Development of high-power Sn-fueled DPP EUV source for enabling HVM

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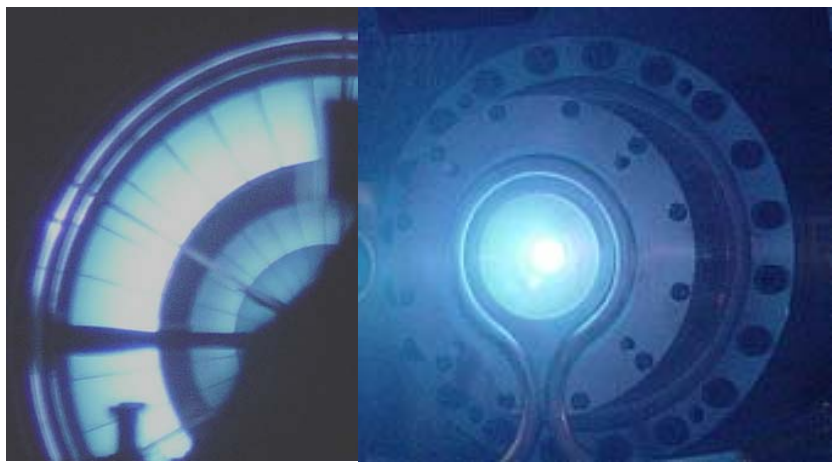

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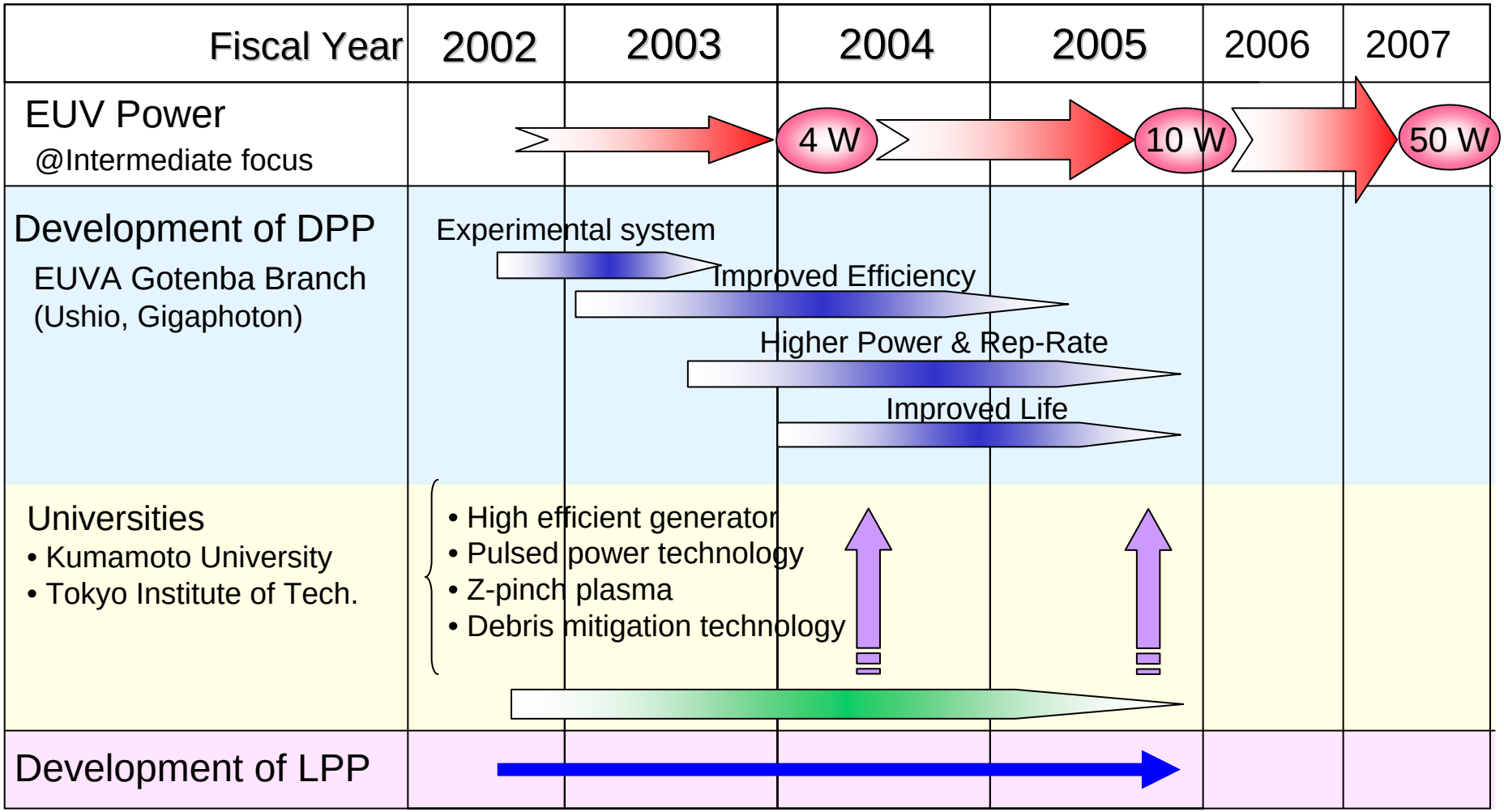
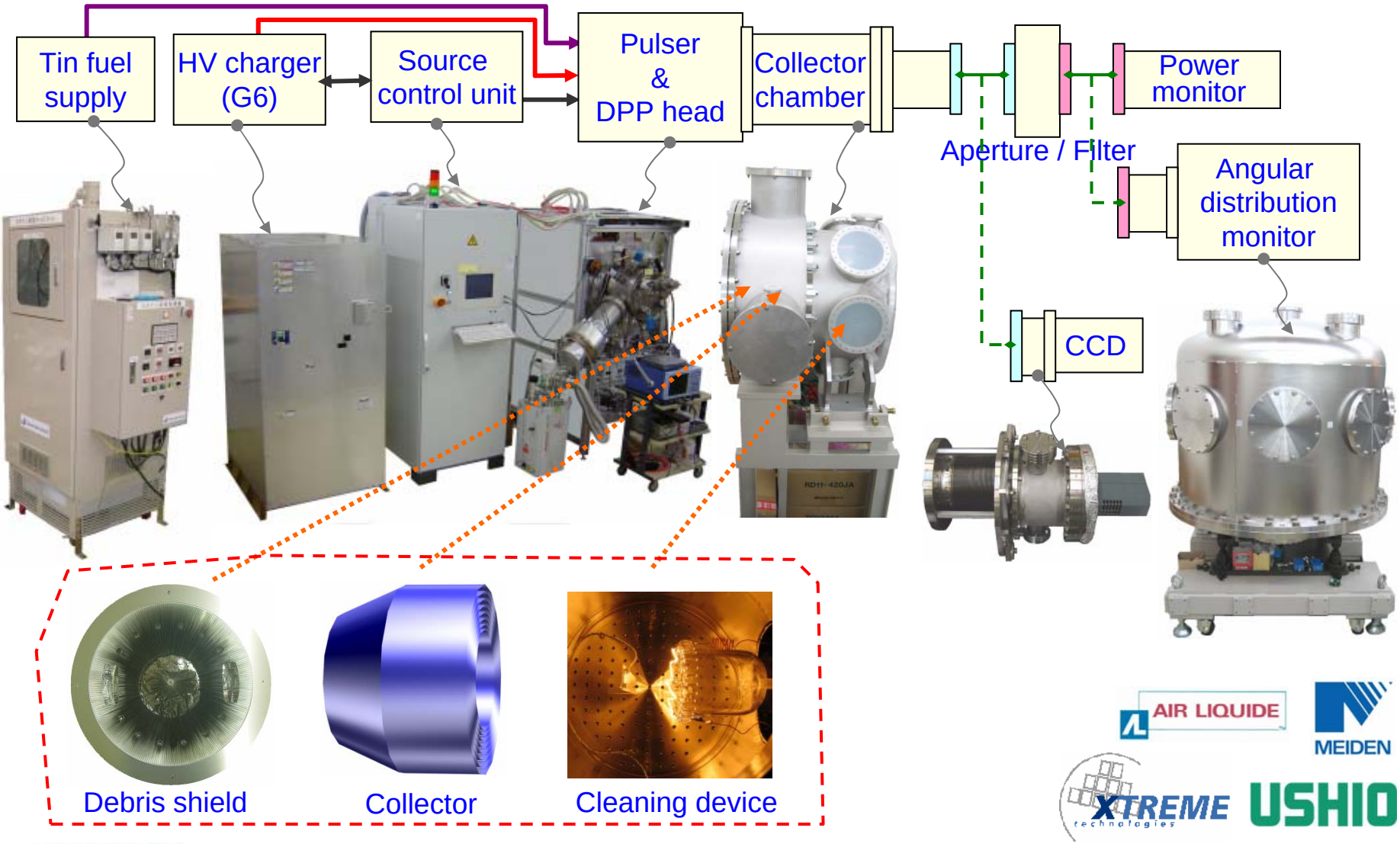
Outline

- Configuration of 50-W-level EUV source
- Source power and lifetime improvement
  - Source power
    - Pulsed power driver
    - Electrode
    - Fuel supply
    - Source and IF power
  - Collector lifetime
    - Debris mitigation technology
    - Cleaning technology
- Future plans for 50 W and HVM
- Summary

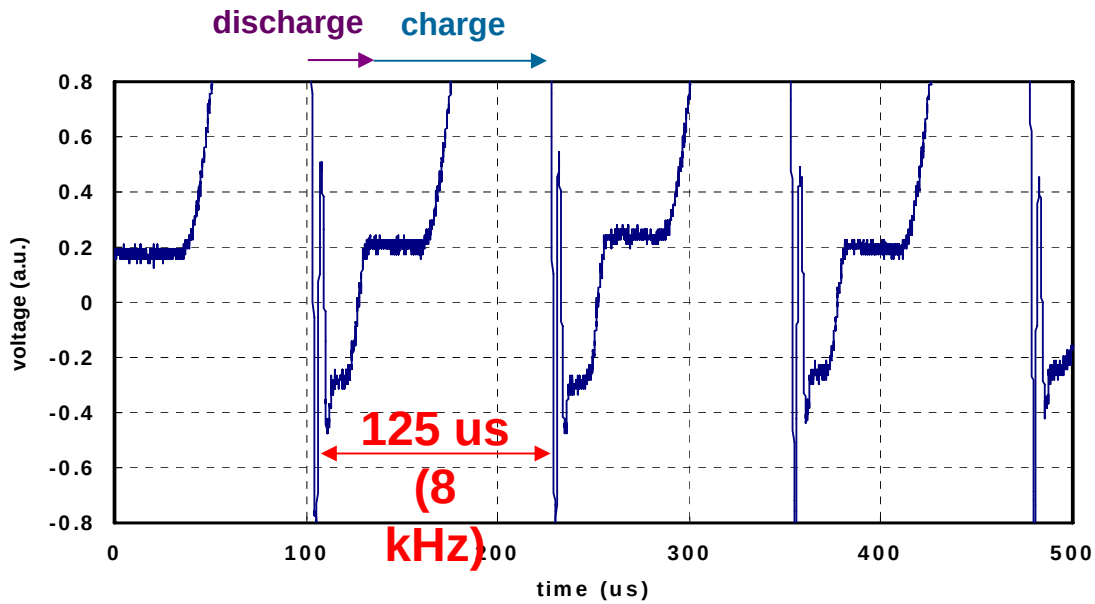
EUVA's plan for DPP source development



Sn-fueled DPP EUV source system



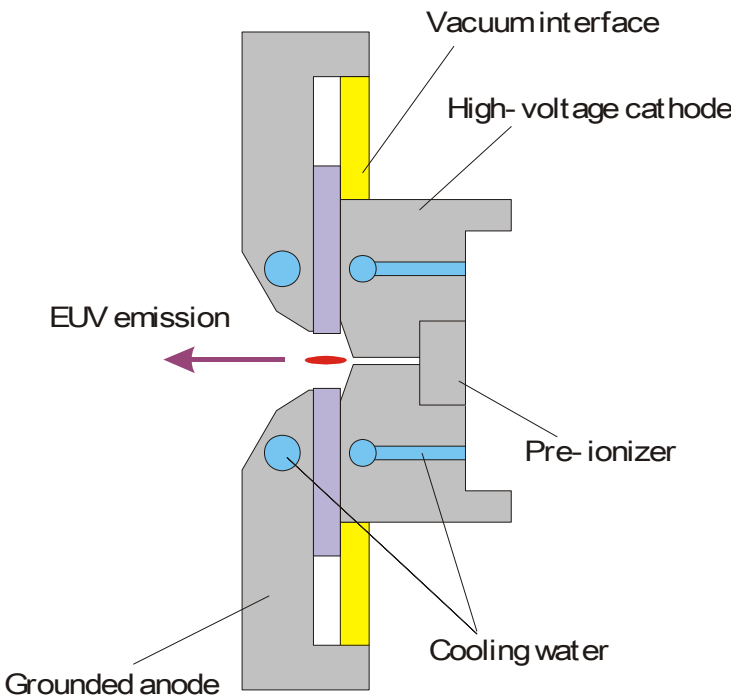
Pulsed power driver “G-6”: a 6-kHz (8-kHz burst) power supply



Waveform of output voltage at 8 kHz operation

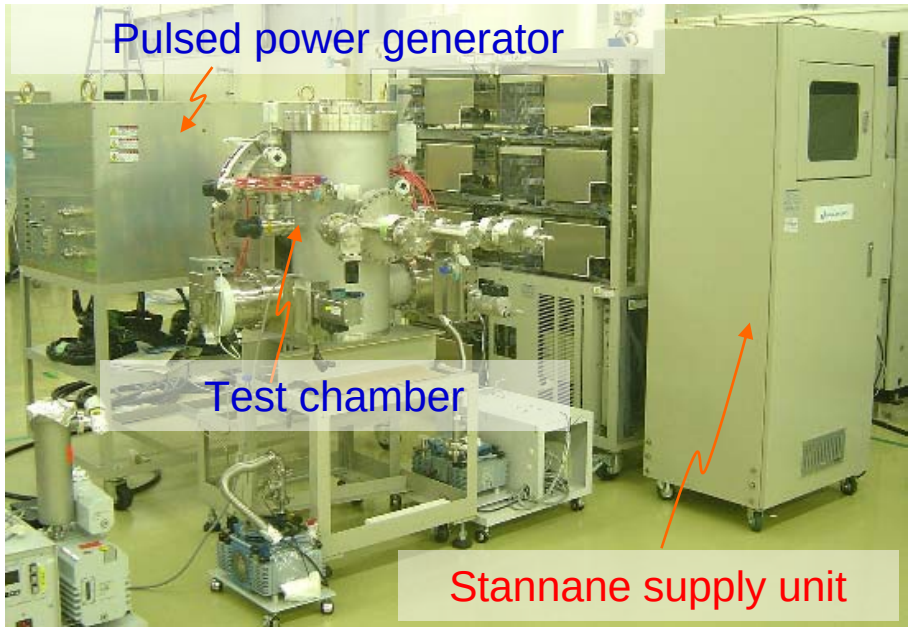
- Maximum output energy: 15.0 J/pulse
- Maximum repetition rate: 8 kHz (DC75 %), 6 kHz (continuous)
- Pulse-to-pulse voltage stability: 0.11 % (σ , at 8 kHz)
- Energy recovery system employed.
- Pulse voltage control equipped.

Z-pinch discharge head



- Low-inductance design for good electrical coupling
- Active pre-ionization system
- High thermal conductivity/operating temperature material
- SnH_4 gas feed system

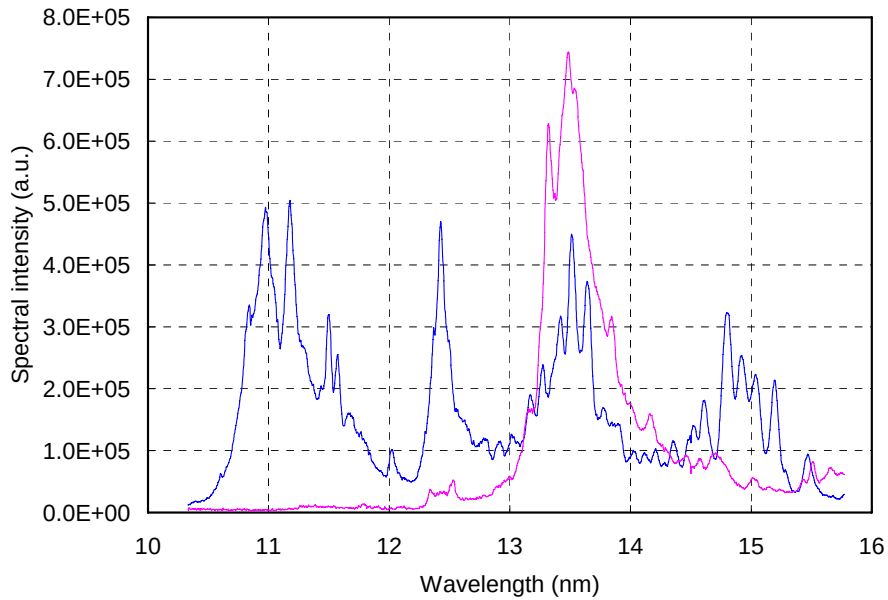
SnH_4-fueled Z-pinch: a clean/effective discharge source.



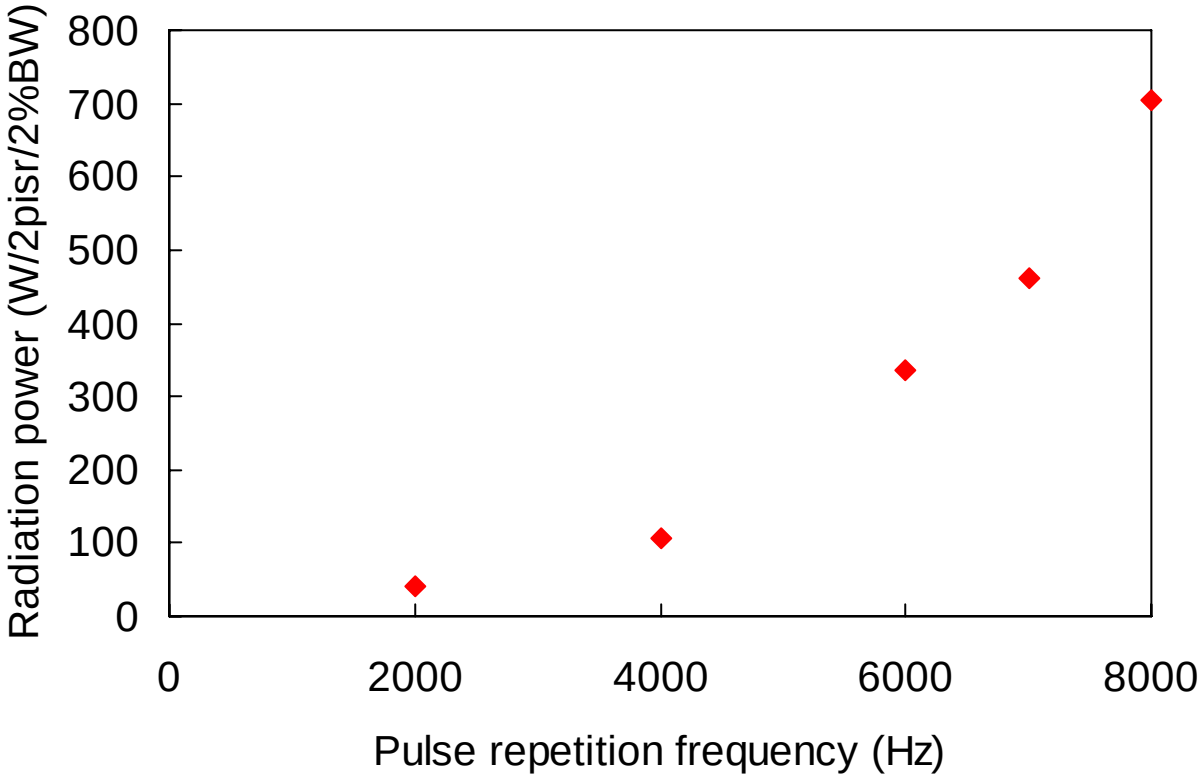
SnH_4 (stannane, tin hydride)

- Melting point: -146 °C
- Boiling temperature: -52 °C

- Gaseous state
- Controllable by a flow controller
- High CE as pure Sn
- Clean



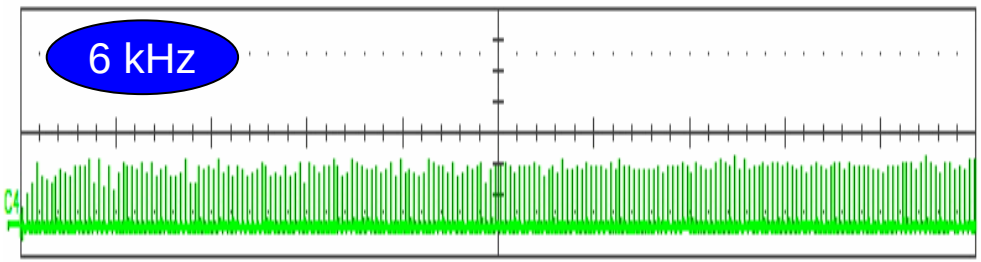
Source power characterization: 700 W/2πsr achieved at 8 kHz



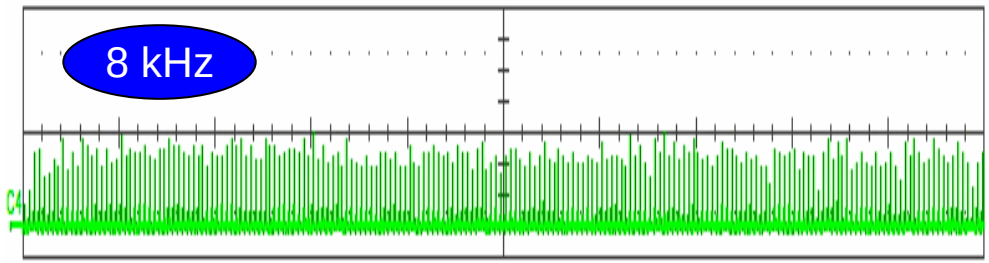
at 8 kHz
702 W/2πsr/2%BW
CE: 1.2 %
Gas consumption: still acceptable

Non-linear scaling over frequency is due to the electrode/feed system designed for high-frequency discharge.

Pulse energy stability example at 6 and 8 kHz



Average energy: 10.7 mJ/sr/2%BW
σ(pulse): 10.7 %
σ(dose): 2.4 %



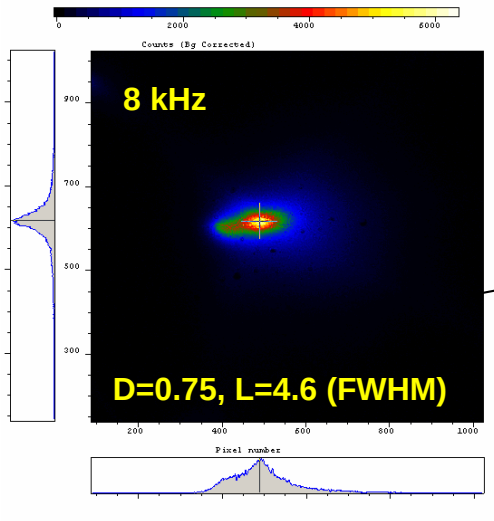
Average energy: 14 mJ/sr/2%BW
σ(pulse): 15.7 %
σ(dose): 2.4 %

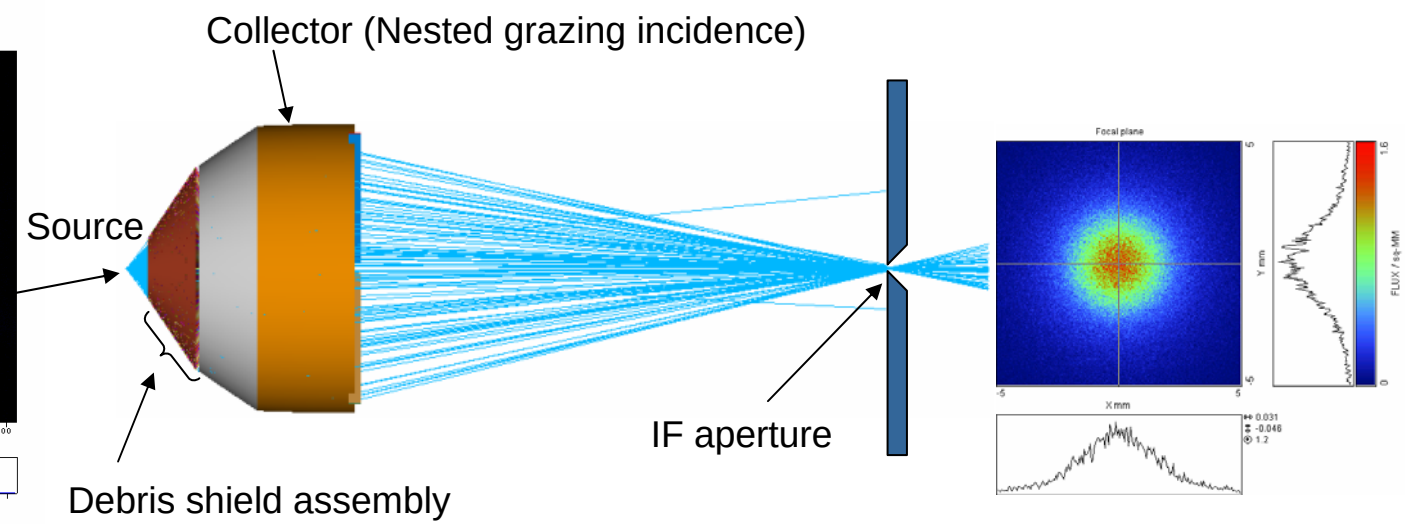
EUV pulse energy at free-running operation

Some pulses were misfired at 8 kHz. Possible reasons are:

- Unstable pre-ionization
- Insufficient pulse compression operation
- Dynamics of gas flow

IF power reached 62 W/3.3 mm^{2}sr



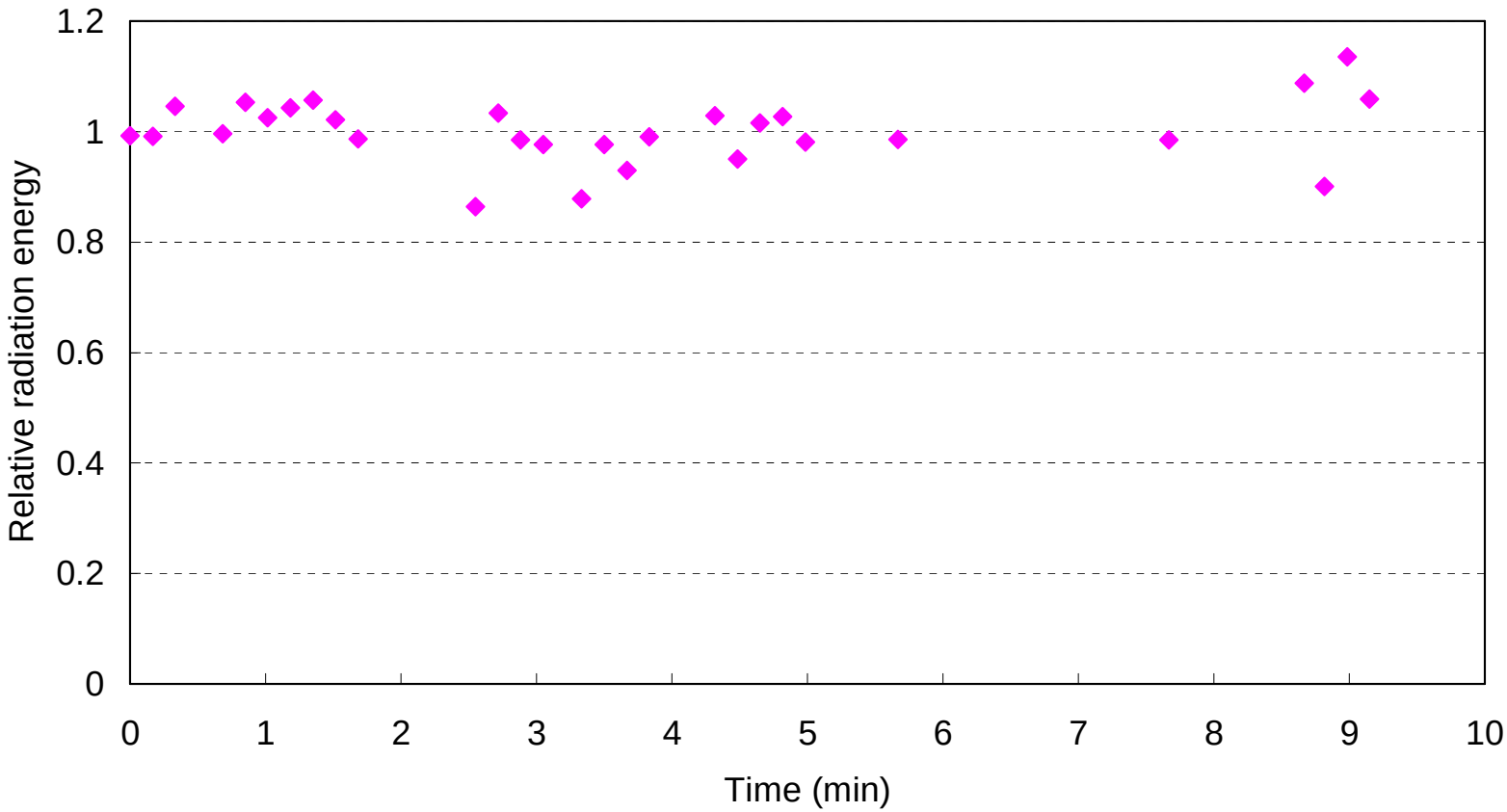


Plasma image (20 deg.)

Intensity distribution in focal plane

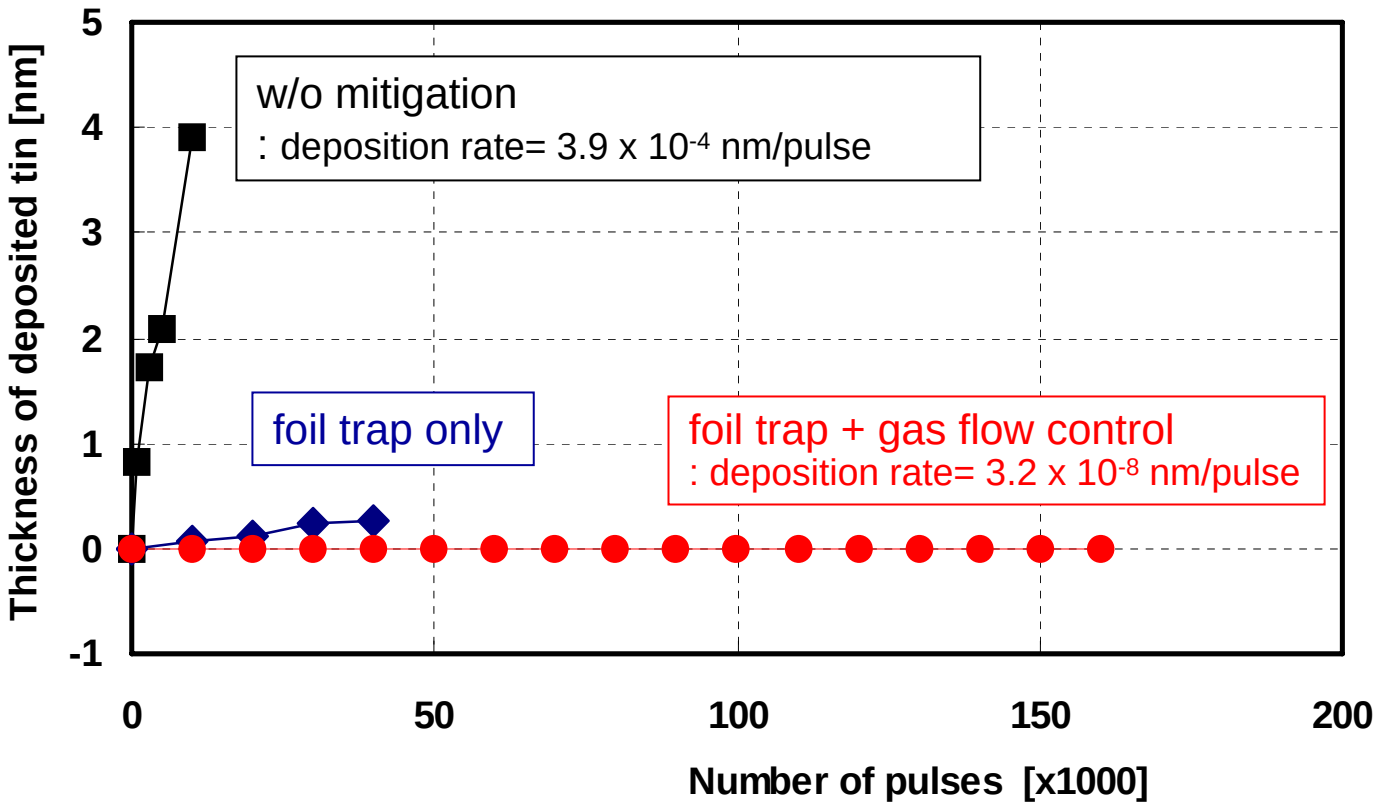
Plasma output	616 ~ 702 W/2πsr
Debris shield transmission	0.80
Effective collection angle & collector transmission	0.28
Aperture (etendue limitation & SPF) transmission	0.45
Gas transmission	0.9
Usable EUV power after IF	55 ~ 62 W/3.3 mm^{2}sr

Long-term discharge experiment at 8 kHz



Long-term discharge experiment result obtained at 8 kHz (DC6.25 %) with SnH_4.

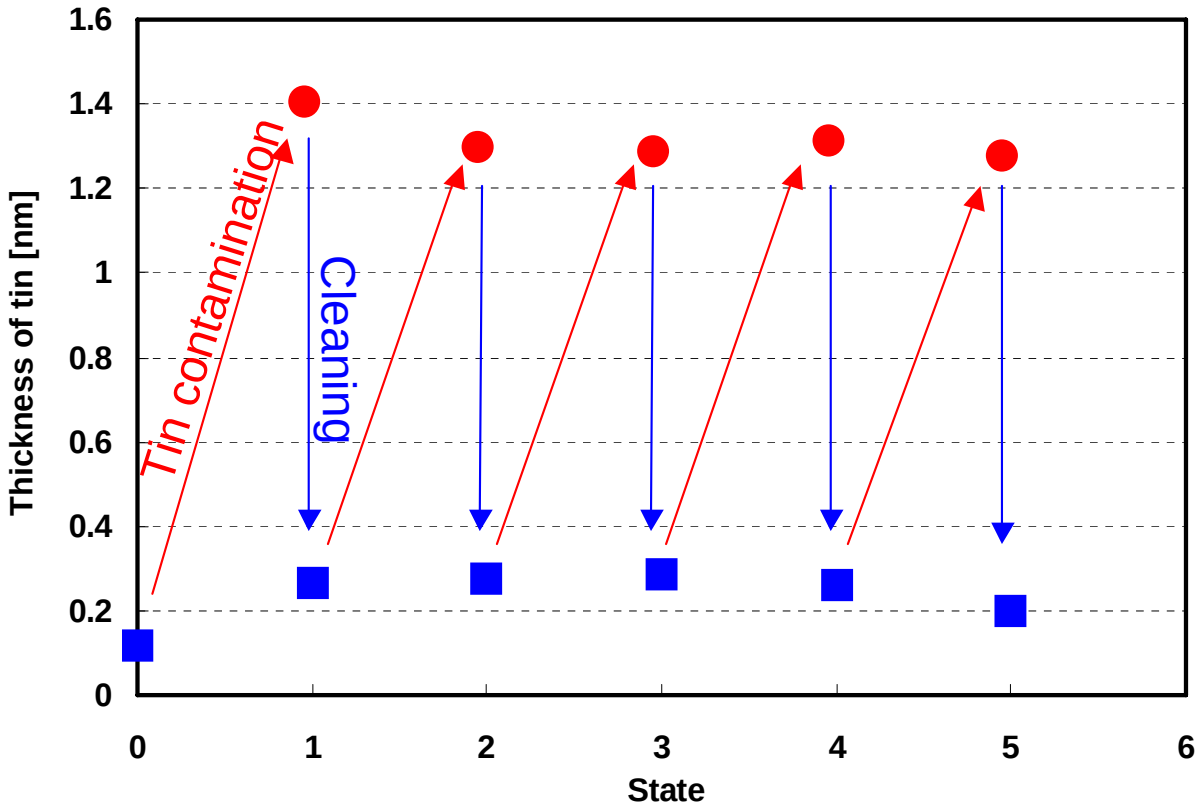
Debris mitigation and collector reflectivity recovery technologies



Cumulative number of pulses and thickness of tin for SnH_4 fueled source

Deposition rate of tin was decreased by >4 orders of magnitude.

Debris mitigation and collector reflectivity recovery technologies



- Contamination medium: SnH_4 gas
- Cleaning medium: Halogen gas
- Thickness measurement: Ru-coated QCM sensor

Tin contamination-removal cyclic test

Most of deposited tin can be removed by cleaning process.

Future plans to 50-W- and HVM-level DPP source

Input

Pulsed power:
- 8 kHz demonstrated.
- 10 kHz under preparation.

Load

Electrodes:
- Design modification for 8~10-kHz CW operation

Output

C2E:
- SnH_4 gas and new feed concept
- Small plasma size

Summary: 62 W of EUV power obtained at IF

Terms	Achievement
Fuel	SnH_4
Source EUV power	702 W/2π sr
Collection efficiency	0.28
Optical transmission	0.8 (debris mitigation) x 0.45 (aperture) x 0.9 (gas)
IF EUV power	62 W (3.3 mm^2sr) *collector design dependent
Plasma size	0.75 mm (D) × 4.64 mm (L)
Stability	15.7 % (pulse), 2.4 % (dose) *at 8 kHz, w/o feedback control
Collector	Nested grazing-incidence collector
CE	1.2 %/2π sr (radiated energy into 2π sr / total dissipated energy in final output circuit)

Summary

<Topics of achievement in 1Q-2Q FY2006)

- 8-kHz pulsed power system installed.
- 700-W source power demonstrated with SnH_4.
- IF power reached 62 W.
- Sn deposition rate decreased <<3.2E-8 nm/pulse

<On-going/future research activities>

- Improvement of stability and plasma size.
- Lifetime testing of electrode and collector.
- Debris shield and cleaning system development for the actual collector.
- Development of active feedback control system.
- Preparation of entire system including collector and IF metrology.

Please visit our DPP-related poster presentation.

Dr. Shirai et.al, “Debris mitigation and cleaning for Sn-fueled EUV Source”