Post fracture surface roughness in the SmartCutTM technology

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Abstract

Light ions implantation in crystalline silicon substrates leads to the formation of nanometer sized cracks when the implantation fluence is high enough. These cracks are often named "platelets". Due to the stress related to implanted ions, the *platelets* are preferentially parallel to the surface and tend to grow when annealing is applied (1). The platelets grow first via Ostwald Ripening mechanism (2), then by successive coalescences (3). When a silicon substrate is bonded on the top of the implanted silicon substrate, platelets can expand up to the micrometer scale (micro-cracks). Finally, a crack propagation is observed through the whole wafer leading to the transfer of a thin silicon layer to the bonded substrate. The SmartCutTM technology takes advantage of this multiscale crack evolution in order to fabricate silicon-on-insulator (SOI) substrates (4). Nowadays, advanced technology nodes require extremely tight tolerances on thickness variations. Understanding the mechanisms that generate surface non-uniformities is therefore key to meet such a restrictive criteria. In this paper we aim at understanding the mechanism of surface roughness formation at the different length scales involved during the defects growth.

Bonded pairs of wafers presenting various conditions of implantation were annealed until fracture occurred. Their post fracture surface was then characterized by the association of three techniques widely used in wafers characterization: Atomic Force Microscopy (AFM), White Light Interferometry (WLI) and Mechanical Profilometry (MP). AFM measurements with the use of a super sharp probe allow imaging the samples surface with a resolution down to one nanometer, which reveals the surfaces opened by the platelets during the very first stage of their growth. The WLI and MP techniques permit larger scale observations and reveal topography patterns associated to both the micro-cracks coalescences and the final fracture that opens the remaining surface. For all measurements, spectral analyses were conducted via the computing of the 2D Power Spectral Density (PSD) and the Height-Height

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Correlation Function (HHCF), two tools widely used to characterize self-affine surfaces (5), (6). The PSD obtained with the different techniques were merged to obtained a single curve of post-fracture SOI wafers (7), which enables the investigation of the physical mechanisms implied in the defect growth – and hence – the roughness generated during the fracture annealing.

The PSD curve highlights two different wavelengths domains in the overall roughness. At small length scales, the growth of platelets generated surface deviations (roughness), with a Hurst exponent H≈0.8. This is a classical value in fractal analysis of post-mortem cracked surfaces for different materials (8). It could indicate that the growth of platelets is driven by coalescences(9). The upper bound ξ of this domain was estimated precisely with both PSD and HHCF, and is observed to be the diameter of the larger platelets on the surface. The relationship between the size distribution of surface features and ξ is in agreement with the observation of characteristic lengths on engineered surfaces (10). This bound is therefore directly set by the implantation conditions as observed previously (7). A second growth regime of the PSD appears at distances larger than ξ. The latter prints typical patterns on the surface, either due to the coalescences of micro-cracks or to the final fracture that passes through the wafer. The measurements showed that the out-of-plane deviations associated to this second regime are small compared to the ones due to the growth of platelets. Indeed, a low value of H was obtained, which indicates that, at this scale, the surface opening paths are overall confined in the vertical width where the platelets have grown.

To conclude, the roughness of post-fracture SOI samples was investigated with several characterization methods. The results show that the growth of platelets prints important roughness on the post-fracture surface of SOI wafers. At larger scales, both the coalescences of micro-cracks and the passage of fracture through the wafer were found out to generate few additional roughness.