21pF-4

Material ablation by focused laser-driven EUV radiation and its applications.
レーザー駆動集光EUV光による物質アブレーションとその応用

Nozomi Tanaka, Masaya Masuda, Ryo Debuchi, Atsushi Sunahara, Masakatsu Murakami, Akifumi Yogo, Shinsuke Fujioka, and Hiroaki Nishimura
田中のぞみ, 増田将也, 出口 亮, 砂原 淳, 村上匡且, 余語覚文, 藤岡慎介, 西村博明

Institute of Laser Engineering, Osaka University, Yamadaoka 2-6, Suita, Osaka 565-0871, Japan
大阪大学レーザーエネルギー学研究センター 〒565-0871 大阪府吹田市山田丘2-6
Institute for Laser Technology, Yamadaoka 2-6, Suita, Osaka 565-0871, Japan
レーザー技術総合研究所 〒565-0871 大阪府吹田市山田丘2-6

Ion expansion from material ablation by focused EUV was studied and compared with that of laser ablation. Noticeable difference was observed in the expanding ion spectra. EUV ablation showed narrower angular distribution of expanding ions compared to laser ablation. The ion kinetic energy spectra of EUV ablation followed exponential decay with high-energy tail, and that of laser ablation showed sharp cut off at low energy with convex shaped energy spectrum. It was assumed that the ions from EUV ablation expands straightforward with one-dimensional planar geometry from high pressure plasma, and those from laser ablation expands with spherical geometry.

1. Introduction

Recently extreme ultraviolet (EUV) light sources have been widely developed and its application usage attracts much attention. One of the possible applications is material ablation by focused EUV [1, 2]. However, the details of EUV ablation, such as heating mechanism, plasma formation, and plasma expansion are not well known yet. An effective approach to investigate the properties of EUV ablation is comparison of ablation characteristics with that of laser ablation.

It is expected that the wavelength difference between EUV and infrared laser result in critical difference in heating and plasma formation mechanism. One hand, the critical density of laser ablation is one or two orders below solid density and the material heating is dominated by thermal conduction of electrons energized by inverse bremsstrahlung absorption of laser energy. On the other hand, the critical density of EUV ablation is beyond solid density and the photon energy is close to ~100 eV. These EUV properties would allow the radiation penetrates through the plasma and resonant excitation of orbital electrons.

In this study, we have studied the plasma formation and its expansion into vacuum. The expanding ions were measured by a charge collector array. The results were compared with laser ablation. Further, simulation study of material ablation was performed using a one dimension Lagrangian radiation hydrodynamic code, Star-1D [3], and theoretical expansion model including geometry of expansion [4] was also used for discussion.

2. Experimental

The laser produced plasma EUV source is described in Fig. 1. A Nd: YAG laser with a wavelength of 1064 nm is focused onto a solid Xe drum target. The Xe cryogenic drum target is cooled by liquid nitrogen inside a rotating cupper drum, so that Xe flowing along the Cu surface is solidified and fresh surface is always supplied. Similar drum target is described in reference [5]. The EUV light emitted from the Xe surface is collected by a toroidal elliptical total reflection mirror with a gold-coated surface, and focused onto a sample. The focused EUV intensity was ~5 x 10^9 W/cm^2, the spot size was ~150 μm, and pulse width was ~10 ns. For the comparison, laser ablation was also studied with the same intensity, spot size, and pulse width by focusing a Nd: YAG laser onto the sample.

Time-of-flight (TOF) spectrum of ions expanding

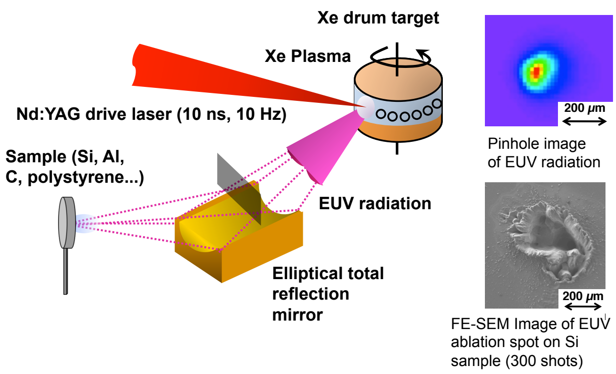

Fig. 1 The EUV source consists with a cryogenic Xe drum target and focus mirror. Pinhole image of the EUV emission on the Xe surface and ablation spot on the sample are also shown.

from the ablation plasma was measured by a charge collector array. Four charge collectors were located at 0 (target normal), 15, 30 and 45 degrees. The TOF spectra were converted to kinetic energy spectra.

3. Results and discussion

The energy spectra of expanding ions of EUV and laser ablations are shown in Fig. 2. Noticeable difference between two spectra was observed. One hand, the expanding ions from EUV ablation include high-energy component and the energy spectra follows exponential curve. The other hand, the energy spectra from laser ablation showed a concave curve and drastic decrease around 100 eV. The spectra were fitted to an ion expansion model including geometries [4]. It was expected that ion expansion of EUV ablation has one-dimensional planar geometry and that of laser ablation has one-dimensional spherical geometry. Further, simulation of EUV ablation by Star-1D code [3] showed compressed plasma about 20 μm behind the original surface position with high electron density and pressure. This might have caused avalanche-like particle expansion into the vacuum resulting in the high-energy tail in the EUV energy spectrum, and straightforward one-dimensional ion expansion along the target normal direction.

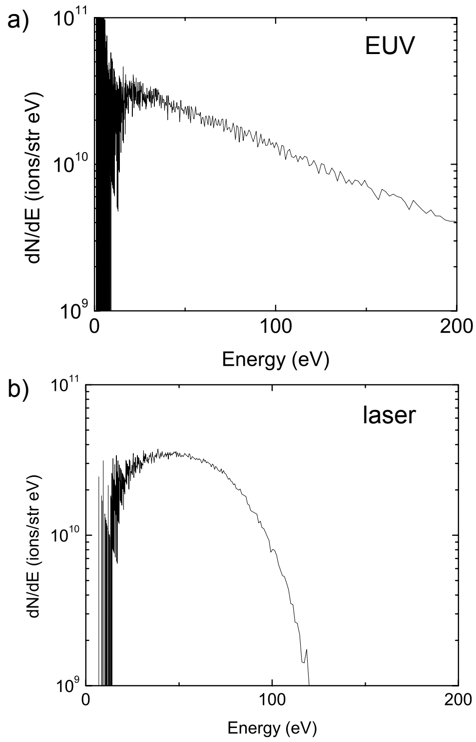

Fig. 2 Kinetic energy spectra of expanding ions. a) EUV ablation, and b) laser ablation. The spectra were measured at the target normal (0 degree).

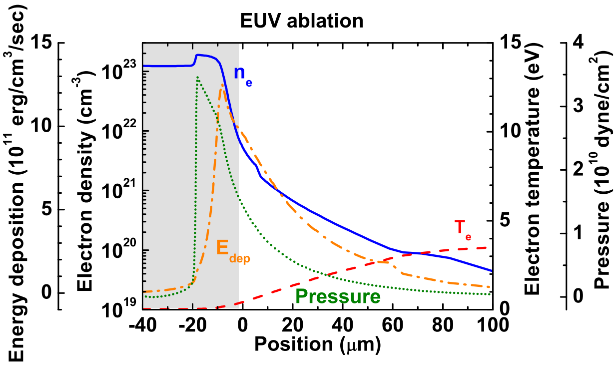

Fig.3. Plasma parameters of EUV ablation calculated by the Star-1D code. Hatched area is original material position.

4. Summary

Material ablation by focused EUV and laser were studied and the ablation characteristics were compared. Noticeable difference in ion energy spectra was observed. It was shown that EUV ablation plasma expands much more straightforward than laser ablation plasma. The geometry of EUV and laser expansion are expected to be one-dimensional planar and sphere by fitting the energy spectra. From the simulation results of EUV ablation, it was assumed that compressed plasma is formed and it expands into the vacuum one-dimensionally.

Acknowledgments

This work was supported by JSPS Grant-in-Aid for Young Scientists (B) number 25800303, Grant-in-Aid for Scientific Research (B) number 22340172, and MEXT Project for Creation of Research Platforms and Sharing of Advanced Research Infrastructure ”Opening up a new photonics industry through high-intensity lasers.

References

[1] T. Makimura, H. Miyamoto et. al, J. Phys. Conf. Ser. **59** 279 (2007)
[2] H. Bravo, B. T. Szapiro et. al, IEEE J. selected topics in quantum electronics. **18** 443 (2012)
[3] A. Sunahara and K. A. Tanaka Fusion Engineering and Design **85** 935 (2010)
[4] M. Murakami, Y.–G. Kang et. al, Phys. Plasmas **12** 062706 (2005)
[5] S. Amano, A. Nagano, T. Inoue, S. Miyamoto, and T. Mochizuki, Rev.Laser Eng. **36**, 715 (2008)