Table of Contents

Raman Microanalysis of Silicon Wafers

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Abstract: Improvement of processes for silicon machining is important for producing silicon wafers with an ultra-high surface flatness and quality. In this work, we report the results of Raman microprobe analysis of silicon wafers after various machining operations [1]. Particularly, different edge grinding conditions have been investigated.

Experimental: Several different regimes and tools were used to grind edges of silicon wafers. For characterization of the samples, Renishaw 2000 Raman microspectrometer was employed. Raman spectra were acquired in a back-scattering geometry utilizing an Ar^+ laser with an excitation wavelength of 514.5 nm. The scattered light was dispersed with a diffraction grating and detected with a CCD detector. Raman spectra were acquired from each sample using a laser spot size of 1-5 µm. Line scanning and area mapping techniques were used. Typically, Raman spectra were taken in each point along a 0.5-mm line on the wafer edge with a step size of 10 µm.

Results and discussion: The line scans corresponding to two different regimes of machining of the wafer edge are presented in Fig. 1. Positions of the scan lines relative to wafer edges are shown in the optical micrographs (Fig. 1b). A typical Raman spectrum from the wafer edge is presented in Fig. 1c. In addition to the peak of pristine Si-I (cubic diamond structure) at 520 cm^{-1}, sharp peaks at 166, 354, 386, 397 and 436 cm^{-1} assigned in the literature to Si-III (body centered cubic phase) and Si-XII (rhombohedral distortion of bc8) [2,3], and the broad peaks around 170 and 470 cm^{-1} corresponding to amorphous silicon [4] were observed on the machined edges.

Positions of Si-I peak across the edge are shown in Fig. 1a. The spectrum of a polished silicon wafer normally used for calibration was selected as a reference (unstressed silicon). In Raman spectroscopy, the displacement of the band from its standard position corresponds to the change in interatomic forces in the lattice, hence such a displacement can be indicative of the residual strains/stresses within the sample [5]. Displacement to the higher wavenumbers corresponds to compressive stresses on the sample surface. It is clear from Fig. 1a that machining using the regime I leads to much lower residual stresses. The stress field in this case is also more uniform compared to regime II. Machined edges of all samples are mostly under compressive stress, although local tensile stresses, which can lead to microcracking, were also observed (points below the reference line in Fig. 1a).

Fig. 1c shows a variation of the amount of amorphous silicon across the machined edge. Since the absolute Raman intensity (number of counts) in each point depends on various factors, the area under the amorphous peak (470-480 cm^{-1}) has been normalized by dividing it over the area under the Si-I peak (520 cm^{-1}) in each point. Samples subject to regime II exhibit a much stronger amorphization than other samples.

In some of the samples after machining using regime I, hardly any amorphous phase was observed.

For the determination of the extent of silicon transformation into r8 phase during machining [6,7], precise peak deconvolution was performed for each spectrum using Galactic Grams software, and the profiles of the normalized intensity of the peak at 354 cm^{-1}, corresponding to r8 [8], were plotted. Fig. 1b shows the distribution of r8 phase (Si-XII) across the machined edges for each sample. Almost no Si-XII was found in the wafers subject to regime II. The presence of Si-XII phase on the surface of the wafer edge suggests a pressure-induced metallization of Si during machining operations. This implies that regime I resulted in preferentially ductile removal of material, leading to a much higher surface quality.

Conclusions: Removal of ductile metallic phase contributes to material removal during machining of silicon, along with brittle fracture and/or plastic deformation of Si-I. Formation of the metallic phase is beneficial for the machining process since (1) it is ductile and can be easily removed by a moving hard tool or abrasive grain, (2) it can be removed without damaging underlying hard semiconductor Si, thus resulting in minimal surface damage. This finding can lead to development of improved machining technologies using the removal of the ductile metallic phase as the major material removal process. The results of this research demonstrate the potential of Raman spectroscopy as a process control metrology for a variety of wafer manufacturing operations.

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Table of Contents

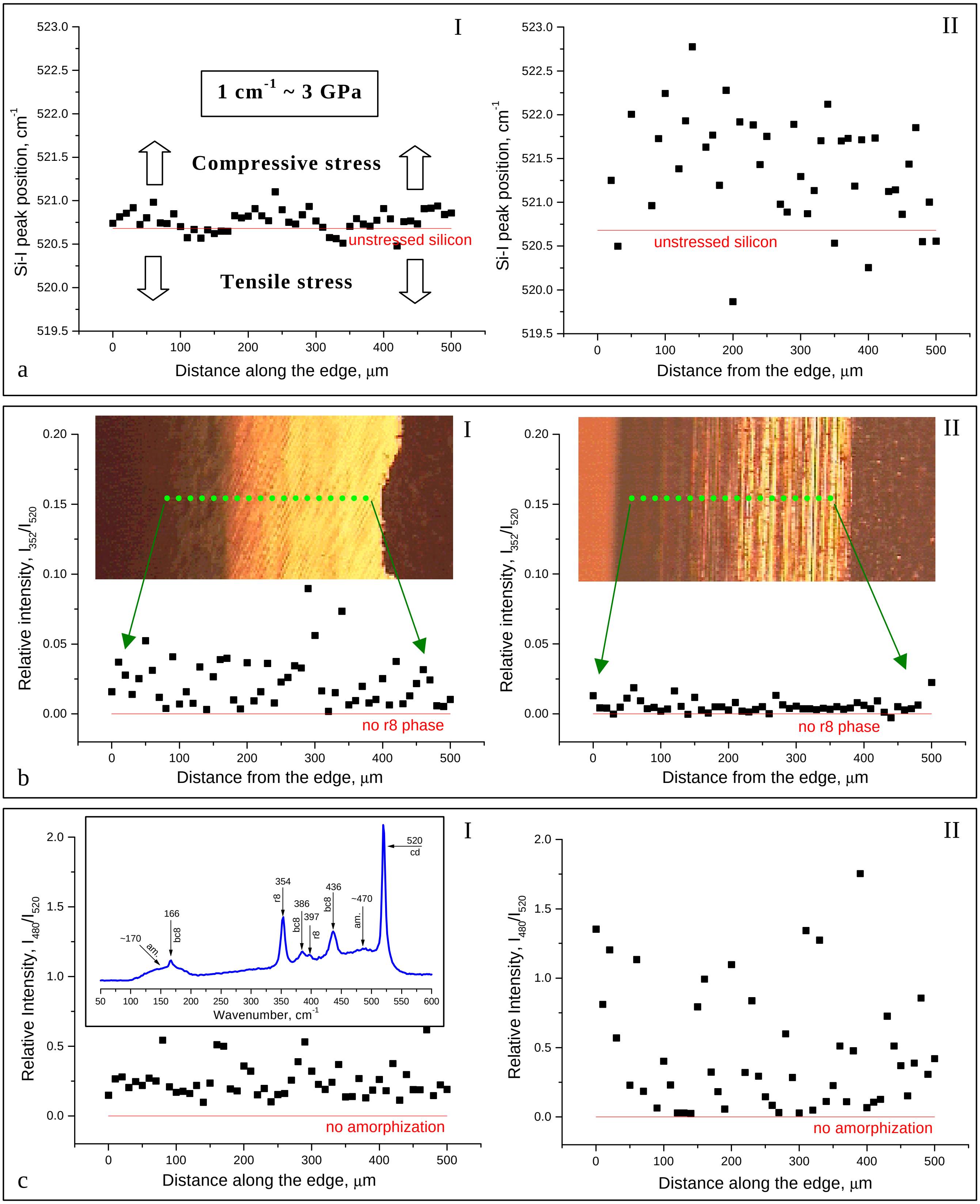

Fig.1. Distribution of residual stresses (a), r8 (b) and amorphous (c) silicon phases across the wafer edge after edge grinding using regimes I and II as marked.