

This research has been supported by SGS grant No

Ablation of Materials by a Single Pulse of Soft X-Rays Emitted from Laser - Produced Plasmas

R. Viskup

`viskup@fzu.cz`

**Department of Physics, Faculty of Electrical Engineering,
Czech Technical University in Prague**

Abstract

It has been demonstrated in numerous papers [1-3] that the interaction of short-wavelength radiation with a solid material in vacuum induces the transfer of macroscopic amounts of the material into the vacuum. Synchrotron radiation and radiation emitted from hot dense plasmas have been used in these experiments as x-ray sources. XUV-radiation-induced removal of solids has been studied for use in micromachining, of microelectronic and micromechanical elements and devices, and for making durability assessments, of potential ICF reactor first wall materials and of optical elements, which are exposed to intense short-wavelength radiation in a laser-plasma interaction chamber or during SASE-FEL radiation focusing. X-ray ablation of metals has also been used for determination of the energy content of intense radiation pulses emitted from hot dense plasma. Ejected material can be collected on a chosen substrate so that high-quality thin films are produced.

The short wavelength radiation sources used for materials removal emit at both low (synchrotron radiation sources) and high peak power (sources based on hot dense plasmas). With low-peak-power sources, materials are removed by photon-induced desorption of material components from the irradiated sample surface. Each x-ray photon carries enough energy to break any chemical bond. This energy is also usually higher than the cohesive energy of any crystal. Therefore the photons absorbed in the near-surface region may also create small fragments of the sample material, which are emitted into the vacuum. It is necessary to underline that, in the case of low-peak-intensity irradiation, material is removed from the surface and a very thin near-surface layer only. Quite a different situation is expected when a high-peak-power source delivers a single high-energy pulse onto the sample. The sample is exposed to a high local dose of radiation (given by the energy content of the pulse and the absorption length of the radiation in the irradiated material) in a short period of time (given by the pulse duration) – thus a very high dose rate. This means that a large number of events which cause radiation-induced structural decomposition (i.e. polymer chain scissions, etc.) occur almost simultaneously in a relatively thick layer of irradiated material. Since a significant part of the radiation energy absorbed in the material is thermalized, sudden overheating of the layer, which is also chemically altered by the radiation, must be taken into account. On the whole, the overheated fragmented region of the sample represents a new phase, which tends to blow off into the vacuum.

In this contribution we present the results of a study of the ablation of PMMA, PTFE, and Si irradiated by intense soft x-ray radiation emitted from laser-produced plasmas. The high - temperature plasma was created by focusing a 1315-nm laser beam from the PALS, iodine laser system (Institute of Physics, ASCR, Prague) on the surface of a metallic target placed in a vacuum chamber. A gas fill in the interaction chamber was used to reduce charged particle emission from the plasma before arriving at the sample surface. By varying the operational parameters of the plasma sources, we covered a wide range of photon energies, pulse energies, and pulse durations of the short-wavelength radiation pulses with which the chosen samples were irradiated.

It has been demonstrated that the operating conditions of these sources can be optimized to provide enough soft x-ray radiation, emitted in sufficiently short pulses, to ablate PTFE, PMMA and Si. Polymer layers with a thickness of several hundred nanometers were ablated by a single shot, under optimum irradiation conditions. Silicon, an example of an inorganic, covalently bound crystalline material, is much more resistant to x-ray ablation than organic

polymers. PTFE sample was ablated to level of depth from 0.1 μm up to 0.6 μm , PMMA up to 0.8 μm and Si up to 0.2 μm through a nickel mesh by intense XUV radiation emitted from laser produced plasma, driven by the laser pulse focusing on the molybdenum-target surface. This finding, plus the hydrodynamic-like structures which were observed in irradiated areas of the polymer samples, supports a model of x-ray ablation based on the assumption of radiation-induced scissions of the polymer chains, resulting in formation of a fluid-like phase. Removal of macroscopic amounts of the material is then realized by expansion, ejection, and vaporization of this phase (overheated by the dissipated fraction of absorbed radiation) into vacuum. Reduction of the soft x-ray fluence by increasing the plasma-sample distance and locating the target at the laser beam focus, results in a dramatic decrease of ablation efficiency. The localization of samples at different distances from the x-ray source made it possible to investigate the x-ray dose and dose rate effects on ablation processes under constant spectral properties of the x-ray source. Comparing this result of ablation depth profiles we can measure the space dependence of X ray intensity with respect to the assumed r^{-2} decrease in the intensity far away from the plasma.

References:

- [1] L. JUHA: *Materials ablation with soft x-rays*, Čs. čas. fyz. 50, 2000, pp. 110-118.
- [2] J. JUHA, J. KRÁSA, A. PRÄG, A. CEJNAROVÁ, D. CHVOSTOVÁ, J. KRAVÁRIK, P. KUBEŠ, YU. L. BAKSHAEV, A. S. CHERNENKO, V. D. KOROLEV, V. I. TUMANOV, M. I. IVANOV, M. SCHOLZ, L. RYČ, K. TOMASZEWSKI, R. VISKUP, F. P. BOODY, J. KODYMOVÁ: *Ablation of PMMA, PTFE and Si by single pulse of soft X-Rays emitted from hot dense plasmas*, High-Power Laser Ablation IV, Claude R. Phipps, Editor, Proceedings of SPIE Vol. 4760, 2002, pp. 1098-1105.
- [3] J. JUHA, A. PRÄG, J. KRÁSA, A. CEJNAROVÁ, B. KRALIKOVA, J. SKÁLA, D. CHVOSTOVÁ, V. VORLÍČEK, J. KRZYWINSKI, A. ANDREJCZUK, M. JUREK, D. KLINGER, R. SOBIERAJSKI, H. FIEDOROWICZ, A. BARTNIK, L. PÍNA, J. KRAVÁRIK, P. KUBEŠ, YU. L. BAKSHAEV, A. S. CHERNENKO, V. D. KOROLEV, M. I. IVANOV, M. SCHOLZ, L. RYČ, K. TOMASZEWSKI, R. VISKUP, F. P. BOODY: *Ablation of Organic Polymers and Elemental Solids Induced by Intense XUV Radiation*, X-Ray Lasers 2002, 8th International Conference on X-Ray Lasers, American Institute of Physics, 2002, pp. 504-509.