Generation of a Mass-Limited Tin Micro-Droplet using Pulsed Laser for EUV Light Sources

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Background

Generation methods for EUV Light source

- LPP (Laser Produced Plasma)
- DPP (Discharge Produced Plasma)

Requirements

Mirror
- Lifetime > 1.6 × 10^{11} Pulse

Intermediate focus
- Power > 180 W @13.5 nm, 2% Band Width)
- PRF : 7~10 kHz
- Etendue < 3.3 mm^2sr

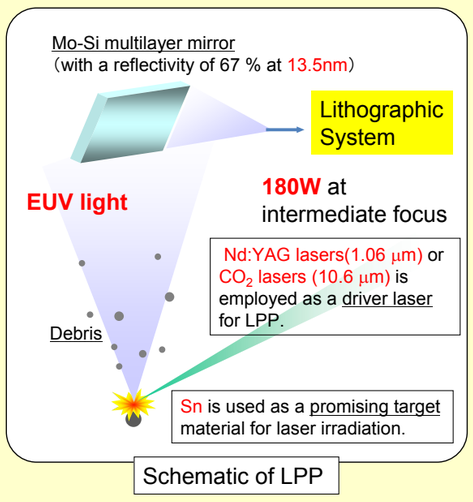
Problems of LPP

1. **The conversion efficiency from laser light to EUV light is low.**

→ Some improvement is achieved by using **CO_2 laser and Sn target**.

2. **Debris generation that limits the lifetime of the optics in the lithographic system.**

It is difficult to mitigate the neutral atoms by a shield because the neutral atoms can not be controlled by the electromagnetic field.



Schematic of LPP

Debris
- Fast ions
- Neutral atoms
- Clusters

Use of a minimum amount of Sn target that can provide a sufficient EUV power is effective. ⇨ **Mass-limited target (Minimum mass target)**

The mass-limited target is effective in producing the clean plasma that emits few neutral atoms.

Purpose

The ablation dynamics of the laser-irradiated Sn droplet has not been well understood.

1. We proposed a simple technique of generating a Sn droplet with help of pulsed-laser.
2. Behavior of the debris from the droplets was investigated byLIF imaging system and high speed shadowgraph imaging system

Requirement of use of the droplet target
- **Sufficient EUV light generation**
- **Few neutral atoms** (Ionized completely by the laser pulse.)

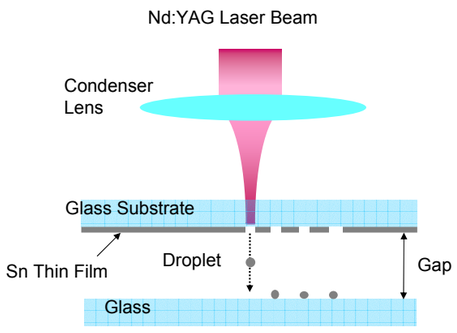
⇩

The droplet size of 10~30 μm is estimated.

1. Experimental Setup for generation of micro-droplet

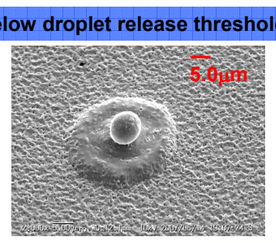
Sn thin film which was deposited by thermal evaporation on a glass substrate was gently irradiated by a Nd:YAG laser at a wavelength of 1.06 μm from the backside through the glass substrate.

Sn droplets were automatically generated with a help of the surface tension of the molten Sn film, and were collected on a glass substrate placed at 1 mm below the thin film.



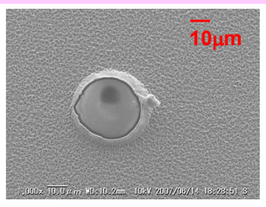
Surface on Sn film after laser irradiation

Below droplet release threshold



A small bump appeared at the center of laser spot on the Sn thin film.

Over droplet release threshold

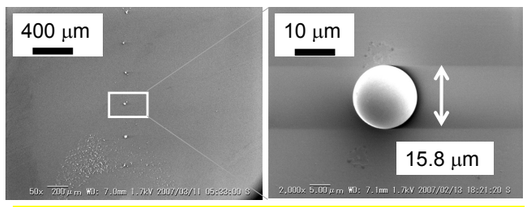


A hole appeared at the center of laser spot after release a Sn droplet.

SEM image of the surface of Sn film

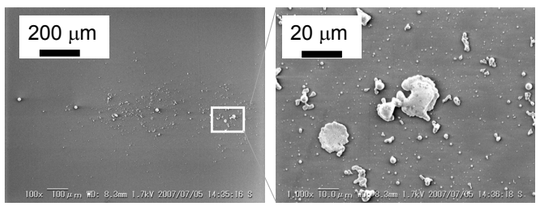
Droplet on the substrate surface

At the optimum laser energy,



The droplet of 15.8 μm in a diameter was generated from the Sn thin film with a thickness of about 2.3 μm

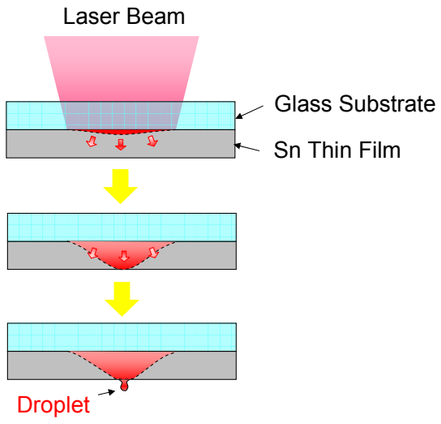
When the laser energy was over the threshold,



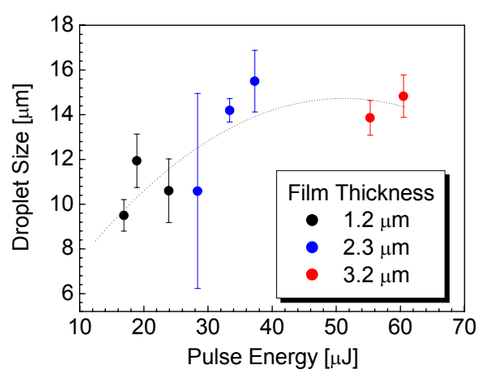
Molten Sn clusters was scattered on the substrate.

Mechanism of the droplet formation

1. The thin film is heated at a interface between thin film and substrate by laser pulse
2. Molten Sn metal expands and reaches the film surface.
3. A droplet is formed at the center of laser spot with surface sension.

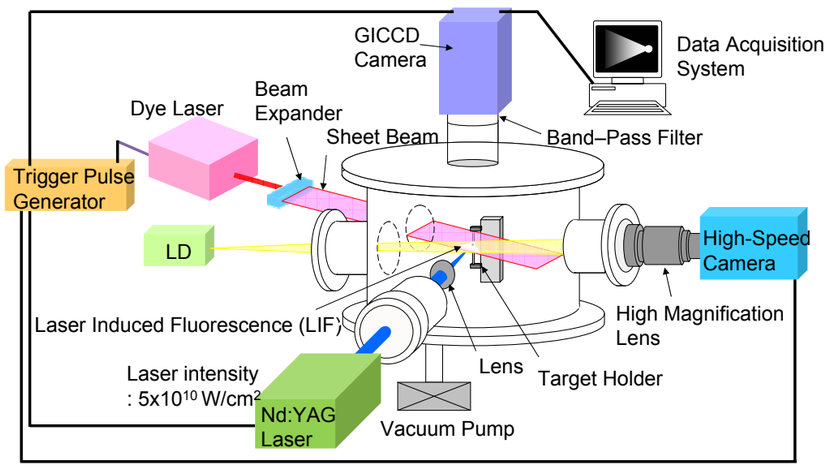


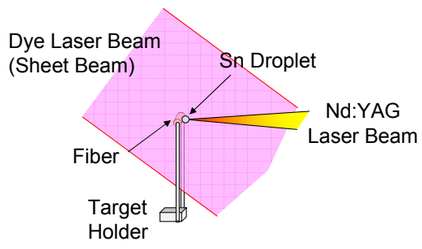
Dependence of Sn droplets size on film thickness



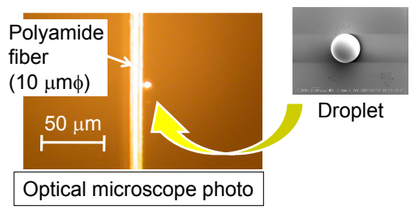
- It was found that the droplet size was changed according to the film thickness.
- The micro-droplet with the size of 6 ~ 16 μm could be generated with help of pulsed-laser.

2. Experimental Setup for investigation of the debris





Spatial configuration of LIF imaging (Top view)

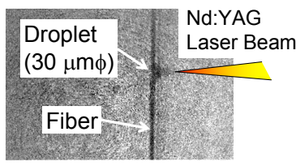


Optical microscope photo

The generated droplet was picked up under an optical microscope and attached on the polyamide fiber of 10 μm in a diameter for a target for laser irradiation.

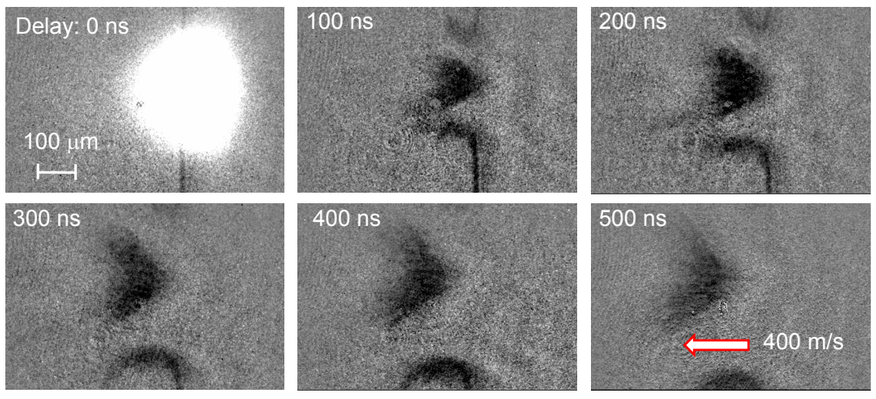
In this system, the LIF image and the shadowgraph can be obtained simultaneously using trigger pulse generator.

The kinetic behavior of debris from the droplet target



The shadowgraphs of the irradiated target debris at the different delay times after the irradiation

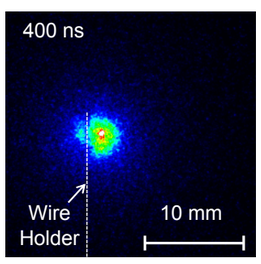
- Gate width: 100 ns



- The behavior of the Sn atoms from the Sn plasma and the spatial distributions of the irradiated droplet target were visualized simultaneously.
- The irradiated droplet was expanded to around 100 μm at the delay time of 100 ns.
- It is found that the ablated droplet was shifted to the left side by the energy of the plasma and the shift velocity was estimated to be approximately 400 m/s.
- The density of the irradiated target was estimated to about 10^{18} cm^{-3}order at the delay time of 100 ns.

The spatial distribution of Sn atoms from the droplet target

- Sn atoms were observed even from a small amount of micro-droplet target. (The droplet was not ionized completely.)
- The kinetic speed, that was estimated from the outer size of the Sn plume and the delay time of 400 ns, is approximately 20 km/s.



This measurement system provides the useful information for progress of development of EUV light sources using droplet targets.

Acknowledgement

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