XUV spectroscopy of mass-limited Sn-doped laser micro-plasmas

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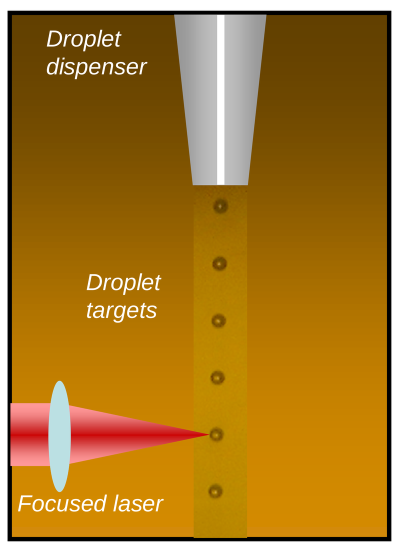
Tin-doped droplet laser micro-plasma source for EUVL

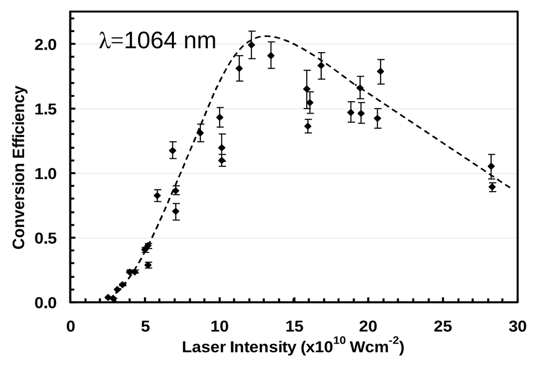
Multi-component spherical droplet target, only 30% of target is Sn

- 35 μm diameter droplet doped with tin
- Stable long-term operation in vacuum
- Precision target positioning (~ 3μm).
- Mass of tin limited to approximately 10^{13} atoms per droplet.
- High frequency droplet generation (20 kHz – 400 KHz)
- Frequency matching to HRR lasers



High CE @ 2.25% in 2% of 13.5 nm

Optimum Intensity: 1×10^{11} W/cm²



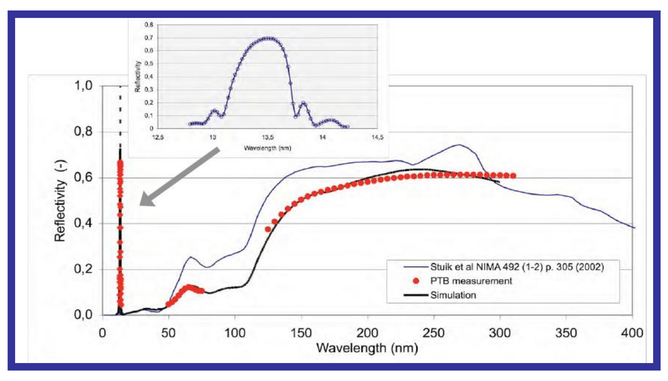
Low debris

- No fast ion generation, target is fully ionized by the end of laser pulse
- No nozzle erosion
- No particulate debris generation with optimized laser-target coupling

Low out-of-band

- Spectral purity assessment
- Out-of-band metrology for all wavelength regions are being completed.
- Atomic physics codes for spectral identification.

Extended Mo/Si mirror reflectivity measurement

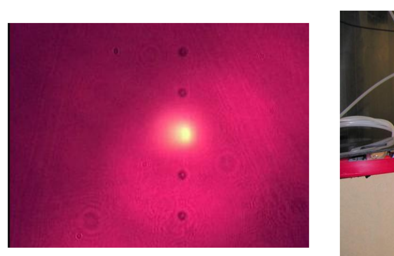


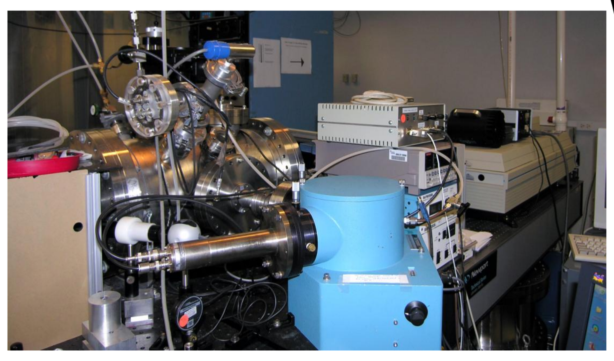
http://www.rijnh.nl/n2/Bijkerk101105SWSpubsympv2.pdf

LPL tin doped droplet EUV source development facility

Target Chambers

Vacuum: ~10^{-4} Torr

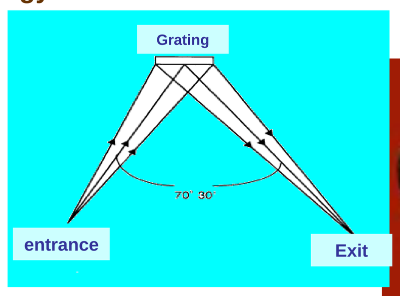




Lasers

Custom built, precision Q-switched, Nd:YAG laser, 11.5 ns pulse, 1064 nm, 1-2 Hz, 1.7J max energy

Spectra-Physics, 1064 nm, 100 Hz, Max. 300 mJ, 10 ns



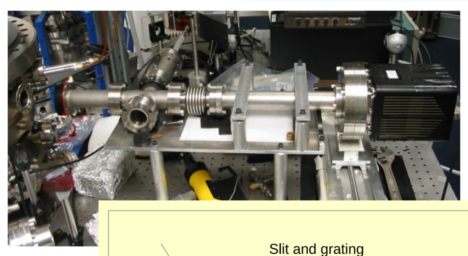
Spectroscopic Instrumentation

In-band: 5 nm – 20 nm

2 Flat-field Spectrometers (FFS)

Near-Band: 1 nm - 30 nm

Transmission Grating Spectrometer (TGS)



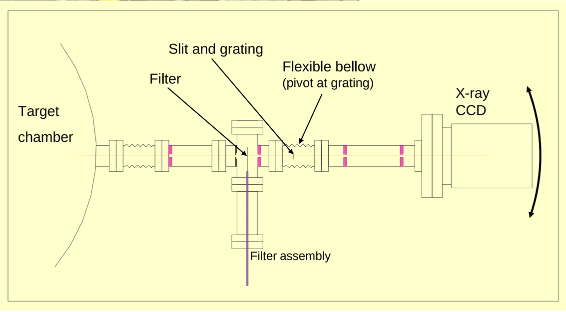
Out-of-Band: 30 nm - 2500 nm

FFS with long wavelength range grating

McPherson Seya-Namioka design based scanning monochromator/spectrometer

Visible/IR grating spectrometer (EG&G)

Ocean Optics HR 4000, NIR256 - 2.5 μm



Emission from tin-doped droplet source at an irradiance intensity of 1×10^{11} W/cm²

Transmission Grating Spectrograph

TGS components

Freestanding silicon nitride grating – XOPT

Line spacing = 10000 lines/mm, or (d=100 nm)

Interchangable metal filter assembly, Sn, Al, Zr

X-ray CCD detector

McPherson Model 234

Based on the Seya-Namioka aberration corrected design

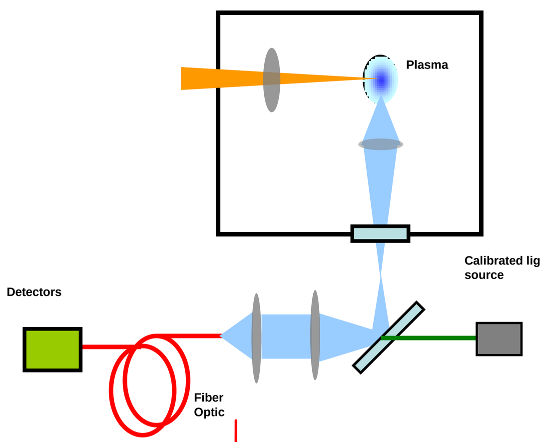
Entrance and exit collimators at fixed distances

Wavelength variation obtained by grating rotation

Mainly used in the vacuum UV region.

Wavelength range: 30 nm - 550 nm
Gratings: 1200 lines/mm, 600 lines/mm
Detector: PMT tube with pico-ammeter
Focal length: 200 mm
Resolution: 0.1 nm

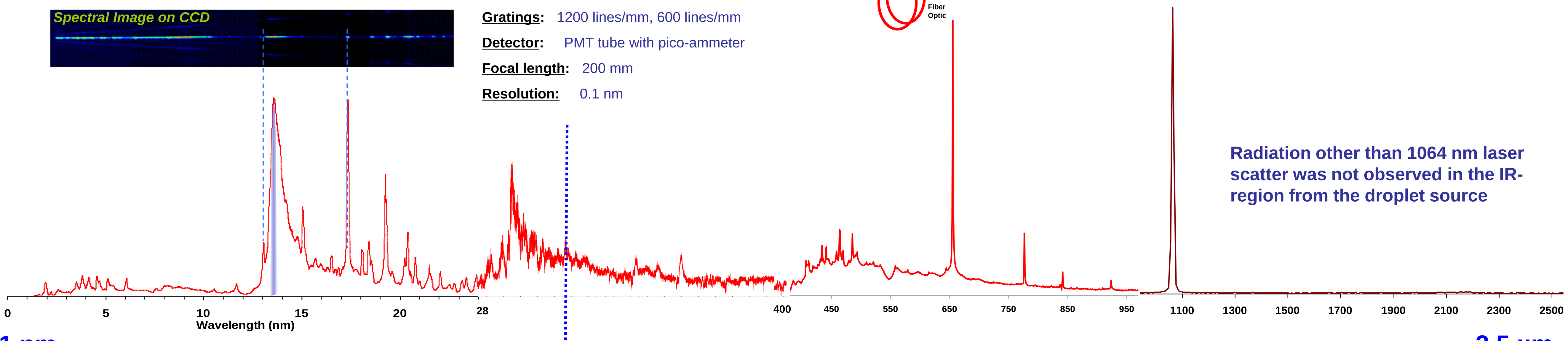
Visible/IR grating spectrometer (EG&G)



Ocean Optics NIR 256 – 2.5

Grating: 150 l/mm blazed at 1.6um
Responsivity Peak: 2.3 μm
Wavelength range: 900-2500nm
Detector: Hamamatsu G9208-256
Detector Temperature: -15°C

Radiation other than 1064 nm laser scatter was not observed in the IR-region from the droplet source



1 nm — 2.5 μm

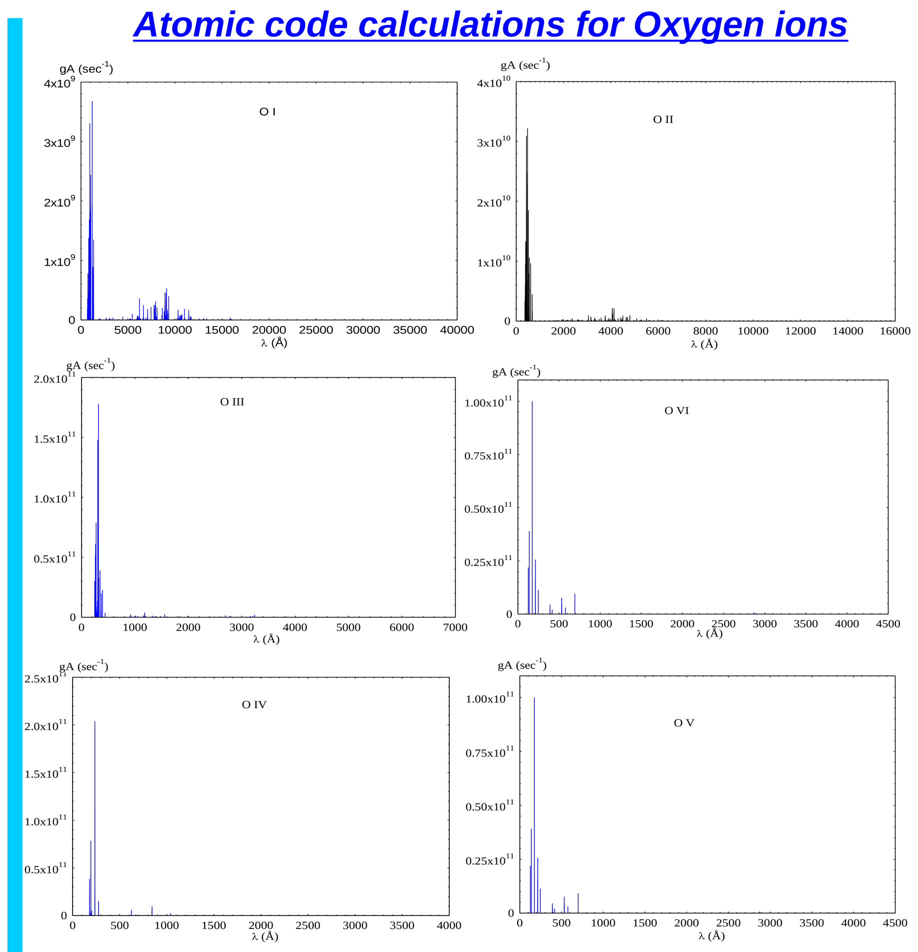
Out-of band emission below 130 nm is not considered critical due to low Mo-Si ML mirror reflectivity in this region

Low emission into visible and IR region above 1 μm is required

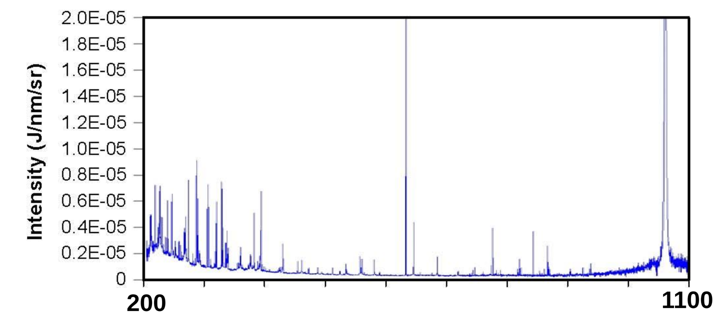
For direct calculation of the energy, a fast photodiode was used. The detector was calibrated using a laser light source of known energy.

Low energy levels are measured in the visible region. Scattered laser energy detected is below critical levels. Resolution improvement and absolute energy calibration of the VUV region to be completed shortly.

Atomic code calculations for Oxygen ions



Solid tin UV/Vis vacuum spectra, copious amount of emission observed in the UV region from solid tin

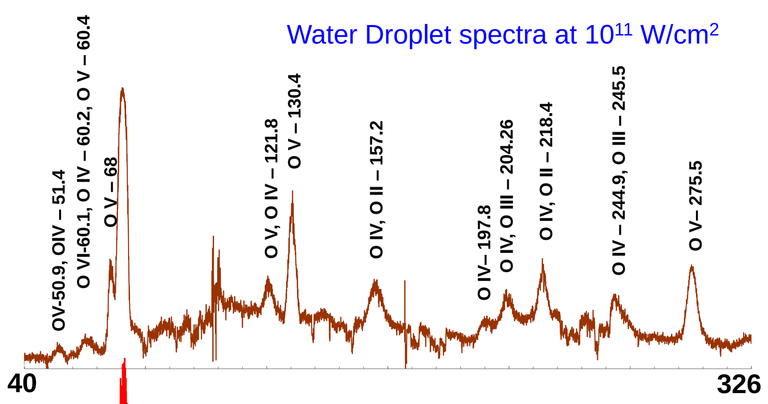


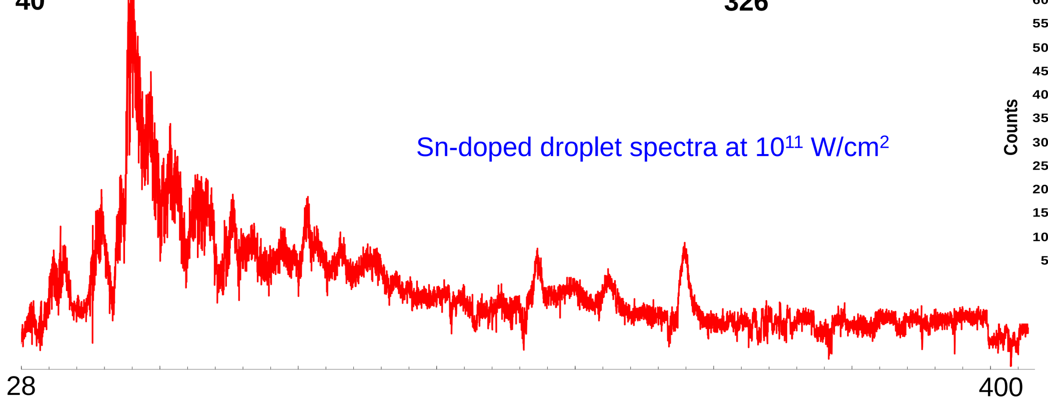
P. Dunne et. al. Technology Transfer #06114813A-ENG, SEMATECH, November 30, 2006

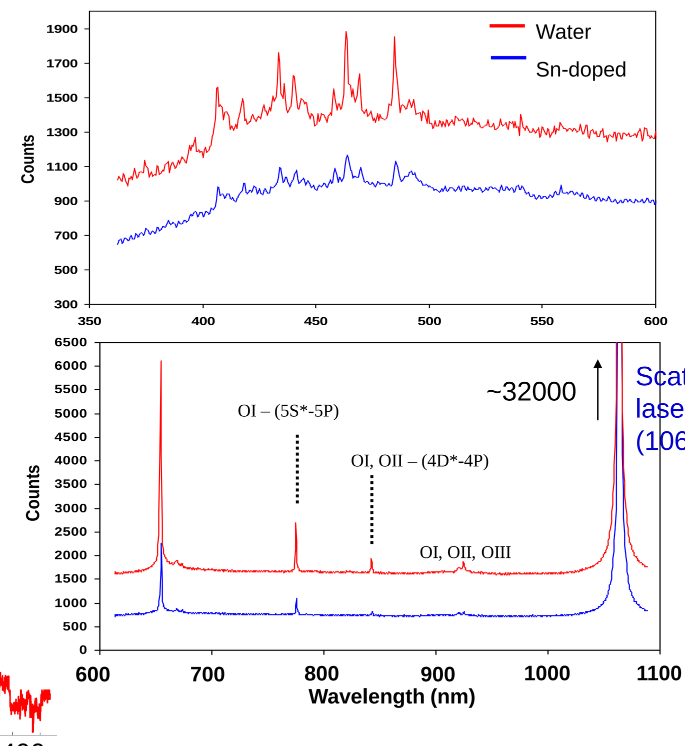
Laser used for these spectral studies: Spectra-Physics, 1064 nm, 100 Hz, Max. 300 mJ, 10 ns

Spectral Characteristics

Data collected for Sn-doped droplets at conditions optimum for high conversion efficiency. For comparison, spectra were obtained for water droplets under the same irradiation conditions.







Observed transitions in the visible region originate largely from Oxygen and Hydrogen in the Sn-doped droplet. Identification of transitions in the VUV region is difficult due to low resolution. Smaller line width grating, as well as controls for noise reduction are being implemented.

Summary

Spectroscopy coupled with hydrodynamic, radiation and atomic physics code calculations, for a quantitative description of emission from tin-doped micro-droplet source.

Inferences obtained from spectral data of tin-based targets have dramatically improved our EUV source performance.

Spectral data in the different wavelength regions have been obtained and are being interpreted.

Absolute energy calibrations of out-of-band emission from the tin-doped droplet target is currently underway.

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