

Characterization of Debris Emitted from Laser-Produced Tin Plasmas for EUV Lithography Application

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Summary



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- **Ion debris emitted from mass-limited Tin targets were measured for EUVL development.**
 - Thin Sn coated (10 - 1000 nm) polystyrene shells were used as a mass limited target.
 - Minimum thickness required for sufficient EUV emission is from 10 to 35 nm.
- **We measured ion debris with a Faraday cup and a Thomson parabola ion analyzer.**
 - Total number of emitted ions are comparable to total number of minimum atoms required for sufficient EUV emission.
 - **Charge state of ions are concentrated between Sn^{2+} - Sn^{4+} . Maximum charge state is observed to be 7+.**
 - **Distribution of ion energy was changed depending on the coating thickness.**
 - With increasing the coating thickness, number of fast ions was increased, and number of slow ions was decreased.



Tin coated polystyrene shell is easy to limit thickness and cross section of target.



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Target Substrate

Polystyrene shell

Diameter 500 μm , Shell thickness 7 - 8 μm

Coating thickness

1000, 500, 280, 210, 100, 40, 35, 20, 10 nm

Laser conditions

Energy

1 - 2 J

Pulse duration

10 ns

Wavelength

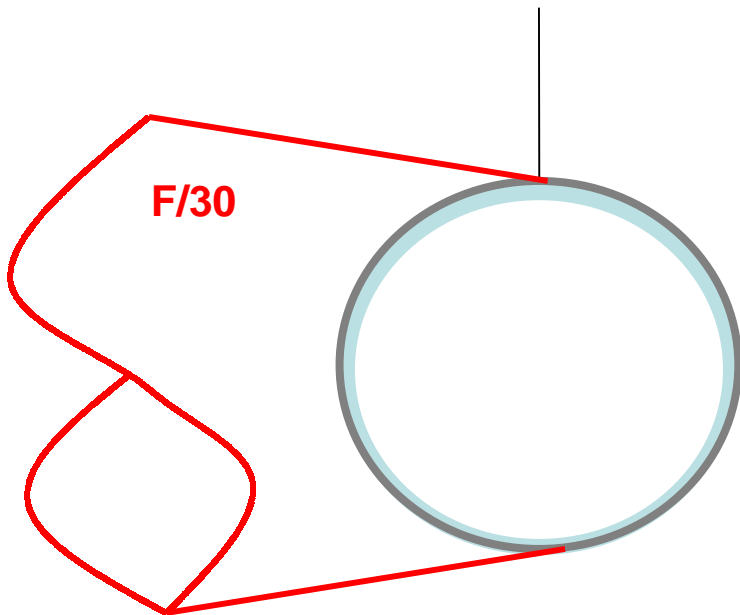
1.064 μm

Spot size

500 μm

Intensity

$0.5 - 1.0 \times 10^{11} \text{ W/cm}^2$



Mass limited target is one of candidates to suppress generation of neutral debris.

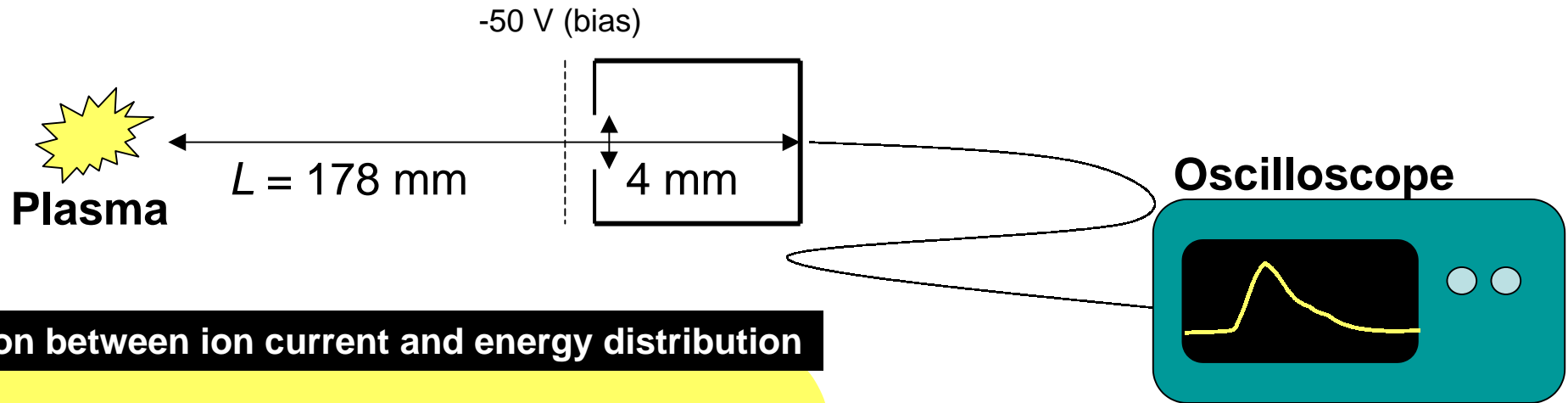


Charge collector

Energy distribution of ion debris was calculated from ion current measured with a Faraday cup.



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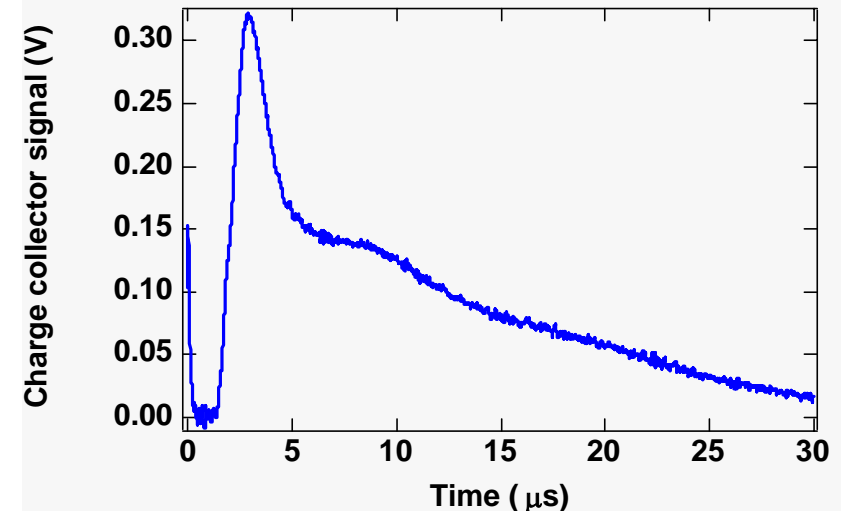


Relation between ion current and energy distribution

$$\frac{dN_i}{dE} = \frac{I(t)}{Z \cdot e \cdot m_i} \cdot \frac{t^3}{L^2}$$

$$E = \frac{1}{2} \cdot m_i \cdot \left(\frac{L}{t} \right)^2$$

Pulse of ion current (@50 Ω)

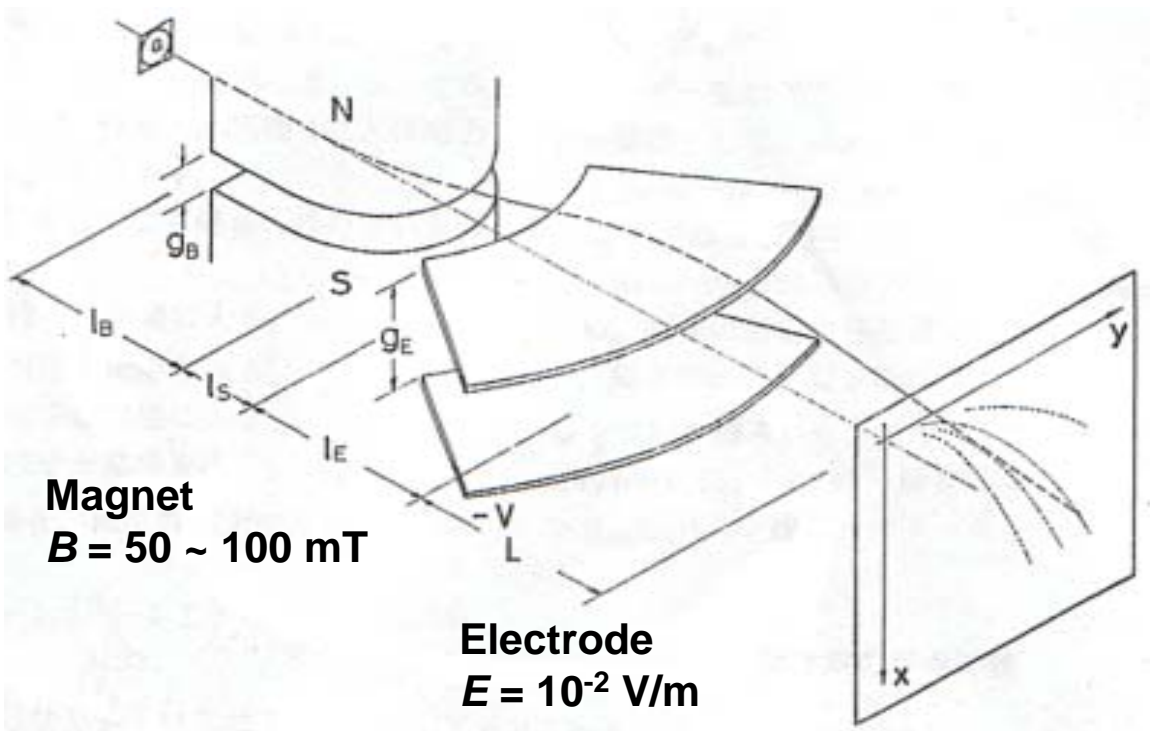


Thomson parabola

Charge state (A/Z) and energy can be measured with the Thomson parabola where electric and magnetic field are parallel.



ピンホール 200 $\mu\text{m}\phi$

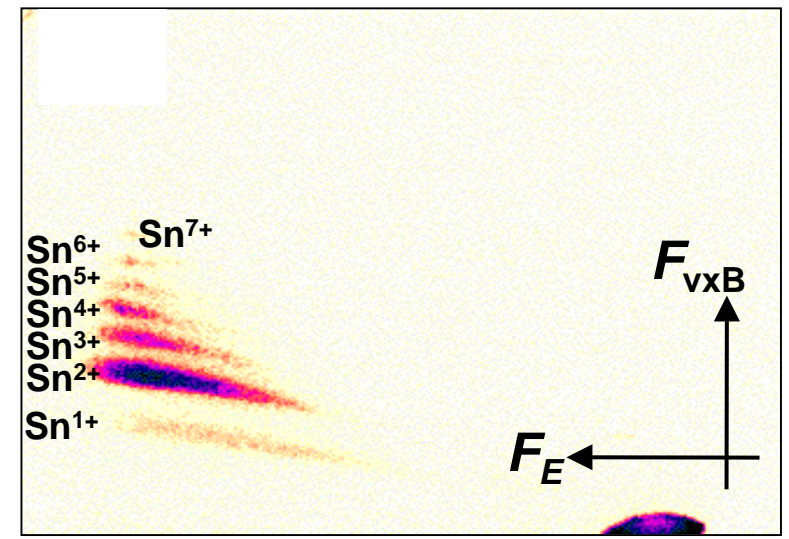


Magnet
 $B = 50 \sim 100 \text{ mT}$

Electrode
 $E = 10^{-2} \text{ V/m}$

Detector
Micro-channel-plate

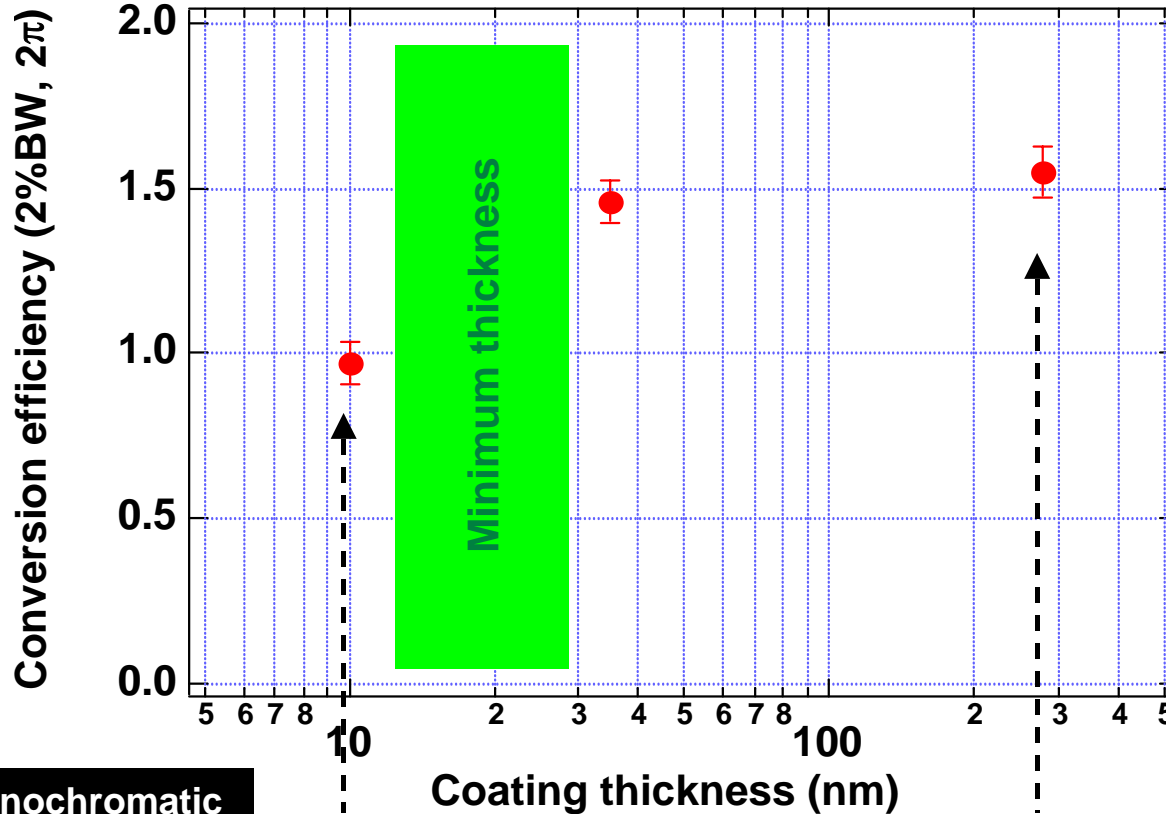
Example of ion trajectory



Minimum thickness for sufficient EUV emission

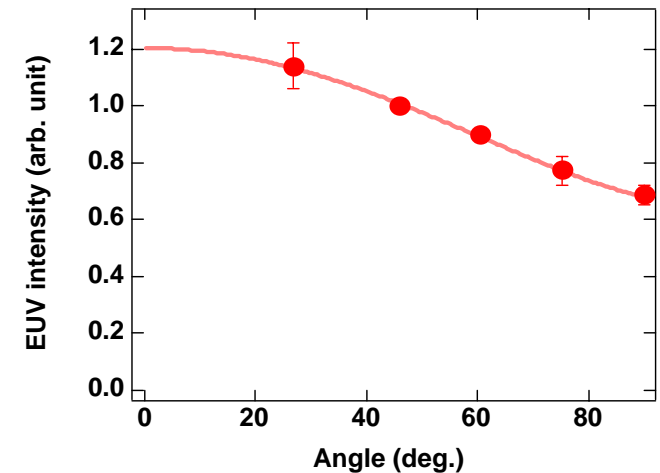
Minimum thickness required for sufficient EUV emission is from 10 to 35 nm. (In the case of 10 ns/ 1.06 μm laser light)

Conversion efficiency depending on coating thickness

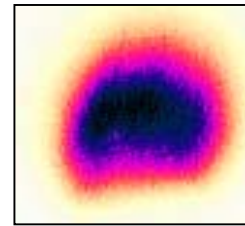
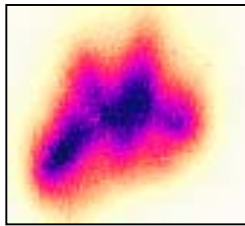


Conversion efficiency for planar targets: 1.7%

Angular distribution of EUV emission from spherical targets



Monochromatic EUV image



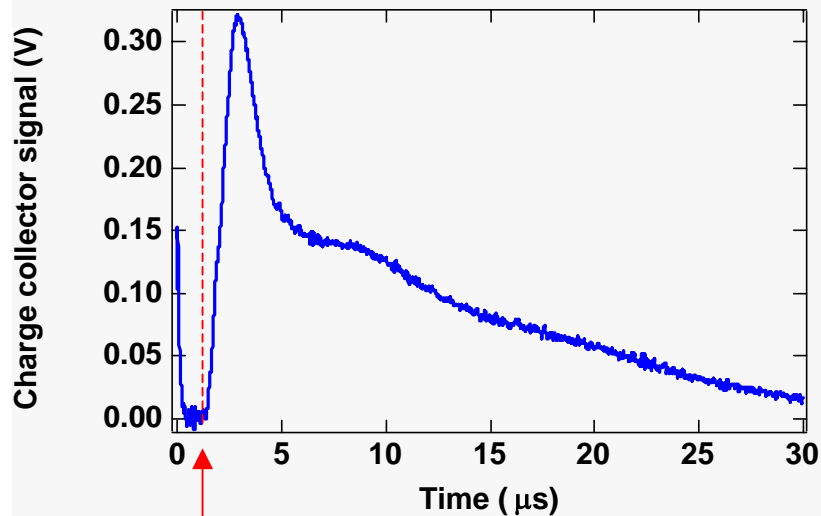
Debris ion spectrum from thick target

Energy distribution of debris ions consists of several temperature components.



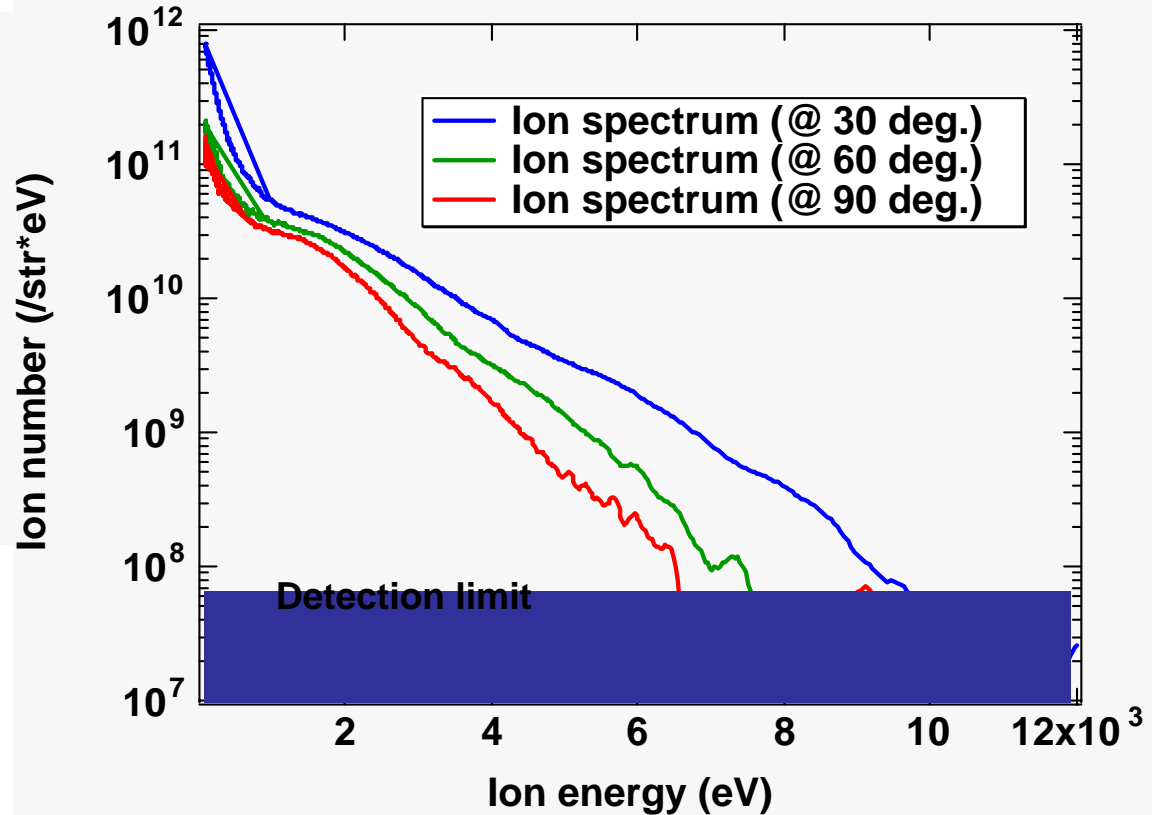
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Pulse shape of ion current (@50 Ω)



1.4 μs (ToF of 10 keV ion)

Energy distribution of ions (assumption of $Z = 2$)



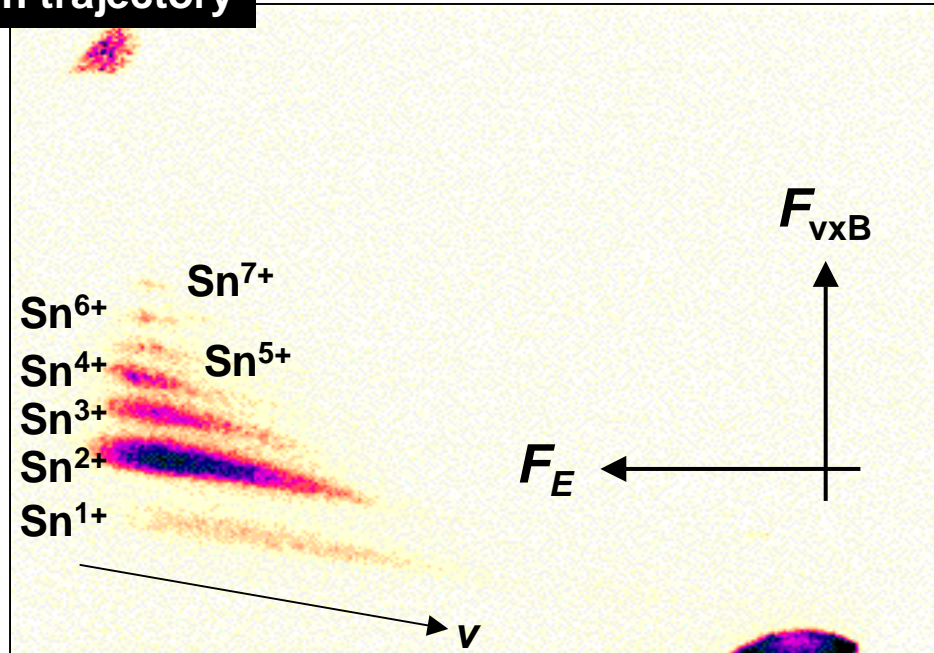
Charge states of debris ions

Charge state of debris ions is concentrate in the range of Sn^{2+} - Sn^{4+} .Maximum charge state that have been measured is 7+.



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Ion trajectory



$$E = 7.5 \times 10^3 \text{ V/m}$$
$$B = 46 \text{ mT}$$

Averaged charge state is $Z = 2.5$



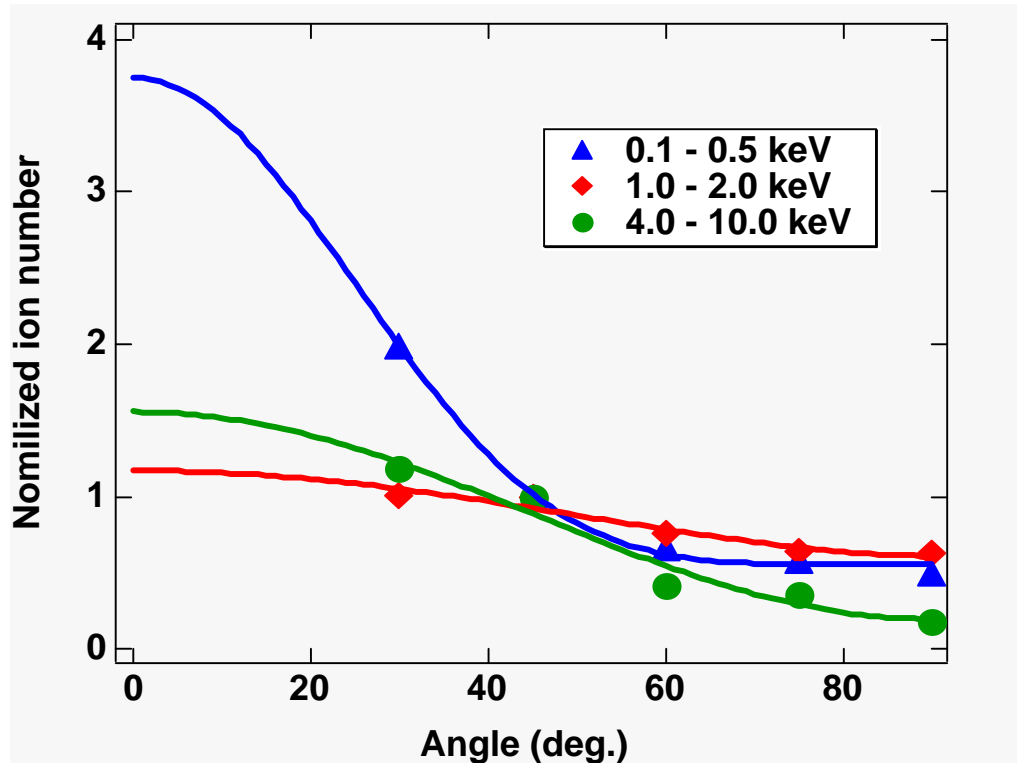
Number of debris ions

Number of ions emitted into 2π str was $2.6 - 3.6 \times 10^{15} \times Z^{-1}$ with consideration of angular distribution of ion emission.



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Angular distribution of ion emission



With assumption of $Z = 2.5$ for all ions, number of ion debris is almost same as number of atoms included inside 70 - 90 nm thickness layer.



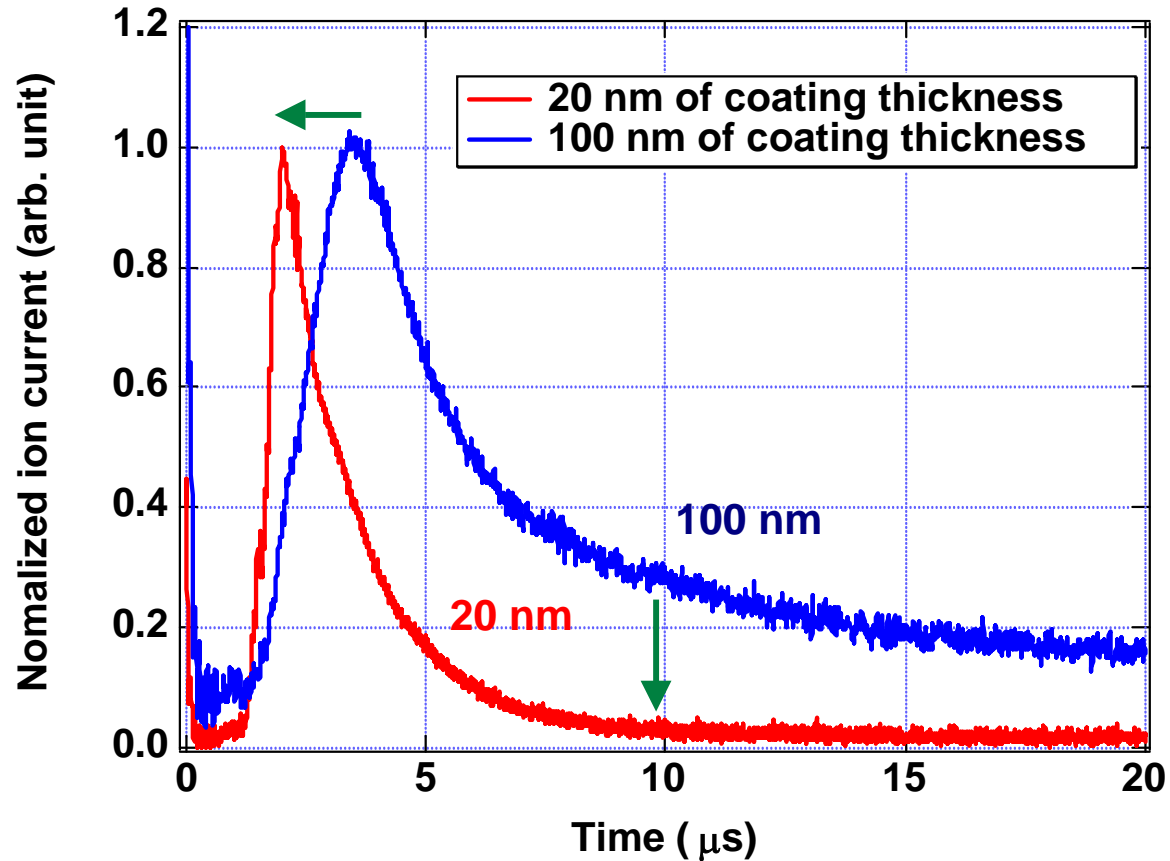
Dependence on target thickness

With decreasing coating thickness, number of fast ions are increased while that of slow ones are decreased.



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Pulse shape of ion current with decreasing coating thickness.



Dependence on target thickness

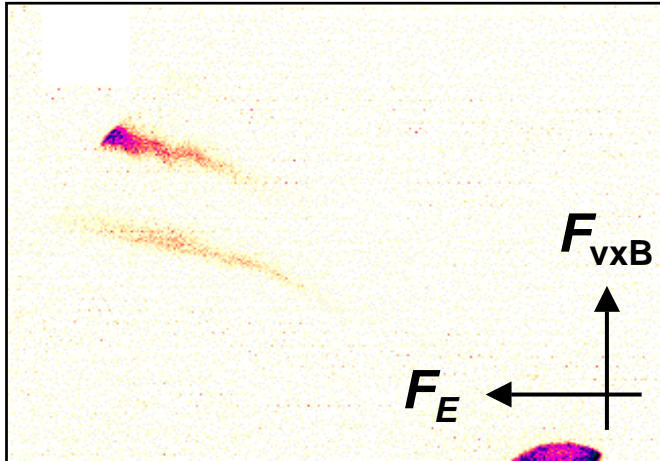
Energy distribution of ion debris was shifted to high energy region with decreasing coating thickness.



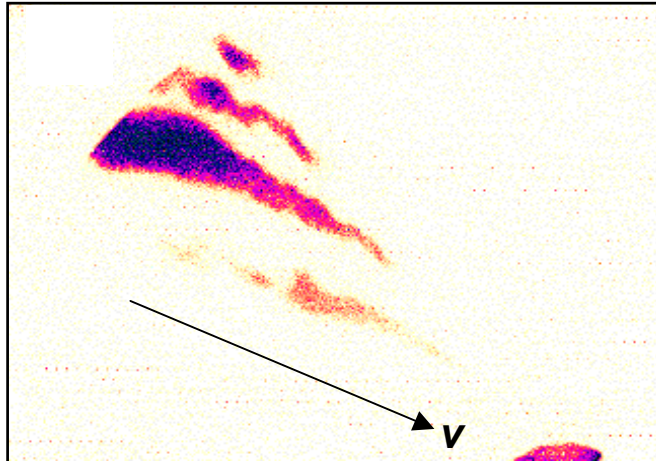
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($E = 10^4$ V/m, $B = 100$ mT)

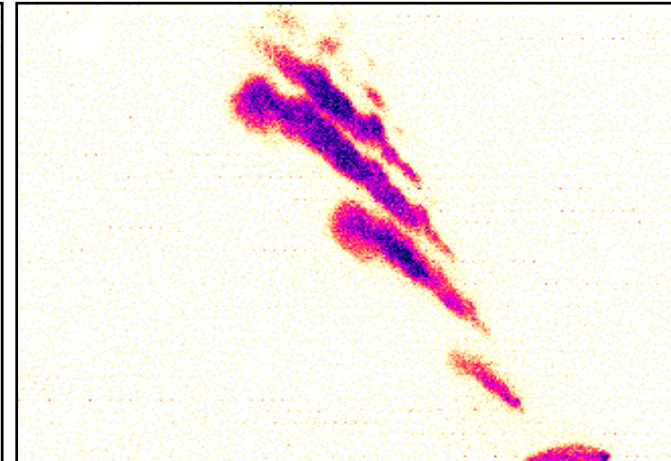
Thickness: 280 nm



Thickness: 35 nm



Thickness: 10 nm



The effect of coating thickness should be considered for optimizing electromagnetic field to shield ion debris.

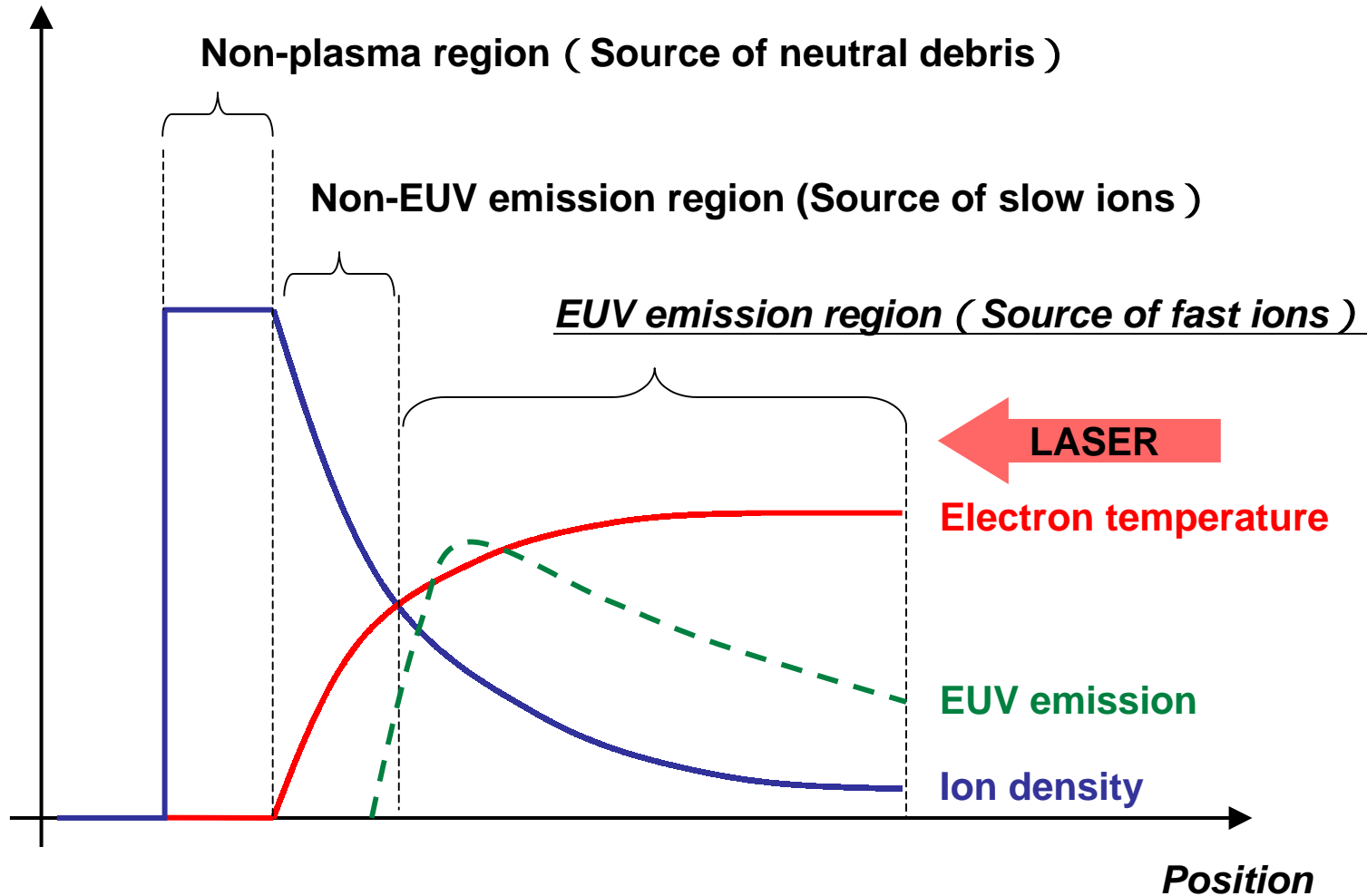


Mechanism of debris ions generation

In the case of mass-limited target, plasma is concentrated into the EUV emission region, therefore number of slow ions are decreased.



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