Femtosecond laser ablation: simulations and X-ray imaging

N. Inogamov[1,2,*], V. Zhakhovsky[2], Yu. Petrov[1], V. Khokhlov[1], D. Ilnitsky[2], M. Nishikino[3], N. Hasegawa[3], M. Ishino[3], A. Faenov[4,5], T. Pikuz[3,4], T. Kawachi[3]

[1]*Landau Institute for Theoretical Physics, Russian Academy of Sciences, Chernogolovka, Russia*
[2]*Dukhov All-Russia Research Institute of Automatics, Rosatom, Moscow, Russia*
[3]*Quantum Beam Science Center, Japan Atomic Energy Agency, Kizugawa, Kyoto, Japan*
[4]*Joint Institute for High Temperatures, Russian Academy of Sciences, Moscow, Russia*
[5]*Institute for Academic Initiatives, Osaka University, Suita, Osaka, Japan*

**E-mail: nailinogamov@gmail.com*

Abstracts: *The report presents results of a set of simulations done to understand recent ultrafast pump-probe observations with optical pump and soft X-ray probe. The main feature of thermomechanical ablation is the kick-off of a spallation shell as a result of condensed matter – vapor phase transformation in a stretched warm dense matter with nucleation of voids and formation of a cavity between the spallation shell and the remnant of a target. We employ a combination of physical models and simulation approaches to describe the early stages of an ablation process and to compare with experimental data.*

Picosecond soft (photon energy 90 eV) X-ray laser made in KPSI is a peculiar tool for ultrafast diagnostics of ablation processes. It is employed in a pump-probe scheme of measurements with a femtosecond Ti:sapp optical laser as a pump. The pump sends ultrashort moderate fluence pulse on to a gold target. Soft X-ray laser with pulse duration 7 ps and wavelength 13.9 nm synchronized with the pump is used as a stroboscopic probe. A sequence of the probe flashes follows real time evolution of an irradiated spot on surface of a target.

Femtosecond optical pump excites an electron subsystem in a skin layer. During excitation the matter does not have time to expand according to temperature achieved because rate of heating is higher than sound speed. Warm dense matter expands later. Thanks to finite expansion velocities and inertia the substance expands over an equilibrium volume corresponding to temperature achieved. Thus stretching and tensile stress appear. Above a certain limit the stress causes nucleation of voids and spallation of a layer inside the irradiated spot. Thus formation of a cavity under spallation layer begins. The cavity locates between the spallation layer and the remnant of a target. Wavelength 13.9 nm of the X-ray probe is much shorter than the optical wavelengths previously used for probing of such spatial structures. Smallness of the soft X-ray wavelength allows us to follow the early stage of evolution of the shell because the short wavelength begins to resonate inside the cavity when the cavity is thin (geometrically cavity has a form of a thin undersurface disk).

Models and simulation approaches are developed in our work. The goal is to extract valuable data from experimental measurements. A scheme to calculate a two-dimensional X-ray snapshot image of an ablation area is created. Results of simulations are compared with the experimental images. A hydrodynamic code including full two-temperature physics is written. The two-temperature effects are especially important at the early stages. Molecular dynamics code is used to estimate electron pressure and to simulate nucleation in stretched matter.

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