LASER PLASMA EUV SOURCE BASED ON A SUPERSONIC DOUBLE JET

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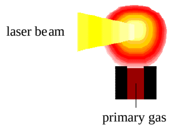
MOTIVATION

- Laser plasmas based on gaseous/liquid targets have perspective for first EUVL operations.
- Gaseous systems suffer from low initial density and high EUV absorbtion:
    - target material expands into a large volume outside focus area,
    - most perspective target gases show high EUV absorbtion.
- Residual debris due to plasma nozzle interaction imposes need to work at safe distance:
    - reduced target gas density results in a low CE.

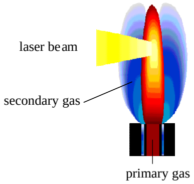
- Jointly with the Institute for Optoelectronics (Warsaw) we have applied a double co-axial jet laser plasma EUV source circumventing absorption in high-Z target gas [1][2].
- The source is based on a central nozzle from which a high-Z target gas is puffed (e.g. Xenon) and a secondary, co-axial annular nozzle from which a low-Z gas (e.g. Hydrogen) is ejected.

SINGLE JET EXPANSION



- Absorption of EUV in low density target gas zone.
- Decrease of CE @ 'safe' distance.

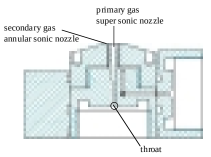
DOUBLE JET EXPANSION



- Reduction of absorption of EUV.
- 'Confinement' of target gas allows safe nozzle-plasma distances.

SUPERSONIC DOUBLE JET GEOMETRY

- Further improvement of CE is expected by increasing target jet density.
- Supersonic nozzle produces higher axial density compared to sonic jet [3].



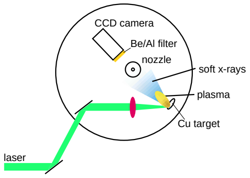
Dimensions central nozzle:
- throat diameter 0.4 mm
- exit diameter 1.2 mm
- half angle = 2 degrees
- length = 11.4 mm

Dimensions secondary nozzle:
- inner diameter = 2 mm
- width = 0.2 mm

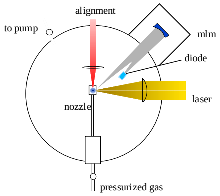
- Second generation, supersonic double jet being employed in this work (nozzle produced by University of Utrecht).
- Third generation being constructed, matches jet size to focus size (to be produced by Stork); target 100 µm throat, double jet geometry.

SETUP

Parameters backlighting setup;
- Nd:YAG, 2 J/pulse @ 532 nm, 15 ns FWHM
- Cu target
- 25 µm Be/8µm Al filter
- CCD camera (Reflex)

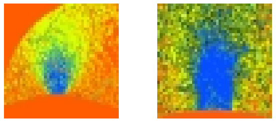


Parameters EUV yield setup;
- KrF laser, 1.0 J/pulse @ 248 nm, 27 ns FWHM
- 68.5% Multilayer mirror reflectivity @ 13.5 nm
- Calibrated IRD AXUV100 junction diodes
- 50 nm Si_3N_4 + 100 nm Nb filter (calibrated)
- a-spherical lens F=100mm, 25 µm spot, $4*10^{12}$ W/cm^2



JET DENSITY

- Density of gas jets determined by x-ray backlighting.
- One-to-one imaging technique.
- Laser-plasma produced keV radiation.
- Shadow of the gas jet recorded using a CCD camera.

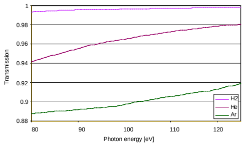


sonic nozzle
0.5 mm orifice

supersonic nozzle

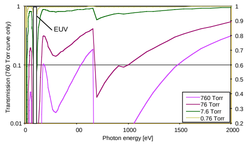
- Supersonic expansion produces a higher density over a length of several orifice diameters.
- Diagnostics of gas density in central zone (locally about 1 bar) requires 1.5 keV radiation.
- Lower pressures (see graph below, at the shock wave zone) require EUV wavelengths.

Transmission at EUV wavelengths for H_2, He and Ar (~5 Torr, 0.5 cm path length).



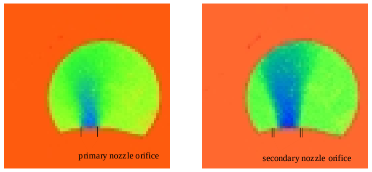
- Note 11% transmission for Xe @ 13 nm.
- H2 is the most suitable buffer gas.

Xe transmission in double jet



- 760 -76 Torr range pressures corresponding to central jet zone, 7.6 - 0.76 Torr range corresponding to blow off zone.

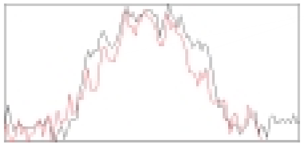
- Supersonic flow shadowgrams.



primary gas only

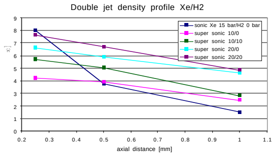
primary and secondary gas

- Cross sections shadowgrams, perpendicular to jet flow @ 1 mm distance.



blow off zone

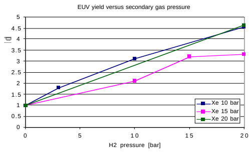
- Jet density profile calculated from shadowgrams.



- Sonic nozzle produces steeper density profile compared to super sonic nozzle.
- Secondary gas does not disturb supersonic profile.
- Target gas density increases when applying H_2 as a secondary gas.
- Flow of supersonic nozzle is not choked:
    - target gas density can be further increased by increasing primary gas pressure,
    - perspective of further enhancement of density/CE.
- Increase of average target gas density at a distance from the nozzle is comparable to the sonic double jet case [4].

EUV YIELD

- EUV yield increases up to 5 times when using H_2 as secondary gas (0.5 mm distance).
- Absolute yield measured still comparable to sonic double jet (close to nozzle).
- EUV yield scales primarily with pressure of secondary gas (H_2).



CONCLUSIONS

- First version of super sonic nozzle has been designed, built and tested successfully.
- Backlighting @ 1.5 kV is a suitable technique to determine Xe gas jet densities.
- Supersonic geometry significantly reduces density drop at practical focus distances.
- Axial density of the supersonic double jet is determined mainly by the primary gas jet density.
- Physical mechanism active in co-axial jet has been found:

⇨ Also in supersonic jets, secondary (buffer) jet increases primary (target) gas density (1.3-1.4 times).
⇨ Gain in EUV yield due to secondary jet: up to factor 5.
➡ EUV gain primarily caused by reduced 'self-absorption' of Xe by low density blow-off zone

FUTURE

- Third version with smaller throat and exit diameters (being constructed).
- Backlighting at longer wavelengths to increase diagnostic power:
    - reveals information on low-density Xe blow-off zone,
    - indicate further direction of optimization.
- Absolute EUV measurements.

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2 H. Fiedorowicz, A. Bartnik, C. C. de Bruijn and F. Bijkerk, Patent Application P-0162.000-US
3 O. Hagena and W. Obert, J. Chem. Phys. 56, 1793 (1972)
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