A miniature hybrid plasma focus extreme ultraviolet source driven by ten kilo-ampere fast current pulse

S.R. Mohanty
JSPS Fellow
Hotta Laboratory

Background

Different types of DPP sources are under investigation, including

- Capillary
- Z-pinch
- Hollow Cathode Triggered Z-pinch
- Gas jet Z-pinch
- Plasma Focus

→ Each source has its merits and demerits.

Plasma Focus EUV light source

- Open source geometry
- High collection angle (up to 2π steradian)
- Good clearing of discharge zone
- Large electrode surface area

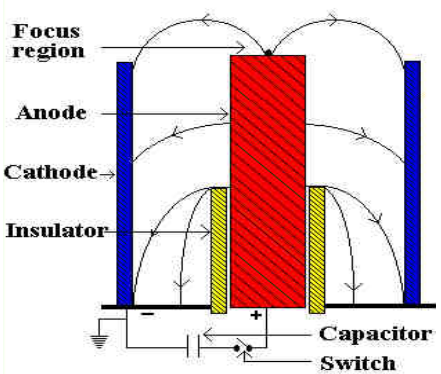
- Till date

Cymer Inc. made an aggressive campaign for developing Plasma Focus as a source for EUVL.

Motivation

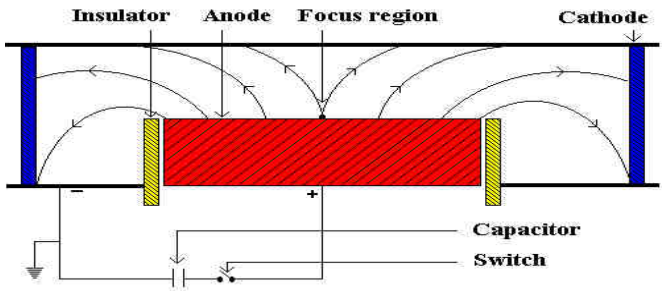
To develop a miniature plasma focus EUV source driven by 10 kA fast current pulse

Plasma Focus head



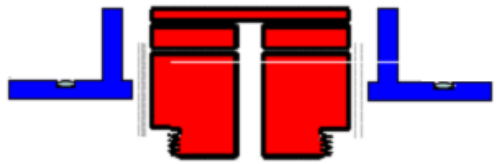
Mather type

(Anode Aspect Ratio>> 1)



Filippov type

(Anode Aspect Ratio<< 1)



Hybrid type

(Anode Aspect Ratio = 1)

Most common empirical formula used to design classical plasma focus staring from few kJ to MJ

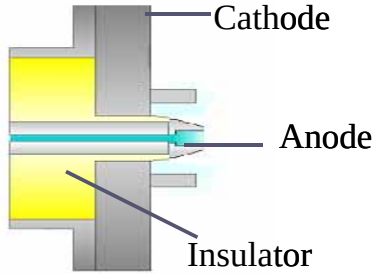
$$CV^2/pl = K_1$$

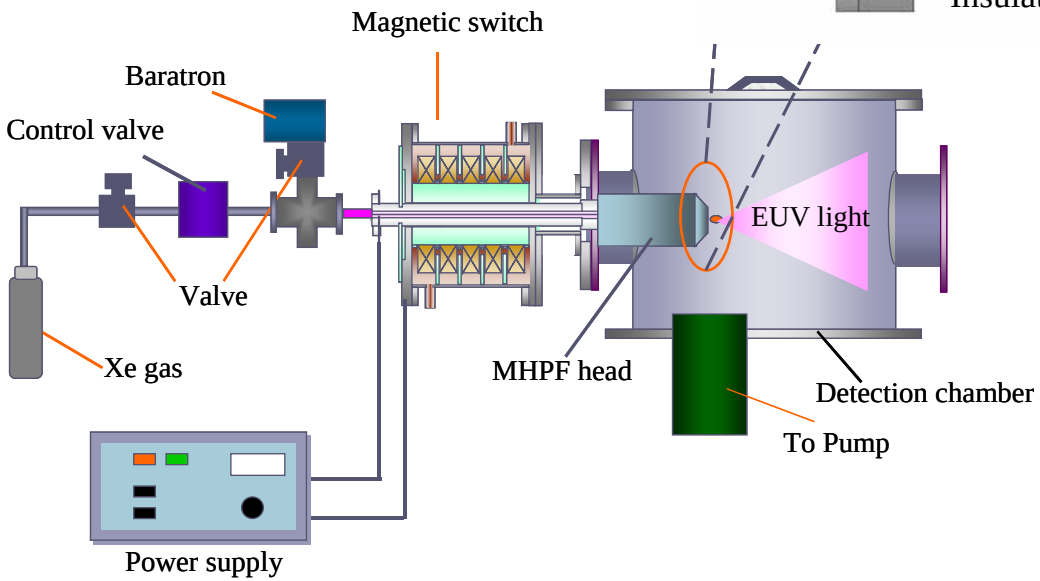
$$CV/rpl^2 = K_2$$

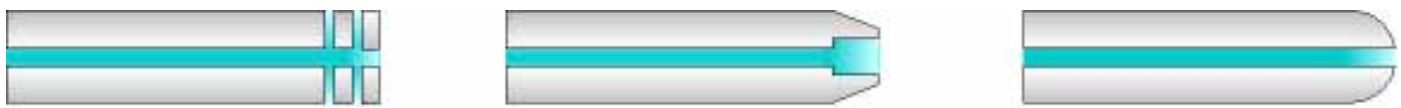
Plasma velocity v_p scales with discharge current I_0, magnetic field B_0, gas density ρ_g, anode outer radius r_0 as

$$v_p = \sqrt{\frac{B_o^2}{2\mu_o \rho_g}}, \quad \text{Where} \quad B_o = \frac{\mu_o I_o}{2\pi r_o}$$

Experimental Arrangement







Different design of electrodes

Diagnostics used

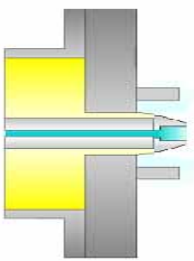
- Visible framing camera
- EUV pinhole camera
- EUV photodiode
- Transmission grating spectrometer

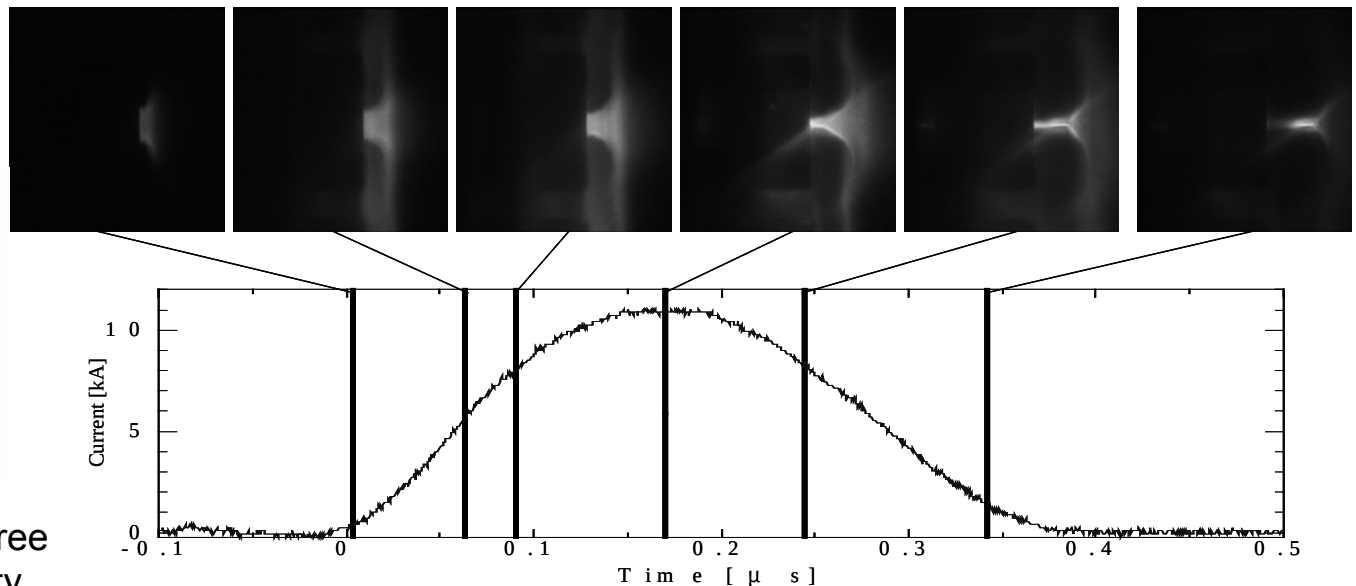
Results

Visible light imaging

Pinch Dynamics in visible region was investigated at different angles by employing IMCON

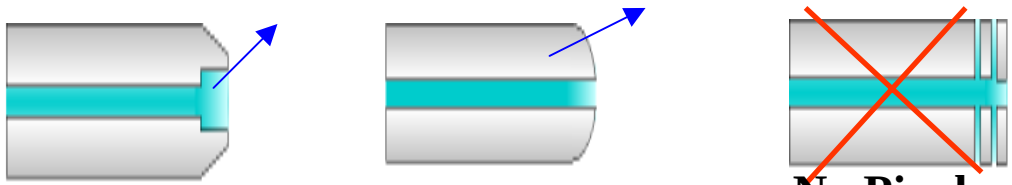
- For different central electrode geometries (cylindrical, tapered, hemispherical)
- For different Xe supply pressures (20 to 30 Torr){Chamber pressure 0.9 Pa to 1.4 Pa}
- Positive and negative polarity



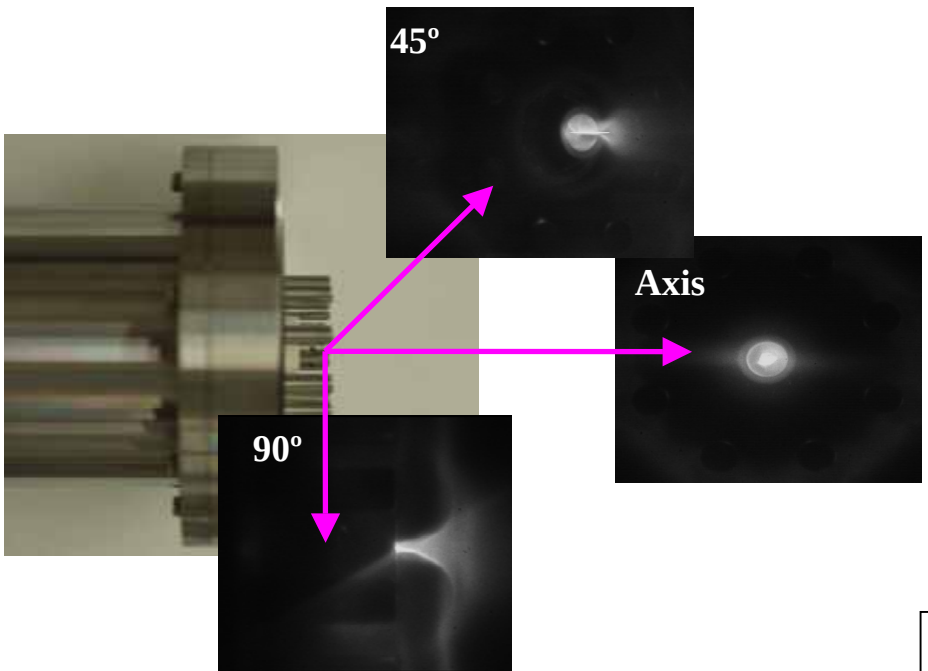


30 Torr, 90 degree
Negative Polarity

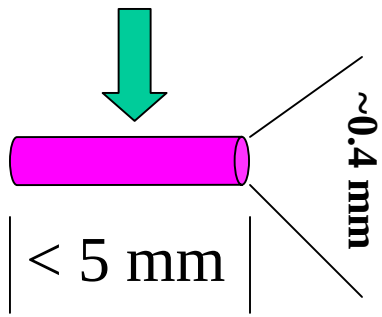
Pinching is observed only in tapered and hemispherical central electrode types…



Pinch view at different angles at $I_{max.}$



Pinch Column



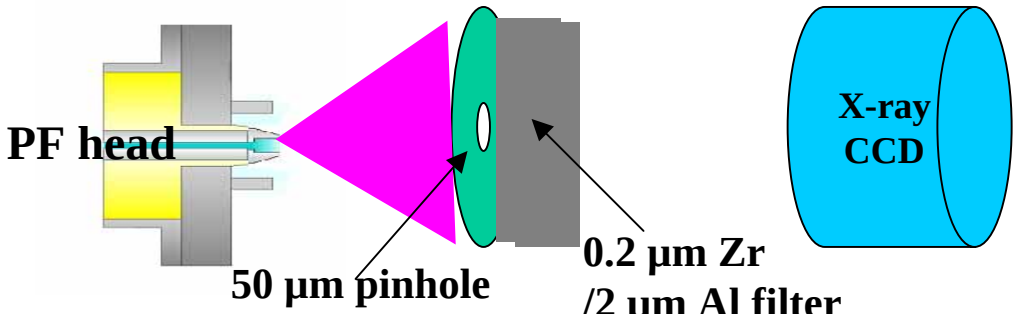
Compression ratio ~ 6 time at highest supply pressure

Pinching is observed in both the polarity and different supply gas pressures…

EUV pinhole imaging

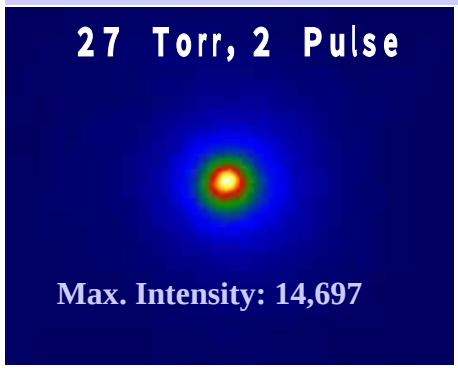
Magnification

- On axis: 1.77
- 45 degree: 2.1
- 90 degree: 3.1

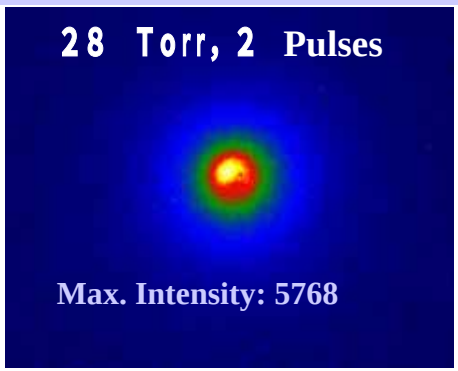


Error: ±14μm

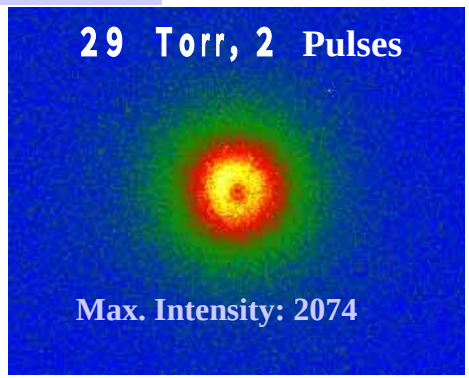
On axis image with Zr filter (transmission 6 to 18 nm)



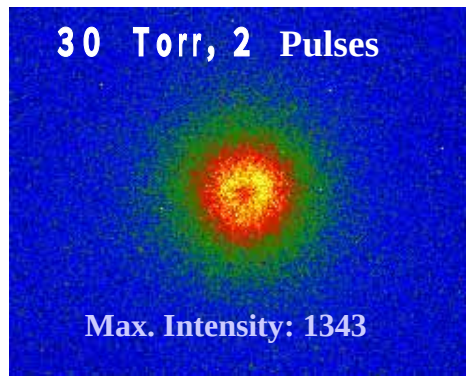
FWHM: 168 μm



FWHM: 205 μm



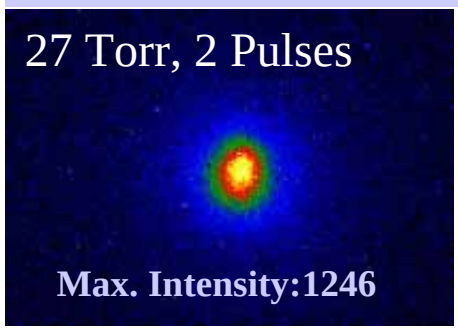
FWHM: 314 μm



FWHM: 373μm

•Error: ±14μm

On axis image with Al filter (transmission 16 to 30 nm)



FWHM: 153 μm

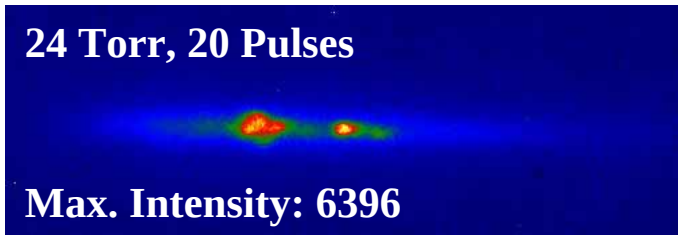
FWHM: 168 μm

FWHM: 168 μm

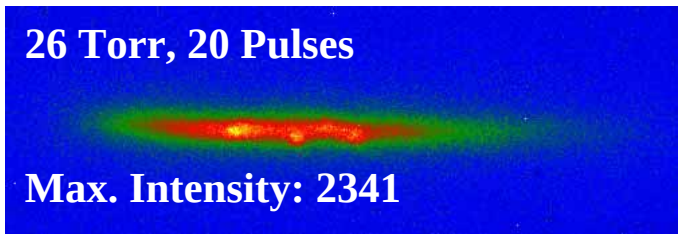
FWHM: 183 μm

Off axis image with Al filter

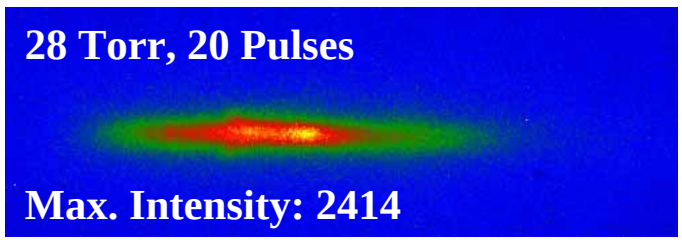
45 degree



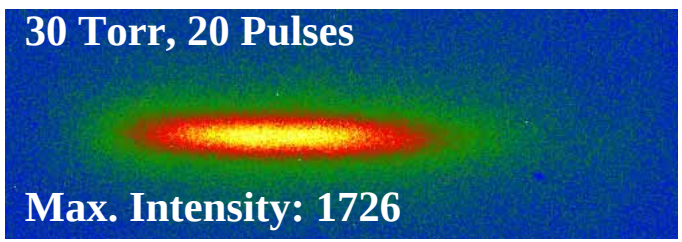
FWHM
L-0.95mm
B-184μm



FWHM
L-1.56 mm
B-166 μm

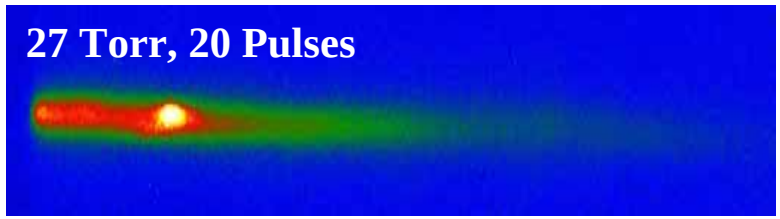


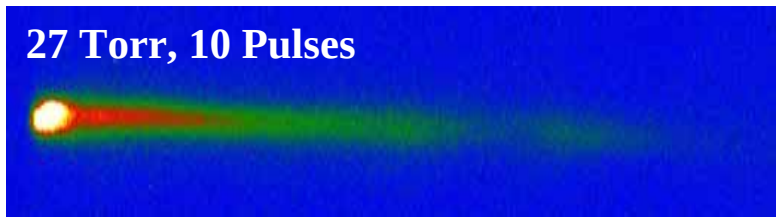
FWHM
L-1.39 mm
B-166 μm



FWHM
L-1.39 mm
B-215 μm

90 degree

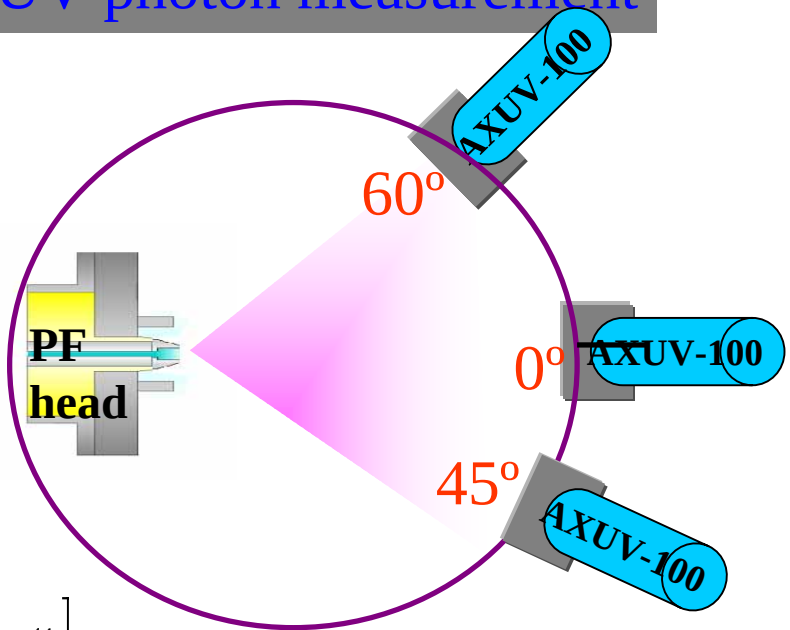


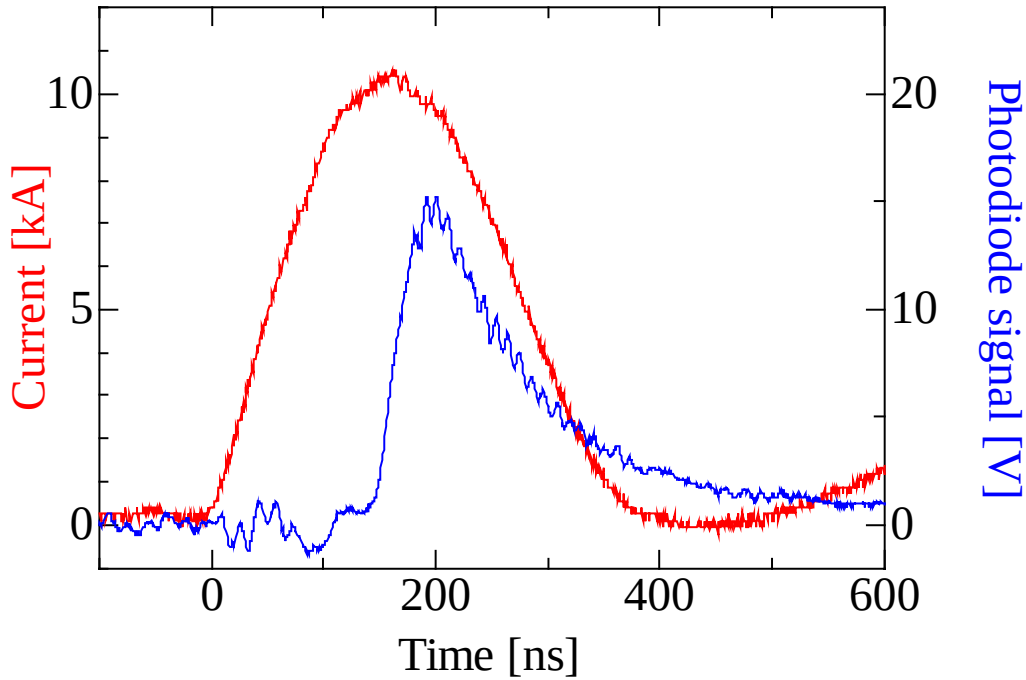


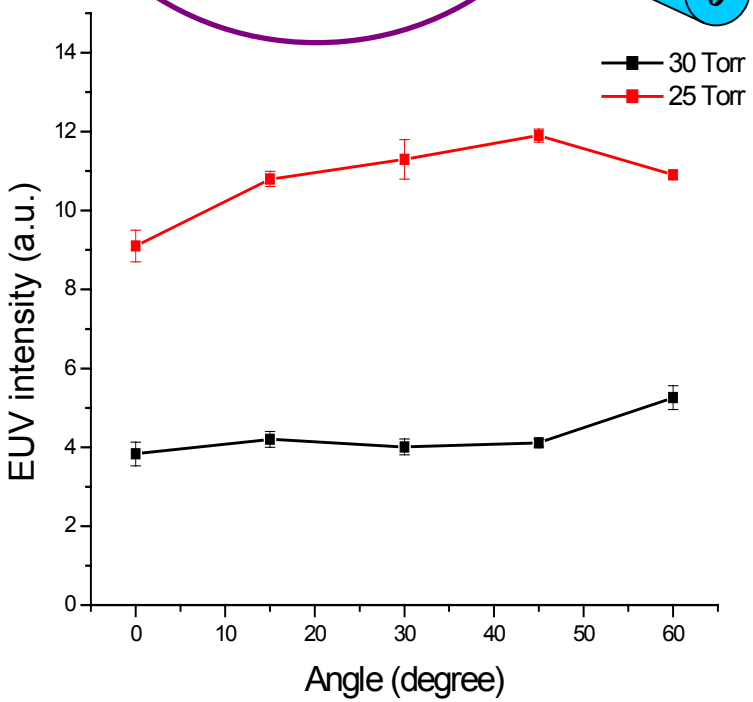
Error
B: ±12μm
L: >±30μm

- Maximum FWHM size: ~ 0.21×1.56 mm
- Positional stability: Maximum centroid displacement ~ 40 **μm**

EUV photon measurement

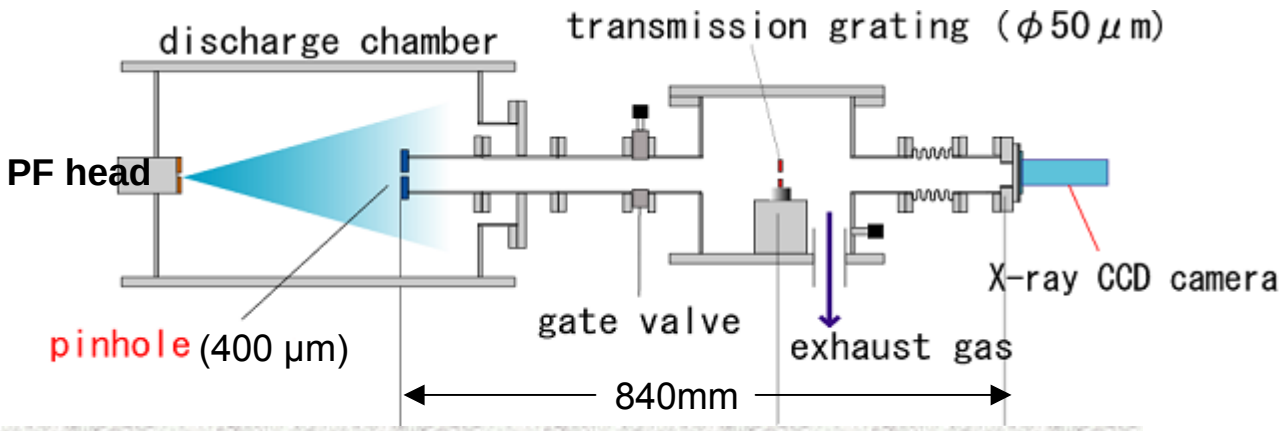




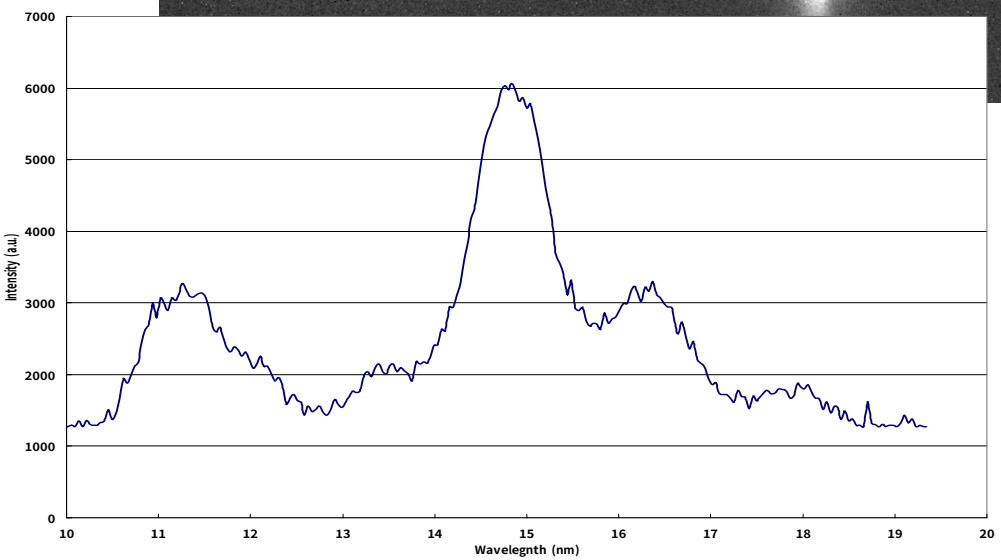


Angular variation of EUV intensity at different supply gas pressure

Transmission Grating Spectrometer



A typical spectrum taken at 27 Torr supply pressure integration of 100 pulses



Spectrum is indicative of Xe ionization stages VIII to XIII

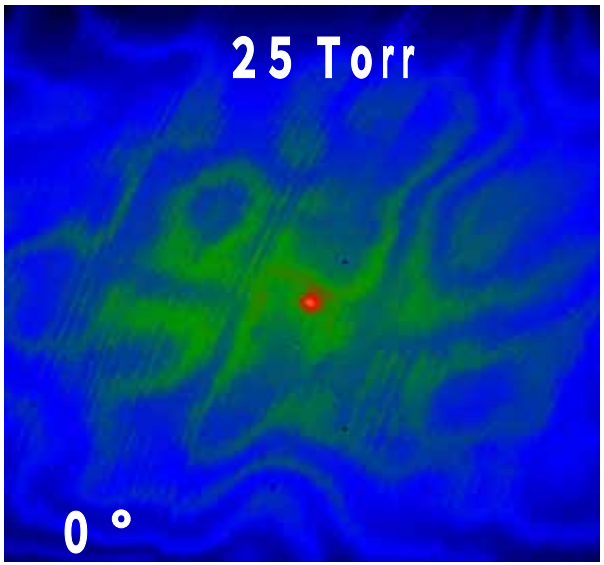
Conclusions

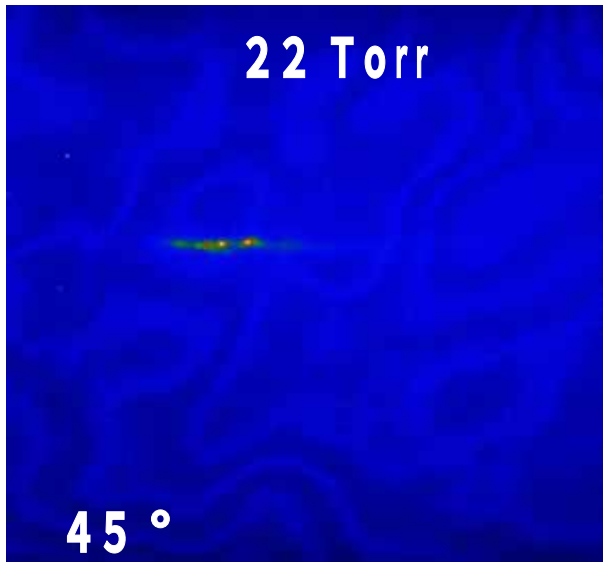
- Demonstration of the effective utilization of a low current pulse (of around 10 kA) to drive the plasma of MHPF discharge head so as to generate intense EUV radiation
- Visible light imaging confirms the occurrence of pinching
- EUV pinhole imaging provides dimension of EUV zone
- Transmission grating spectra shows emission mainly around 11 to 17 nm

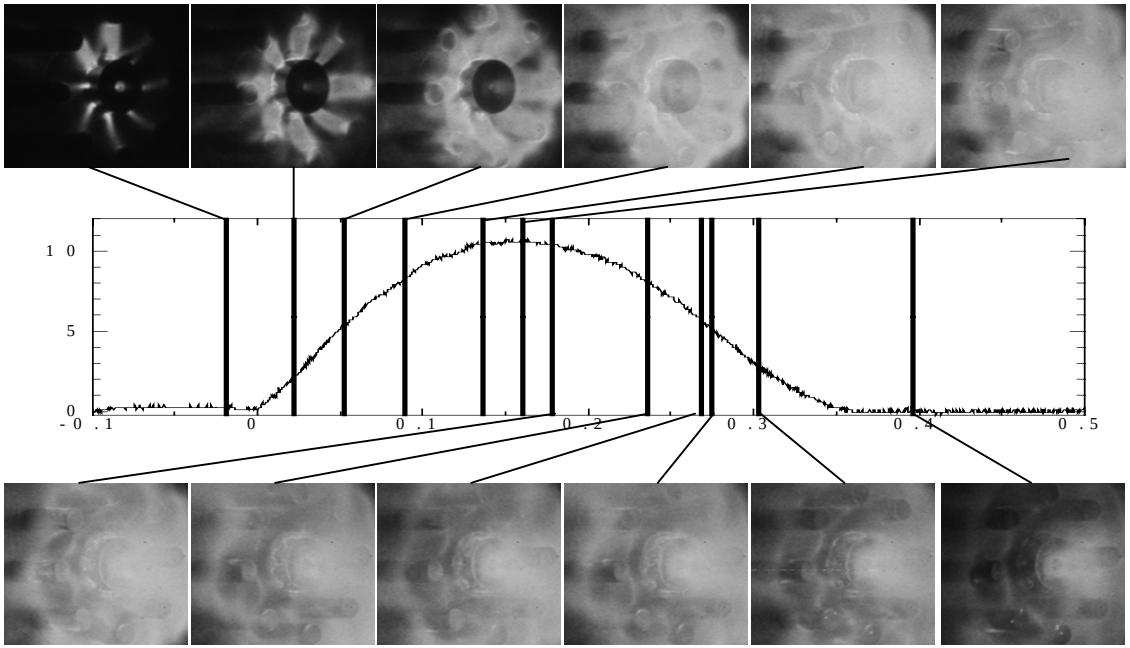
Thank you for your attenetion....

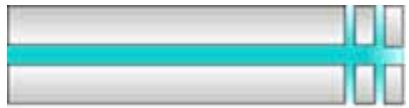
Thank you for your attenetion....

Saturation of CCD detectors at low supply pressure….

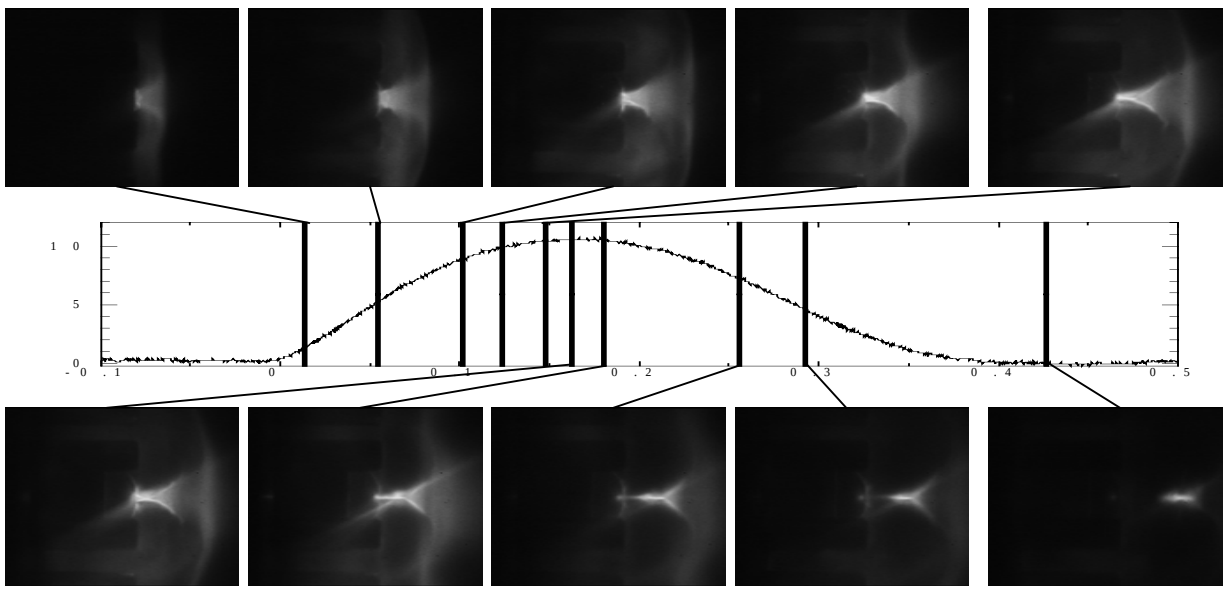


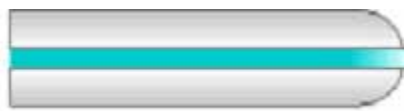






45 degree, Xe 30 Torr





90 degree, Xe 30 Torr

At Xe =0.1mbar/ 10P, r_0 = 5 mm and discharge current = 15 kA: v_p ~0.016 mm/nsec

At Xe =0.01mbar/ 1P, r_0 = 5 mm and discharge current = 15 kA: v_p ~0.05 mm/nsec

At Xe =0.1mbar/ 10P, r_0 = 3 mm and discharge current = 15 kA: v_p ~0.03 mm/nsec

After 150 nsec, plasma sheath moves around 2.5 mm

After 150 nsec, plasma sheath moves around 7.5 mm