High resolution investigations of ripple structures formed by femtosecond laser irradiation of silicon

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Surface structures, formed by femtosecond laser ablation from crystalline silicon targets placed in ultrahigh vacuum, are investigated by means of high resolution transmission electron microscopy (HRTEM), electron energy loss spectroscopy (EELS) and Raman spectroscopy. After repetitive illumination with several thousand laser pulses, a crater morphology emerges that indicates the development of periodic structures at the crater bottom [1,2], with the orientation depending on the laser beam polarization. Raman spectra display a whole series of structural changes as a result of the fast phase transition [3]: amorphization and transformation in different silicon crystalline phases. The periodic structures exhibit the typical signature of pressure-induced transformation similar to the case of mechanical indentation.

Transmission electron microscopy offers the possibility to achieve more detailed information about the distribution of defects and phases inside the ripples which may help to understand the fundamental processes of the formation of these particular surface patterns.

In our ablation experiments we used pulses at 800 nm, each with a duration of 100 fs. The crystalline silicon sample was mounted in an ultra-high vacuum chamber (~10^{-9} mbar). The linear polarised beam of an amplified Ti : Sapphire laser was focused onto a spot of about 150 µm (FWHM) at normal incidence on the sample surface. Chains of ablation spots were produced by repetitive illumination with 3 000 pulses per spot (intensity per pulse: ~1.8×10^{12} W/cm²). Cross sections of the samples were prepared in order to obtain electron transparent samples for HRTEM and EELS.

HRTEM images recorded with a Jeol 4010 show several defects in the prepared samples: grains with different orientations or crystal structures, respectively, are present at the upper part of the ripples. A correlation in the location of the silicon high pressure phases identified by Raman microscopy and the grains is supposed.

Other defects, like dislocations, stacking faults and twins, occur at both the bottom part and the flanks of the ripples. The surface of the ripples consists of an amorphous layer which appears in comparable sample systems, too [4]. The composition of this layer is determined by EELS investigations.

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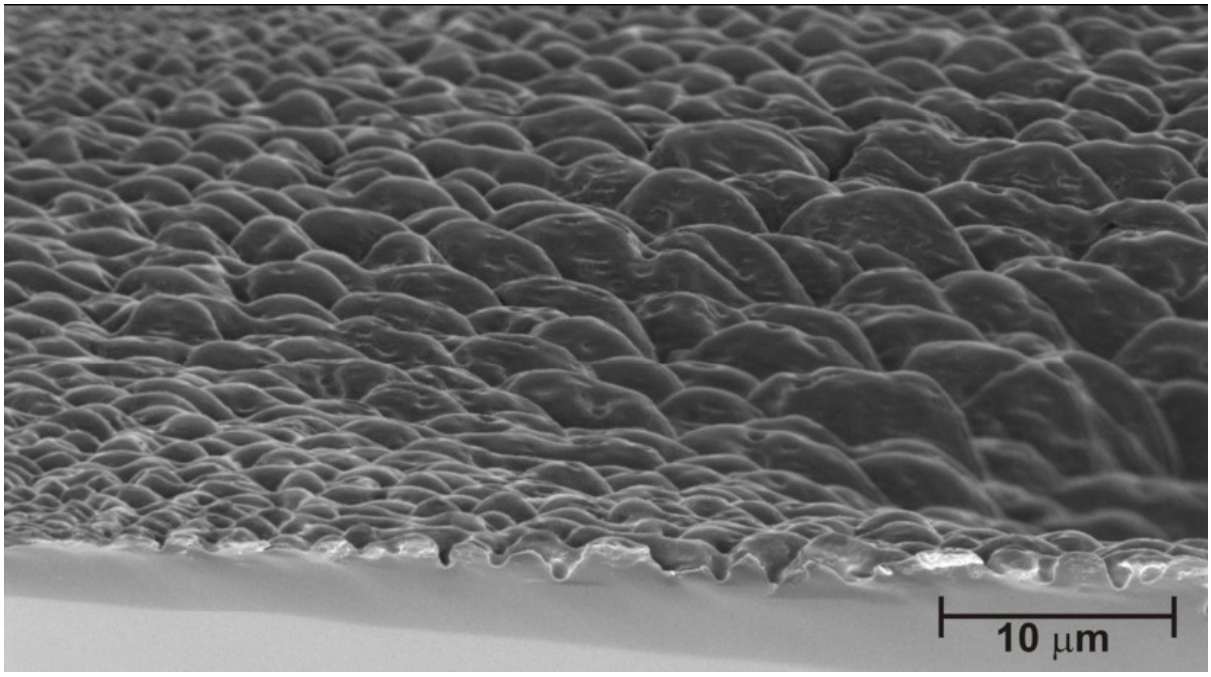

Figure 1. Cross-sectional SEM image of an ablation spot. The ripples in the center of the spot have a bigger size than the ripples at the edge.

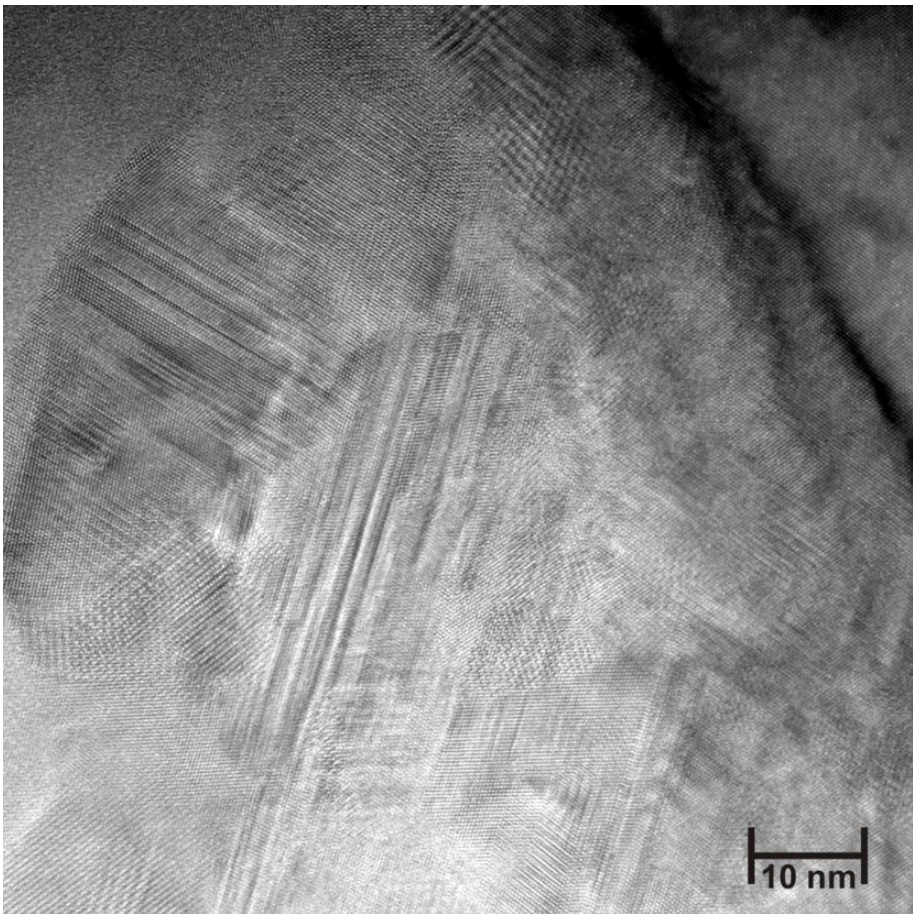

Figure 2. HRTEM image of the cross section of a ripple. Several types of defects occur inside the ripple.

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