01-SO-05

Low-debris, EUV source using a colloidal microjet target containing tin dioxide nanoparticles

Shoichi Kubodera, Sumihiro Suetake, Yusuke Senba,
Yusuke Sato, and Takeshi Higashiguchi
kubodera@opt.miyazaki-u.ac.jp

Department of Electrical & Electronic Engineering and Photon Science Center,
University of Miyazaki, Miyazaki, Japan

2006 International Symposium on Extreme Ultraviolet Lithography
October 15–18, 2006
World Trade Centre, Barcelona, Spain

Joint requirements for EUV source

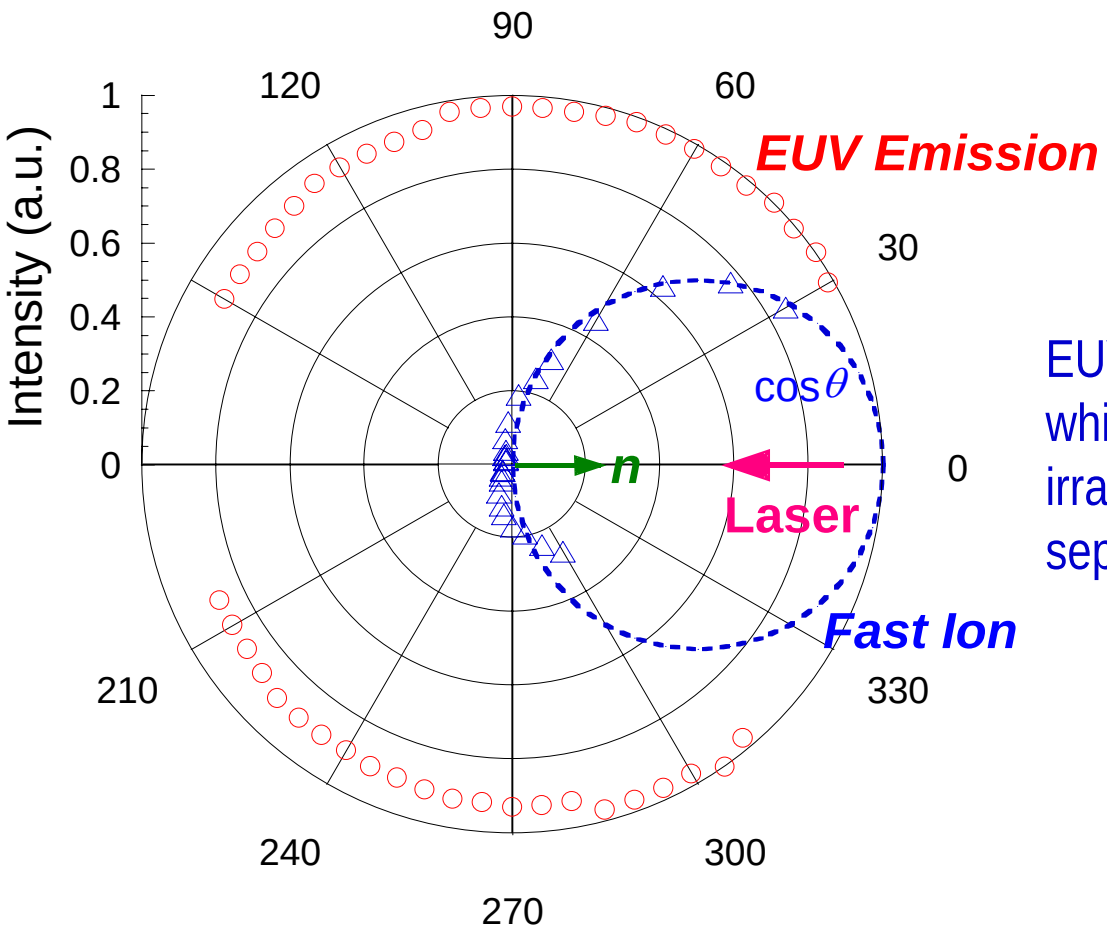
Joint Requirements for EUV Source

SOURCE CHARACTERISTICS	REQUIREMENTS
▪Wavelength	13.5 (nm)
▪EUV Power (in-band)	> 115 (W) (180 W) (after intermediate focus)
▪Repetition Frequency	> 7 - 10 kHz *
▪Integrated Energy Stability	± 0.3% (3σ over 50 pulses)
▪Source Cleanliness	≥ 30,000 hours (after intermediate focus)
▪Etendue of Source Output	1 – 3.3 mm^2sr (max)*
▪Maximum Solid Angle to Illuminator	0.03 – 0.2 (sr) (depending on particular optical scheme)*
▪Spectral Purity	
130 - 400 nm (DUV/VUV)	≤ TBD – 7% (design dependent)*
> 400 nm (Vis/IR)	TBD

* Not agreed among participants

V. Banine, Source Workshop, San Diego, CA, USA (2006).

EUV and ion emissions by use of a water jet target

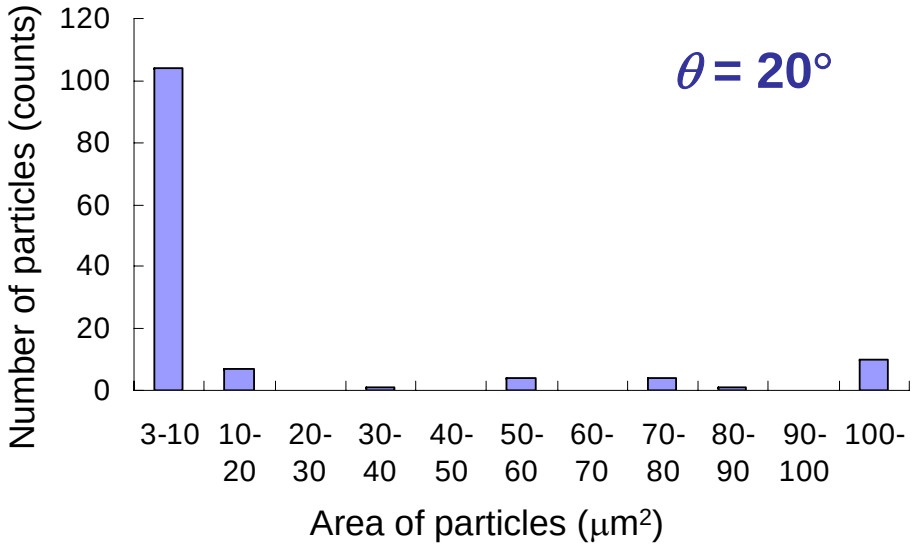


EUV emission was almost isotropic, while fast ions emitted towards the laser irradiation. This suggested a spatial separation between ions and emissions.

Appl. Phys. B **79**, 669 (2004).

Debris emissions from a solid tin target

Tin debris deposited on a Si witness plate

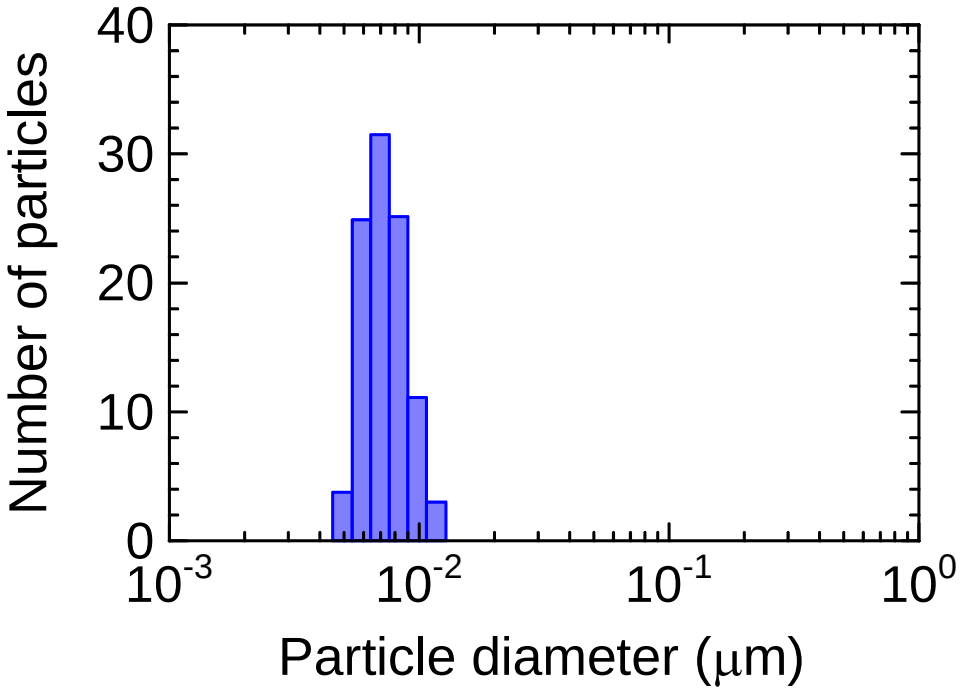


Laser intensity: 7 x 10^{10} W/cm^2
Spot size: 300 μmϕ (FWHM)
Maximum EUV CE: 1.2%
Laser energy: 500 mJ
Laser pulse width: 10 ns

Micro-order debris emission was unavoidable with a solid target.

Rev. Sci. Instrum. **76**, 126102 (2005).

Colloidal jet target containing SnO_2 nano particles



SnO_2 nano-particle size distribution of a colloidal target

Tin oxide nano-particles as a starting material would reduce micro-debris.

Low-density SnO_2 colloidal target would further reduce the amount of debris.

Low density nature should be compensated by using double pulses to control plasma characteristics.

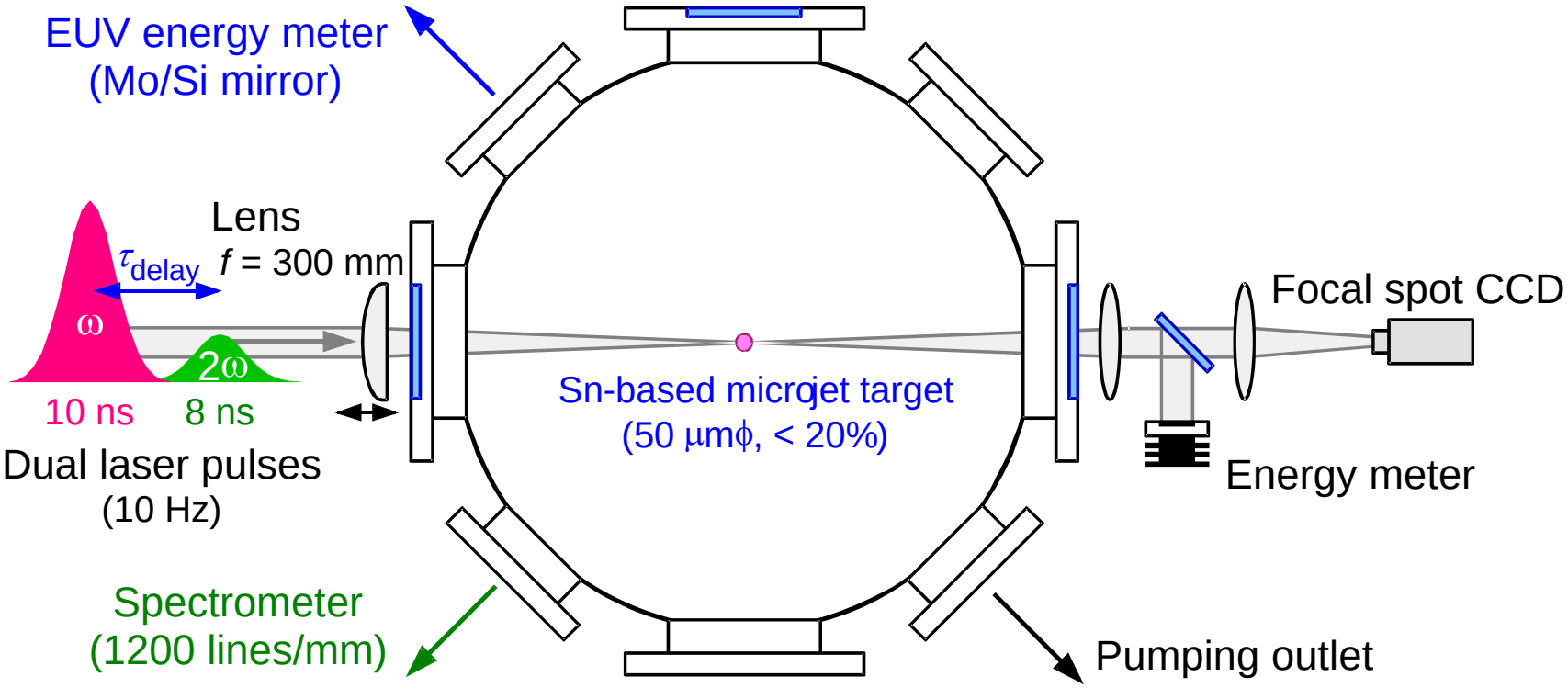
Objective

We investigate various characteristics of a low-density colloidal jet target containing SnO_2 nano particles and answer the following questions.

Can we obtain a nominal EUV CE by use of a low-density colloidal target?
Is the amount of debris really reduced with such a target?
Is this target comparable to other viable targets?

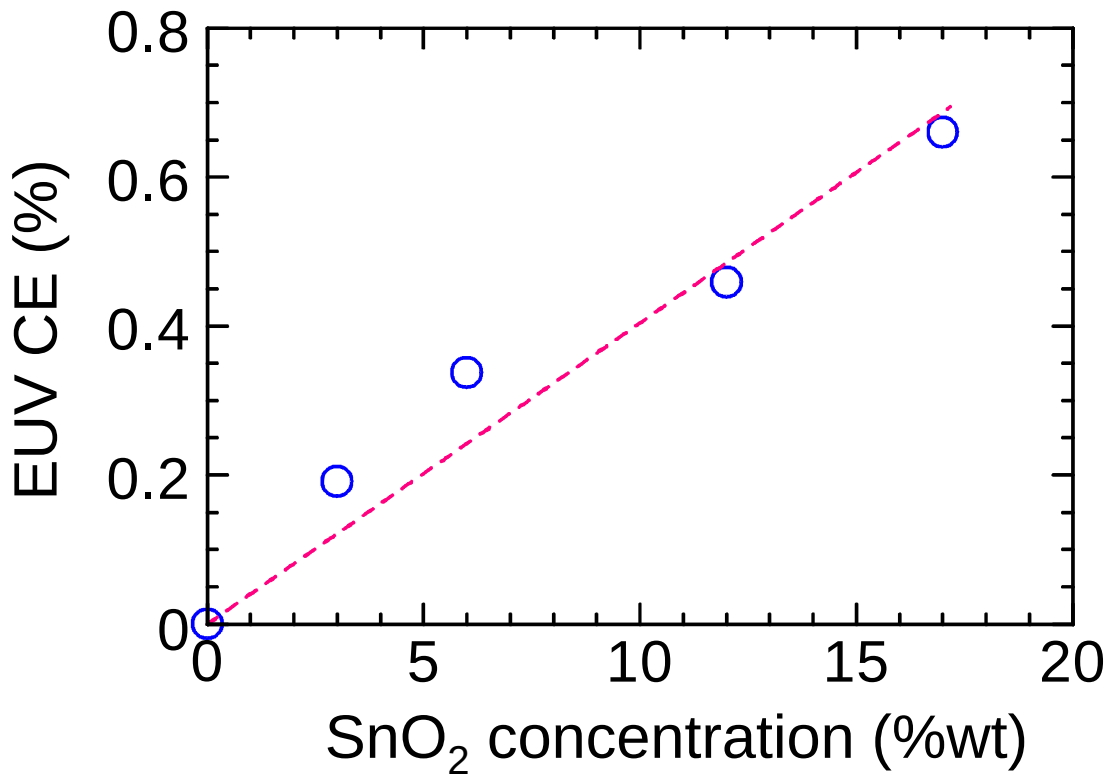
We especially pay our attention to debris characteristics emitting from a colloidal target.

Experimental setup for EUV CE



EUV CE as a function of SnO_2 concentration

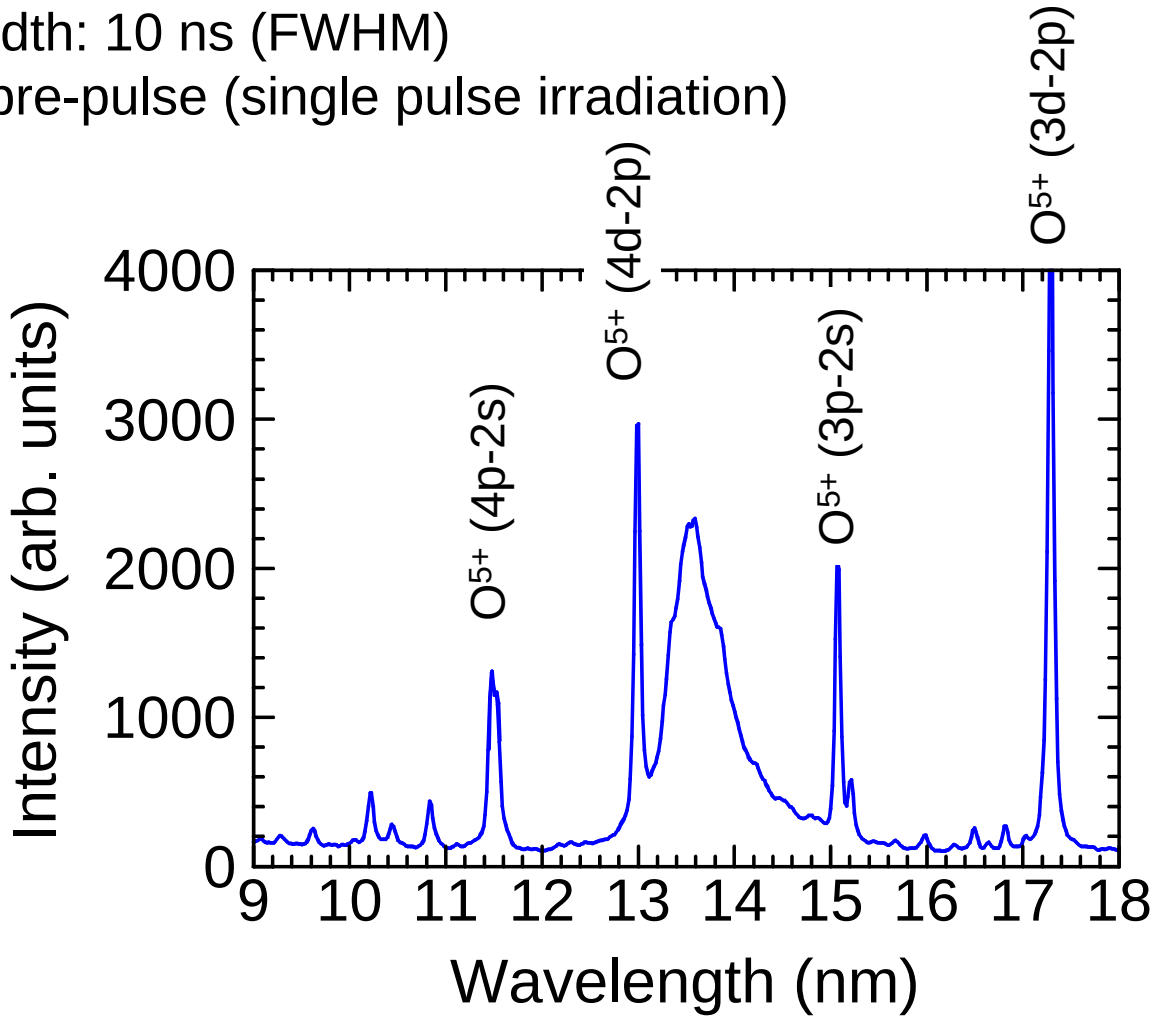
Laser pulse width: 10 ns (FWHM)
Spot size: 175 μmϕ (FWHM)



The EUV CE was proportional to the SnO_2 concentration, however, relatively low concentration produced a CE less than 1%.

Typical EUV spectrum from a SnO_2 colloidal jet target

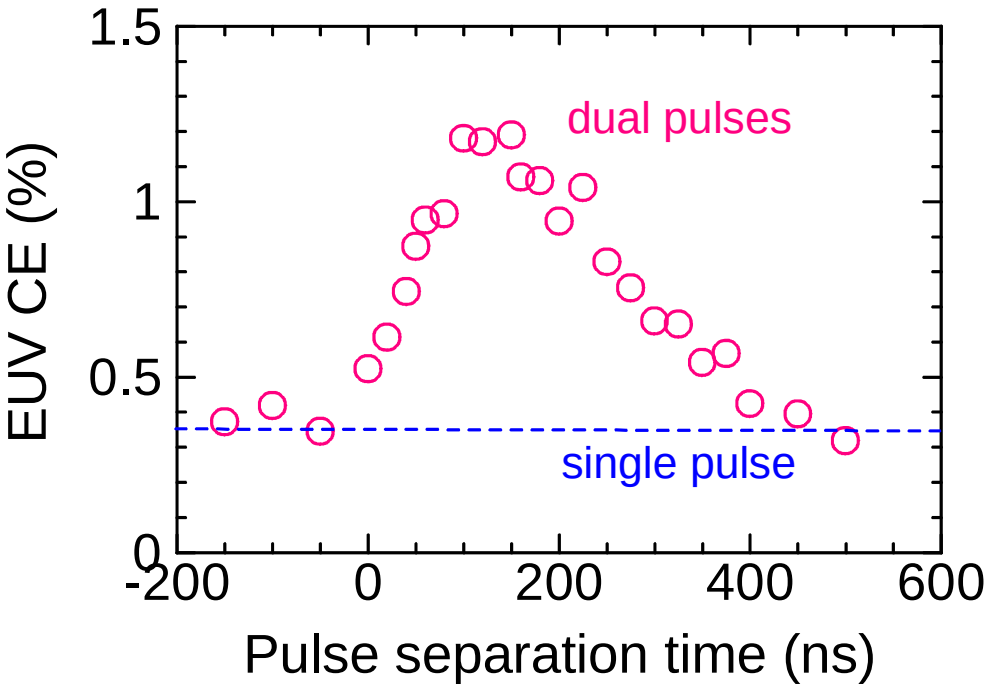
Laser wavelength: 1064 nm
Pulse width: 10 ns (FWHM)
without pre-pulse (single pulse irradiation)

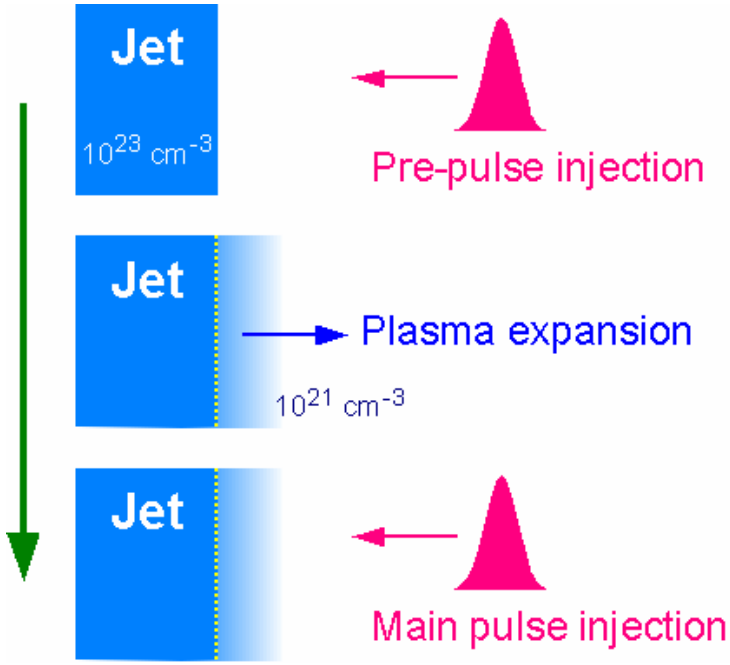


Appl. Phys. Lett. **88**, 201503 (2006).

EUV CE as a function of double pulse delay time

SnO_2 concentration by mass: 6%



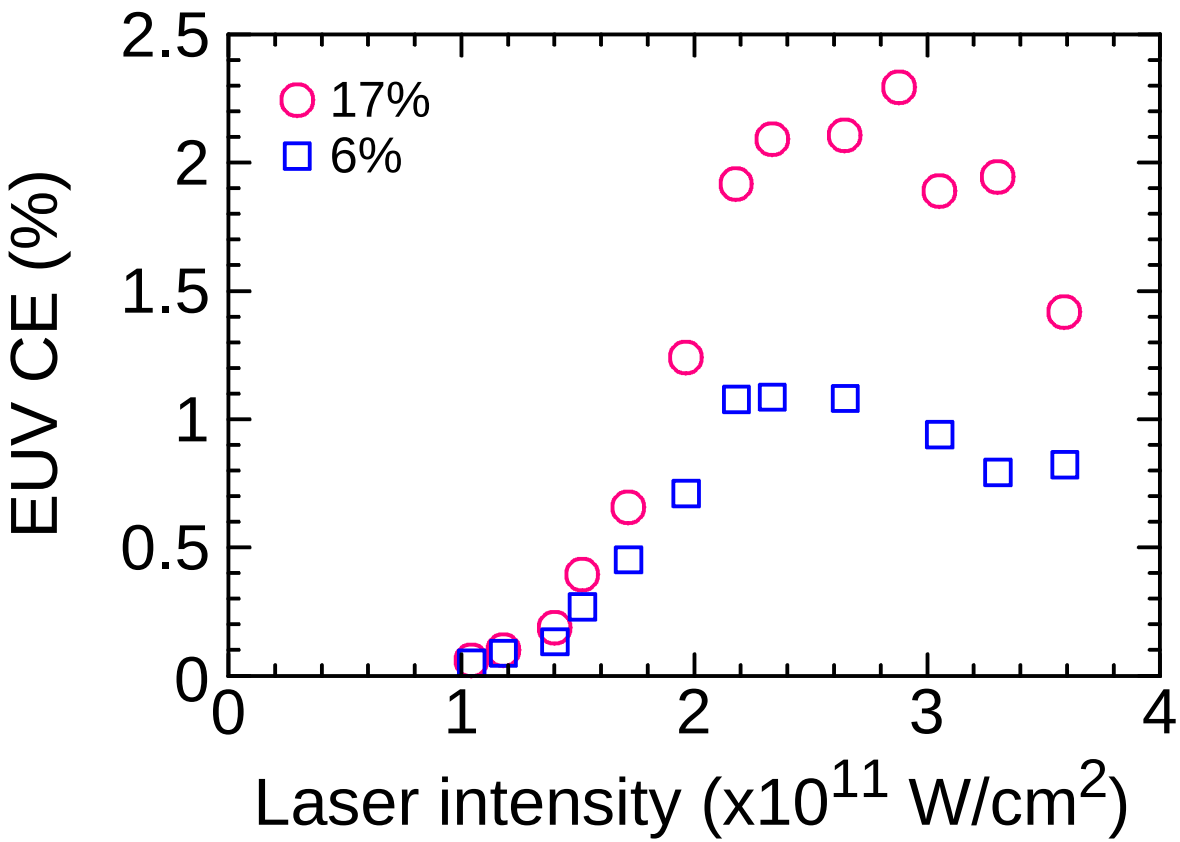


Low CE value originated from a low concentration jet target was well compensated by changing plasma characteristics with controlled double pulse irradiation.

Appl. Phys. Lett. **88**, 201503 (2006).

Main pulse intensity dependence of EUV CE

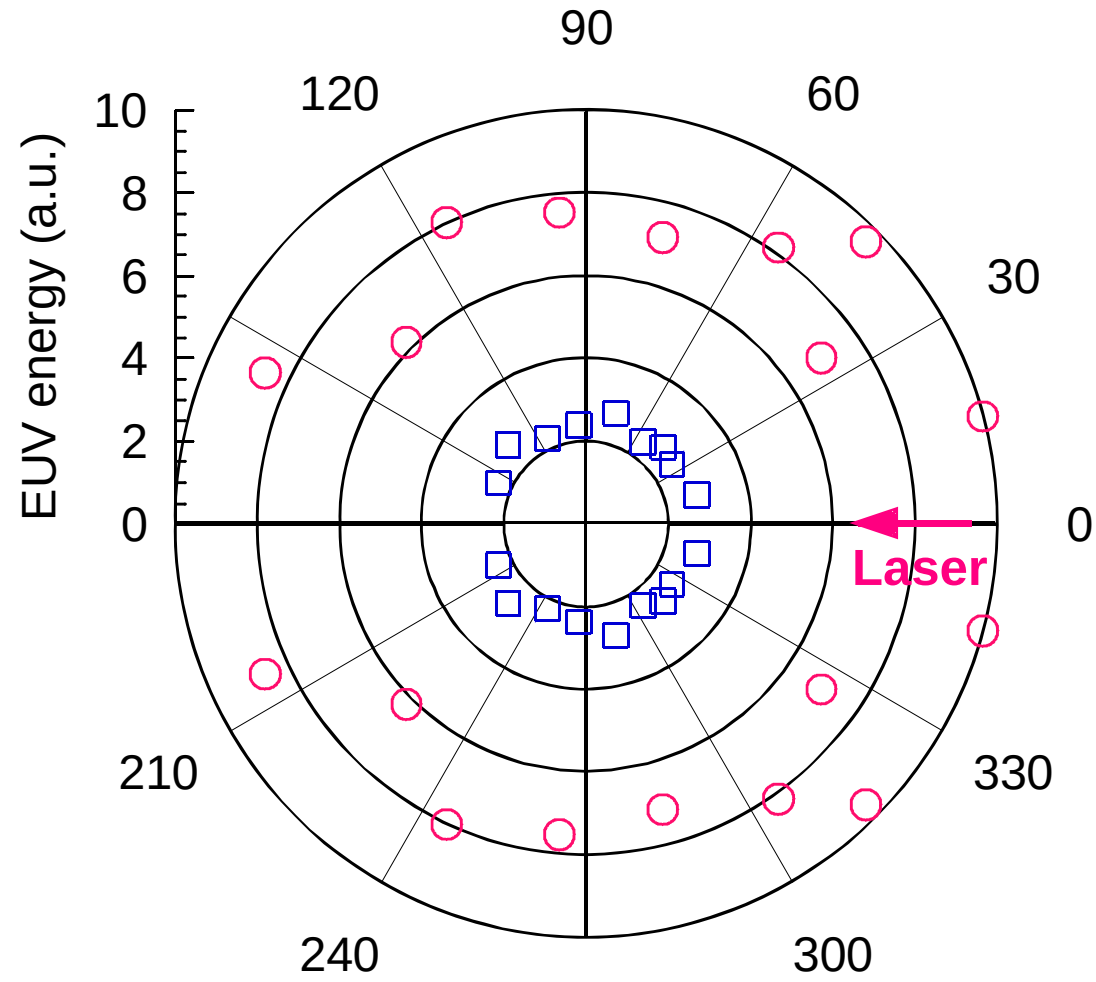
Dual laser pulses irradiation (with pre-pulse)
Optimum pulse separation time: $\Delta\tau$ = 100 ns



Both concentrations produced maximum CEs within a similar intensity range.

SPIE **6151**, 615145 (2006).

Angular distribution of the EUV emission



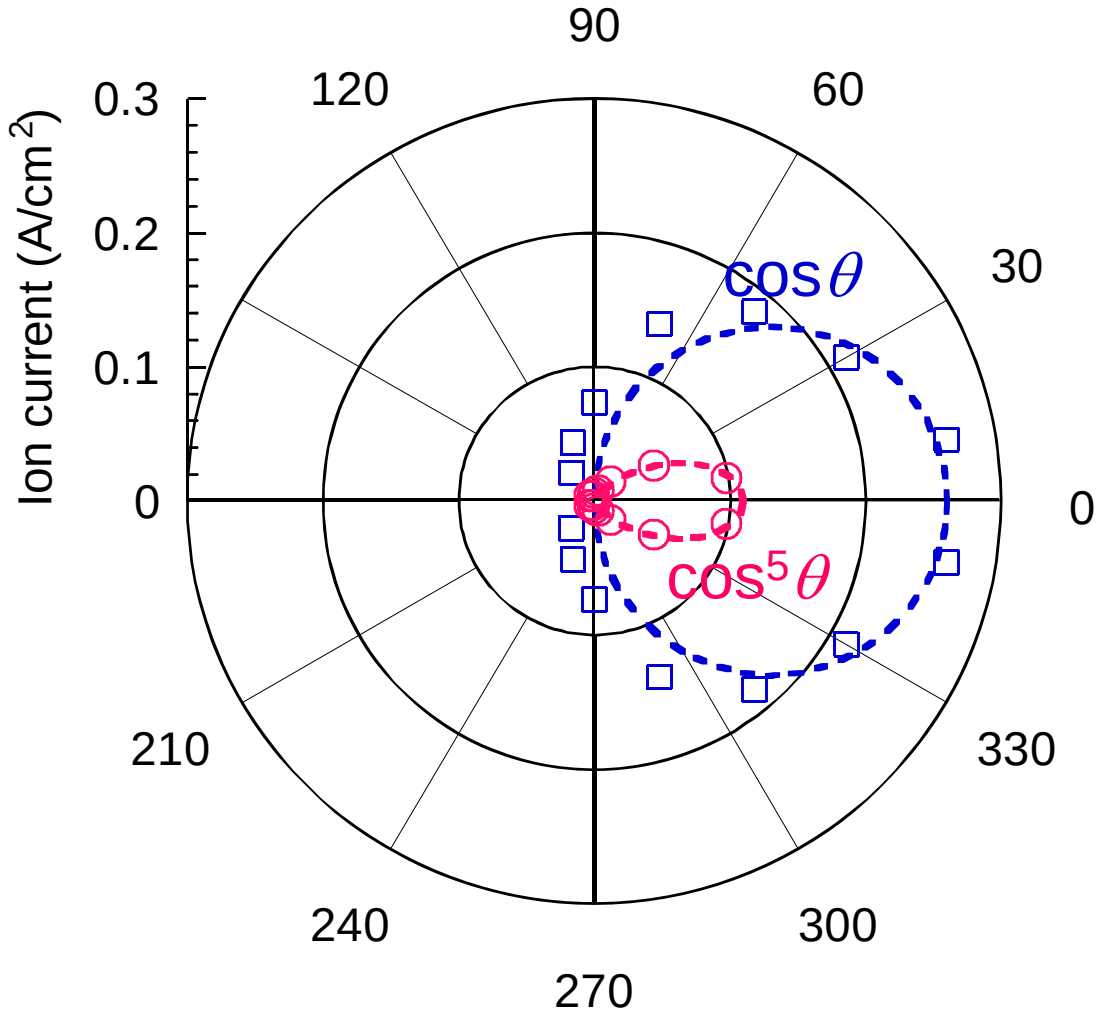
□ Single pulse
○ Dual pulses ($\Delta\tau$ = 100 ns)

Even using a colloidal jet target, EUV emission was almost isotropic.

Slight scattering of the EUV energy with the double pulse irradiation may be originated from an anisotropic nature of a pre-plasma.

SPIE **6151**, 615145 (2006).

Angular distribution of the ion current



Ion current distribution of the single laser irradiation was similar to that of a point source emission.

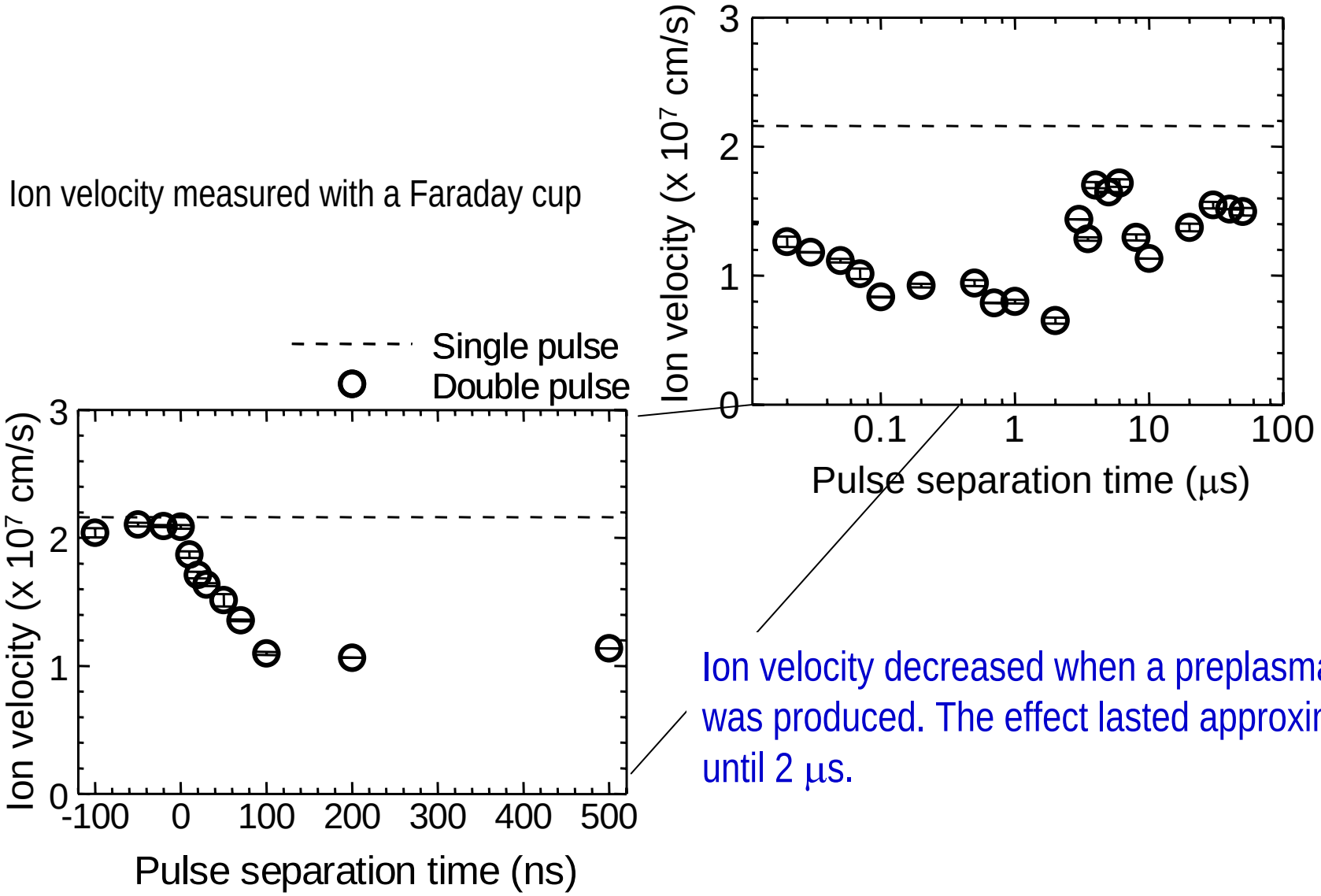
On the other hand, the distribution was contracted for the pre-plasma, which may be reflected on the spatial distribution of the main laser pulse.

□ Single pulse
○ Dual pulses ($\Delta\tau$ = 100 ns)

SPIE **6151**, 615145 (2006).

Ion velocity as a function of double pulse delay time

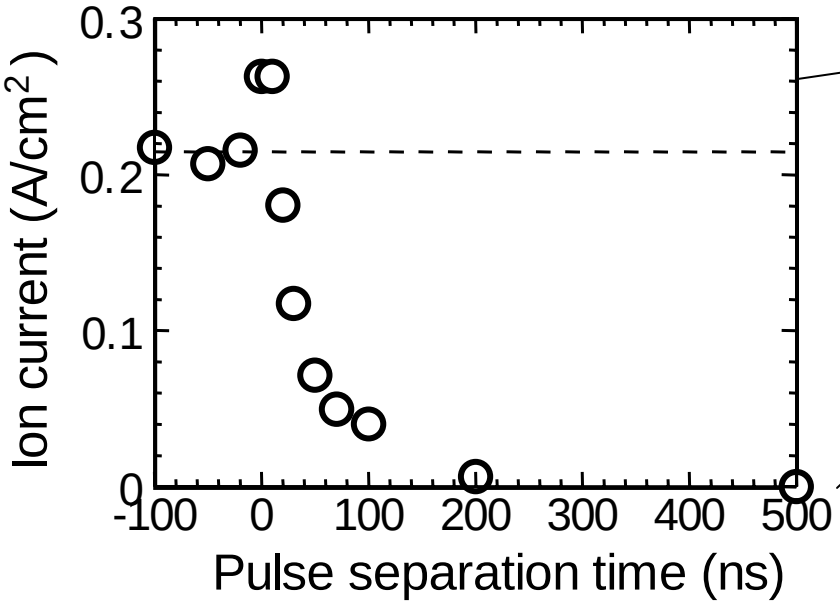
Ion velocity measured with a Faraday cup

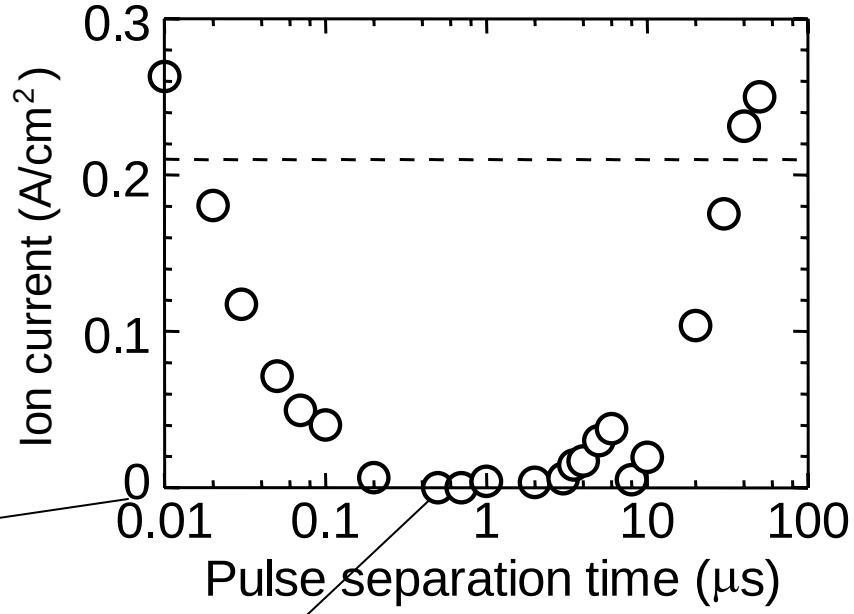


Ion velocity decreased when a preplasma was produced. The effect lasted approximately until 2 μs.

Ion current as a function of double pulse delay time

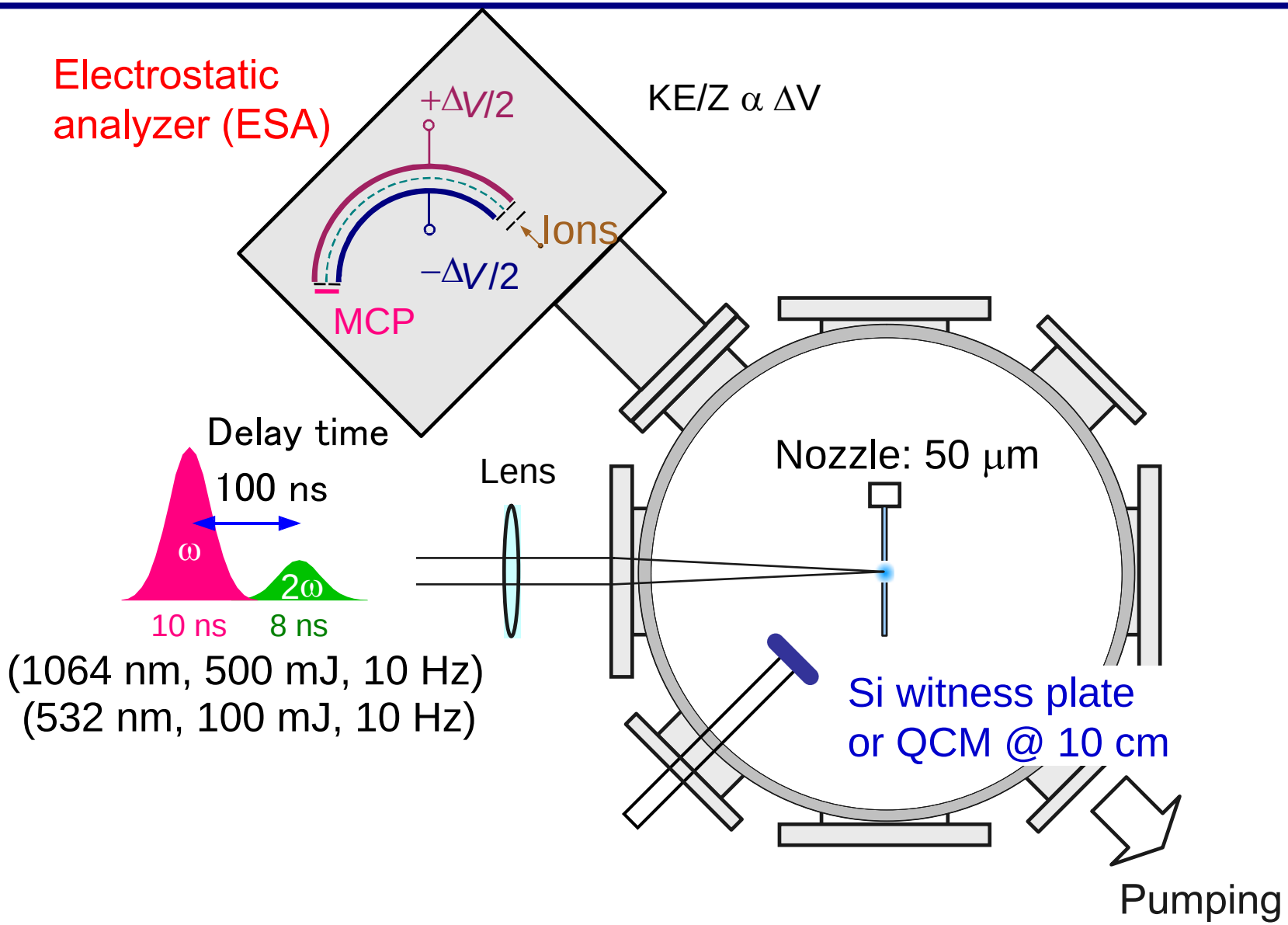
Ion current density measured with a Faraday cup





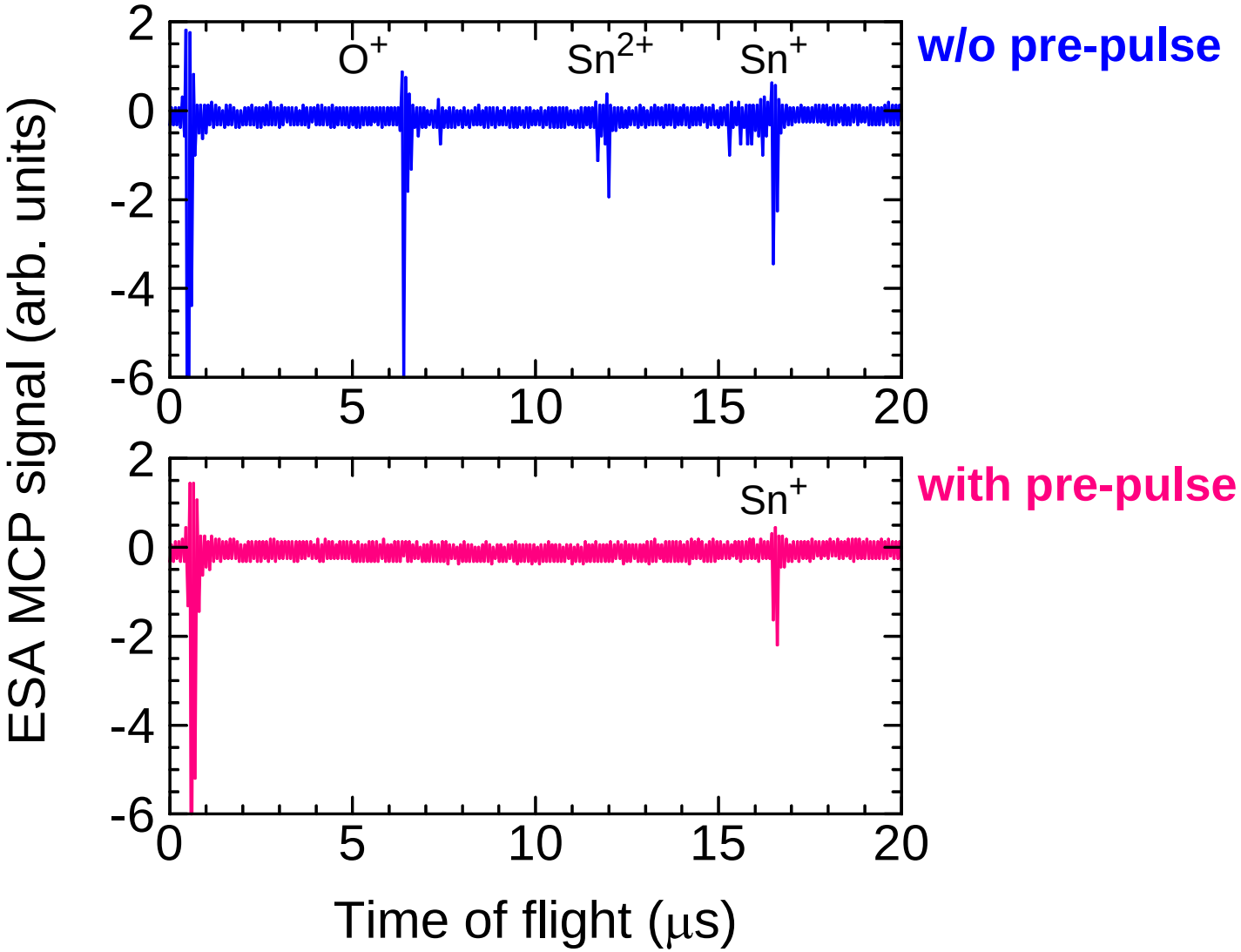
Ion current density decreased when a preplasma was produced. The effect of a preplasma vanished after 50 μs.

Experimental setup for ionic debris

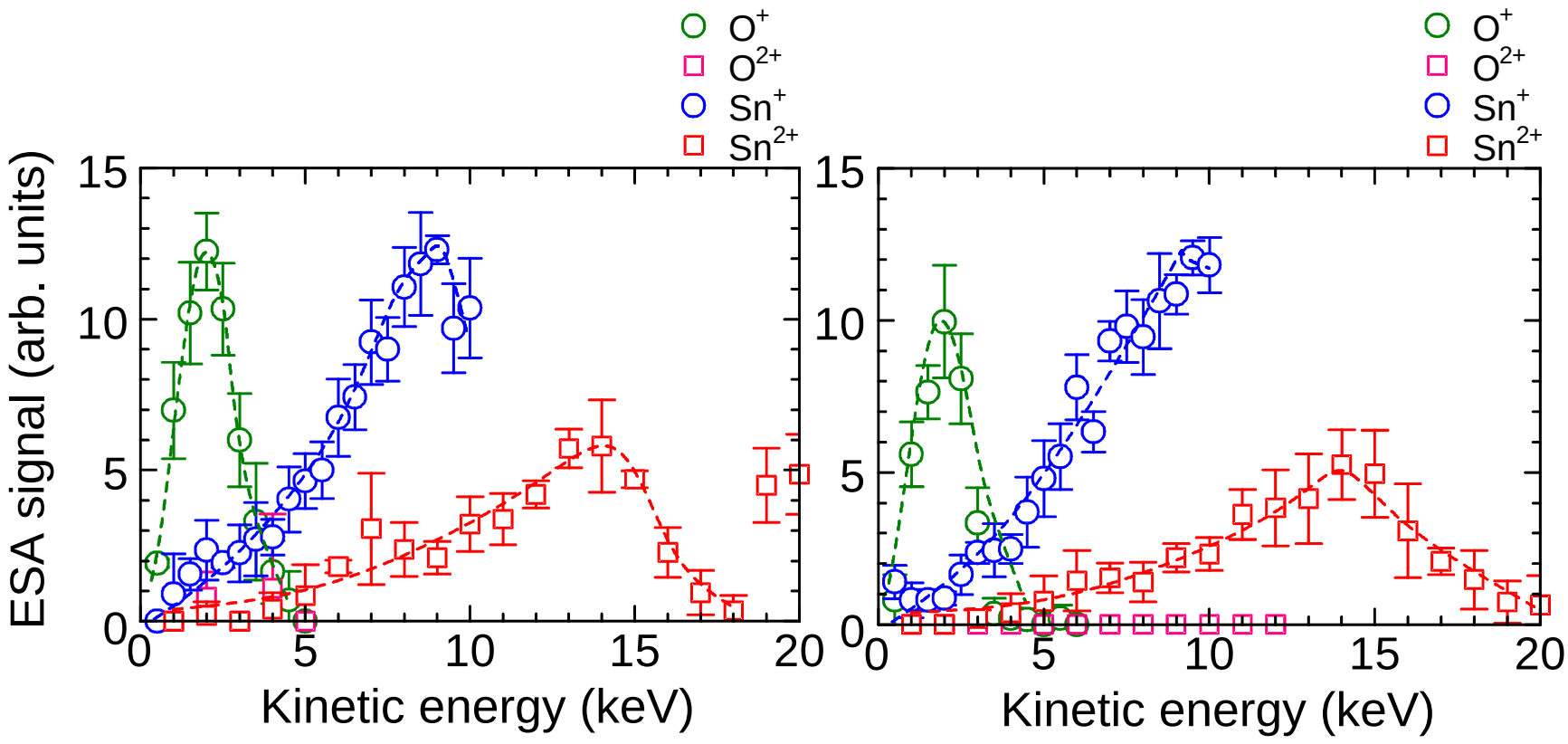


(1064 nm, 500 mJ, 10 Hz)
(532 nm, 100 mJ, 10 Hz)

Typical TOF signals @ *E*/*Z* = 3 keV



Change of the ion energy distribution (1)

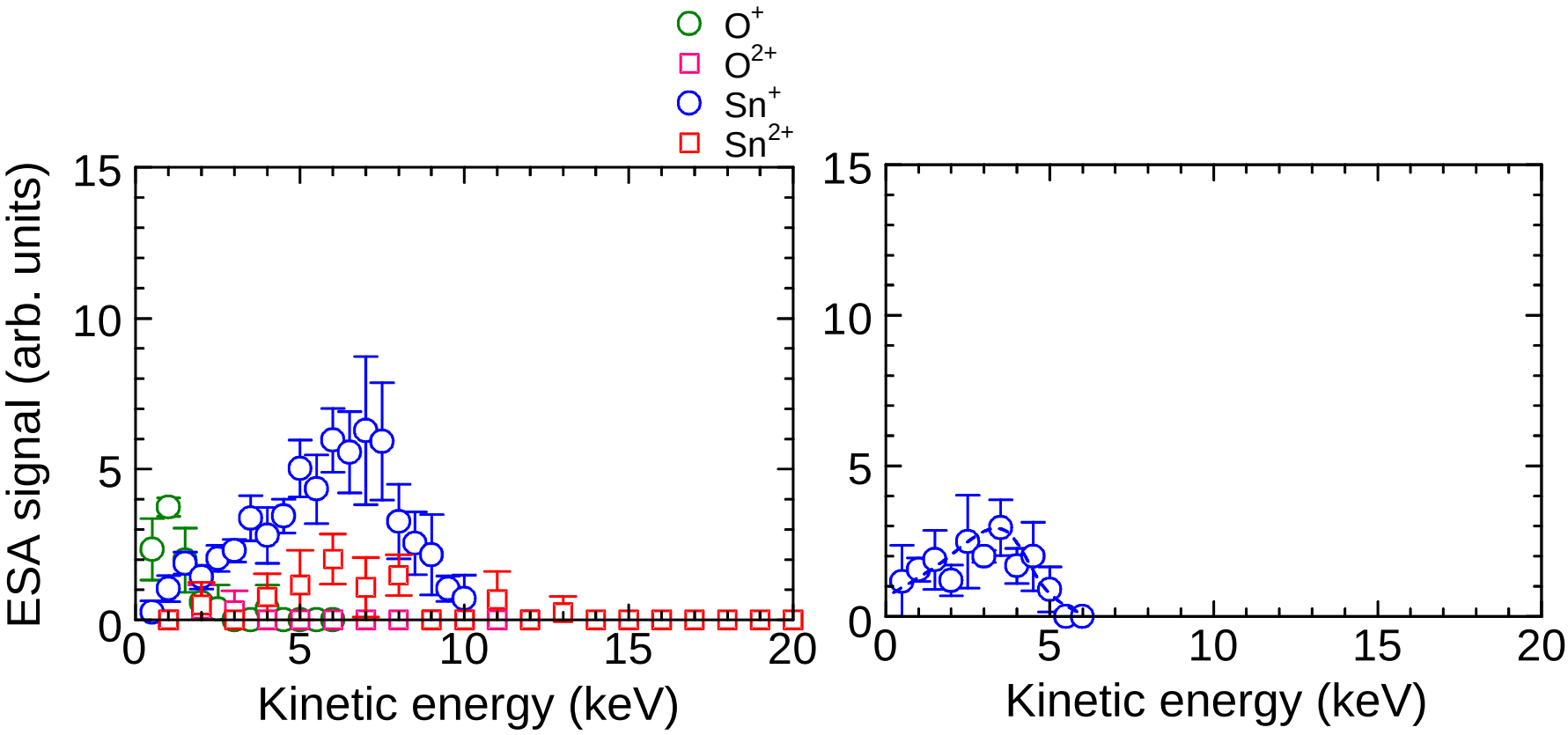


Without a prepulse

Main pulse 100 ns prior to a prepulse

There is a good coincidence, leading to a negligible prepulse effect with a negative delay.

Change of the ion energy distribution (2)

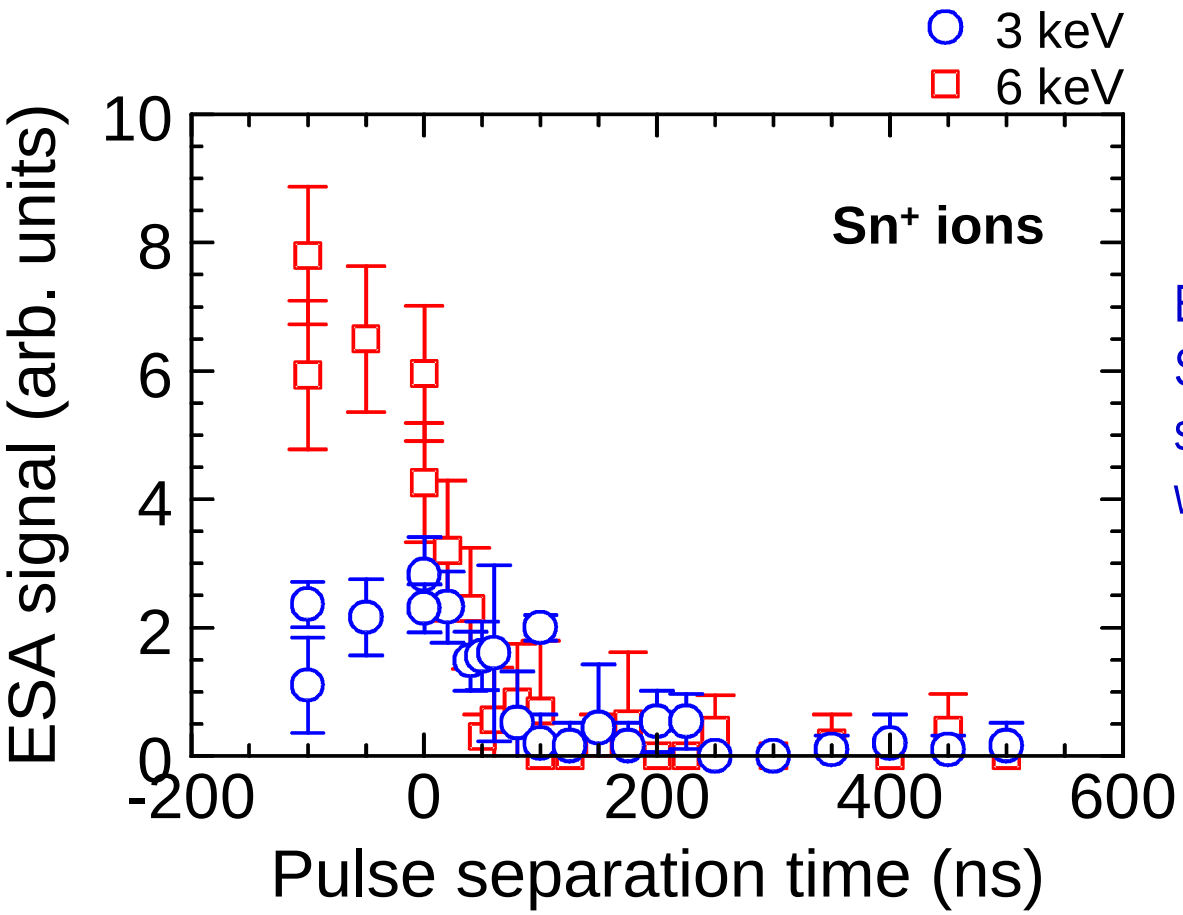


Main pulse coincident to a prepulse

Prepulse 100 ns prior to a main pulse
(optimum EUV emission condition)

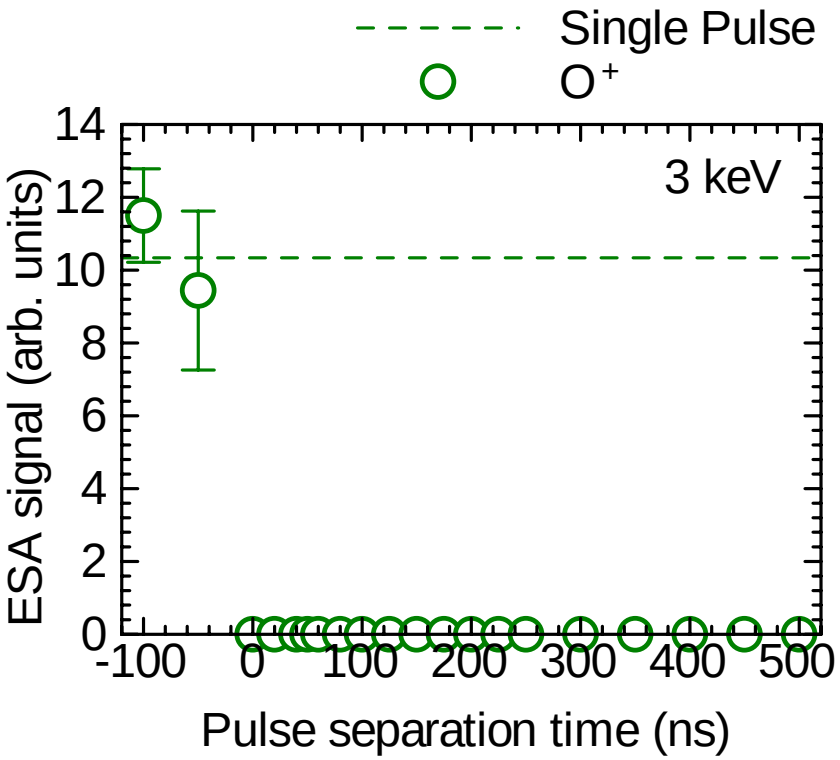
Peak ion energy and signal intensity both decreased when a delay increased.
With an optimum delay, only Sn^+ ions were observed within a detector sensitivity.

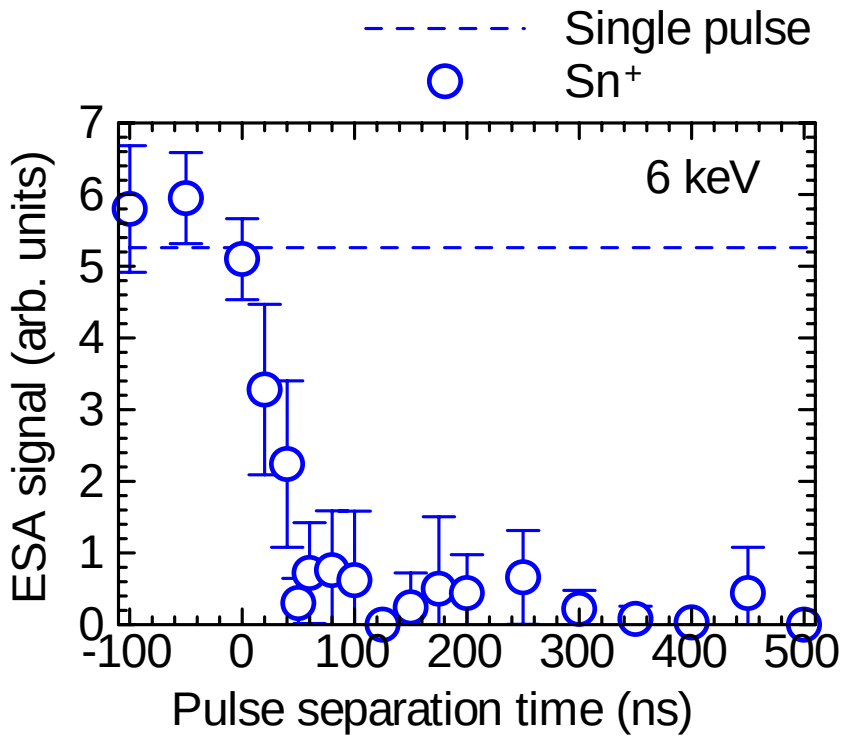
Effect of a preplasma to minimize Sn^+ ion emissions



ESA signal originated from Sn^+ ions decreased significantly when a delay time was increased.

Effect of a preplasma to minimize ion emissions

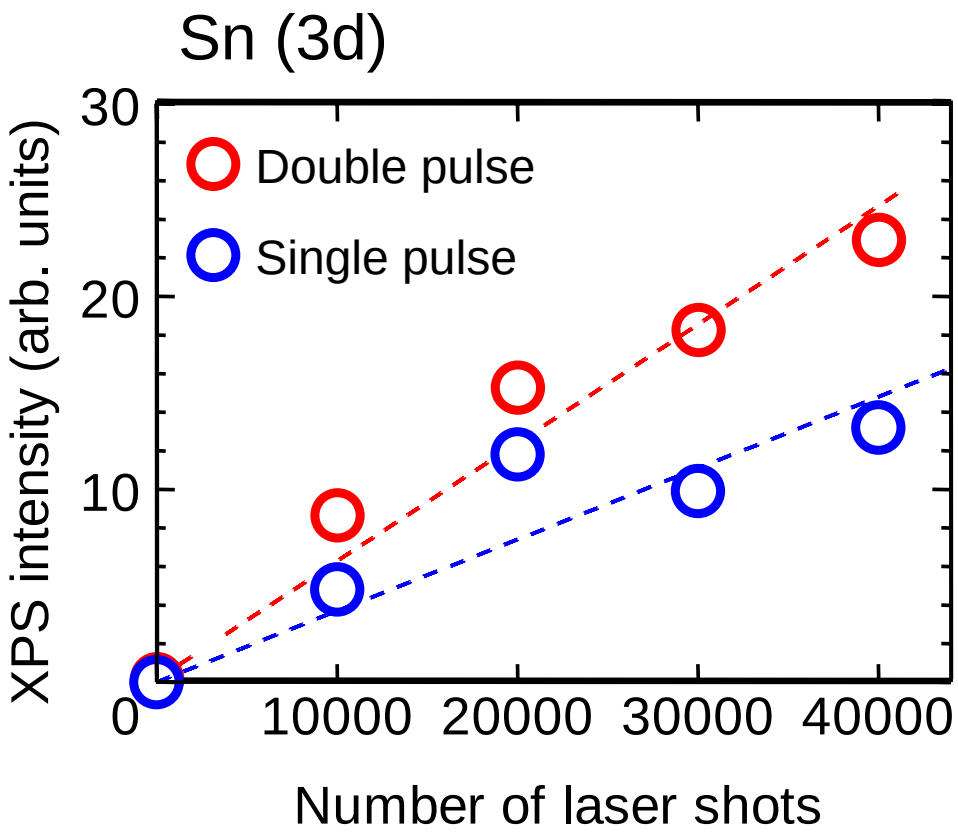


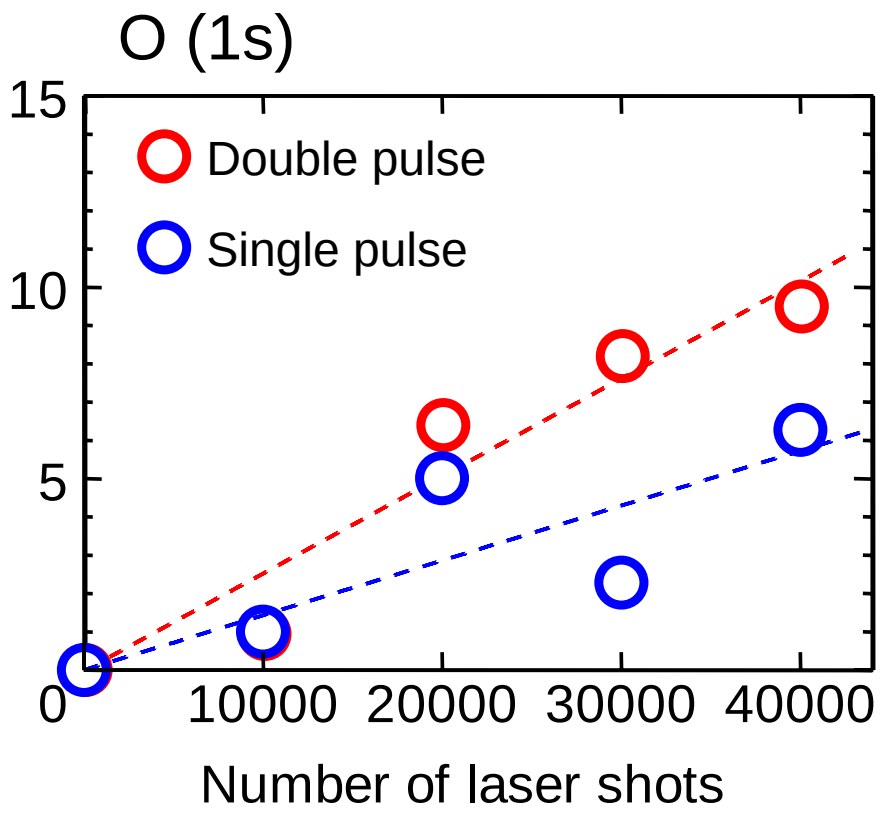


Even different ionic species showed a similar behavior.

Tin and oxygen signals as a function of laser shots

A silicon witness plate was placed 10 cm from a colloidal jet target.

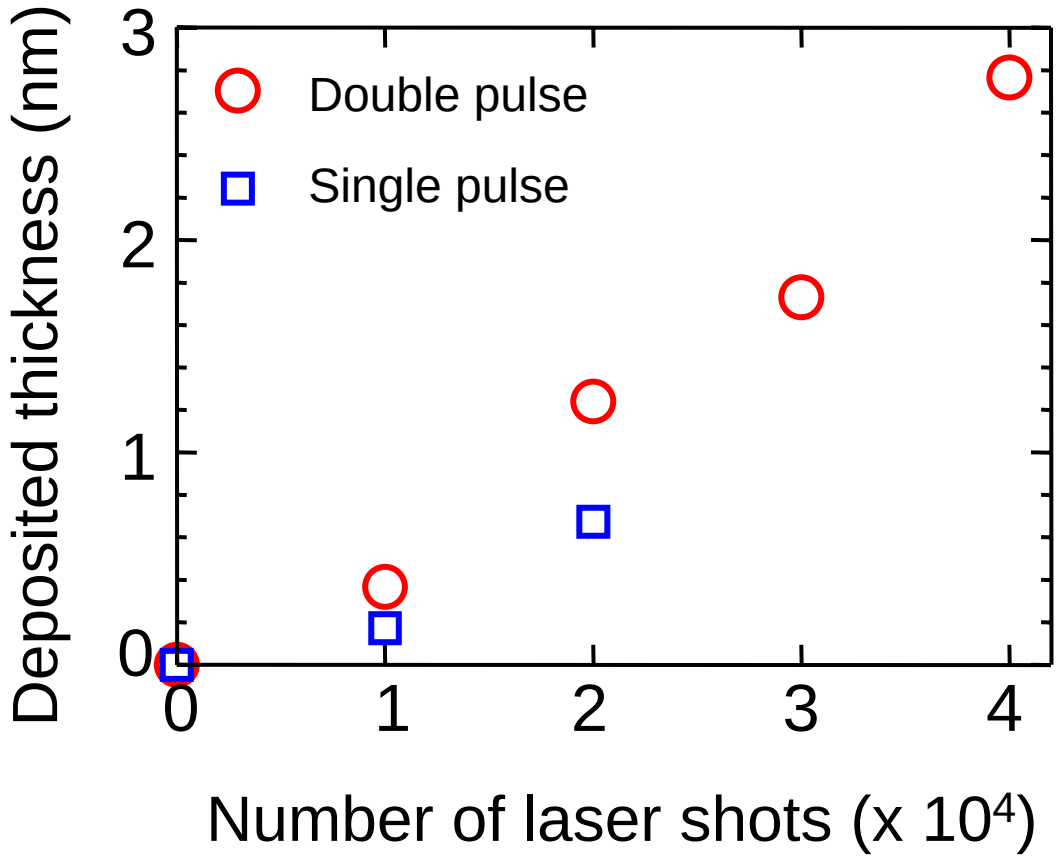




In contrast to the ionic debris, there were almost no differences between double and single pulse irradiation in terms of the deposited amount of atoms.

Deposited amount as a function of laser shots

Quartz crystal deposition monitor was placed 10 cm from a target.



As the XPS data suggested, the deposition amount of Sn/O showed similar values for both pulse cases, indicating the deposited amount simply proportional to the amount of the total laser energy, as seen in the laser ablation experiments.

Summary

We investigated various emission and debris characteristics of a low-density colloidal jet target containing SnO_2 nano particles.

Can we obtain a nominal EUV CE by use of a low-density colloidal target?

→ *Yes, we were successful to increase the CE more than 1% even with a low-density colloidal target with a help of a preplasma.*

Is the amount of debris really reduced with such a target?

→ *Yes, the amount of ionic debris significantly decreased when the optimum CE conditions were fulfilled simultaneously. The deposited amount of debris, however, seemed to be no change.*

Is this target comparable to other viable targets?

→ *Yes or no, we need more investigation, especially need more knowledge about quantitative behaviors of debris. The QCM data suggested that we should move to a droplet target to further minimize the debris.*

Acknowledgements

This work was supported by MEXT (Ministry of Education, Culture, Science and Technology), Japan under contract subject “Leading project for EUV lithography source development”.

The authors would like to acknowledge Wataru Sasaki for his continuous support.

They also thank our former graduate students, Naoto Dojyo, Keita Kawasaki, and Naoya Hamada for their technical assistance and experimental expertise.