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Development of Debris-free Laser Plasma Sources for EUV Lithography in CIOMP

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Abstract: We have been developing debris-free laser plasma sources for EUV lithography since 1996. Two types of debris-free sources, such as cryogenic target and gas-puff target laser plasma sources, were designed and built up in CIOMP. EUV radiation spectra of the sources with a variety of targets have been obtained by different ways.

Key words: EUV lithography; laser plasma; debris-free; cryogenic target; gas-puff target
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1 Introduction

Laser-produced plasma (LPP) is an attractive tabletop EUV source for application in EUV lithography due to its small size, high peak power and spatial stability. However, the conventional LPP source with metal target has a serious disadvantage of ejecting high-temperature and high-speed debris, which may damage the sensitive EUV optics close to the plasma source. LPP source is believed to be one of the most suitable light sources for the EUV lithography, if the side effect of debris can be eliminated. So far several methods such as liquid-droplet target[1-5], cryogenic target[6,7] and gas-puff target[8-10] have been tried to eliminate the side effect of the debris in the past few years. In this paper, we present some experimental results of cryogenic CO_2 target LPP source and gas-puff target LPP source in CIOMP, respectively. The LPP sources based on both types of target produce no debris.

2 Experiment

2.1 Cryogenic CO_2 target LPP source

2.1.1 Target form

Liquid compound composed of low Z elements or inert gas are usually chosen as cryogenic target. In our experiment, solid state CO_2 is used as target material. Low temperature gas deposition technique is employed to capture CO_2 molecule and form a cryogenic target in vacuum environment. To do this, it is necessary to form a low temperature gas deposition surface in the vacuum chamber beforehand. If the temperature of the surface goes down to the critical temperature of CO_2 gas-solid phase change, the CO_2 molecule coming to the surface will be captured. Fig. 1 shows the schematic design of our cryogenic target chamber. In practical use, a cold finger with gas deposition surface is inserted into the chamber, and the temperature of the cold finger is kept low enough by liquid nitrogen located outside chamber to capture CO_2 molecule. CO_2 gas is continuously fed into the chamber through a target material transportation system. A tiny solid state CO_2 target can be formed on the tip of the gas deposition surface. A successive gas feeding can be realized by optimizing the

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gas supplement rate and gas pressure in the chamber. It's hard to keep an acceptable CO_2 pressure in our vacuum system both for slightly absorbing the EUV light and forming the solid state CO_2 target quickly. A special-design differential unit is employed to solve the problem, and the measured pressure is 10^{-1}Pa in the target chamber and 10^{-3} Pa in the optical system, respectively.

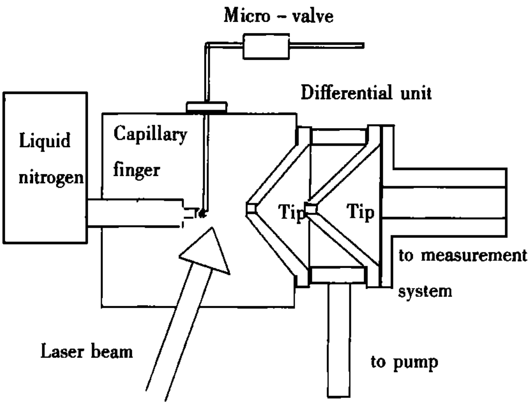

Fig. 1　Diagram of the laser plasma source

2.1.2 Spectrometer

Fig. 2 shows a self-made transmission grating spectrometer for measuring the spectral emission of the low debris cryogenic target plasma source.

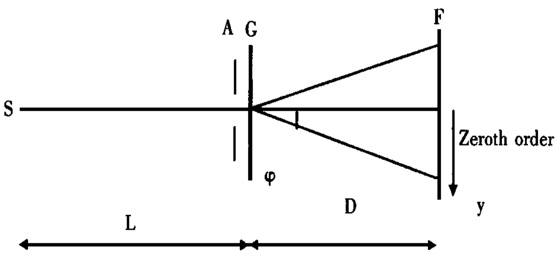

Fig. 2　Schematic diagram of the transmission grating spectrometer

Dispersion element G is a self-support transmission grating with 1000l/mm. The entrance aperture A is a 100μm slit located immediately in the front of the grating and aligned parallel to the grating lines. The size of plasma source S is about 100μm. The distances L from the EUV source to the grating and D from G to the recording film are 500mm and 450mm, respectively. Dispersion of EUV light by the grating is governed in the far field of Bragg relation.

$$d\sin\varphi = m\lambda (m = 1, 2, 3...) \qquad (1)$$

Where φ is the diffraction angle, d is the grating period, m is the diffraction order, and λ is the wavelength. According to equation (1), in small angle approximation, $\sin\varphi = y/D$ is obtained, where y is the distance from zeroth order. Linear dispersion of the EUV spectrum is $dy/d\lambda = D/d (m = 1)$. Spectral resolution $\Delta\lambda$ of the grating spectrometer is governed by several factors such as size of source, aperture of grating and diffraction limitation etc.. Diffraction $\Delta\lambda_d$ is equal to groove number. $\Delta\lambda_d = \lambda/M$ (M is groove number in use). Considering the size of EUV source and aperture of grating, $\Delta\lambda$ can be expressed as

$$\Delta\lambda = d(S + A)/L + dA/D \qquad (2)$$

In our case, the linear dispersion and spectral resolution are 0.45mm/nm and 0.6nm, respectively.

2.1.3 Results

A YAG laser system with 1J/5ns pulse duration and 1.06μm wavelength enters the target chamber through a quartz window and is focused by an aspherical lens to a spot of approximate 100μm in diameter. The peak power density at the focus is up to 10^{12}W/cm^2, which is high enough to produce EUV radiation in 8nm~14nm wavelength band. Fig. 3 shows a typical spectrum obtained from the laser plasma EUV source by means of the transmission grating spectrograph.

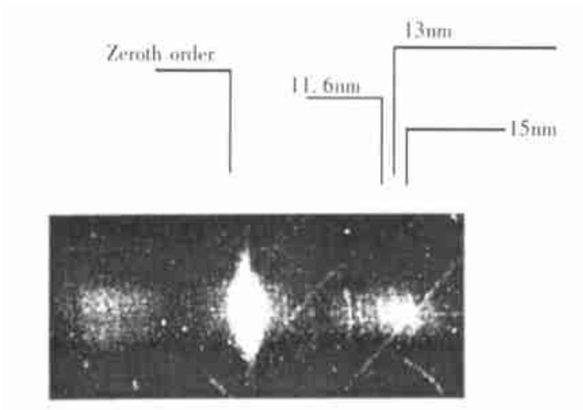

Fig. 3　Emission spectra obtained from a solid-state CO_2 target EUV source (power density is 10^{12} W/cm^2, λ= 1.06μm)

2.2 Gas- puff target LPP source

2.2.1 Gas- puff target light source

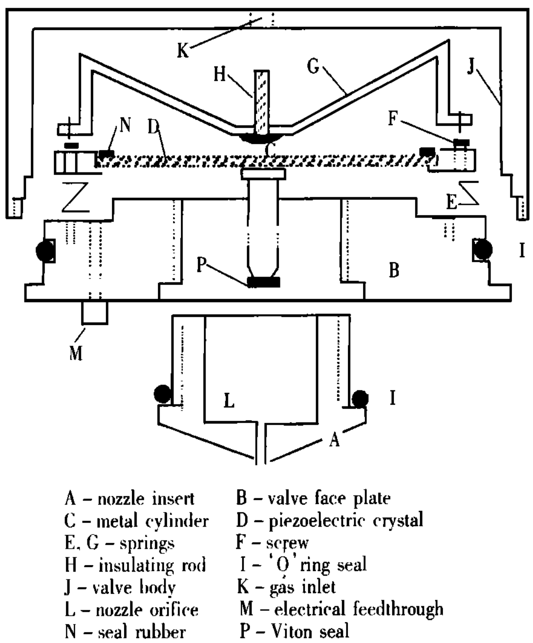

Fig. 4 Structural illustration of piezoelectric gas jet

Figure 4 shows a structural diagram of the gas - puff target valve. The main part of the gas- puff valve is a circular piezoelectric ceramic membrane, which is stuck on a circular copper sheet of 43mm in diameter. In application, piezoelectric ceramic membrane must be clamped on its copper sheet boundary. A small cylinder stuck on the piezoelectric ceramic membrane. And a piece of Viton seal is stuck on another end of the cylinder, which is used as a seal and cover of the nozzle of valve. When voltage isn' t applied across the piezoelectric crystal, it is in a state of stillness. When the voltage is applied between the center and the edge of the piezoelectric crystal, a downward force produced by the piezoelectric crystal drives the cover to stop the gas flowing out of the nozzle. When a high voltage pulse whose amplitude ranges from 150 V to 260 V is applied to the piezoelectric crystal membrane, the gas- puff target operates. As soon as the oscillation of the piezoelectric crystal is produced, a cluster of pulsed gas puffs up out of the nozzle of the target in supersonic expansion way. The diameter of the nozzle is 0. 5mm. Gas pulse duration is 150μs- 2ms. The oscillating amplitude of the piezoelectric crystal is proportional to the applied voltage. Operating frequency of the piezoelectric crystal is between 1Hz and 400Hz. The maximum background pressure that the piezoelectric crystal can tolerate is about 18 atm.

2.2.2 Experimental setup

An experimental setup for measuring EUV emission from plasmas produced by gas- puff target is shown in Figure 5. A plasma is created by focusing the laser beam from a commercial Nd: YAG laser (continuum 9000) with 10Hz repetition rate, 10ns pulse duration and 1J per pulse at $\lambda = 1.06\mu m$. Both the operation of the gas- puff target and the shot of Nd: YAG laser are controlled by the same voltage signal generator, which can make each pulse laser shot synchronously focus on gas pulse. Laser beam is focused on a spot around 1mm away from the nozzle of the gas- puff valve. The laser power density at focus is about 5×10^{11} W/ cm^2. In addition, spectra were measured by a monochromator with a 3- meter- diameter grazing incidence spherical grating of 600l/ mm and 50 cm length × 32 cm width. To block visible radiation, a thin foil filter of approximately 200nm aluminum is placed in front of the detector. The detector is a channeltron (Magnum 5900 CEM made in Burle Industries, Inc.) , and a charge- sensitive preamplifier is used for amplifying pulse signal from the channeltron.

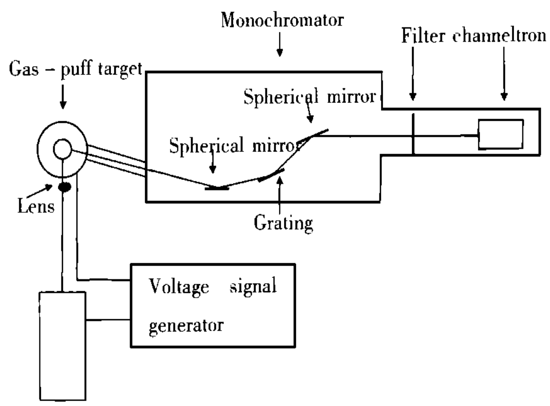

Fig.5 Experimental arrangement

2.2.3 Experimental results

We take measurement on emission spectra from CO_2, O_2 and Kr high-temperature plasma and make the EUV source with the gas-puff target in vacuum operating continuously for several hours. The source does not produce any debris.

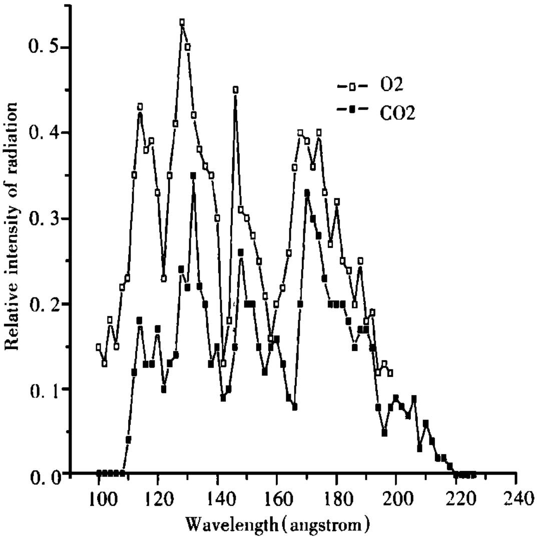

Fig.6 Emission spectra of CO_2, O_2

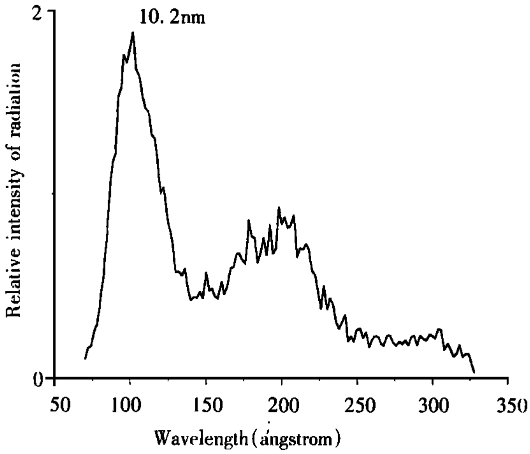

Fig. 7 Emission spectra of Kr

Figure 6 and Figure 7 show the emission spectra of CO_2, O_2 and Kr in EUV wavelength band. The background pressure in the gas-puff valve is 10 atm.. The spectra were measured under an identical condition.

3 Conclusion

Both the cryogenic CO_2 target LPP source and the gas-puff target LPP source can produce strong EUV radiation in the interesting wavelength range for EUV lithography. And the two kinds of LPP sources are debris-free.

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