

Microscopic tin-doped droplet laser plasma source

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

Principles of the mass-limited target

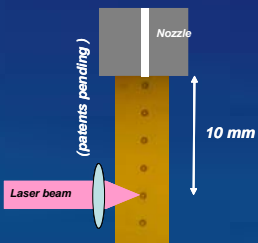
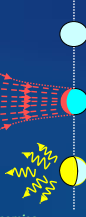
1. Target size limited to the number of atoms that are required as radiators in the plasma.
2. No particulate debris from target.
3. Minimal mass of target material used.

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 x 10¹² 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.



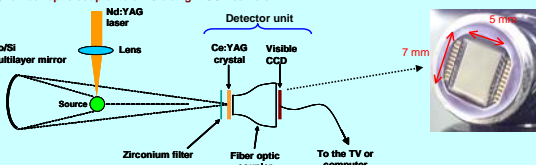
Backlite image of actual droplets

Visible light image of the laser plasma source

Imaging technique

A novel alternative technique

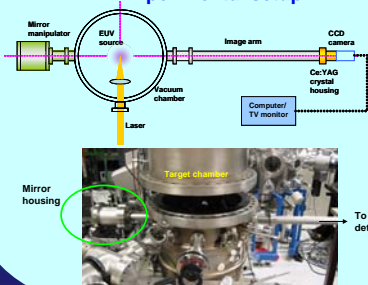
The laser plasma source is imaged to a Ce:YAG crystal by a spherical Mo/Si mirror. The image is transferred through a fiber optic coupler to a visible light CCD camera.



Motivation for an alternative

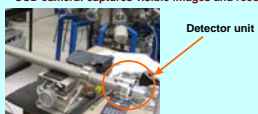
- Develop a new mode of EUV radiation detector based on a Ce³⁺:YAG crystal EUV-visible wavelength converter for short wavelength imaging application.
- Conventional techniques relies on films, channel plates or expensive x-ray CCD. The new technique provides an alternative to the presently used methods.
- Luminescent materials have been used as radiation detectors in many applications i.e. medical imaging, tomography, gamma-camera and others
- We have characterized Ce³⁺:YAG as an EUV wavelength-to-visible light converter, and integrated this into a novel high resolution laser-plasma, 13.5 nm (2% bandwidth) imaging camera.
- We are also incorporating this new EUV recording technique into other devices including spectrographs.

Experimental setup



Components

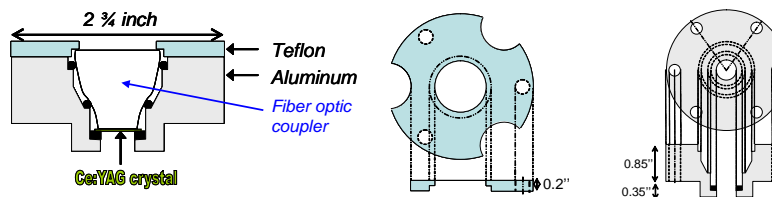
- EUV Source: Laser plasma source of tin material, size ~100 um, the Object to be imaged.
- Laser: Spectra-Phys 100Hz, 1064nm, 13ns
- Mirror manipulator: Controls the orientation of Mo-Si multilayer mirror; adjusts object-to-mirror distance; mirror roc = 500mm
- Image arm: Adjustable length to obtain sharp image
- Ce:YAG crystal housing: Houses the Ce:YAG scintillator crystal (thickness 500µm) which converts EUV to visible; a fiber optic coupler (magnification 2.2) transfers the scintillation to a CCD camera
- CCD camera: captures visible images and recorded by computer



Detection components

I. Engineering of the detector unit

The detector unit is designed to work in vacuum. Image formed on the crystal is relayed through a fiber optic coupler to a visible CCD. The FO is an ordered fiber-optic bundle whose numerical aperture is ~1 and magnification is 2.2. About 15 times more efficient in collecting power than a lens-based relay optics.



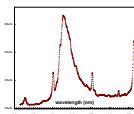
Relay schemes

Fiber optic coupler relay
High transmission ~70%

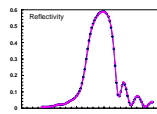
Lens based relay
Low transmission ~5%

II. In-band wavelength selection

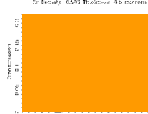
The tin-doped LPP source emits EUV as well as visible light. The in-band wavelength selection is made by using a combination of a Mo/Si multilayer mirror and a 500 nm thick Zr metal filter.



Typical spectrum of the tin-doped droplet laser plasma source in the EUV electromagnetic wave region, showing an intense UTA at 13.5nm. The source also emits visible light.



The multilayer made of Molybdenum-Silicon bilayers. A fresh mirror usually has peak reflectivity ~69%. Peaks at 13.5nm, passes a narrowband 3.9% (FWHM). It reflects the visible light too, but this later is cut by the zirconium filter.

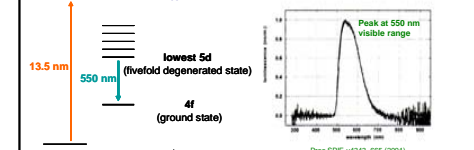


Zirconium filter (0.5um thick) blocks visible light from reaching the YAG:Ce crystal but passes EUV in the band from 7nm to 15nm.

III. Ce³⁺:YAG converts EUV to visible

When the EUV light irradiates the Ce³⁺:YAG, the high energy photon is absorbed by the host lattice (YAG) and is converted in lattice excitations which stimulates the transition from the lowest 5d state to the 4f state (ground state) of the Ce³⁺. This transition is accompanied by the emission of photons at 550 nm.

The conversion efficiency (the rate between the photons emitted in the green and the incident photons at 13.5 nm) is 74%.

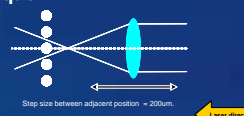


EUV images of the source

Images from Ce³⁺:YAG technique

Images of the tin-doped laser plasma source were recorded as the separation distance between the lens and target was varied.

Gradual change of plasma size as function of focus was observed as expected due to laser beam shape.



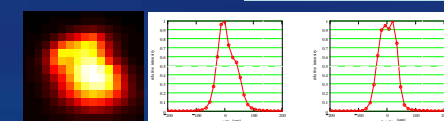
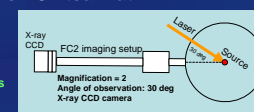
Plasma size across P0 - P8 measured to be ranging from 75µm to 125µm. The smallest is at P4, the position of minimum focal spot.



Images collected by the FC2 team at LPL

An imaging experiment was performed on the tin-doped laser plasma source by the FC2 team at LPL (6/18/2003).

The image recording technique was based on an x-ray CCD.



The source size determined is 75µm width by 79µm height.
Image analysis in collaboration with S.A. Weston (FCM)

Summary

New High-resolution EUV imaging techniques. Avoids the use of expensive back-thin soft-X-ray CCD's

Technique incorporated into high-resolution 13.5 nm imaging camera Results of source size measurements obtained by this technique are compared with images obtained with using x-ray CCD camera.

Future work include (i) improving resolution by using thinner crystal and large CCD chip, (ii) performing time resolved imaging, (iii) extending this technique to other areas of EUV detection.