Pulsed Power Laboratory
Kumamoto University

2nd EUVL Symposium
Antwerp, Belgium
09/30～10/1, 2003

Z-pinch EUV Source Driven by 100 ns Current Pulses*

Sunao KATSUKI, Akihiro KIMURA, Akira HONGO,
Takashi SAKUGAWA, Hidenori AKIYAMA

Department of Electrical and Computer Engineering, Kumamoto University,
39-1 Kurokami 2chome, Kumamoto 860-8555, Japan
Email : katsuki@eecs.kumamoto-u.ac.jp

* This research has been supported by NEDO.

Abstract

This paper includes mainly the following two topics,

(1) Z-pinch Xe plasmas driven by very short current pulses.

Current pulses with 85 ns or 140 ns duration and 20 kA amplitude were delivered to the z-pinch chamber (3 mmØ, 5 mmL). An EUV radiation from the z-pinch plasma was characterized, which is based on the temporal behavior of EUV intensity and the pinhole images. Two maximum EUV radiation, which are sensitive to the Xe flow rate and the discharge current, occur. The 1st radiation is relatively short duration while the 2nd radiation lasts as long as the 1st period of the current flows. EUV source size due to the 1st radiation is approximately 300 μm, that is half of one due to the 2nd radiation.

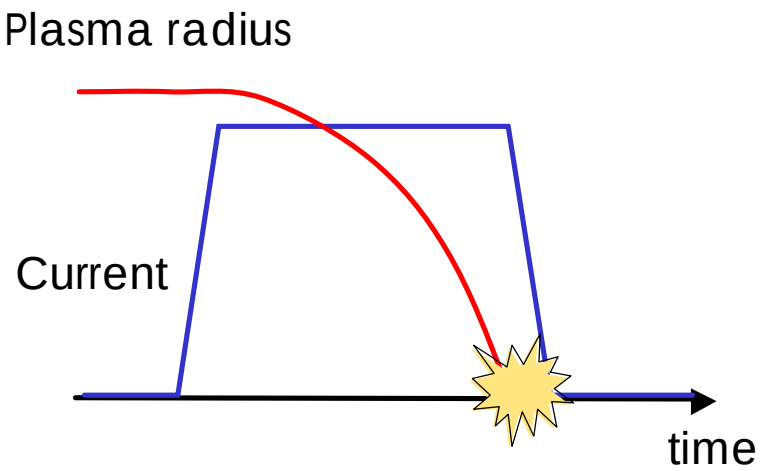
(2) Applying an external magnetic field B_z to the z-pinch plasma

The magnetic field delays the pinching time and tends to stabilize the 1st EUV radiation in terms of the intensity and the spatial distribution. However, there was no evidence that the magnetic field influences the 2nd EUV radiation.

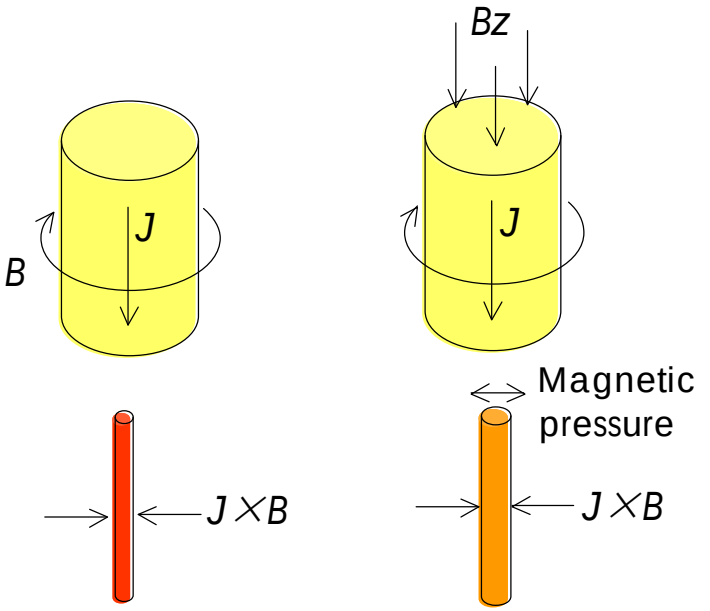
Also, the modification of the driving circuit is presented in this paper.

Concepts

- Minimize the electrical energy
  → current pulse shaping

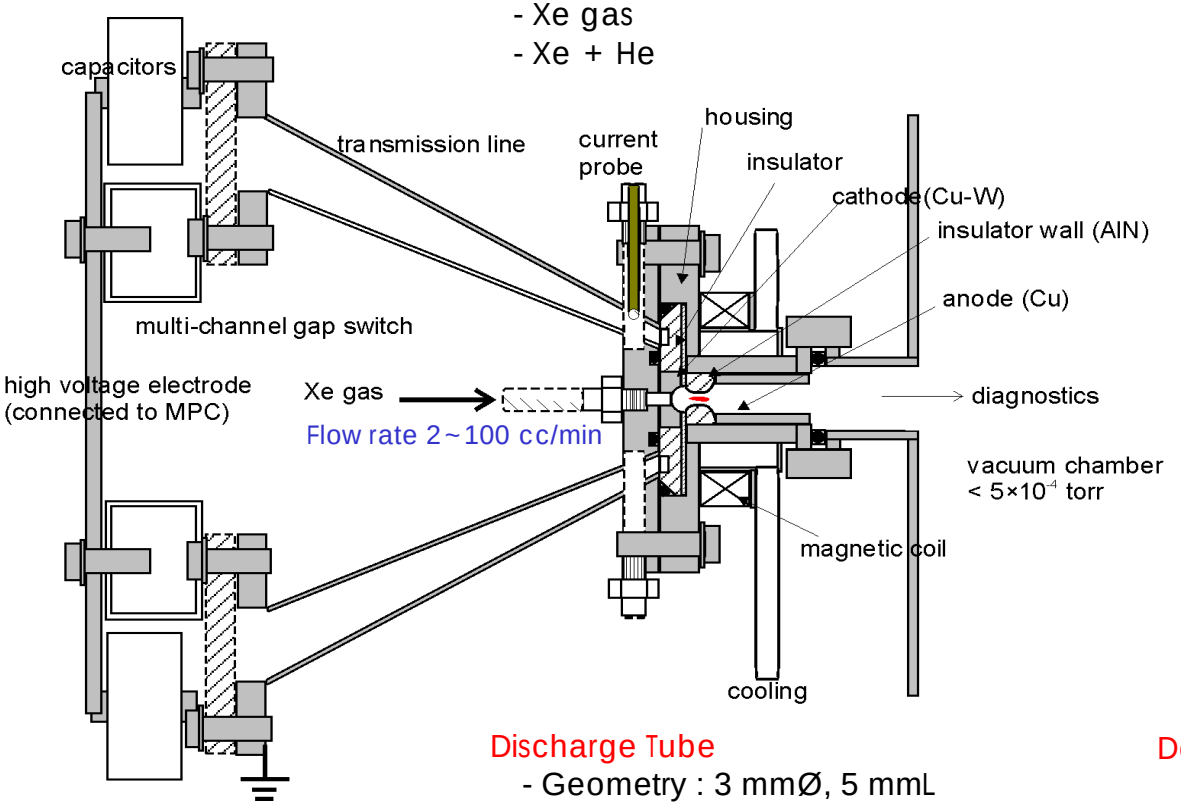


- Controlling plasma temperature
  → current pulse shaping
  → external magnetic field

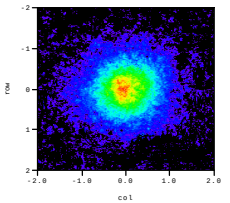


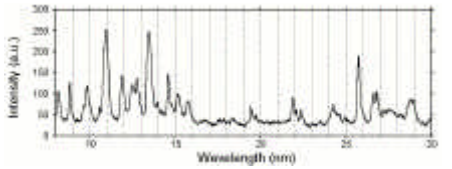
Z-pinch and Driving Circuit

Target
- Xe gas
- Xe + He



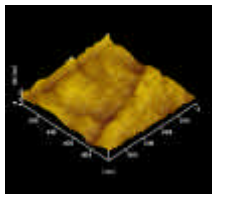
EUV Diagnostics
- Temporal behavior
  PIN photo diode +Zr filter
- Energy (EMON, AIXUV)
- Spectra
  2400 l/mm
- Spatial distribution
  pinhole camera (50 μmØ)
- angular distribution



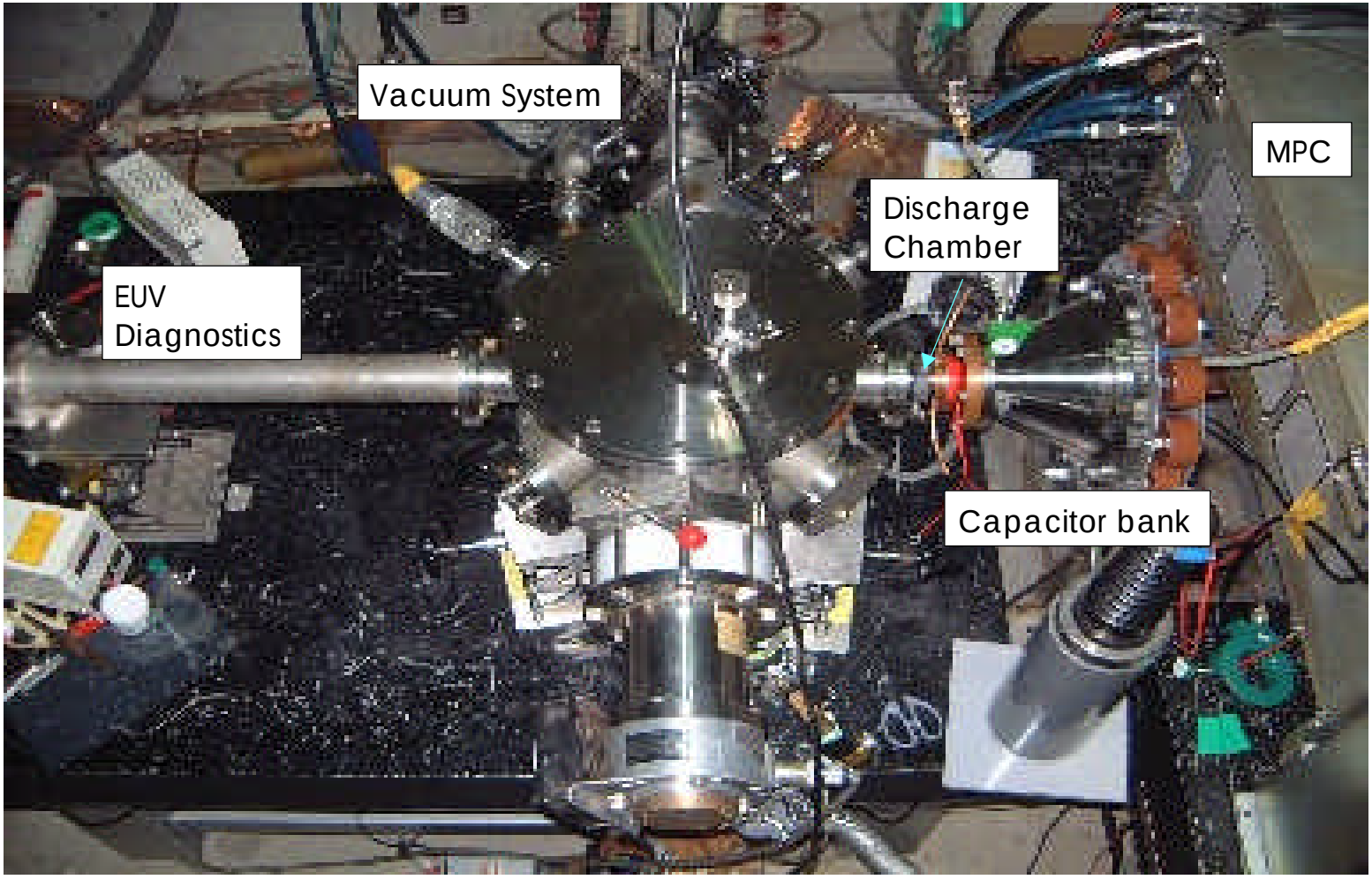


Discharge Tube
- Geometry : 3 mmØ, 5 mmL
- Insulator : AlN
- Electrodes : Cu (Anode)
  Cu-W (Cathode)

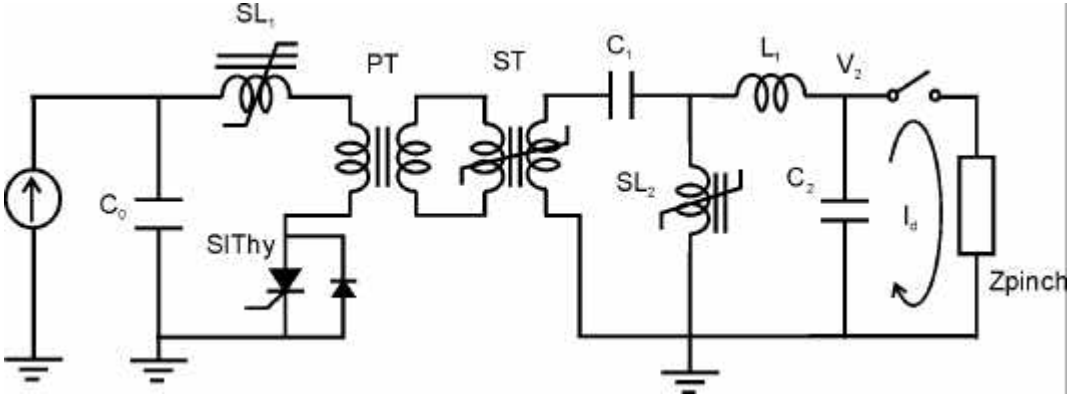
Debris
- EPMA
- SEM
- FEM



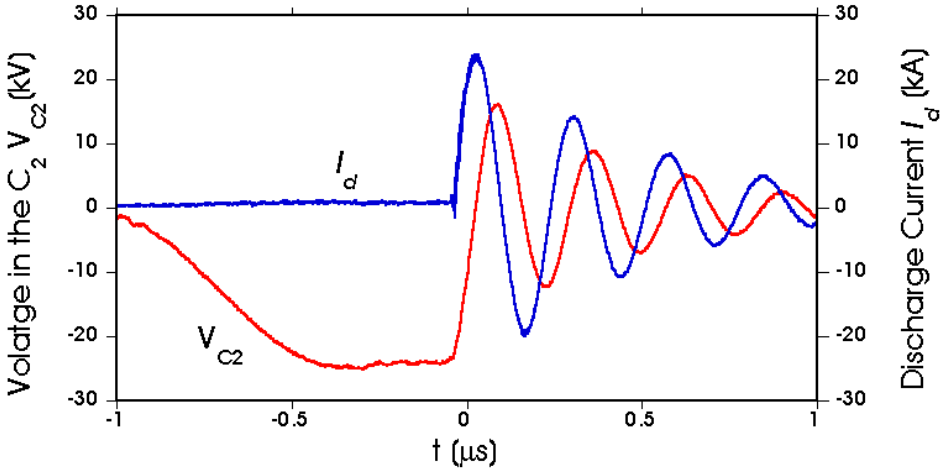
Overview of Experimental Setup



Equivalent Circuit and Typical Waveforms



Magnetic pulse compression circuit (MPC)



Circuit parameters

C_0 = 3.5 µF
C_1 = 42 nF
C_2 = 50 nF, 24 nF
PT 1:3
ST 1:3

I_d < 30 kA
E_d < 20 J/pulse
REP. Rate < 200 Hz

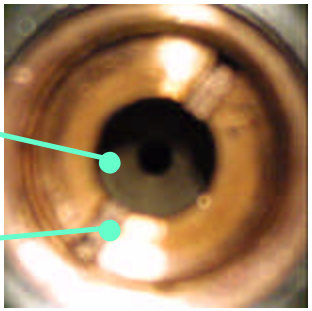
T/2 = 140 ns, 85 ns
L = 20 nH
R = R_0 + R_Z
0.08 + 0.09 O

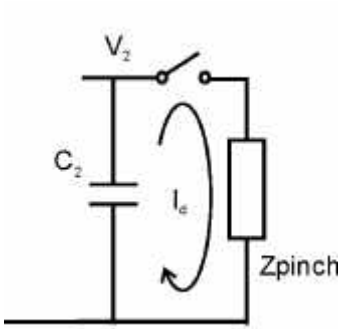
Pre-ionization

Discharge tube

Ceramic tube
(2 mmØ)

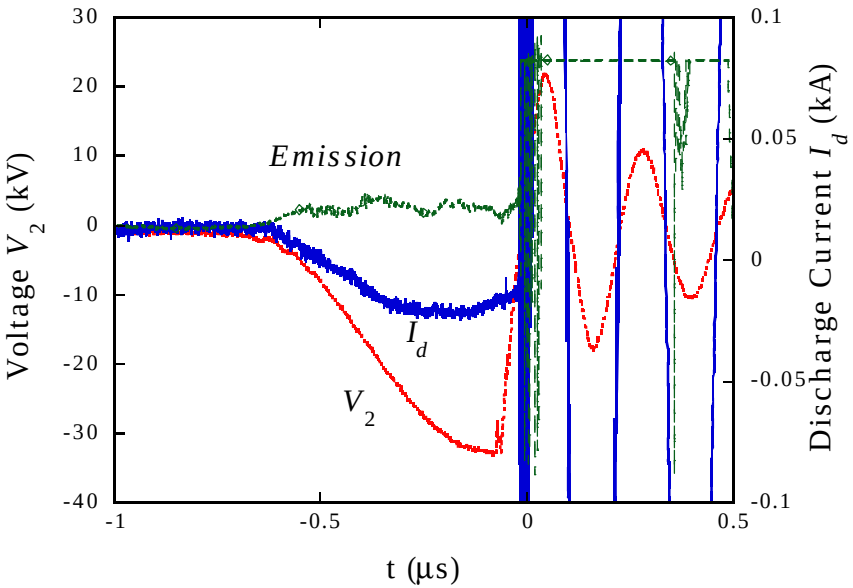
Ring anode



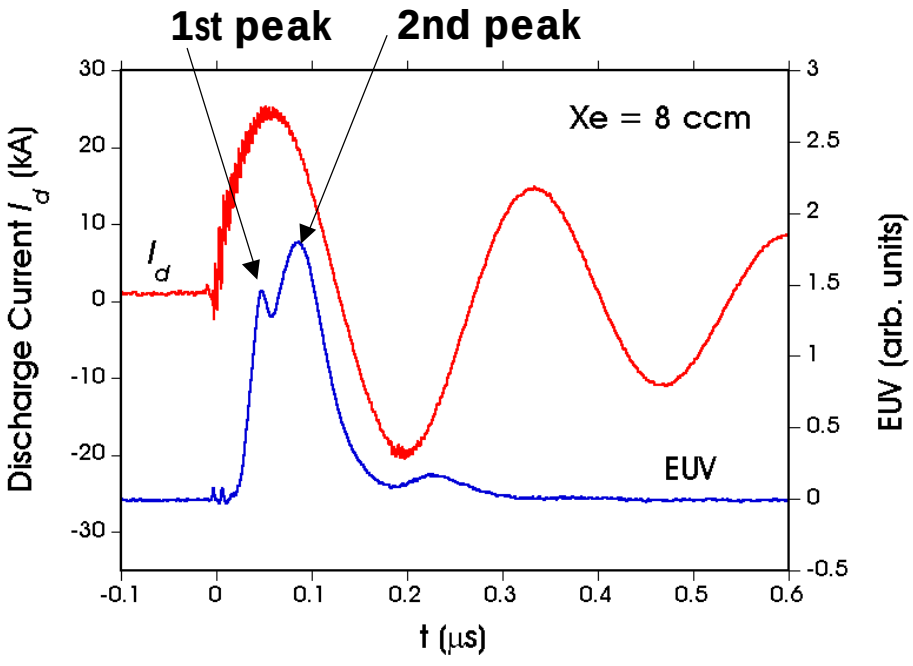


Pre-ionization

Main discharge

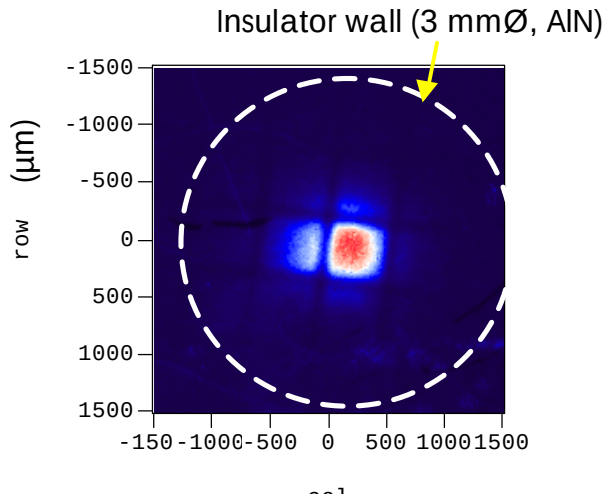


Typical EUV Radiation (T/2 = 140 ns)



Discharge current and EUV signal

T/2 = 140 ns, Ip = 23.5 kA
EUV signal: Hamamatsu PIN diode, 1.5 GHz
Cover glass was removed.
Luxel Zr Filter (Zr on mesh)

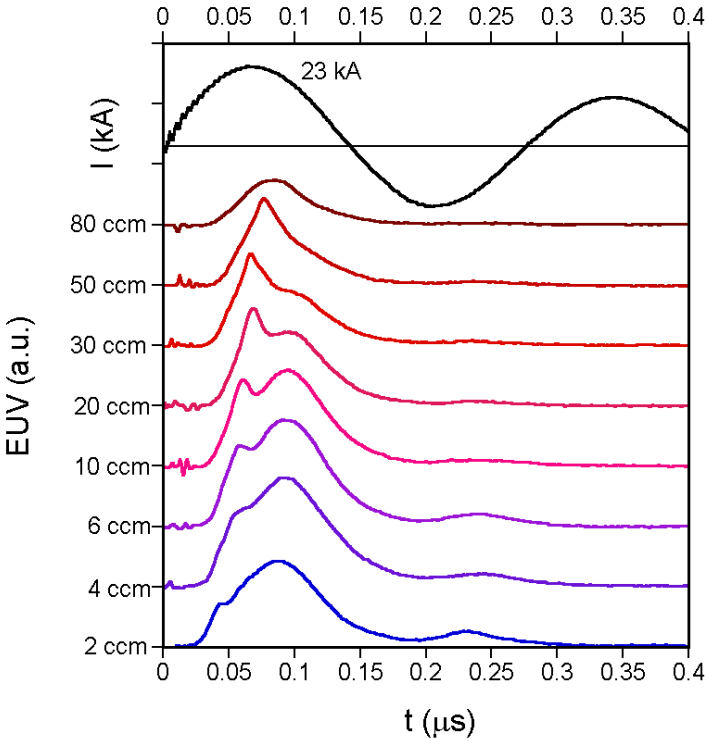


EUV pinhole image

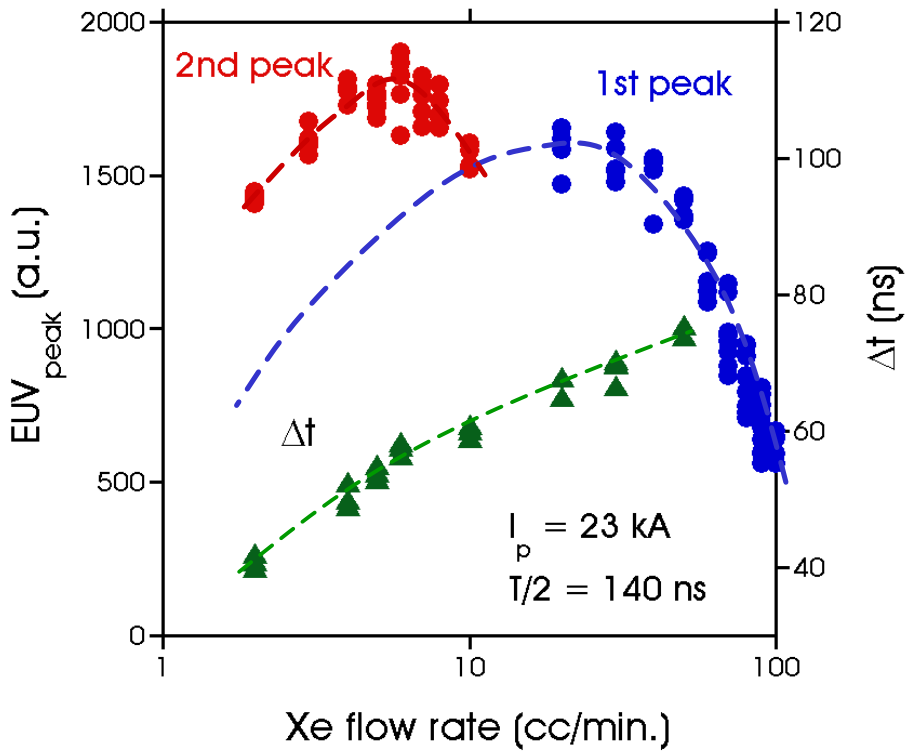
pinhole 100 μm, mag. ratio 5 (18 cm: 90 cm)

- Two peaks occur in EUV signal. The first peak is more sharp.
- EUV is still irradiated even when the current crosses zero.
- Only the first current pulse generates the EUV radiation.

EUV Radiation Dependent on Xe Flow Rate (T/2 = 140 ns)

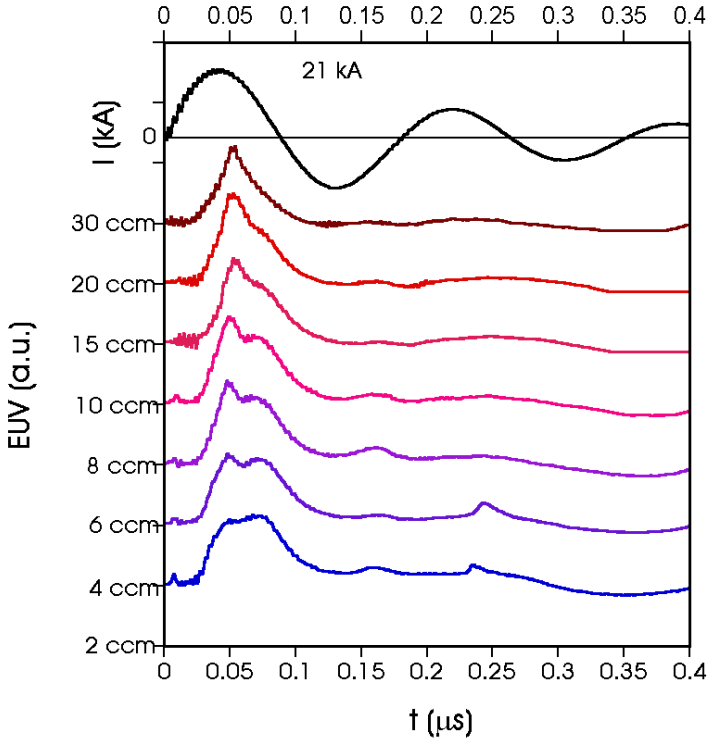


Discharge current and EUV signals for different Xe flow rate

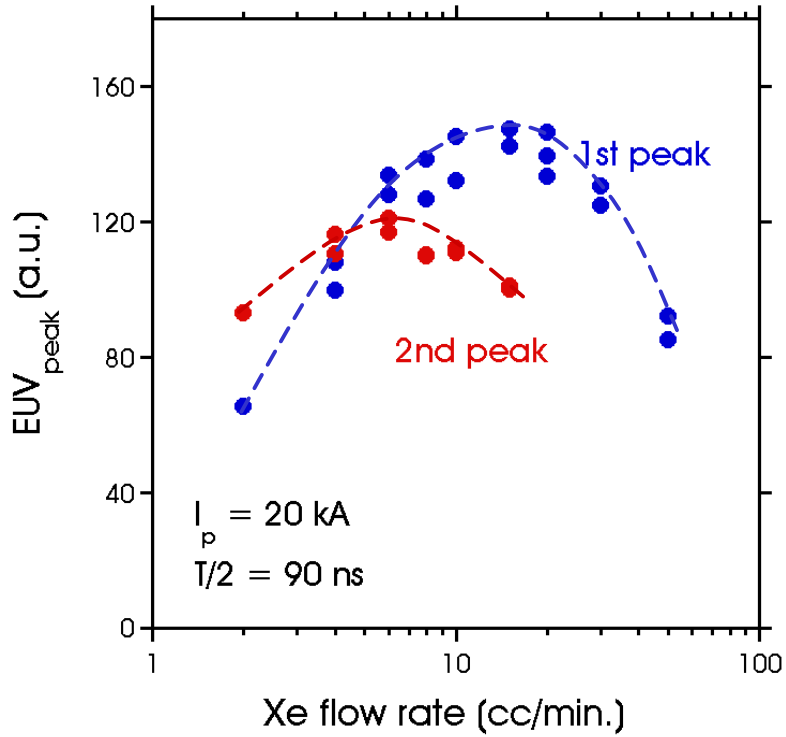


Intensity of EUV due to the 1st 1nd 2nd peaks and the time when 1st peak occurs as a function of Xe flow rate

EUV Radiation Dependent on Xe Flow Rate (T/2 = 85 ns)

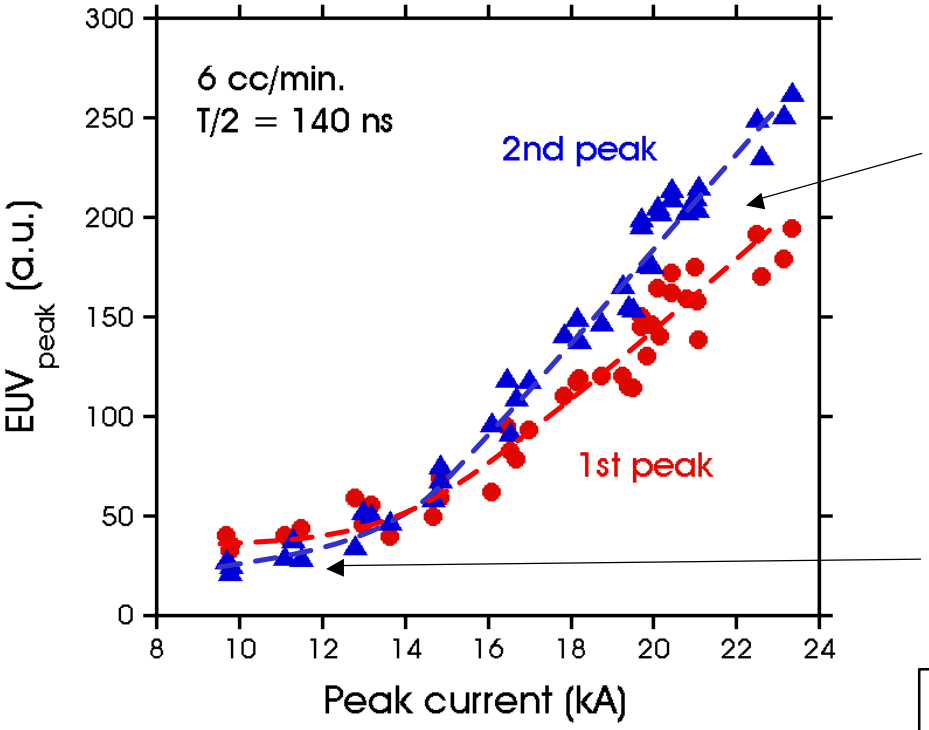


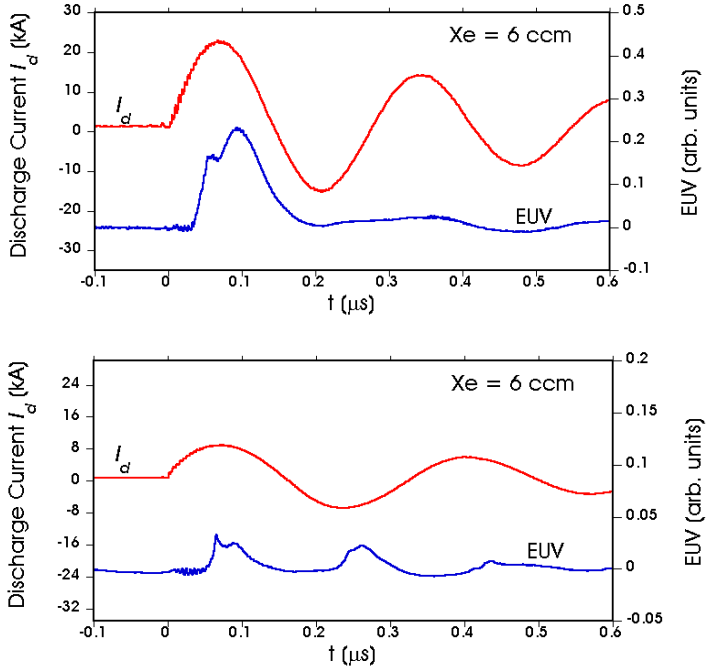
Discharge current and EUV signals for different Xe flow rate



Intensity of EUV due to the 1st 1nd 2nd peaks and the time when 1st peak occurs as a function of Xe flow rate

Dependence on Discharge Current

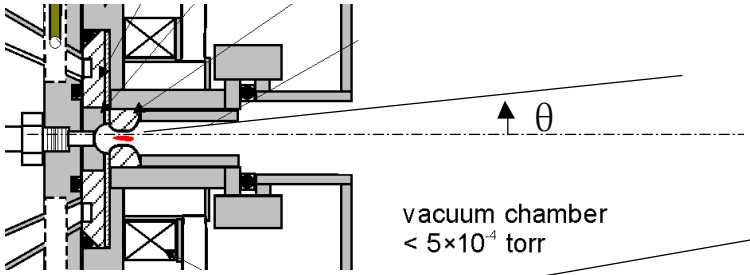


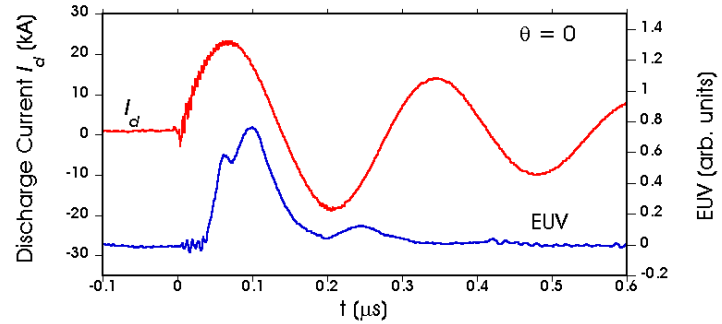


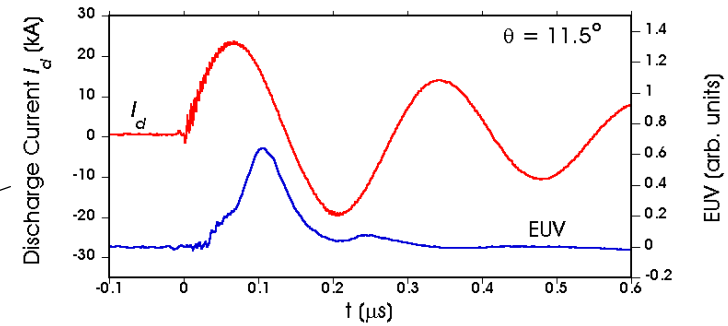
EUV intensity
as a function of the discharge current

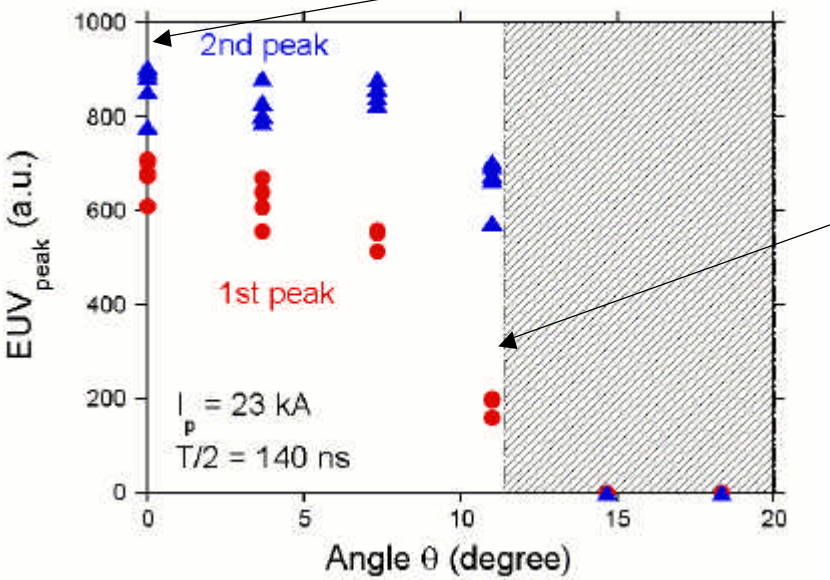
- With small current, the 1st peak is more intense than the 2nd peak. Larger current encourages the 2nd peak.
- EUV radiation occurs in every current pulses.

EUV Radiation Angular Distribution









◆ Possibility:

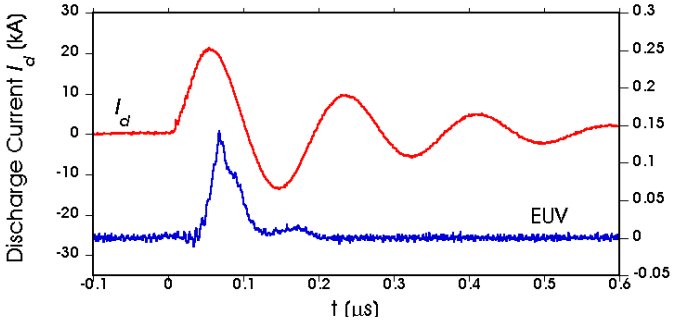
→ Radiation in 1st peak is directional, but that in 2nd peak is uniformly irradiated.

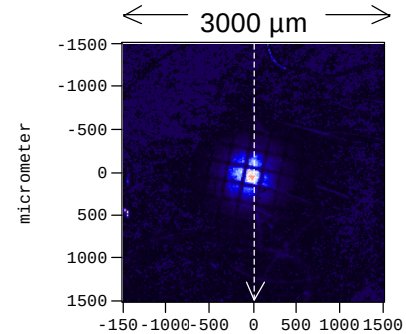
or

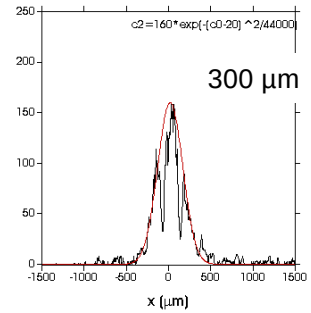
→ Position of radiation source is different between 1st and 2nd peaks.

Source Size due to 1st and 2nd radiation

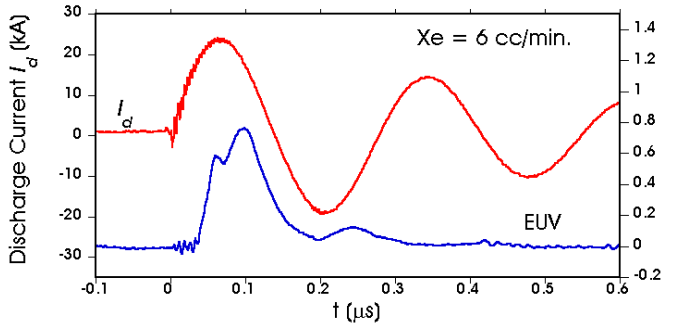
1st domain
T/2 = 85 ns
Xe = 20 cc/min

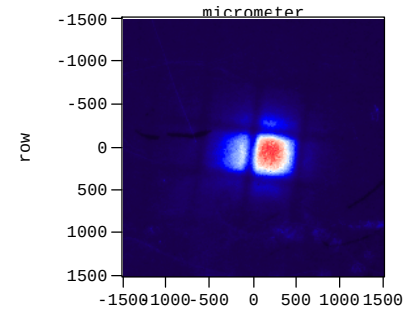


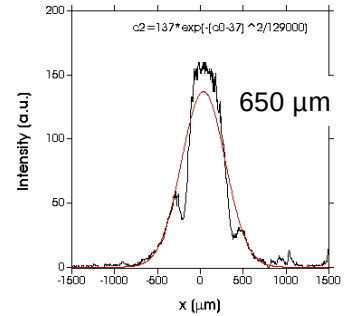




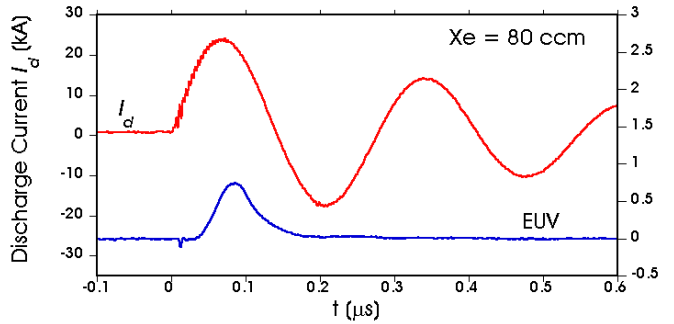
1st + 2nd
T/2 = 140 ns
Xe = 6 cc/min

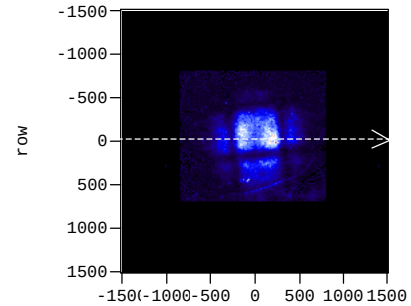


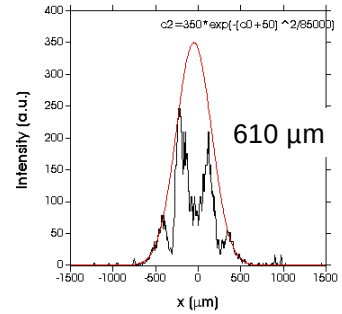




?? 2nd
T/2 = 140 ns
Xe = 80 cc/min



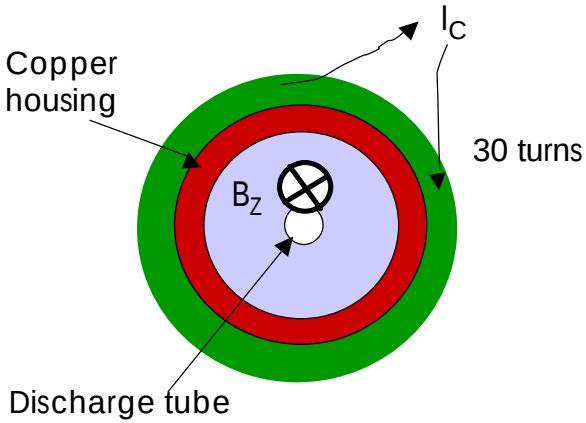


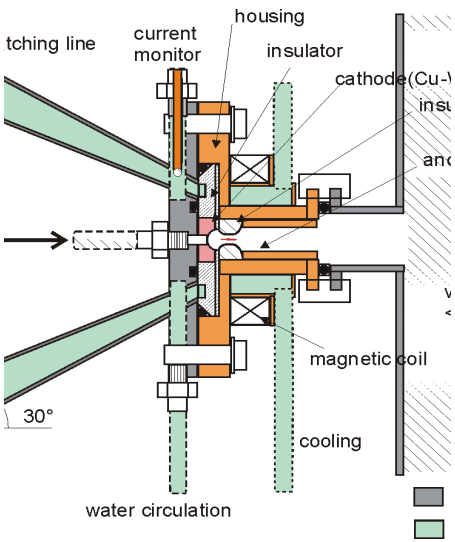


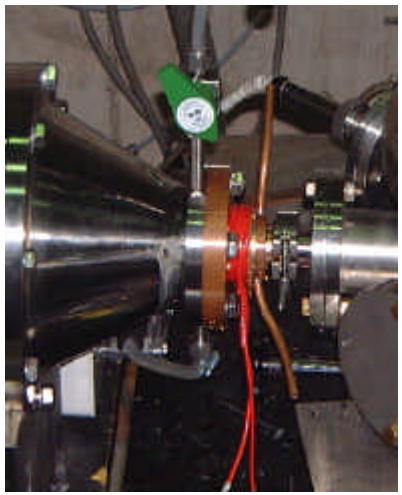
Longitudinal Magnetic Field B_z

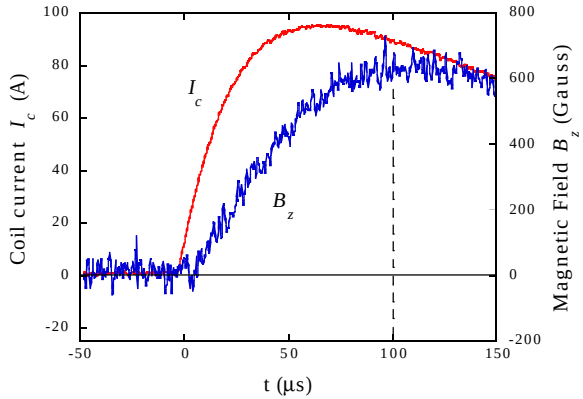
Purpose:

- **To control the plasma temperature**
  → spectrum optimization
- **To stabilize the pinched plasma**
  → spatial and temporal stability





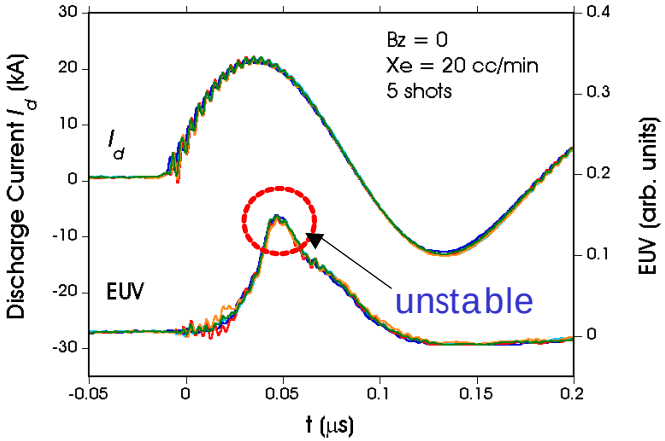


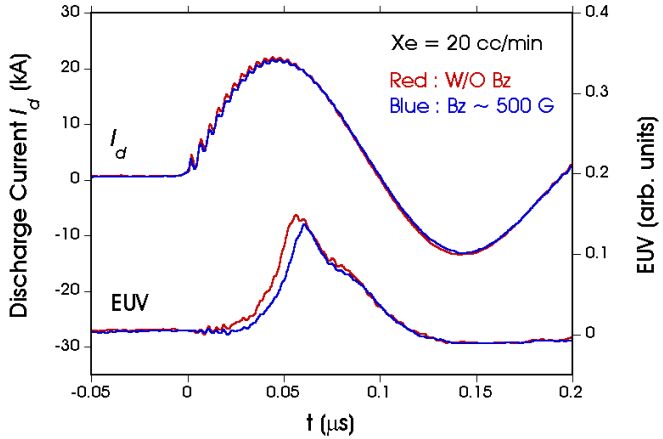


Penetration of B_z into the discharge tube

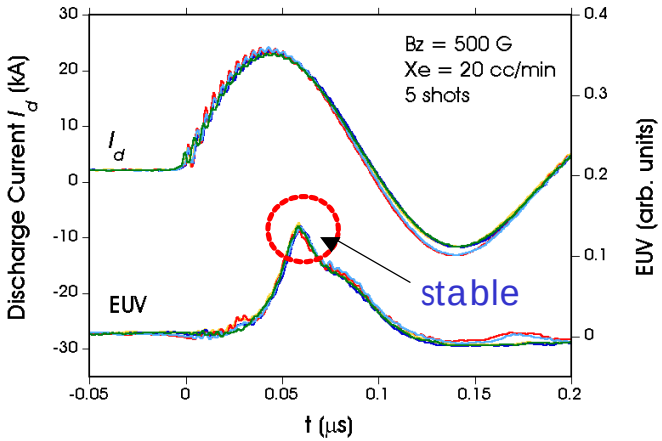
Effect of B_z - EUV output

B_z = 0
20 cc/min.
5 shots





B_z = 500 G
20 cc/min.
5 shots



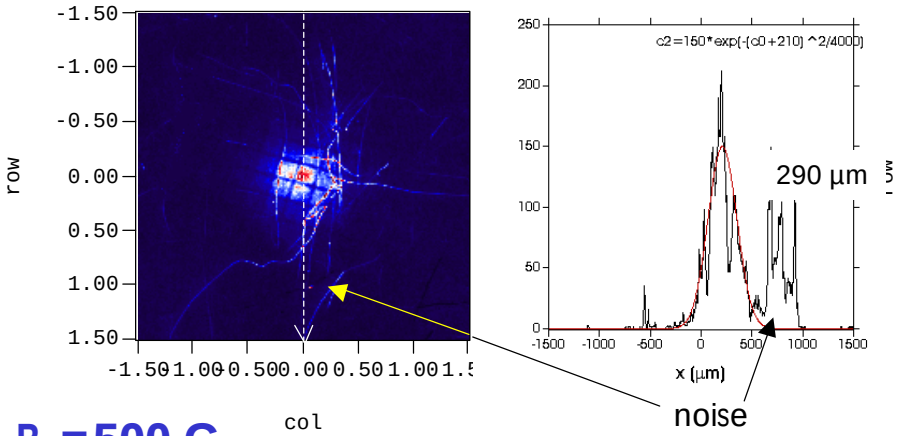
- ◆ The longitudinal magnetic field delays the 1st peak of EUV radiation.
  → Plasma might be compressed softly.
  → Plasma temperature is expected to decrease.
- ★ Spectroscopic investigation is being performed now!!
- ◆ The magnetic field does not give any influence on the 2nd peak.

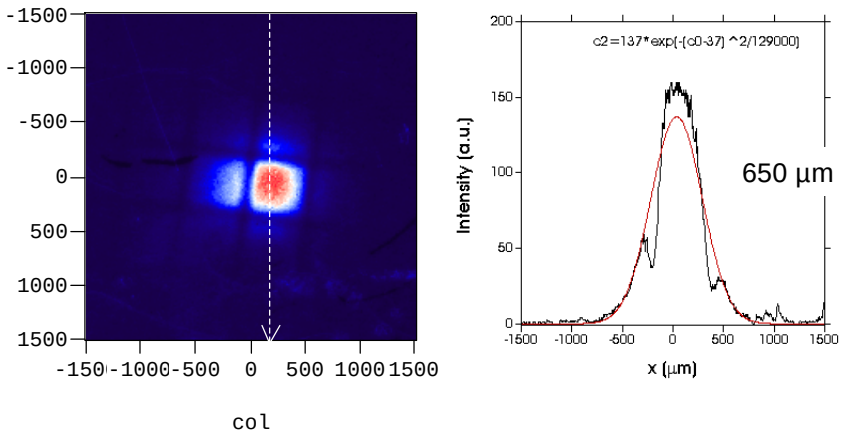
Effect of B_z - EUV Source Profile

B_z = 0

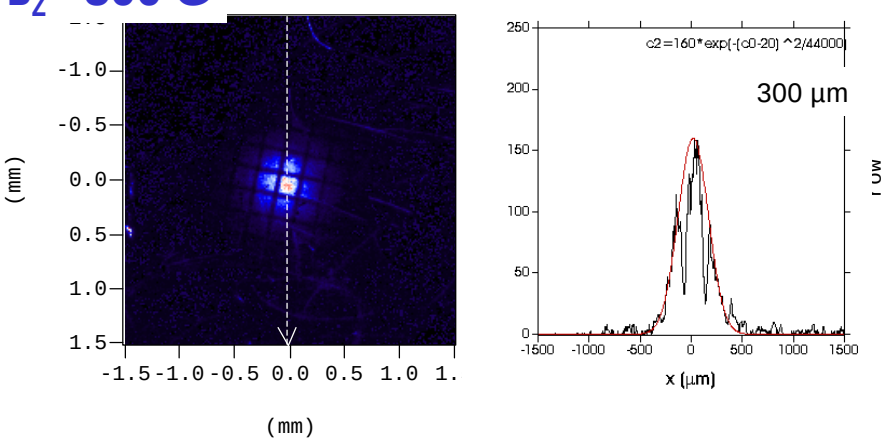
T/2 = 85 ns (1st peak)

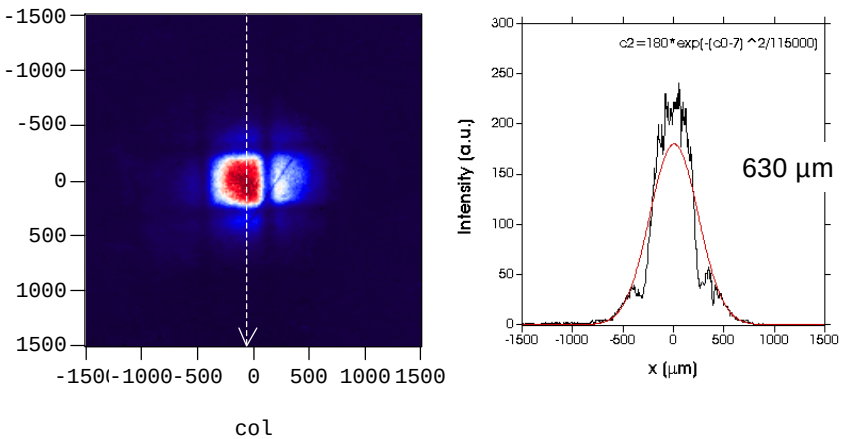
T/2 = 140 ns (1st and 2nd)





B_z=500 G





Summary

1. Z-pinch Xe plasmas were driven by 85 ns or 140 ns duration current pulses.

(1) Two maximum EUV radiations occur. Smaller Xe flow rate makes larger intensity in the 2nd radiation. Current with a larger amplitude and a longer duration encourage the 2nd radiation.

(2) EUV radiation angle distribution is different between the 1st and the 2nd radiations.

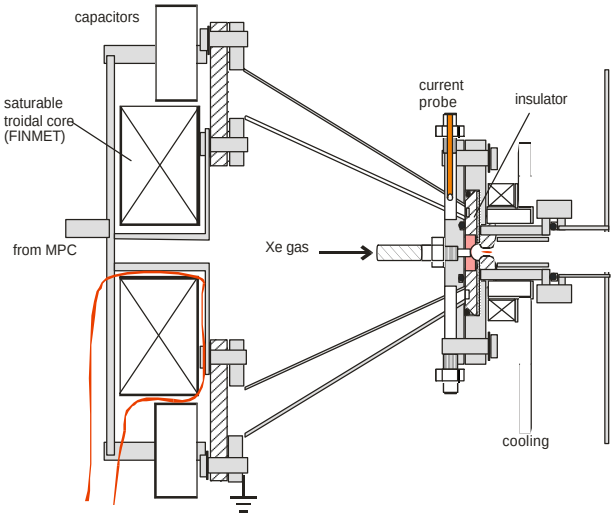
(3) EUV source size (FWHM) due to the 1st radiation is 300 μm, which is smaller than half of that due to the 2nd radiation.

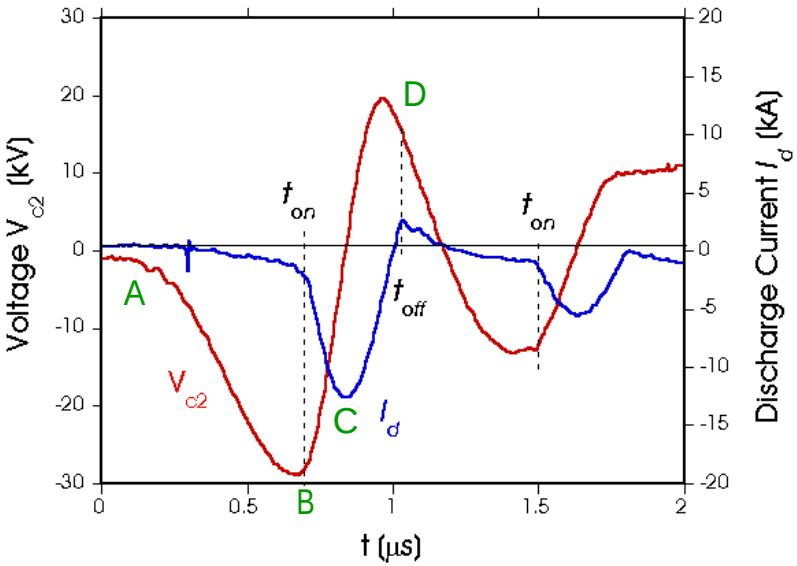
2. The longitude magnetic field (~500 G) was applied to the z-pinch plasma.

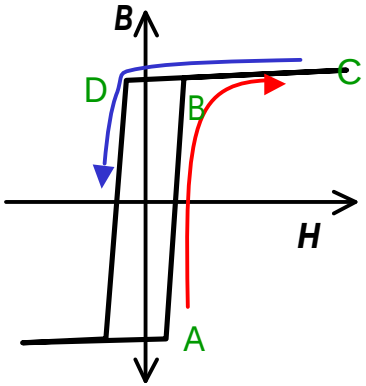
(1) The magnetic field delays the pinching time and tends to stabilize the 1st EUV radiation in terms of the intensity and the spatial distribution.

(2) There was no evidence that the magnetic field influences the 2nd EUV radiation.

Single Pulse – Magnetic Switch Installation



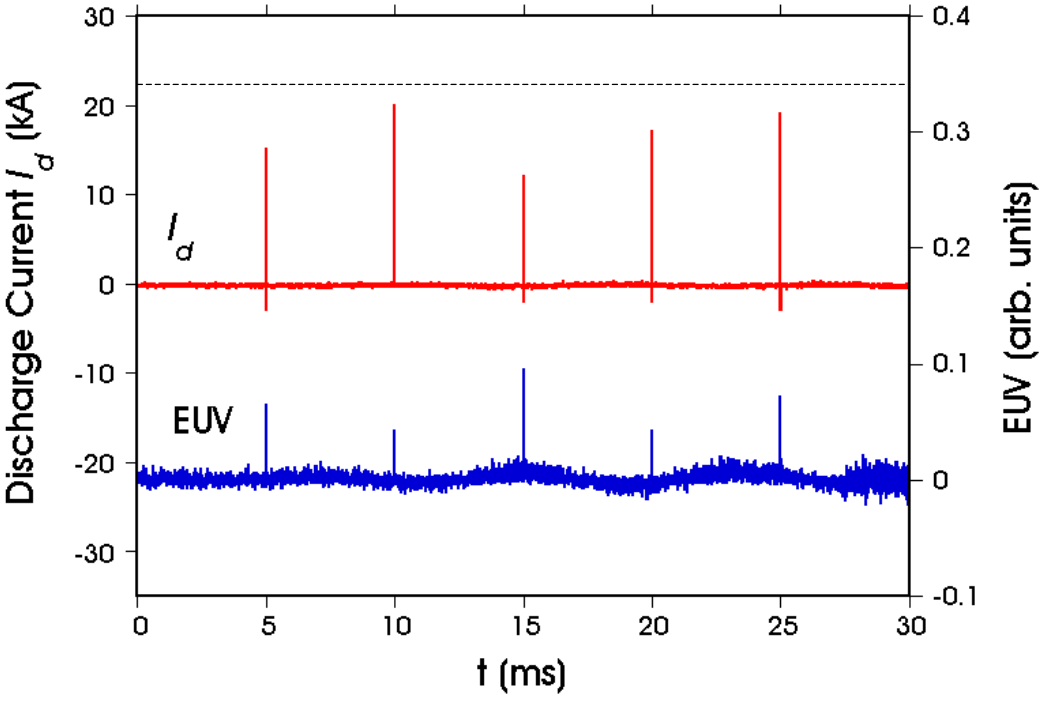




Typical operation of the circuit with the magnetic switch

◆ Energy recovery circuit is needed.

Repetitive Operation（200 pps, burst）



Current pulses and EUV radiation
200 pps, 10 s
Values of the each pulses are not correct.