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Observation of femtosecond laser ablation on Tungsten by using soft x-ray laser

軟X線レーザープローブによるタングステン表面のフェムト秒レーザーアブレーション過程の観測

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Femtosecond laser ablation processes on gold and tungsten were observed by the single shot pump and probe imaging using a soft x-ray laser probe. A clear difference was found in the temporal behavior of the dynamical response of the soft x-ray reflectivity depending on the irradiated laser fluence in two materials. The duration of the femtosecond laser ablation of the tungsten case is shorter than the gold case and the narrow dark rings were found in the tungsten case. Our result gives the experimental data lead to better understanding of the initial process of the laser ablation dynamics.

1. Introduction

Femtosecond laser ablation, leading to drilling, pattern formation, and surface modification is one kind of the non-repetitive and non-reversible phenomena[1-3]. Although these phenomena are often observed after multiple laser pulse irradiation, it is supposed that the essential material alteration process occurs on single shot base. For example, the pattern formation, such as ripples, is often observed on the several hundreds of nanometer scale, while the fundamental process of the femtosecond laser ablation is suggested to be initiated through the nanometer scaled structure formation, such as nano-bubbles. This means that single-shot observation with the sufficient temporal and spatial resolutions is necessary for a better understanding of the femtosecond laser ablation process. In order to observe the surface morphological change during the fs laser ablation process, we have developed soft XRL reflectmeter and interferometer system and reported the surface morphology of the fs laser ablated metal surface over a long period of time of several hundreds of ps after laser irradiation[4-6]. In this proceeding, we report a pump and probe reflectivity imaging of the tungsten (W) surface during the femtosecond laser ablation by using the laser-driven soft x-ray laser as a probe beam. We found the temporal evolution of reflectivity strongly depends on the fluence of the femtosecond laser as a pump beam and the quality of material.

2. Experiment

The laser-driven plasma soft x-ray laser (SXRL) in Japan Atomic Energy Agency was used for the probe beam. The pulse width of the SXRL beam at the wavelength of 13.9 nm (89.2 eV) is 7 ps (FWHM) and the output energy of the XRL beam is about 200 nJ/pulse. A schematic view of the experimental setup of the femtosecond laser pump and the soft x-ray probe microscopy is shown in Fig.1. The sample was W or gold (Au) thin film with 100 nm thickness evaporated on fused silica substrates. The initial surface roughness of root mean square was measured by atomic force microscope (AFM) and found to be below 1.0 nm. The refractivity is estimated about 20-30 % at 13.9 nm for each material. The sample image was transferred onto the CCD camera by the imaging mirror with a magnification factor of 40. The pumping laser used for ablating materials was a Ti:Sapphire laser. The laser emitted 80 fs pulses of linearly polarized light at a central wavelength of 795 nm. The emitted pulses were focused by a lens (f = 600 mm) onto the sample surface at nearly normal incidence. The focal spot size ($1/e$) on the sample surface was measured to be about 73 μm. The typical peak fluence and excitation intensity on the sample surface were 1.4 J/cm^2, and 2 x 10^{13} W/cm^2.

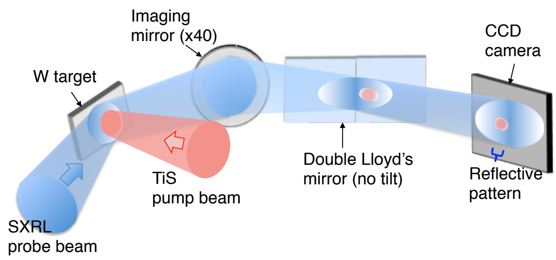

Fig.1. Experimental setup of reflective imaging

Figures 2 shows the soft x-ray reflective images of the W surface at the delay time t after the irradiation from 19 to 258 ps. The scale-bar corresponds to 50 μm for all images, and the contrast was optimized for each image in Fig. 2. The diameter of disk-shaped dark area gradually increases and reaches to maximum values at 260 ps. The diameter of disk-shaped area at t = 260 ps coincides with that at $t = +\infty$. In the W case, the duration of the observed reflectivity change is similar to that on Platinum (Pt) case[5]. The difference of delay time of the reflectivity indicates that the observed phenomena are strongly fluence dependent. It is worth noting that the width of the dark ring at t = 41 ps, indicated by red arrow, is very narrow compared to that on Pt. On the other hand, the elliptic shadow was observed from 100 ns to 200 ns. The elliptic shadow was caused by the transmission through the dome structure exfoliated from the sample surface. We derived the form and expansion of exfoliated thin film by using soft x-ray shadowgraph. The time evolution of the height and expansion speed of the thin film are evaluated from the edge of the elliptic shadow.

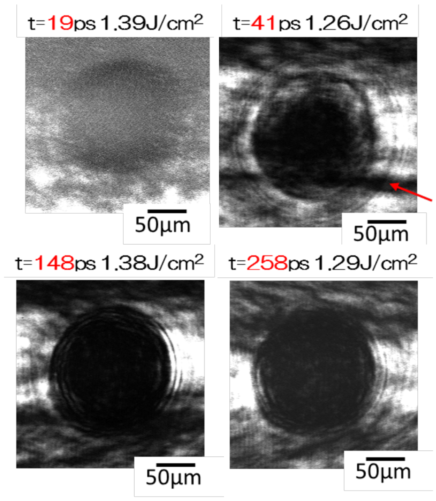

Fig.2. X-ray reflective image in early time

3. Summary

In conclusion, the Ti:Sapphire laser pump and the soft x-ray laser probe imaging was carried out for the observation of femtosecond laser ablation dynamics on the W film. The reflectivity and image of the x-ray are seemed to be caused by the structure change, such as surface roughness and evaporation of sample on the ablation front. By using the Gaussian profiled beam, the fluence dependence of laser-induced phase transition process was deduced. Regardless the continuous intensity profile of the pump beam, the dynamical behavior of soft x-ray reflectivity showed discontinuous irradiation fluence dependence. The further comparison between experimental results and the numerical calculation is needed for the better understanding of the femtosecond laser ablation process.

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