2nd International Workshop on EUV Lithography

A High-Power Laser-produced Plasma EUVL Source for ETS

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Scale-up of the Laser-produced Plasma EUVL source has required significant re-engineering.

Status:

Pulsed Xe cluster jet: 0.8% conversion efficiency w/40W Coherent laser
Continuous Xe Dew Point 2-phase jet: 0.6% CE w/1500W TRW laser
Continuous Xe Liquid Jet: expect more EUV, greater stability, w/1500W laser

Advantages:

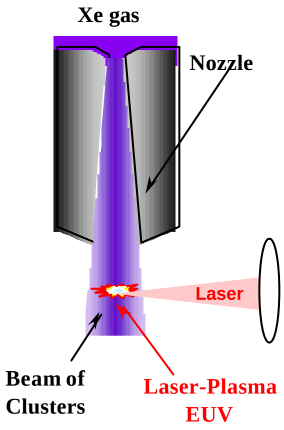
Low debris production
Scalable to multi-kHz operation
Low source cost via Xe gas recirculation
Open geometry for EUV collection

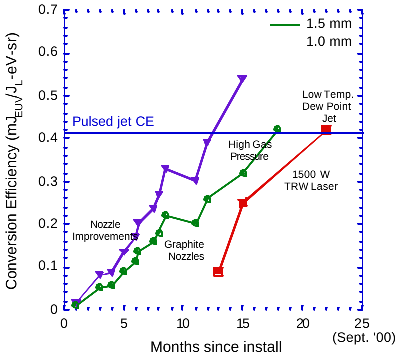
Scale-up issues:

Impact of high-average-power laser pulseshape
Thermal loading of source
Condenser lifetime

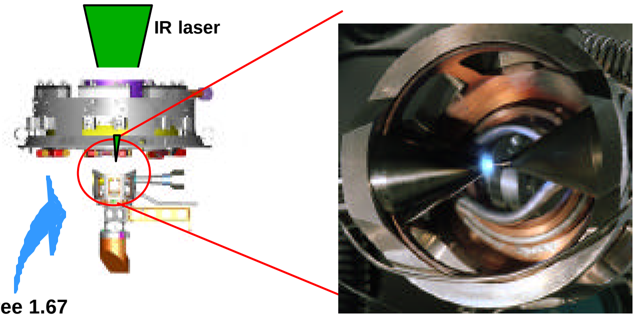
Scale-up of the Laser-Plasma Cluster Jet for EUVL showed reduced conversion under continuous operation.

Vaporized clusters produced EUV, but no particulate debris; scalable to > 6 kHz



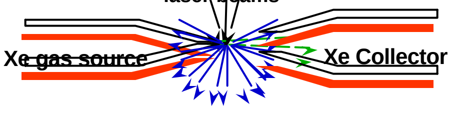


The Xe cluster jet is housed within the Illuminator of ETS.



Continuous
re-circulating
Xe gas jet source

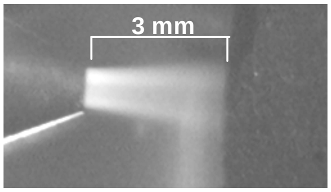
Three 1.67
KHz
multiplexed
laser beams



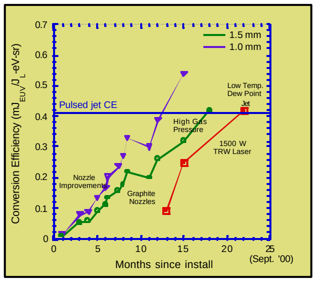
EUV
light

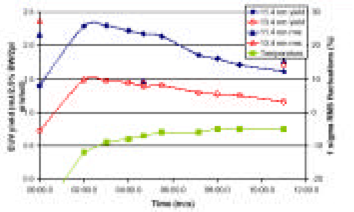
Approach
- 1500 watt, 5 KHz laser from TRW
- Use 100 % Xe gas recycling
- Optimize gas jet EUV efficiency
- Maximize condenser lifetime

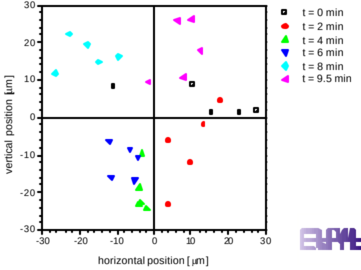
The continuous dew point jet improved CE, but showed low pulse stability with time (cf. ASML results).



- **1250W TRW laser**
- **0.75 J/pulse**
- **ASML measurements at Sandia**

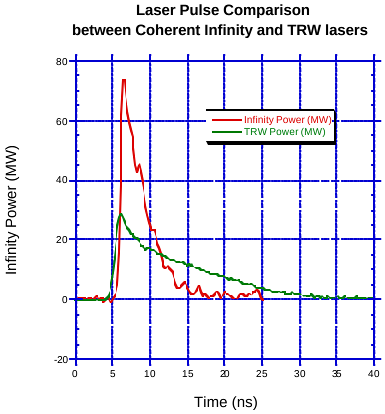


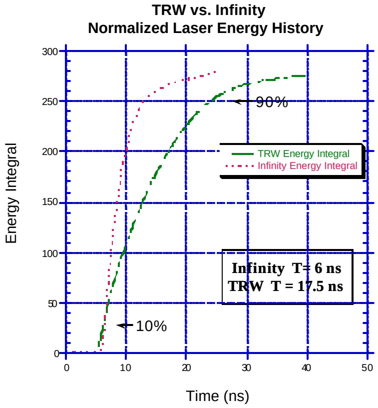




Laser pulseshape drove nozzle design to higher density liquid jet targets and better nozzle cooling.

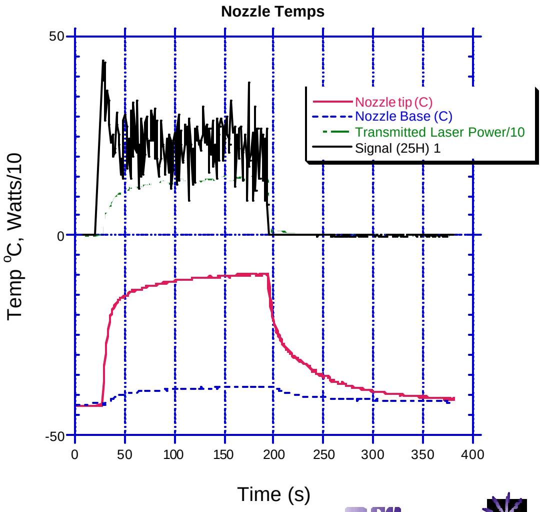
- One chain of the TRW laser (290mJ) was limited in its ability to produce breakdown in the dew point jet.





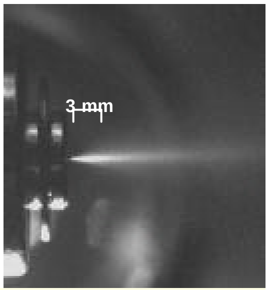
Thermal loading has been clearly seen to reduce EUV output in the dew point, partially condensed jet.

- Thermocouples were placed both in the cooling block and in the nozzle tip.
- EUV signal decrease corresponded to the nozzle temperature increase.
- Heated nozzle heats the Xe jet and reduces target density.



The prototype Xe liquid jet increased target density and allowed for larger laser-nozzle separation.

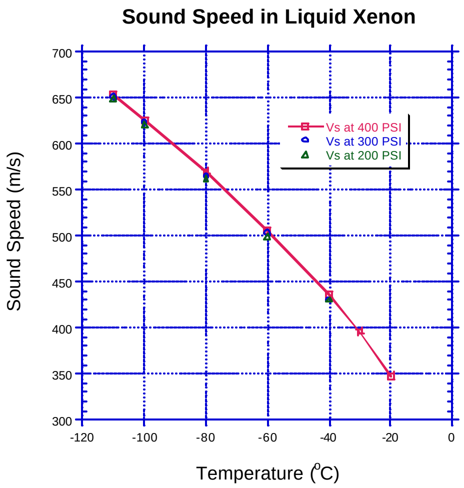
- Operation at a greater distance from the nozzle should enhance condenser lifetime.
- Improved condensation should result in less surrounding neutral gas and improved EUV transmission.
- EUV Conversion Efficiency of solid Xe is 1.3% in 2.5% BW and 2π, setting a benchmark for jet EUV production. (Best continuous dew point jet CE was ~0.6% at 1.5 mm.)



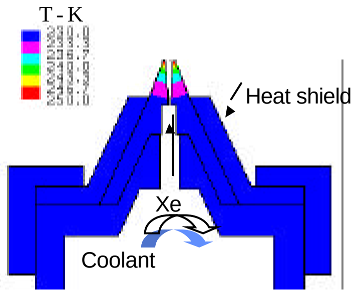
Light scattering from jet revealed sub-mm diameter stream

The measured liquid jet flowrate indicates sufficient flow to operate at frequencies in the 10’s of kHz.

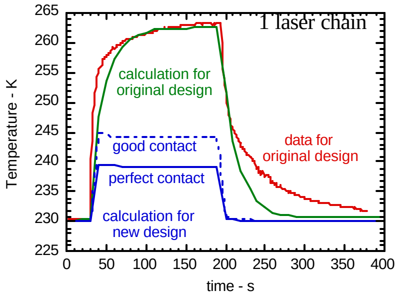
- Disruption wave moves through 3mm long jet in ~5 µs.
- Next laser pulse arrives in 200 µs at 5 kHz.


Sound Speed in Liquid Xenon

A new nozzle was designed and built to address these thermal loading issues at high power.



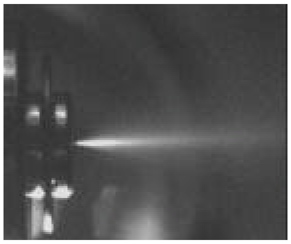
flow rate = 1 g/s



- New design has been shown to keep the nozzle cool when subjected to plasma heating

Scale-up of all EUV sources will require significant attention to thermal and high power driver issues.

- We have moved to a high density, Xe liquid jet source to address laser issues and background gas issues.



- Our new nozzle tip design has reduced heating by re-radiation from the laser-target volume.
- Operation at 25-50 kHz is readily feasible with the liquid jet source.