Characterization of ion plumes generated by laser-driven intense extreme ultraviolet (EUV) light

R. Deguchi[1], N. Tanaka[1], N. Wada[1], A. Sunahara[2], M. Murakami[1], A. Yogo[1], and H. Nishimura[1]

[1]*Institute of Laser Engineering, Osaka University, Suita, 565-0871, Japan*
[2] *Institute for Laser technology, Suita, 565-0871, Japan*
**E-mail: deguchi-r@ile.osaka-u.ac.jp*

Abstracts: Material ablation caused by a laser-driven, intense extreme ultraviolet (EUV) light pulse was studied in comparison with that caused directly by laser under the same irradiance and time-duration. Ionic states and expansion energy of ablation material were measured with an ion analyzer. Ions of single ionization state were observed for the EUV ablation whereas those of multiple ionization states were for the laser ablation. The experimental results were compared with simulations made with a radiation hydrodynamic code to infer difference in density and temperature of energy deposition.

Extreme ultraviolet (EUV) light source has attracted much attention in material processing, e.g. surface modification[1] or nano-scale machining.[2] The physics of EUV material ablation followed by plasma formation are expected to be quite different from that of conventional laser ablation. It is thought that EUV light can penetrate though an expanding low-density plasma and directly deposit its energy into a dense region at the ablation front via photoionization or collision with electrons generated by the ionization because of its high photon energy ($h\nu$~100 eV) and high critical density beyond solid density (~10^{24} cm^{-3}).[3] However mechanism of material heating and plasma characteristics is not fully understood. Thus, this study aims, first at characterization of the material ablation induced by intense EUV light, and second clarifying difference of EUV ablation behavior from that with laser in order to deepen understanding the underlying physics in material heating and plasma formation.

An EUV pulse (9-25 nm in wavelength, 10 ns in duration, and 10 Hz repetition rate) emitted from laser-generated Xe plasma was focused onto the surface of a silicon plate by a total-reflection toroidal mirror overcoated with Au. EUV energy per pulse was 13 mJ, spot size was ~ϕ200 μm, and intensity on the plate was ~4×10^9 W/cm^2. We measured ionic states and energy distributions of corresponding ions expanding from the plasma with a Thomson Parabola mass-charge analyzer. In the analyzer, magnetic and electric fields are applied perpendicular to ion trajectory. We conducted identical experiment with a Nd:YAG laser at the same irradiation parameters for comparison.

Only singly charged ions were detected in the EUV ablation whereas multiple states ranging from Z=1 to 3 were detected in the laser ablation. Plasma parameters such as pressure, temperature, density, and average charge state of ion were calculated by Star1D code [4]. Comparison of the experiments with simulations showed that electron temperature of energy deposition region tends to be lower for the EUV ablation, resulting in singly charged ions.

[1] A. Bartnik et. al, Nuclear Instruments and Methods in physics Research A 647(2011)125-131

[2] T. Makimura et. al, Journal of Physics Conference Series, **59**, 279 (2007)

[3] N. Tanaka et. al, Applied Physics Letters 107, 114101(2015)

[4] A. Sunahara and K. A. Tanaka, Fusion Engineering and Design, **85**, 935 (2010).