Using soft X-ray lasers for direct nano-structuring

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We carried out ablation experiments using plasma-based and FEL XUV/x-ray lasers. XUV/x-ray ($\lambda < 100$nm) ablation of materials was first studied with plasma-based sources of incoherent short-wavelength radiation (for a bibliography of this subject see[1]). Initial ablation experiments using XUV/x-ray lasers have been realized only recently[1-4]. This was made possible by progress during the last-decade in developing these sources, in measuring and optimizing their output parameters, and in the focusing of their beams.

The XUV/x-ray lasers represent promising tools for applications in the field of nano-patterning of solids, as they will enable printing of features having dimensions comparable to the wavelength (Fig. 1). A key advantage of the XUV/x-ray lasers for fabrication of nano-structures is the unique combination of exceptionally short wavelength, spatial coherence, and high peak power. Due to the ablation threshold for processing of materials, it is necessary that the XUV/x-ray sources deliver enough fluence and thus sufficiently high power onto the irradiated surface area. Although non-coherent sources developed for XUV/x-ray lithography can also pattern the materials surface at a sub-10-nm resolution, they cannot produce directly a three-dimensional structure using only a single or few shots at a processing step.

For selected materials, soft X-ray laser ablation conditions were optimised yielding minimal thermal damage. Both projection and contact mask-based schemes for direct high-aspect-ratio structuring are described and our initial results in this field are reported in this contribution.

1. L. Juha et al.: Short-wavelength ablation of molecular solids: pulse duration and wavelength effects, *J. Microlith. Microfab. Microsyst.* **4**, 033007 (2005) and references cited therein.
2. L. Juha et al.: Ablation of organic polymers by 46.9-nm laser radiation, *Appl. Phys. Lett.* **86**, 034109 (2005).
3. T. Mocek et al.: Focusing a multimillijoule soft x-ray laser at 21 nm, *Appl. Phys. Lett.* **89**, 051501 (2006).
4. N. Stojanovic et al.: Ablation of solids using a femtosecond extreme ultraviolet free electron laser, *Appl. Phys. Lett.* **89**, 241909 (2006).

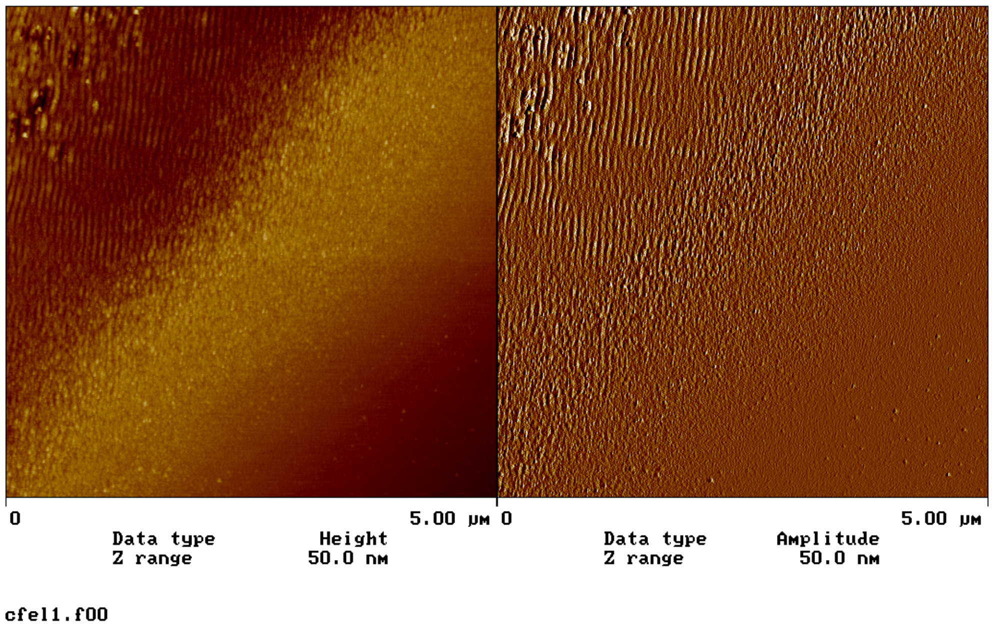

Fig. 1: AFM images of amorphous carbon (a-C) surface irradiated at normal incidence with 98-nm free-electron laser radiation (average pulse: 30-100 fs, ~10 μJ) focused on the material by an ellipsoidal mirror (maximum intensity at target surface ~10^{13} W/cm^2). Periodic surface structures with a spatial period of (76±8)nm were formed due to the interference of the incident laser beam with a wave diffracted by periodic features in the surface. For more details see B. Steeg, L. Juha, J. Feldhaus, S. Jacobi, R. Sobierajski, C. Michaelsen, A. Andrejczuk, J. Krzywinski: Total reflection amorphous carbon mirrors for VUV Free Electron Laser, *Appl. Phys. Lett.* **84**, 657 (2004).