Small Field Exposure Tool (SFET) Light Source

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ABSTRACT

A laser produced plasma light source for a small field exposure tool (SFET) has been developed at the EUVA Hiratsuka R&D center. The light source consists of the following components: The drive laser of the xenon plasma source is a short-pulse, high-power KrF laser that has been developed in cooperation with Gigaphoton Inc. and Komatsu Ltd. The laser has an unstable resonator and produces a maximum output power of 580W at 4kHz repetition rate. The xenon target is a 50 micrometer diameter liquid jet with a speed of about 35 m/s. The source has been designed to generate 0.5W in-band power at the intermediate focus (IF) at a collecting solid angle of pi sr. The source includes automatic control, e.g. jet and plasma position control, and an electrical interface for the exposure tool. The performance of the source at IF has been evaluated by Canon Inc. This paper explains source performances. Especially, results of IF parameters like image size, position stability and out of band radiation are presented.

Keywords: EUV lithography, exposure tool , laser produced plasma, KrF laser, Xenon

1. INTRODUCTION

The development for next generation EUV lithography makes steady progress which materializes in light source systems that are integrated in small field exposure tools[1] or alpha-tool full field exposure tools[2]. These tools are essential for the evaluation and for the development of the full EUV lithographic process to which the light source is evidently a key component. The Extreme Ultraviolet Lithography System Development Association (EUVA) in Japan started the HVM light source development in 2002 with research and development of discharge and laser produced plasma sources (DPP[4], LPP[5]). In 2005 the development of a small field exposure (SFET) tool was decided by EUVA and Canon Inc. The EUVA Hiratsuka R&D center developed the light source based on a KrF laser-produced xenon plasma. Last year, i.e. 2006, the light source was transferred to Canon where SFET was installed. This paper describes the performance of the light source in detail and demonstrates the progress obtained in development during recent years.

2. OVERVIEW

The SFET system after its installation at Canon is shown in **Fig. 1** and system specifications are listed in **Table 1**. The light source consists of three main units including the high power KrF laser, the beam delivery unit and the EUV emission chamber. The KrF laser has a maximum power of 580W at a repetition rate of 4 kHz. The resonator of the KrF laser is an unstable resonator which provides good beam quality for focusing. The beam delivery unit includes optics that improves beam size and divergence. The EUV emission chamber finally includes the xenon jet target, the EUV collector mirror, a spectral purity filter (SPF) and various sensors and actuators.

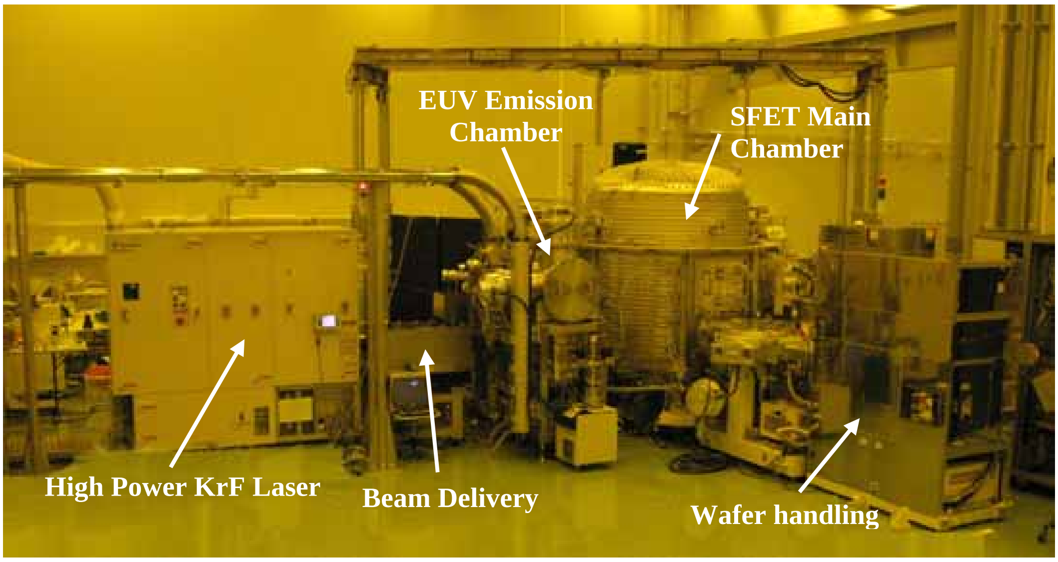


Fig. 1: Picture of the small field exposure tool (SFET) system with the LPP light source at Canon.

Table 1: Main specifications of SFET

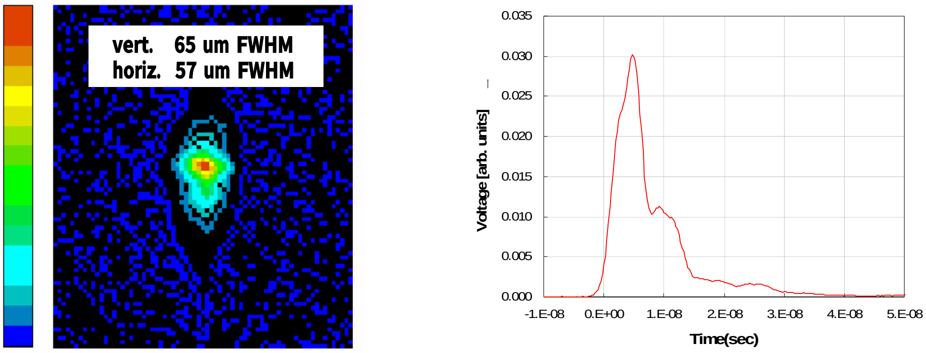
NA	0.3
Magnification	1/5
Field Size	0.2 x 0.6 mm
Flare	< 7%
Source Power	0.5 W at IF (Target)

3. LIGHT SOURCE

3.1 KrF Laser

The drive laser has been developed by Gigaphoton Inc. and Komatsu Ltd. The laser is based on a Gigaphoton lithography laser (see **fig. 2**) and has been mainly chosen for two reasons: 1) Gigaphoton lasers are well established in the current lithography light source market and their reliability is outstanding, 2) the interface for laser control and system integration is already available and also well proven. The 248nm KrF excimer laser has a maximum output power of 580W at a repetition rate of 4kHz. An unstable resonator is used to obtain good beam quality; for example the horizontal and vertical beam divergence is approx. 0.2 milliradian (fwhm). **Fig. 3-a)** shows the focused laser spot at the jet position having horizontal and vertical fwhm values of 57 and 67 micometer respectively. Horizontally, the laser spot has about the dimension of the jet diameter in order to efficiently heat the plasma. The temporal dependence of the laser pulse is shown in **Fig. 3-b)**, having a fwhm pulse length below 10 ns.

Fig. 2: High power KrF drive laser



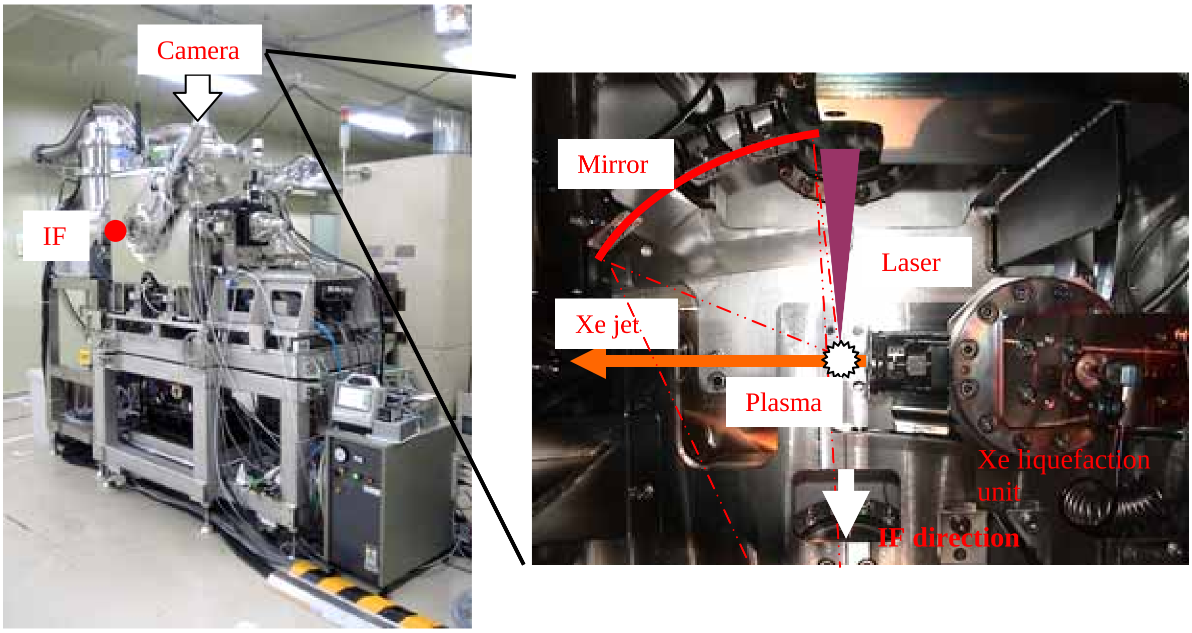
a) Spot image on the xenon jet

b) Temporal pulse shape

Fig. 3: Drive laser characteristics.

3.2 EUV Emission Chamber

The EUV emission chamber is shown in **Fig. 4**. The chamber has a volume of approx. 250liter. It is equipped with a xenon jet recovery tube that is differentially pumped and three turbo-molecular pumps (TMP). With a total xenon pumping speed of about 2000 sccm a pressure below 0.2 Pa is maintained inside the vacuum chamber during xenon jet injection. The pressure drops below 10^{-5} Pa without xenon jet injection. The pump down time of the vacuum chamber is about 0.5 hour from atmospheric pressure of the N_2 buffer. The xenon jet generation time is about 2 hours. The xenon liquefaction system operates at a maximum pressure of 2MPa and a temperature range of approx. 163.0 K$\pm$0.5K during xenon jet generation. The liquid xenon is horizontally injected into the vacuum chamber through a nozzle having a maximum diameter of 50 micrometer. The laser beam enters at an angle of 20 degrees from the horizontal plane. The EUV optical axis is horizontally.



a) KrF laser driven xenon light source

b) Configuration of the EUV emission chamber; the xenon jet is injected horizontally.

Fig. 4: EUV emission chamber

3.2.1 Collector mirror

Fig. 5 shows the EUV collector mirror of the source. The mirror geometry is 1/3 of a full circular mirror due to tool maker requirements and cost considerations. Radial and angular variations of the reflectivity and the center wavelength are shown in **Fig. 6-b)** and **Fig. 6-c)**, respectively. The reflectivity is above 60% and the center wavelength 13.5nm± 0.1nm.

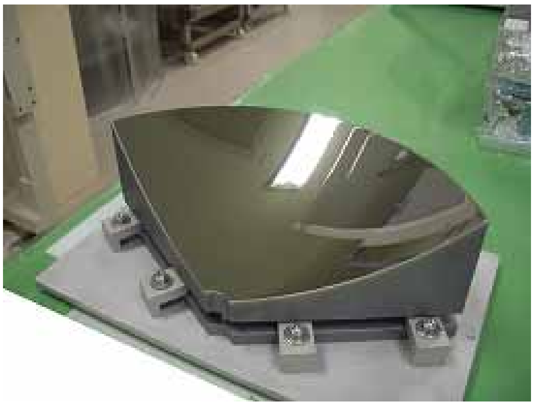
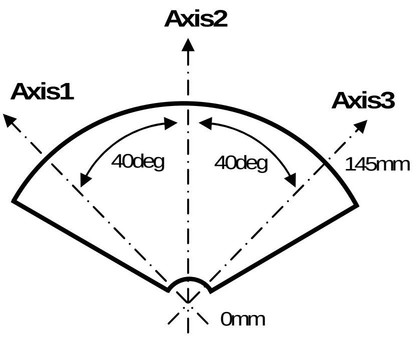
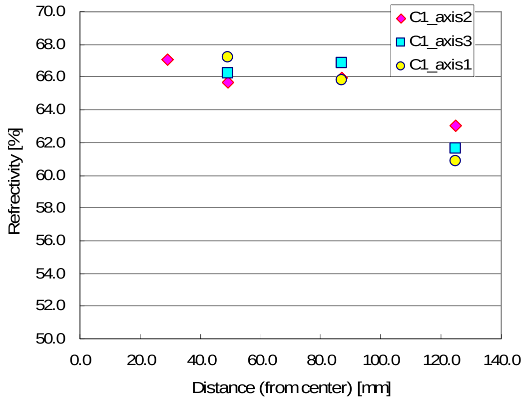


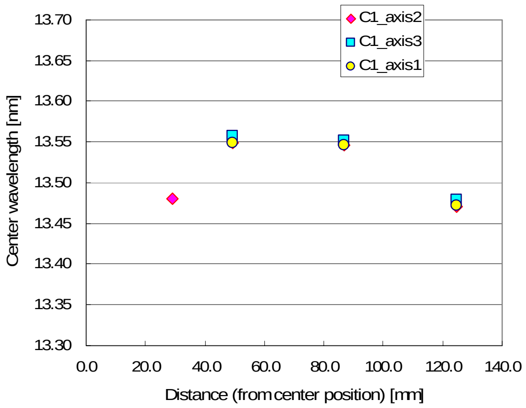
Fig. 5: EUV collector mirror. Collector angle is equivalent of pi/3 sr.



a) configuration of axis directions



b) Mirror reflectivity



c) Mirror center wavelength

Fig. 6: EUV mirror reflectivity and center wavelength; measured by PTB.

3.2.2 Spectral purity filter

A spectral purity filter (see **Fig. 7**) is used to suppress out-of-band radiation including scattered laser light. The filter has a clear aperture of 50mm. It is supported by a mesh and has a Silicon/Zirconium/Silicon structure to efficiently cut-off the scattered KrF laser light. The thickness is 50nm for each layer resulting in a transmission of about 50%. In addition, the SPF is used to separate the tool from the light source in order to improve the residual gas environment inside the tool. To optimize the pressure gradient the filter can withstand at a still acceptable transmission, filters with different thicknesses were prepared. The selected SPF was 50nm:Silicon /150nm:Zirconium /50nm:Silicon.

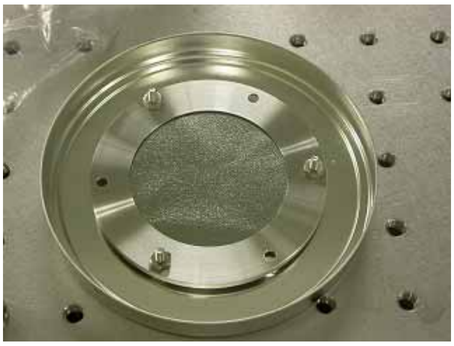


Fig. 7: Spectral purity filter. Si:50nm/Zr:50nm/Si:50nm.

3.2.3 Xenon jet and plasma position control

The LPP light source requires the ability of mechanical control of, for example, target position, laser spot position and EUV mirror position. These positions have to be controlled at predefined values. The emission chamber is therefore equipped with various sensors and actuators. A schematic of the control set-up is shown in **Fig. 8**. CCD cameras with high magnification lenses are located at three positions. One CCD camera is used to monitor the plasma position and the other two are used to monitor the xenon jet position. Three actuators are used for control. The nozzle actuator has a 2-axis stage that allows for movements within the vertical plane of the xenon jet. The laser focusing lens actuator has a 3-axis stage that allows parallel and perpendicular lens movement related to the laser beam axis. Finally, the collector mirror actuator has a 5-axis stage to control the IF image position. The nozzle actuator and the lens actuator are controlled by the processed image of each CCD camera.

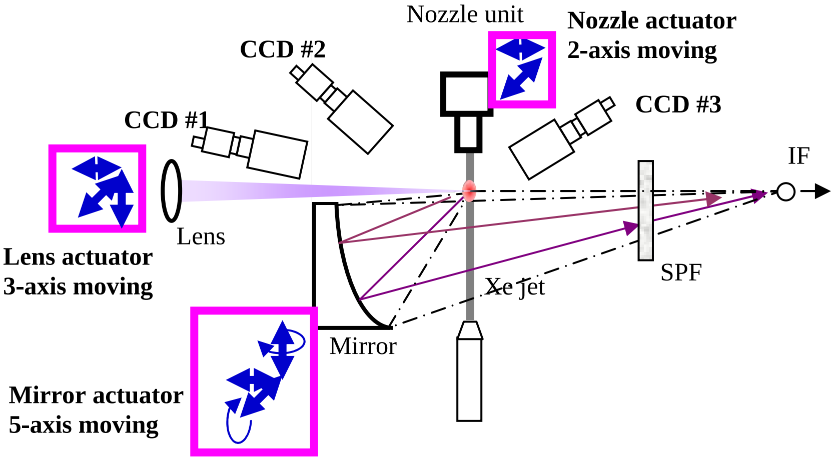
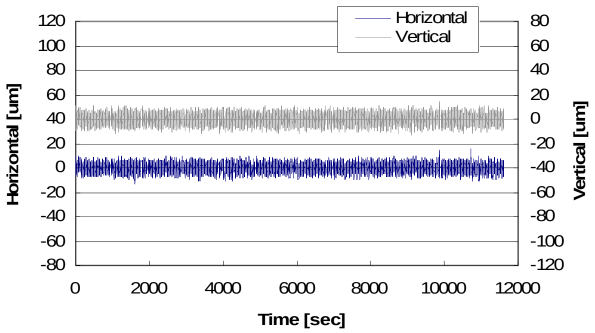
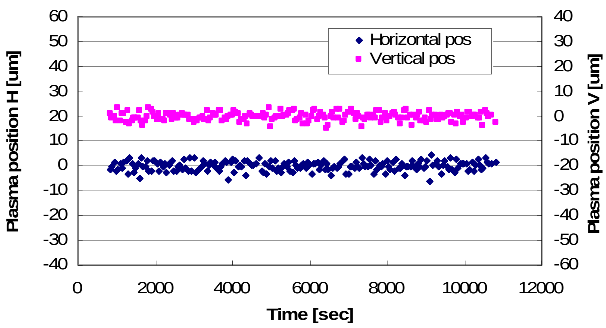


Fig. 8: Schematic of xenon jet and lens position control

Results of the controlled xenon position stability and plasma position stability are shown in **Fig. 9-a)** and **Fig. 9-b)**, respectively. EUV operation conditions are as follows; the laser average power is 100W with a repetition rate of 1kHz. The duty cycle of the EUV emission is 10 seconds on, i.e. with EUV emission, followed by 40 seconds off, i.e. without EUV emission. The xenon jet position stability is below ±10 micrometer during 3 hours (**Fig. 9-a)**. The sampling time of the xenon jet image is approx. 1second. **Fig. 9-b)** plots 200 cycles of the average plasma position during the 10-second emission phase. A plasma position stability below ±5 micrometer has been achieved for 2.8 hours.



a) Xenon jet position



b) Plasma position

Fig. 9: Position stability with control

3.3 EUV Characteristics at IF

3.3.1 EUV Image

Fig. 10 shows the in-band plasma emission at the intermediate focus. The fwhm plasma size is 640 and 330 micrometer, horizontally and vertically respectively. The calculated *etendue* is below 1 mm^2sr fulfilling the *etendue* requirements of 3.3 mm^2sr. The direction of the long emission axis of the image corresponds to the jet direction in order to obtain efficient laser heating of the plasma.

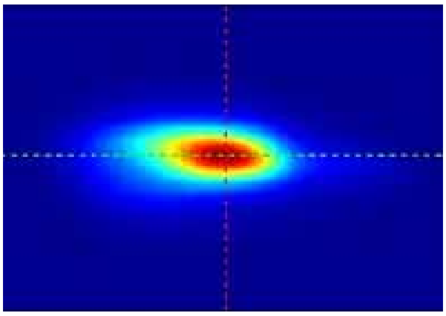


Fig. 10: In-band plasma emission; measured by Canon Inc.

3.3.2 IF position stability

The position stability at the intermediate focus is an important parameter for the EUV light source specification. The stability is affected by heat load from the plasma emission and by the plasma position stability at the source. The plasma position stability at the source, however, is already controlled by the xenon jet and the plasma image feedback control. In order to prevent the IF position drift, mainly the cooling mechanism of the collector mirror, the mirror holder and other chamber parts has been optimized. **Fig. 11** shows the result of the position stability at the IF. The operation condition of the EUV emission is as before, i.e. as for **Fig. 9**. For 2.8 hours, horizontal and vertical position stability at the IF of approx. ±25 micrometer has been achieved.

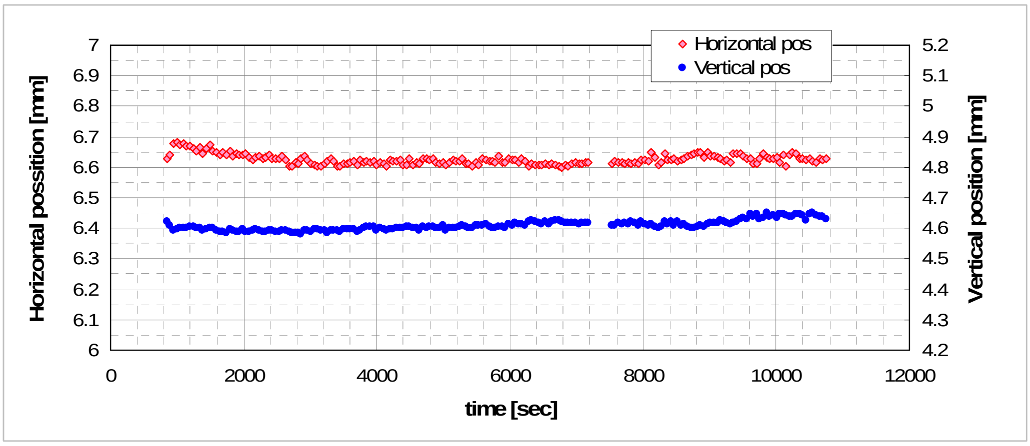


Fig. 11: Plasma position stability at IF; measured by Canon Inc.

3.3.3 Out of band radiation

The out of band (OoB) radiation requirements are given by the joint EUV source requirements of the tool manufacturers[1]. The DUV band radiation, i.e. 130-400nm radiation, has to be less than 1% of the in-band radiation at wafer level. In the case of a KrF drive laser, especially scattered KrF photons at 248nm have to be removed by a spectral purity filter having a high attenuation in the DUV band. In order to confirm that the DUV radiation is well below the SFET requirements, we measured the OoB radiation using various filters. **Fig. 12** shows a schematic of the OoB measurements. The filter wheel #1 and #2 includes various filters, like e.g. Zr, Al ,CaF_2 and mesh filters. The filter wheel is placed at the IF and the transmitted energy for various filter configurations is measured with an AXUV-100 photodiode. The DUV band radiation has been obtained by subtracting measurements using a CaF_2 filter from measurements of the full spectrum resulting in less than 0.1% DUV radiation at IF. Analogous measurements have been performed for the other spectral ranges and results are listed in **Table 2**. As can be seen sufficiently low levels of OoB radiation were always obtained.

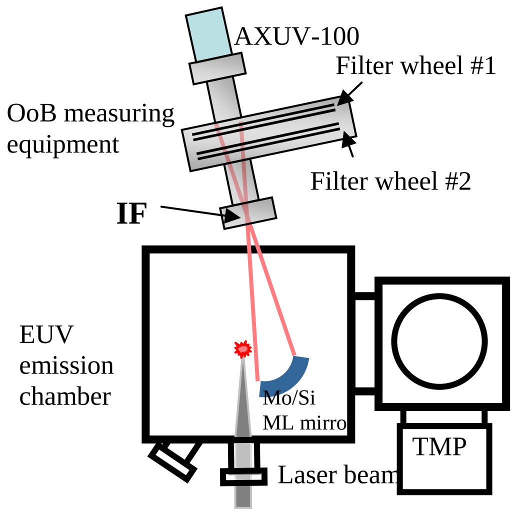


Fig. 12: Schematic of OoB measurement.

Table 2: Out of band radiation at IF of KrF driven EUV light source

Approx. Wavelength range	Ratio of 13.5nm 2% BW
6 ~ 18nm	200%
18 ~ 80nm	7%
80 ~ 130nm	8%
130 ~ 400nm	<0.1%
400 ~ 700nm	<0.1%
700nm ~	<0.1%

4. CONCLUSION

A laser produced plasma light source for a small field exposure tool has been developed by EUVA. The source uses a KrF laser that drives a Xenon plasma. The plasma target is supplied as a xenon jet. Various control systems, including CCD cameras with image processing for control feedback, have been applied to obtain a high jet and plasma position stability of ±10 and ±5 micrometer respectively. The collector mirror had an overall reflectivity above 60% and was water cooled for further stability improvement at the IF. Finally, a spectral purity allowed for sufficient out-of-band reduction of the generated radiation. In conclusion, the successful development of the SFET light source is a very important step for the EUVL development in Japan.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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