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Development of laser-produced Au plasma for water window x-ray radiation sources

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Soft X-ray sources developed by laser produced plasma (LPP) are highly anticipated for their potential use in diagnostic and manufacturing nano-devices [1]. In particular, soft X-rays in the so-called water-window (WW) region (2.3-4.4 nm) produces characteristic features for biological diagnostics, as the K absorption edges for *C* (4.4 nm), *N* (3 nm) and *O* (2.3 nm) lie in this wavelength range, exhibiting high transmission contrasts between these elements, which are the main constituents of living organisms. Consequently, it is utilized as WW X-ray microscopy for biological diagnostic in many circumstances. Because it not only allows imaging of relatively thick living organ samples without sample pretreatments (such as dehydration and sectioning), observing organelles in the cytoplasm with high contrast also becomes achievable.

The imaging resolution and quality for WW X-ray microscopy are highly limited by the WW photon fluence reaching to the sample surface. However, only large facilities like free electron laser or synchrotron radiation can produce output over 10^{14} photons/ (sr · s · μm^2 · 0.1% Band width) for a high-quality imaging [2]. Since the widespread deployment of WW X-ray microscopy is hindered because of the associated costs and availability of the required devices, it is crucial to enhance the photon fluence produced by the table-top devices.

One of the methods is to use laser-produced Au plasma. Due to the n=4-4 and 4-5 transitions in the highly ionized Au ions attributed to Au^{20+} - Au^{30+}, X-ray emissions emitted from countless energy levels forms the unresolved transition array (UTA) with a peak wavelength lying in the WW region [2]. On the other hand, WW X-ray emission enhances when generating laser-produced Au ions in a low pressure N_2 gas atmosphere, benefiting from the KLL-Auger electrons emitted from *N* atom interact with the highly charged Au ions [3]. These make Au a suitable material for LPP scheme to develop a WW X-ray source.

To farther enhance the WW emission from the Au plasma, optimization of laser-target interactions and laser pulse features is then craved. An electron temperature of ~400 eV in the plasma is required to generate highly charged Au ions for WW emissions. However, since the laser ablation intensity is not linear associated with the X-ray emission area. In this work, we investigate the dependence of WW spectrum on laser pulse energy and laser ablation spot size. The dependence of WW emission on Au target thicknesses is also investigated to test different ablation processes and their plasma expansion behaviors. Simulation for laser ablation process is conducted by using STAR2D and FAC code.

The experiment setup is shown in Fig. 1. A seeder injected table-top Nd:YAG laser (1064 nm, 6.2 ns, 10 Hz, >10^{13} W/cm^2) was used in this work. The laser spot focused though a f = 10-mm lens onto the Au target is measured to have a minimum FWHM= 15 μm. Au foils and deposition targets with different thicknesses ranging from 300 nm to 0.1 nm were used for plasma generation. A grating incident spectrometer, a pinhole camera with Ti filters, a Si photodiode with integration circuit were installed to characterize the spatiotemporal plasma behavior.

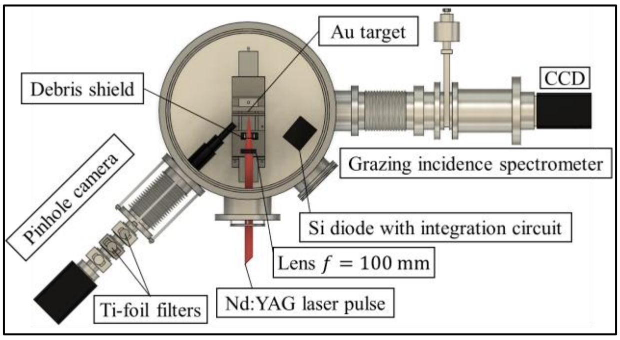

Fig. 1 Schematic of the experiment setup.

The results show a minimum Au target thickness of ~1 μm is obtained for a laser intensity of ~10^{13} W/cm^2 by observing the intensity drop in the WW spectra. Au targets produced by thermal evaporation are found to have a higher conversion efficiency than commercial foil targets for WW X-ray radiation. In addition, optimal laser spots for fixed laser energies (240 mJ and 650 mJ) are found for an Au target ~1 mm in front of the focal point, where suitable conditions for plasma temperature and plume volume coupling are achieved.

References

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