SoP22

Enhancement of EUV emission from a liquid microjet target by use of dual laser pulses

Takeshi Higashiguchi
Chirag Rajyaguru, 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"

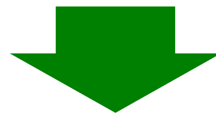
1-1 Gakuen Kibanadai, Miyazaki, Miyazaki 889-2192, JAPAN, TEL/FAX: +81-985-58-7358

Objective: Enhancement of EUV CE

宮崎大学

- Further enhancement of the EUV CE by use of ***dual*** laser pulses, where the plasma hydrodynamic motion can be regulated.

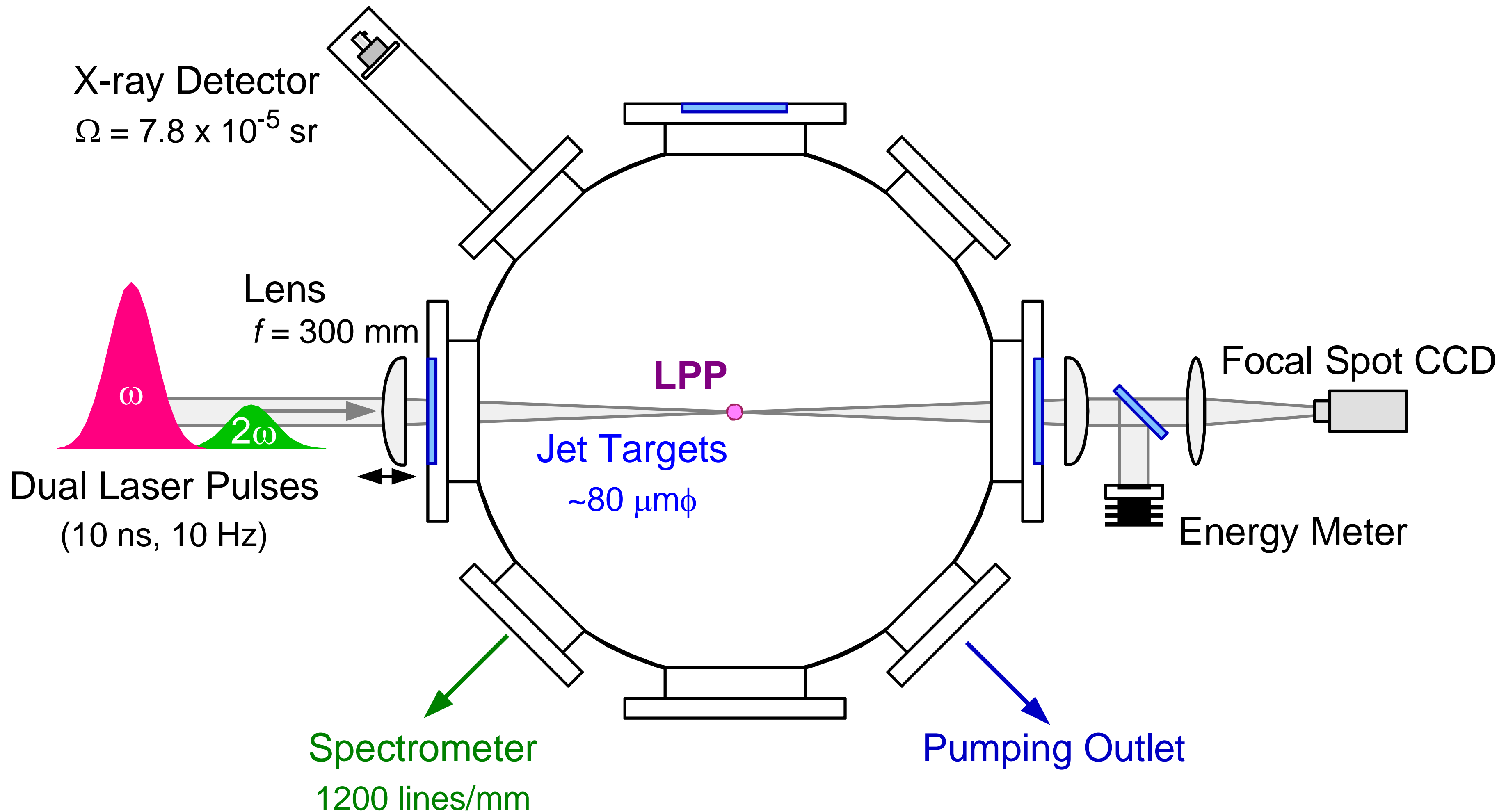
- Enhancement of the EUV CE by matching the laser focal spot size and the micro-jet target diameter



SoP21
"Optimization of extreme ultraviolet yield from a large size continuous water-jet"
Chirag Rajyaguru, Takeshi Higashiguchi, : Wataru Sasaki, Shoichi Kubodera

Dual laser pulse experiment: Setup for dual ns laser pulses

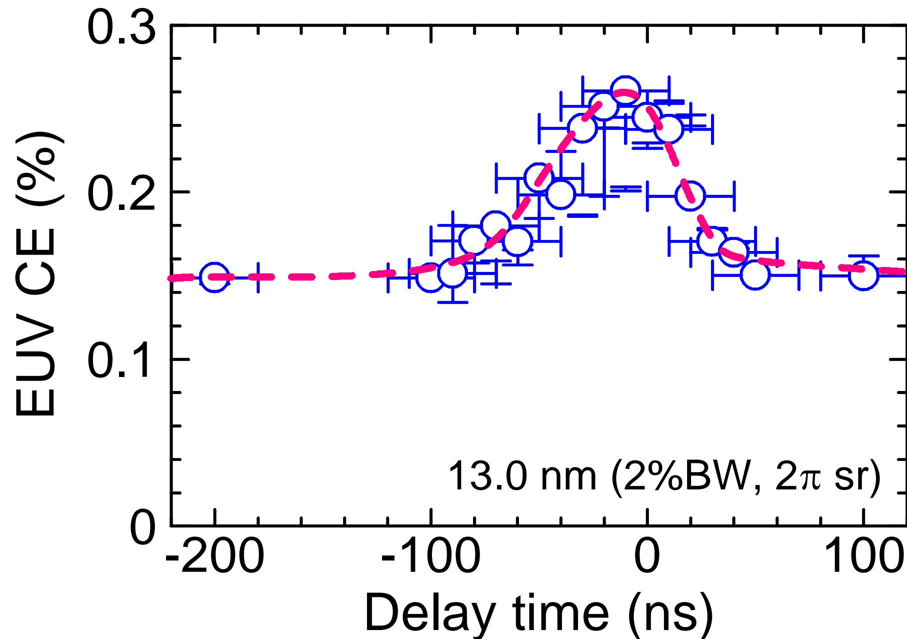
宮崎大学



Enhancement of EUV CE by use of dual ns pulses

宮崎大学

Pump laser intensity: 4.9 x 10^{11} W/cm^2
Laser energy: 245 mJ (1064 nm)
Pre-pulse energy: 25 mJ (532 nm)
Focal spot size (FWHM): 80 μmϕ
Jet diameter: 80 μmϕ

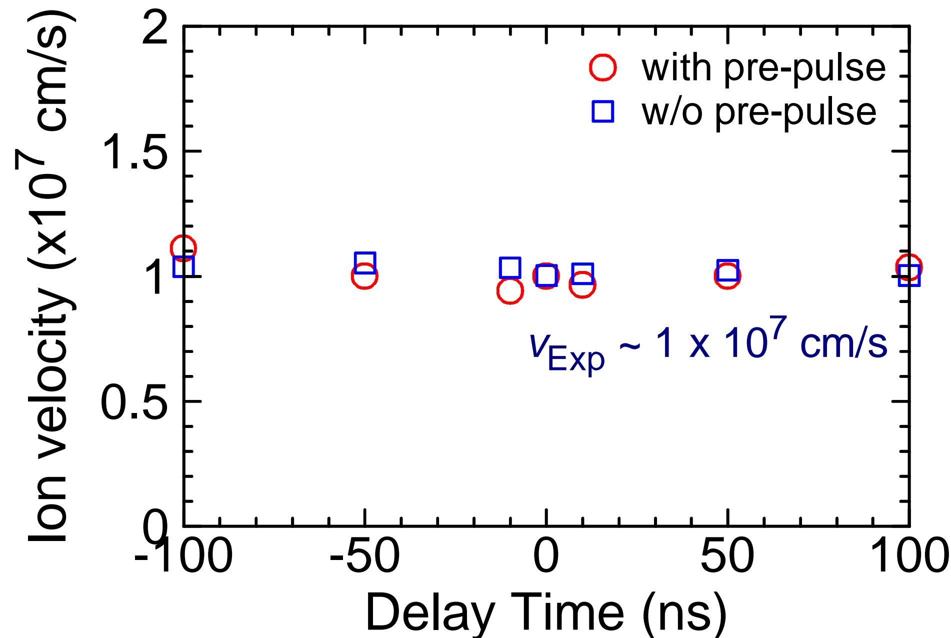


Intensity (arb. units)
w/o pre-pulse
Δτ = -200 ns
Δτ = -10 ns
5000
4000
3000
2000
1000
0
9 10 11 12 13 14 15 16 17 18
Wavelength (nm)

Enhancement of EUV CE using water jet: Plasma expansion time

Pump laser intensity: 4.9 x 10^{11} W/cm^2
Laser energy: 245 mJ (1064 nm)
Pre-pulse energy: 25 mJ (532 nm)
Focal spot size (FWHM): 80 μmϕ
Jet diameter: 80 μmϕ

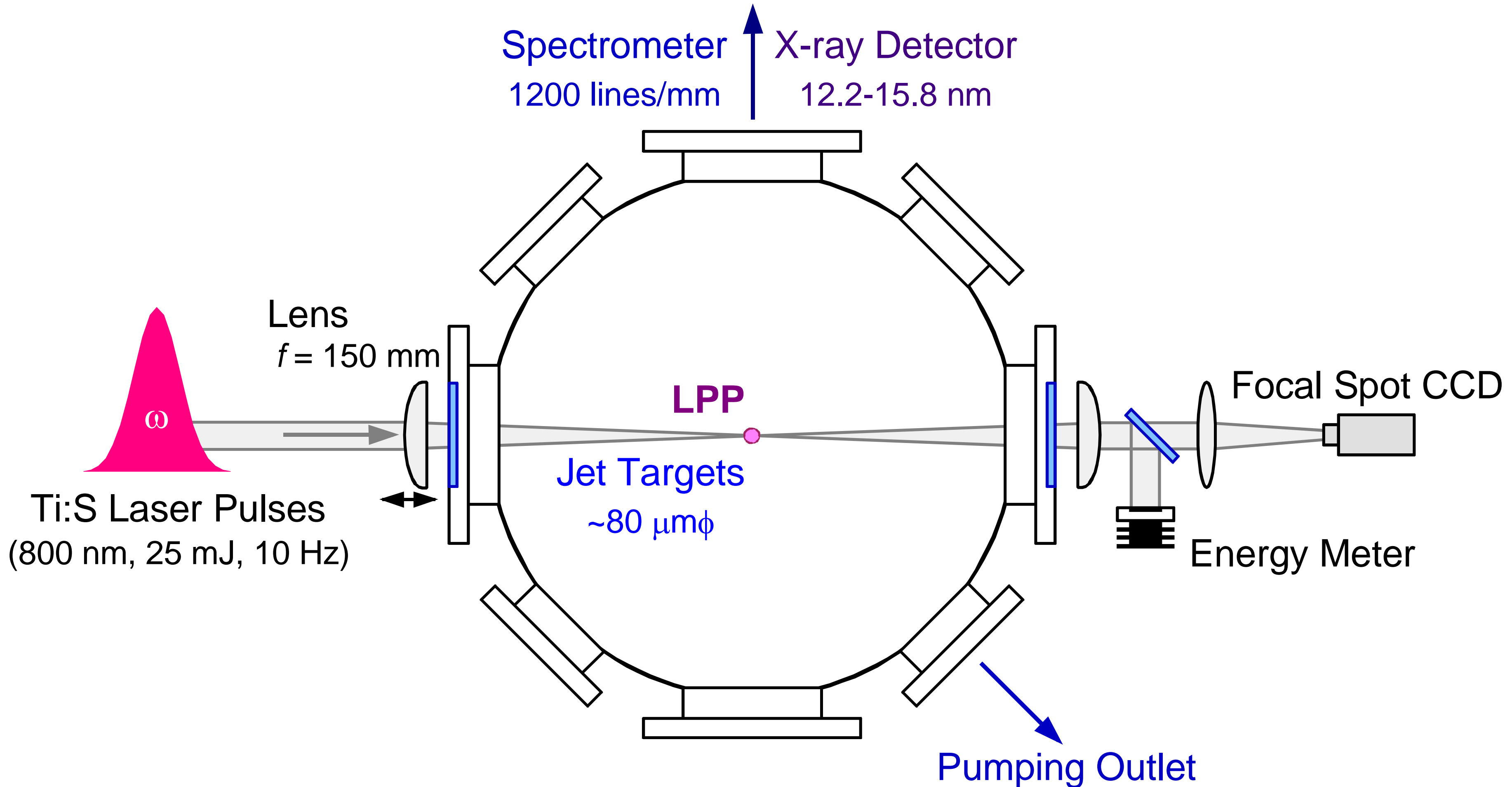
$$\tau_{crit} \approx \left(\frac{n_{e0}}{n_{crit}}\right)^{1/3} \frac{r_{Jet}}{v_{Exp}} \approx 2\,\text{ns}$$



$n_{e0} = 10^{23}$ cm^{-3}
$n_{cric} = 10^{21}$ cm^{-3} @ $\lambda_L = 1$ μm
$2r_{Jet} = 80$ μm
$v_{Exp} = 1 \times 10^7$ cm/s

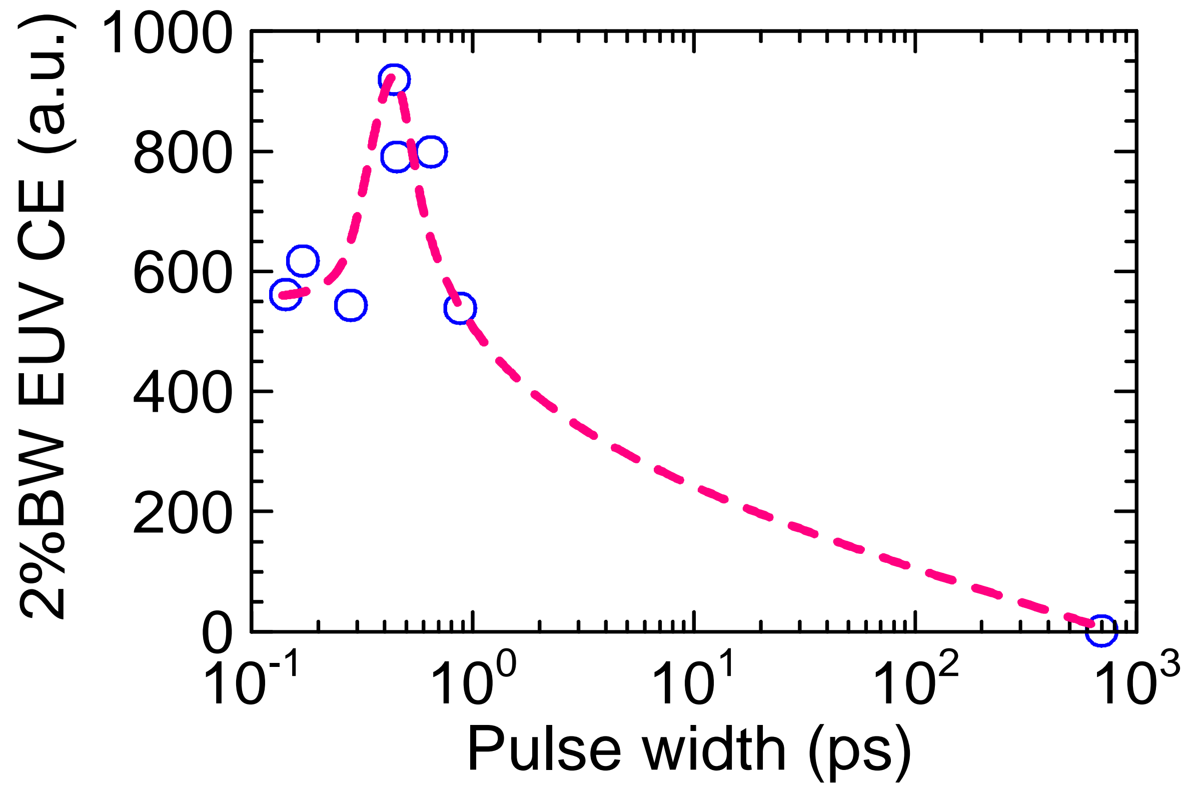
Experimental setup: EUV emission by use of ultrashort, high-intensity laser pulse

宮崎大学



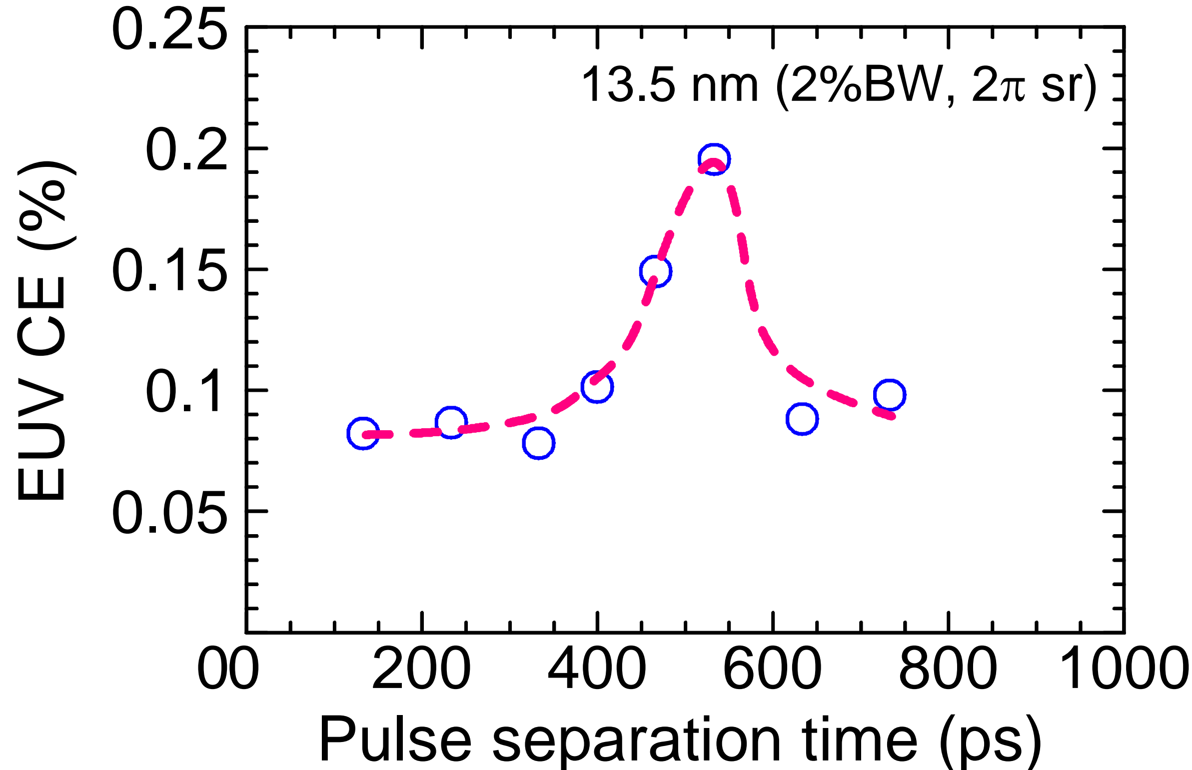
Sub-ps laser experiments: Pulse width dependence of EUV CE

Jet diameter: 80 μmφ
Laser energy: 25 mJ



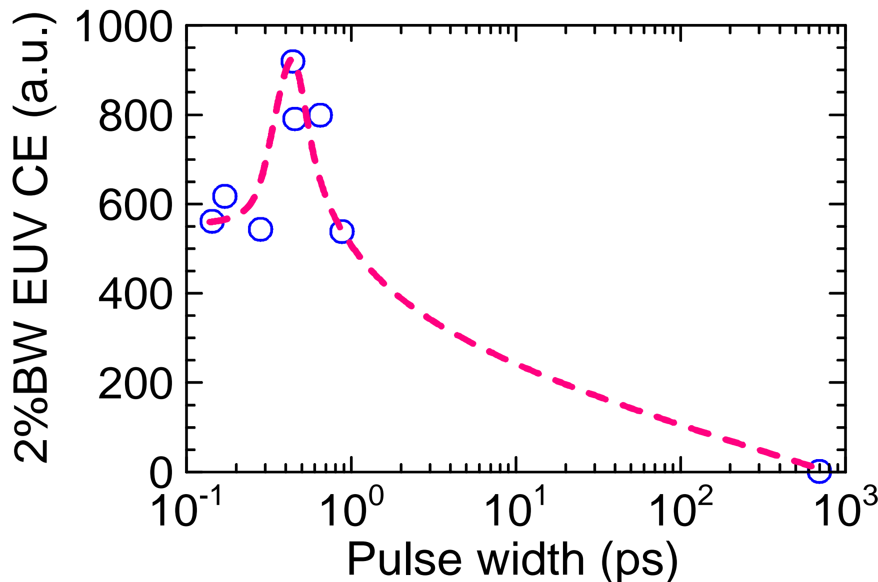
Sub-ps laser experiments: Pulse separation time dependence

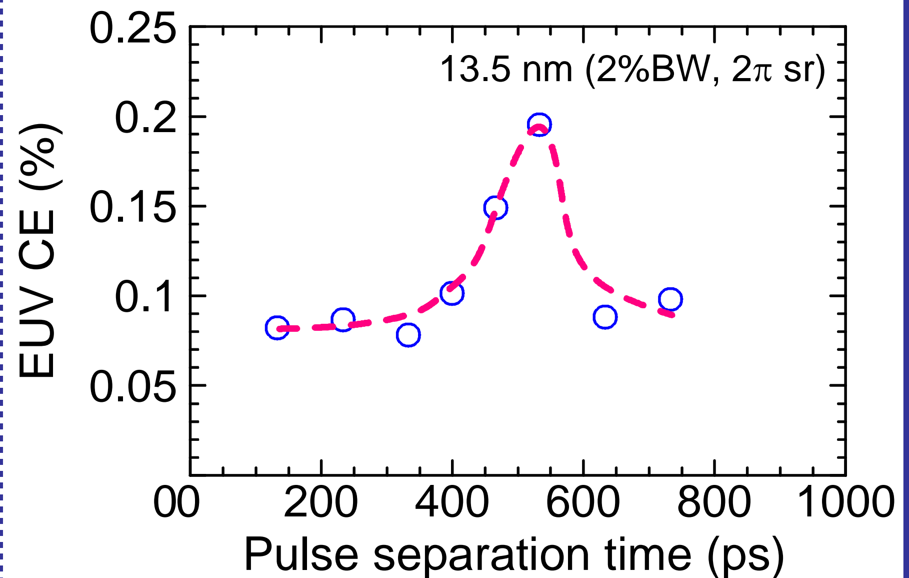
Main pulse energy: 5.3 mJ (9 x 10^{14} W/cm^2)
Pre-pulse energy: 5.8 mJ (6.1 x 10^{13} W/cm^2)
Pulse width: 300 fs (FWHM)



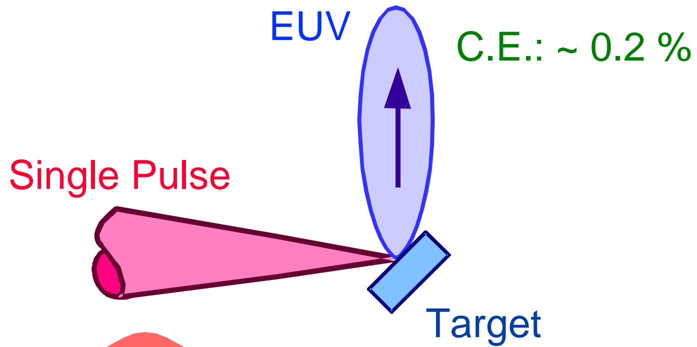
Enhancement of EUV CE: Difference between time scales at optimal CE

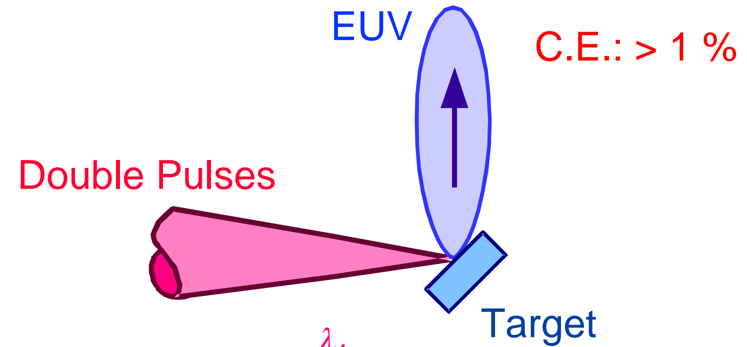
Pulse width dependence	Pulse separation time dependence
τ_{pulse} ~ 400-500 **fs**	τ_{delay} ~ 500-600 **ps**
Resonant absorption thickness $\tau \approx$ 800 fs	Plasma expansion diameter $\tau \approx$ 780 ps



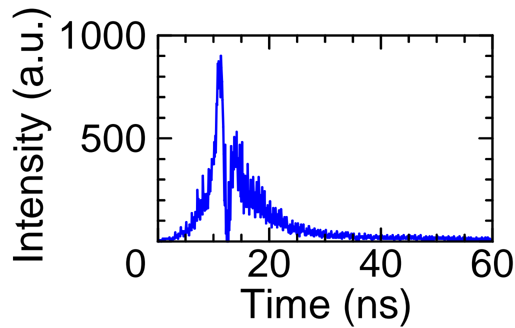


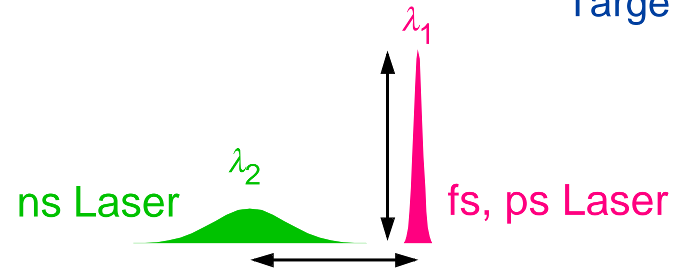
Future plan: Enhancement of EUV CE using sub-ps/ns dual laser pulses



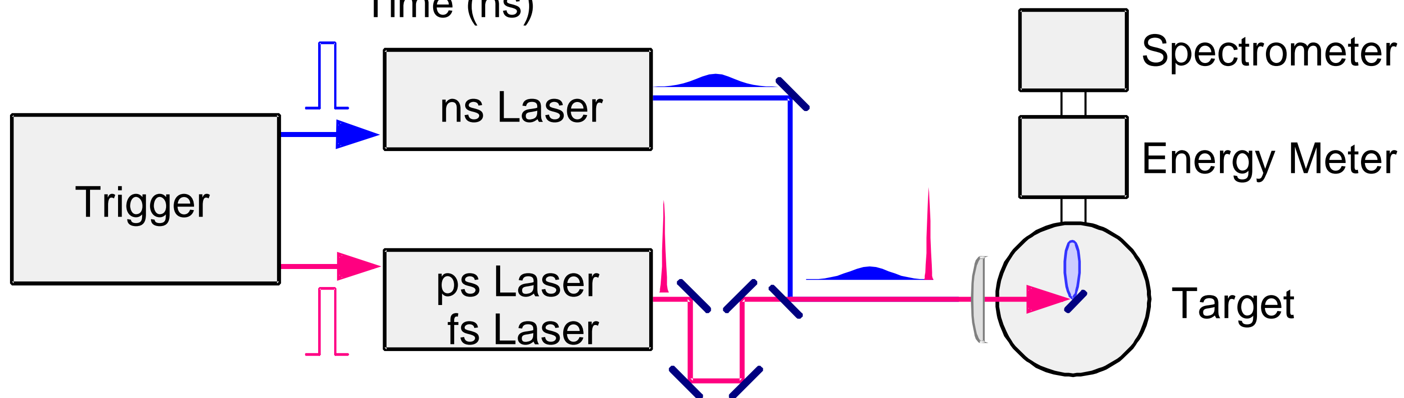


10 ns Laser





- ps laser for **plasma production**
- ns laser for **energy coupling**



Summary:
LPP EUV source using liquid microjet target

■ Enhancement of the EUV CE for dual ns lasers

- Increases the EUV CE (η = 0.15% to 0.26%) for ns lasers.
- Regulates the plasma expansion, leading to the efficient energy coupling.

■ Optimal EUV CE for high intensity lasers

□ Pulse width dependence

- Reveals the optimum pulse width of 400-500 fs by use of high-intensity laser.
- Regulates the resonant absorption, leading to the efficient energy coupling.

□ Pulse separation time dependence by use of dual laser pulses

- Increases the in-band EUV CE (η = 0.08% to 0.2%) for sub-ps lasers.
- Regulates the plasma expansion, leading to the efficient energy coupling.
- Reveals the optimum delay time of 400-600 ps by use of sub-ps lasers.