

# Precision 13.5nm metrology of the microscopic tin-doped laser plasma EUV source

## Microscopic tin-doped droplet target

For many years, LPL has been developing laser plasma sources for EUVL based on mass-limited targets

### Principles of the mass-limited target

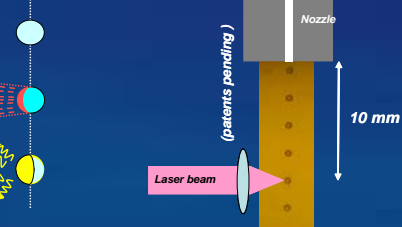
1. Target size limited to the number of atoms that are required as radiators in the plasma.
2. No particulate debris from target.
3. Minimal mass of target material used.

### Precision spherical droplet targets

1. Stable source of targets.
2. New target for each shot.
3. High repetition-rates (~ 100 kHz) possible.
4. Precision target positioning required (~ 3µm).
5. Small mass of target material in source chamber.
6. Low background vapor pressure.

### Source conversion efficiency

1. Dependent on laser target energy coupling.
2. Detailed understanding of plasma and radiation dynamics



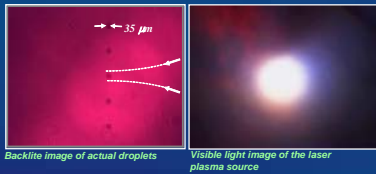
Small diameter droplet target, contains small tin mass

Mass of tin per target ~ 900 pgram (for 10% tin by mass).  
Only ~  $4 \times 10^{12}$  tin atoms per target.

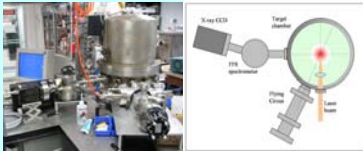
Positional stability in target region ~ 3micron

High-repetition rate operation > 10kHz, convenient for power scaling with high power laser

Plasma located far from nozzle. No nozzle erosion.



## Laser Plasma EUV Source Development Facility



Vacuum target chamber:

Cylindrical 45cm dia, 12 ports

Laser

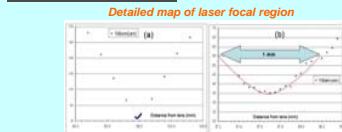
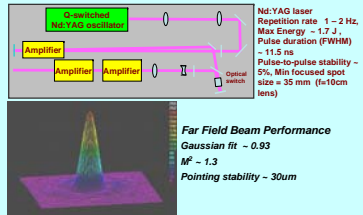
Precision Nd:YAG laser, 11.5 ns pulse, 1064 nm wavelength, 1-2 Hz, 1.7J max energy

Diagnostics

Flat Field Spectrometer, Flying Circus, Transmission Grating Spectrometer, MCP/IGS (upcoming), Sub-nanosecond plasma interferometer

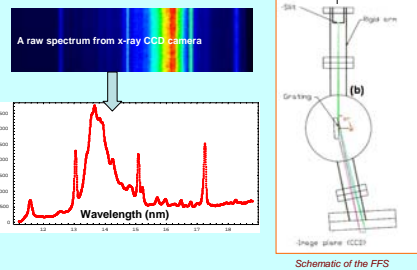
### Precision Nd: YAG laser

Interaction science and radiation physics of the metal -doped targets being studied using a precision laser that provides flexibility and precision output performance



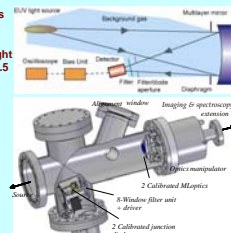
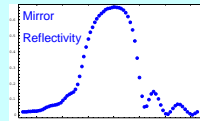
### Flat-field spectrometer

- 1200 lines/mm, gold-coated, variable spaced reflective grating
- 0.5 µm thick, freestanding Zr filter to select wavelengths from 6.5 - 16.8 nm (FWHM).
- a back-thinned x-ray CCD camera to record spectrum
- a selection of collimation slits (from 10µm to 80 µm), spectral resolutions 0.006 nm to 0.01 nm.



### EUV energy measurement

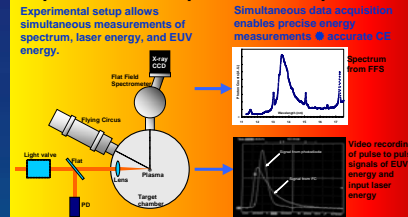
- The "Flying Circus" diagnostic measures absolute EUV energy
- a Mo/Si multilayer mirror, narrow band reflectivity peaks at 13.5nm, to collect light
  - a Zr metal filter to select wavelength: 6.5 - 16.8 nm (FWHM).
  - a Si-PIN x-ray photodiode from IRD to detect EUV



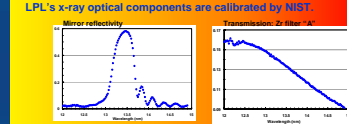
FC2: Figures from International SEMATECH Technology Transfer #04024490A-TR (2004)

## Experimental design and Data analysis

### Experimental setup and Data acquisition



### Calibrated optics for precise metrology



### Method for calculating Conversion Efficiency (CE)

In calculating CE, we use the same method as the FC2 team [1]. From [1], the inband energy over 2π sr, assuming isotropic emission, is

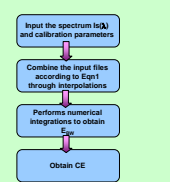
$$E_{EW} = \frac{2\pi A_{\text{mirror}}}{\Omega R_{\text{source}}} \int_{\lambda_{\text{min}}}^{\lambda_{\text{max}}} I_{\text{e}}(\lambda) d\lambda \quad (\text{Eqn.1})$$

Ω is the collection solid angle of the FC mirror from the source.  
A<sub>mirror</sub> is the integrated area under the EUV signal waveform displayed on an oscilloscope.  
R<sub>source</sub> is the impedance of oscilloscope channel.  
I<sub>e</sub>(λ) is the transmission curve of the gas in the vacuum chamber (from CXRO).  
R<sub>mirror</sub>(λ) is the calibrated mirror reflectivity curve.  
T<sub>Zr</sub>(λ) is the transmission curve of filter(s) used to block visible light from entering AXUV detector.  
R<sub>axuv</sub>(λ) is the calibrated responsivity curve of the AXUV detector in the FC.  
I<sub>e</sub>(λ) is the spectrum of the EUV source.

$$CE = \frac{E_{EW}}{E_{\text{laser}}} \times 100 \quad \text{Units: } \% \text{ over } 2\pi \text{ steradian and within } 2\% \text{ BW centered at } 13.5\text{nm}$$

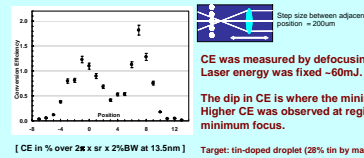
[1] International SEMATECH Technology Transfer #04024490A-TR (2004)

A numerical analysis computer program was developed for this purpose

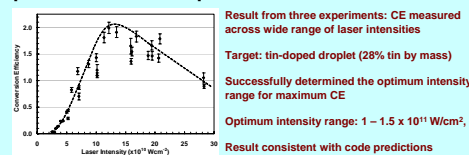


## Experimental Results

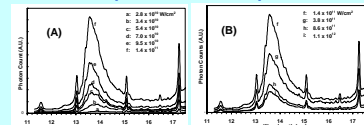
### I. Conversion Efficiency - function of focus position



### II. Conversion Efficiency - intensity studies

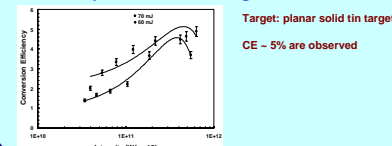


### III. CE and Spectra relationship



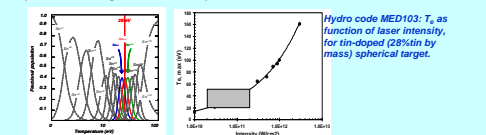
The 13.5nm UTA from Sn ions (Sn<sup>4+</sup> - Sn<sup>13+</sup>) in the spectra. Peak of UTA rises (A) as intensity until  $1.4 \times 10^{11}$  W/cm<sup>2</sup> (at spectrum F). Then, UTA peak decreased with increasing intensity (B). The intensity  $1.4 \times 10^{11}$  W/cm<sup>2</sup> corresponds to optimum intensity for max CE. Rise and fall of UTA peak consistent with CE trend.

### IV. CE of planar solid tin target



### V. Code predictions for optimum irradiation condition

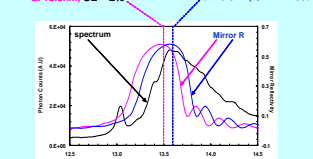
Sn ion distribution and hydrodynamic calculations predict optimum intensity for max CE to be  $0.2 - 2.0 \times 10^{11}$  W/cm<sup>2</sup>, consistent with experimental result. Prediction provides useful guide for source optimization.



### VI. Effect of adjusting the wavelength of choice

At present, the wavelength of choice for EUVL is 13.5nm within a 2% spectral bandwidth. For the tin-doped droplet LPP source, a slight adjustment in the wavelength of choice, from 13.5nm to 13.6nm, significantly increases the CE.

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



## Summary

High repetition-rate, particulate-free, laser plasma sources possible with mass-limited targets. Low mass target with very small amounts of tin.

Improved source performance through broad parametric studies.

Performed precise metrology using calibrated optics.

CE in excess of 2.2% realized at 13.6 nm. With solid tin targets, CE = 5%. Absolute CE calculated according to method set by FC2 team.

Radiation modeling is important in optimization of source efficiency. We are committing resources to this end.

### Acknowledgements

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