The Tin-Doped Droplet Laser Plasma Source – Meeting Roadmap Requirements

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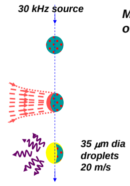
SEMATECH

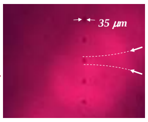
The LPL tin-doped micro-droplet laser-plasma EUV source



Mass-limited target regime – mass of tin within droplet limited to the number of atomic radiators heated by the laser –typically ~ 10^{13} atoms per droplet.

Droplet technology minimizes target debris

High frequency source matched to high rep rate laser



30 kHz stable laser irradiation demonstrated

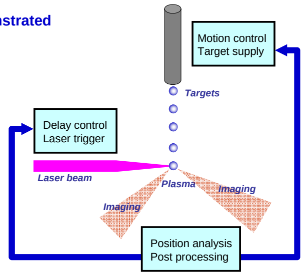
Laser shoots every droplet!

3-D droplet stability of 3 μm

Intelligent 3 –D imaging feedback system controls target and laser beam pointing

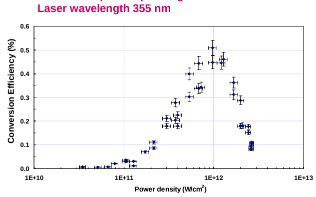
24 hour operation at 30 kHz

Single term operation for several days already demonstrated



3Ω – CE and spectral measurement

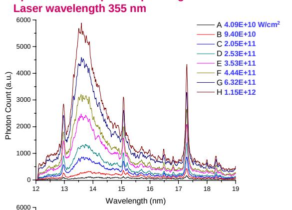
CE of tin-doped droplet target EUV source
Laser wavelength 355 nm

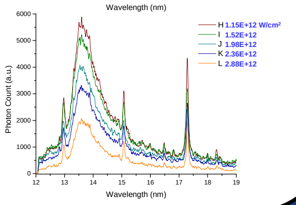


Power density for optimum CE
$\Phi_{optimum} = (1.0 \pm 0.2) \times 10^{12}$ W/cm²

Maximum CE
~0.5%

Spectra of tin-doped droplet target EUV source
Laser wavelength 355 nm





CoO – kW source model

Low cost architectures for SS laser source

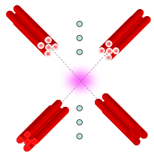
Laser Requirements for Current Source:
100 W @ IF ➡ 200 W Source Power
(η_{coll} =50%, 2π collection, no SPF)
CE = 2% ➡ Laser Power = 10 kW

SOURCE COSTS
Collection mirror + source $1.0M - $1.5M

Laser costs: (10kW)

(a) GA Liquid Laser ~ $2M
(b) 100 kHz Fiber Laser ~ $1M

UCF – UMICH (Galvanauskus) are planning a 500 W demonstration = 5W @ IF



Conclusion

- *CE ~ 2.3% demonstrated with droplet target - > 5% with solid tin. CE > 3% possible*
- *Lower CE measured from 355nm laser irradiation*
- *Long term 30 kHz laser- droplet irradiation demonstrated – 100% fuel consumption*
- *Mirror erosion estimated by measured ion emission characteristics – Factor of 50*
- *Advanced mitigation combined with Repeller field – Satisfy lifetime requirement*
- *Cost effective laser plasma source modeled*

FUNDING
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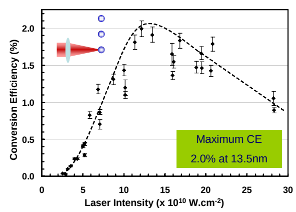
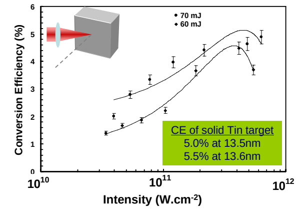
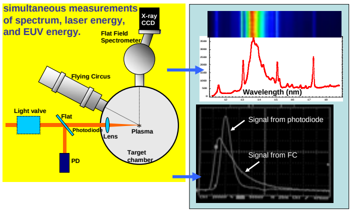
CE Measurement & Optimization

Flying Circus instrument
FOM team
F. Bijkerk
S.A. vd Westen
C. Bruineman

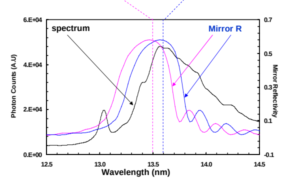






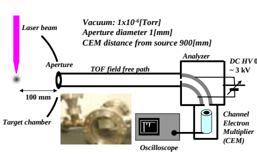
Shifting mirror reflectivity by 0.1 nm increases CE by 12%

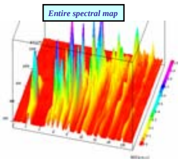
at 13.5nm, CE = 2% at 13.6nm, CE = 2.25%

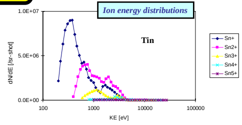


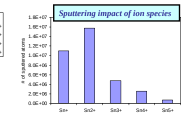
Quantitative Mirror erosion study

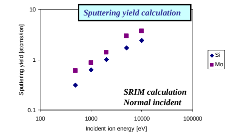
Ion spectrometer

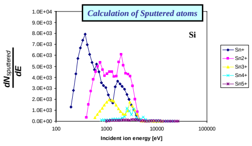












Sputtering rate
Si : 1.4 x 10^{8} shots/nm
Mo: 1.3 x 10^{8} shots/nm

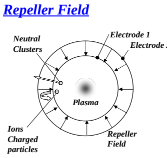
After 1.4 x 10^{10} shots — layer pair of 6.9nm 40 ➞ 25 bilayers Reflectivity 0.73 ➞ 0.66

592 hours at 7kHz, 95% operation — Requirement 30,000hrs

Factor of ~ 50 shorter than the requirement

Debris mitigation

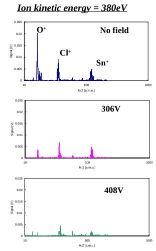
Repeller Field



Repeller field captures anything charged

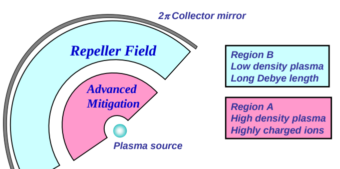
Advantages:
Simple structure
Works for particles as well

Ion kinetic energy = 380eV



Repeller field reduces # of ions ~1 order of magnitude for Tin

Combination of mitigation schemes



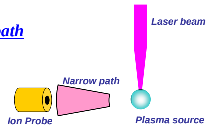
Region B
Low density plasma
Long Debye length

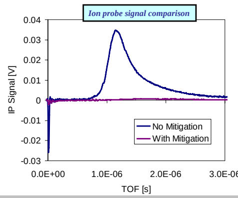
Region A
High density plasma
Highly charged ions

Advantages:
High transmission for EUV collection
Negligible erosion of materials
Neutral atom mitigation expected

Two mitigation approaches

Narrow path





Integrated signals
Without Mitigation: 4.5E-10 [As]
With Mitigation: 2.4E-11 [As]

Reduction factor of ~ 20 for Advanced mitigation

High NA