Evaluation at the intermediate focus for EUV Light Source

Takashi Suganuma, Georg Soumagne, Masato Moriya, Tamotsu Abe,
Akira Sumitani, Akira Endo

Extreme Ultraviolet Lithography System Development Association (EUVA)
Research & Development Center, Hiratsuka
1200 Manda, Hiratsuka-shi, Kanagawa, 254-8567, Japan

ABSTRACT

We are developing a CO_2 laser driven Sn plasma light source for HVM EUVL. This source enables cost-effective high-conversion efficiency (CE >4%) and EUV power scaling. To evaluate light source characteristics we developed a metrology tool for the EUV and for the out of band (DUV, IR) wavelength region.

The EUV plasma light source emits radiation ranging from the EUV to the IR. To evaluate a particular wavelength region, spectral purity filters are used to select the region of interest. For the in-band EUV emission the power, the energy stability and the radiation profile are measured. The power is measured with an attenuating filter and a powermeter. The energy stability is measured with a filterd X-ray diode. The radiation profile is measured with a phosphor plate and a VIS-CCD camera. For the out of band emission, the radiated power is measured with an attenuating filter and a powermeter. The out of band region includes the CO_2 laser which is partly scattered by the plasma and reflected towards the IF and needs therefore to be included into the measurement.

Keywords: Extreme Ultraviolet Lithography, Laser Produced Plasma, Evaluation of EUV, Intermediate Focus

1. INTRODUCTION

Extreme ultraviolet lithography (EUVL) at 13.5 nm is a major candidate of next generation lithography (NGL) planned to manufacture IC devices below the 32 nm node. The required EUV output power of 115W for a high volume manufacturing (HVM) EUV lithography tool is very high in order to meet industry's required throughput of more than 100 wafer / hour. Table.1[1] lists the most critical requirements for a HVM EUVL source.

Table 1. Joint Requirements for EUV Light Source

Source Characteristics	Requirements
Wavelength [nm]	13.5 nm
EUV power [in-band]	115 – 180 W
Repetition Frequency	> 7 – 10 kHz (no upper limit)
Etendue of Source output	Max 3.3 mm^2 sr
Spectral purity	(compared with 13.5 nm in-band energy)
130 – 400 [nm] (DUV/UV)	< 1 % at wafer (design dependent)
> 400 [nm] (IR/VIS)	< 10 – 100 % at wafer (design dependent)

*t.suganuma@euva.or.jp; phone 81 463 35-8823; fax 81 463 35-9352; http://www.euva.or.jp

The etendue of the source output is given by the plasma size, i.e. in-band emission area, multiplied with the collection solid angle of the collector mirror and is an important parameter of the exposure tool. A smaller value is preferred for higher efficiency.

The spectral purity at 13.5nm at the IF is decided by the plasma emission and the reflectivity of the collector mirror. Except for 13.5nm (in-band), all out-of-band radiation results in thermal loading of the exposure tool. Therefore it is necessary to evaluate the out-of-band power, i.e. the ultraviolet, visible, infrared contributions at the IF point.

In this paper the characteristics of our high power EUV light source system and the evaluation of EUV power, energy stability, radiation profile and spectrum at the intermediate focus are described.

2. HIGH POWER EUV LIGHT SOURCE SYSTEM

2.1 System configuration

A schematic of the high power EUV system is show in Fig.1. Recent theoretical[2] and experimental[3] data demonstrate the advantage of the combination of a pulsed CO_2 laser with a Sn target to achieve a high conversion efficiency from laser pulse energy to EUV in-band energy. The EUV system included a high power CO_2 MOPA (Master Oscillator Power Amplifier) laser, a solid rotating Sn disk target and a collector mirror to evaluate the EUV output performance at the IF point, i.e. the second focus of the ellipsoidal mirror with the plasma being placed at the first focus.

The CO_2 laser beam was guided into the EUV generation chamber. The laser output power was about 6 kW at the entrance window of the chamber. The laser beam was focused onto a solid rotating Sn disk that was preliminary used as a target supply. The laser incidence angle to the normal of the disk surface was 45 degree. The EUV radiation was collected to the IF point by the ellipsoidal collector mirror. The EUV pulse energy, EUV in-band image and EUV spectrum were measured. The EUV in-band image size is an important parameter as a lithography light source regarding the etendue limit requirement.

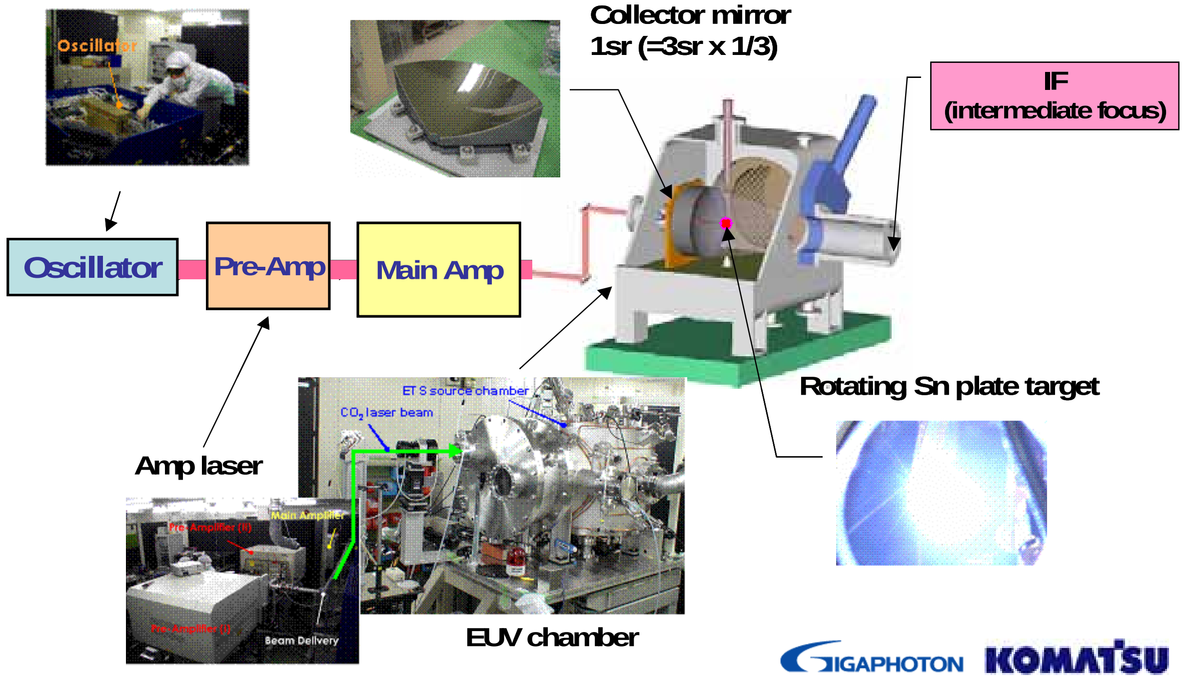


Fig.1 High power EUV system configuration

2.2 High power CO_2 laser

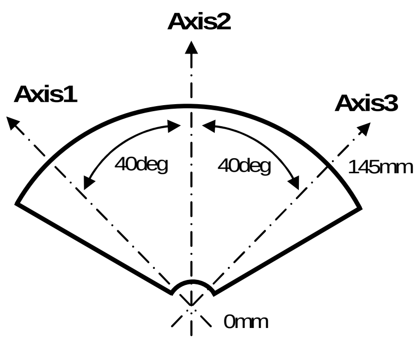
We developed a MOPA high power 6kW CO_2 laser. A CO_2 laser power of several kW with a pulse width of 15~30 ns is very difficult to realize with a single amplification stage. Therefore we developed a multi stage amplifier system. Fig. 1 shows the laser system configuration. The system consists of a short pulse high repetition rate oscillator and a multi stage amplifier.

A short pulse oscillator is the seeder for the amplifiers. The oscillator was a 15~30 ns, single P(20) line, RF pumped waveguide CO_2 laser with 60 W output at a repetition rate of 100 kHz.

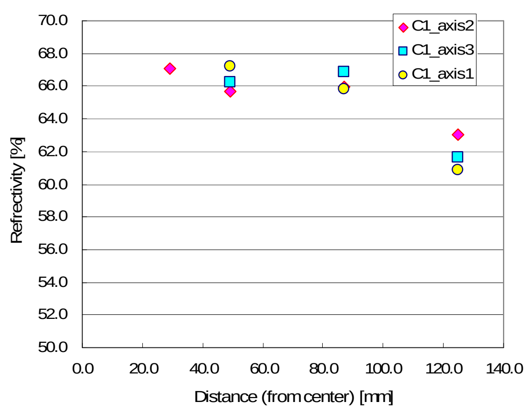
Commercial 5 kW and 15 kW CW CO_2 lasers were installed at our laboratory as amplifiers. Each unit is a 13.56 MHz RF-excited fast axial flow laser. Lasers were set-up as amplifiers by replacing all cavity mirrors with ZnSe windows.

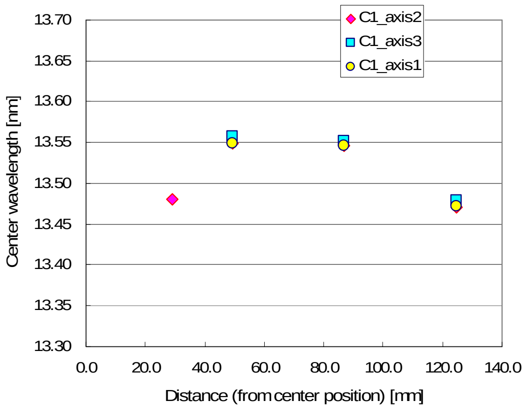
2.3 Collector mirror

A schematic of the EUV collector mirror is shown in Fig.1. The mirror is a 1/3 section of a full circular mirror. The mirror's optical surface is ellipsoidal and the magnification is 4.5. Radial and angular variations of the reflectivity and the center wavelength are shown in Fig. 2-b) and Fig. 2-c), respectively. The reflectivity is above 60 % and the center wavelength 13.5 nm±0.1 nm. We estimated the EUV power at the IF point using this reflectivity data and the collection solid angle and compared the obtained values with the measurements performed at IF.



a) mirror geometry and axis directions of mirror measurements





b) Mirror reflectivity c) Mirror center wavelength

Fig. 2: EUV mirror reflectivity and center wavelength; measured by PTB (Germany).

3. EVALUATION AT INTERMIDIATE FOCUS

3.1 EUV energy

Fig.3 shows the EUV energy measurement configuration at intermediate focus. This system consists of a ND filter and a EUV detector. The light collected by the C1 mirror is too intense and will damage the detector and the spectral purity filter. Therefore a ND filter was inserted between the C1 mirror and the detector. The detector (IRD, SXUV-100 based) is coated (Mo/Si/SiC) to select the EUV region only. The responsivity in the EUV region was calibrated by NIST and Fig.4 shows the responsivity of the detector between 10 nm to 16 nm.

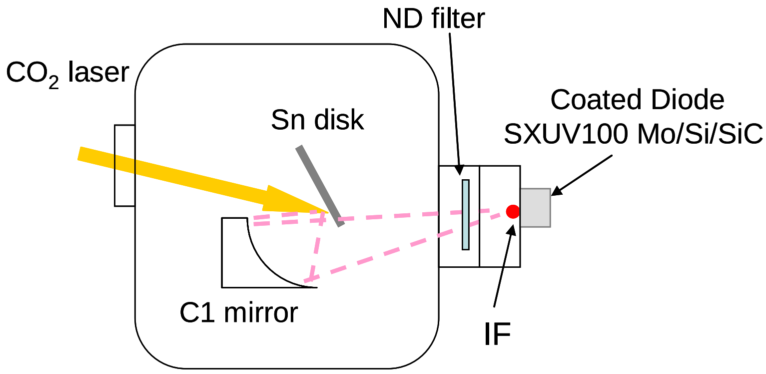


Fig.3 EUV energy measurement configuration at intermediate focus

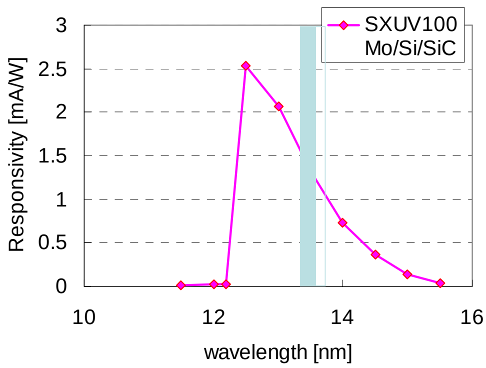


Fig.4 Responsivity of the detector in the EUV region

The measured average EUV output energy and power collected by a 1-sr mirror at 100 kHz operation were 0.16 mJ and 16 W, respectively. The estimated EUV power is 60 W, assuming a 4-sr collector mirror. The measured power corresponded to the estimated power based on conversion efficiency, i.e. laser pulse energy to EUV in-band energy, C1 mirror reflectivity and the collection solid angle values.

Fig.5 shows the in-band EUV energy stability measured at the IF point at 100 kHz operation. The EUV output energy stability was 3.8% (3 sigma, 500 pulses). This energy stability will be improved by improving the irradiating laser pulse energy stability.

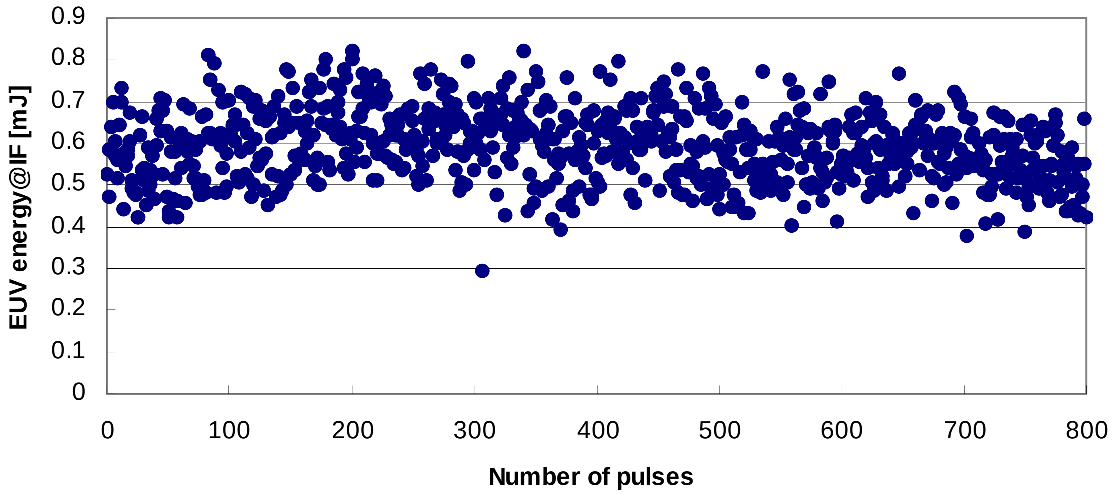


Fig. 5. EUV pulse energy stability at intermediate focus.

3.2 EUV profile

Fig.7 shows the EUV profile measurement configuration at intermediate focus. This system consists of ND filter, Zr filter, a fluorescence plate and a visible CCD camera. The Zr filter is a spectral purity filter that only transmits the in-band EUV. The fluorescence plate, irradiated with EUV light, emits visible light that is detected with the CCD camera which is placed outside the vacuum chamber. We verified that the fluorescence plate emission under UV irradiation is negligible by adding an additional CaF_2 filter that cuts the EUV wavelength region.

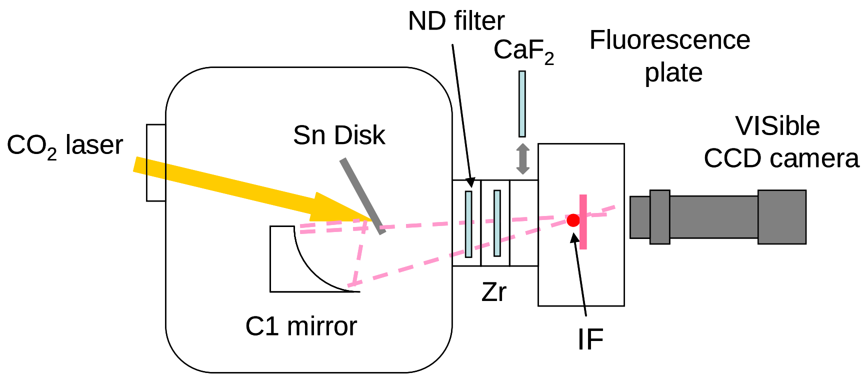


Fig.7 EUV profile measurement configuration at intermediate focus

A measured EUV in-band image is shown in Fig. 8. A symmetric profile was obtained. The horizontal and vertical image sizes were 3.6 mm and 3.3 mm, respectively, at $1/e^2$ of the peak intensity. The etendue of the source was 1.9 mm^2sr calculated from the source size at $1/e^2$ of the peak intensity and assuming a 4 sr collector mirror. This value is well below the etendue limit requirement of the exposure tool developers listed in Table.1.

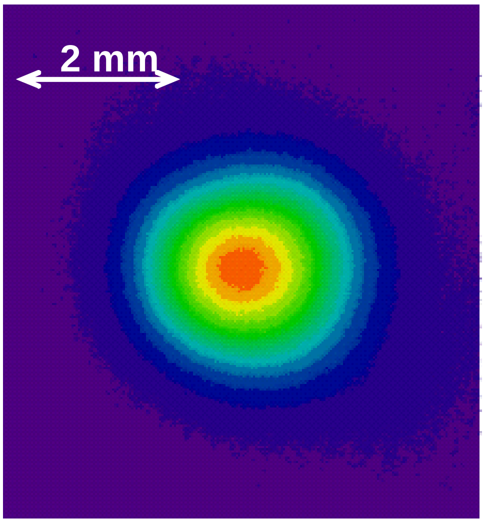


Fig. 8. EUV profile at intermediate focus

3.3 EUV spectrum

Fig.9 shows the EUV spectrum measurement configuration at intermediate focus. The system consists of a ND filter and a flat field grazing incidence spectrometer using a variable-line-spacing grating (1200 grooves/mm). The spectrometer includes a toroidal mirror that images the IF point onto the entrance slit of the spectrometer. The resolution of the spectrometer is below 10 pm between 10 nm to 20 nm.

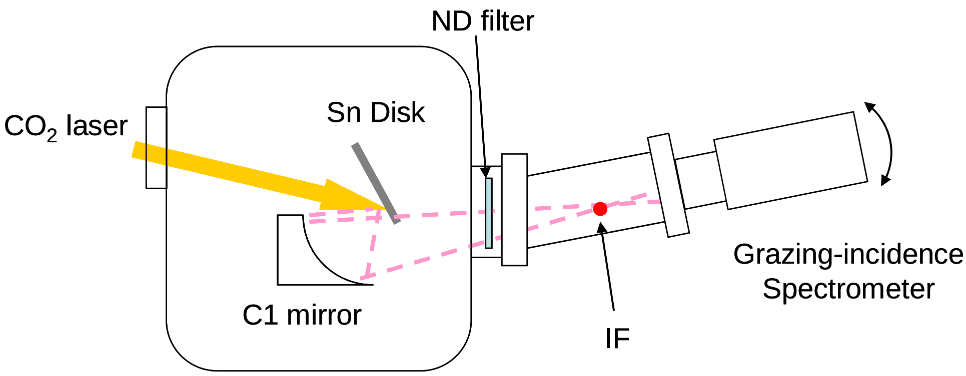


Fig.9 EUV spectrum measurement configuration at intermediate focus

Fig.10 shows the CO_2 laser driven Sn plasma spectrum, the reflectivity of a typical Mo/Si mirror and the IF spectrum. The Sn plasma spectrum has a peak at 13.5 nm. The reflectivity of a typical Mo/Si mirror has its peak at 13.5 nm and a spectral bandwidth of 4 % at 13.5 nm. The IF spectrum is given by multiplying the Sn plasma spectrum with the reflectivity of the C1 mirror.

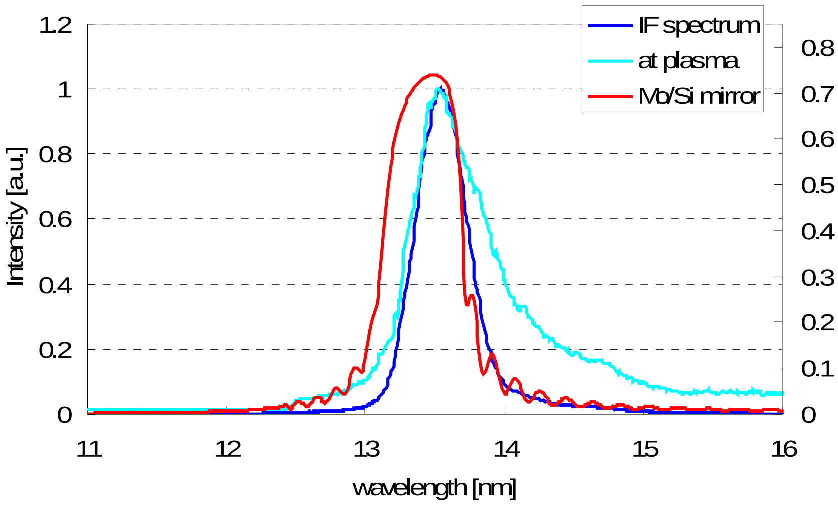


Fig.10. EUV spectrum at intermediate focus.

3.4 OoB radiation

We reported earlier the out-of-band radiation of a Xe plasma[4]. The out-of-band energy distribution was measured ~~by~~ using colored glass filters and a photodiode (IRD, AXUV 100G). This Si based photodiode is sensitive up to 1 μm wavelength. Therefore this detector does not monitor the infrared region, especially the 10.6 μm of the CO_2 laser beam scattered from the CO_2 laser driven Sn plasma. But it is important that the infrared region within 10.6 μm is monitored due to thermal load issues of the lithographic exposure tool. We therefore prepared a thermopile type power meter that has a flat response in the ultra-violet, visible and infrared region and also covers the 10.6 μm of the CO_2 laser beam. In the near future we will measure the out-of-band radiation with this equipment at IF point for a CO_2 laser driven Sn plasma light source.

4. CONCLUSION

We developed a high power EUV light source system and demonstrated the performance of our evaluation system at the intermediate focus. We measured the energy stability, the intensity profile and the emission spectrum at the intermediate focus for the in-band EUV. The EUV energy stability was 3.8% (3 sigma, 500 pulses). The EUV profile was symmetric. The horizontal and vertical image sizes were 3.6 mm and 3.3 mm, respectively, at $1/e^2$ of the peak intensity. The etendue of the source was 1.9 mm^2sr calculated from the source size at $1/e^2$ of the peak intensity and assuming a 4 sr collector mirror.

5. ACKNOWLEDGEMENTS

This work was performed under the management of the Extreme Ultraviolet Lithography System Development Association (EUVA), a research and development program of the New Energy and Industrial Technology Development Organization (NEDO), Japan.

REFERENCES

[1] A. Miyake, H. Kanazawa, V. Banine and K.Suzuki : "Joint Requirements", EUV Source Workshop, Barcelona, SPAIN, Oct. 19 (2006)

[2] K. Nishihara, A. Sasaki, A. Sunahara, and T. Nishikawa, *EUV Sources for Lithography*, Chap. 11, ed. V. Bakshi, SPIE, Bellingham, (2005).

[3] H. Tanaka, A. Matsumoto, K. Akinaga, A. Takahashi, and T. Okada, "Comparative study on emission characteristics of extreme ultraviolet radiation from CO_2 and Nd:YAG laser-produced tin plasmas" Appl. Phys. Lett. 87, 041503 (2005)

[4] H. Mizoguchi, A. Endo, T. Ariga, T. Miura, H. Hoshino, Y. Ueno, M. Nakano, H. Komori, A. Sumitani, T. Abe, T. Suganuma, G. Soumagne, H. Someya, Y. Takabayashi, K. Toyada, "Development of CO_2 Laser Produced Xe Plasma EUV Light Source for Microlithography", Proc. SPIE 6151, 61510S (2006)