Laser and target optimization for the highest conversion to 13.5 nm EUV light with laser produced, minimum-mass tin plasma

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Outline

1. A **Minimum-mass target** has been suggested to provide the highest conversion to EUV but substantially mitigating plasma debris :
   - Sn droplets
   - Punch-out target

2. Moreover, **target of low density state** is prefarable because
   - adequate balance between emissibity and opacity
     optimum density and temperature
   - matching to YAG/ω or CO_2 laser drive
   - an order of mag. reduction in ion kinetic energy

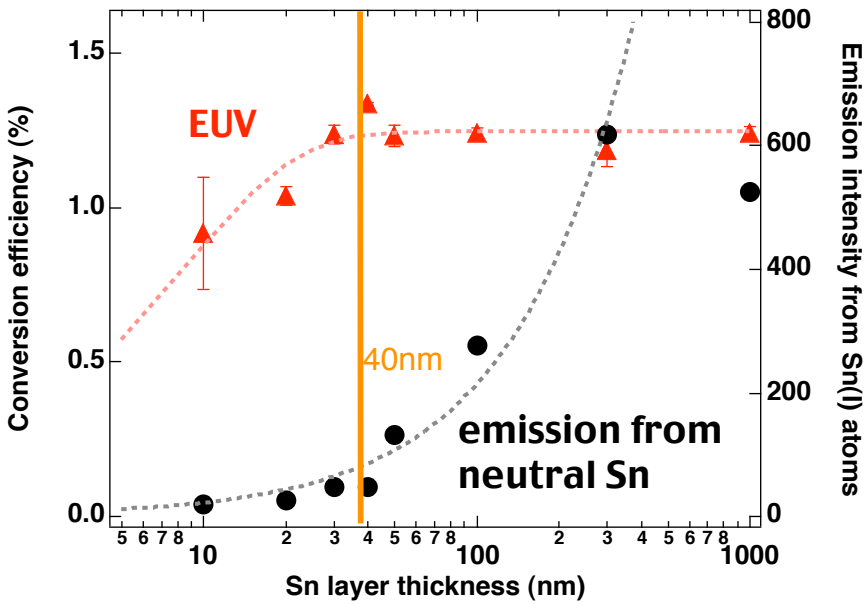
3. Experimental evidences and thoretical predictions, supporting this guide-line, are discussed.

minimum mass target

Minimum-mass target is important to reduce neutral atoms

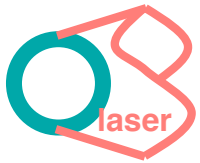
Osaka U., Hiroshima U.

CE was measured as a function of Sn overcoating thickness

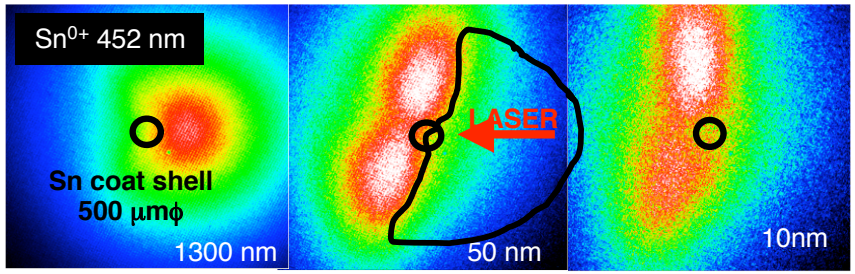


emission from Sn neutral atoms is in proportion to the overcoat thickness, in contrast to EUv emission.

Sn coated target
intensity : 10^{11} W/cm^2
duration : 2ns



emission from Sn neutrals



With decease in the overcoat, emission along the laser axis decreases

↓

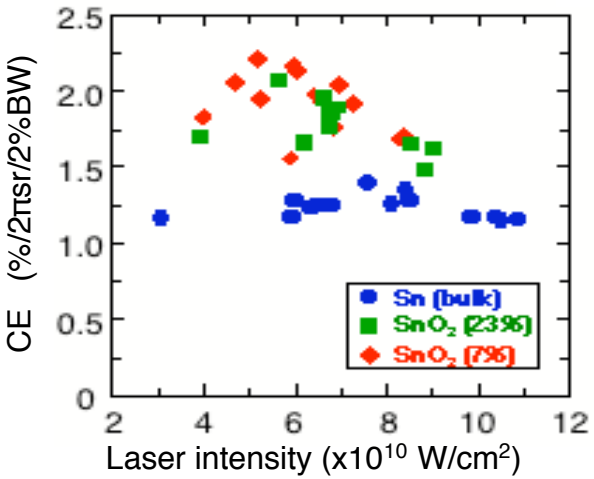
control of Sn neutrals

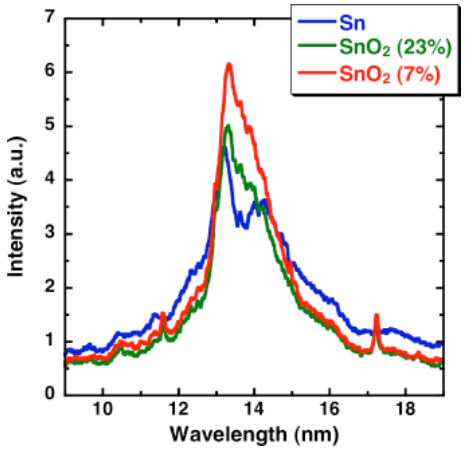
Expt. database : Sn

With the use of low-density targets, CE is substantially improved

low density SnO_2 target

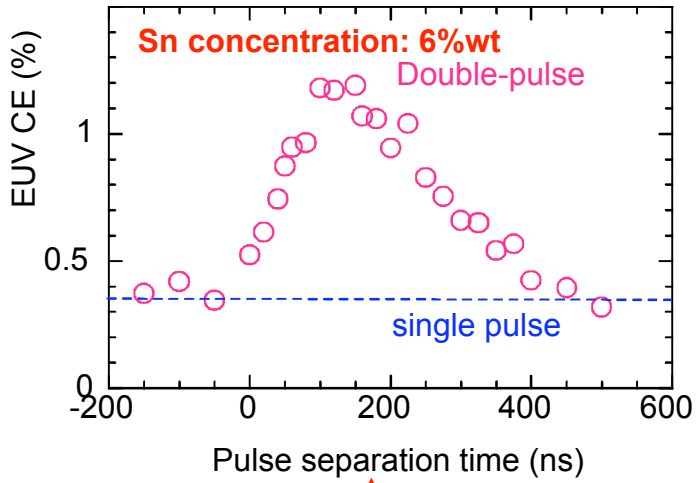
Nd:YAG [1064 nm, 10ns] **ILE, Osaka U.**





A colloid including Sn fine particles

Pre-pulse: 0.1 J (<10^{10} Wcm^{-2}) 0.5 μm **Miyazaki U.**
Main Pulse: 0.5 J (2 x 10^{11} Wcm^{-2}) 1μm



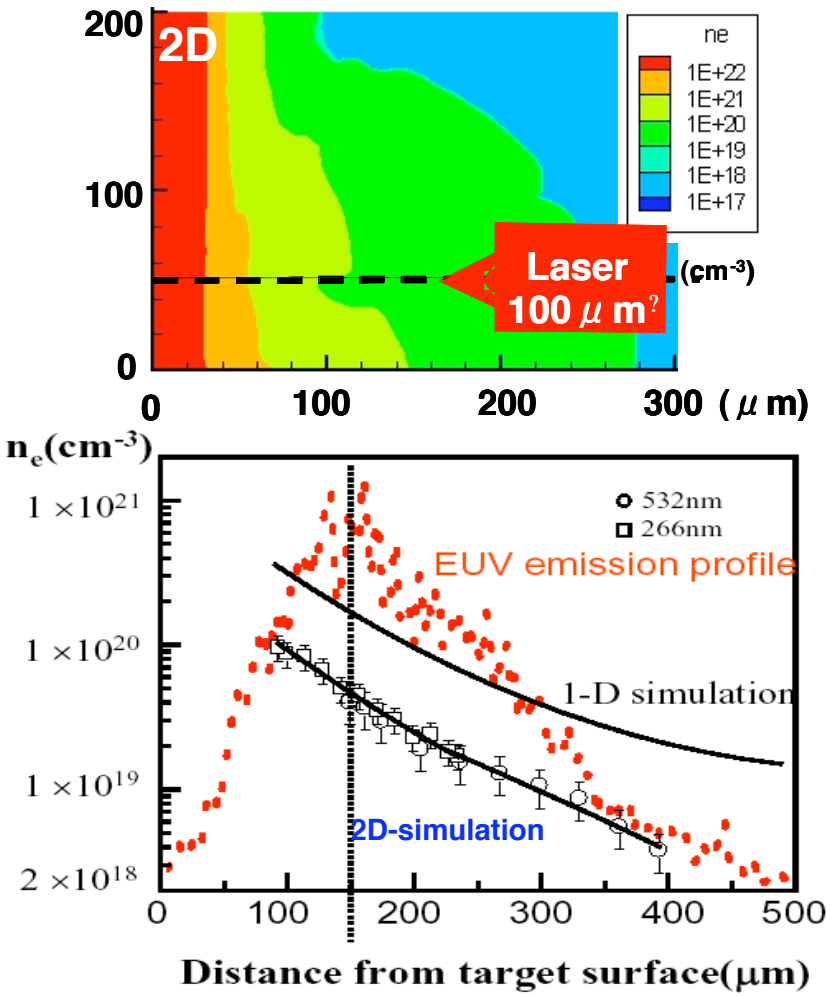
low density plasma created with a pre-pulse fits well with CO2 laser drive

The use of low density targets improves CE

High CE is obtained even with 10-ns drive due to weak opacity arising from low density target

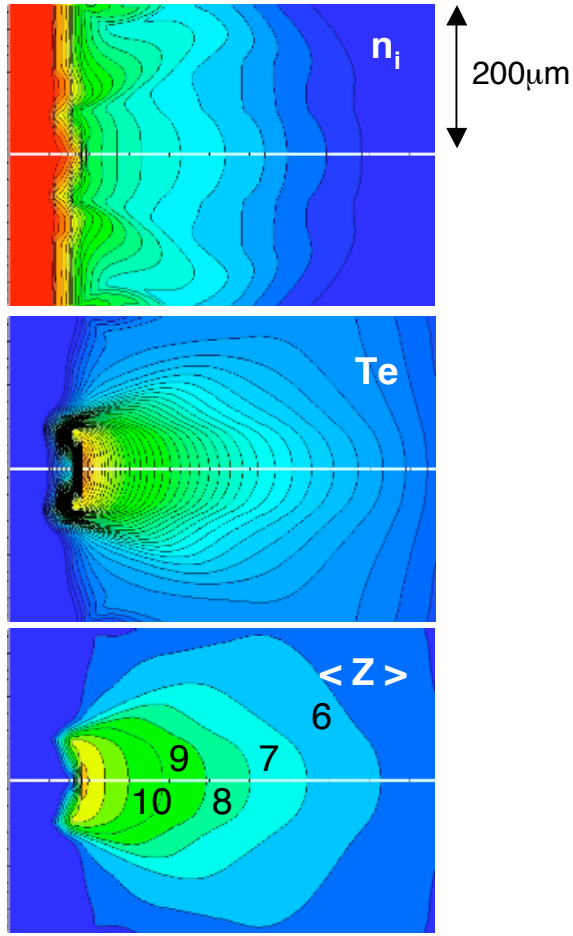
simulation code

2D Radiation hydrodynamic code has been developed for more realistic simulations



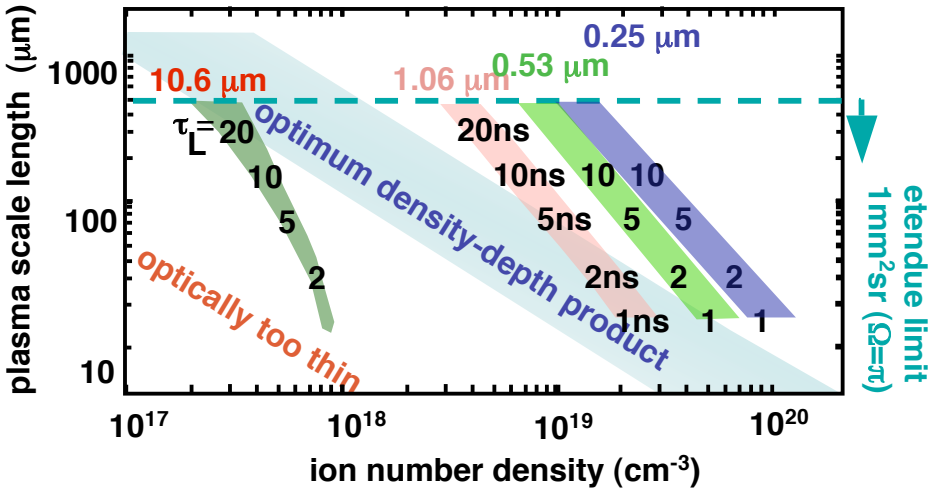
ne profiles are well reproduced with 2D code

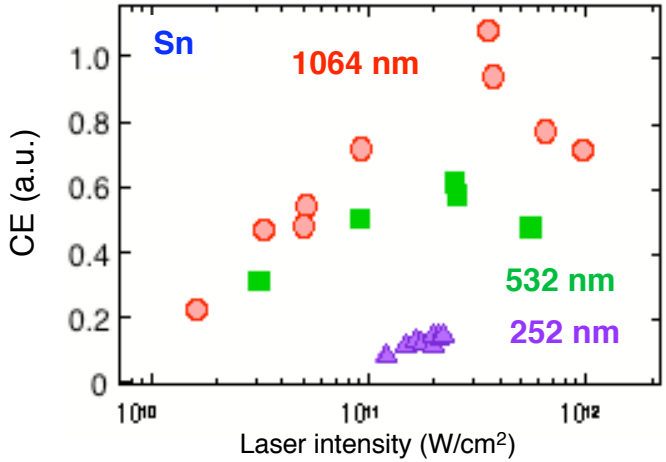
Ni, Te, and average Z distributions

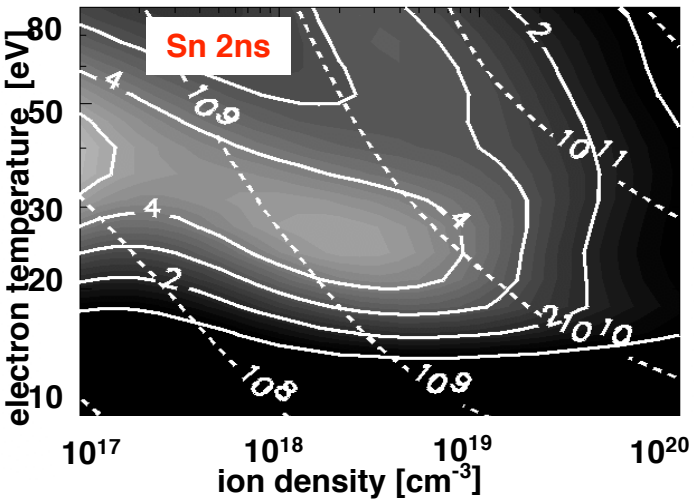


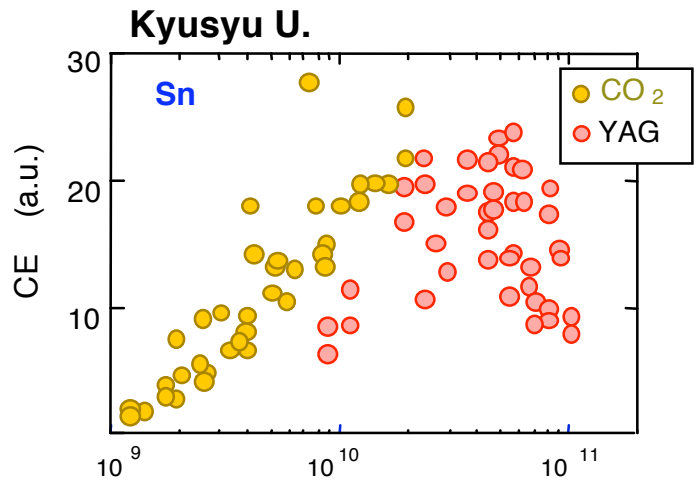
Sn planar targets
laser spot diam.100μm

Optimum plasma conditions are theoretically and experimentally confirmed



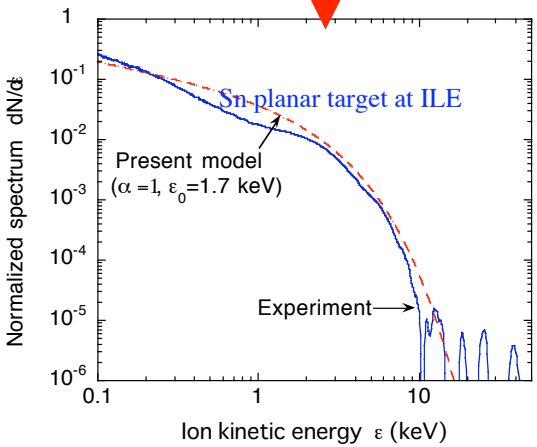


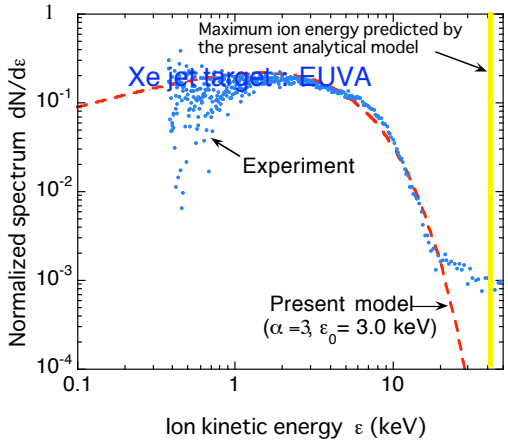


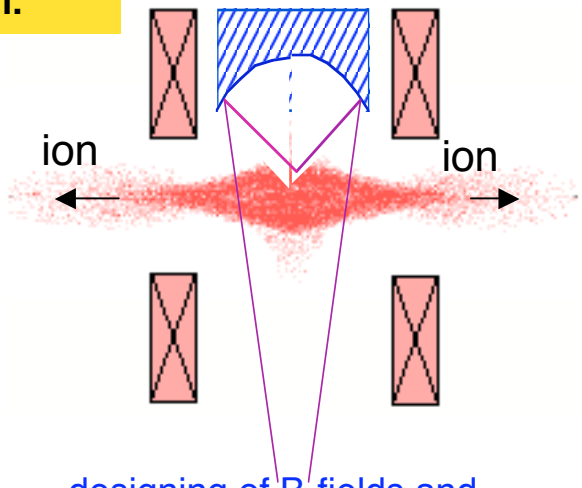


Analytical model for ion energy distribution clearly interprets the experimental results

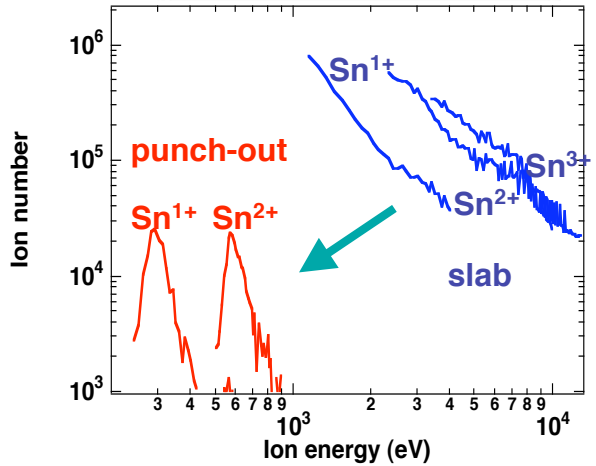
Isothermal expansion model replicates experiments well.





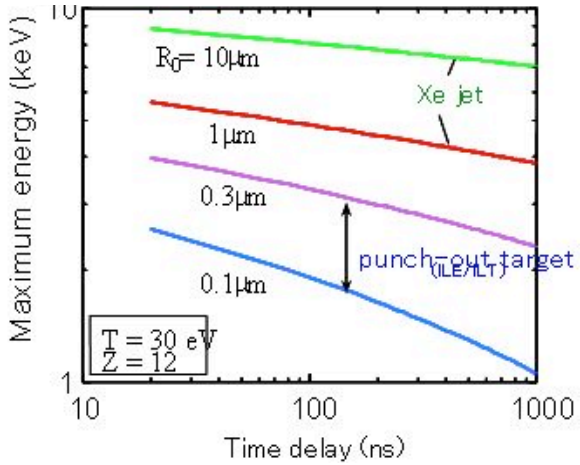


designing of B-fields and analysis of ion expansion with a hybrid code



It has been demonstrated, for low density targets, that the amount of ions as well as energy are substantially reduced.

prediction of maximum energy



M. Murakami, Phys. Plasmas ***12****, 062706 (2005)*

minimum mass target

Minimum-mass of Sn corresponds to a solid sphere of 50 μm in diam.

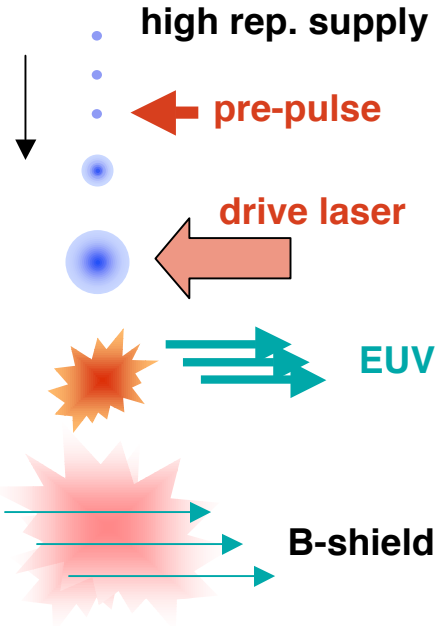
double pulse irradiation : EUV energy needed : 30 (3) mJ @ 10 (100) kHz

→ Sn atoms : 2×10^{15} (10^{14}) particles
diam. of Sn droplets : 50 (20) μm

→ drive intensity 10^{11} W/cm^2
duration 10ns

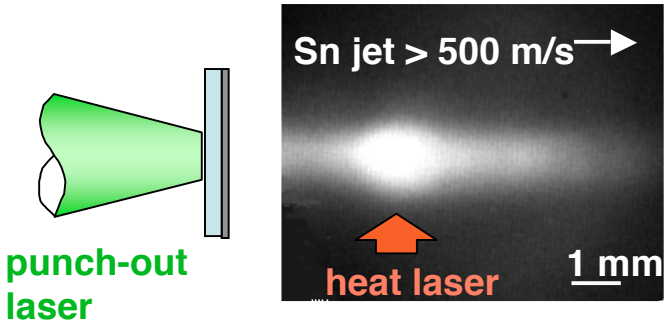
↓ expansion with a pre-pulse

→ diameter : 400 (150) μm



Sn droplets

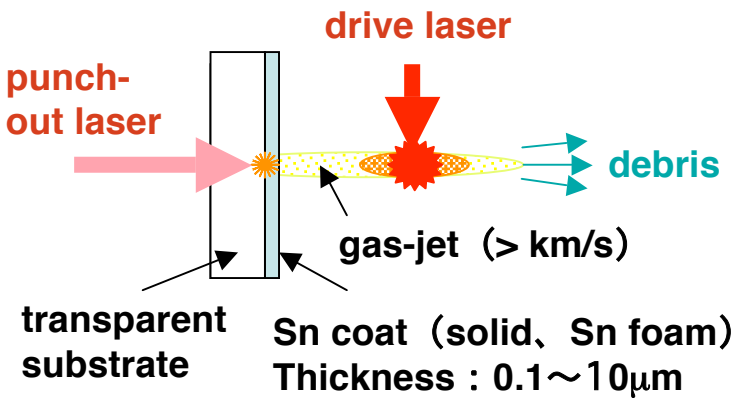
Hyogo U.

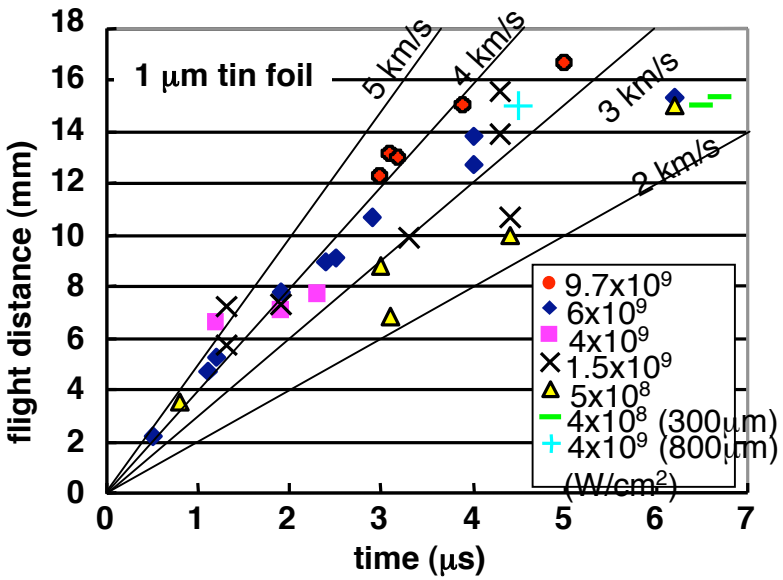


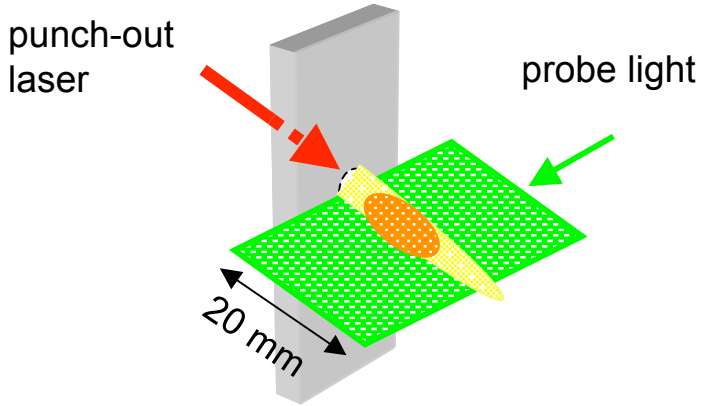
punch out target
ILE and ILT

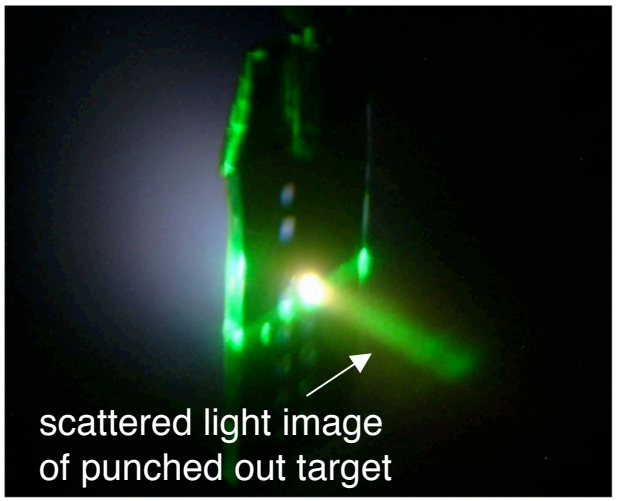
punched out target

Low density Sn is generated with the punch-out method









Target supply with minimum-mass and debris-free will be possible

Summary

1. **Minimum number of Sn atoms needed for LPP EUV are ~10^{15} per pulse (@10 kHz, 10 ns, 10^{11} W/cm^2 drive)**

2. **Optimum density and temperature are nearly n_i=10^{19} /cc, T_e=30 eV.**

3. **Low density state is preferable for debris mitigation**

4. **These are attained only when a target of the minimum mass is supplied successively with**
   - **a solid-droplet, made low-density with a pre-pulse laser before main-drive**
   - **a punched-out target**

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