FOM-Institute for Plasma Physics Rijnhuizen

EUV yield enhancement due to propagating shockwaves in laser produced plasmas

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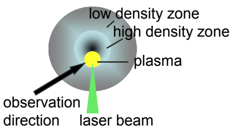
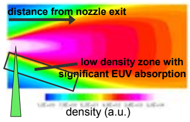
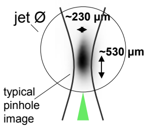
GASEOUS/VAPOUR JETS AS TARGET FOR EUV GENERATION

- Common problem of Xe jets, Sn vapour jets is reduced EUV yield due to increase in density
- Expansion results in low density Xe/Sn volume → major absorption loss, occurring in most EUV sources [1,2]

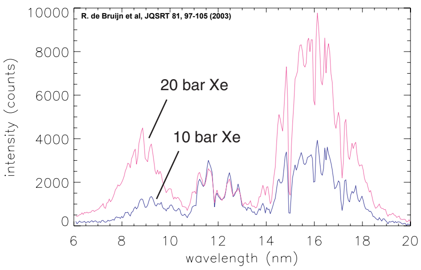






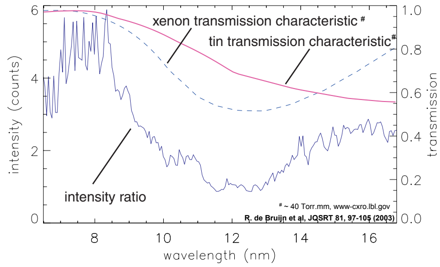
- EUV losses due to absorption in low density zones!
- Elongated plasma shape due to fractional absorption of laser pulse by xenon.

CHANGES IN XUV INTENSITY DUE TO HIGHER DENSITY



Standard method, increase of yield by increasing backing pressure does not lead to similar increase between 11-14 nm!

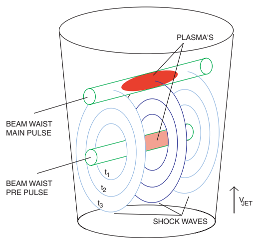
RATIO OF XUV XENON SPECTRA



Low absorption in Xe (< 11, >16 nm)→ Intensity ∝ (density)^2
High absorption in Xe (~13.5 nm) ⟶ Intensity ≈ constant

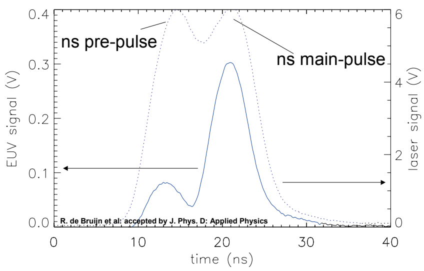
Solutions: replace xenon by EUV transparent buffer gas or increase density inside the jet only!

PRINCIPLE OF THE SHOCK WAVE ENHANCED DENSITY TECHNIQUE



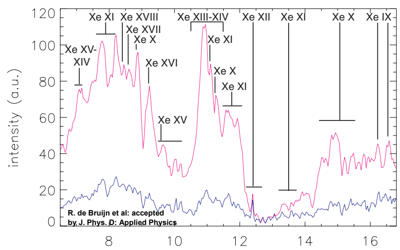
Scouting experiment using ns prepulses:
1) Apply pre-pulse to produce shock wave, jet density is increased locally!
2) Produce EUV by main-pulse interaction with shockwave. (fixed delay 7 ns)
Laser: Nd:YAG, 6 ns, 532 nm, 10^{12} W/cm^2

FIRST STAGE: SCOUTING EXPERIMENT AT FOM NARROW BAND EUV YIELD @ 13.5 nm



Narrow band EUV yield increase 4 times with respect to use of main pulse only!
Note: 140 mJ pre-pulse energy used.

CHANGE IN SPECTRAL INTENSITY



Up to 5 times increase in broad band yield!

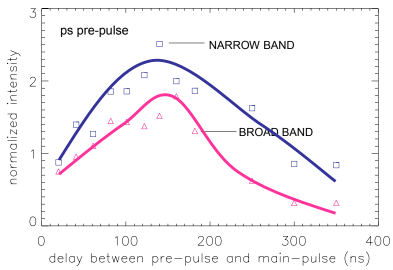
SECOND STAGE: EXPERIMENTS USING PS PRE-PULSES AT CCLRC RUTHERFORD APPLETON LABORATORY

shockwave density ∝ shockwave velocity and
shockwave velocity ∝ laser power density/energy

Increase distinct separation pre- and main-pulse
No EUV contribution from pre-pulse

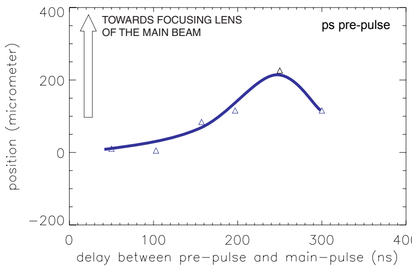
Pre-pulse 4 ps, 248 nm, 4 x 10^{14} W/cm^2
Main-pulse 6 ns, 532 nm, 7 x 10^{12} W/cm^2

NARROW AND BROAD BAND EUV YIELD



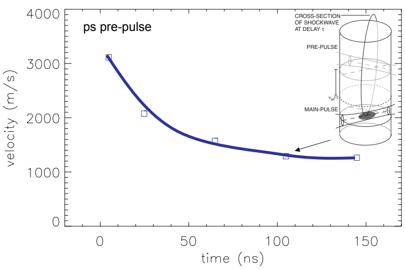
- Increase was still 2.5 times!
- Maximum increase at delay of 150-160 ns!
- Note: only 10 mJ pre-pulse energy used.

SHIFT IN PLASMA POSITION



1) < 100 ns → increase due to higher density
2) 100-200 ns → lower shock wave density BUT decreased EUV absorption results in net gain, due to plasma-edge position.
3) > 200 ns → too low target density

MODELING OF SHOCKWAVE PROPAGATION BY EPPRA SAS WITH Z* CODE [3-6]



The average shockwave velocity at 150 ns is 1.2 x 10^4 m/s.
From measurements we found 1.0 x 10^4 m/s
→ Modeling with Z* code confirms experiment!

SUMMARY

- Laser pulse interaction with shockwaves results in a higher yield without increased EUV absorption. Up to 4 times increase @ 13.5 nm is measured.

- A delay between pre- and main-pulse can be used to control the plasma position, and thus reduce EUV absorption.

- The use of ns pre-pulses results in a higher increase due to higher shockwave density compared to ps pre-pulses. This is explained by on going heating of pre-pulse during main-pulse interaction.

OUTLOOK

- Laser pulse interaction with oppositely moving shockwaves like in ICF.
- Use of new beam waist geometries.

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