Confidential

[7969-100]

Characterization and optimization of tin particle mitigation and EUV conversion efficiency in a laser produced plasma EUV light source

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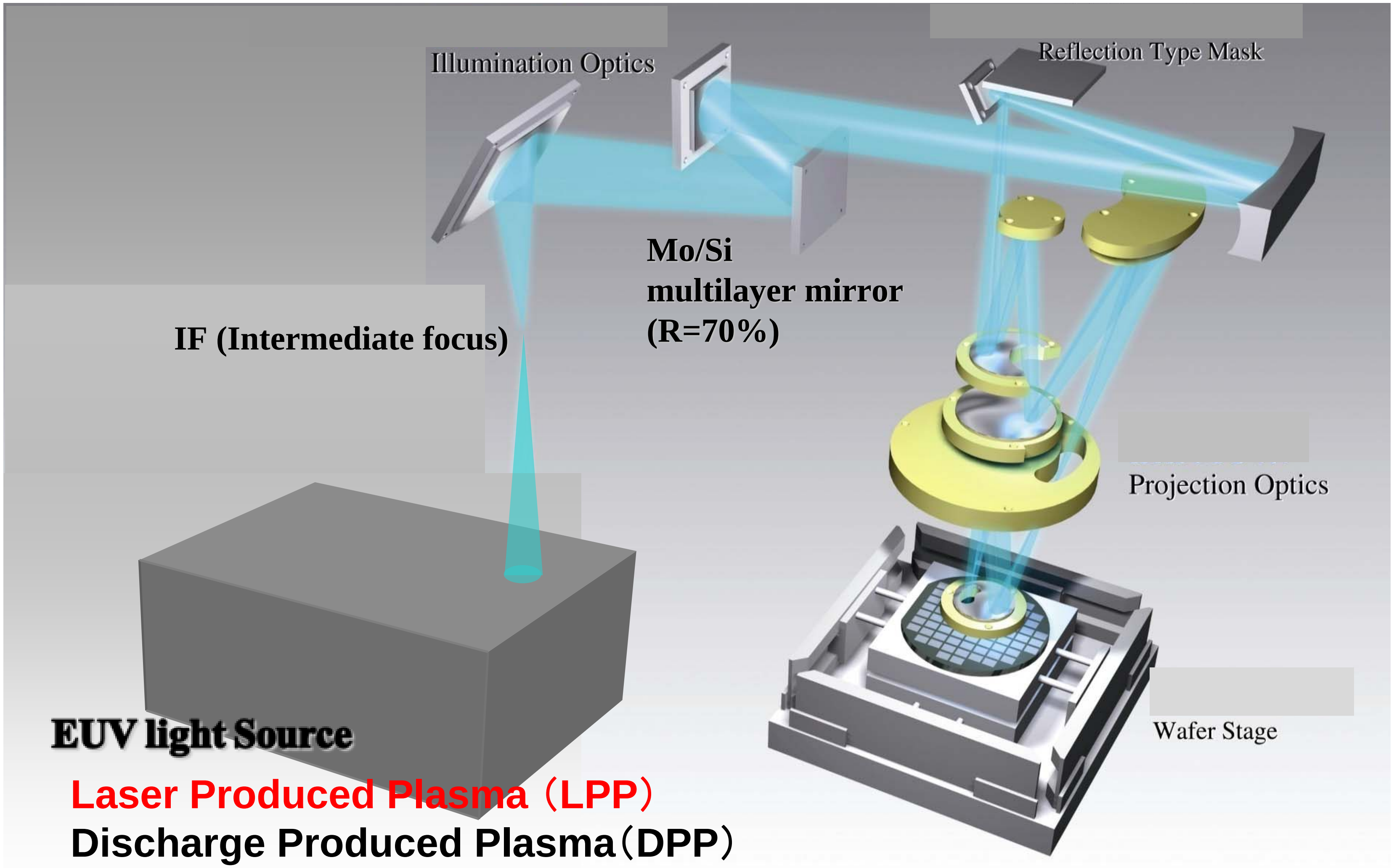
Outline

1. Introduction
2. Concept of Sn particle mitigation
3. Experimental setup
4. Experimental results
   - 4-1. Sn fragment Imaging
   - 4-2. LIF measurement of Sn neutrals
   - 4-3. EUV CE measurements
5. Summary

EUV Lithography system

EUVL based on High vacuum environment, Multilayer coated reflective optics



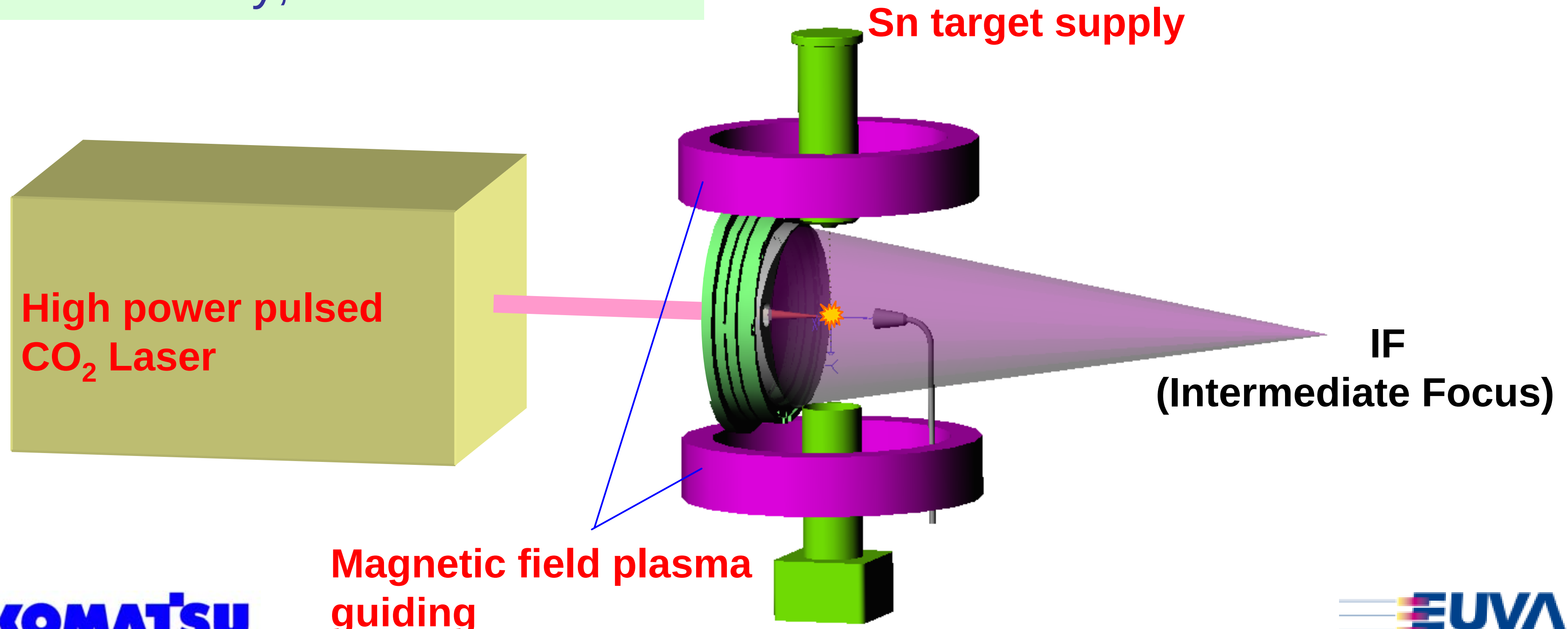
LPP EUV Light Source

Requirements for HVM EUV source

- High EUV power
- Long collector mirror lifetime
- EUV Stability
- Low CoG / CoO
- Reliability, ･･･

EUVA LPP concept

- CO_2 laser
- + Sn target
- + Magnetic field plasma guiding



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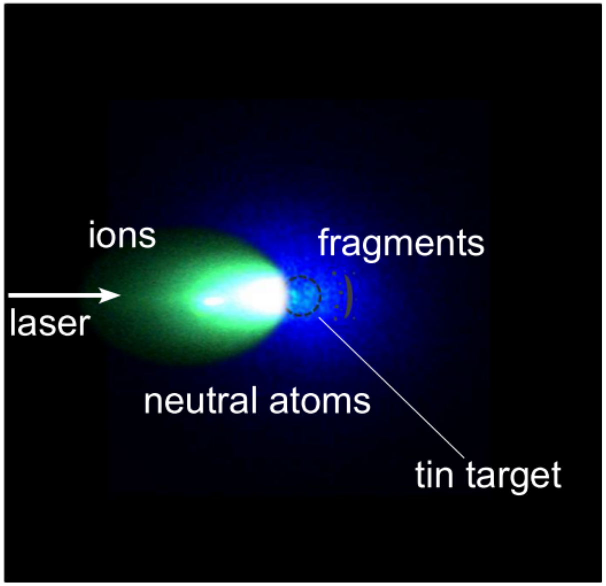
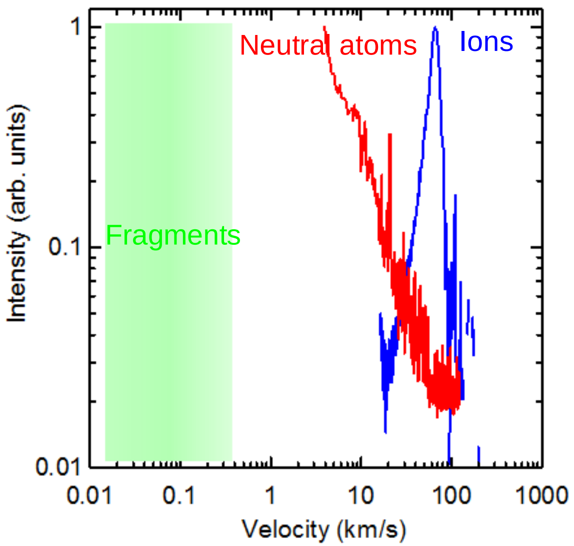
Characteristics of produced Sn particles (debris)

- Sn particles are classified into fragments, neutral atoms, ions





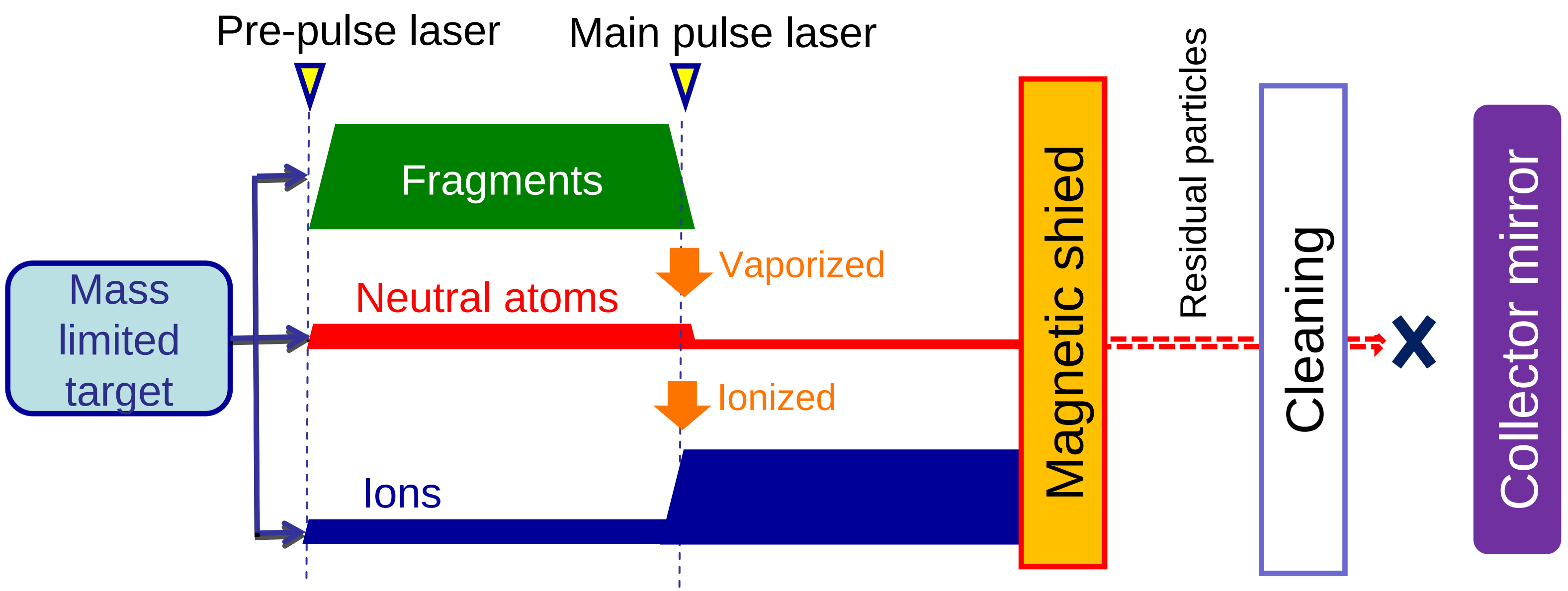
Velocity distribution

	Ions	Neutral atoms	Fragments
Direction of expansion	Towards the laser incident direction	All direction	Same direction as laser pulse
Velocity	10 - 100 km/s	5 - 40 km/s	0.01 - 0.5 km/s
Kinetic energy	60 - 6000 eV	15 - 980 eV	-

Concept of Sn particle mitigation

In our LPP system, Sn particles are reduced to practical level by the following method,

- Mass limited Sn supply
- Fragments are vaporized and ionized by the main pulse laser.
- Ions are trapped by the magnetic field and collected.
- Residual Sn particles are cleaned.



Subject of this work

We investigated behavior of Sn particles, and studied the optimization of particle mitigation condition with a compact EUV experimental system.

- Fragments observation with a shadowgraph imaging (20 μm droplet target)
- Neutral atoms imaging in a strong magnetic field by a laser induced fluorescence (LIF) method. (Planar target)

EUV Conversion Efficiency (CE) with smaller droplets are also optimized.

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Experimental setup of a compact EUV system

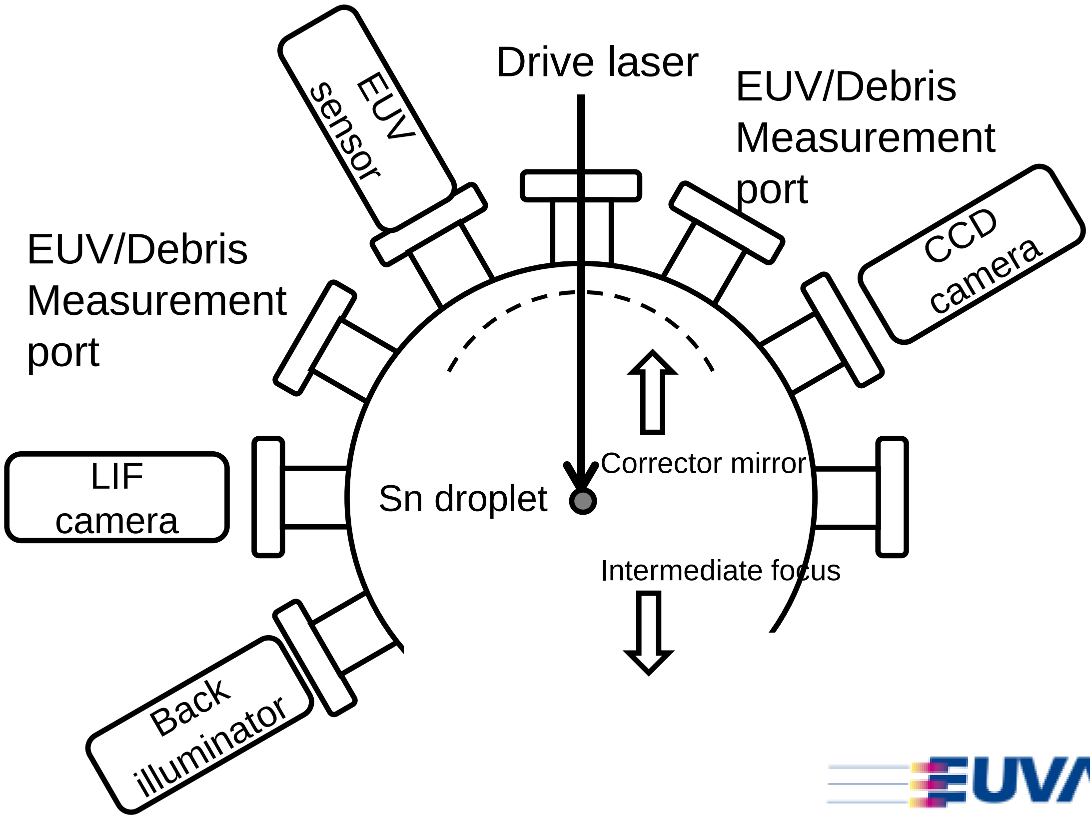
It can simulate a same condition as our high-power EUV light source except for a pulse repetition rate.

・System configuration

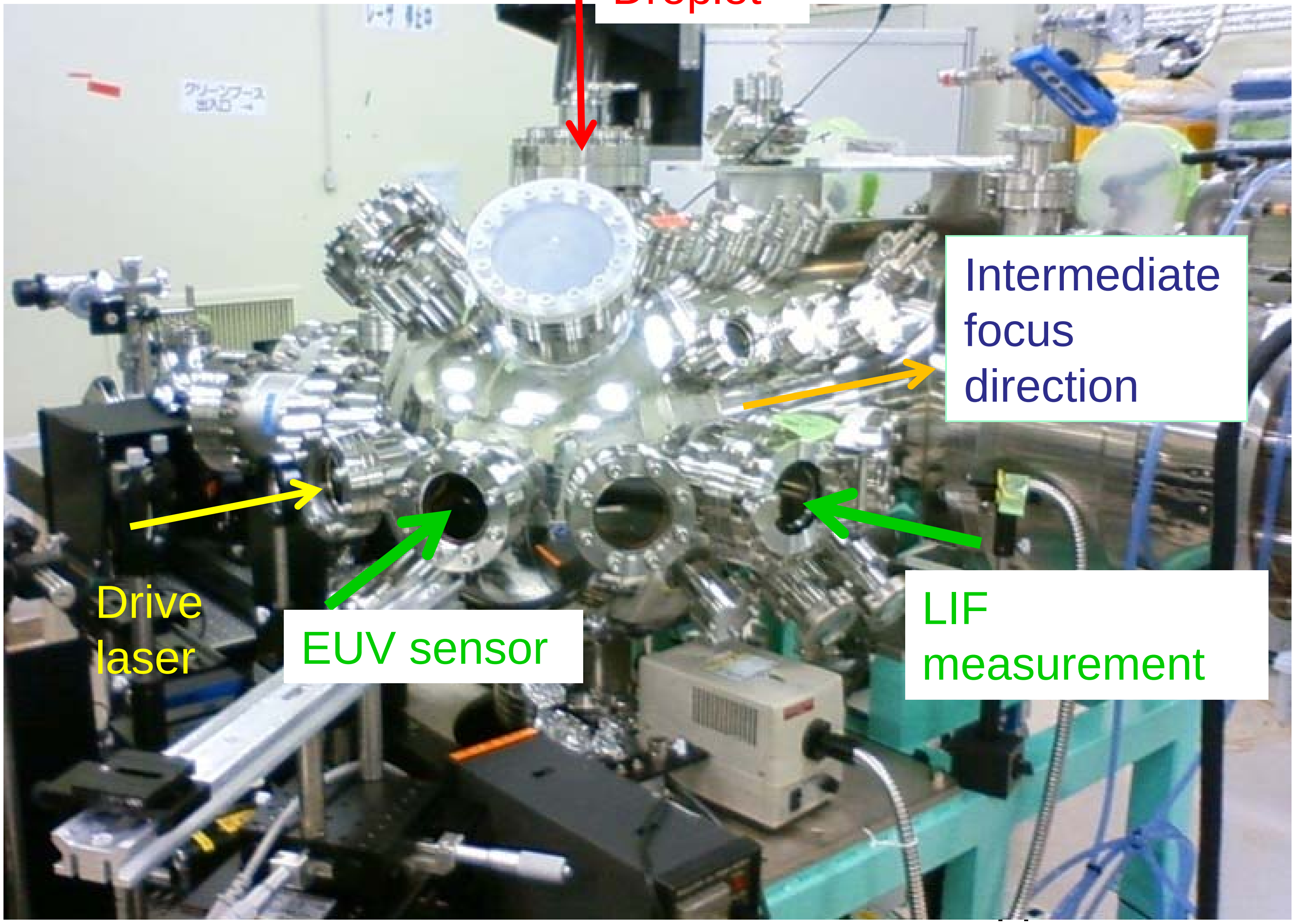
- Droplet generator, Pre-pulse laser, Main CO_2 pulse laser, Magnetic field
- Pulse repetition rate : 10Hz

・Measurement tools

- Shadowgraph for fragments
- LIF for neutral atoms
- EUV sensor(power, image, …)



Outlook of the EUV system

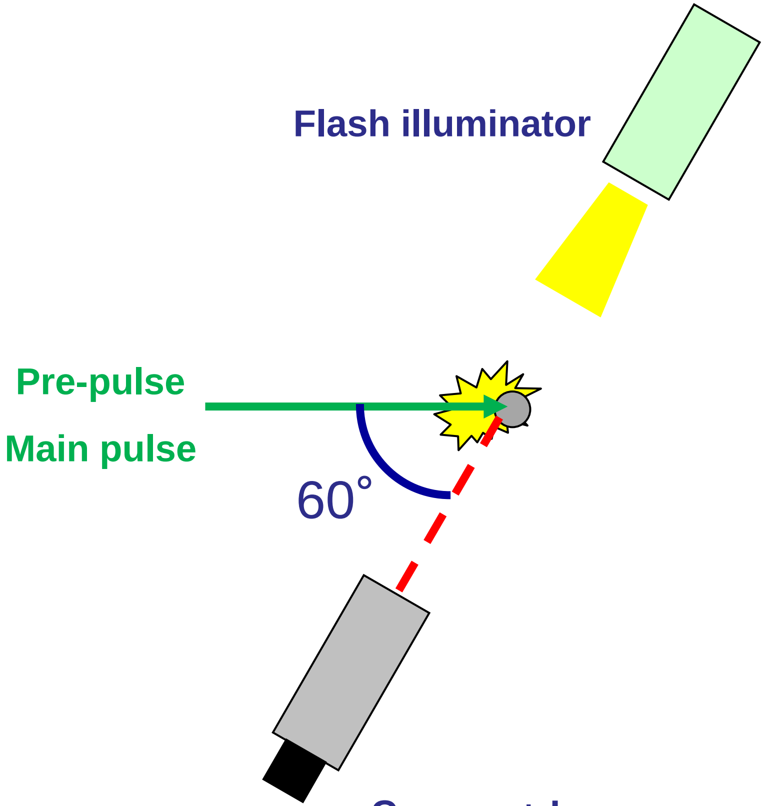


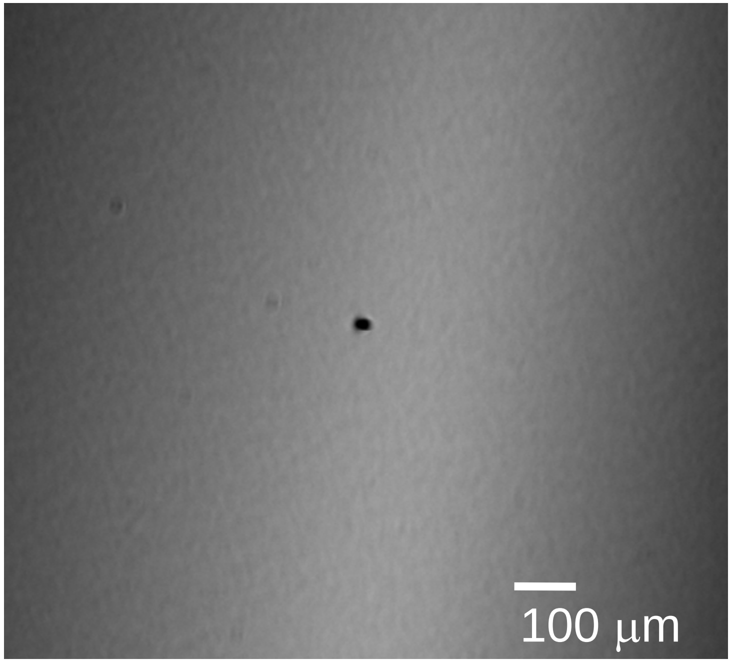
Size : 2 m X 3 m X 2 m

Outline

Shadowgraph imaging for Sn fragment measurement

- Time resolution ~ 40 ns
- Spatial resolution ~ 6 μm
- 60 degree observation angle to laser axis



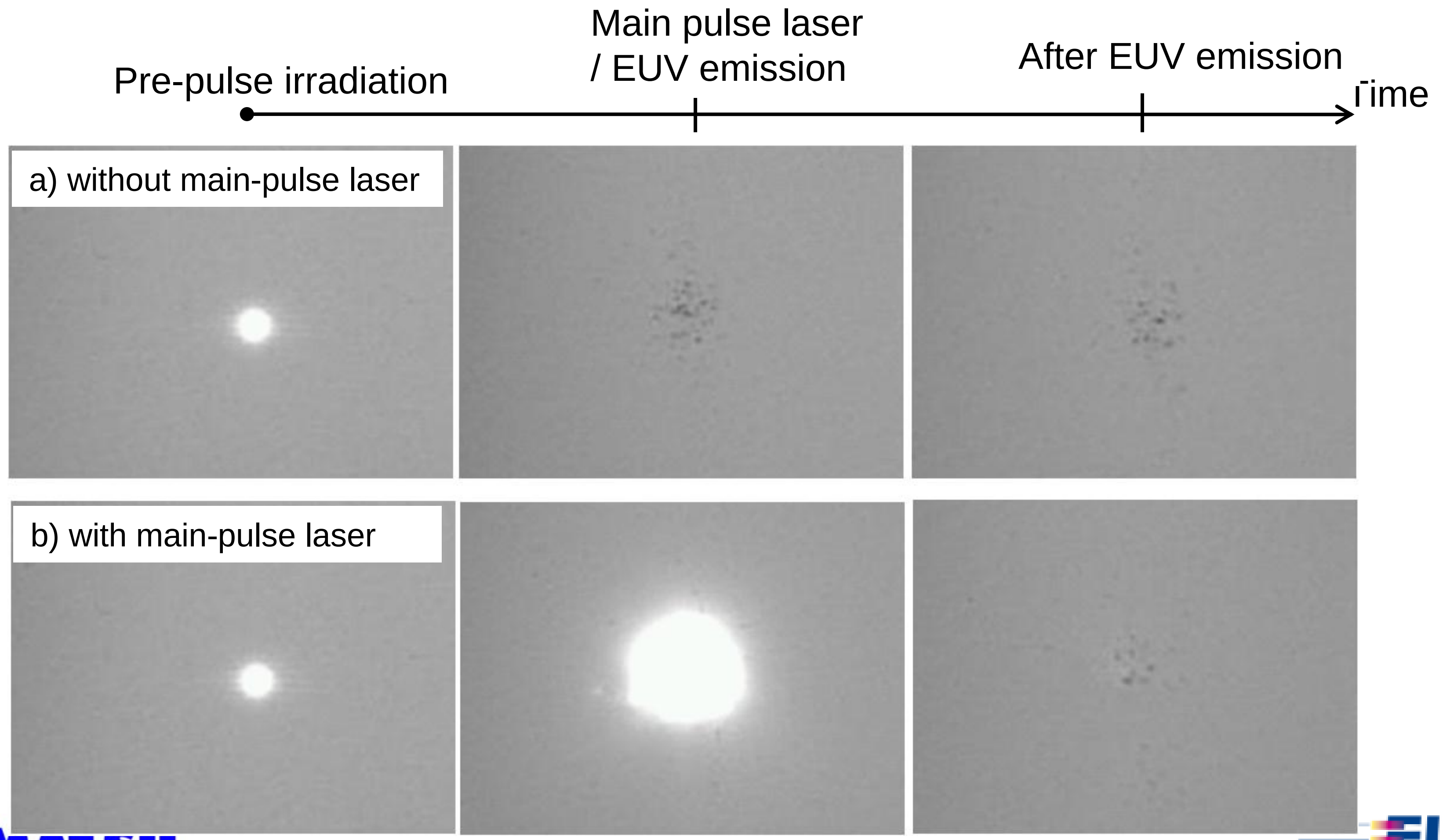


Example of shadowgraph image
(20μm droplet)

Sn fragments after laser irradiation

Wrong laser condition

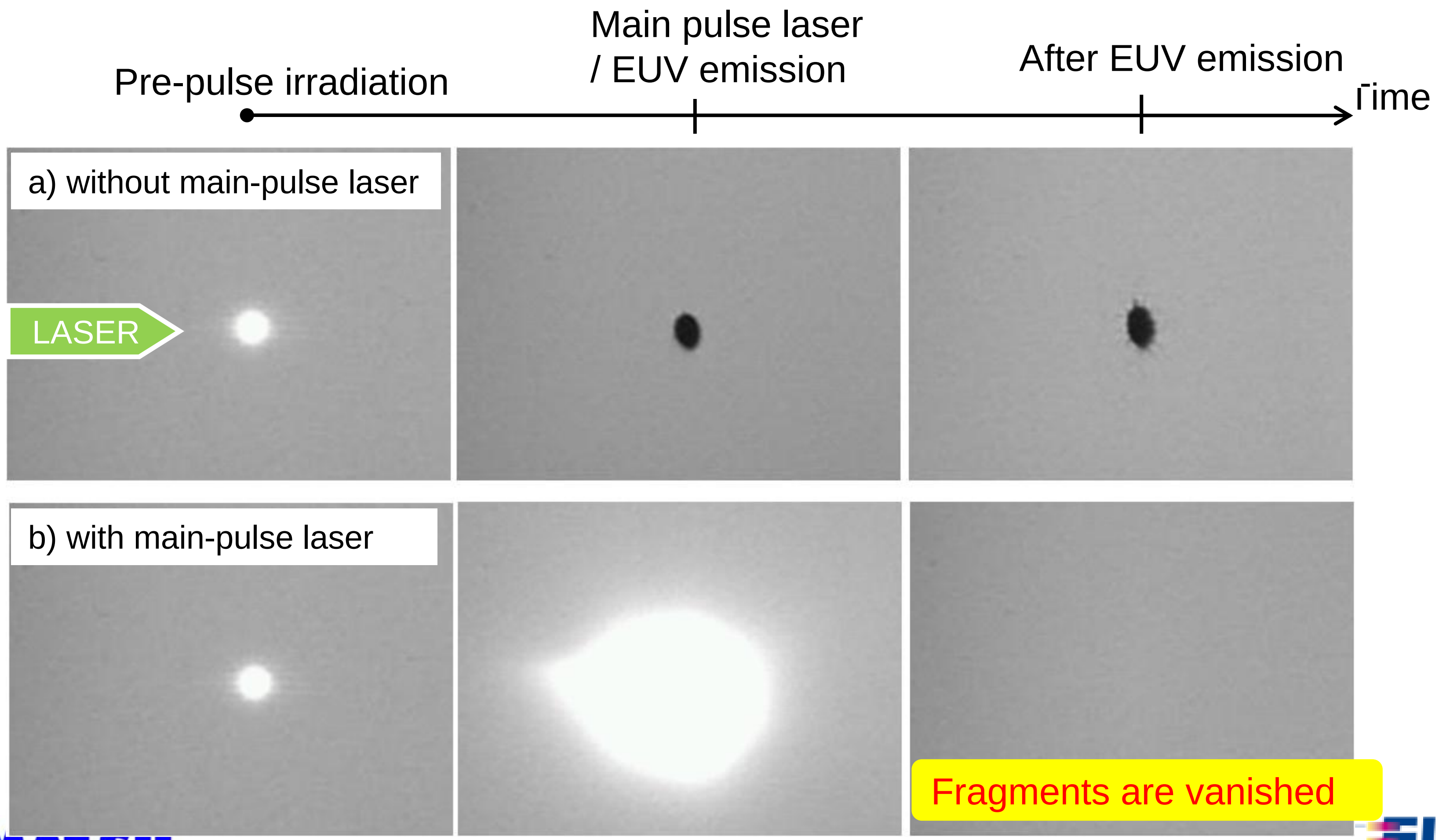
- 20 μm droplet, pre-pulse + main-pulse lasers
- Fragments generated after pre-pulse irradiation.
- Quite a few fragments still remain without vaporization after EUV emission.



Sn fragments after laser irradiation

Appropriate laser condition

- Fragments are vanished after EUV emission.
- We believe almost all of the fragments are vaporized, then probably ionized.

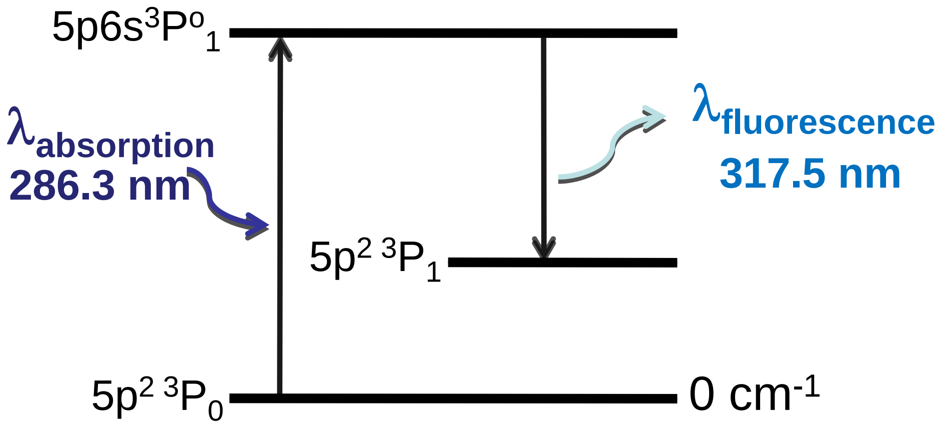


Outline

Laser induced fluorescence (LIF) imaging for Sn atoms

Advantages

- Spectrally selective pumping and observation
- High sensitivity
- Cross sectional imaging with a sheet laser beam

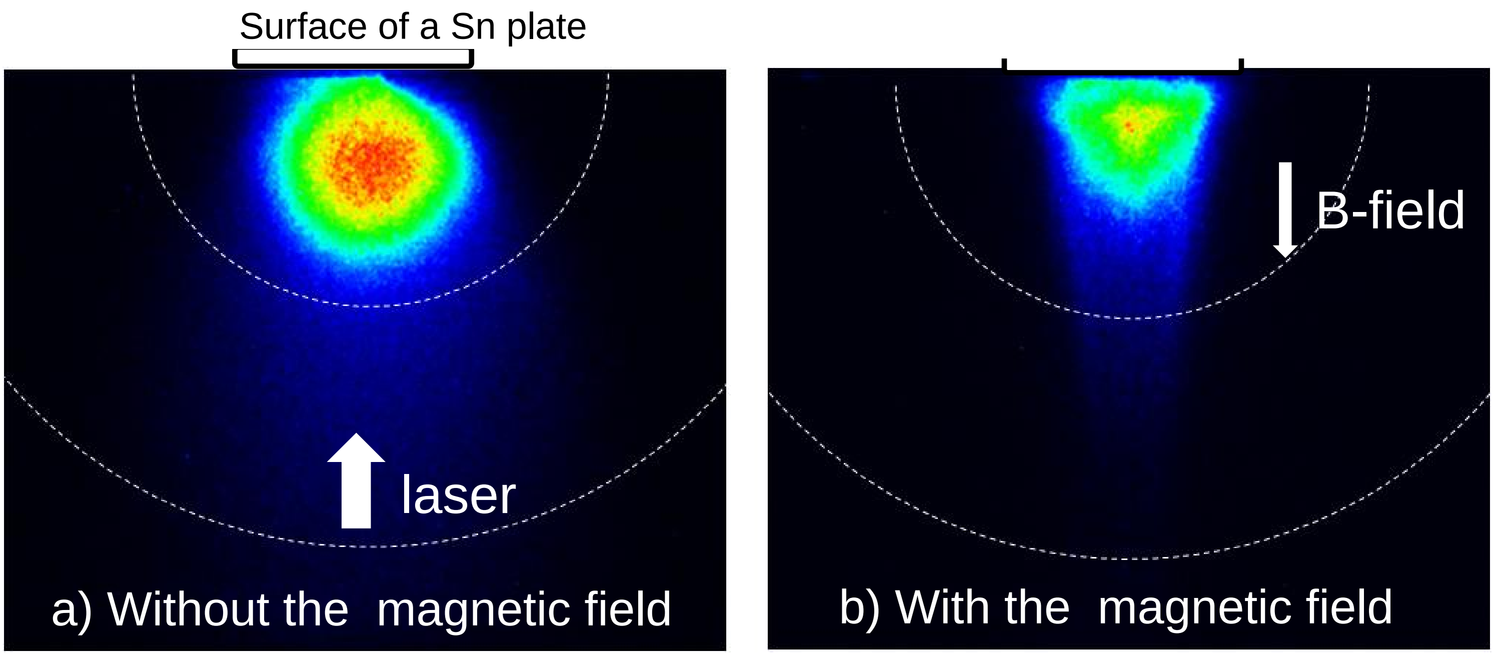


Energy level of Sn atom

Sn neutral distribution under strong magnetic field

- Planar target + pre-pulse laser with / without magnetic field
- Magnetic field helps guiding the Sn particles of not only the charged particle but also the neutral atom.

2D LIF image of Sn atom distribution at 1 μs after laser irradiation



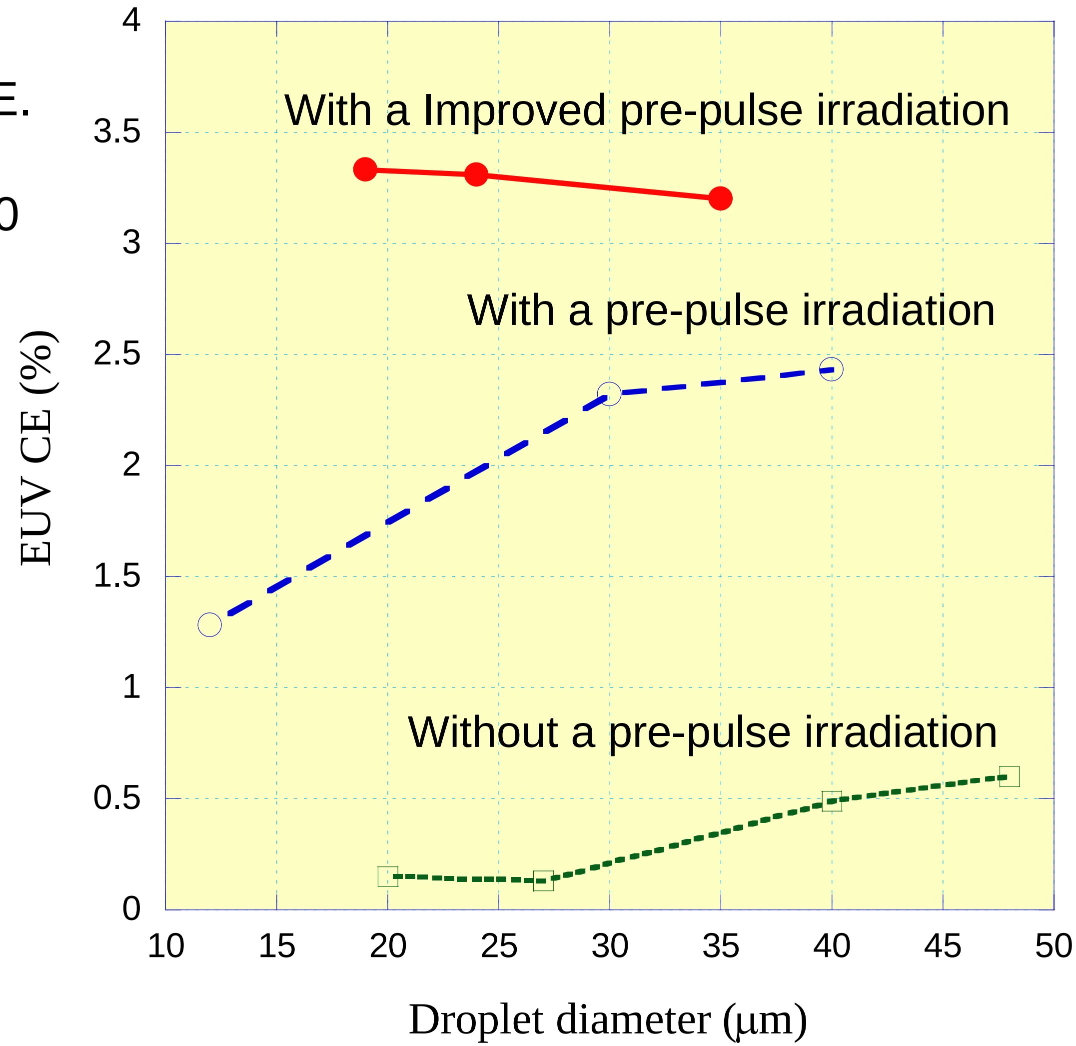
Isotropic expansion

Sn atoms strongly converge on the direction of the magnetic field.

Outline

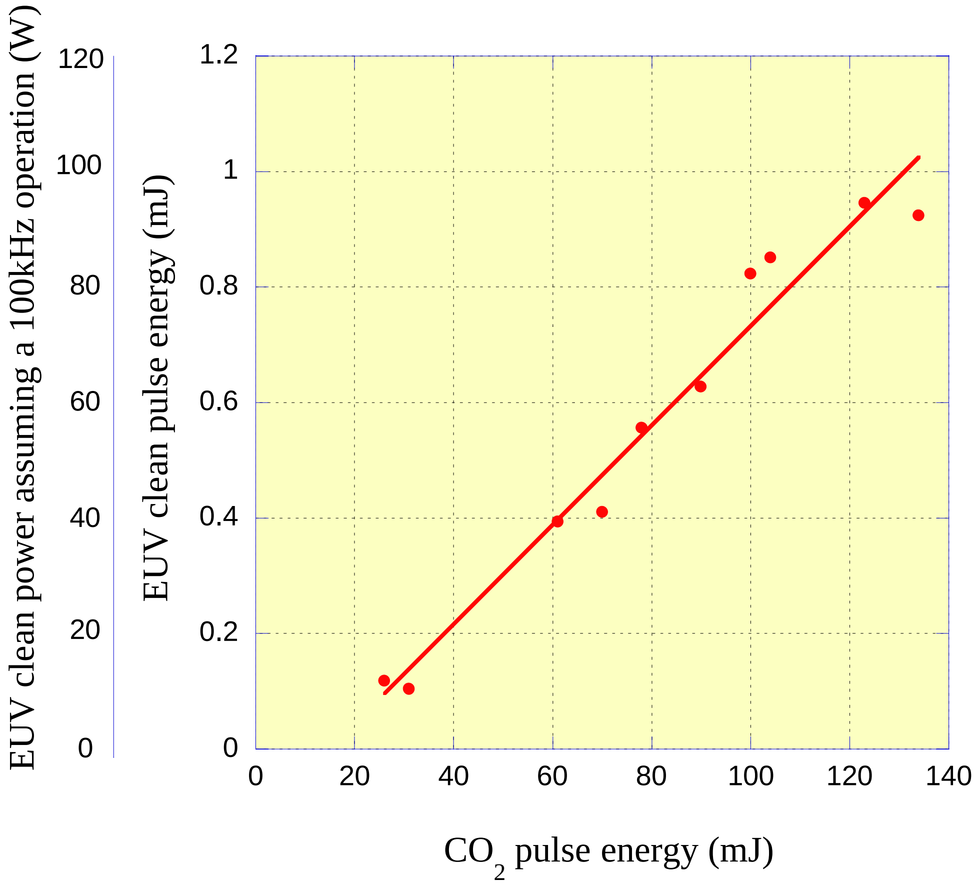
Droplet size vs. EUV CE

- ➢ Pre-pulse laser irradiation is a key parameter for a higher EUV CE.
- ➢EUV CE reached to 3.4% for a 20 μm droplet by optimizing the pre-pulse laser conditions.



CO_2 laser pulse energy vs. EUV pulse energy

- EUV CE doesn't saturate at least up to 134mJ CO2 laser input.
- Clean EUV power of 100 W is expected for our developing system with a pulse repletion rate of 100kHz.



Summary

The optimization of tin debris mitigation and EUV CE with the compact EUV generation system is presented.

1. Sn fragments generated from the 20 μm diameter droplet was vaporized almost entirely by the laser optimization.

2. Sn neutrals generated after the pre-pulse irradiation converge to the magnetic field. (planar target)
   The magnetic field is beneficial to the Sn particles guiding of not only the ions but also the neutrals.

3. No EUV CE degradation even for 20 μm diameter droplet
   - Maximum EUV CE of 3.4% for 20 μm diameter droplet
   - Clean EUV power of 100 W is expected for our developing system.

Acknowledgement

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