EUV Source Parameters of the laser-produced tin-doped micro-plasma

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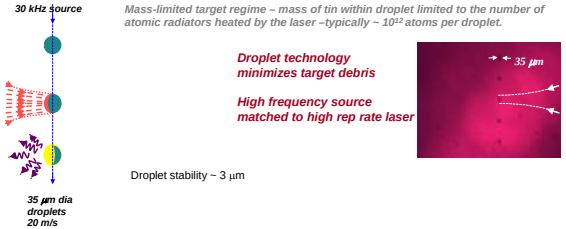
The LPL tin-doped micro-droplet laser-plasma EUV source



Mass-limited target regime – mass of tin within droplet limited to the number of atomic radiators heated by the laser –typically ~ 10^{12} atoms per droplet.

Droplet technology minimizes target debris

High frequency source matched to high rep rate laser

Droplet stability ~ 3 μm

30 kHz stable laser irradiation demonstrated

Laser shoots every droplet!

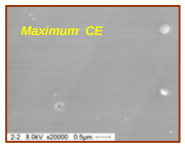
3-D droplet stability of 3 μm

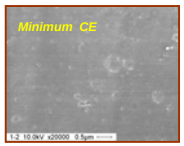
Intelligent 3 –D imaging feedback system controls target and laser beam pointing

24 hour operation at 30 kHz

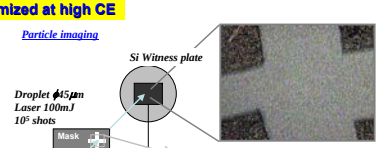
Single term operation for several days already demonstrated

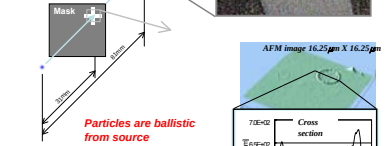
Particle generation minimized at high CE





Particle imaging





Particles are ballistic from source

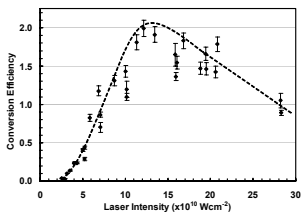
Particles generated as small nano-aerosols

Highest Conversion Efficiency with Tin

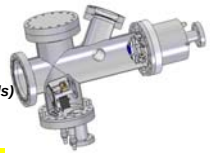
CE > 2% with Sn droplet targets at 13.5 nm

CE = 2.0% at 13.5 nm

Radial illumination leads to higher CE



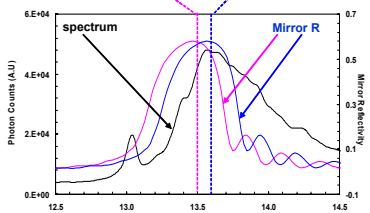
Measured with FC 2
Santi van der Westen, Caspar Bruineman & Fred Bijkerk (FOM – The Netherlands)



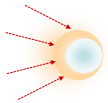
CE increases to 2.3% if λ moved from 13.5 nm to 13.6 nm

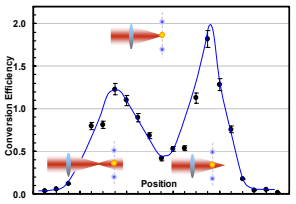
at 13.5nm, CE = 2%

at 13.6nm, CE = 2.25%

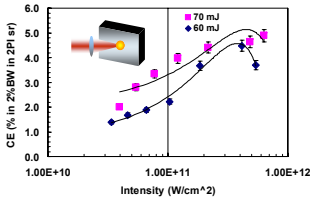


Radial illumination leads to higher CE





In-band CE > 5% with solid tin at 13.5 nm

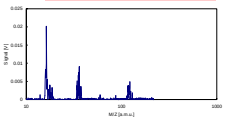


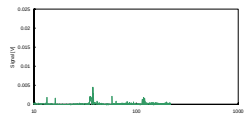
Ion and Particle mitigated by Repeller Field

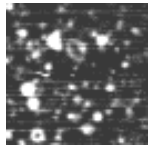
Without Repeller Field

Ion spectrometer signal

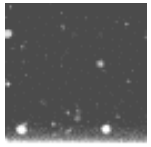
With Repeller Field





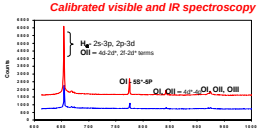


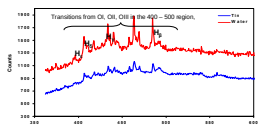
Auger Electron Microscope (Sn particles)

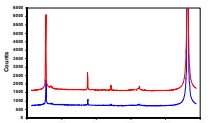


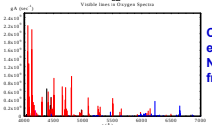
Visible and IR Emission

Calibrated visible and IR spectroscopy







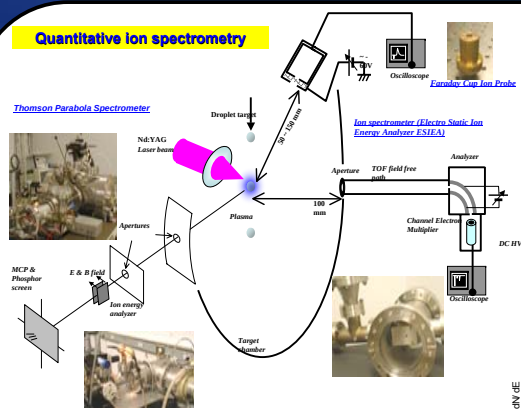


Dominant emission in the visible and IR – scattered laser light

Code predictions of emission from O
No emission lines from Sn predicted

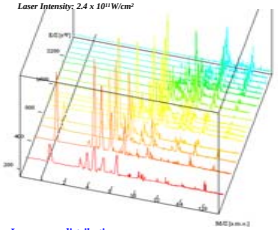
Scattered laser light - 0.6 mJ/pulse/2π - 0.54%
Visible & IR self-emission – 0.24 mJ/pulse/2π – 0.2%

Quantitative ion spectrometry



Ion spectrometer signal

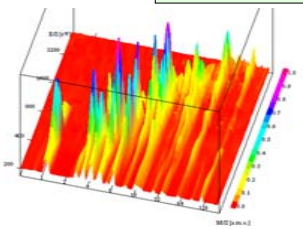
Laser Intensity; 2.4 x 10^{13} W/cm²



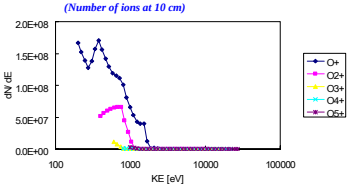
Interpolation

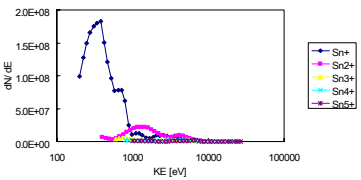
Ion mass (M/Z) spectra

Entire ion spectral map obtained for each plasma condition



Ion energy distribution (Number of ions at 10 cm)





Summary

- *CE ~ 2.3% demonstrated with droplet target - > 5% with solid tin. CE > 3% possible*
- *Long term 30 kHz laser- droplet irradiation demonstrated – 100% fuel consumption*
- *Full characterization of ion emission – no anomalous ion components*
- *Particle emission inversely dependent on CE – further reduction possible*
- *Scattered laser emission and visible/IR self-emission < 0.75%*
- *Short wavelength self-emission manageable ~ 10x in-band emission*
- *Ions AND particles mitigated by Repeller Field – other approaches also needed*

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