Optimization of extreme ultraviolet yield from a large size continuous water-jet

Chirag Rajyaguru

Takeshi Higashiguchi, Wataru Sasaki, Shoichi Kubodera

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

宮崎大学

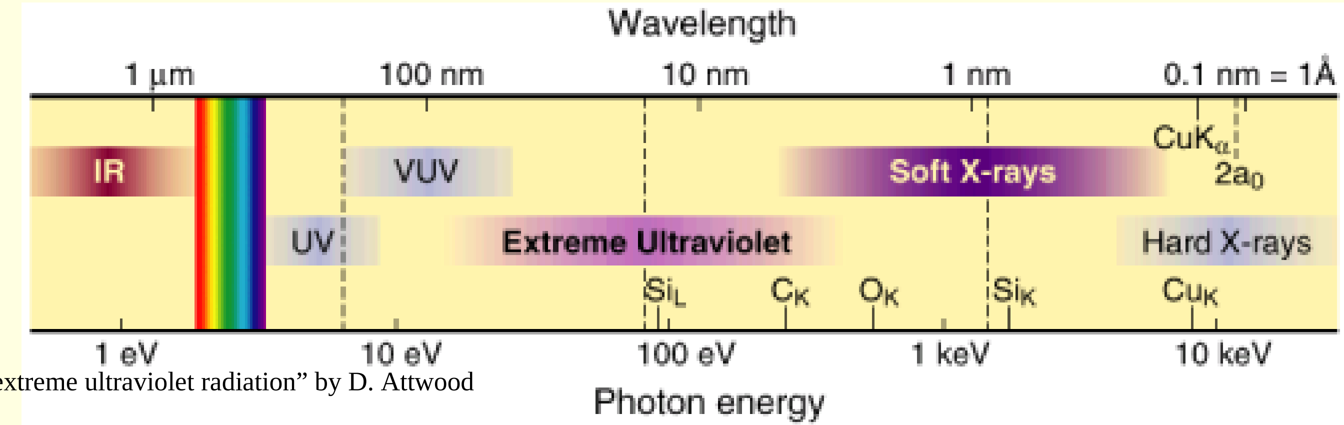
UNIVERSITY OF MIYAZAKI

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

Poster SoP21, 3rd International EUVL Symposium November 1-4, 2004Miyazaki, Japan

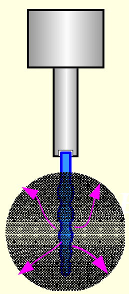
1-1 Gakuen Kibanadai, Miyazaki, Miyazaki 889-2192, JAPAN, TEL/FAX: +81-985-58-7358

Background



From "Soft x-rays and extreme ultraviolet radiation" by D. Attwood

Laser produced plasmas using liquid targets



- ❖ **Target size can be controlled.**
- ❖ **Mainly ionized debris is produced.**
- ❖ **Electromagnetic fields could be used to reduce or divert debris**

- **EUV conversion efficiencies ranging from 0.06% to 0.3% in 2π sr using water as a target have been reported.**
  - **Different laser parameters**
  - **Different target sizes**

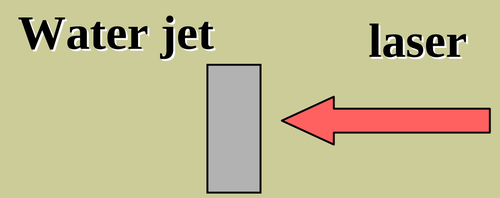
Objective

<u>To find optimized laser and target parameters to improve the EUV CE.</u>

Why water ?

- **Oxygen has a sharp emission line at 13 nm.**
- **There is negligible off-band emission.**
- **Other materials, like Sn, Li, can easily be dissolved to fine tune the emission wavelength.**

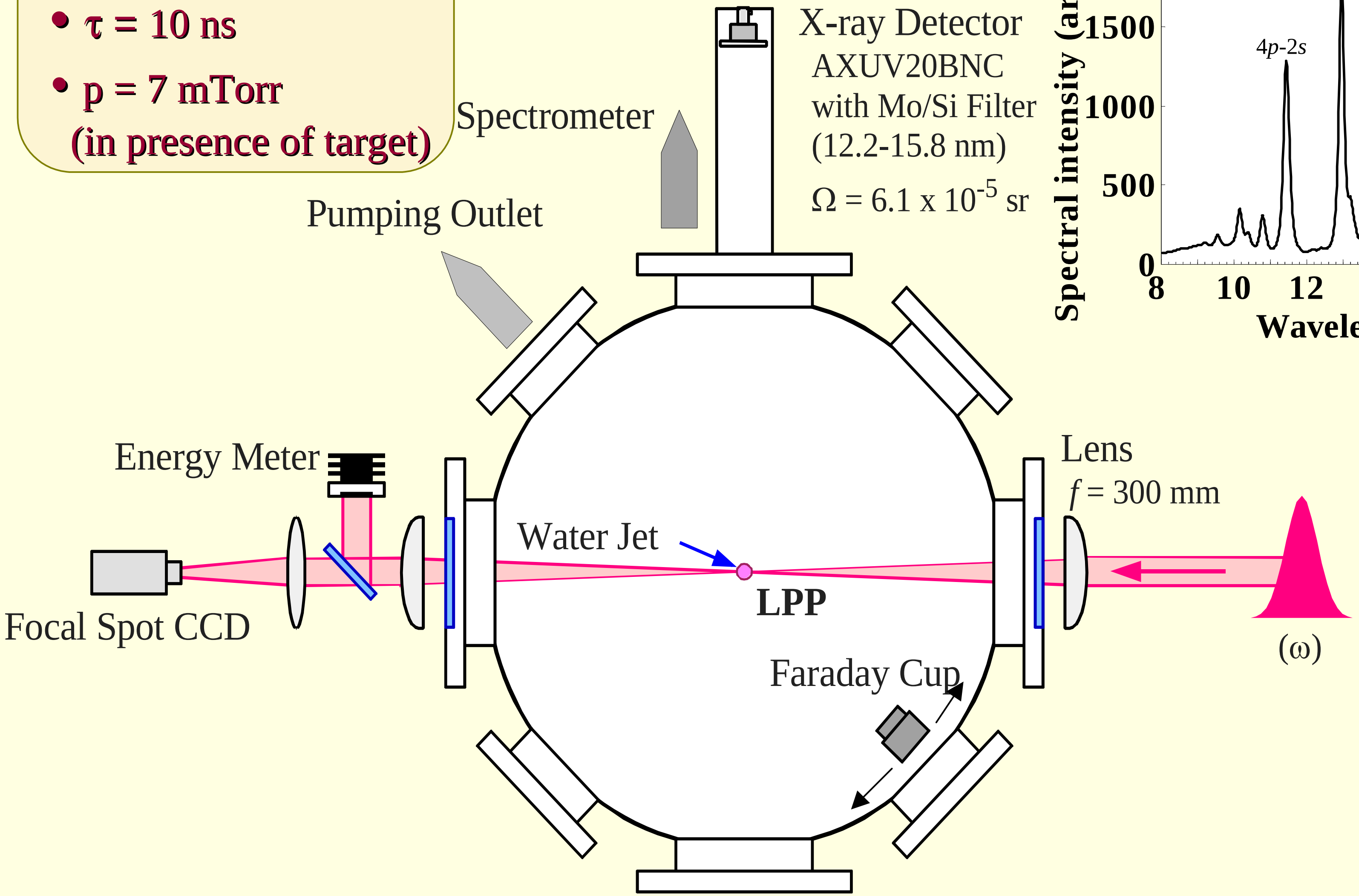
Why Jet ?

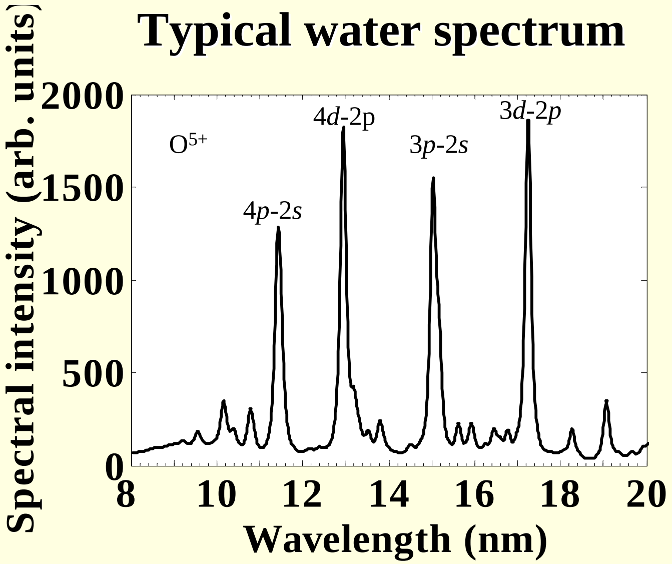


No temporal synchronization is required.

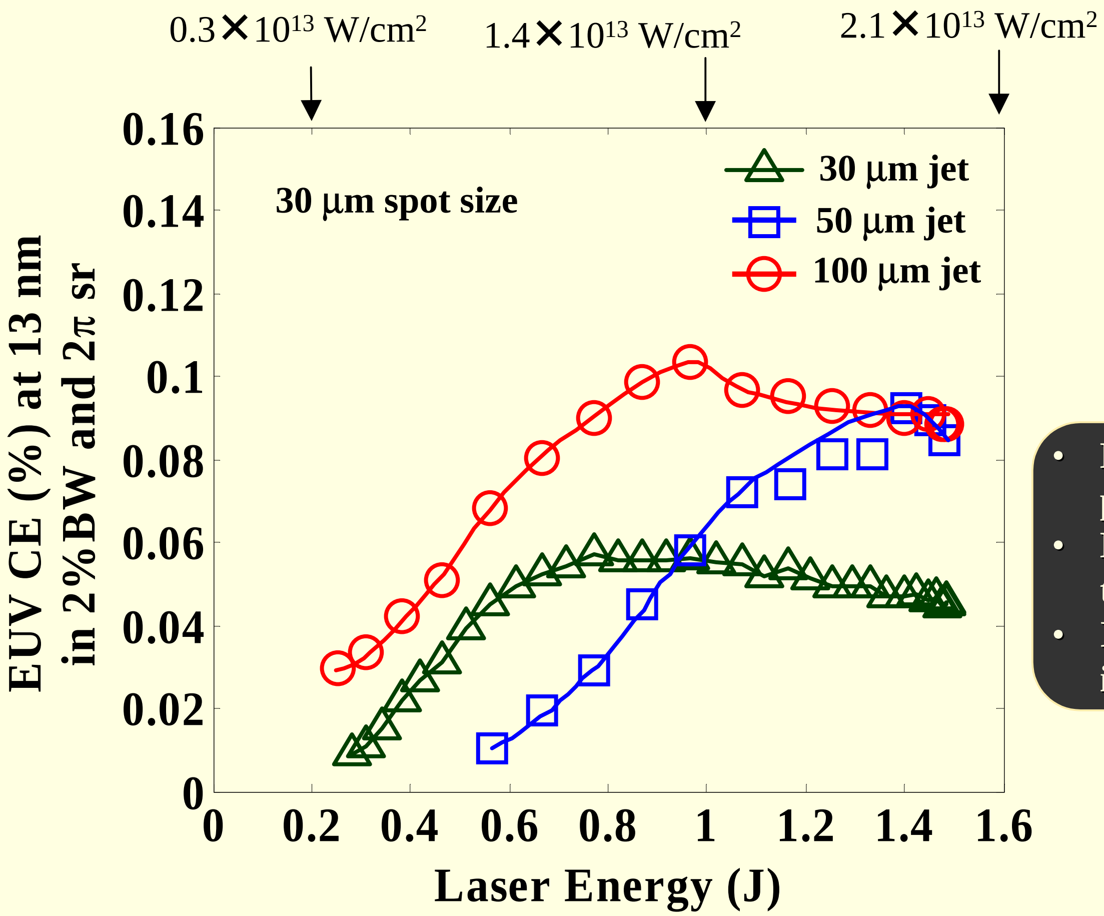
Experimental setup

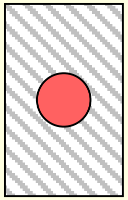
- λ = 1064 nm
- ε_{max} = 1.5 J
- τ = 10 ns
- p = 7 mTorr (in presence of target)





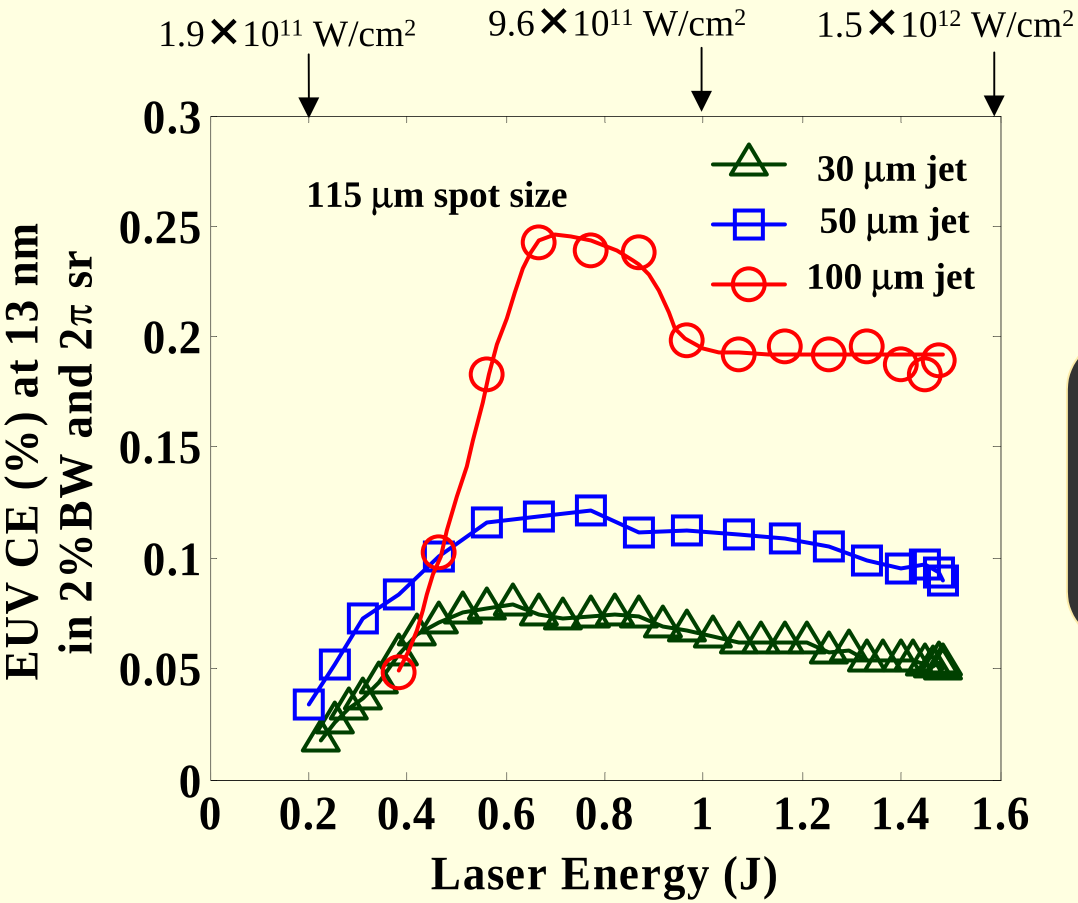
Dependence of conversion efficiency on laser energy and spot size

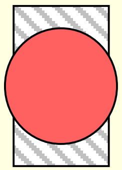




- Material outside the focal spot blows off partially or unionized.
- Energy is transported from a local spot within the target material.
- Ineffective use of target material and increase in required laser energy.

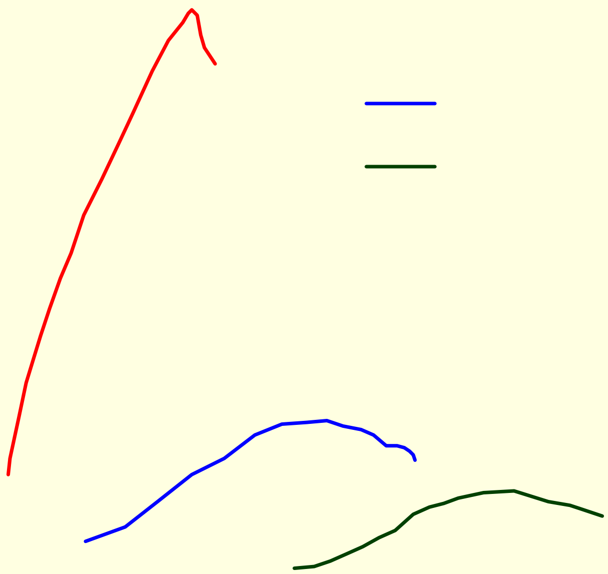
Dependence of conversion efficiency on laser energy and spot size





- Matched spot size improves CE drastically.
- Laser energy and target material are utilized effectively.
- There seems to be optimum spot size for a given jet diameter.

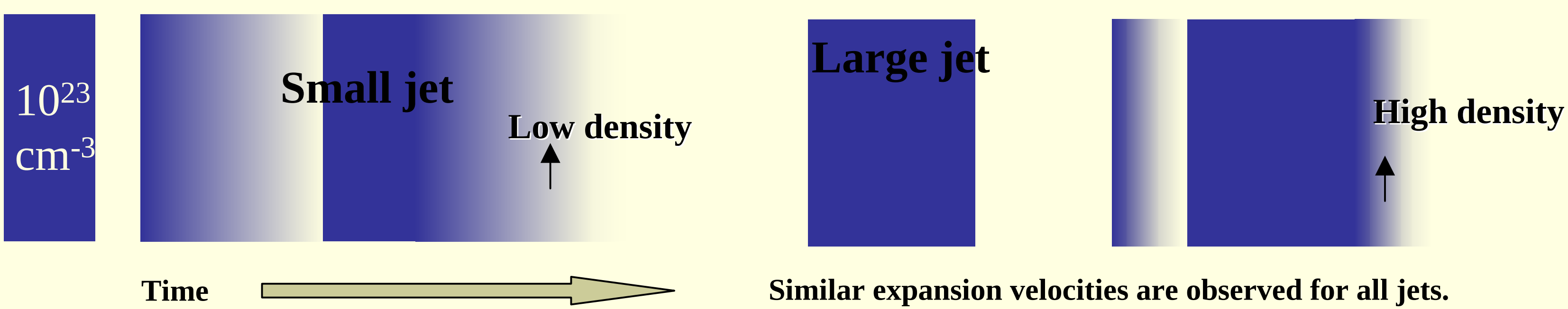
Effect of plasma expansion on EUV CE



$$Sn = \frac{\text{Spot size}}{\text{Jet diameter}}$$

- Even if the incident spot size is closely matched, larger diameter jet offers high EUV CE.
- At any given time, fractional change in plasma density during the expansion is small for larger diameter jet as compared to smaller ones.

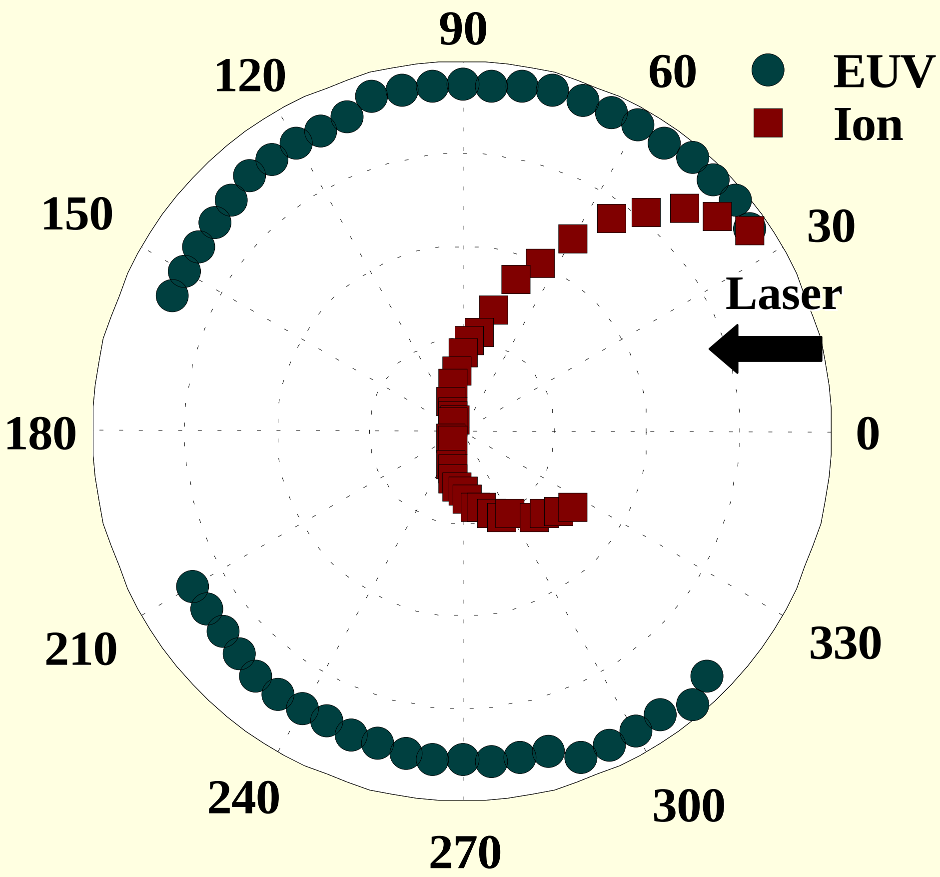
$$n(t) = \frac{n_0}{(1+\Delta r(t)/r_0)^3}$$



Similar expansion velocities are observed for all jets.

Spatial distribution of EUV emission and energetic ions

100 μm jet and 140 μm spot size.



- Similar spatial distribution is observed irrespective of the incident spot size and jet diameter.
- Typical ion velocities observed are of the order of 10^6 to 10^7 cm/s.

EUV emission and debris are clearly isolated in the direction opposite to laser incidence

Summary

- Maximum EUV CE of 0.41% in 2π sr at 13 nm was observed.
- Incident laser spot size should be slightly larger than jet diameter to achieve improved EUV CE.
- Larger diameter jets allow interaction of incident laser at higher density in expanding plasma as compared to smaller jets and offers higher EUV CE.
- Uniform angular distribution of EUV emission and forward directed ions distribution remain unchanged for any value of incident laser spot size.

Future plan

- To carry out the ***interferometric measurements*** of plasma density and its evolution as a function of the incident laser parameters.
- To ***control the plasma density*** at the time of interaction using combination of ***sub-pico second laser and nano-second laser pulses.*** *See SoP22*
- To perform ***pinhole imaging*** to measure EUV source size.