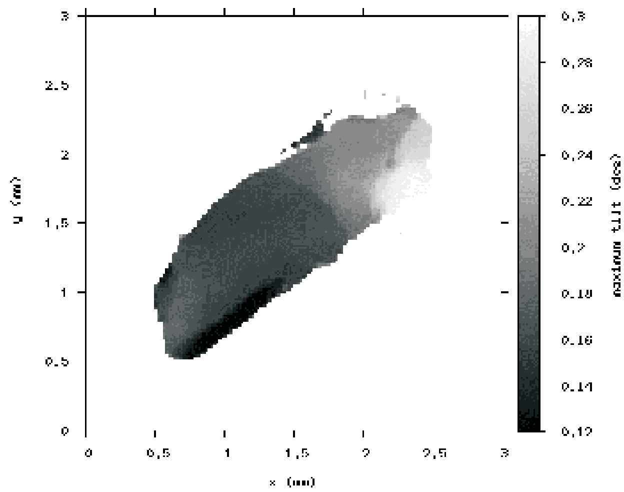

Fig. 4. Distribution of maximum of the lateral lattice misorientation angle onto a defective area of a GaAs wafer.

The procedure is based on measuring Bragg-diffraction rocking scan by area diffractometry in three mutually non-coplanar scattering planes by an area detector such as the ESRF FReLoN camera which allows pixel resolution up to micrometer. Therefrom the complete spatially resolved three-dimensional lattice-orientation maps are reconstructed. Beside the advantages of μm-resolution and the use of a fast imaging technique instead of conventional X-ray scanning techniques inherent ambiguity problems have to be solved. Our reconstruction algorithms solve particular problems of multi-peak pixel analysis and subsequent back projection from the area detector to the sample surface.

The method is experimentally employed on reconstruction of lattice tilt misorientation of specific macroscopic crystallite-like defect structures in 6-inch GaAs wafers. The projection of the lattice tilt onto any given plane can be calculated from the lattice misorientation tensor. Figure 4 shows maximal value of (001)-projected lattice misorientation with respect to the mean wafer lattice mapped onto a defective wafer area.

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