

# Emission Characteristics of Neutral Atoms and Ions of Laser-Produced Tin Plasma

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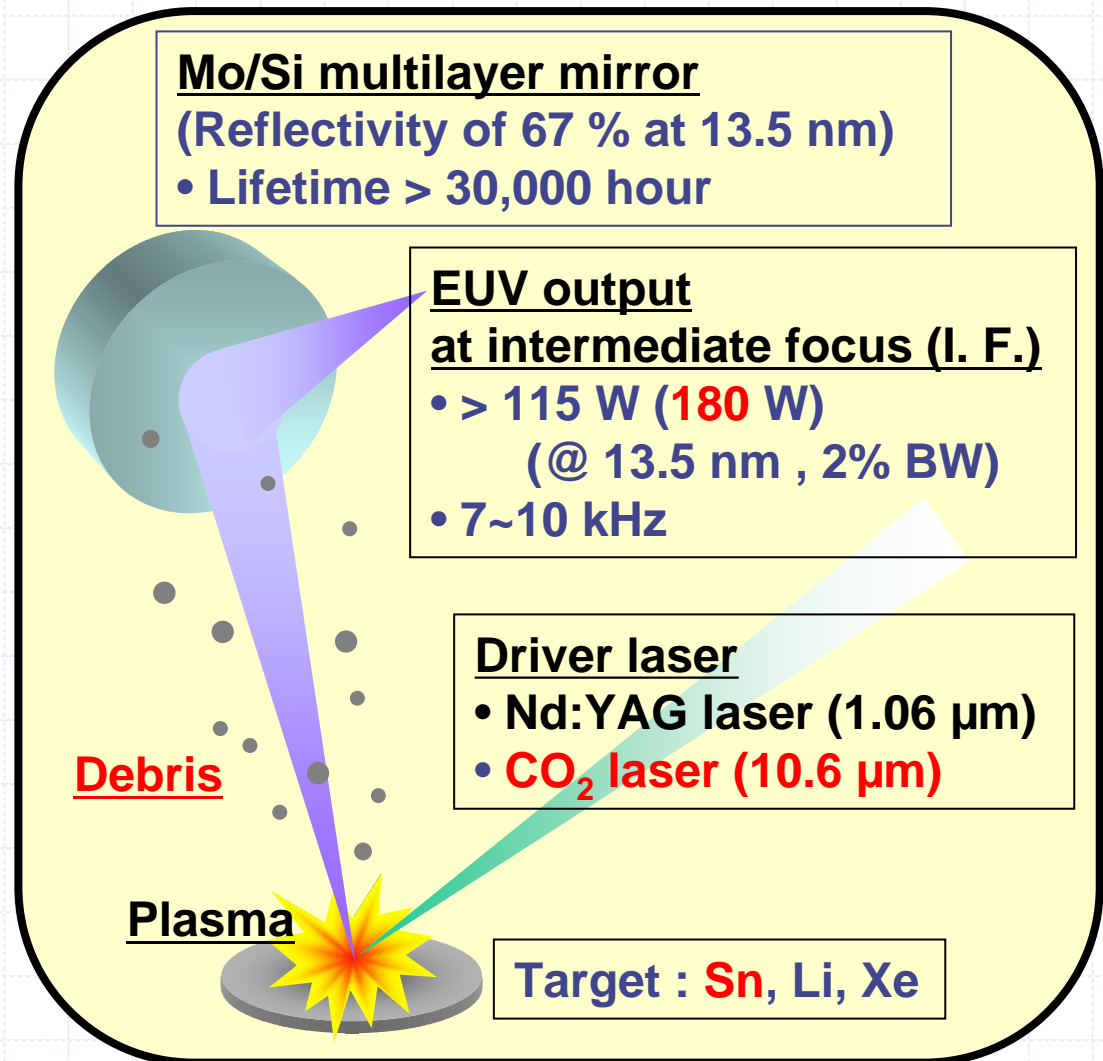
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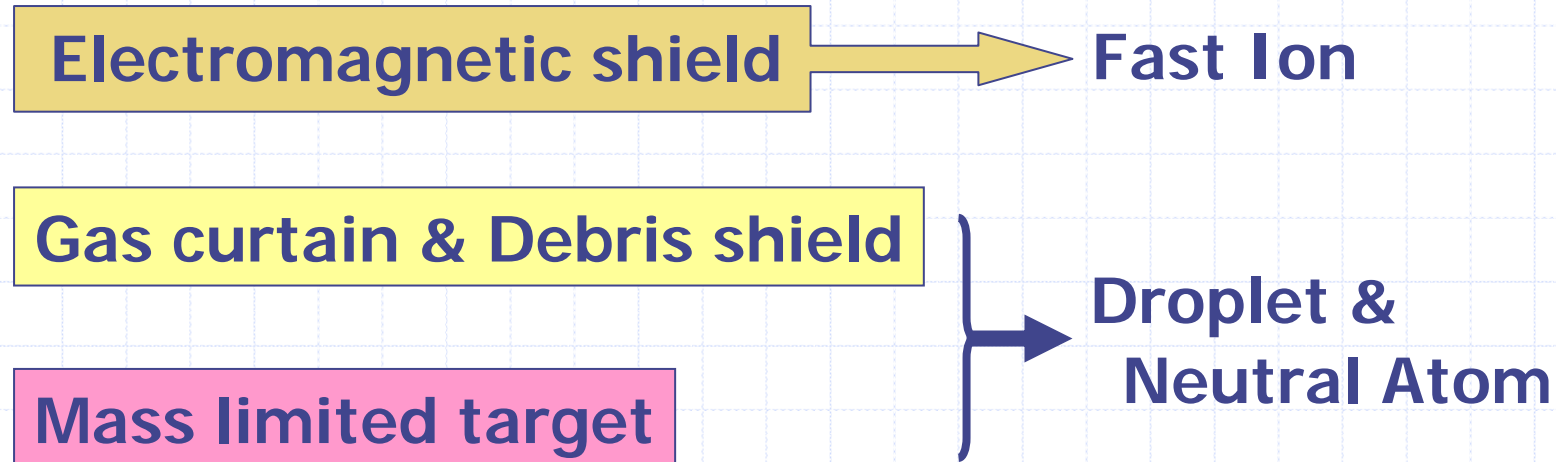
# Current Problem for LPP-EUV lithography

is **Debris...**

Debris (droplet, ion, neutral atom) harms the optics and limits the lifetime.



## Measures against Debris are ...



Anyway, it is necessary to understand the characteristics of debris emission for the effective measures.

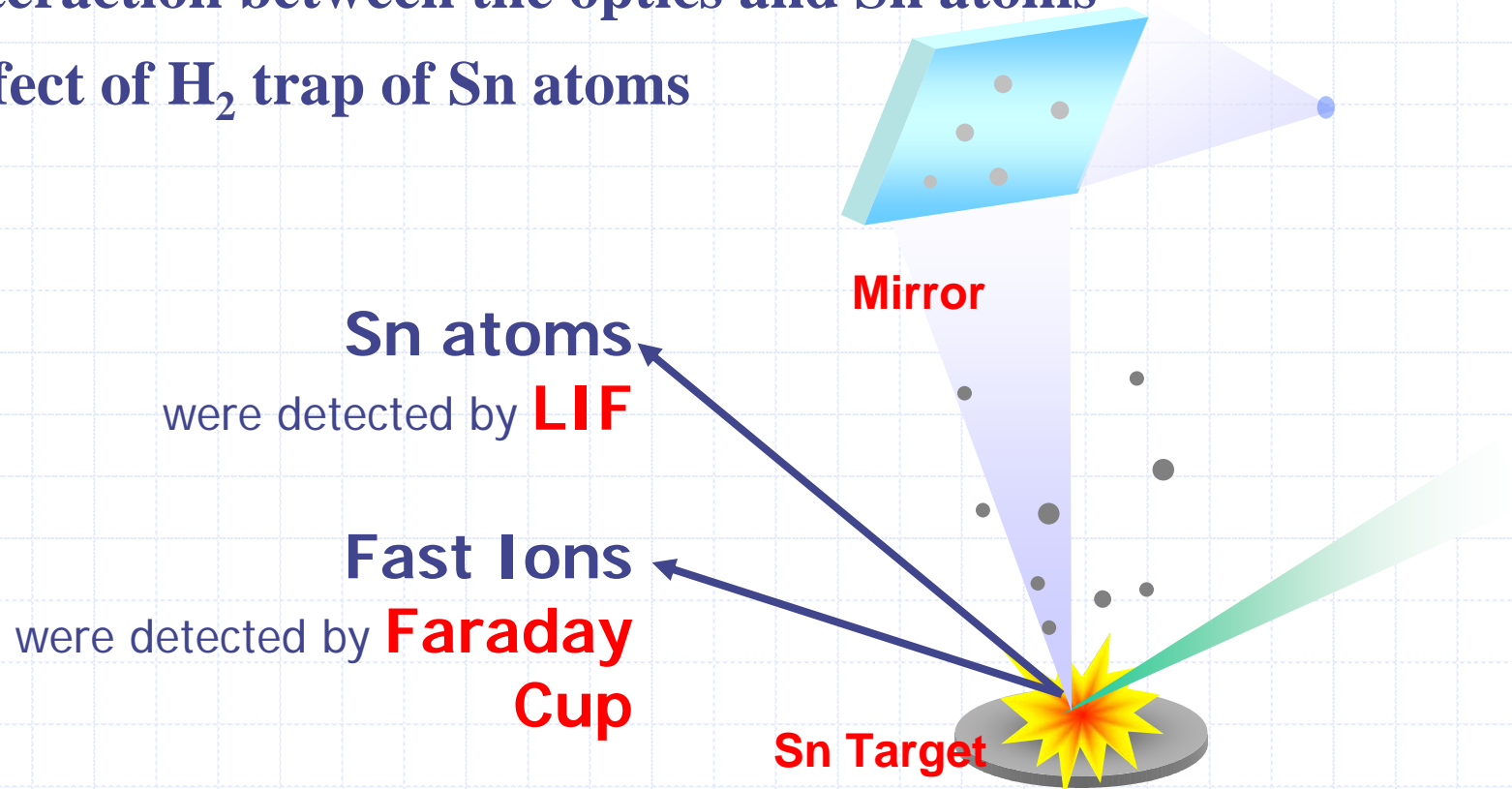
## **The purpose of our study is**

to investigate the debris behavior, in order to estimate debris and ions generation and obtain the guidelines for the measures.

# In this work, we visualized

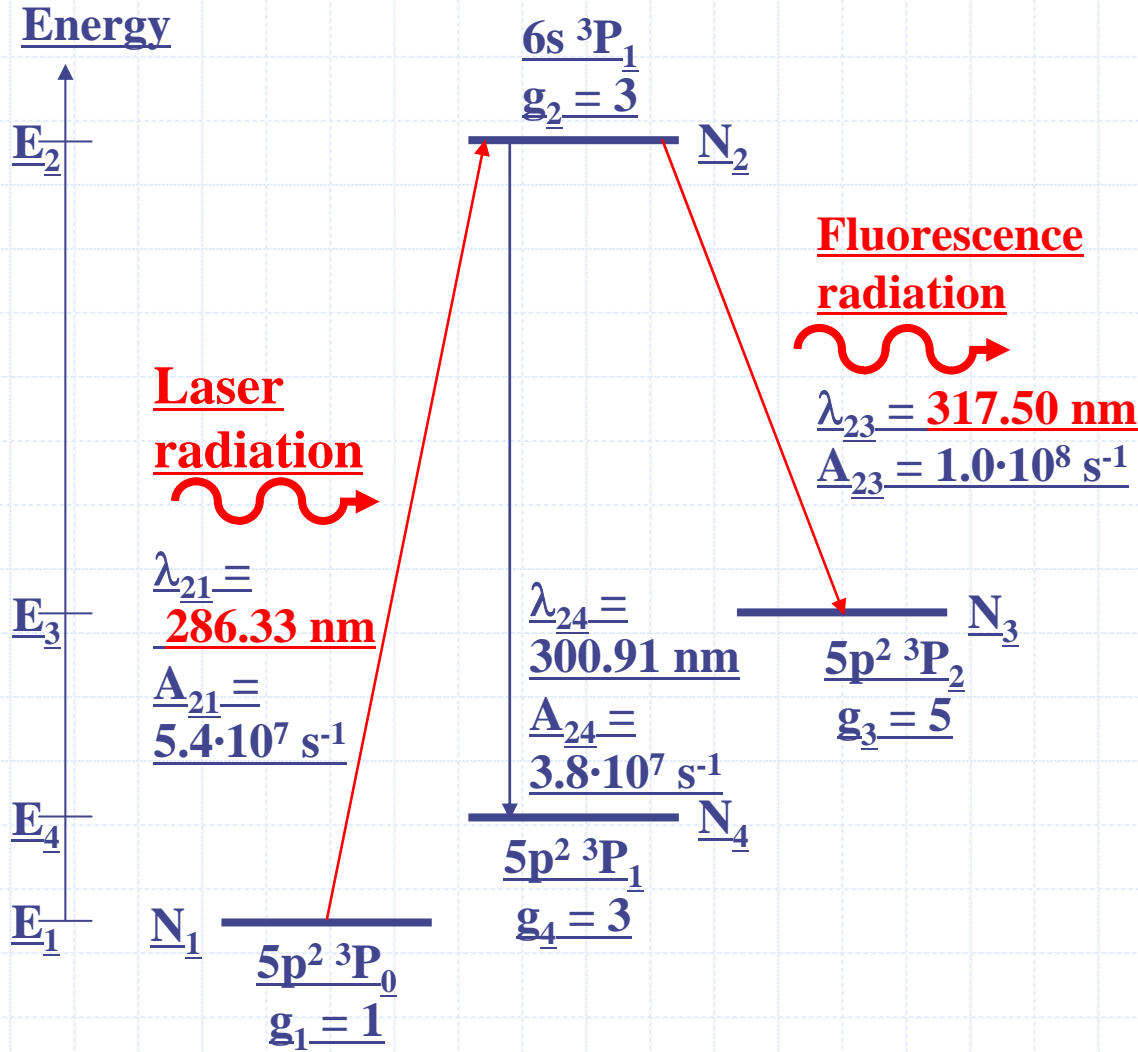
the behavior of neutral Sn atoms by **Laser Induced Fluorescence (LIF)**

- Density distribution & TOF
- Effects of thin film target
- Interaction between the optics and Sn atoms
- Effect of H<sub>2</sub> trap of Sn atoms

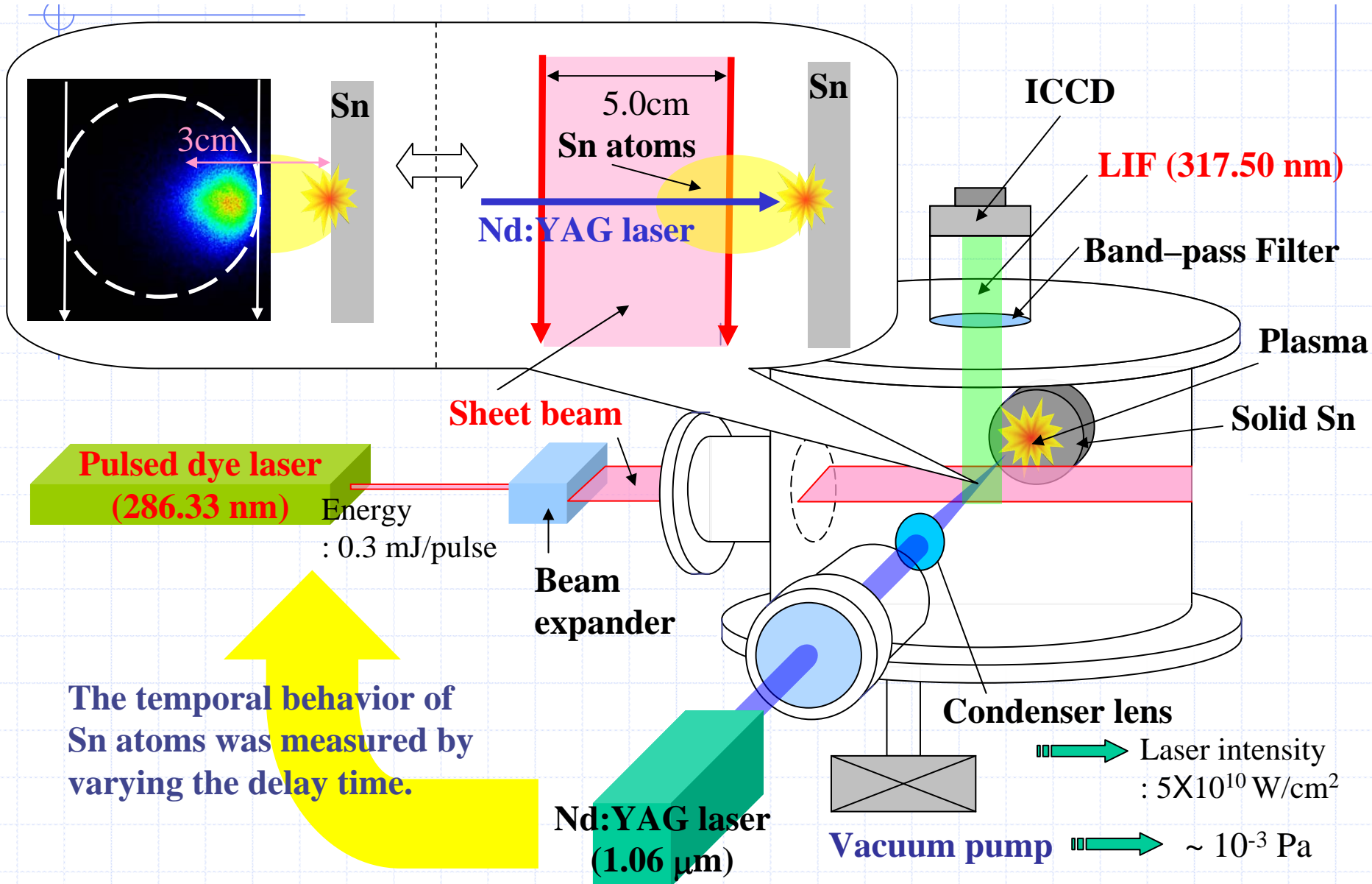


# Energy Diagram of Sn Atom for LIF

In this experiment, we detected the fluorescence at 317.50nm

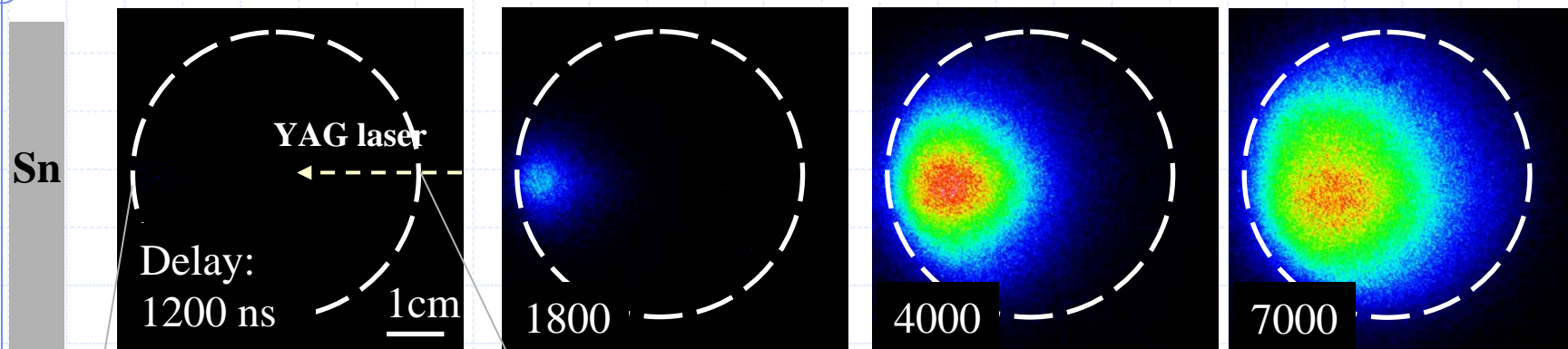


# Experimental Arrangement for LIF Imaging

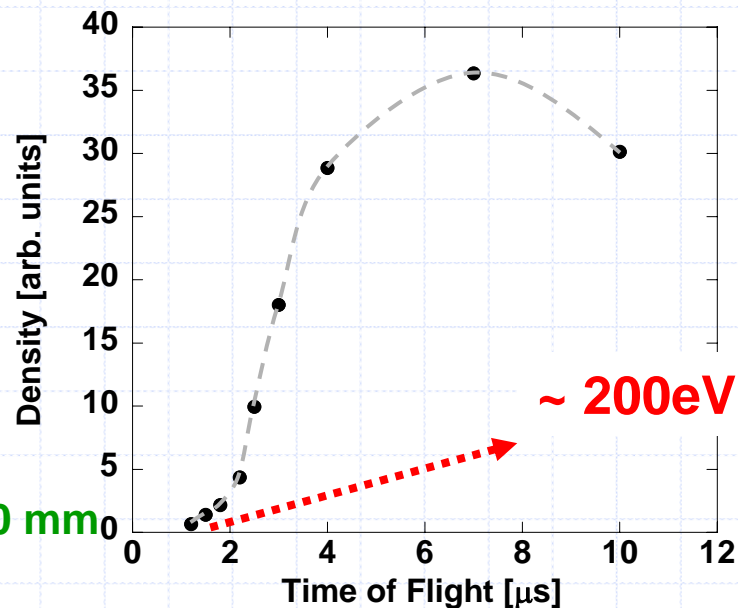
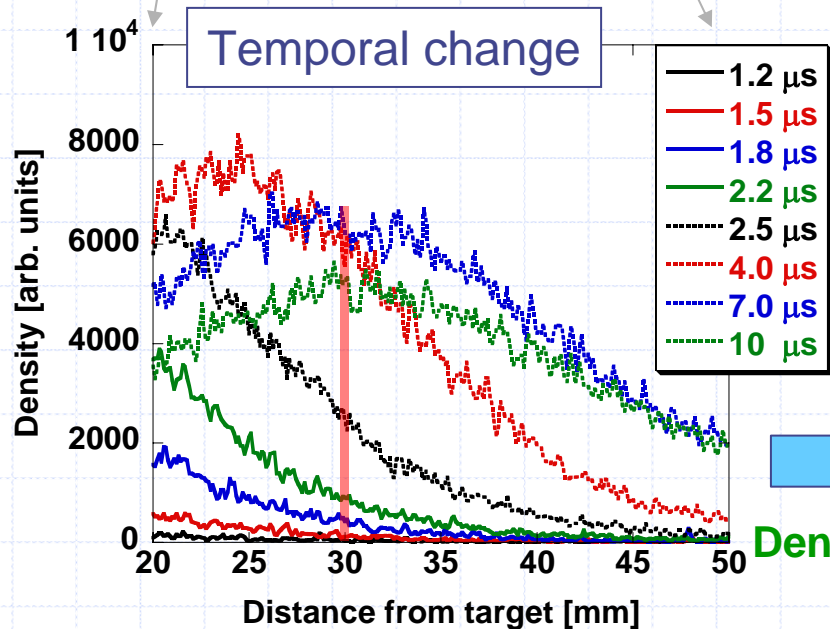


The temporal behavior of Sn atoms was measured by varying the delay time.

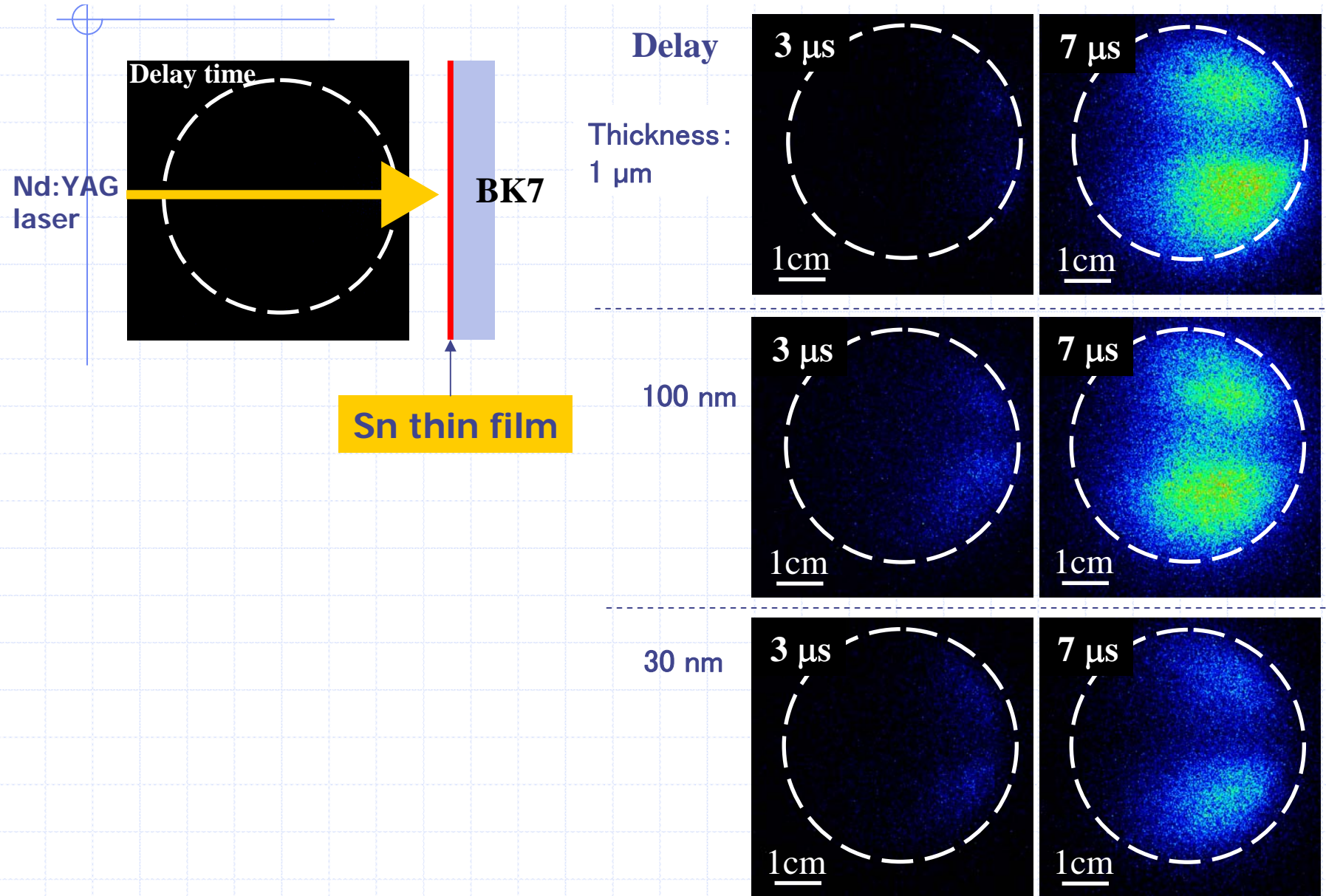
# Density Distribution & TOF



The present system can detect the neutral tin atom with 200 eV of kinetic energy.

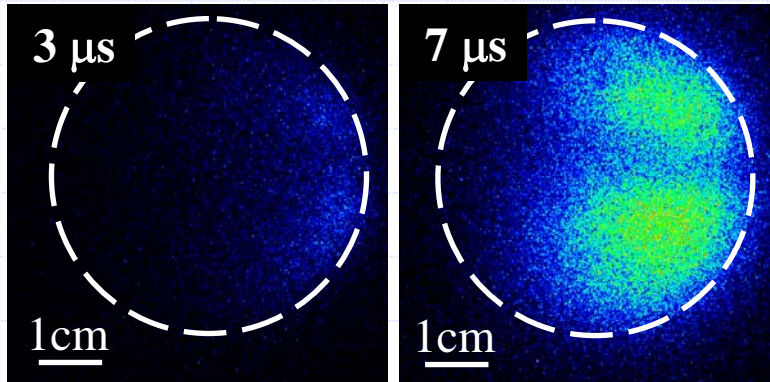


# Density Distribution of Sn for Thin Film Target

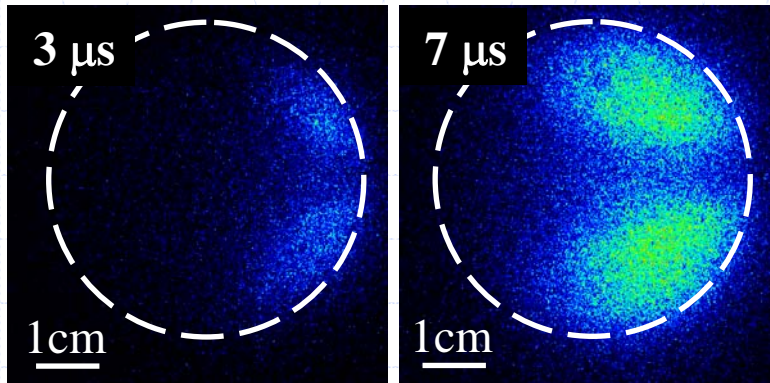


# The tin atoms inside the laser spot are completely ionized, while the neutral atoms remain around the spot.

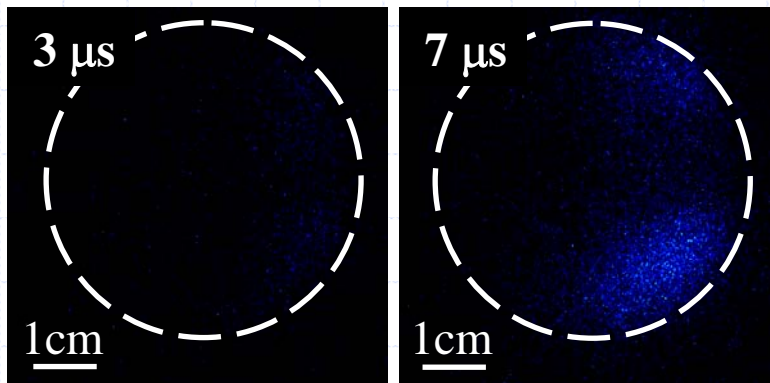
Thickness  
200 nm



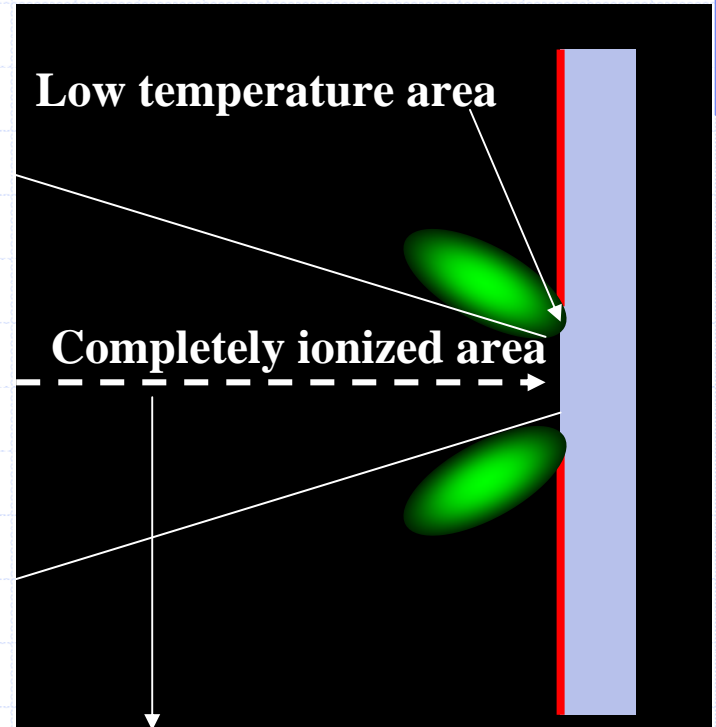
60 nm



15 nm

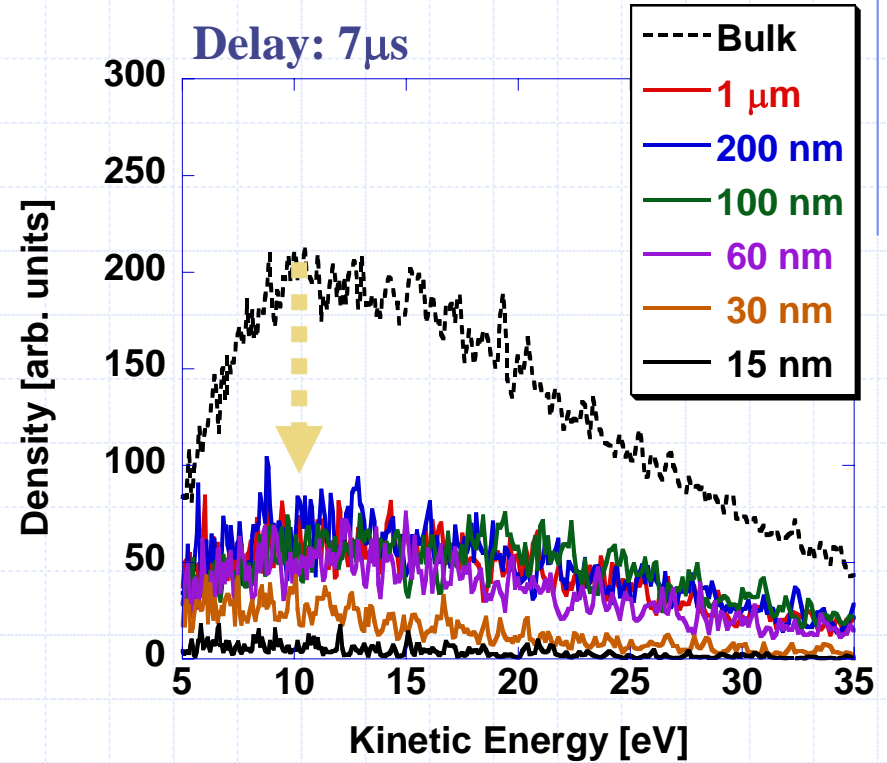
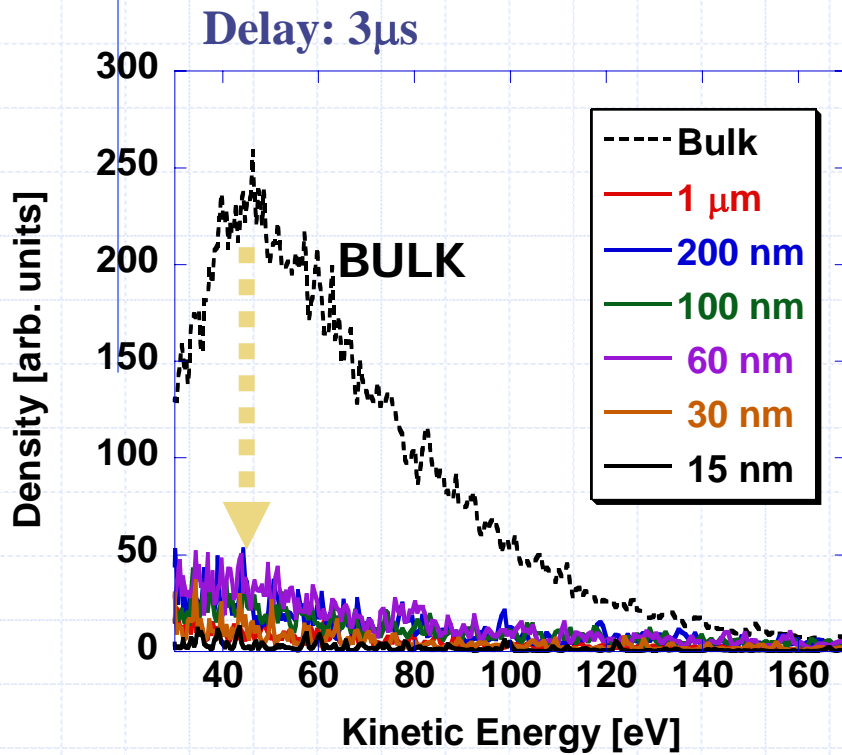


while the neutral atoms remain around the spot.



The energy distribution of Sn atoms along this axis is....

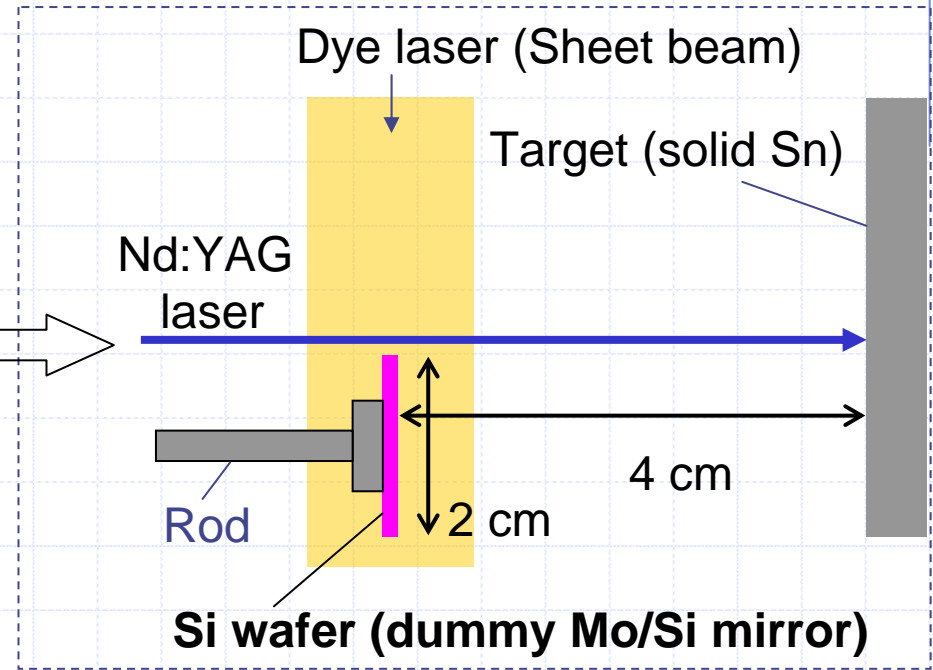
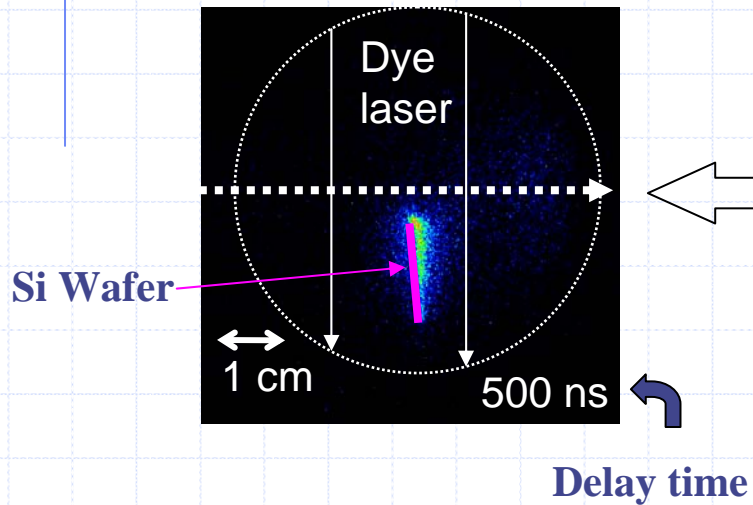
# The Energy Distribution of Sn Atoms



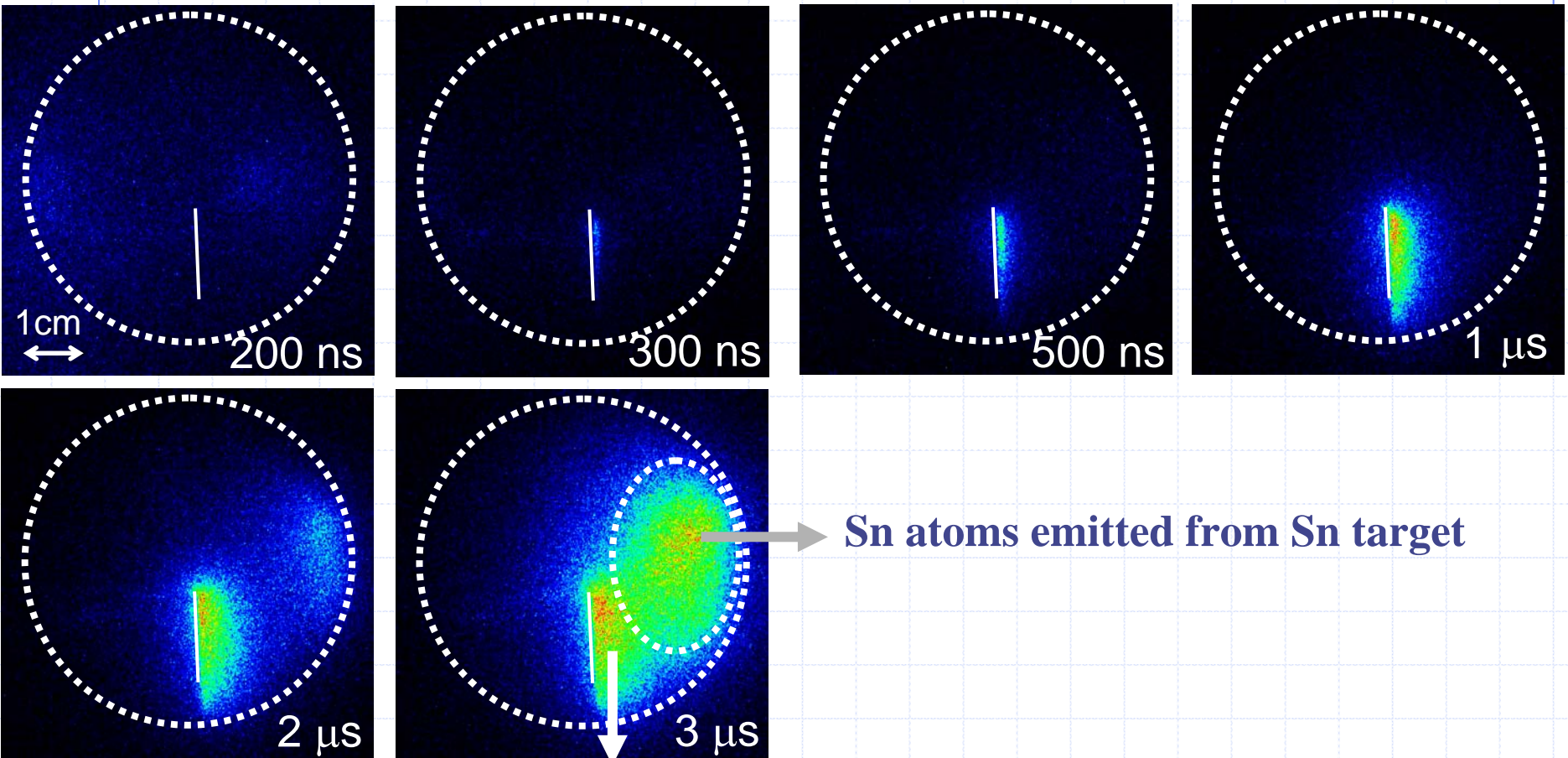
**A mass limited target is very effective to reduce the neutral debris.**

# Interaction between the Optics and Sn Atoms

## Example of LIF Image



# Temporal Behavior of Sn Atoms around Si Wafer

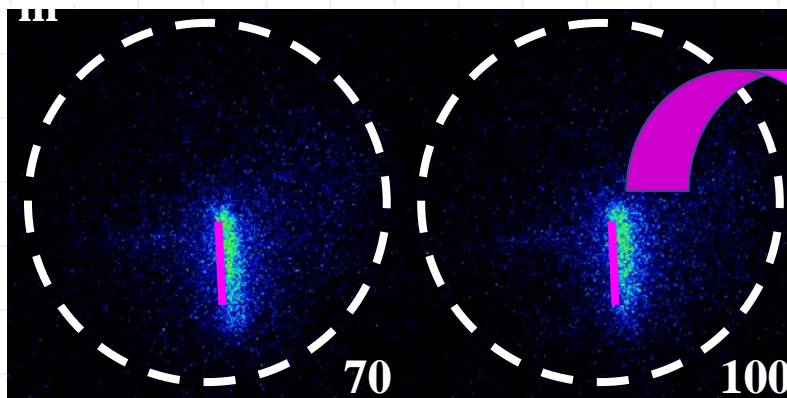
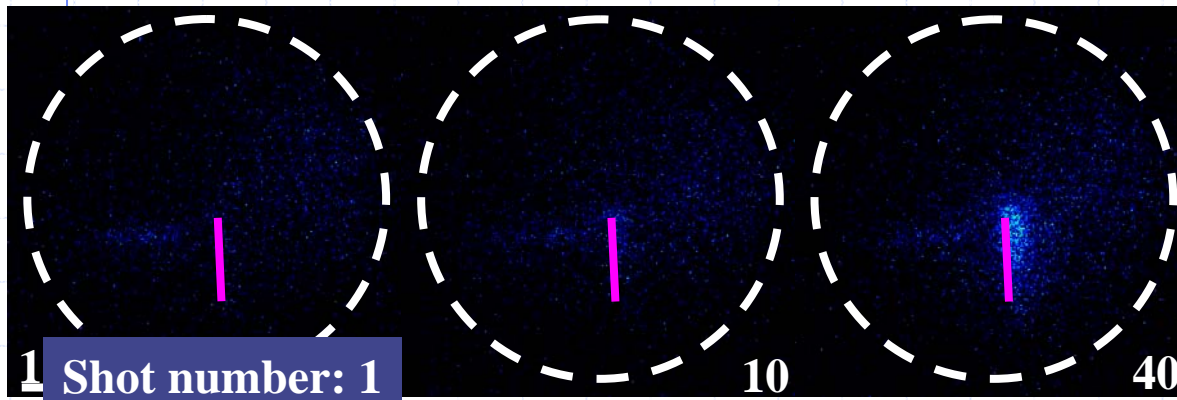


These Sn atoms could be formed by

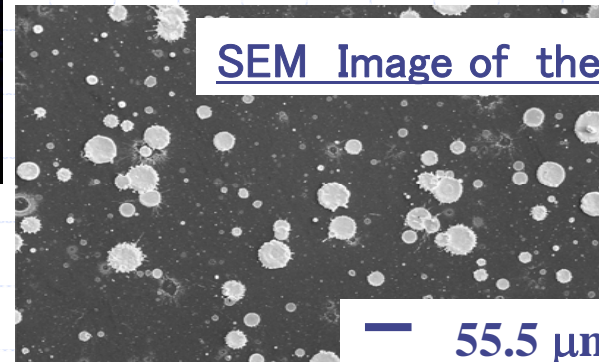
1. recombination of Sn ions on the wafer, or/and
2. sputtering of Sn atoms deposited in previous events

# LIF signals increased with shot number,

therefore, the Sn atoms were deposited on the wafer surface in the pervious events, and sputtered by Sn ions.

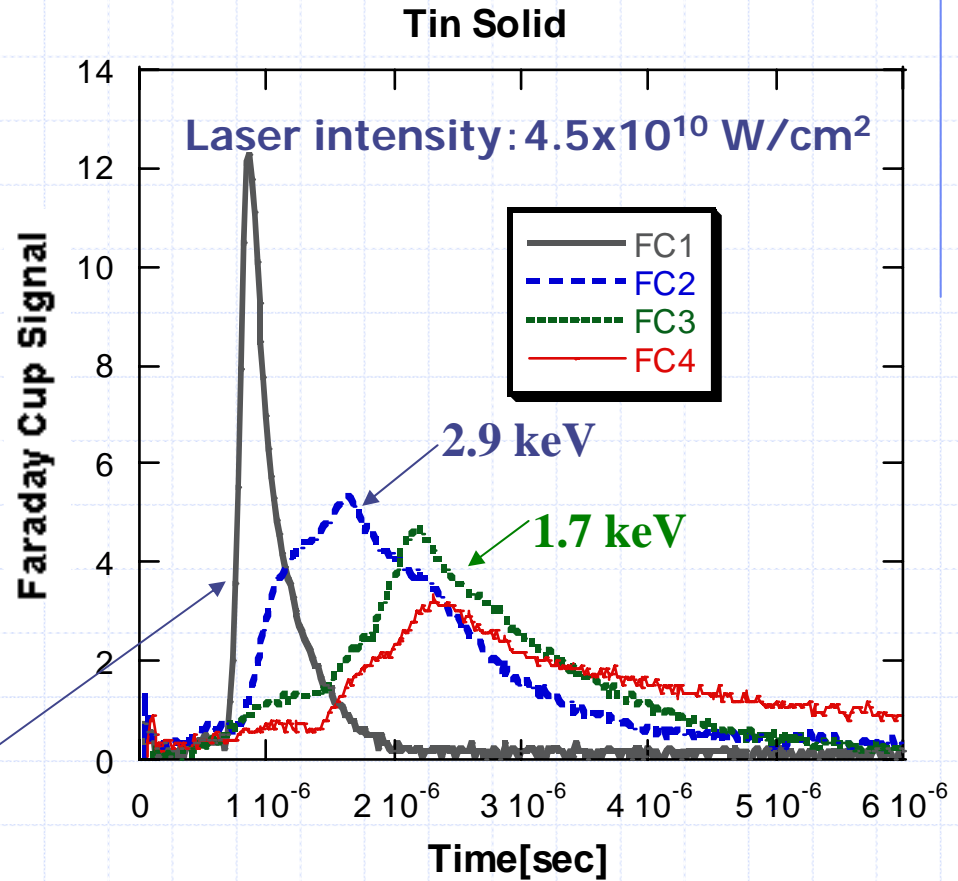
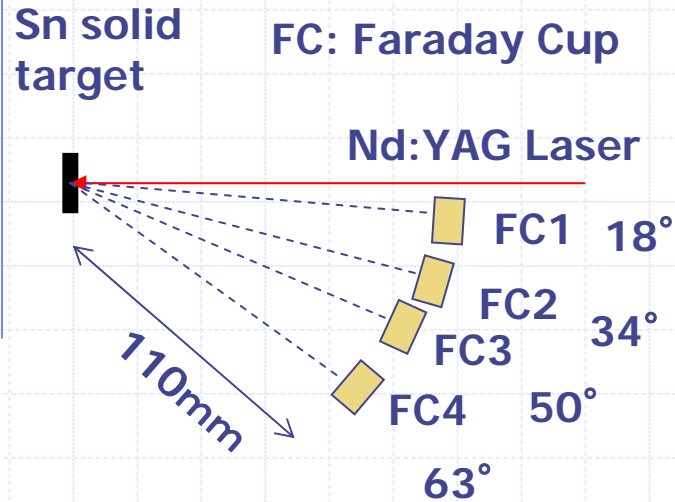


Delay Time: 600 ns



The LIF signal observed even at the delay time of 300 ns (See previous sheet). This indicates that **the kinetic energy of the Sn ions exceeds 10 keV**.

# Ion Energy measured by Faraday Cup

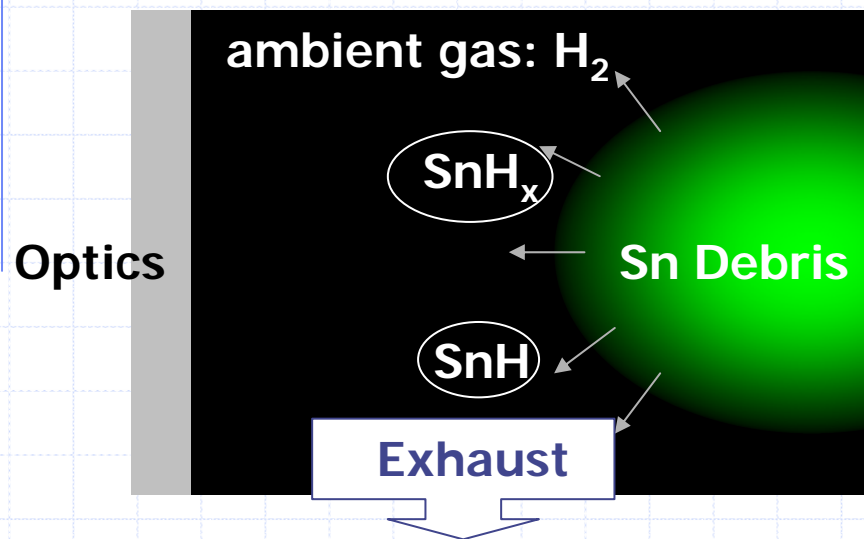


**10 keV**

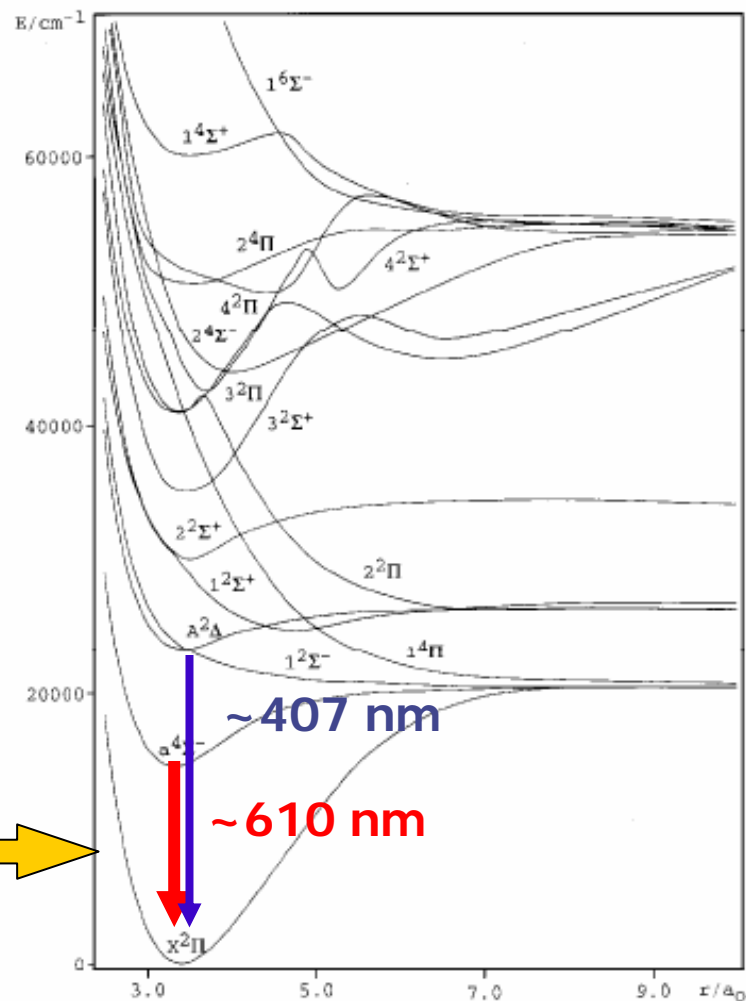
This agrees with the result obtained in LIF.

# Detection of SnH - Effect of H<sub>2</sub> Trap

## H<sub>2</sub> trap of Sn debris

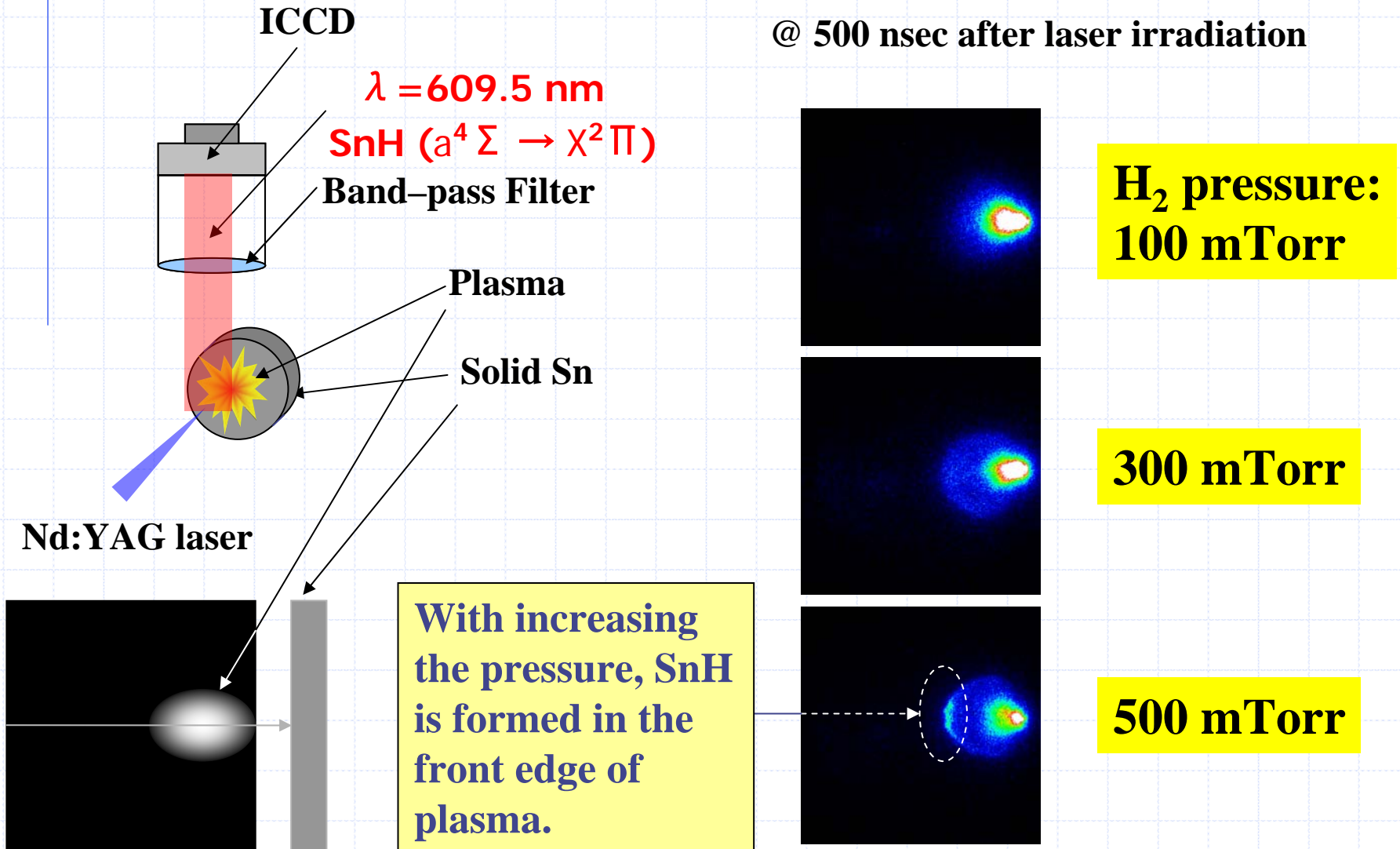


We tried to detect SnH.



Potential energy curve of SnH

# Radiation from LPP in Hydrogen Gas



# Radiation from LPP in Hydrogen Gas (II)

$\lambda = 609.5 \text{ nm} : \text{SnH} (a^4 \Sigma \rightarrow X^2 \Pi)$

@ 500 mTorr of  $\text{H}_2$  pressure

500 nsec

600

700

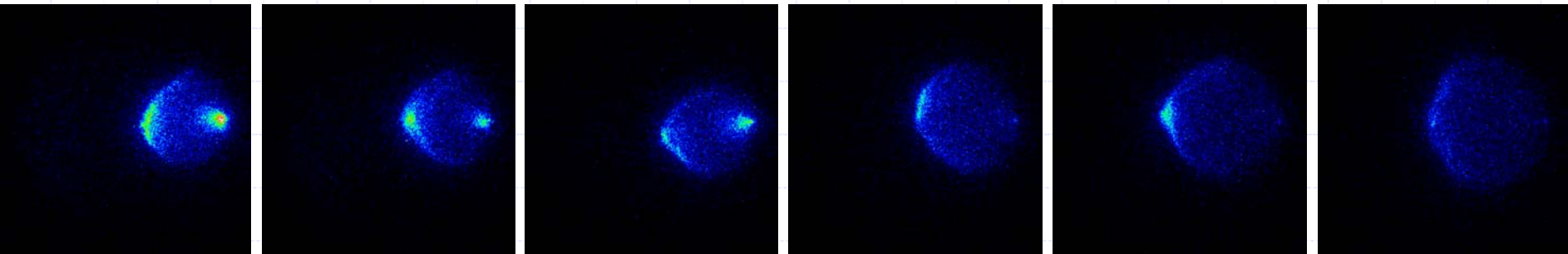
800

1000

1200

after laser  
irradiation

$\lambda = 407 \text{ nm} : \text{SnH} (A^2 \Delta \rightarrow X^2 \Pi)$



# Summary

We develop the LIF imaging system for visualizing neutral debris emitted from Nd:YAG-LPP.

## Temporal behavior of neutral atoms

We investigated the density distribution of Sn atoms emitted from thin film target to estimate a mass-limited target. As the results, it was confirmed that a mass-limited target is very effective to reduce the neutral debris.

## Interaction between mirror and debris

It was confirmed that the Sn atoms around mirror are sputtered by fast Sn ions. The results suggests that the kinetic energy of the Sn ions exceeds 10 keV. This agrees with the result obtained by Faraday cup detector.

## H<sub>2</sub> trap of Sn atoms

Radiation from LPP suggested that Sn debris are trapped in H<sub>2</sub> atmosphere, but LIF signal of SnH has not been obtained yet.

## Our next plans are

- ◆ Measurements with CO<sub>2</sub> LPP
- ◆ LIF measurements of SnH
- ◆ Development of mass-limited target

# Aknowlegement

This work was performed under the auspices of MEXT (Ministry of Education, Culture, Science and Technology, Japan) under contract subject “Leading Project for EUV lithography source development”.

We would like to thank Prof. H. Nishimura at Institute of Laser Engineering, Osaka University for the preparation of the Sn thin film targets, and also **Dr. H. Tanaka** and Mr. A. Matsumoto for his technical assistance in this work.