Session 2

EUV emission from a laser-produced tin plasma by use of a liquid microtarget

Takeshi Higashiguchi

E-mail: higashi@opt.miyazaki-u.ac.jp

Naoto Dojyo, Masaya Hamada, Wataru Sasaki, and Shoichi Kubodera

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

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

1-1 Gakuen Kibanadai, Miyazaki, Miyazaki 889-2192, JAPAN, TEL/FAX: +81-985-58-7358

Joint requirements for EUV source: 13.5 nm (2%BW), 115 W, 7-10 kHz

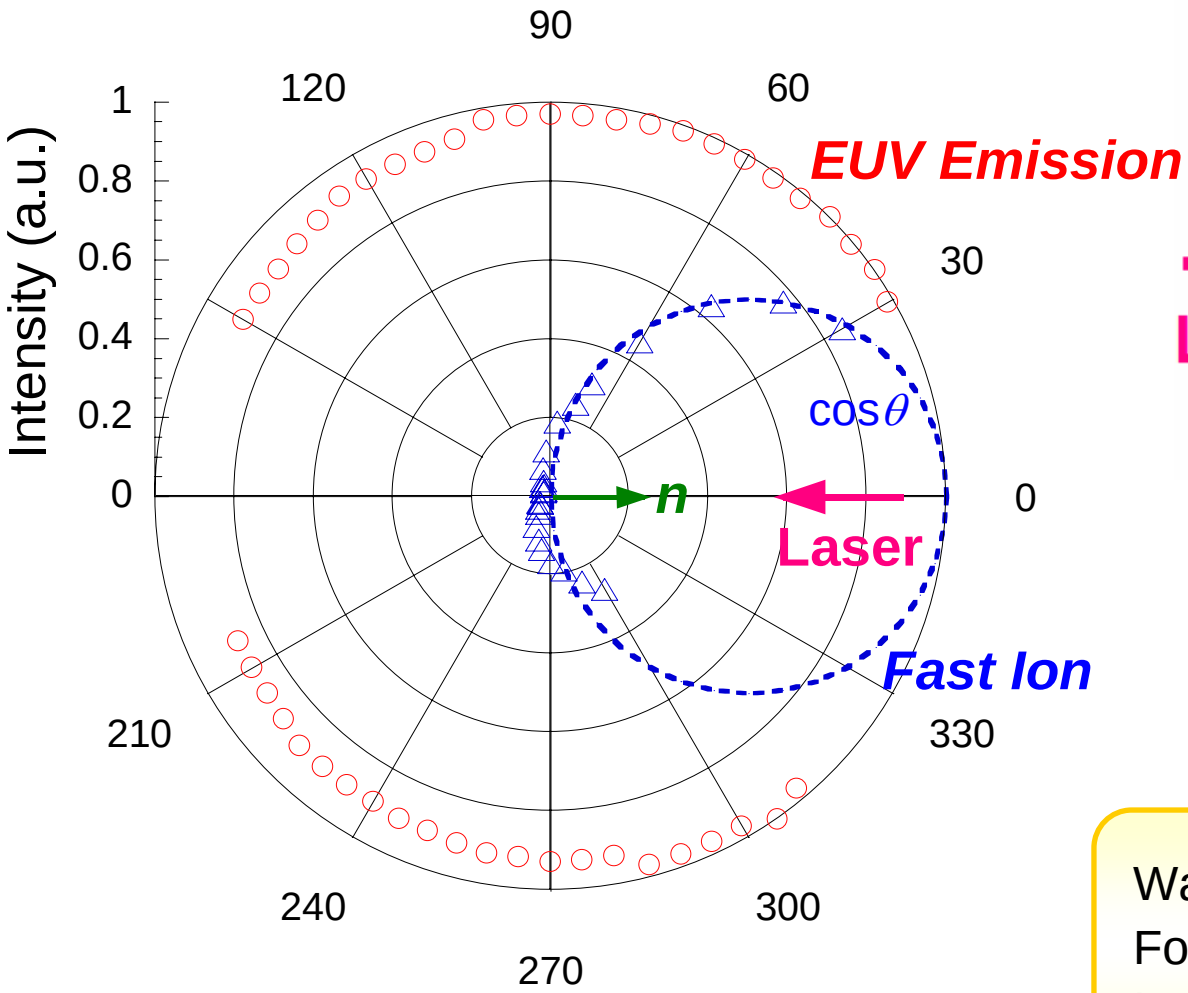
Joint Requirements for EUV Source

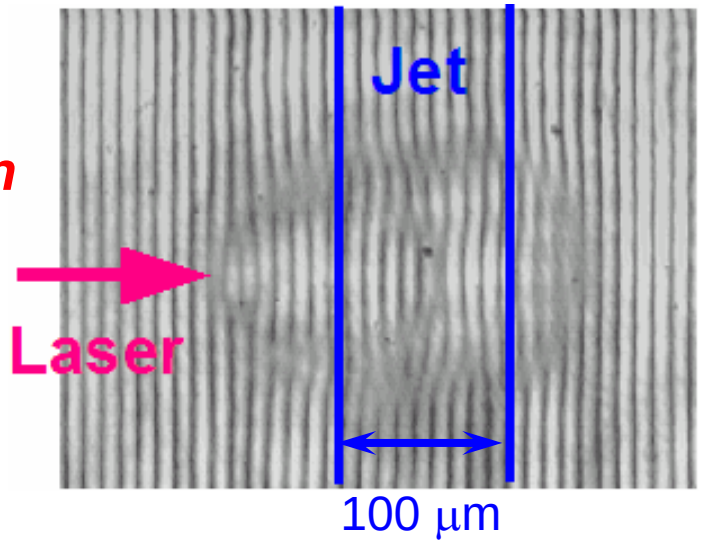
SOURCE CHARACTERISTICS	REQUIREMENTS
▪Wavelength	13.5 (nm)
▪EUV Power (in-band)	115 (W) (after intermediate focus)
▪Repetition Frequency	> 7 - 10 kHz *
▪Integrated Energy Stability	± 0.3% (3σ over 50 pulses)
▪Source Cleanliness	≥ 30,000 hours (after intermediate focus)
▪Etendue of Source Output	1 – 3.3 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

Kazuya Ota, Source Workshop, Santa Clara, CA, USA (2003).

Background 1
EUV emission by use of liquid micro-target

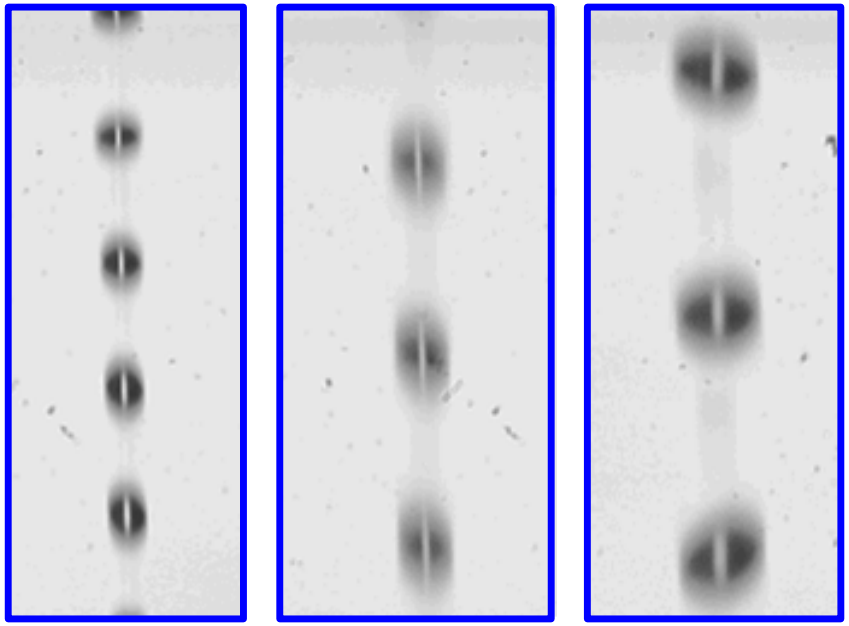




Water jet diameter: 170 μmϕ
Focal spot size: 175 μmϕ
Laser Intensity: 3 x 10^{11} W/cm^2

C. Rajyaguru *et al*., Appl. Phys. B **79**, 669 (2004).

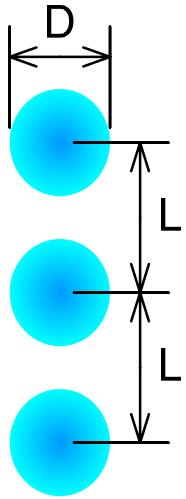
Background 2
Development of micro-droplet target



(a) (b) (c)

Backing pressure = 0.3 MPa
Velocity = 24 m/s

d: nozzle diameter
$\lambda = v / f$
v : target velocity
f : piezo frequency



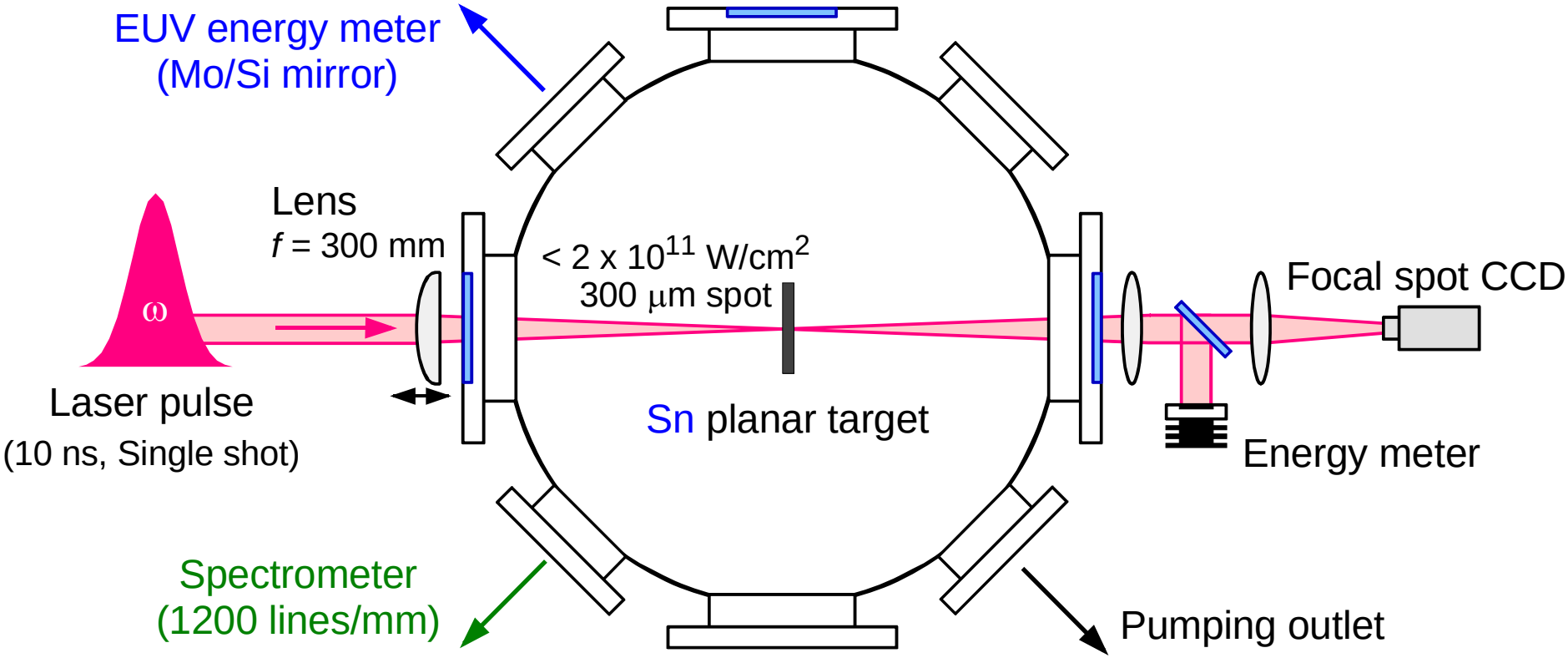
d (μm)	Freq. (kHz)	λ/d	*D* (μm)	*L* (μm)
(a) 50	75	5.4	90	270
(b) 70	40	5.7	116	400
(c) 100	40	5.3	180	530

Objective:
Enhancement of the EUV CE

- Characteristics of a laser produced tin plasma EUV source
  - EUV and debris emissions from a planar target
  - EUV emission from a filament target

EUV emission by use of a planar tin target

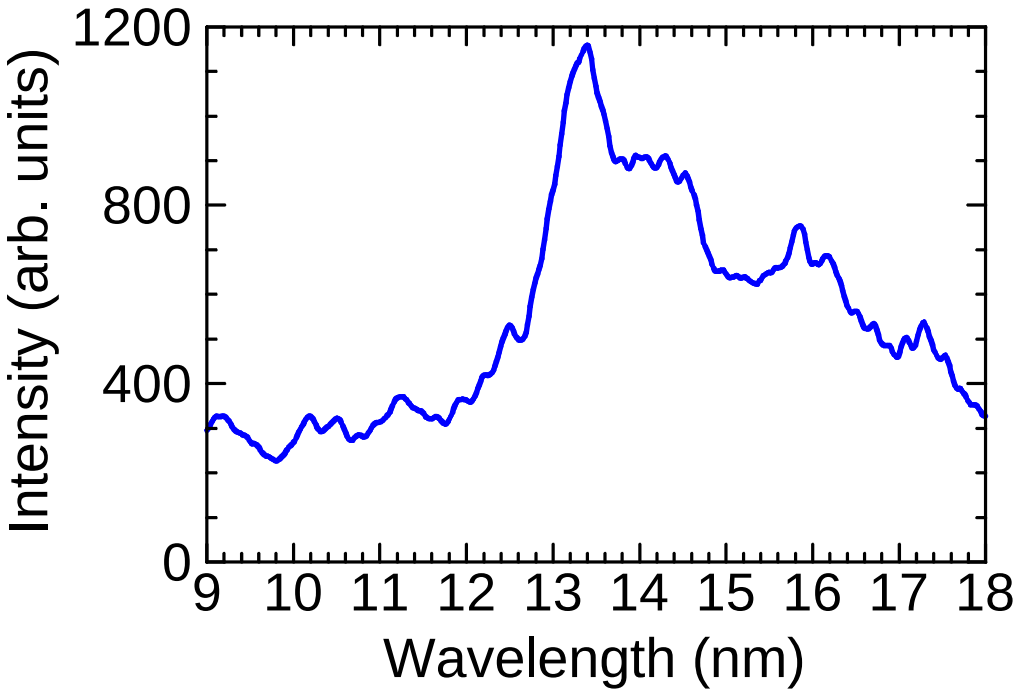
Schematic diagram of experimental setup



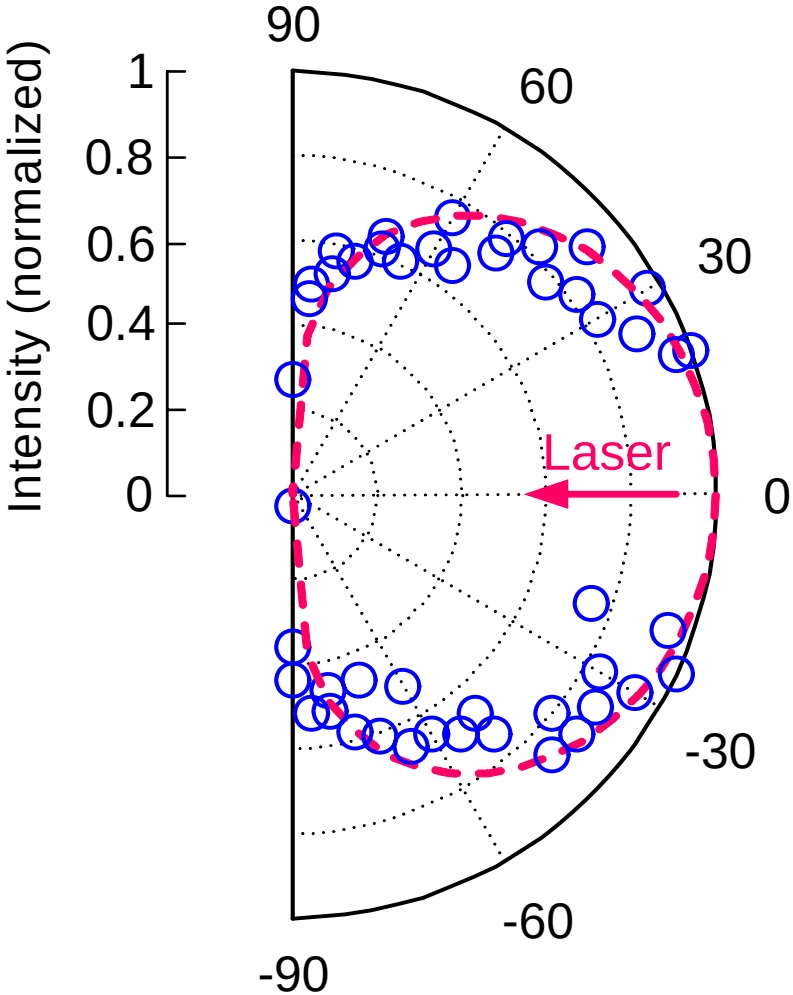
EUV emission by use of a planar tin target

EUV spectrum and angular distribution

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

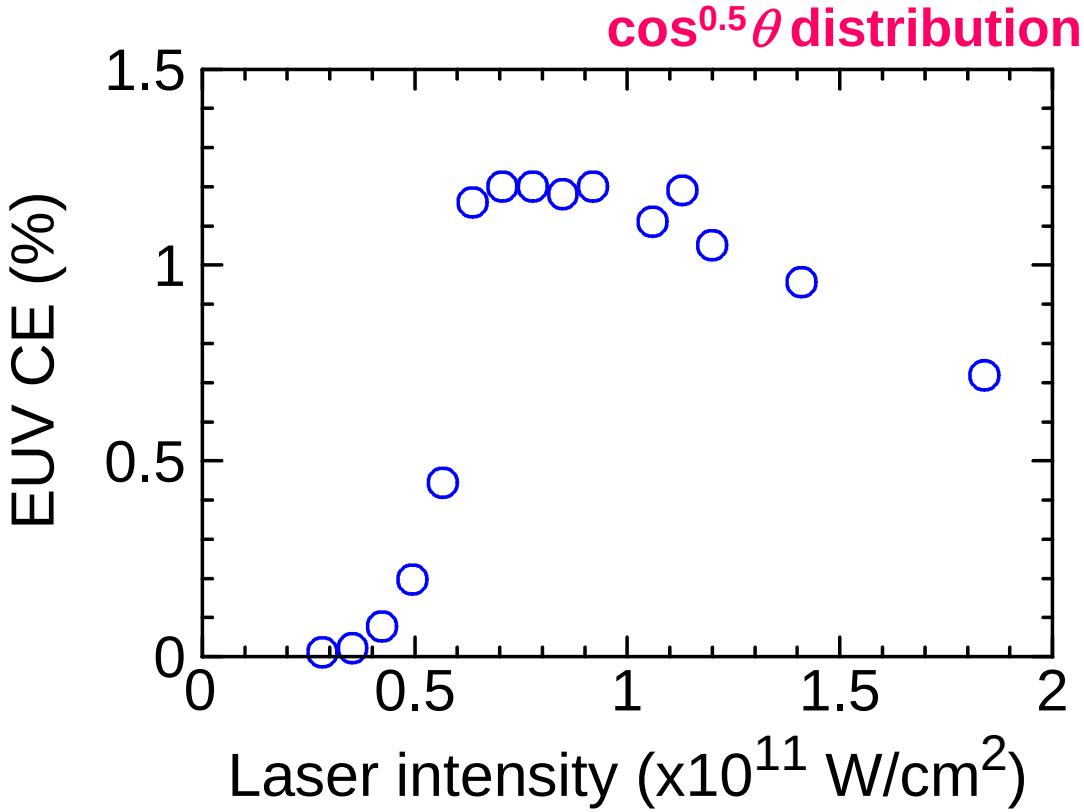


$\cos^{0.5}\theta$ distribution



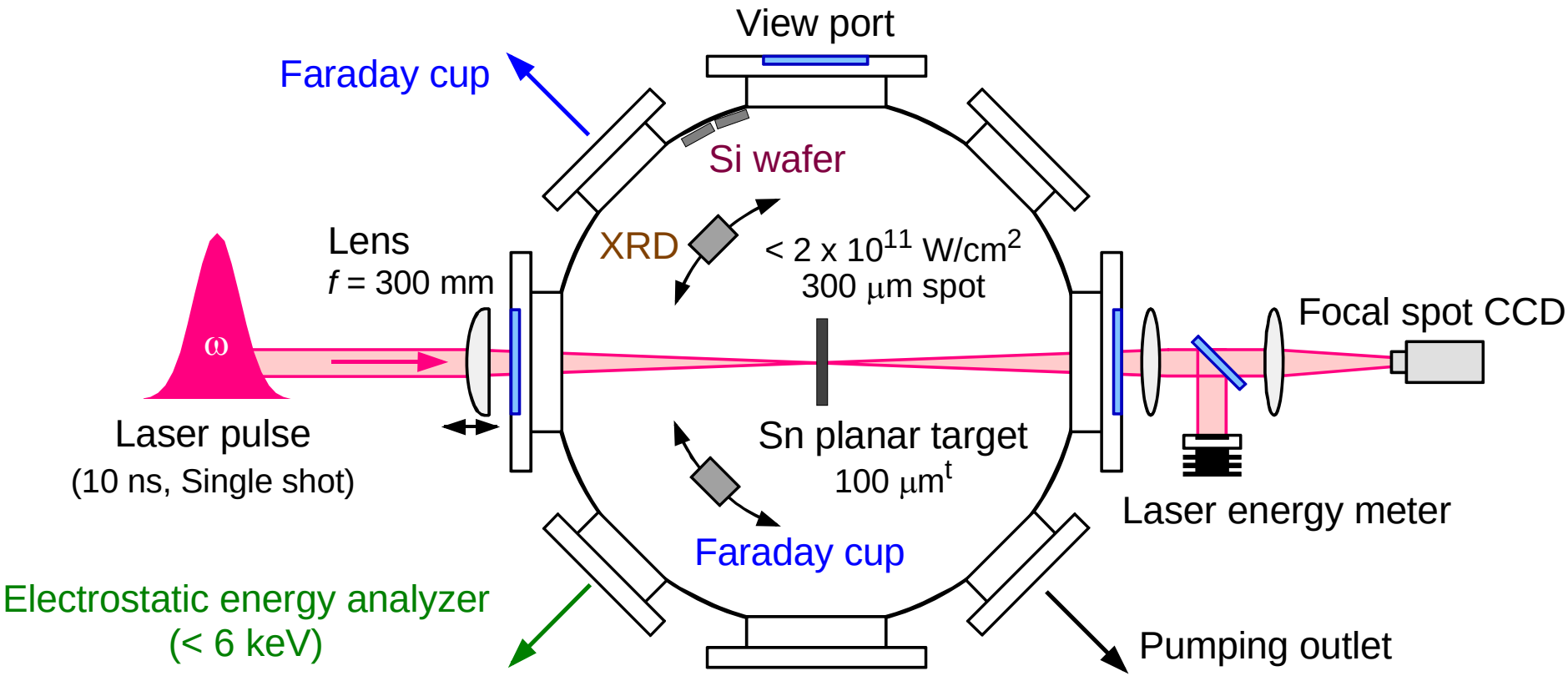
EUV emission by use of a planar tin target

Laser intensity dependence of EUV CE



Debris emission by use of a planar tin target

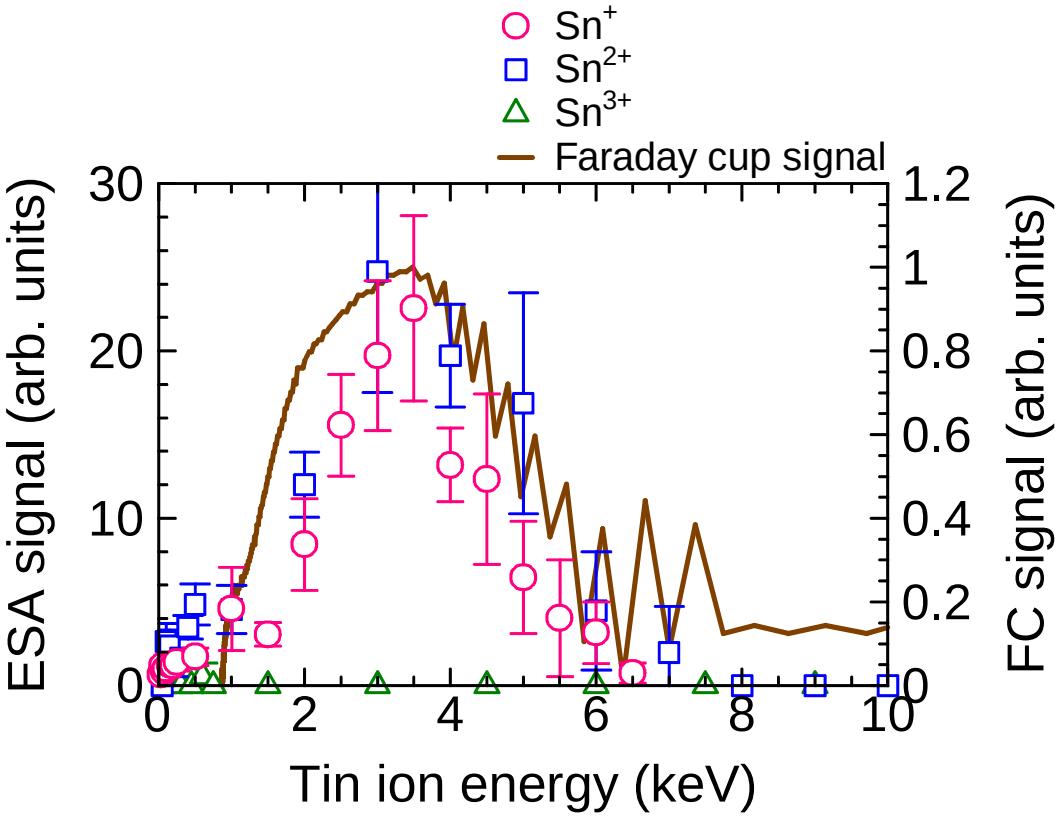
Schematic diagram of experimental setup

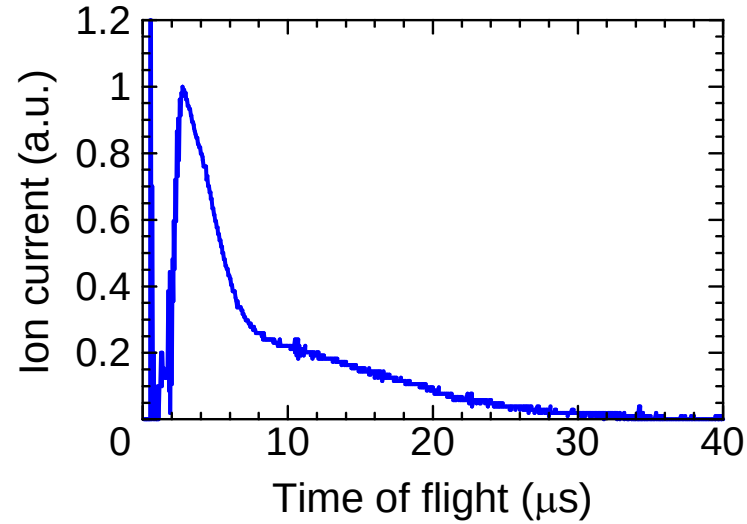


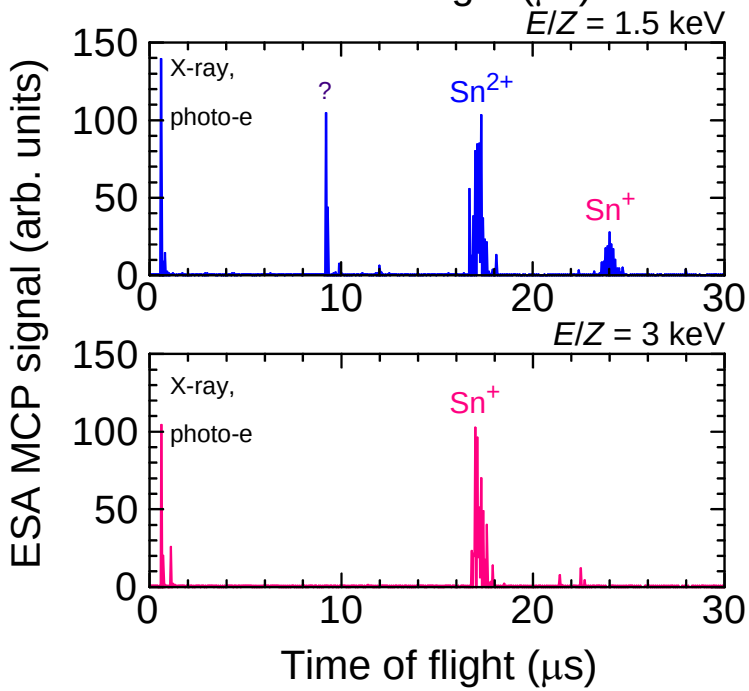
Debris emission by use of a planar tin target

Energy spectrum & charge state of fast ions

Laser intensity: 7 x 10^{10} W/cm^2
EUV CE: 1.2%
Laser pulse width: 10 ns





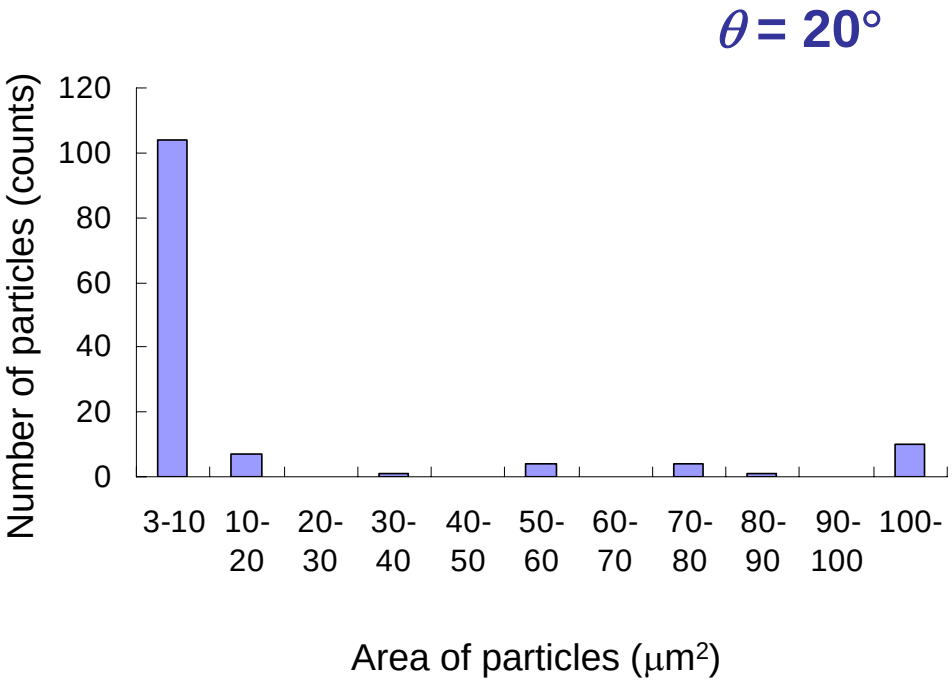


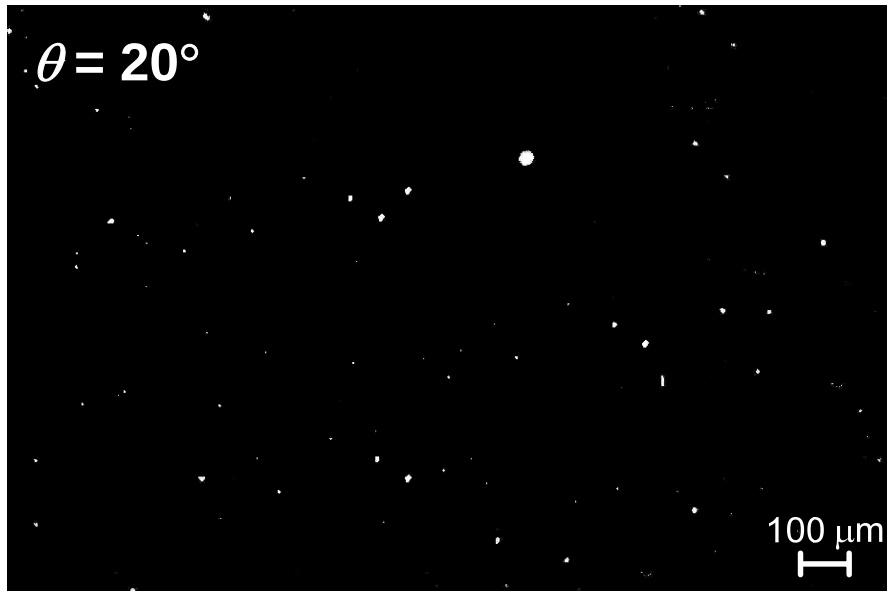
T. Higashiguchi *et al*., RSI (to appear in 2005).

Debris emission by use of a planar tin target

Observation of neutral fragments

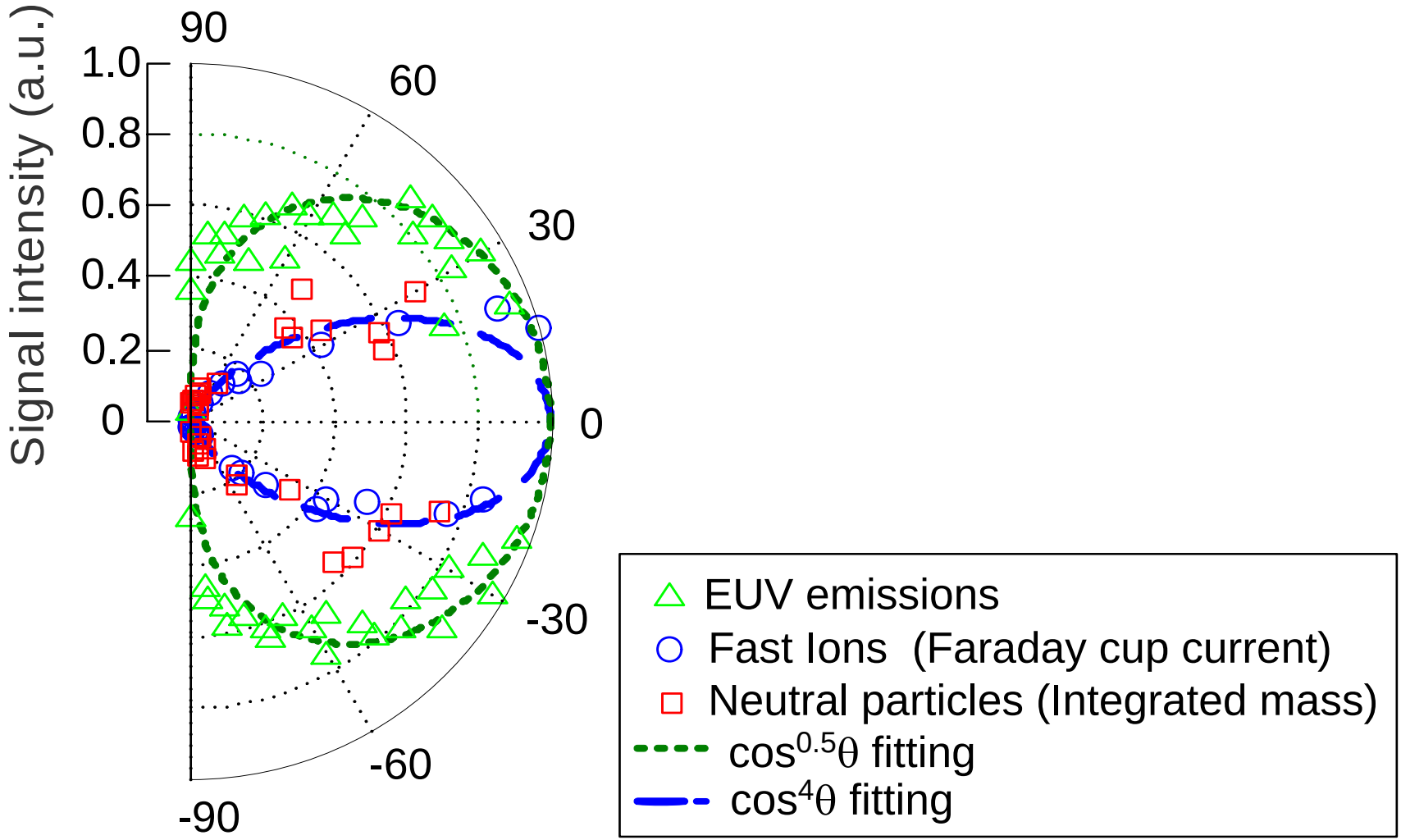
Laser intensity: 7 x 10^{10} W/cm^2
Spot size: 300 μmϕ
Laser energy: 500 mJ
Pulse width: 10 ns
1000 shot





T. Higashiguchi *et al*., RSI (to appear in 2005).

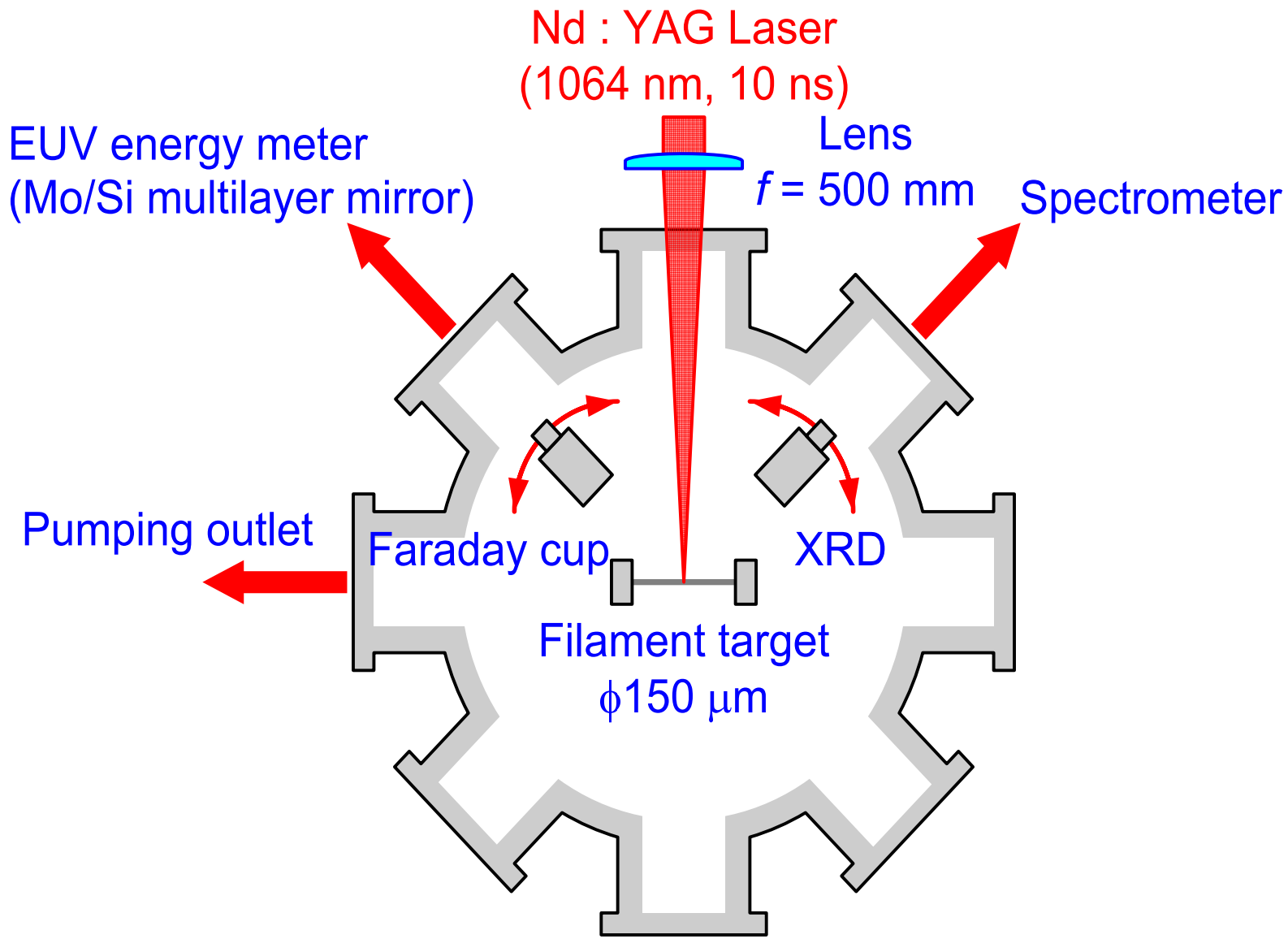
EUV and debris emissions
Comparison of angular distributions



T. Higashiguchi *et al*., RSI (to appear in 2005).

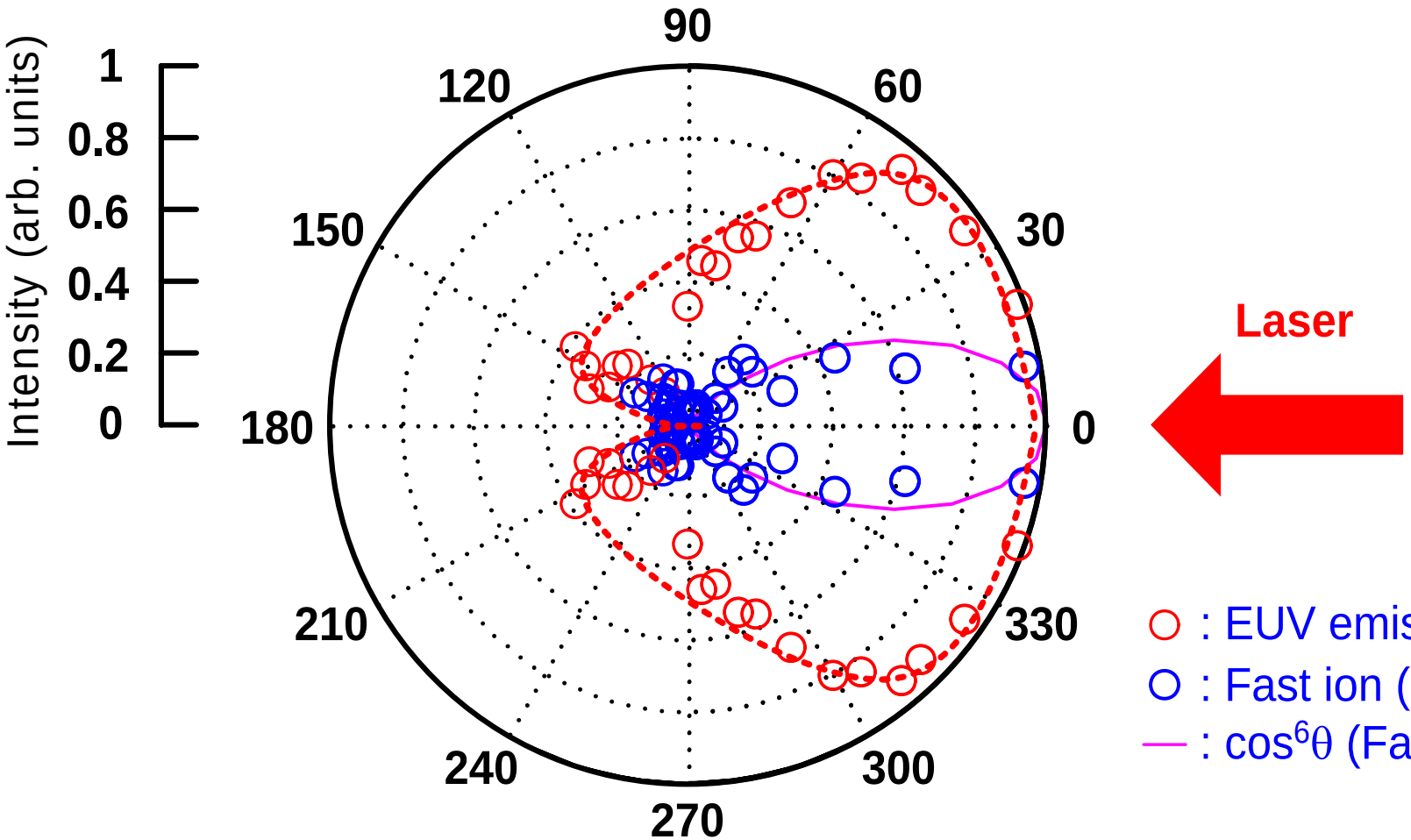
Use of a filament target

Schematic diagram of experimental setup



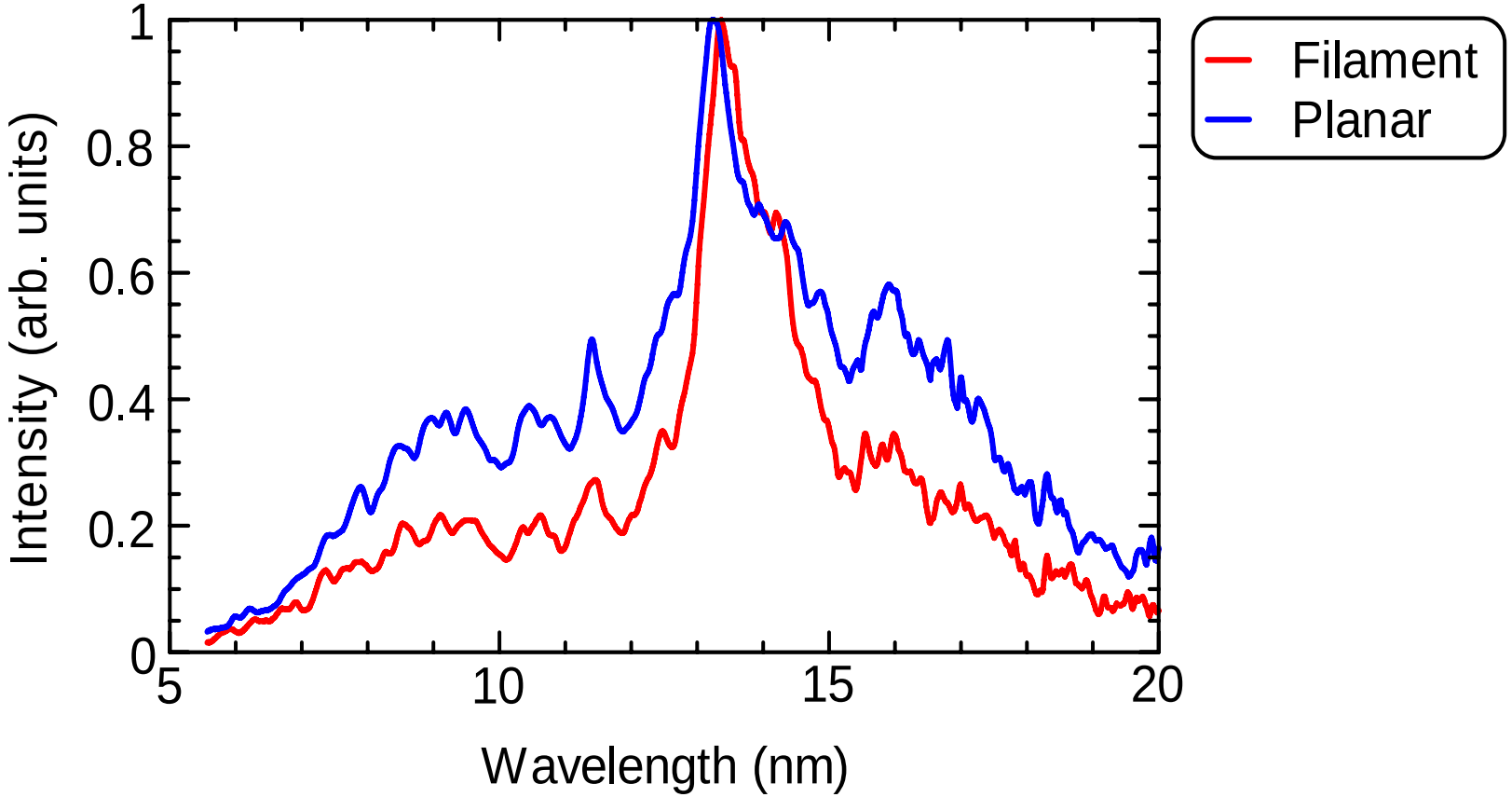
Use of a filament target

Comparison of angular distributions



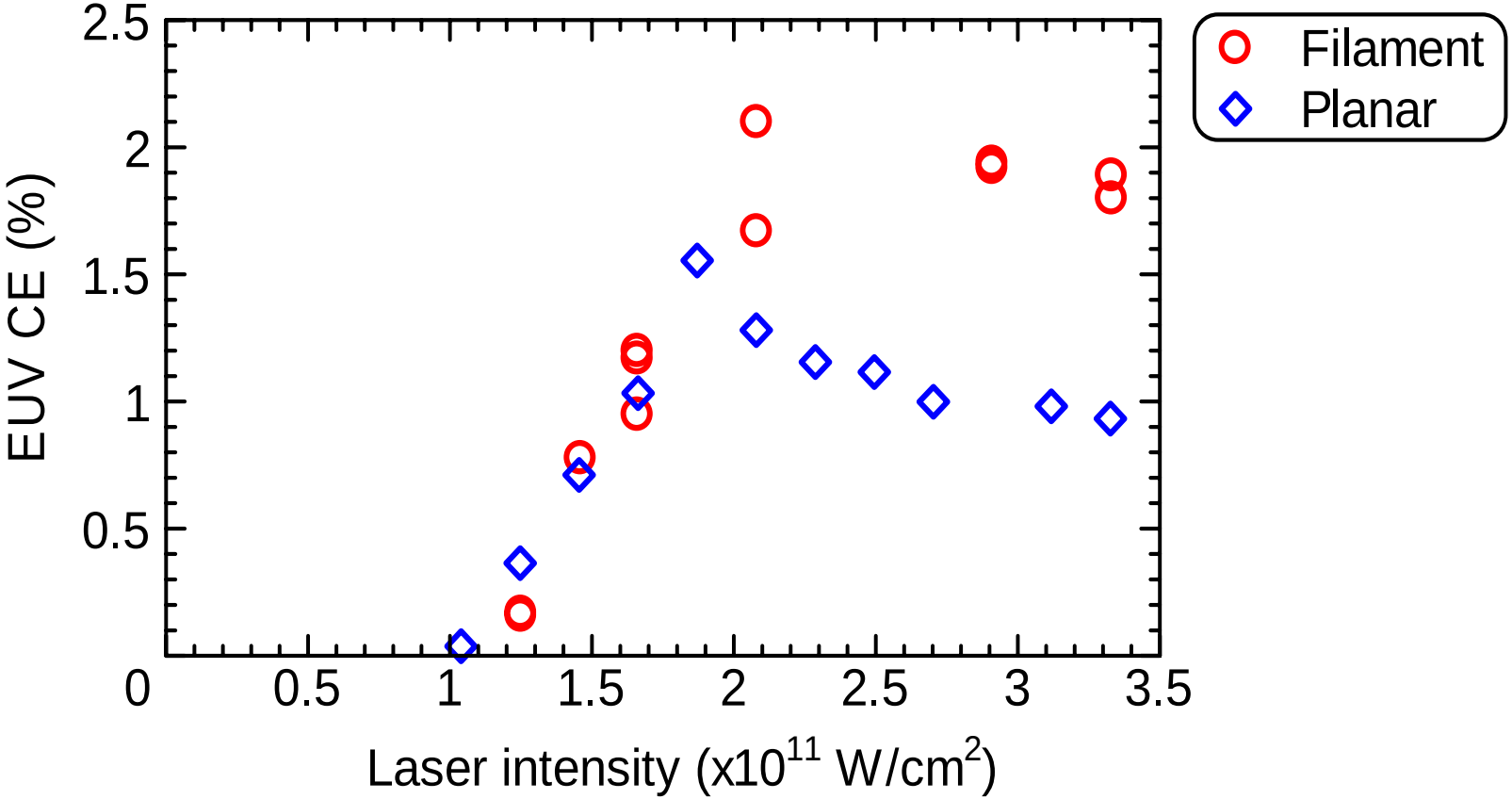
Use of a filament target

Comparison of EUV spectra



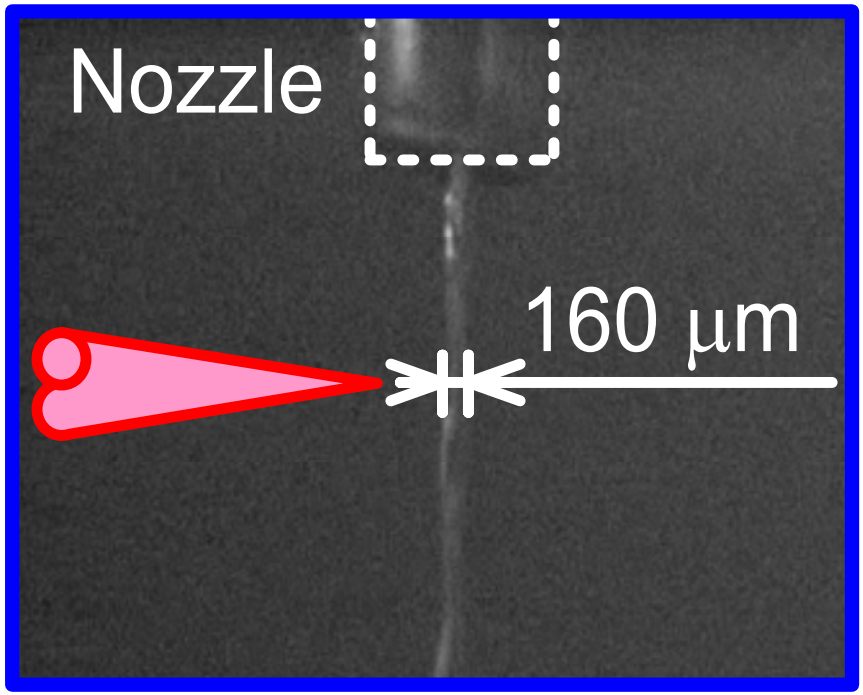
Use of a filament target

Laser intensity dependence of EUV CE



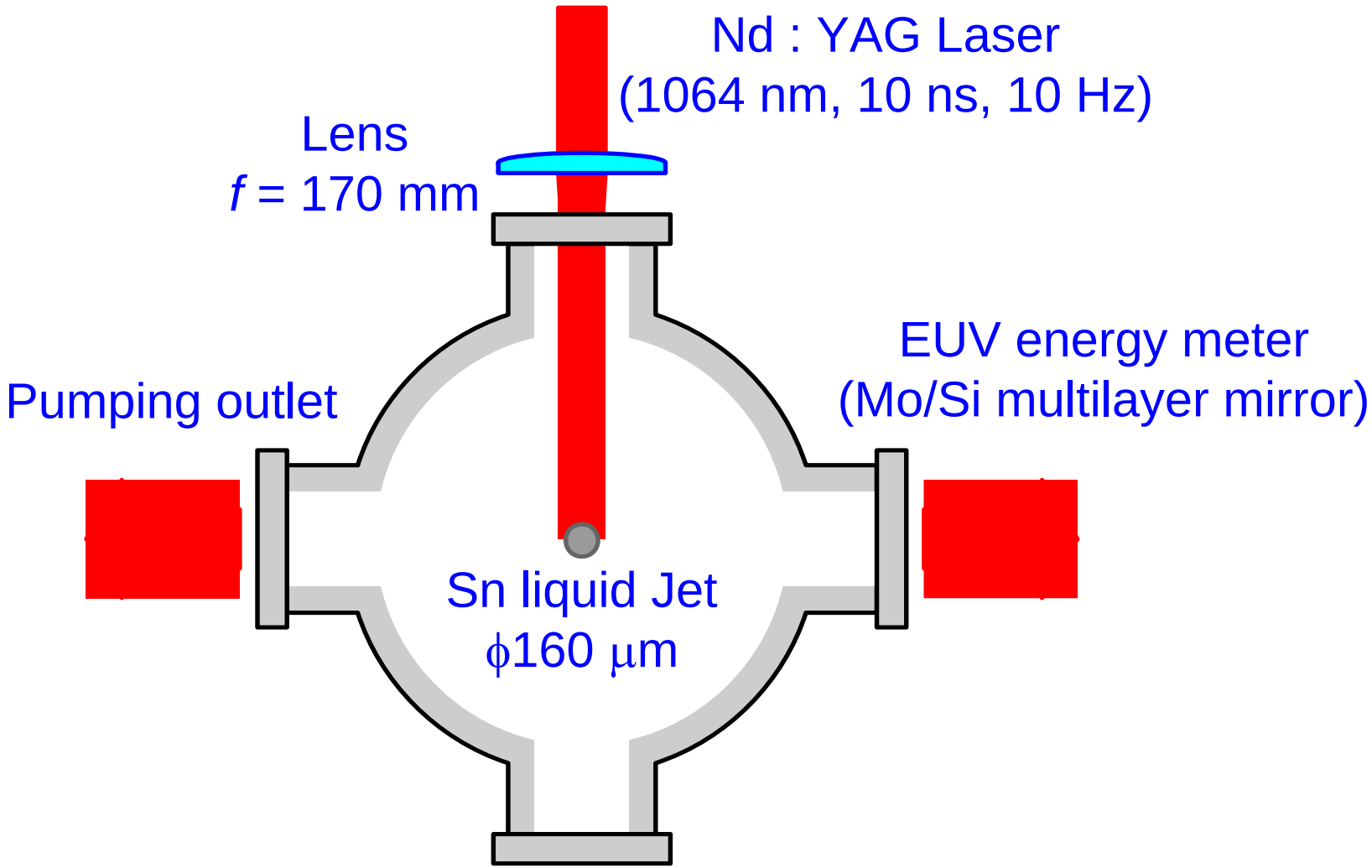
Use of a filament target

Development of a liquid tin microjet target



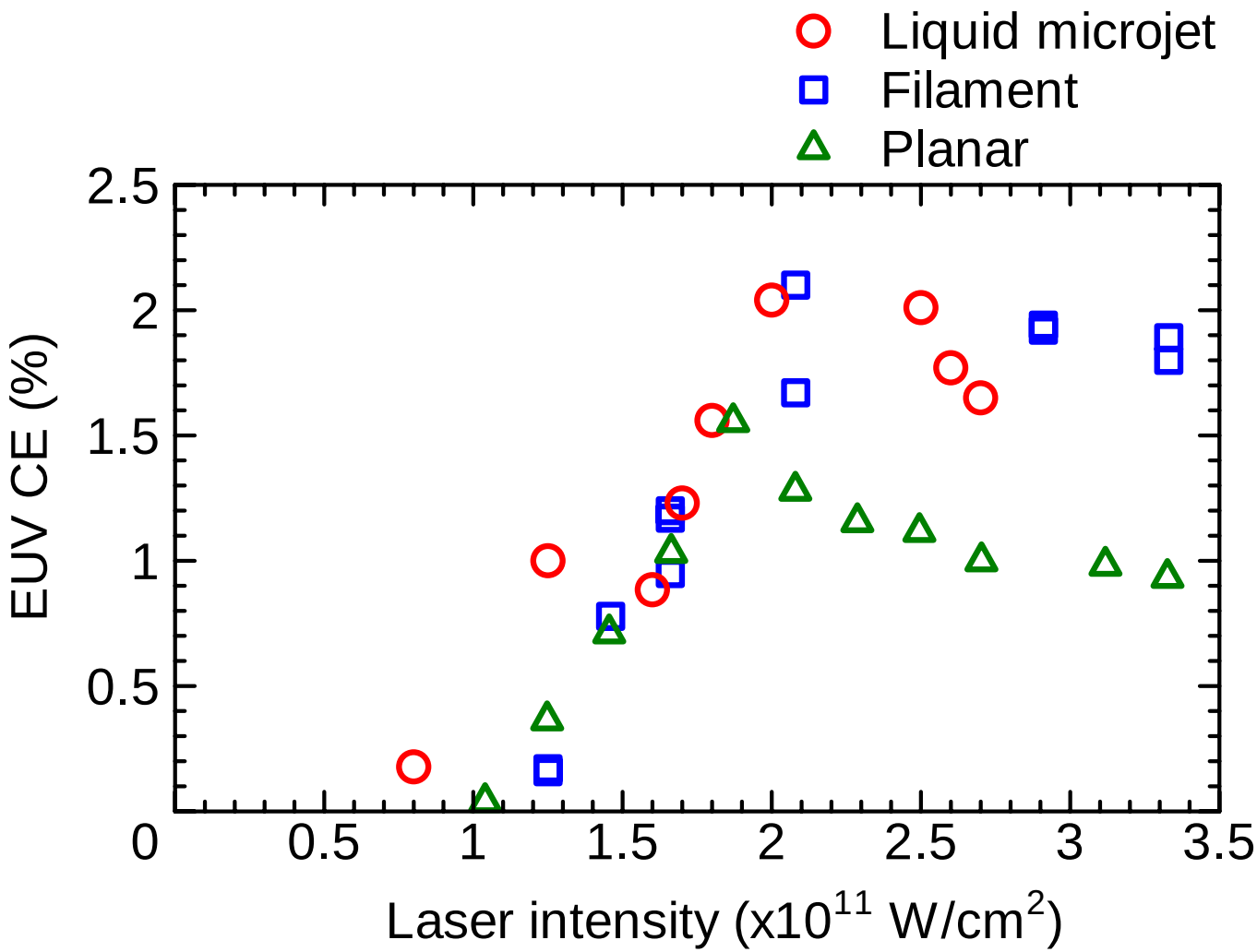
Use of a liquid tin microjet target

Schematic diagram of experimental setup

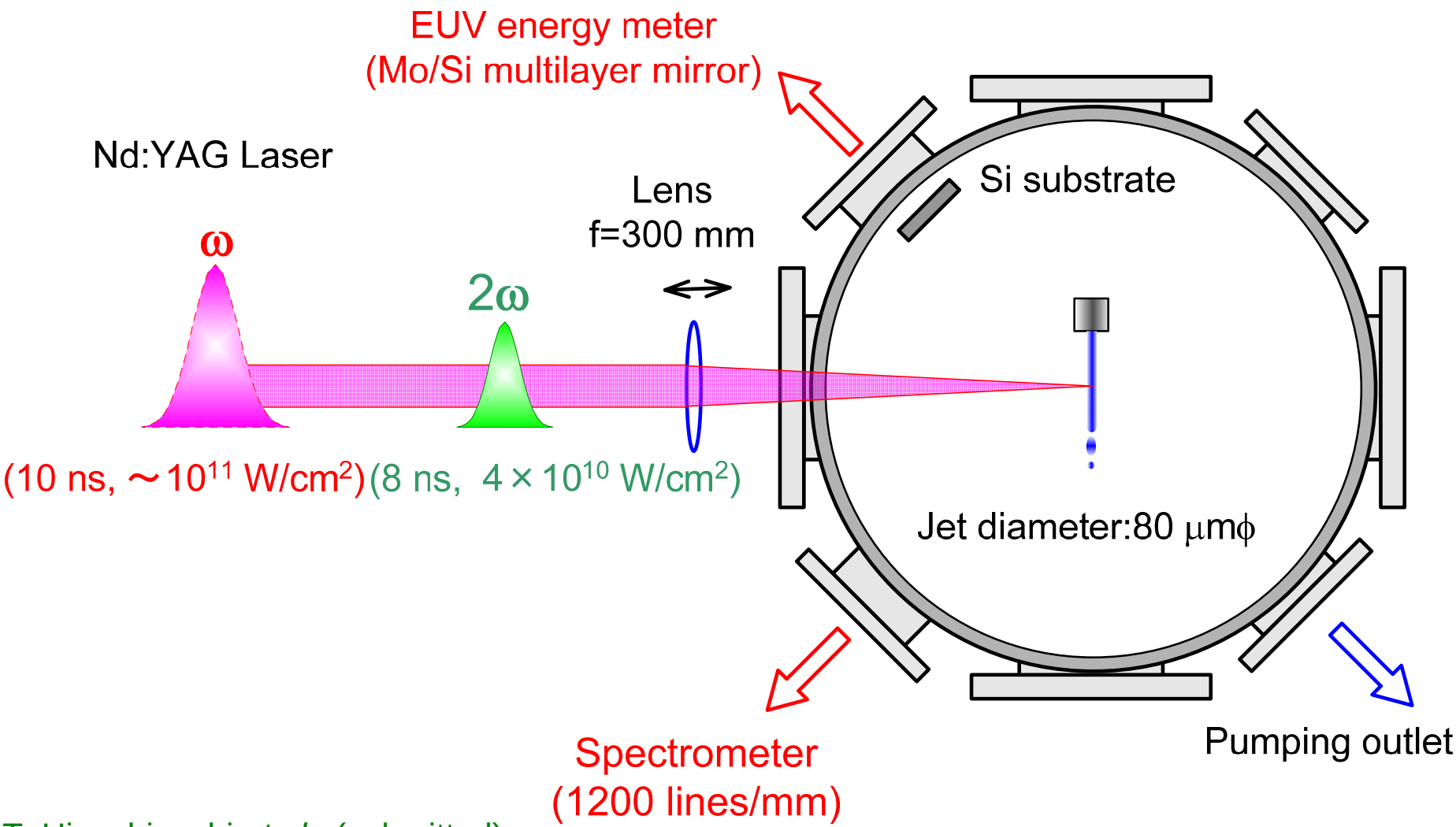


Use of a liquid tin microjet target

Laser intensity dependence of EUV CE

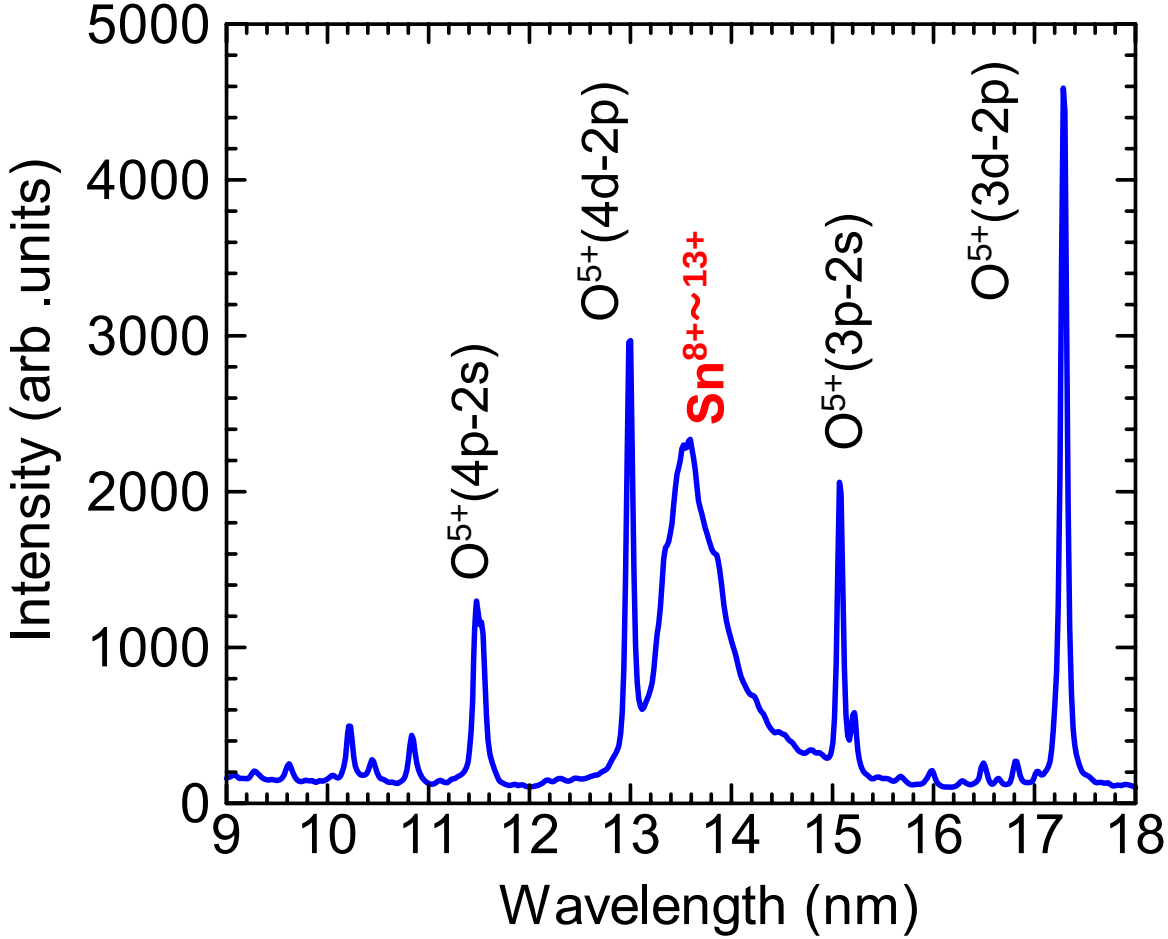


Use of an aqueous solution containing SnO_2 particles: Experimental setup



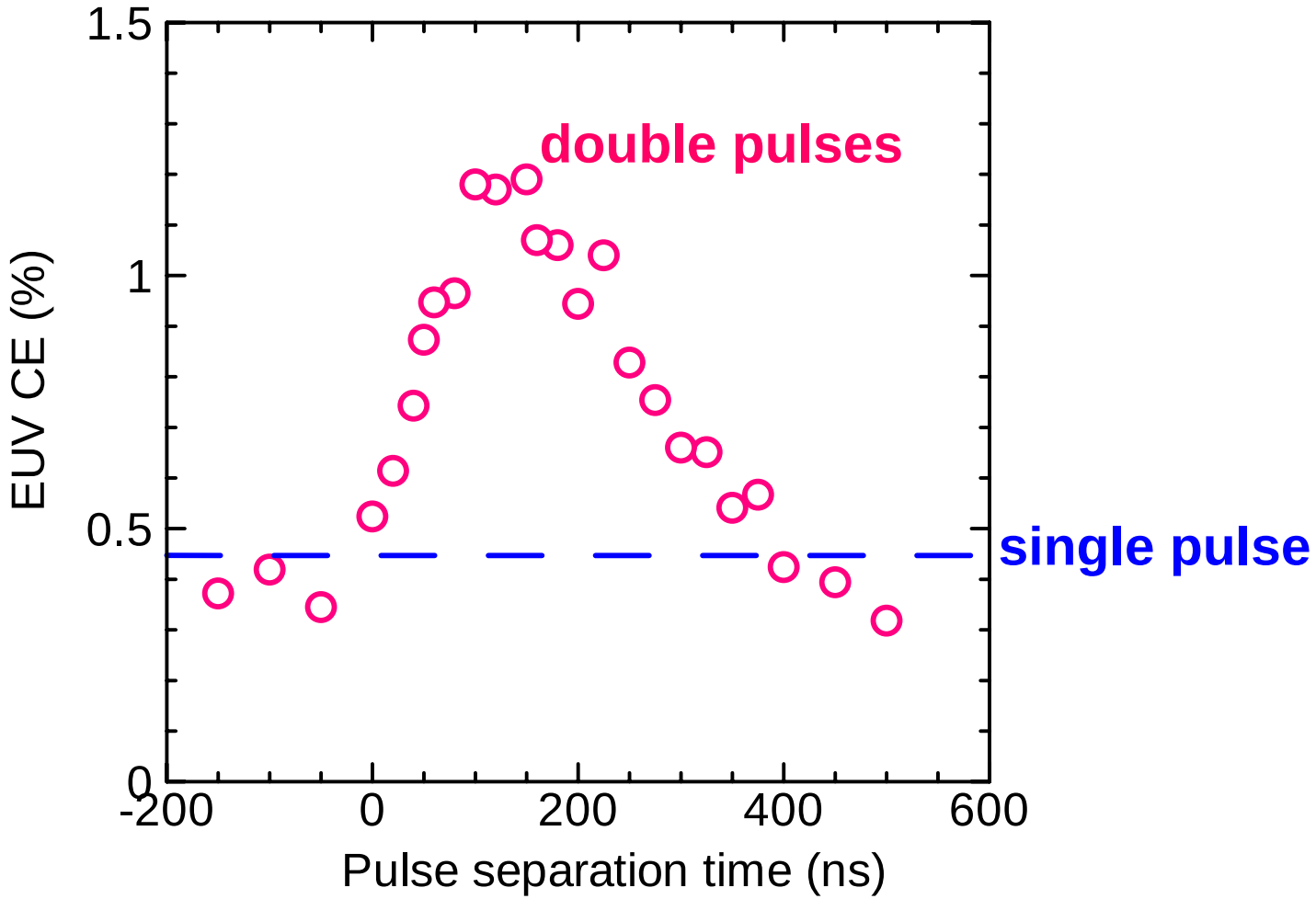
T. Higashiguchi *et al*., (submitted).

Use of an aqueous solution containing SnO_2 particles: Typical EUV spectrum



T. Higashiguchi *et al*., (submitted).

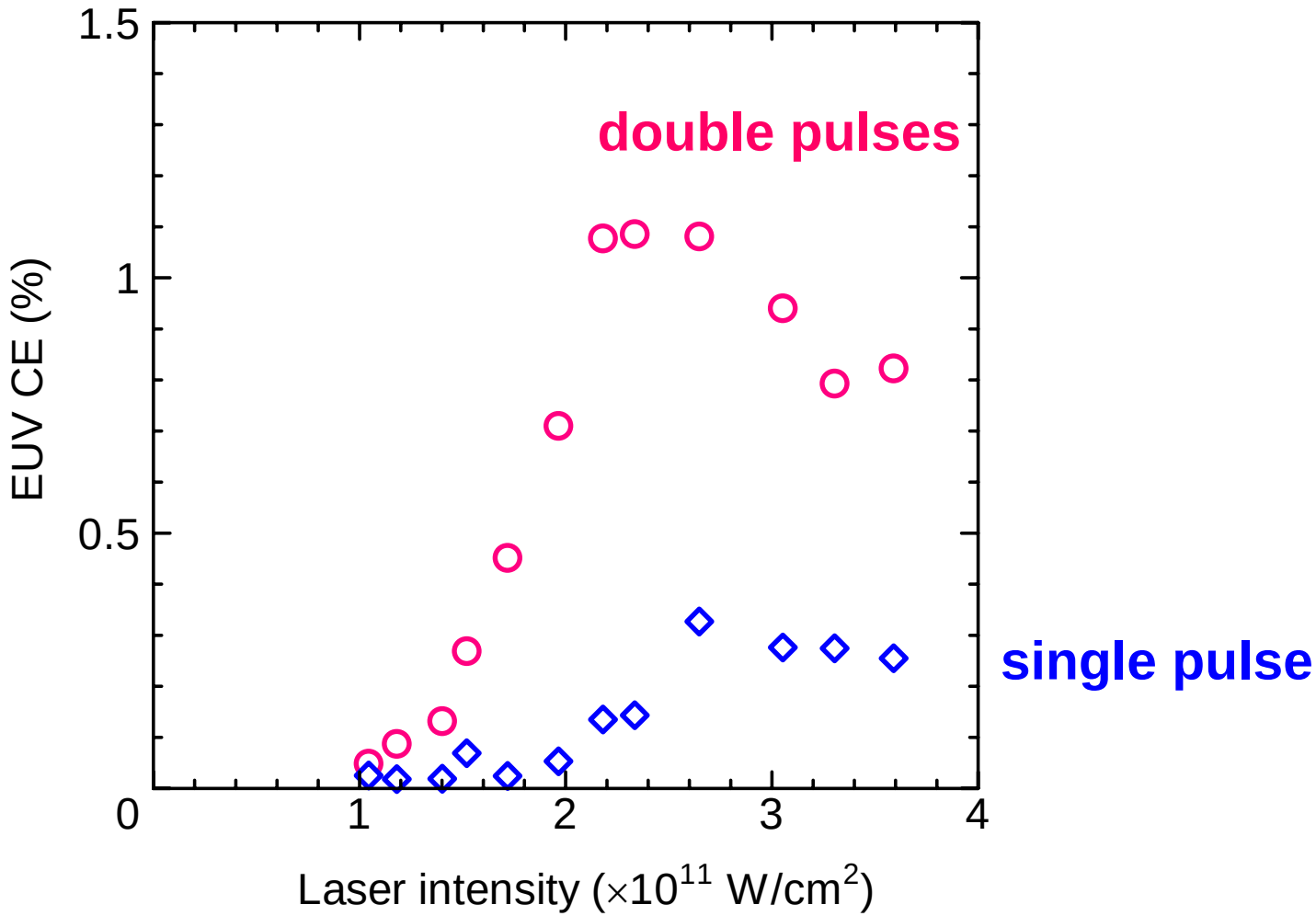
Use of an aqueous solution containing SnO_2 particles: Delay time dependence



T. Higashiguchi *et al*., (submitted).

Use of an aqueous solution containing SnO_2 particles: Laser intensity dependence

Pulse separation time: 100 ns



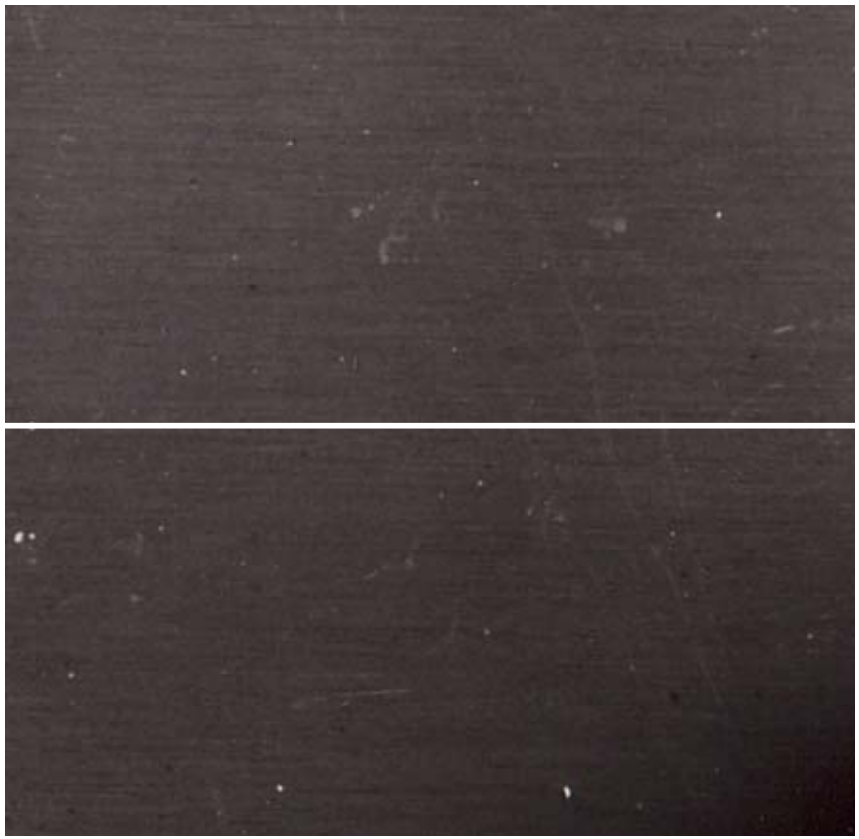
T. Higashiguchi *et al*., (submitted).

Use of an aqueous solution containing SnO_2 particles: Photograph by use of SEM

Shot counts:10000 shots

unexposed

exposed



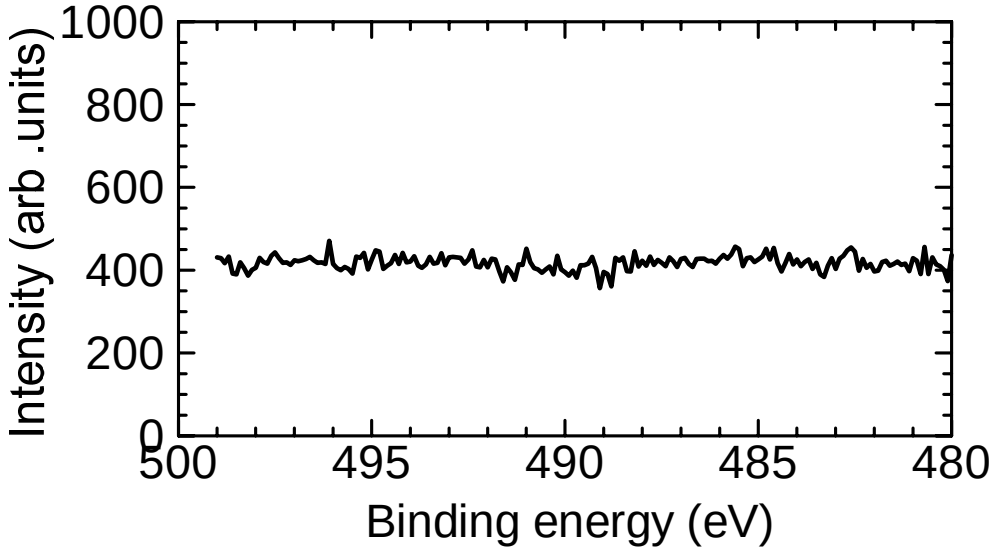
100 μm

T. Higashiguchi *et al*., (submitted).

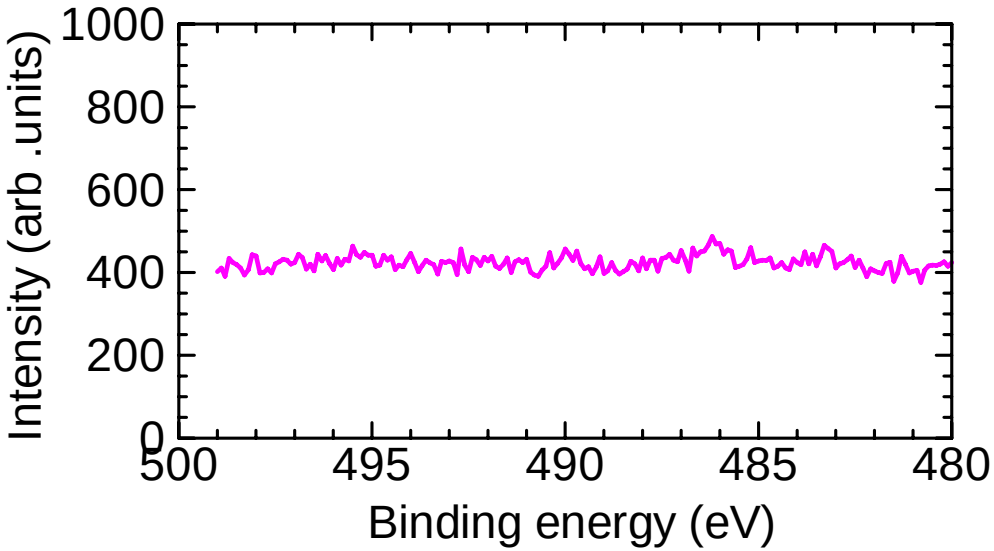
Use of an aqueous solution containing SnO_2 particles: XPS spectra (Sn-3d)

Shot counts:10000 shots

unexposed



exposed

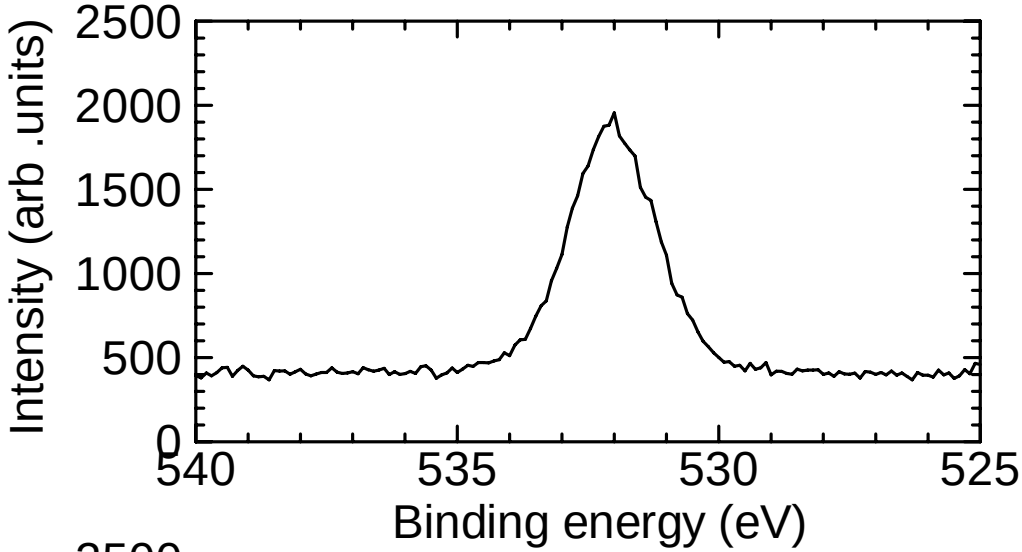


T. Higashiguchi *et al*., (submitted).

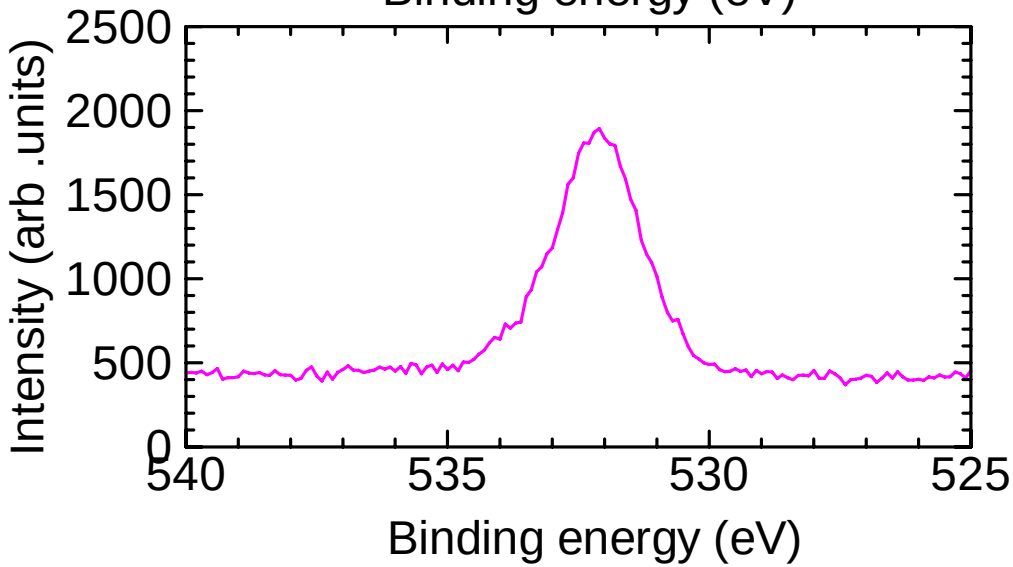
Use of an aqueous solution containing SnO_2 particles: XPS spectra (O-1s)

Shot counts:10000 shots

unexposed



exposed



T. Higashiguchi *et al*., (submitted).

Use of an aqueous solution containing SnO_2 particles: Summary

We demonstrated a **debris-free, efficient LPP EUV source** by use of an aqueous solution containing SnO_2 nano-particles.

EUV CE: 1.2 %

Pulse separation time: 100 ns
Laser intensity: (2-3) x 10^{11} W/cm^2
SnO_2 concentration : 6%

This low SnO_2 concentration made the debris-free emission possible and realized the EUV emission source with the CE larger than 1 %.

T. Higashiguchi *et al.*, (submitted).

Summary

Characteristics of a laser-produced tin plasma EUV source

- EUV and debris emissions from a planar tin target.
  - EUV conversion efficiency: ~ 1.2% with $\cos^{0.5}\theta$-angular distribution
  - Optimum laser intensity: ~ 7 x 10^{10} W/cm^2 with a spot size of 300 μm (FWHM)
  - Suprathermal ion emission around 3 keV at a peak current with Sn^+ and Sn^{2+} ions
  - A maximum ion energy: ~ 7 keV
  - Comparison of angular distributions
    - * EUV emissions: $\cos^{0.5}\theta$
    - * Suprathermal ions and neutral fragments: $\cos^4\theta$
    - * Angular distribution of debris was narrower than that of the EUV emission

- EUV emissions from a filament target as a model of a liquid microjet target.
  - EUV conversion efficiency: ~ 2% with narrowed spectrum
  - Isotropic EUV emission between ±60°
  - Development of a liquid tin microjet target with a diameter from 50 to 150 μm