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Experimental investigation of laser-produced-plasma EUV source based on liquid target

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Abstract: A laser-produced plasma(LPP) source was built using liquid as target and a Nd:YAG laser as the irradiation laser, and the LPP source's radiation with ethanol and acetone target respectively was measured by an AXUV100 silicon photodiode combined with a McPHERSON model 247 grazing incidence monochromator of the resolution $\Delta\lambda \leqslant 0.075$ nm and the wavelength scanning interval 0.5 nm. Both ethanol and acetone target LPP source had EUV emission at 11～20 nm wavelength. The comparison between the spectra of the two kinds of target materials shows that all the two kinds of target source's spectra are the result of oxygen ions' transitions under current source's parameters, but the spectrum intensity from different target sources is different. The spectra intensity from the ethanol target is higher than that from the acetone target. In addition, the target liquid is forced into the vacuum chamber by the background pressure supported by the connected external high pressure gas, and the influence of the background pressure on the source's intensity is investigated.

Key words: laser-produced plasma; spectrum; spectral measurement; soft X-ray; EUV source; liquid target

1　Introduction

LPP sources hold great promise as bright sources of extreme-ultraviolet (EUV) and soft X-ray radiation for applications such as projection lithography[1-2], microscopy[3]. However, with LPP source, the applicability is restricted due to the emissions of debris, which may damage sensitive metrology components close to LPP source. To reduce the debris, methods concentrating on two aspects have been applied before the appearance of gas and liquid targets. One aspect is to reduce the amount of debris, the other is to interdict the debris from reaching the optics. In experiments, the metal targets with interdiction facilities cannot meet the need of actual applications. Thus the change of target design is putting forward, that can reduce or eliminate the debris fundamentally. There are the following types of sources until now: gas target, gas cluster target, cryogenic target and liquid target LPP source[4-11]. In this paper, we propose a LPP source with liquid target. It is a low-debris and high-efficiency soft X-ray source, which can be operated chronically and continuously. It has wide applications and good prospects in various fields. For ethanol and acetone are materials common, cheap and consisting of oxygen ions, they are chosen to be the source's target.

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2 Source structure and experiments

We developed a liquid target LPP source, and its schematic diagram and principle for work is shown in Fig. 1. The source comprises a temperature-controlled electromagnetic valve, a Q-switch Nd: YAG laser, a pulse signal-generator and a liquid collector. The laser is a Q-switch Nd: YAG laser delivering 10 Hz of ~1 J ~7 ns long pulses at λ=1 064 nm. The beam is focused onto the liquid droplet with a lens, which is below the nozzle 10 mm away. An AXUV-100 photodiode (IRD company) is used to record the spectra combined with the monochrometer.

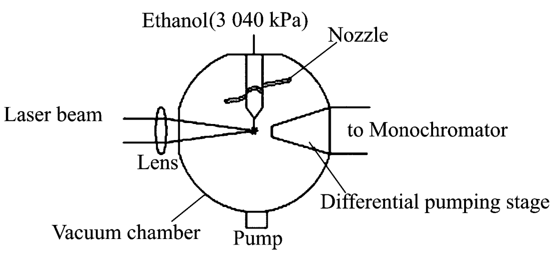

Fig. 1 Schematic diagram of the LPP source

There are two operation modes for this source: pulse mode and continuum mode. For the former, three pulses generated by the signal-generator trigger Xe-lamp of laser, Q-switch and electromagnetic valve respectively in terms of certain time sequence. The laser beam focuses on the liquid micro-droplet exactly, generating LPP, and emitting soft X-ray. For the latter, liquid is injected into the chamber continuously from the nozzle, forming LPP and emitting stronger soft X-ray.

The target material is reagent-grade liquid, being forced into the vacuum chamber by high pressure gas connected with the liquid tank. The high pressure is about 3 040 kPa. The vacuum chamber is pumped by turbo-molecular pump. Besides, to keep the main chamber pressure of the monochromator, a differential stage is used.

The spectrum measurement system is composed of a monochromator, a detector and the amplification circuit, shown in Fig. 2.

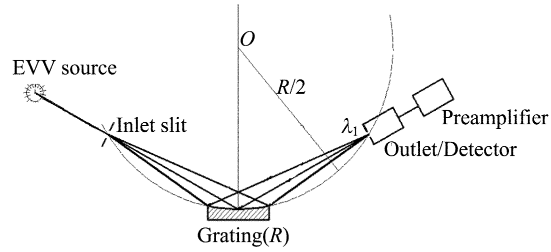

Fig. 2 Experimental setup

The monochromator is the grazing incidence monochromator, with a 600 lp/mm blazed grating. For the grating, the spectrum resolution is 0.015 nm when the incidence angle is 88° and the slit width is 10 μm. The scanning slit together with the detector moves along the Rowland circle when the wavelength scans.

Spectra were recorded by an AXUV 100 silicon photodiode. Because of the weak signal, a charge sensitive preamplifier is used to amplify the output signal from the diode. A data acquisition card (NI-DAQ6023E) transfers the analog signals into digital signals and a VI program based on NI-labview processed the data and saved them in a PC computer.

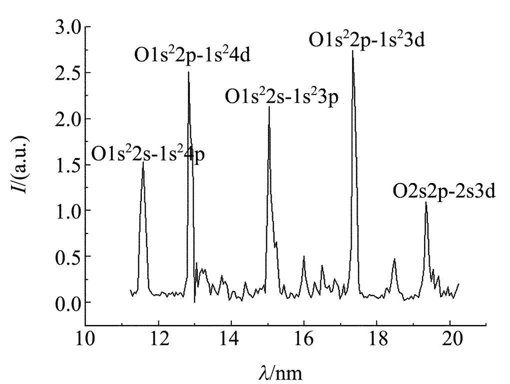

Fig. 3 EUV emission spectra obtained from ethanol target LPP source

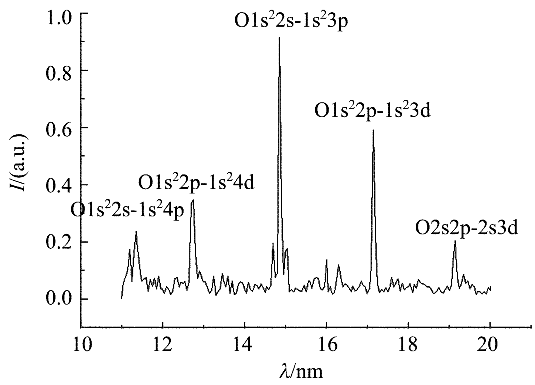

Fig. 4 EUV emission spectra obtained from acetone target LPP source

3 Results and discussion

In the experiment, the laser pulse's peak intensity is 8×10^{11} W/cm^2. Ethanol and acetone were used as target respectively and the spectra at 11～20 nm were recorded. Fig. 3 and Fig. 4 show the spectra obtained from the two kinds of target LPP source. They show that there exist five strong line emissions in the 11～20 nm region. According to spectrum calculation by COWAN program[12], these lines are all generated from electronic transitions in oxygen ions. They are transitions of $1s^22s$-$1s^24p$ (11.58 nm), $1s^22p$-$1s^24d$ (12.98 nm), $1s^22s$-$1s^23p$ (15.01 nm), $1s^22p$-$1s^23d$ (17.30 nm) and 2s2p-2s3d (19.37 nm), respectively.

Though the intensity is not the absolute value, it demonstrates that the spectra from the ethanol target are higher than those from the acetone target since the spectra were recorded at the same conditions. Because the ratio of oxygen in ethanol is higher than in acetone, so under the same conditions one laser pulse can interact with more oxygen ions in ethanol than in acetone.

In the process of the experiment it was found that the pressure forcing the liquid into the vacuum chamber has an important influence on the spectrum intensity. So at a certain wavelength, we measured the intensity while changing the pressure. Figure 5 shows the result.

It can be seen that below 2020 kPa, the spectrum intensity is weak because liquid injected into the chamber is little. From 2020 kPa to 3 040 kPa, with the pressure increases, the intensity increases for the liquid interacting with the laser pulse increases. While above the 3 040 kPa, this kind of trend disappears, which shows that 3 040 kPa maybe the suitable background pressure for the current nozzle orifice.

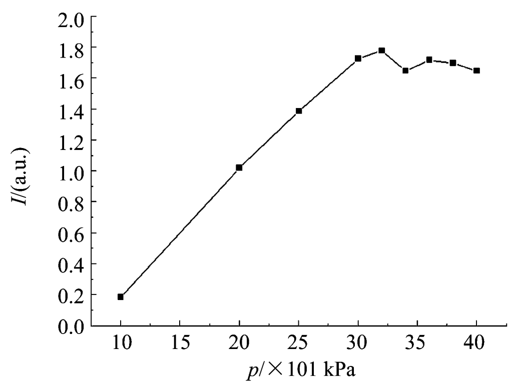

Fig. 5 Gas pressure influence on spectrum

4 Conclusion

The LPP EUV source with liquid target can be used as a high brightness source for soft X-ray and EUV generation. It is debris free and suitable for more kinds of liquid target. In the future, work can be done focusing on how to improve the laser's in tensity at the focus point, how to improve the source's stability and how to improve the conversion effieciency from laser to EUV. This source is now working in State Key Lab of Applied Optics on a daily basis.

References:

[1] SILFVAST W T, RICHARDSON M C, BENDER H, *et al*. Laser-produced plasmas for soft X-ray projection lithography[J]. *J. Vac. Sci. Technol*, 1992, B10: 3126-3133.

[2] KAUFFMAN R L, PHILLION D W, SPITZER R C. X-ray production 13 nm from laser-produced plasma for projection X-ray lithography application[J]. *Appl. Opt.*, 1993, 32: 6897-6900.

[3] MICHETTE A G. X-ray microscopy[J]. *Rep. Prog. Phys.*, 1988, 51: 1525-1604.

[4] FLORA F, MEZI L, BOLLANTI S, BONFIGLI F, LAZZARO P, LETARDI T, ZHENG CH. Krypton as filter ions, debris useless radiation in EUV projection lithography system[J]. *SPIE*, 2001, 4504: 77-86.

[5] BARTNIK F H, ZBIGNIEW A P. X-ray generation from Nd laser-irradiated gas puff target[J]. *SPIE*, 1993, 2015: 57-62.

[6] KUBIAK G D, BERNARDEZ L J, KRENZ K. Scale-up of a cluster jet laser plasma source for extreme ultraviolet lithography[J]. *SPIE*, 1999, 3676: 669-678.

[7] KUBIAK G D, KRENZ K D, BERGER K W. Cryogenic pellet laser plasma source targets[C]. *OSA Proceedings*, 1995, 21: 248-254.

[8] HANSSON B A M, RYMELL L, BERGLUND M, *et al*. Liquid-xenon-jet laser-plsma source for EUV lithography[J]. *SPIE*, 2001, 4566: 1-8.

[9] LIN J Q, YASHIRO H, AOTA T, *et al*. EUV generation using water droplet target[J]. *SPIE*, 2004, 5374: 906-911.

[10] RICHARDSON M, KODAY C S, TAKENOSHITA K, *et al*. High conversion efficiency mass-limited Sn-based laser plasma source for extreme ultraviolet lithography[J]. *J. Vac. Sci. Technol. B*, 2004, 22(2): 785-790.

[11] JASSON P A C, HASSON B A M, HEMBERG O, *et al*. Liquid-tin-jet laser-plasma extreme ultraviolet generation[J]. *Applied Physics Letters*, 2004, 84(13): 2256-2258.

[12] NI Q L. *Study on laser-produced plasma soft X-ray source with liquid aerosol spray target* [D]. Ph. D. Thesis, Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, 2003. (in Chinese)

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