LPP-EUV light source for HVM lithography

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ABSTRACT

We have been developing a laser produced plasma extremely ultra violet (LPP-EUV) light source for a high volume manufacturing (HVM) semiconductor lithography. It has several unique technologies such as the high power short pulse carbon dioxide (CO2) laser, the short wavelength solid-state pre-pulse laser and the debris mitigation technology with the magnetic field. This paper presents the key technologies for a high power LPP-EUV light source. We also show the latest performance data which is 188W EUV power at intermediate focus (IF) point with 3.7% conversion efficiency (CE) at 100 kHz.

Keywords: EUV light source, EUV lithography, Laser Produced Plasma, CO2 laser, Debris mitigation,

1. INTRODUCTION

LPP-EUV light source is the most promising solution as the high power light source for 13.5nm lithography because of its power scalability [1]. It produces the light of 13.5nm wavelength from tin plasma which is produced by high power CO2 laser shooting to tin droplet. Engineering difficulties of LPP-EUV light source are the shooting to tin droplet by high power CO2 laser and the tin debris mitigation on collector mirror. Tin debris generated after EUV emission deposits on the collector mirror surface resulting in power degradation due to mirror reflectivity loss. Tin debris deposition can be mitigated by optimum hydrogen (H2) flow in vessel. However, an increase of H2 flow for higher EUV power induces the shooting difficulty due to H2 gas heating effects. To cope with this situation, we developed the dual wavelength shooting by combining the high power short pulse CO2 laser and the short wavelength solid-state pre-pulse laser, and the debris mitigation technology with magnetic field [2,3]. This paper presents these key technologies and the performance in our EUV light source system.

2. LPP-EUV LIGHT SOURCE SYSTEM

2.1 Configuration

Figure 1 shows the configuration of our LPP-EUV light source system which consists of driver laser, beam transfer and EUV chamber system. Driver laser system consists of CO2 laser and pre-pulse laser. CO2 laser is a master oscillator and power amplifiers (MOPA) system. The master oscillator consists of multiple quantum-cascade laser (QCL) seeders, a regenerative amplifier and post-amplifiers based on RF-discharge excited, slab-waveguide, and multi-pass amplifiers. The wavelengths of QCL seeders address four lines of a regular band of CO2 molecule (P-branch, 10.6μm), namely P18, P20, P22 and P24 [4]. Pre-and main amplifier are multi-stage system of amplifiers employing RF-discharge-excited, fast-transverse-flow and fast-axial-flow CO2 amplifiers [5]. This CO2 laser produces a power of over 20kW with a pulse width of below 20ns (FWHM) shown in Fig 2 (a) and (b). Pre-pulse laser is the solid-state laser with a pulse width of 10ps (FWHM) and a wavelength of 1.06μm and its power level is a few 100W. Pre-pulse laser and CO2 laser beam are combined at combiner unit through beam transfer system and they are introduced to tin droplets at plasma point through focus unit inside EUV chamber system. EUV light produced from tin plasma is collected and it is introduced to exposure tool by collector mirror. Super conductive magnets are set outside EUV chamber and it produces high power magnetic field inside EUV chamber for protecting the collector mirror from high speed tin ions produced from plasma. And also, this system has several shooting control loops for ensuring shooting accuracy of μm and ns level between droplets and lasers, which are droplets position control, laser beam axis control and timing control.

XXI International Symposium on High Power Laser Systems and Applications 2016, edited by
Dieter Schuöcker, Richard Majer, Julia Brunnbauer, Proc. of SPIE Vol. 10254, 102541A

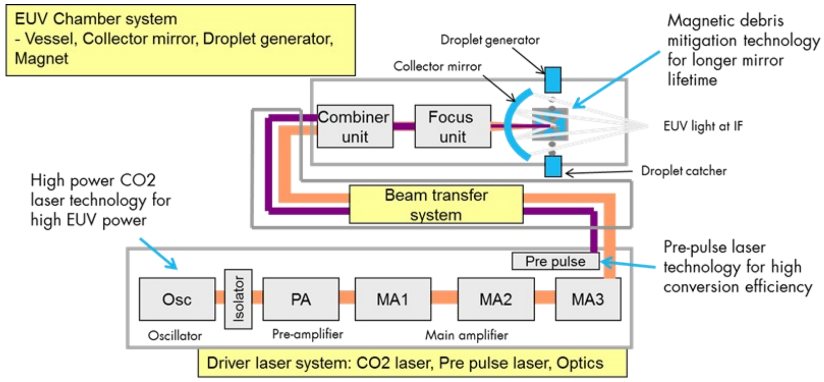

Figure 1. Configuration of LPP-EUV light source system

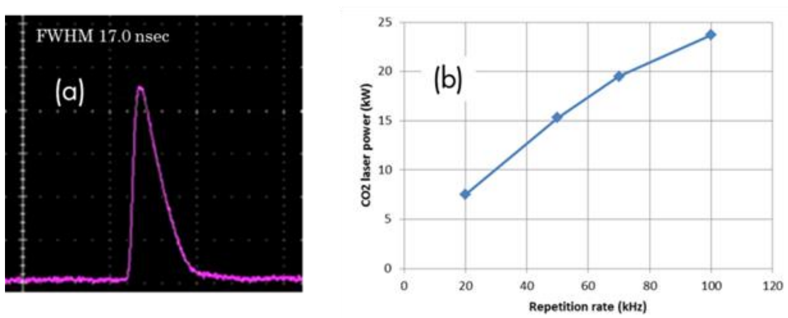

Figure 2. (a) CO2 laser pulse shape (b) CO2 laser power dependency on repetition rate

2.2 Pre-pulse laser technology

Pre-pulse laser technology is one of key technologies for producing the high CE. High CE performance is the most reasonable way for increasing EUV power to 250W, which is the current HVM target. Figure 3 (a) and (b) show tin mist shapes after 10ns (a) and 10ps (b) pre-pulse laser irradiation before CO2 laser irradiation. Figure 3 (c) shows the light emission just after CO_2 laser irradiation (upper: visible CCD image, lower: X-ray CCD, EUV light image) using 10ps pre-pulse laser. The other hand, it with 10ps pre-pulse laser is a dome like target. This dome like target produces the high CE by wide EUV emission area shown in Fig 3 (c). Figure 4 (a) and (b) shows the CE and ionization rate performance using ns and ps pre-pulse laser in small EUV light source experimental device. Pre-pulse laser technology using ps laser produces the high CE of over 4.5%. And also, it achieves the high ionization rate of over 98%.

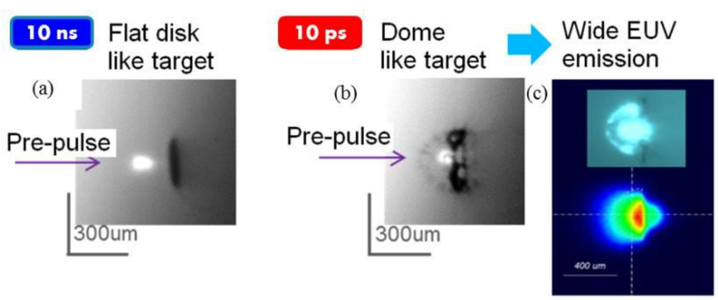

Figure 3. Tin mist (a) with 10ns pre-pulse laser (b) with 10ps pre-pulse laser
(c) Images after CO2 laser irradiation with 10ps pre-pulse laser, upper: visible light distribution, lower: EUV emission distribution

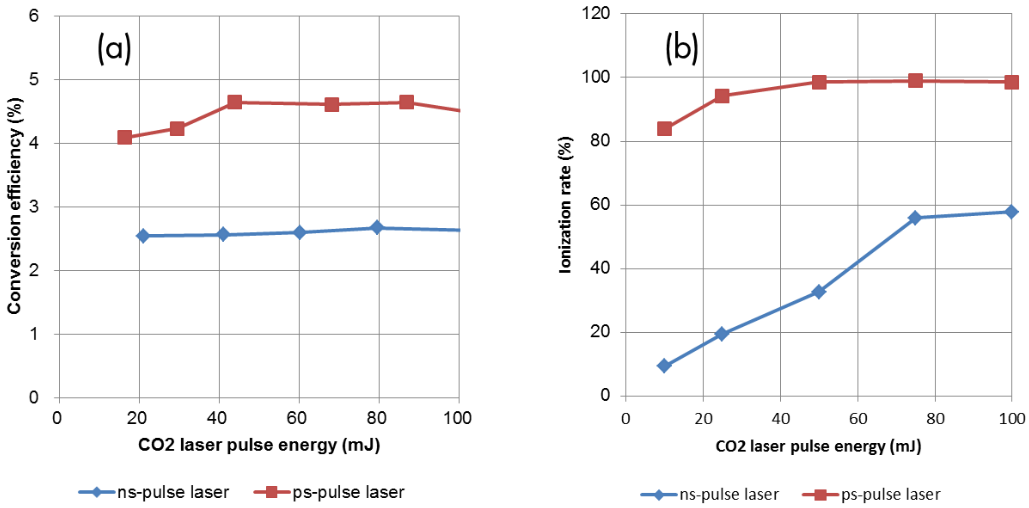

Figure 4. (a) Conversion efficiency and (b) Ionization rate performance using ns and ps pre-pulse laser.

2.3 Magnetic debris mitigation technology

The high ionization rate shown in Fig. 4 (b) is a key parameter in magnetic debris mitigation concept to maximize the lifetime of the collector mirror. Pre-pulse laser produces the uniform mist from the liquid tin droplet. The EUV light is emitted from the tin plasma produced by the high power CO2 laser. Tin ions are guided towards ion catchers by the powerful magnetic field generated by the superconducting magnet. Remaining tin atoms deposit on the collector mirror and are etched by H2 gas. In this concept, H2 gas flow can be minimized because almost tin debris can be trapped as tin ions by the magnetic field. And also, high CE shown in Fig. 4 (a) can reduce the CO2 laser power. These mean the gas heating effect generated by high power CO2 laser shooting to tin droplets can be minimized in the high EUV power operation.

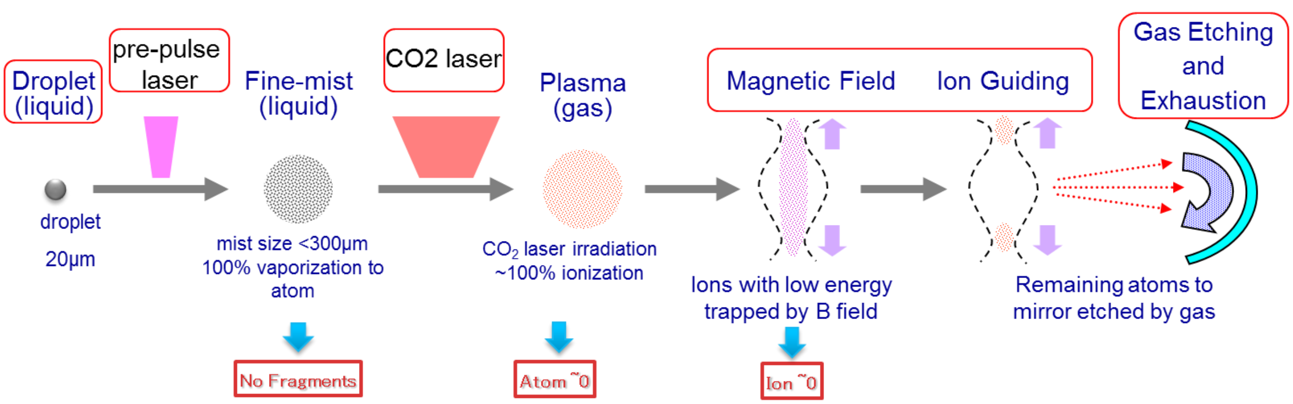

Figure 5. Concept of magnetic debris mitigation

3. SYSTEM PERFORMANCE

3.1 Debris mitigation performance

Figure 6 shows the recent tin deposition data on the collector mirror. These data were measured with using witness plates on collector mirror. Tin deposits clearly near ion catcher areas in the data of (a) and (b). This means that tin ions are effectively trapped by magnetic field and magnetic debris mitigation function effectively operates. Tin deposition near ion catcher area is due to the tin back diffusion from ion catchers. This has been improving by improving ion catchers, shown in Fig.6 (c).

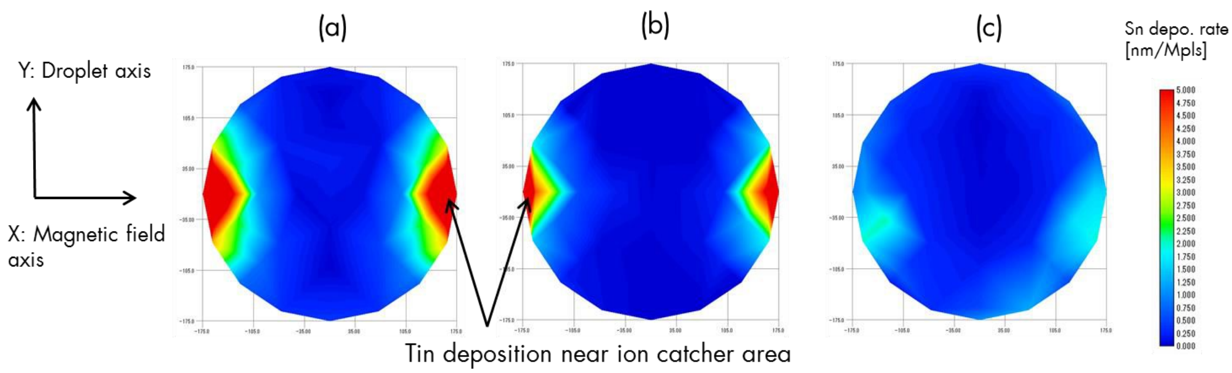

Figure 6. Tin deposition rate data on collector mirror

3.2 EUV power

Figure 7 (a) shows EUV power and CE dependency on CO2 laser power w/o dose control at 100kHz, 50% duty cycle. Maximum EUV power is 268W with 3.5% CE at 22kW CO2 laser power. We already achieved over 4.5% CE with over 100mJ CO2 pulse energy in small EUV light source experimental device. This means that there is a room for further optimization in our EUV light source system. Figure 7 (b) is the long term operation data with dose control. EUV power is 188W with below 0.3% dose stability (3sigma), which is controlled by CO2 laser power. Operation time is 7 hours. Average CE is 3.7% with about 15kW CO2 laser power. The EUV power in our EUV light source system has been approaching the power target of 250W for HVM. And also, these data support the advantage of our technology concepts such as the dual wavelength shooting and magnetic debris mitigation.

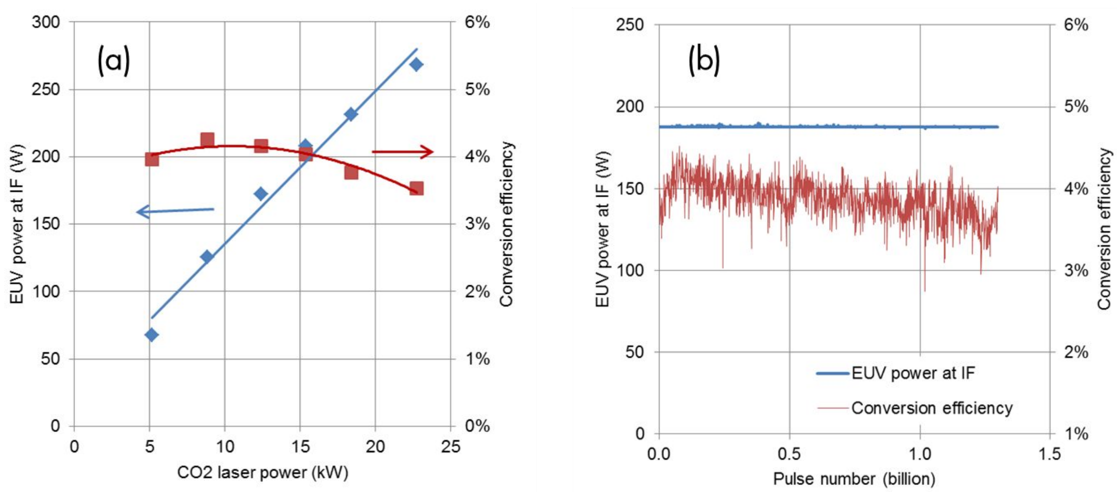

Figure 7. **(a)** EUV power and CE dependency on CO2 laser power w/o dose control at 100kHz, 50% duty cycle, **(b)** EUV power and CE with dose control at 100kHz, 50% duty cycle as a function of pulse number

4. CONCLUSIONS

We have developed LPP-EUV light source for HVM lithography. We showed the key technologies such as CO2 laser, pre-pulse laser and magnetic debris mitigation technology. We also show the latest performance data which is 188W EUV power at intermediate focus (IF) point with 3.7% conversion efficiency (CE) at 100 kHz.

ACKNOWLEDGEMENTS

This work was partly supported by New Energy and Industrial Technology Development Organization (NEDO).We acknowledge to following researchers and organizations; Plasma simulation is supported by Dr. Jun Sunahara in Osaka University. Plasma diagnostics is supported by Dr. Kentaro Tomita, Prof. Kiichiro Uchino and others in Kyushu University. Laser engineering is supported by Dr. Akira Endo in HiLase Project (Prague). CO2 laser amplifier development is supported by Dr. Junichi Nishimae, Dr. Shuichi Fujikawa and others in Mitsubishi electric CO2 laser development team.

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