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CThB2 8:30 am

Liquid Droplet-target Laser Plasma Sources for EUV Lithography

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EUV lithography is now considered to be the most likely technology to follow 193 nm deep UV lithography to satisfy the needs for computer chip manufacture with feature sizes of 70 nm and lower.[1] The roadmap for this technology, which is based on narrow-band (<3%), multi-layer coated reflective optics, calls for the development of stable, debris-free, light sources producing collectable in-band emission at ∼13.5 nm with power levels of ∼100 W.[2] This challenge is currently being met by two light source technologies, small dense plasma electric discharge lamps, and high repetition-rate laser plasma sources. The latter is now favored as the source of choice for the first engineering tests of an EUV lithography tool.[3] For laser plasmas to be a viable choice for this application they must operate continuously at repetition rates of ∼5 kHz with a pulse-to-pulse stability of better than 2% in a regime that protects the high NA (>0.25) collection optics from deleterious effects of target debris for periods of ∼1 year. Moreover they must demonstrate a conversion efficiency from laser light to in-band EUV plasma emission sufficiently high to (i) provide the projected required collectable power levels with viable commercial lasers and (ii) permit the overall cost of the source, including the laser, to remain within economic models of the overall EUV lithography stepper tool.

Several materials have been investigated as optimum continuous targets for 13 nm laser-plasma sources for EUV lithography. High density Xe which emits a broadband 10–14 nm of emission from Xe^{9+} ions, has been investigated with pulsed and continuous cluster targets[4] and liquid jets[5] and droplet targets[6] being studied. The liquid water droplet target,[7] and has undergone extensive investigation.[8] It emits a bright line at 13.0 nm from the 4 d- 2 p transition of Li-like Oxygen, which is narrower than the bandpass of the EUV multilayer mirrors (∼03 nm), and has demonstrated extended operating lifetimes without significant debris contamination.[9] Both these approaches demonstrate conversion efficiencies to in-band radiation of <0.8%, making achievement of the required powers difficult with available laser technology. Recently we have reported a new target configuration having >2% conversion efficiency[9] making >60 W possible with diode-pumped Nd:laser technology.[10]

We are currently undertaking a combined theoretical and experimental investigation of laser-plasmas produced in this regime. This includes measurements of the plasma and radiation dynamics with particle, radiation and optical diagnostics, (Fig. 1 shows a nanosecond optical Schlieren micrograph of the plasma expansion of a droplet target), coupled with detailed hydrodynamic and atomic physics code calculations.

Laser-plasma sources must also meet stringent long-term operation and debris-free conditions for EUV lithography. We are making detailed studies of these issues. For instance the sputtering effects plasma ions on Mo/Si optics is under study. Fig. 2 shows a SEM image of the ablation of several coating layers resulting from prolonged exposure to a water droplet source.

Several debris inhibition approaches are also being investigated, including gas curtains,[11] foil-traps,[12] and the use of repeller electrostatic fields.[12] We will review the efficacy of these techniques for different laser plasma sources, and report our latest developments on repeller field configurations.

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11. A flowing He gas curtain located in front of the source to stop particulate matter.
12. A concept devised by FOM in the Netherlands and developed by Cymer Corp.
13. G. Schriever, M. Richardson & E. Turcu "Laser plasma source for EUV lithography" (to be published).

CThB3 8:45 am

Enhancement of Laser-plasma EUV Conversion Efficiency by Introduction of Prepulses

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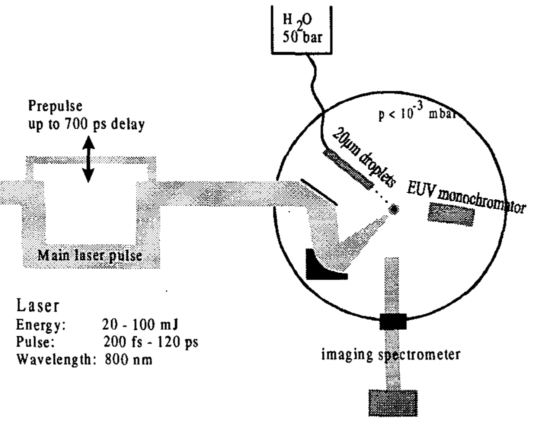
Until today laser plasma based EUV sources for lithography are still lacking to provide sufficient EUV output power for industrial use. The straight forward way to get more EUV power is to increase the incident laser energy or repetition rate. However, a tricky method is to modify the laser pulse in a way to improve the EUV conversion efficiency from laser radiation into EUV radiation. One way is to use prepulses to create the right preplasma conditions for optimum absorption of the main pulse. We show that by introducing a prepulse the conversion efficiency can be improved within a factor 6–8.

In our experiments water droplets with 20 µm diameter were irradiated with laser pulses, focussed to a 20 µm diameter focal spot, from a



CThB3 Fig. 1. Setup used for the EUV conversion measurement.