Radiation Characteristics of a Capillary Z-Pinch EUV Source*

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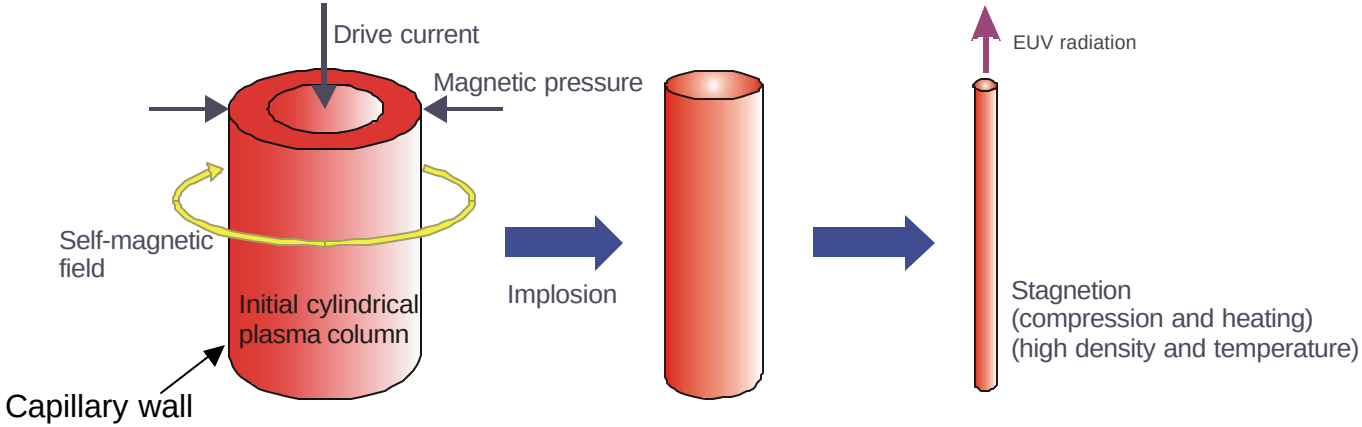
Overview

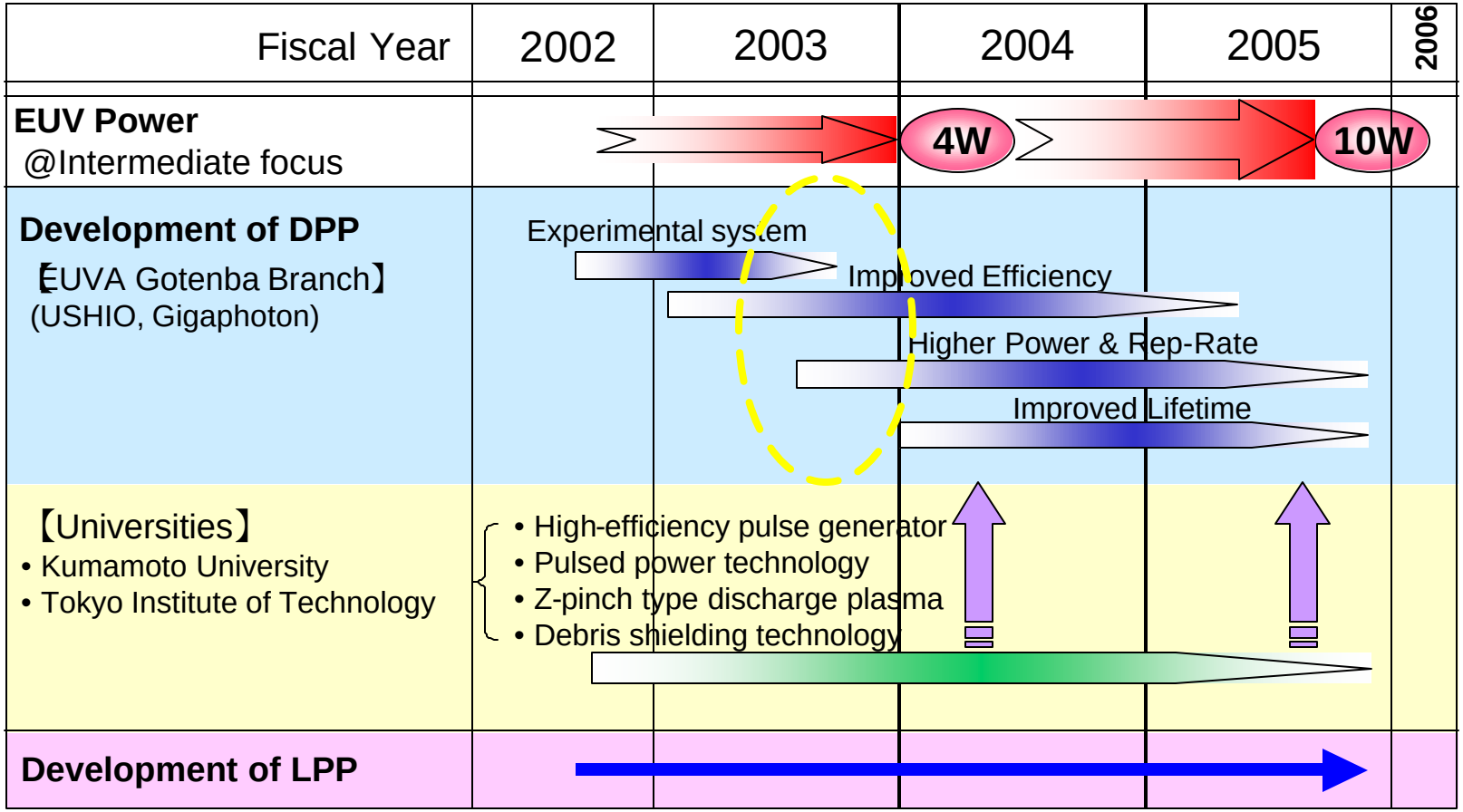
1. Schedule of DPP source development in EUVA/Gotenba Lab.
2. “D-2” (prototype): capillary Z-pinch discharge head
3. “G-2” (prototype): 2-kHz pulsed power generator
4. Diagnostics system: EUV energy, spectrum, radiation profile
5. Experimental results: low and high rep-rate
6. Summary of latest achievement

“Cartoon” of Z-pinch

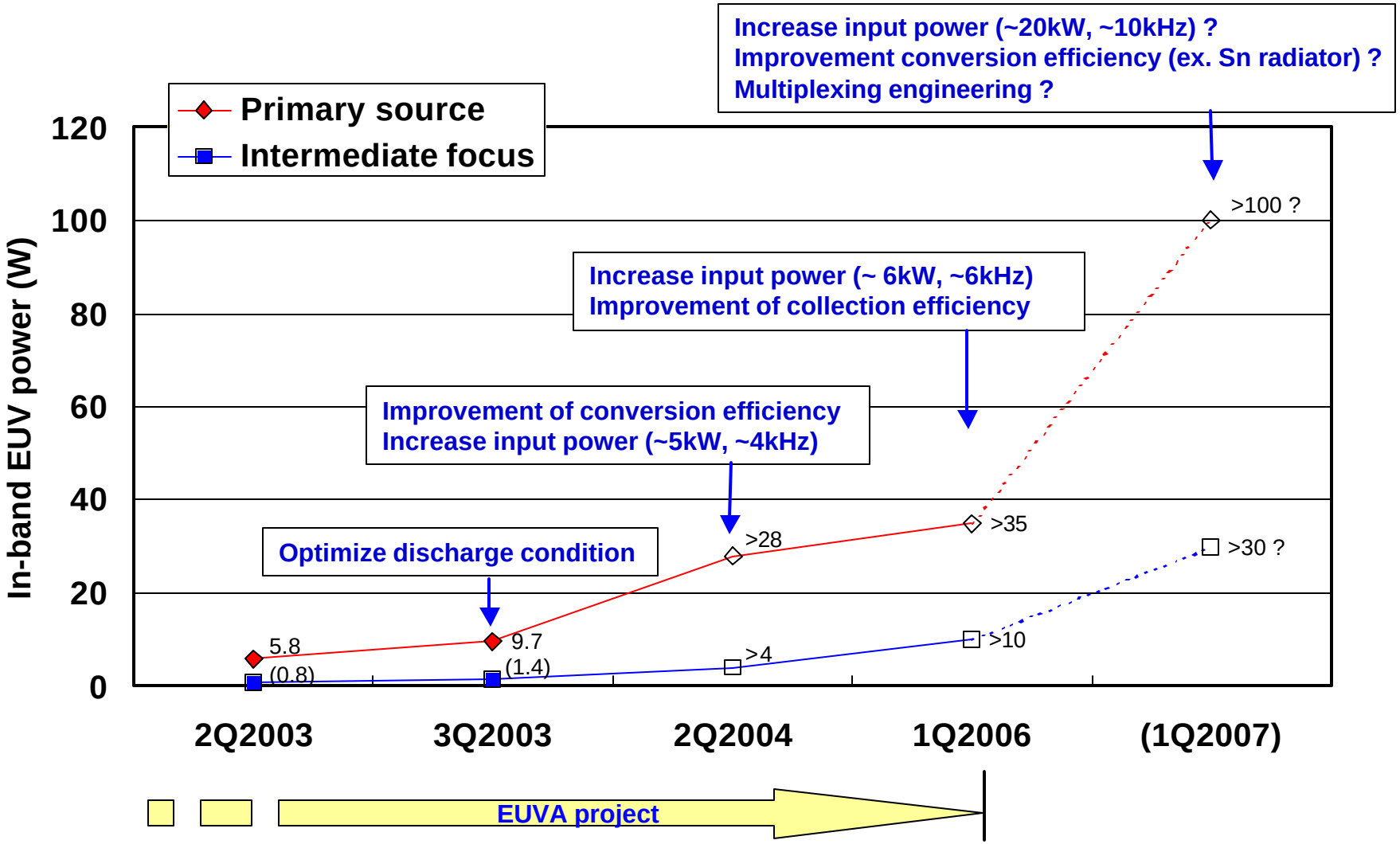


DPP source R&D plan of EUVA

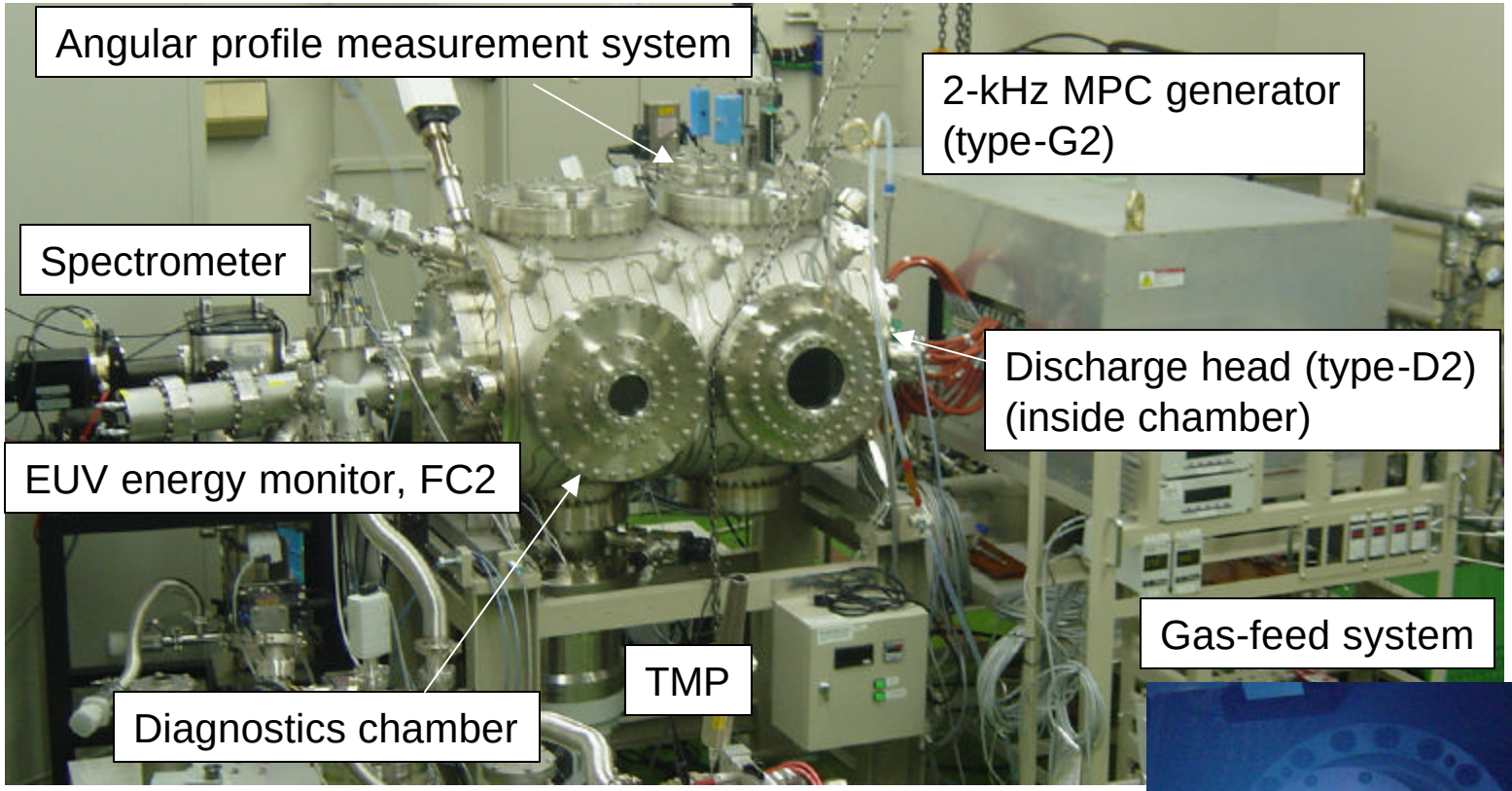
EUVA project: 4-W source and 10-W source are to be developed in fiscal year 2003 and 2005.

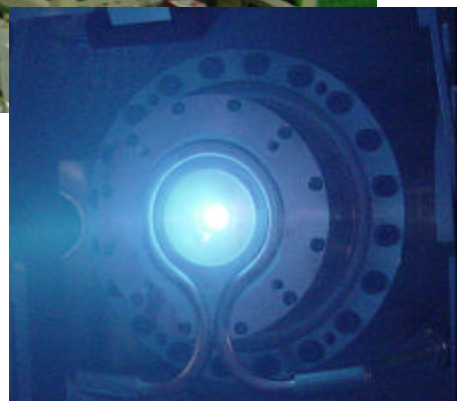


DPP source power scaling



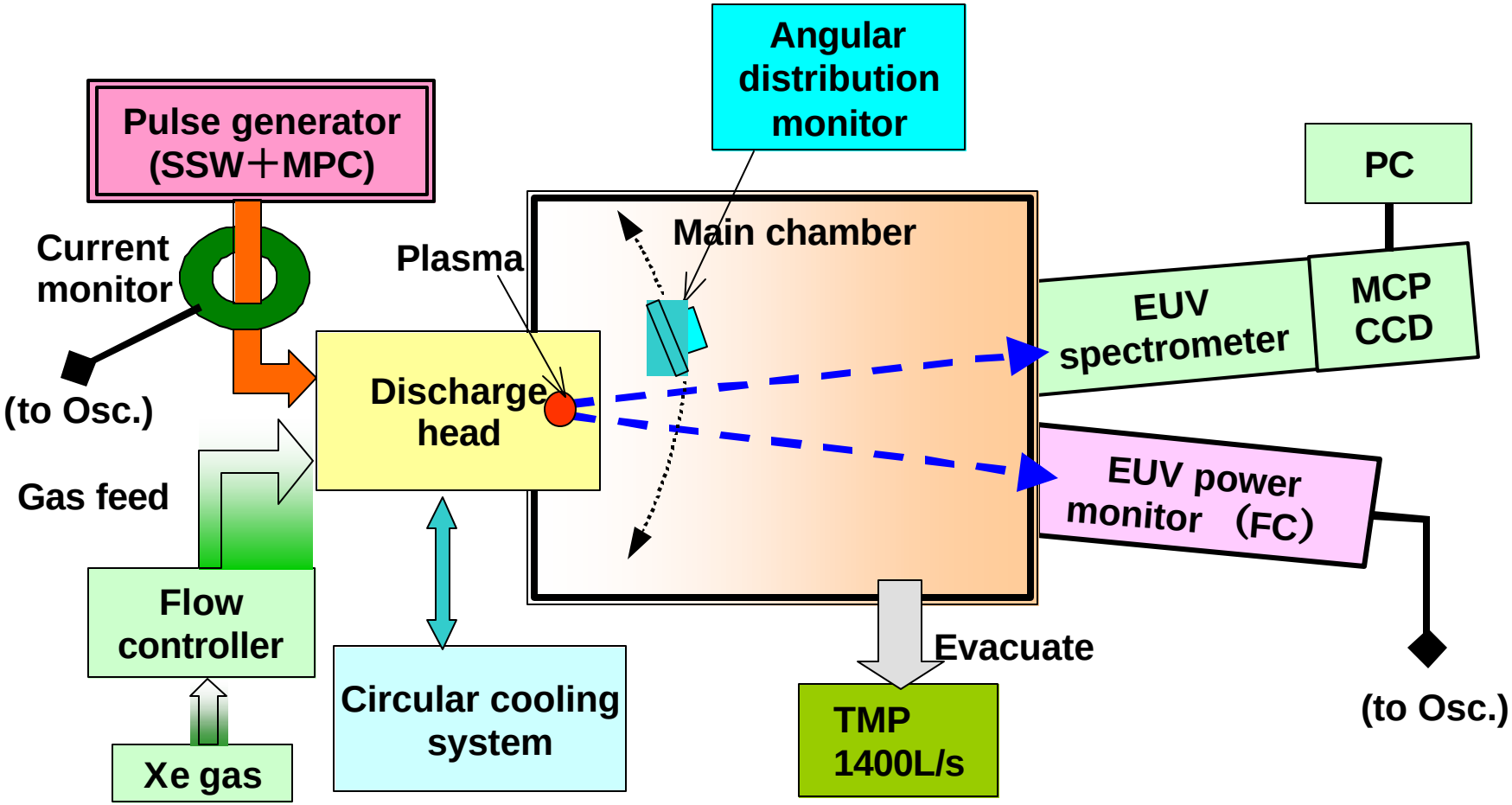
Picture of experimental test stand (including G2, D2)



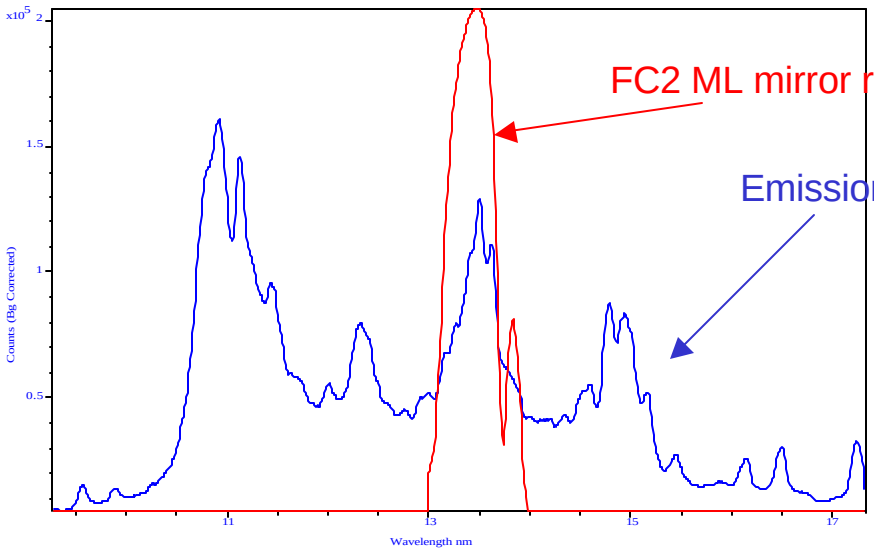


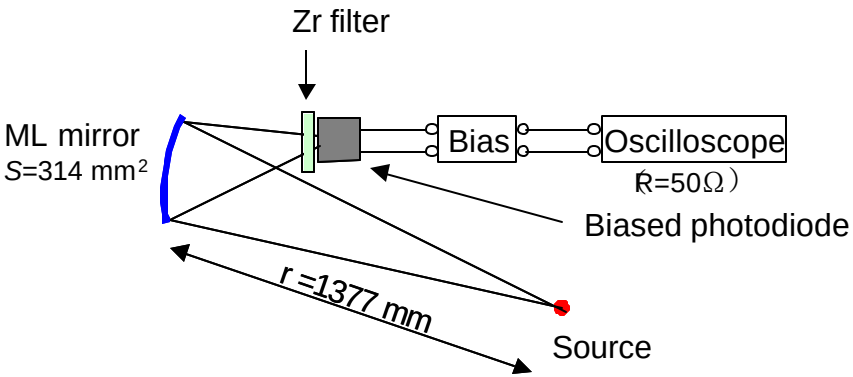
Top: experimental test stand
Right: visible picture of discharge

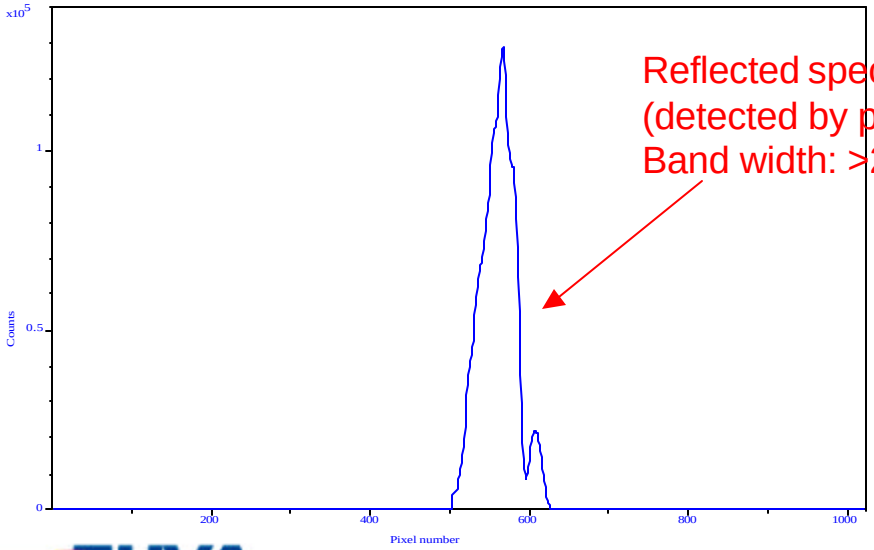
Diagnostics system arrangement



In-band EUV energy measurement

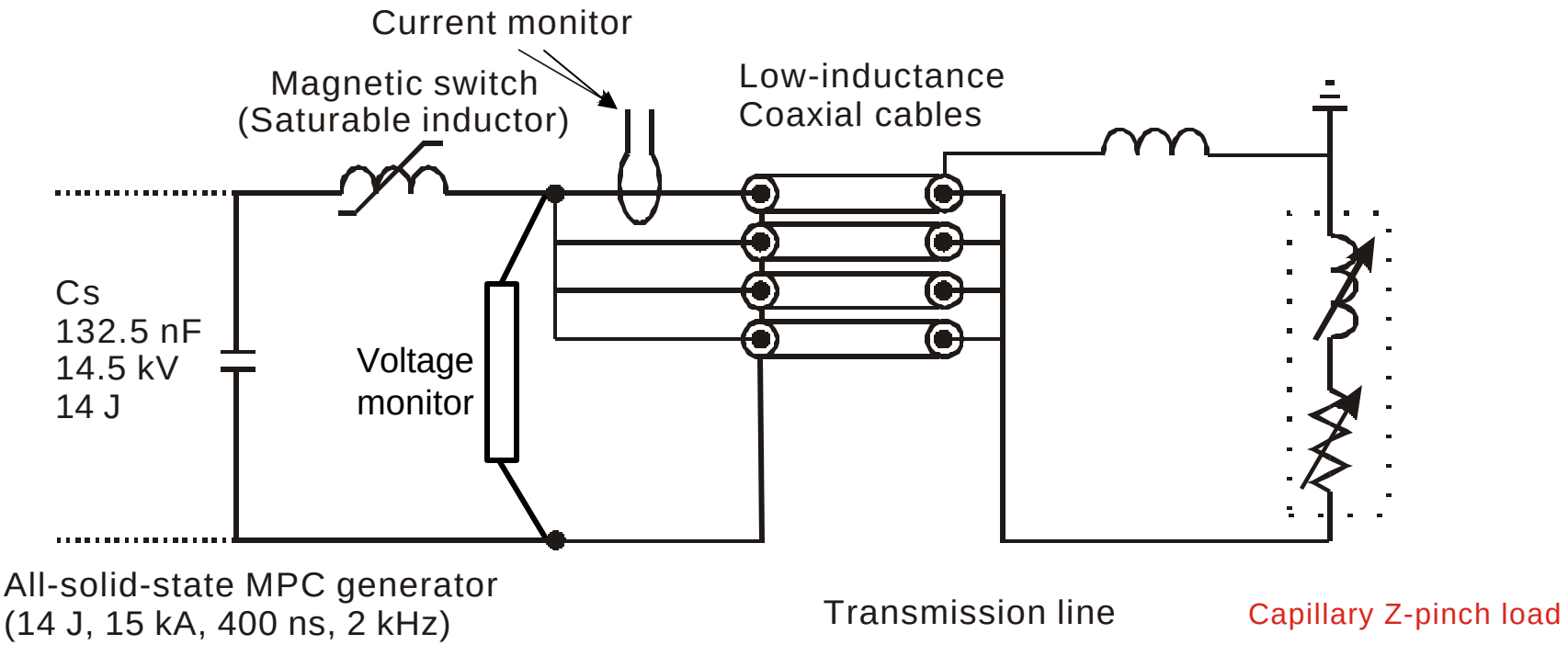






Calculation of coefficient for EUV energy within 2 % bandwidth (13.365-13.635 nm)

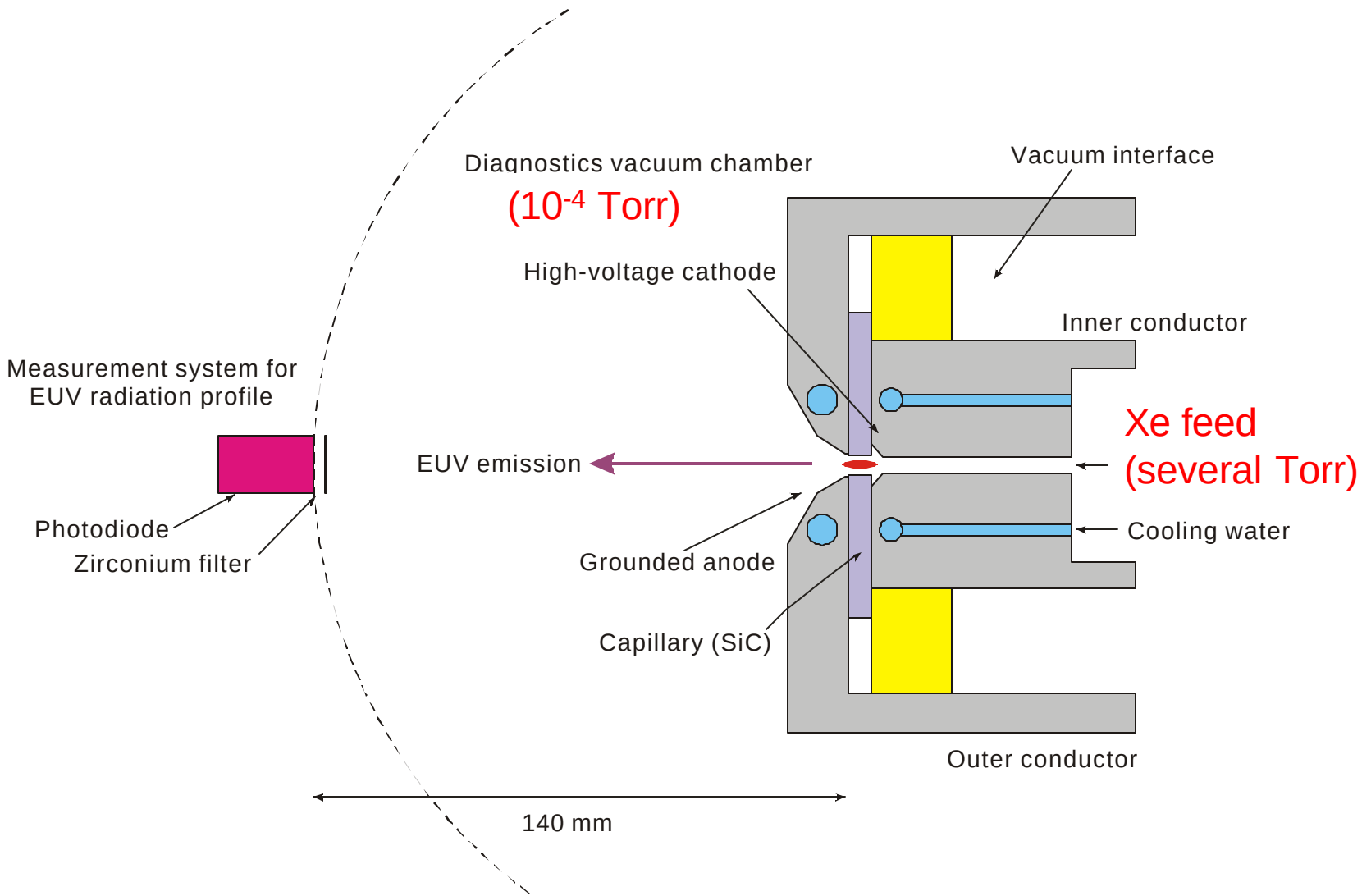
2-kHz all-solid-state pulsed power generator “G2”



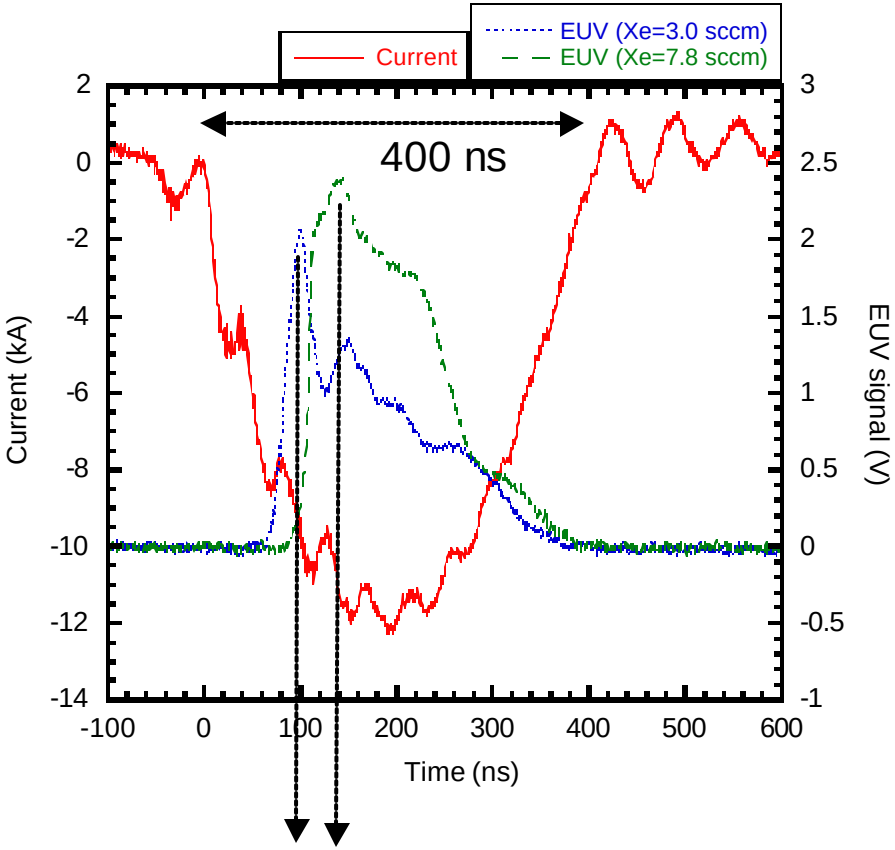
Equivalent circuit of magnetic pulse compression (MPC) generator and capillary Z-pinch load.

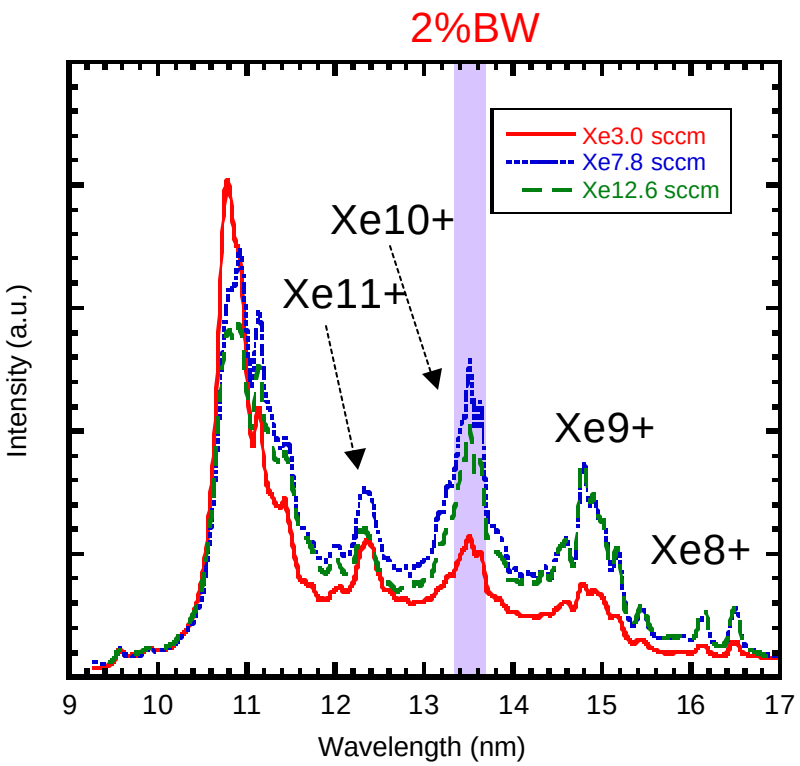
- Passive pre-discharge by leakage current of final output magnetic switch.
- Dissipated energy is <10 % of stored energy. Rest of the energy can be used for re-charge in subsequent pulse.

Experimental discharge head “D2”



Typical waveforms and emission spectra

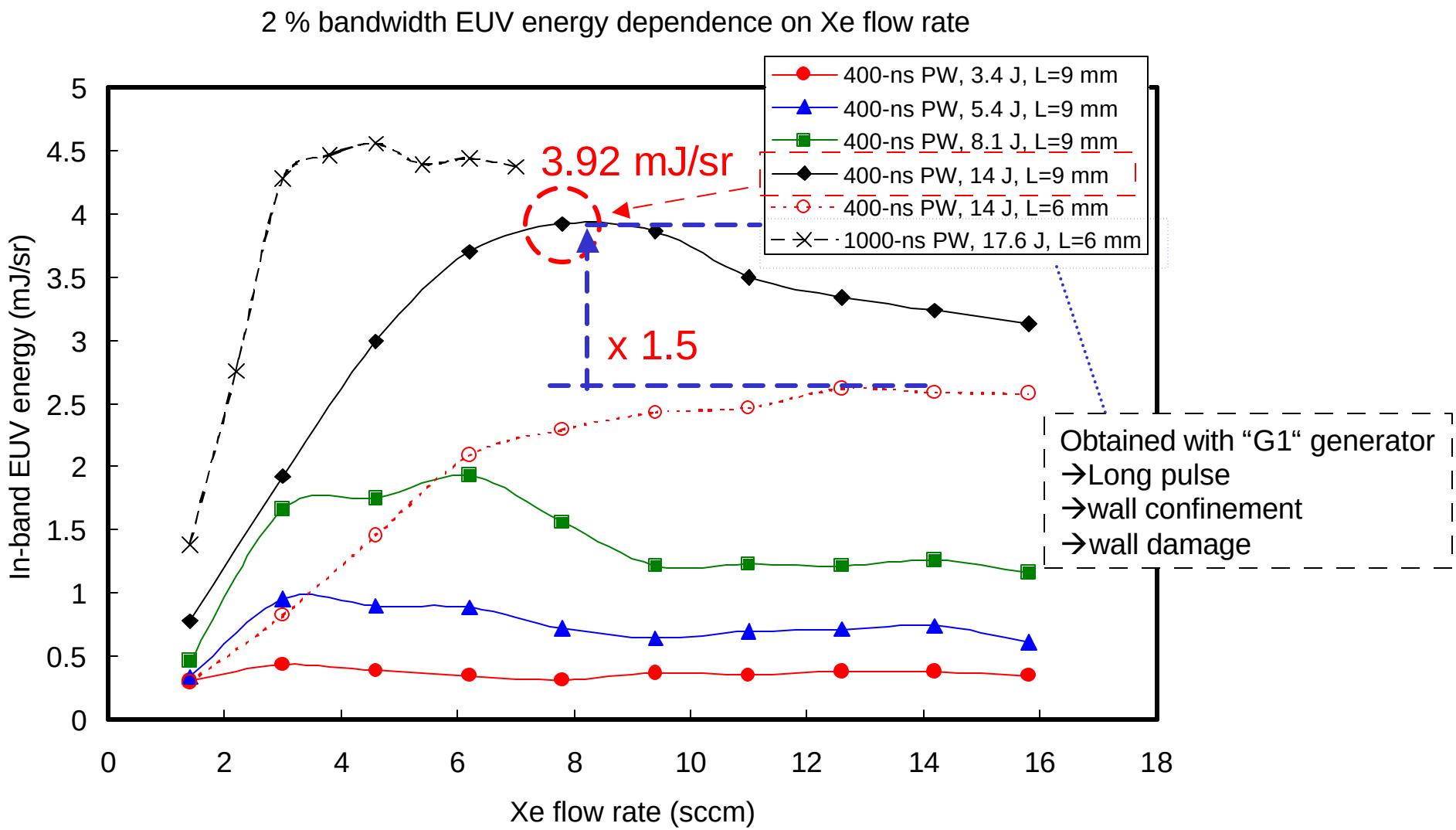




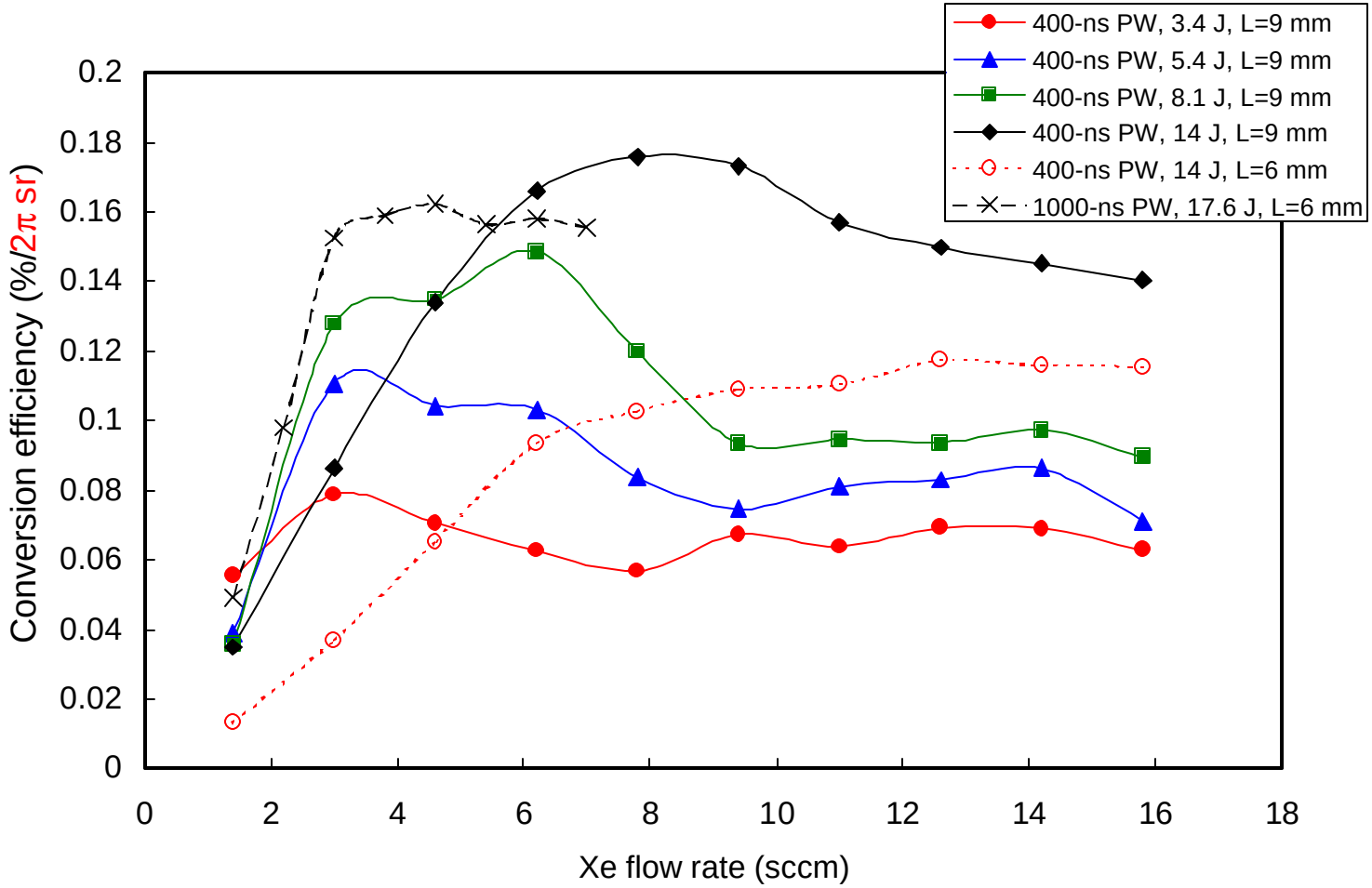
- Implosion time: 100-150 ns
- Peak current amplitude and duration depend on circuit inductance.

~7 % of EUV (9-17 nm) is in 2 % BW around λ=13.5 nm.

Flow-rate dependence of EUV energy



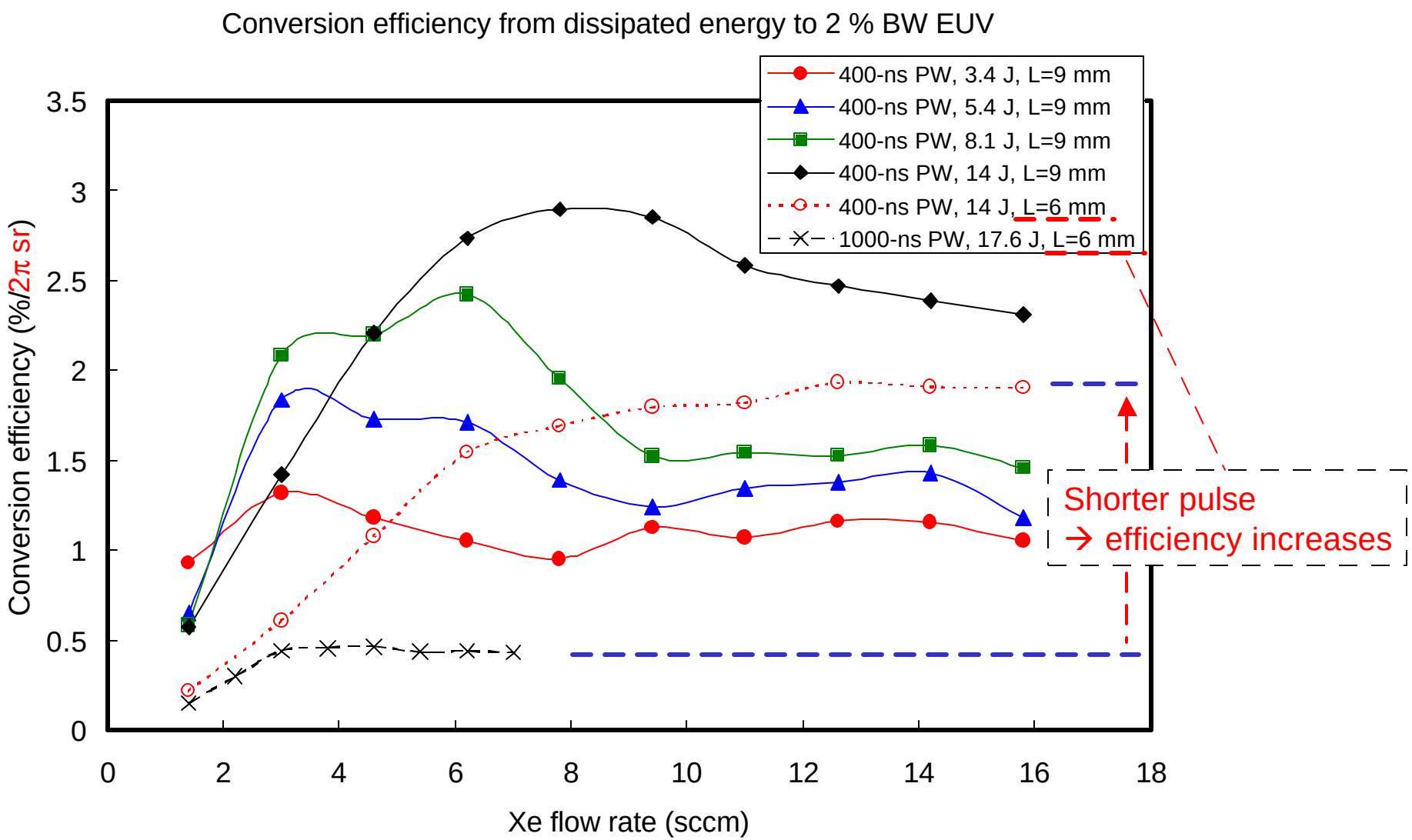
Conversion efficiency from stored energy



Low conversion efficiency is due to low energy dissipation.

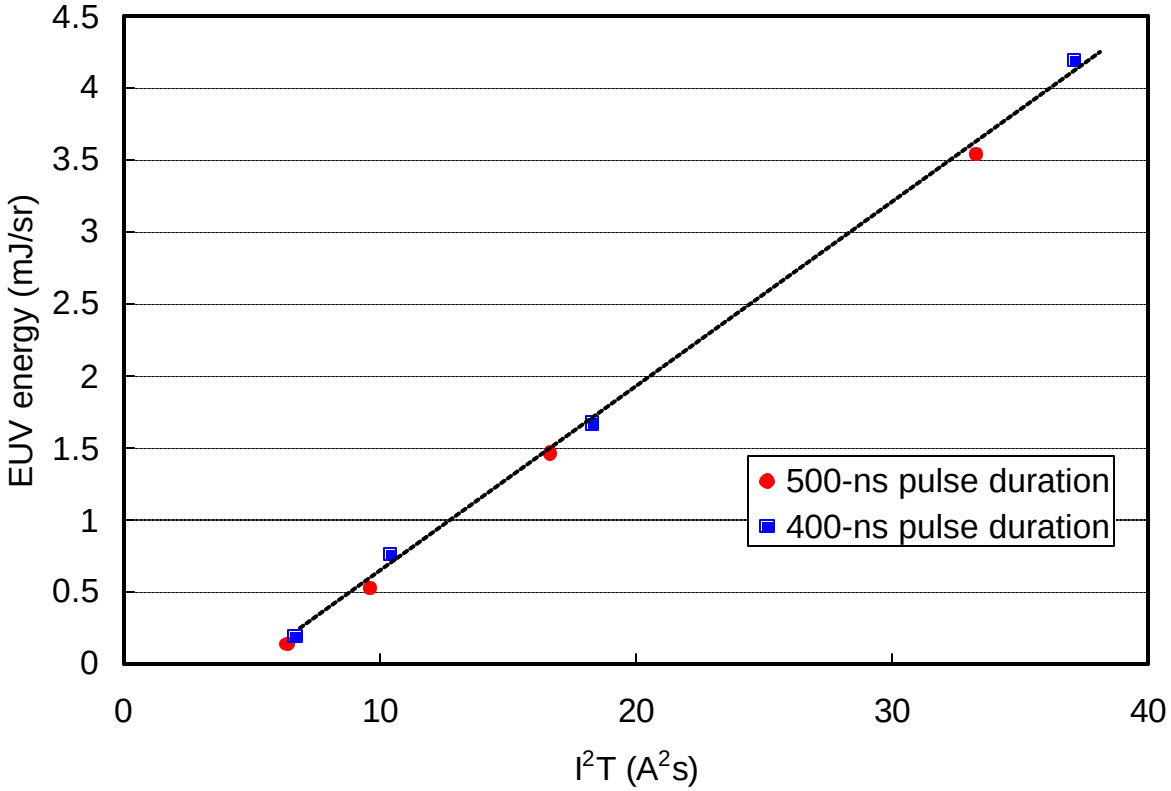
→Possibility of conversion efficiency (EUV energy) improvement with same generator capacity.

Conversion efficiency from dissipated energy



I^2T dependence of EUV energy

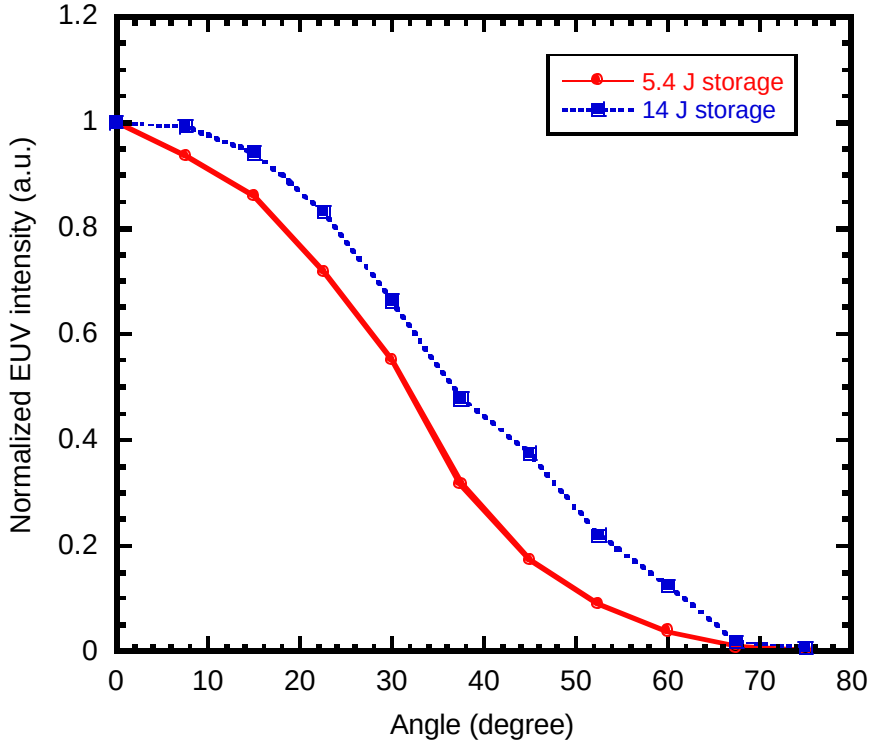
EUV energy linearly increases in proportional to I^2T.
(I: drive current, T: pulse duration)



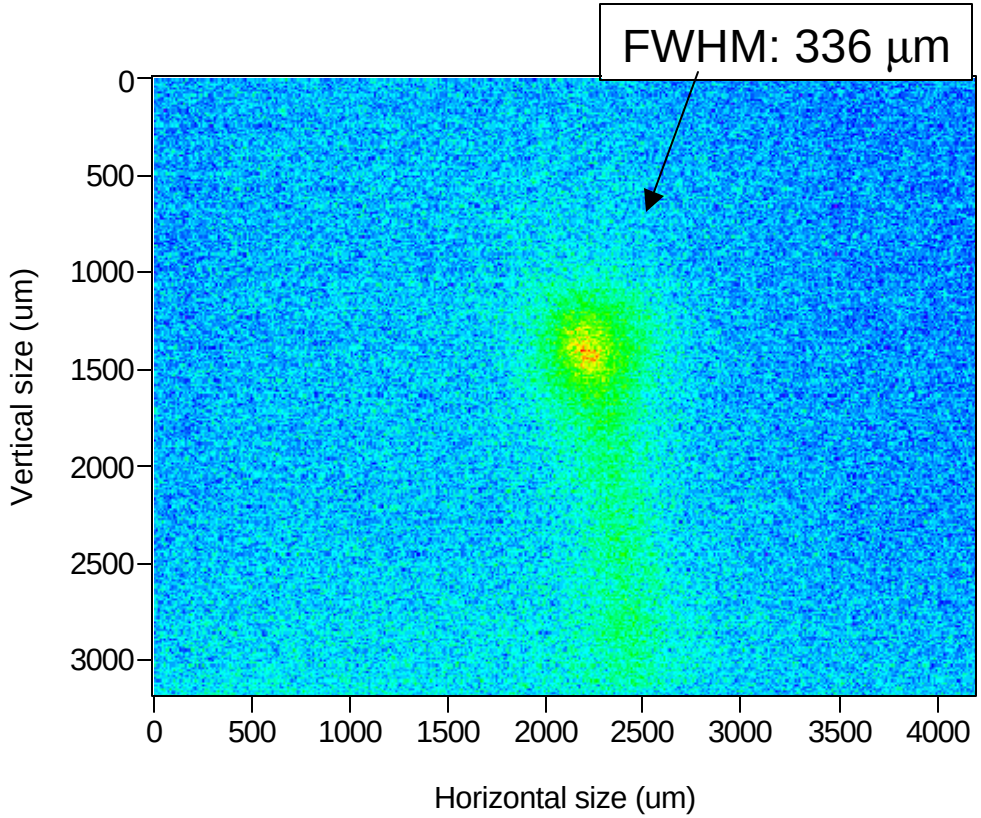
Modification of circuit inductance results in increase in I^2T → EUV energy increases.

Source image and spatial profile of radiation

Equivalent solid angle: ~1.55 sr



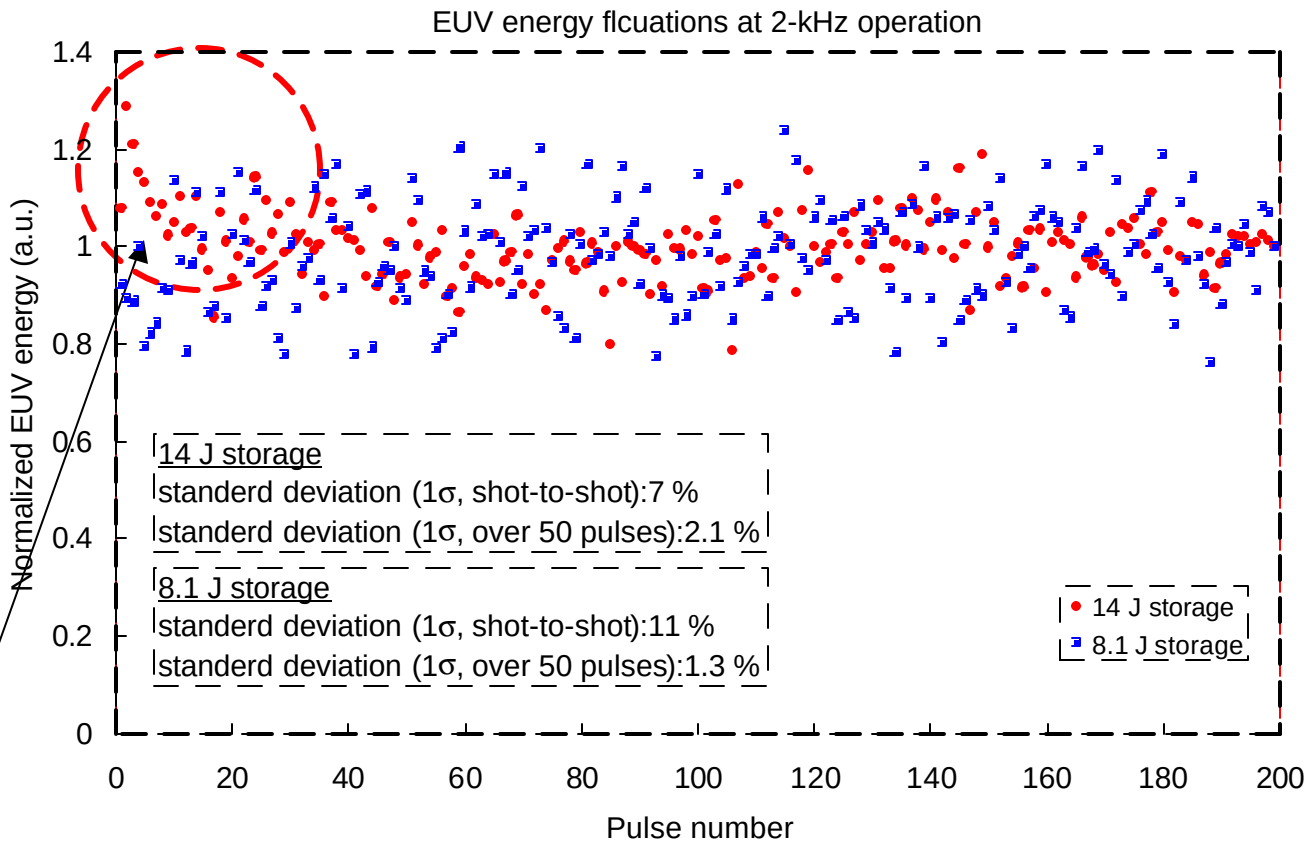
Measured by Zr-filtered photodiode



20-degree off-axis EUV image taken by pinhole camera with Zr filter.

If stored energy (drive current) increases, pinch diameter decreases.
→ smaller source size and wide emission solid angle.

Fluctuation of EUV energy at 2-kHz operation



Decrease in EUV energy at higher electrical (thermal) input
→ might be due to a property of capillary material. (can be improved)

Summary

Electrical properties

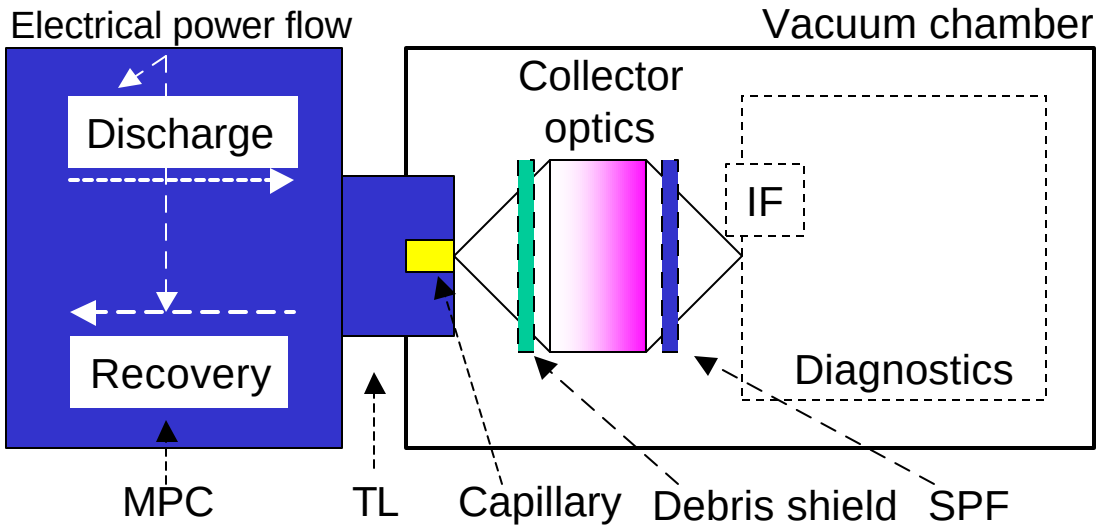
Scheme: capillary Z-pinch
Pulsed power generator: all-solid-state MPC
Rep-rate: 2 kHz (continuous)
Stored energy per pulse: 3.4-14 J
Dissipated energy (electrical or thermal input): <10 % of storage → <2 kW at 2 kHz

Radiation properties

Gas: Xenon
Highest EUV energy (2 % BW): 3.92 mJ/sr (low rep-rate), 3.14 mJ/sr (2 kHz)
Effective equivalent solid angle: 1.55 sr
Conversion efficiency (stored energy): 0.04 %/1.55 sr, 0.18 %/ 2π sr
Conversion efficiency (dissipated energy): 0.71 %/1.55 sr, 2.9 %/2π sr
Average EUV power at source (at 2 kHz): 3.14 [mJ/sr] x 1.55 sr x 2 [kHz]=**9.7 [W]**

Future plan

Conceptual plan of 4-W EUV source



Terms of evaluation:

1. Spectroscopy
2. In-band EUV energy measurement
3. Image of in-band EUV radiation at multiple angular positions

Path to higher EUV power:

1. Improvement of generator-load coupling
2. Increase of dissipated energy
3. Improvement of cooling system
4. Design and material modification of electrode and capillary
5. Increase of pulse repetition rate

etc