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Report:

The evolution of surface morphology during ion bombardment has been the subject of intensive studies and controversial discussions [1]. In particular the evolution of solid surface topography during ion-beam sputtering with ion energies from few keV to several hundred keV is governed by the interplay and competition between the dynamics of surface roughening on the one hand and material transport during surface diffusion on the other. This competition is responsible for the creation of characteristic surface patterns such as nano scale periodic ripples when the ion beam is tilted to the surface normal. Nano-scale periodic ripple formation has been observed on Si(100) bombarded by $^{40}Ar^+$ beam at 60° angle of incidence with respect to surface normal [2].

In order to investigate the induced morphology and depth dependence of the treated sample a series of Si(001) surfaces was bombarded by $^{40}Ar^+$ ion beam accelerated with E = 60, 80 and 100 keV under 60° with respect to [001]. The implanted dose ranges from $\phi = 3\ 10^{17}\ cm^{-2}$ to $3\ 10^{18}\ cm^{-2}$. To do this the focused beam was homogeneously scanned over the sample by magnetic *x-y* sweeping system. After irradiation, the samples were investigated by atomic force microscopy (AFM) in contact mode under ambient condition. For all samples the appearance and the direction of ripples was already visible by eyes.

A few of these samples of this series have been investigated by X-ray grazing-incidence diffrcation at the ID1 beamline of ESRF. The incident beam energy was 8 keV. The strain sensitive (220) and strain in-sensitive (-220) in-plane reflections were selected to investigate the ion-beam induced strain and morphology [3,4]. The scans were performed in reciprocal space parallel and perpendicular with respect to the ripple pattern at incidence angles ranging from α_i =0.1° to 0.7° corresponding to an information depth of 5nm to 300nm, respectively. Typical tarnsversal scans of two samples with $\phi = 7\ 10^{17}\ cm^{-2}$ are shown in Fig.1 compared with AFM pattern of the respective samples. The diffraction curves show the presence of grating peaks which clearly indicate the appearance of ripple formation seen in AFM. The curve shape changes as a function of α_i and the implantation energy as well. For E = 60keV we found transition from a narrow curve to a broad curve indication the onset of defect formation. The depth of this transition obviously corresponds with the penetration depth of the implanted ions. It starts appearing at α_i = 0.7° for E=80 keV and is no more visible for E=100 keV. This finding corresponds to the decreasing ripple height changing E in the same direction.

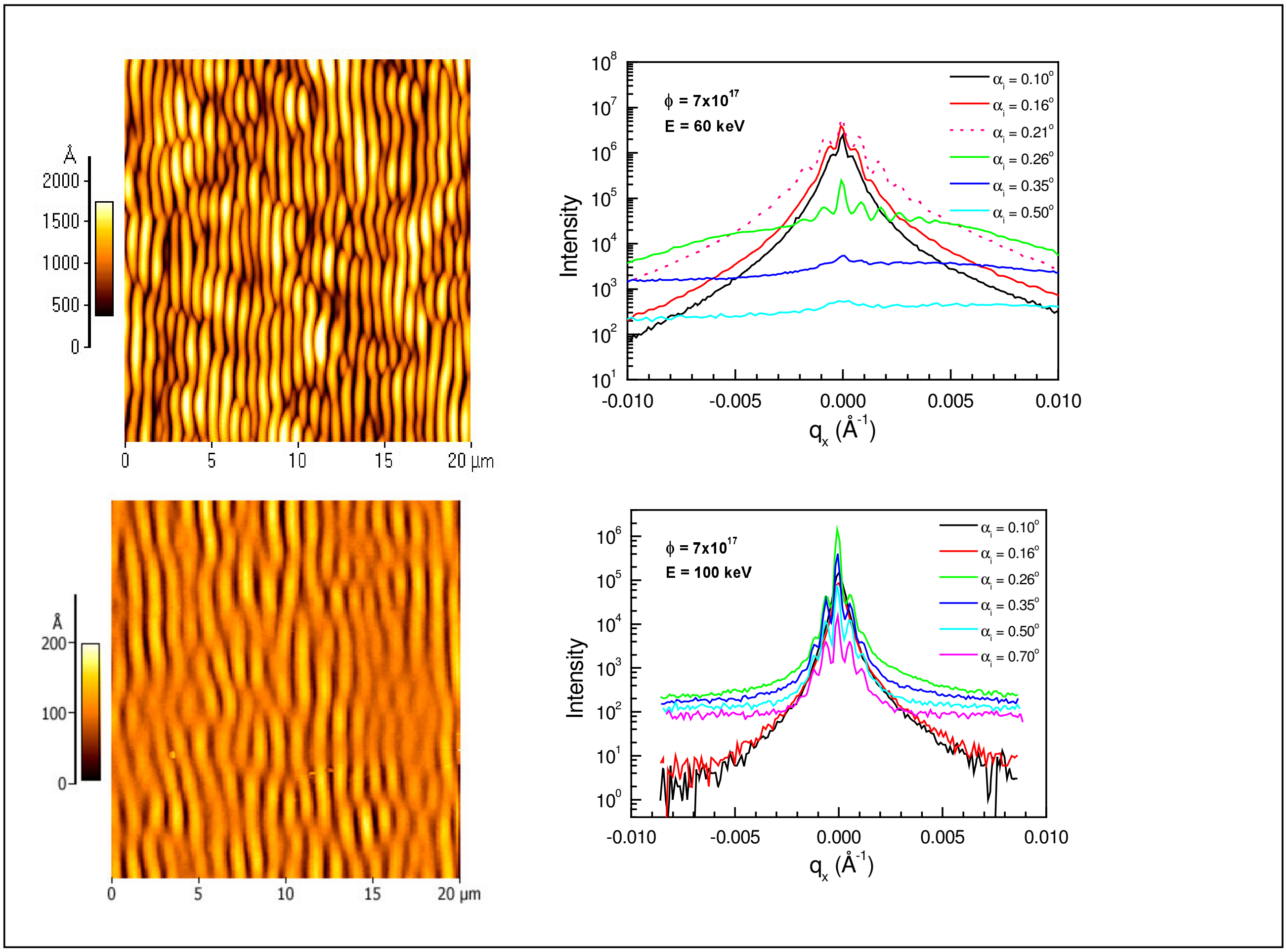

Fig.1 AFM and in-plane diffrcation curves for si(001) samples after implantation with ^{40}Ar^{+} ions under 60°.

The measured lateral ripple wavelength λ is found to depend on the implantation energy E. It changes from λ=720 nm, 915nm and 1070 nm increasing the energy from 60, 80 and 100 keV. This is in complete quantitative agreement with the reasults of the AFM measurements (see fig.1, left). Moreover, the depth dependent diffraction curves show clear evidence that the crystallinity of the material is almost conserved. In-plane peaks did appear up to the smallest α_i measured. Thus implantation induced amorphisation must be limited to a thickness of less that 10 nm below the surface. Unfortunately, the strain sensitive (longitudinal) scans did not display grating peaks, obviously washed out due to the strongly inhomogeneious strain field. Finally the transition depth to the defect induced sample area show remarkable dose dependence. Reducing the implantation dose to $\phi = 5\ 10^{17}$ cm^{-2} the peak broadening was not observed.

In summary, X-ray grazing-incidence diffraction is an unique tool for nondestructive analysis of implantation induced nano-rippling. Using this method we could measure the depth of induced ripple formation and the transition depth of defect formation. These measurements help to optimize the implantation process with respect to the producuction optical surface wave guides and other electonic devices. A detailed analysis of the diffraction curves will provide the depth dependence of ripple correlation [5].

Unfortunately the time was to short to investigate the dependence of the inclination angle for pattern formation which might be the most important parameter to understand the physical process of nano-rippling.

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