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Laser Plasma VUV~X-Ray Sources Using Solid Rare Gas Targets
固体希ガスによる連続発生レーザープラズマVUV〜X線源

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To generate continuously repetitive VUV ~ X-ray pulses from laser-produced plasmas, a translating substrate system with a cryostat that can continuously supply solid rare gas targets for 1~ 10 Hz laser pulses has been developed. The system successfully supplied solid Ar, Kr and Xe targets continuously, and stable output powers were achieved continuously from the plasma emissions. The X-ray powers were estimated to be 19 mW at 3.2 nm, 33 mW at 10.0 nm and 66 mW at 10.8 nm, with 10% bandwidths, from the Ar, Kr and Xe solid targets, respectively, with a laser power of 1 W.

1. Introduction

Laser plasma radiation from high density, high temperature plasma which is achieved by illuminating a target with high-peak-power laser irradiation, constitutes an attractive, high brightness point source for producing VUV to X-ray radiation. There have been many studies on application of laser plasma X-ray sources such as X-ray microscopes, EUV lithography and micro processing. To apply these studies in industry, a plasma source, which can generate continuous repetitive pulses, not a single shot, is required. Therefore, we have been studying it using a plasma target of solid rare gas [1]-[3]. The rare gas is considered to be an ideal deposition-free target because of an inert gas, and its chemically inactive debris will vaporize instantly, rather than be deposited on mirrors near the plasma. This is an advantage in a continuous operation. We had also decided to use a cryogenic solid target to provide higher conversion efficiency and higher brightness because of its higher solid density. Additionally, a smaller gas load for evacuation by the exhaust pump system was also expected in the solid state when compared with gas and liquid jets. To continuously supply the solid rare gas target, we originally developed a translating target system. Using this system, we succeeded in supplying Ar, Kr and Xe solid targets continuously and demonstrated continuous generation of laser plasma emission up to a repetition rate of 10Hz, produced by a commercial Nd:YAG Q-switched rod laser. In this paper, we report characteristics of the plasma emissions from the solid Ar, Kr and Xe plasma targets.

2. Experimental Setup

Figure 1 shows the experimental set-up of the laser plasma source, composed of a target supply system and a driving laser. The target system was installed in a vacuum chamber. A conventional Q-switched Nd:YAG rod laser (Spectra-Physics, PRO-230) was used as a driver and could deliver pulses at a wavelength of 1ω (1064 nm) with a pulse width of 10 ns. The maximum pulse energy and repetition rate are 1 J and 10 Hz, respectively. The pulses were expanded using a beam-expander, passed through the window and were focused perpendicularly on the target by a lens with a focal length of 500 mm, so that a plasma was produced and VUV ~ X-ray radiation was emitted. The generated X-ray pulses were monitored using an X-ray diode; XRD (IRD, SXUV-100 Mo/Si).

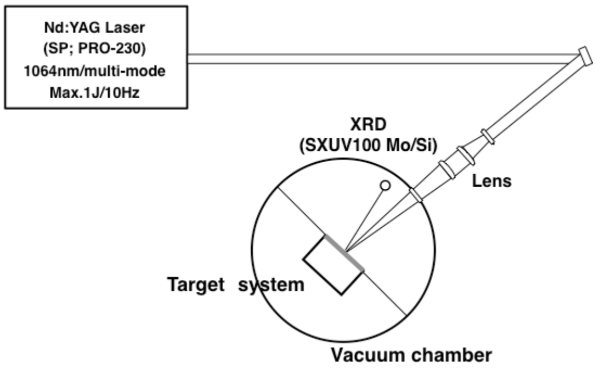

Fig.1. Experimental set-up (top view).

Figure 2 shows a side view of the developed target system [4]. A copper substrate was attached to the tip of a cryostat head with a He gas closed loop, thereby chilling the substrate surface. The lowest temperature at the substrate surface was measured to be 15 K. The target gas is blown on the surface and condensed to form a solid layer. The substrate that was coated with the solid target layer translates up and down, in only one dimension, so that a fresh target surface is supplied continuously for every laser shot. The translation speed is tunable in the 0–12 mm/s range over a translation range of 60 mm. Apart from the area around the laser focus point, a container wall and two wipers surround the substrate surface. The wipers adjust the solid layer thickness to 500 μm and to assist with recovering of the laser craters on the target. We found 500 μm to be a sufficient thickness to prevent a 1 J laser shot damaging the substrate surface. In this experiment, Ar, Kr and Xe were used as target gases.

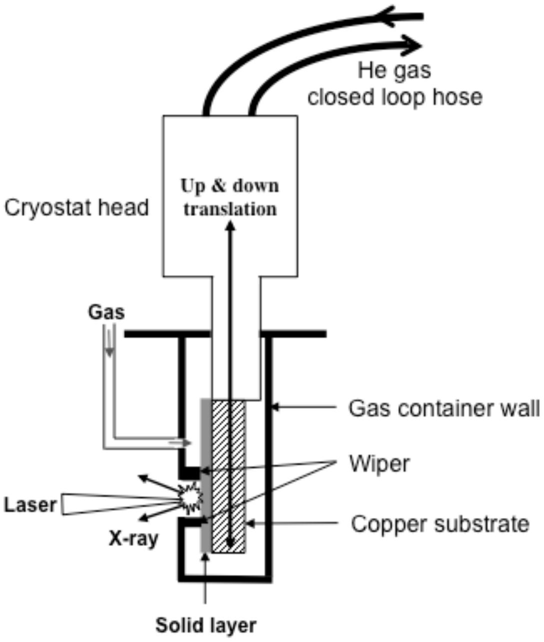

Fig.2. Illustration of the target system (side view).

3. Results & Discussion

To operate the laser plasma source continuously to generate repetitive pulses, we studied optimum parameters of a translation speed and a gas flow rate for a laser frequency. Under the optimum conditions, the source was tested. For example, the laser pulses with energies of 1 J at 1 Hz, or 0.1 J at 10 Hz, were focused on the Ar target surface. The results of the continuously generated repetitive X-ray pulses monitored using an XRD, are shown in Fig. 3. This shows stable output power without any influence from the turning of the target up and down, even for round trips of 9–10 times in both the 1 Hz and 10 Hz cases. This indicates that a freshly recovered target surface was supplied continuously for each laser shot, as designed; we therefore succeeded in the demonstration of the design rule. We also similarly achieved the generation of continuous repetitive X-ray pulses from the Kr and Xe targets, again corresponding to the design rule.

The observed spectral peaks for the Ar, Kr and Xe targets are at 3.2, 10.0 and 10.8 nm [5]. When the targets were irradiated with 1 J energy pulses at 1 Hz, the spatially integrated average powers with the 10% bandwidth were roughly estimated to be 19 mW at 3.2 nm, 33 mW at 10.0 nm and 66 mW at 10.8 nm, for the Ar, Kr and Xe solid targets, respectively.

The developed source continuously generates not only the X-ray pulses but also VUV. We are also studying characteristics in VUV emission. The laser plasma source emitting continuously in VUV~X-ray region will be useful for numerous applications, including soft X-ray microscopy, microprocessing, and surface modification.

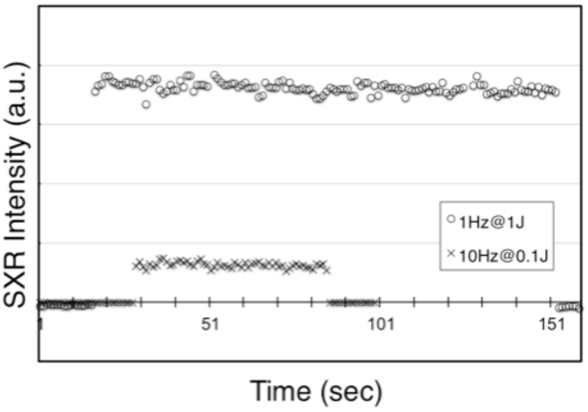

Fig.3. Soft X-ray intensity from the Ar target.

Acknowledgments

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