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Fracture and remnant surface stress imaging of point-contacts in Si

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Abstract – We studied remnant surface stress in indented Si(111) wafers by means of high spatial resolution and stress sensitivity Raman imaging. The images highlight a deterministic and counterintuitive relation between the remnant stress distribution and fracture growth orientation. The results also strongly indicate local switching between tensile to compressive stress during the indenter load/unloading cycle. Furthermore, by assessing stress, the images highlight a directional dissymmetry in Si(111) most commonly observed by wet anisotropic etching. These findings are relevant to fabrication, reliability engineering and assessment in MEMS and microelectronics.

Nowadays microelectronic industry is increasingly taking advantage of improved carrier mobility featured by strained semiconductors [1]. Furthermore, micro-electromechanical systems (MEMS) and nano-electromechanical systems (NEMS) are becoming more and more part of our quotidian. As a consequence, research on stress in high resolution and sensitivity has become crucial to engineer and characterize devices in suitable length scale, as well as to guarantee proper reliability assessment and get better understanding of stress related issues regarding semiconductor processing, such as reliability engineering, thermal budgets, chemical mechanical polishing, chipping, dicing and packaging [2].

Among the several techniques suitable to address stress and strain in semiconductors, Raman spectroscopy stands out as non-destructive and highly sensitive [3]. In this work, indented Si wafers were imaged by confocal Raman microscopy. By means of hyperspectral imaging, we studied the remnant stress distribution resulted from 5 µm spherical indentations produced with increasing loads on Si (111) wafers. The images exhibited here correspond to indentation loads near the fracture nucleation threshold.

Our results evidence that regions around the imprinted area switch between tensile and compressive stresses during the load/unloading cycle. Furthermore, although we used the well established Yoffe model to underline our understanding of the fracture nucleation in the Si (111) surface, our results show that more elements have to be added to this kind of model.

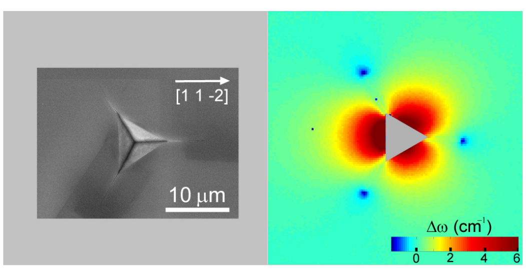

Figure 1: To aid interpretation of Fig. 2, here we show a SEM (grey) and a hyperspectral Relative Raman Shift (color) image of a 400 mN Berkovich indentation on Si (111). The color map is adjusted so that the light turquoise color corresponds to the unshifted (unstressed) 520.5 cm^{-1} Raman scattering. The red shifted (positive) Raman scattering appears as a red shift in the color map and corresponds to compressive stress. Analogously, the blue shifted (negative) Raman scattering appears in blue in the color map and is related to tensile stress. The grey area corresponds to the imprinted area where no 520.5 cm^{-1} Raman scattering was detected. In this way, it is easy to see how the compressive stress intensifies (down to ~ -3.5 GPa) towards the faces of the indenter (evidenced by the red shift in the Raman scattering) as a response to the plastic deformation generated by the indenter. Furthermore, we observe that tensile stress (up to 0.5 GPa) regions are restricted to the crack-tips.

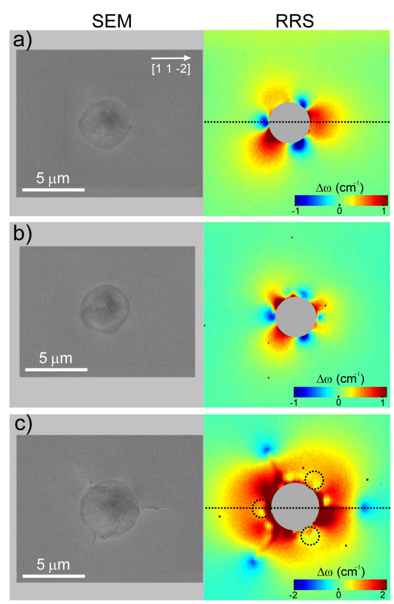

Figure 2: SEM (grey) and RRS (color) images of 5 µm spherical indentations with loads **a)** 150 mN, **b)** 150 mN and **c)** 200 mN.

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