Laser Produced Plasma Light Source for EUVL

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ABSTRACT

This paper describes the development of laser-produced-plasma (LPP) extreme-ultraviolet (EUV) source architecture for advanced lithography applications in high volume manufacturing. EUV lithography is expected to succeed 193 nm immersion technology for sub-22 nm critical layer patterning. In this paper we discuss the most recent results from high qualification testing of sources in production. Subsystem performance will be shown including collector protection, out-of-band (OOB) radiation measurements, and intermediate-focus (IF) protection as well as experience in system use. This presentation reviews the experimental results obtained on systems with a focus on the topics most critical for an HVM source.

Keywords: EUV source, EUV lithography, Laser Produced Plasma

1. INTRODUCTION

EUV Lithography is the front runner for next generation critical dimension imaging after 193 nm immersion lithography for layer patterning below the 32 nm node; beginning in 2013 according to the International Technology Roadmap for Semiconductors (ITRS). NAND Flash and DRAM devices are expected to have the need for this manufacturing technology as soon as 2012, with pilot line system introduction starting this year (2011). The availability of high power 13.5 nm sources has been categorized as high risk and ranked as critical with other technologies requiring significant developments to enable the realization of EUV lithography. High sensitivity photoresists with good line-edge-roughness (LER) and line-width-roughness (LWR) are needed to keep the required source power within reasonable limits. Photoresist sensitivity and other light absorbing elements are the basis to derive EUV source power requirements within the usable bandwidth (BW) of 2 %. Scanner manufacturers are requiring clean EUV power of 250 W at the intermediate focus (IF) to enable > 100 wph scanner throughput assuming 15 mJ/cm^2 photoresist sensitivity. The need for a Spectral Purity Filter (SPF) increases the requirements for Raw EUV power even higher. Clean EUV Power is calculated by taking the Raw EUV power and subtracting the losses associated with the SPF and dose control.; For the current sources these losses are estimated to be 35% and 20%, respectively. A scalable EUV source architecture is needed to enable the evolution of EUV lithography during the life cycle of the technology. Laser-produced-plasma (LPP) sources are expected to deliver the necessary high power for critical-dimension high-volume manufacturing (HVM) scanners for the production of integrated circuits in the post-193 nm immersion era.[1,2]

A schematic of a source vessel is shown in Figure 1. An HVM I source is shown in Figure 2. Eight sources have been built and are operational, four of these have been shipped to customers. As described in details previously[3-5], the HVM I sources use a 5 sr normal incidence collector, tin droplets of 30 microns diameter, and a ~30 kW (average power) CO$_2$ laser. The HVM I source is shown in its inclined position of 27 degrees as it is positioned when integrated into the scanner.

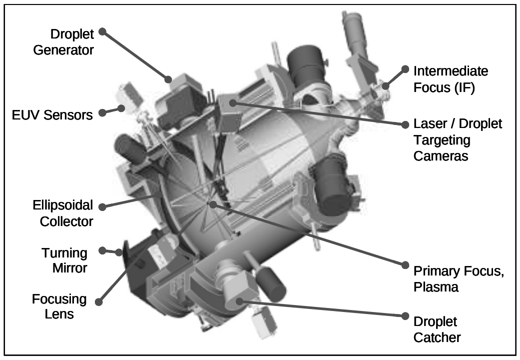

Figure 1: Schematic of source vessel

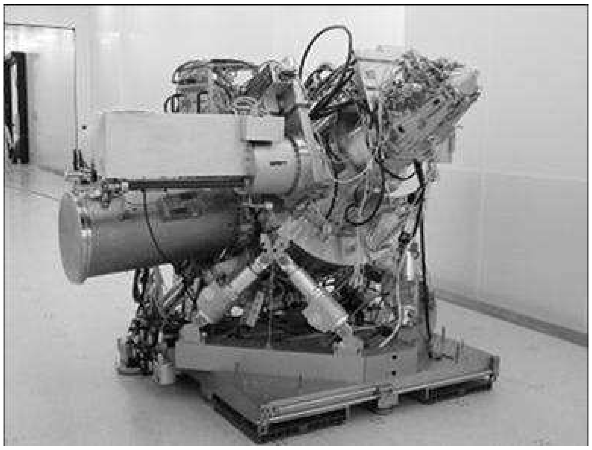

Figure 2: HVM I source vessel as shipped

2. SOURCE CHARACTERIZATION TOOL

A tool for qualification of the LPP sources was developed. The Far Field Test Tool (FFTT) is positioned behind IF and receives the light that would go onto the illumination optics if it were attached to a scanner. The FFTT provides capability of measurement of many parameters of the source.; This paper describes only few of them: the far field collector imaging, out-of-band measurements, and capabilities of the IF Protection module to suppress contamination.

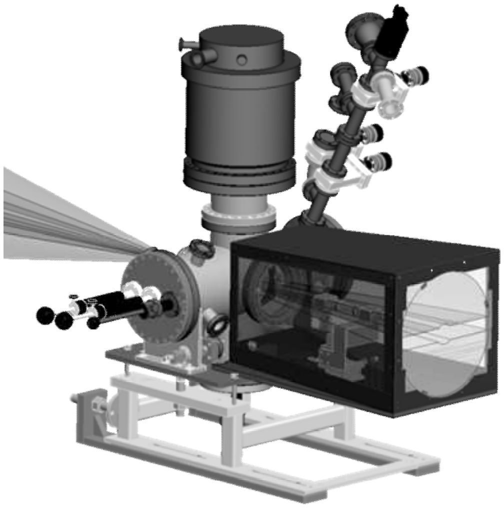

Figure 3: Far Field Test Tool (FFTT)

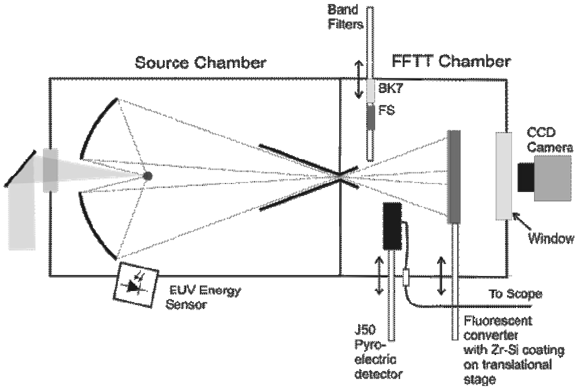

Figure 4: : FFTT Schematic

3. COLLECTOR QUALIFICATION

Cymer's LPP EUV source employs near-normal-incidence mirrors with a large solid angle for light collection. Such a geometry has numerous advantages, which has been discussed elsewhere.[6] As we reported earlier[1], the complete infrastructure is in place for manufacturing of large-size normal-incidence collector mirrors. For demonstration of the light collection capabilities of our source several 1.6 sr subaperture versions (300 mm optical diameter) have been produced and used in the development system for testing. Full size (650 mm diameter) collectors with 5 sr collecting angle were fabricated for HVM I tools. The collectors have been coated with graded multilayer coatings with layer periods optimized for high EUV reflectance at the corresponding incidence angles.

A collector was installed into a HVM I source and run under operating conditions of 11W average exposure power (21 mJ dose controlled operation) for 90 hours. The quality of the collector protection was monitored during this long duration run with the FFTT taking an image every hour.

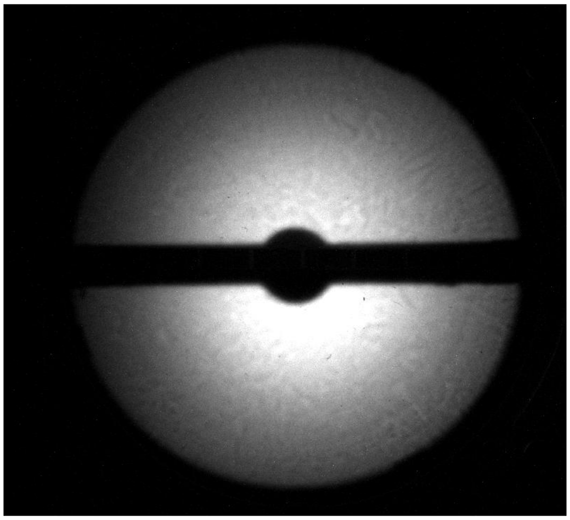

Figure 5: Initial far field image of the collector past IF (very few pulses)

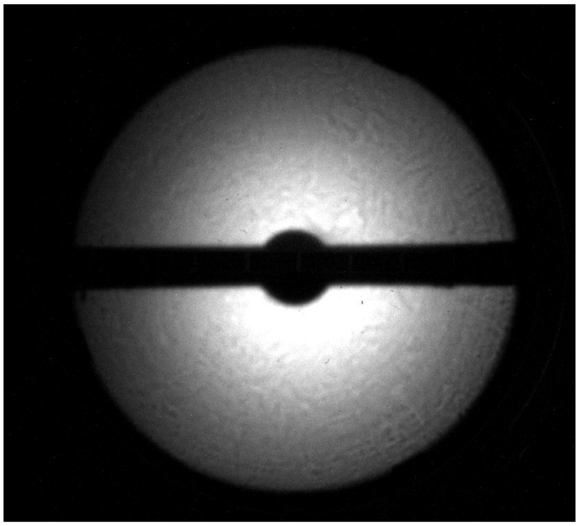

Figure 6: Far field image of the collector past IF after 6 billion pulses / 90 hours

The evolution of relative reflectivity versus exposure dose from this test is shown in a companion paper of these proceedings[7]. Before this test additional improvements in the gas flow distribution which is used for debris mitigation and multilayer coating have been implemented and resulted in no measurable loss of EUV reflectivity. This is evident by no visible change in EUV image after 6B pulses as shown in Figures 5 and 6. Further improvement in flow arrangement, vacuum environment cleanliness and multilayer coating are expected to provide continuous advancements throughout 2011 to allow the device makers to use the sources with less downtime associated with changing of the collector.

4. OUT-OF-BAND MEASUREMENTS

This section describes the development of a tool for OOB radiation measurements and discusses the measurements taken on Sn targets with a CO_2 laser. The tool uses three different fiber optics spectrometers with calibrated intensity from both solar spectrum and deuterium light source. A MatLab code was developed to apply the calibration curve to the radiation measured from plasma and presents the absolute intensities of the measured spectra in J/nm (into 2π solid angle) versus wavelength in nm for the spectral range from 200 to 950 nm. The exponential extrapolation of the measured spectral densities into the short and long wavelength ranges enables us to estimate the OOB radiation for the bands from 130 to 350 nm and from 1 to 5 μm, which are most critical for the EUV source application. Measurements with three spectrometers optimized for different bands revealed perfect stitching of the measurements in overlapped bands.

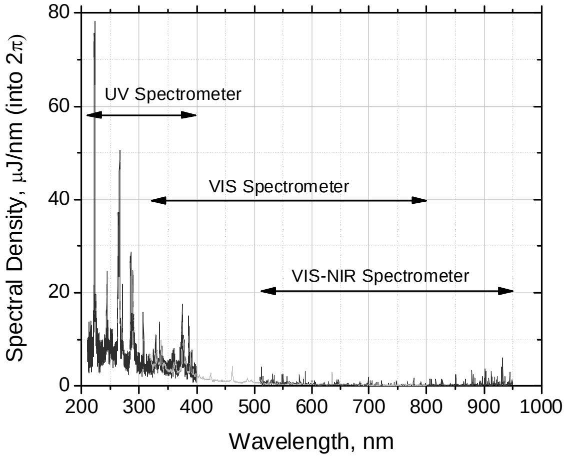

Figure 7: CO_2 laser / Sn droplet plasma OOB spectrum as measured with three different spectrometers

The requirements for OOB radiation are dictated by the requirements for high contrast patterning for a given photo-resist. Thus, several aspects of the process should be considered when determining the critical wavelength bands and critical radiation dose in these bands which are acceptable for the EUV tool. One aspect is the spectral sensitivity of the photo-resist. Another aspect is reflectivity of MLM collector for OOB radiation. OOB measurements taken with fiber optics spectrometers were calibrated by energy measurements with band filters on HVM I tools. The FFTT provides good measurement accuracy for the radiation energy within a given wavelength band-pass. Fused-Silica (FS) and Borosilicate glass (BK7) filters were used in the FFTT to take the measurements shown in Table 1. Most important is the energy difference from the measurements of these two filters, which provides a good indication of the energy that may expose a 193 nm based resist. The measurements show that only 1% of the in-band EUV radiation is in the wavelength range from 200 to 310 nm.

Band	**Measurement results**
EUV OOB, 10-35nm	FWHM calculated for reflectivity curve
DUV, 35-115nm	All radiation Absorbed by H2
UV+Visible+NIR, 200nm-3mm, (FS filter)	6-8% of In-Band EUV
UV, 200-310nm, (FS-BK7)	~1% of In-Band EUV

Table 1: Summary of out-of-band measurement results

5. IF PROTECTION

The IF Protection Module works on the basis of a dynamic gas lock with differential pumping. The FFTT provides a method to quantify the suppression of a surrogate contaminate (Ar) introduced into the source vessel side and measured on the FFTT side used an RGA. The measurement results shown provide three curves for three different pressures inside the FFTT vacuum chamber. A known quantity of Ar was injected into the source vessel, a differentially pumped RGA was used after IF for characterization of the gas lock. Initially differentially pumped RGA was calibrated with known partial pressure of Ar behind IF.. The ultimate suppression of Ar with full flow of the DGL is greater than the measurement capability of differentially pumped RGA. Extrapolating the suppression values for higher flow rates suggest capabilities well above the requirements.

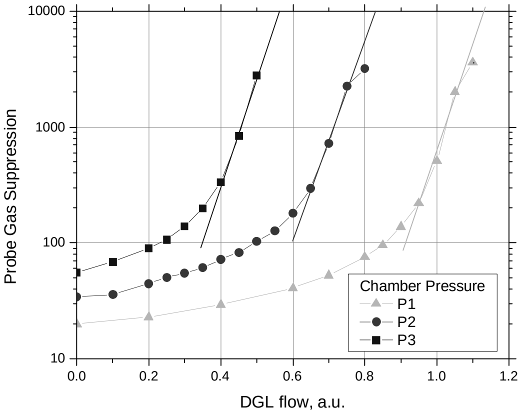

Figure 8: Contamination suppression vs. flow across the IF Protection Module

The IF Protection module not only provides suppression of contaminations which might migrate from the EUV source chamber into the vacuum space of the illumination optics, it also serves as an interface between the source and the scanner. Significant development by both Cymer and ASML have gone into the design of this module. It is now complete and has been adopted by ASML as the standard interface for EUV Scanners.

6. SUMMARY

Laser-produced plasma has been shown to be the leading source technology with scalability to meet requirements from leading scanner manufacturers and provide a path towards higher power as the lithography tools evolve over their life cycle. Normal-incidence collector mirrors of diameter > 650 mm, with > 5 sr light collection and average reflectivities >50% are produced and integrated into production LPP systems. The developed technique for debris mitigation proved stable operation of the collector without measureable degradation for at least 6B pulses which corresponds to the dose of about 4000 kJ. Measured out of band radiation from the source behind IF in visible and DUV bands meets industrial requirements dictated by high contrast patterning for the photo-resist. The IF Protection module demonstrates high suppression of possible contaminates from the EUV source for safe operation of the illuminator optics.

Eight HVM I LPP EUV source systems have been built and are operational, four of these sources have been shipped to customers. EUV lithography is expected to be the critical dimension imaging solution in the post-193 nm immersion era. LPP source technology with power levels exceeding 400W is expected to enable the IF power requirement projected in the future, and to provide the much needed margin for photoresist sensitivity, spectral purity filters, optics degradation, process latitude, and overall equipment throughput. Cymer is developing second generation (HVM II) EUV light sources in 2011. The company continues to meet its EUV source development commitments to industry, customers and suppliers.

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