High-power DPP EUV source development toward HVM

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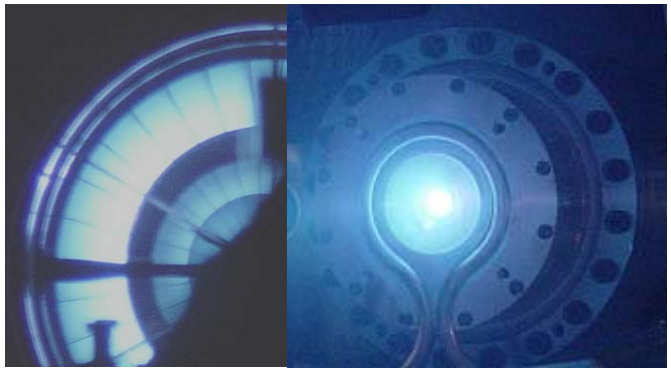
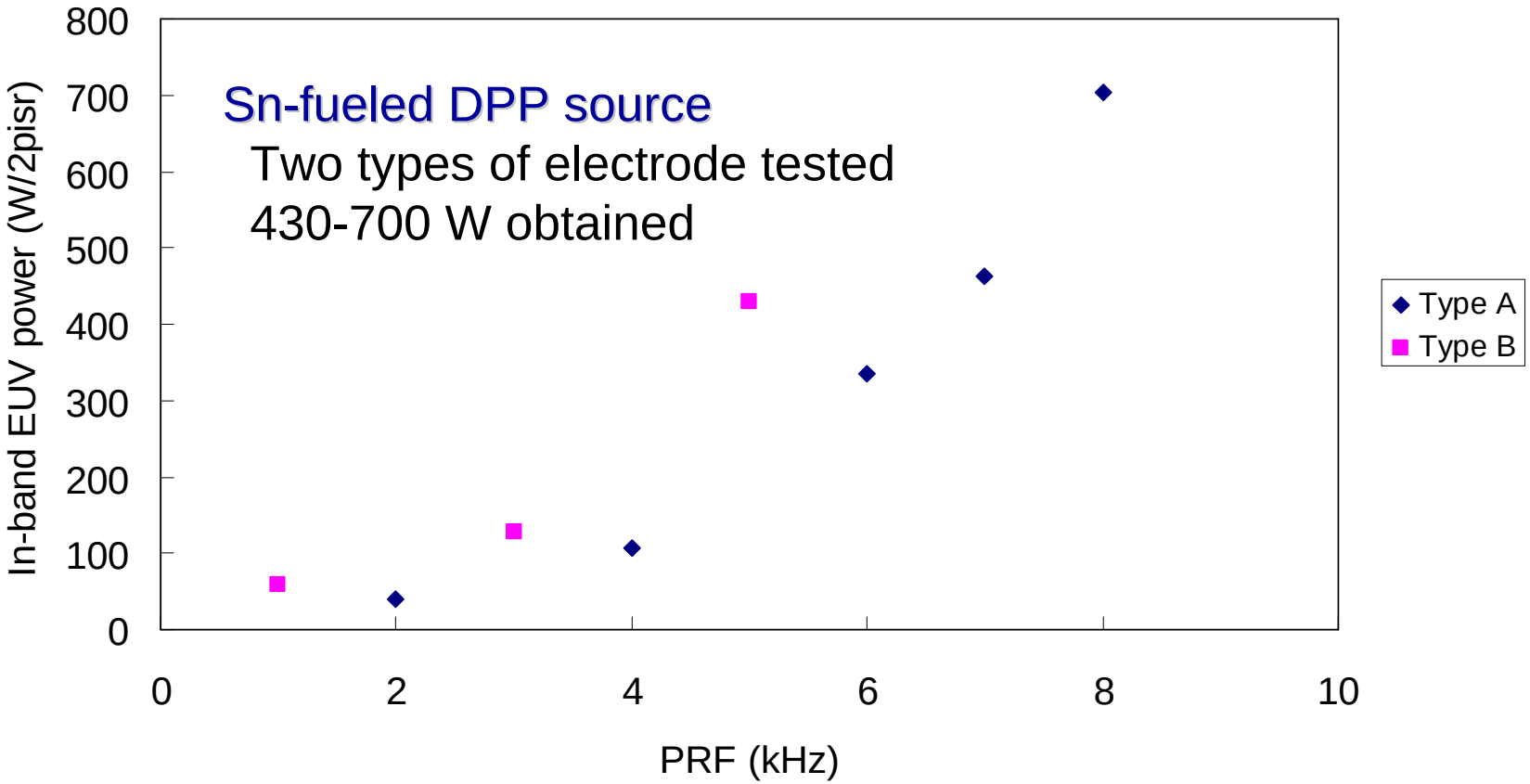


This work is supported by New Energy and Industrial Technology Development Organization (NEDO).

Outline

- Evaluation of Sn-fueled DPP source at/after intermediate focus
- A potential solution for obtaining sufficient source power for HVM
- Debris shield and cleaning
- Summary

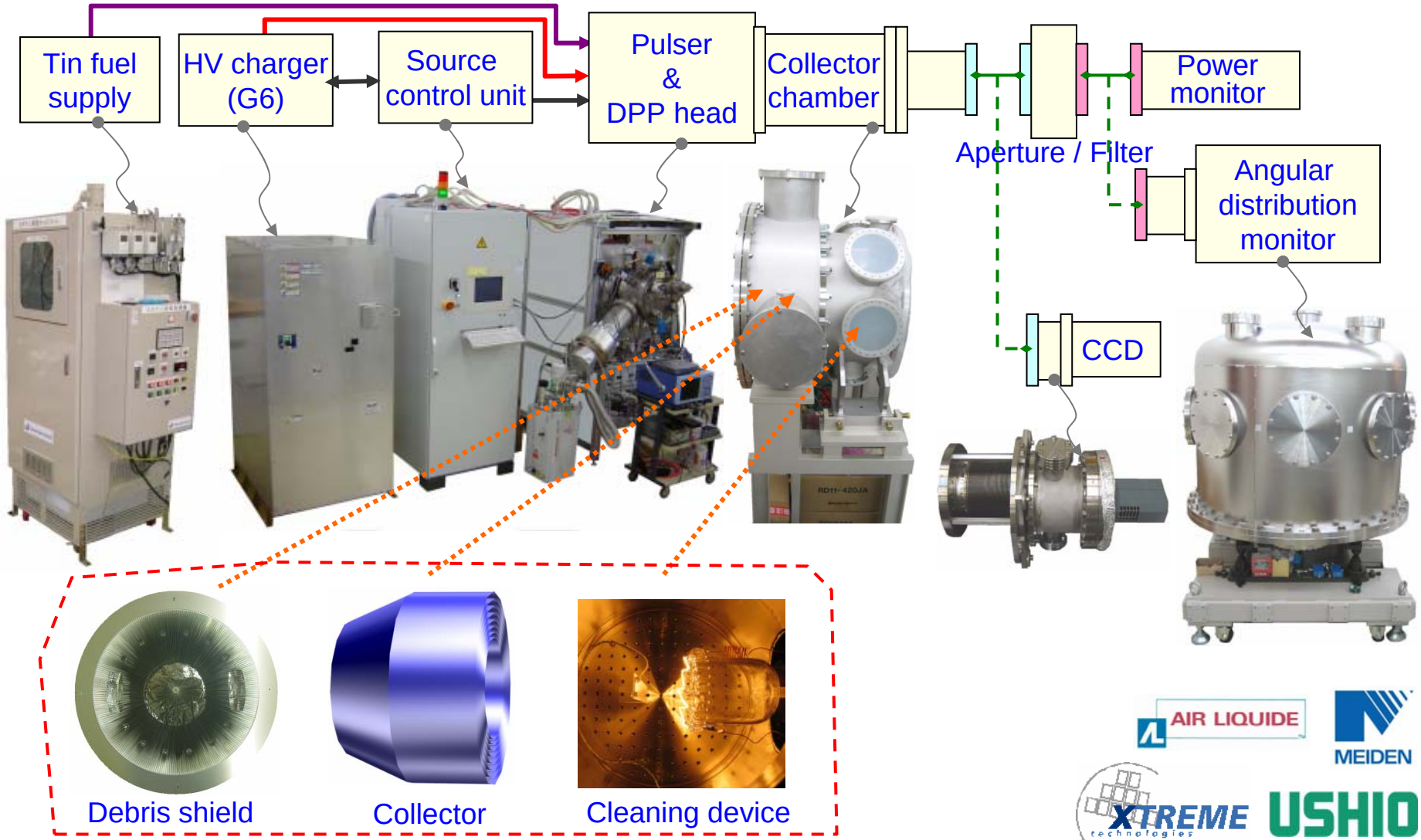
Source power for 50-W demonstration



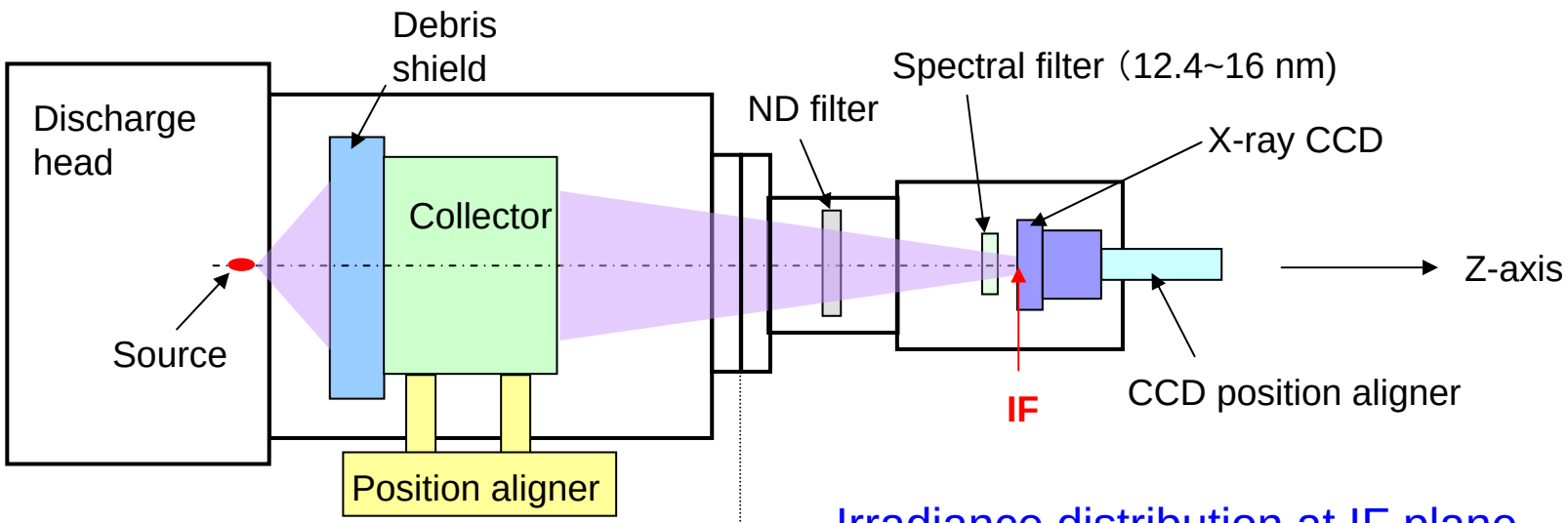
- Reliability
- Plasma shape
- Collection efficiency

430-W source selected for comprehensive IF performance evaluation

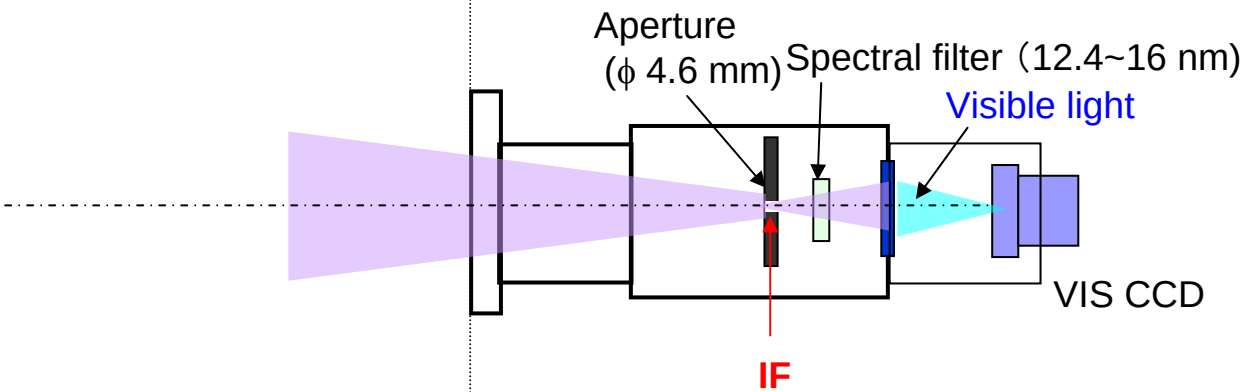
Sn-fueled DPP EUV source system for 50-W demonstration



IF metrologies

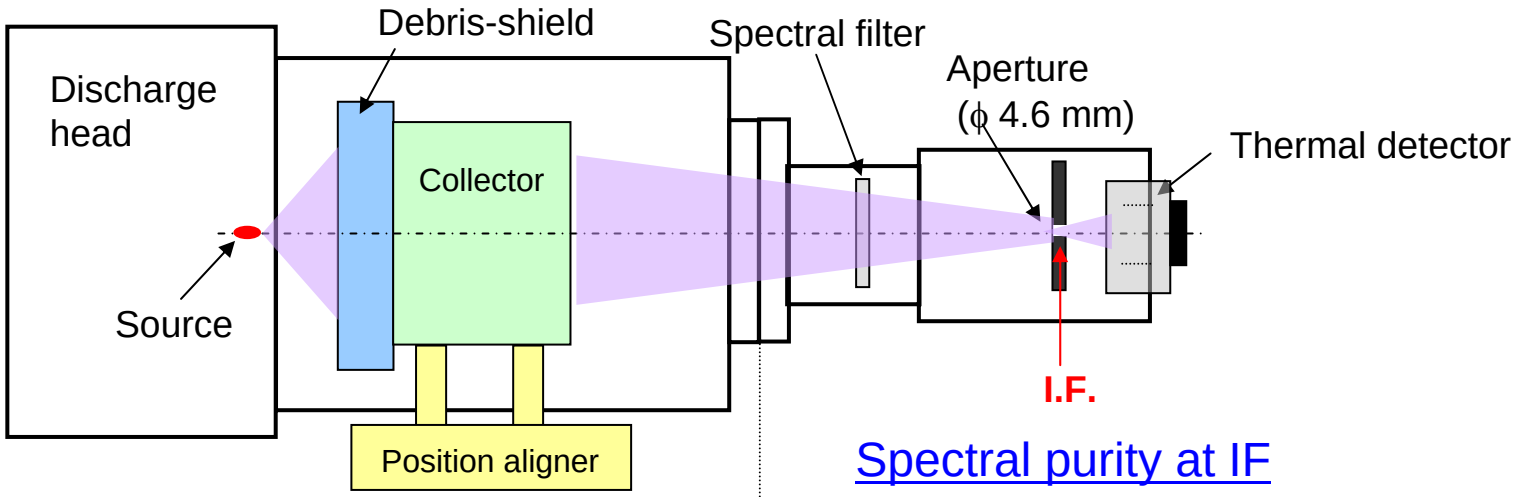


Irradiance distribution at IF plane

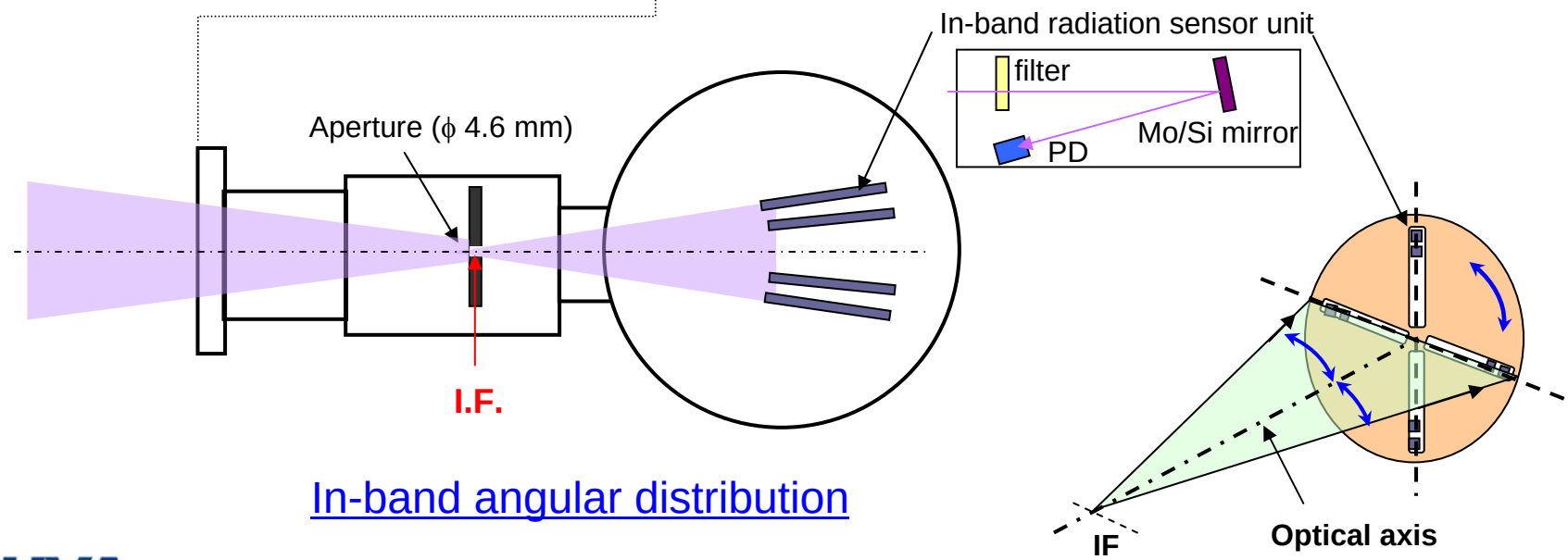


Approximate far-field image

IF metrologies

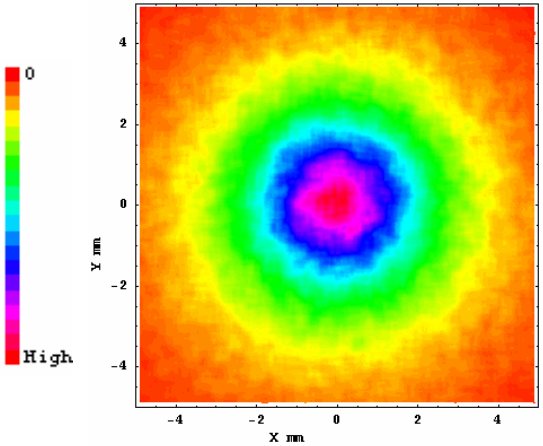


Spectral purity at IF

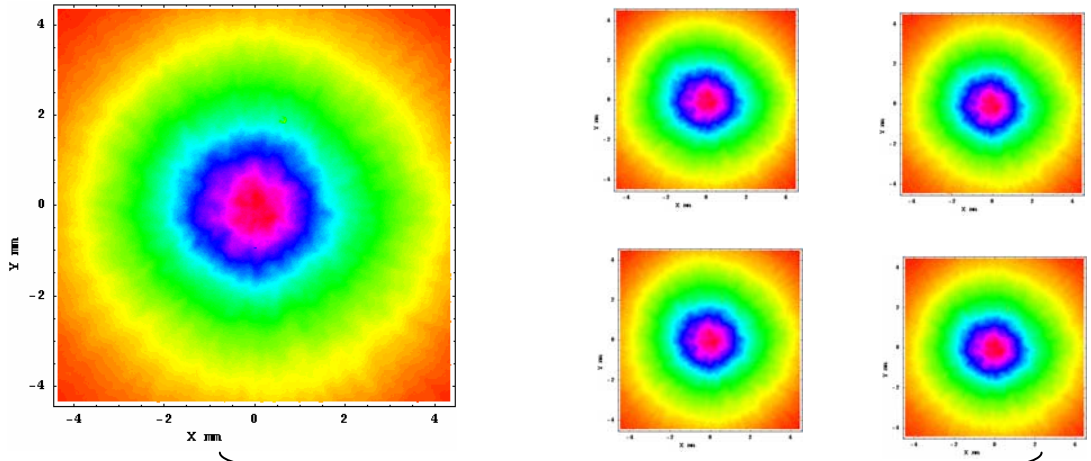


In-band angular distribution

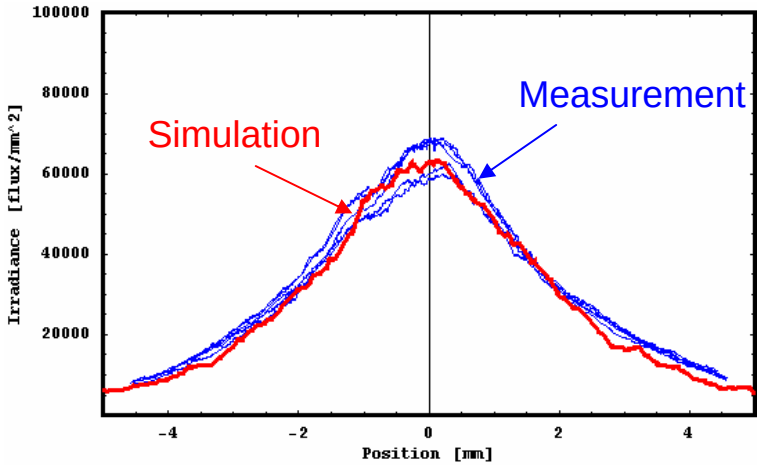
Irradiance distribution at IF



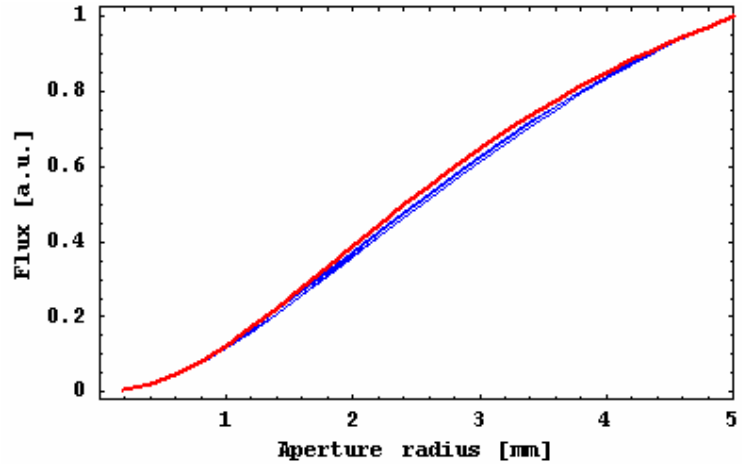
(a) Simulation



(b) Measurement

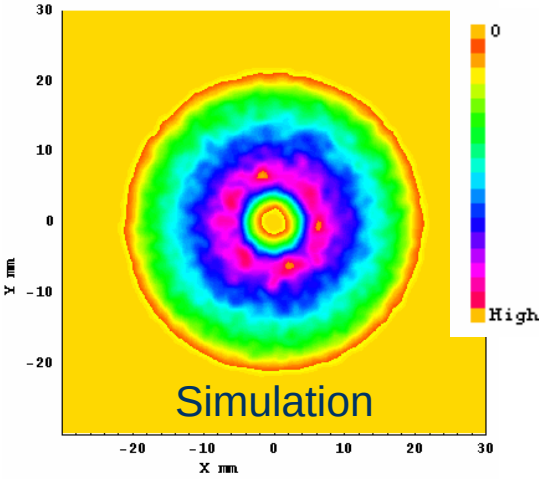


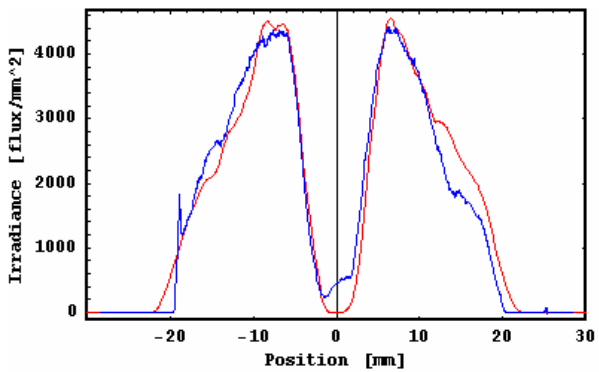
Irradiance profile



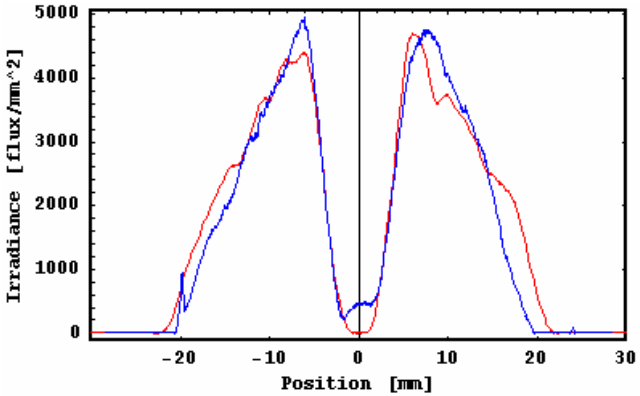
Radius-flux curve

Approximate far-field image

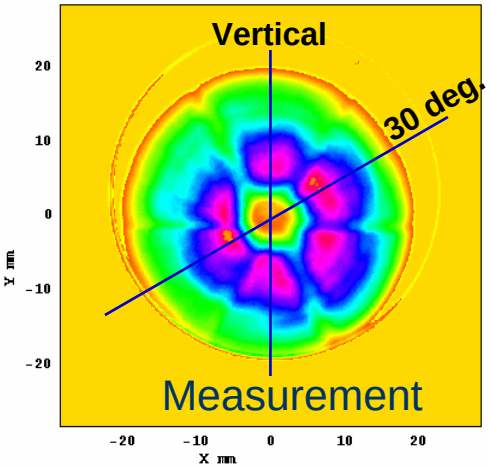


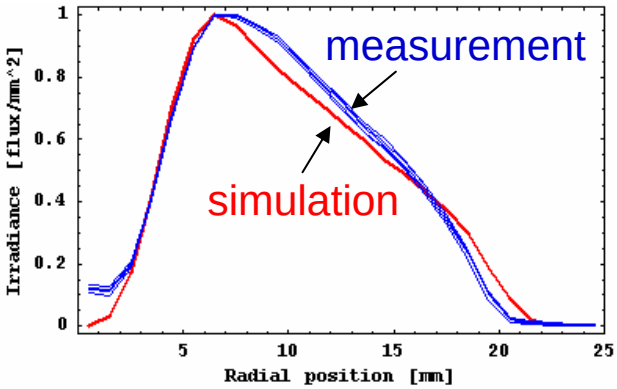


Vertical profile

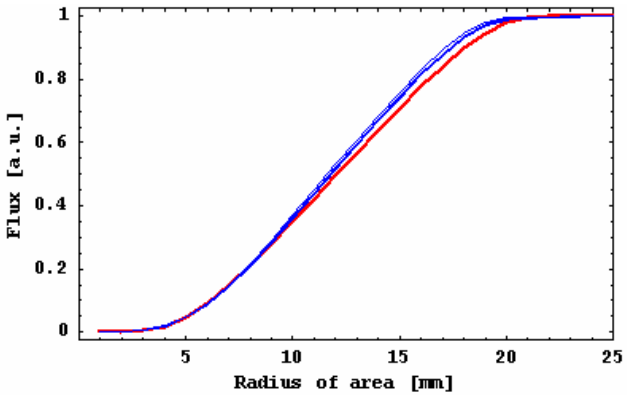


30-deg. profile



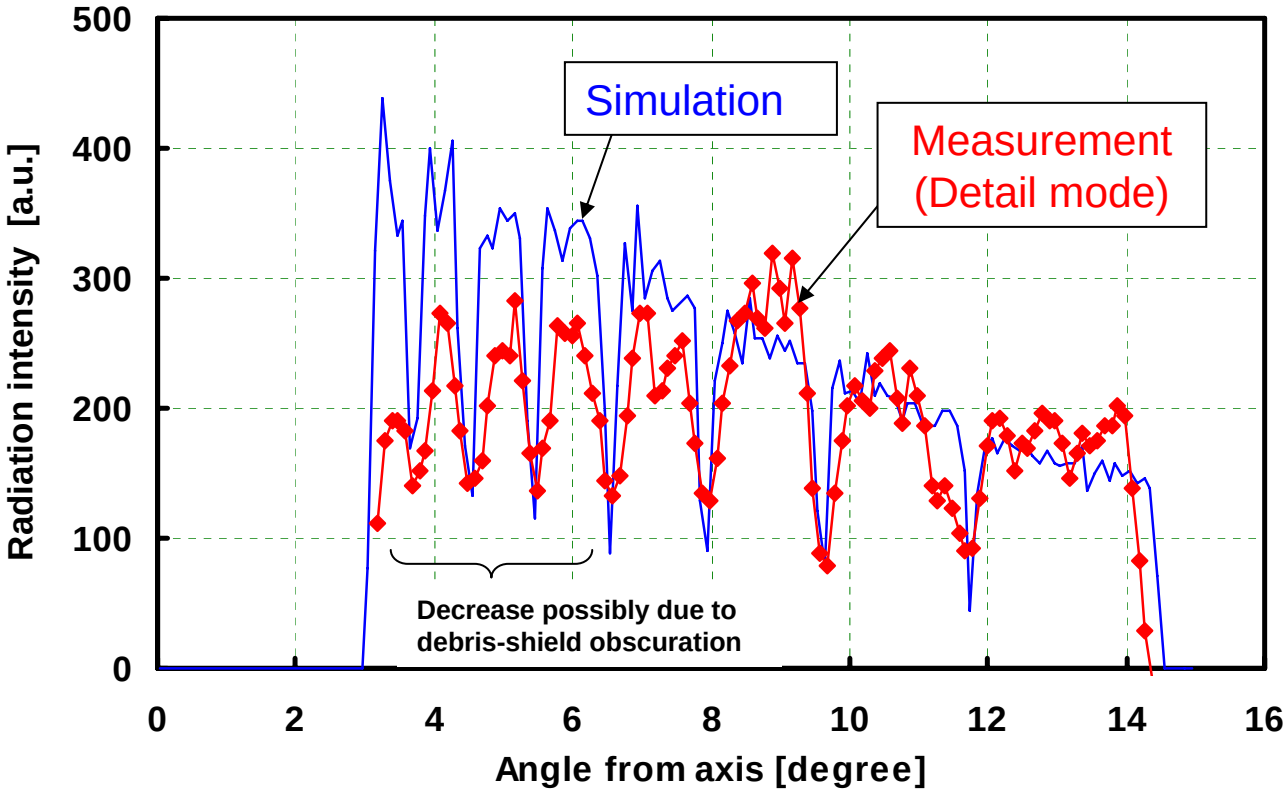


Radial profile



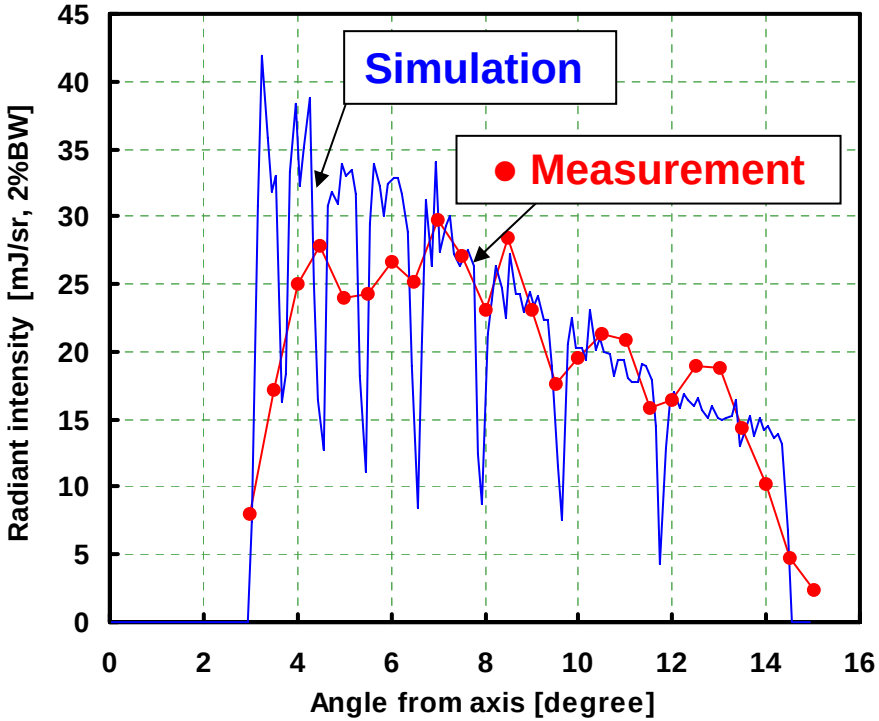
Radius-flux curve

Angular distribution after IF

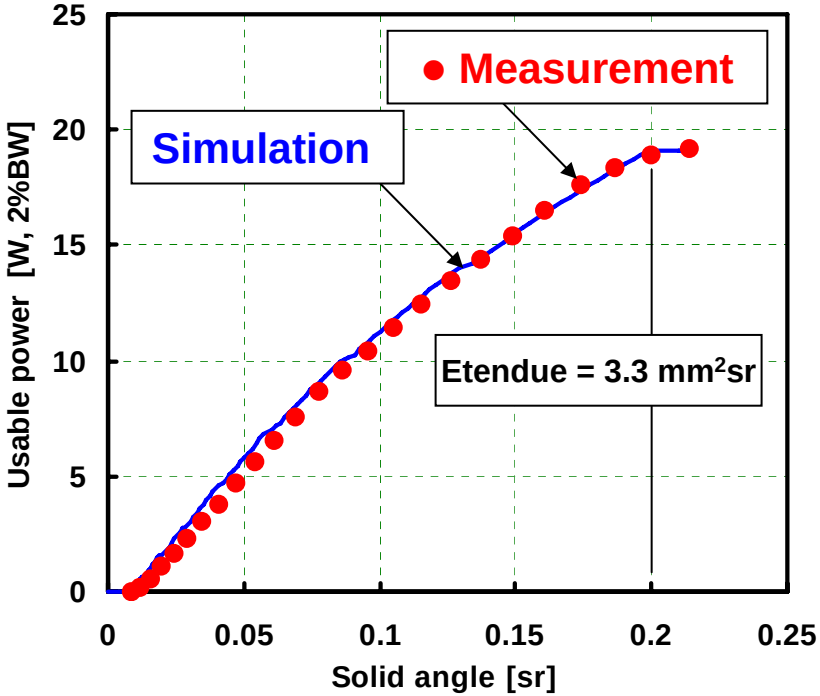


Angular distributions of simulation and measurement

In-band power at IF: 19 W of average power measured

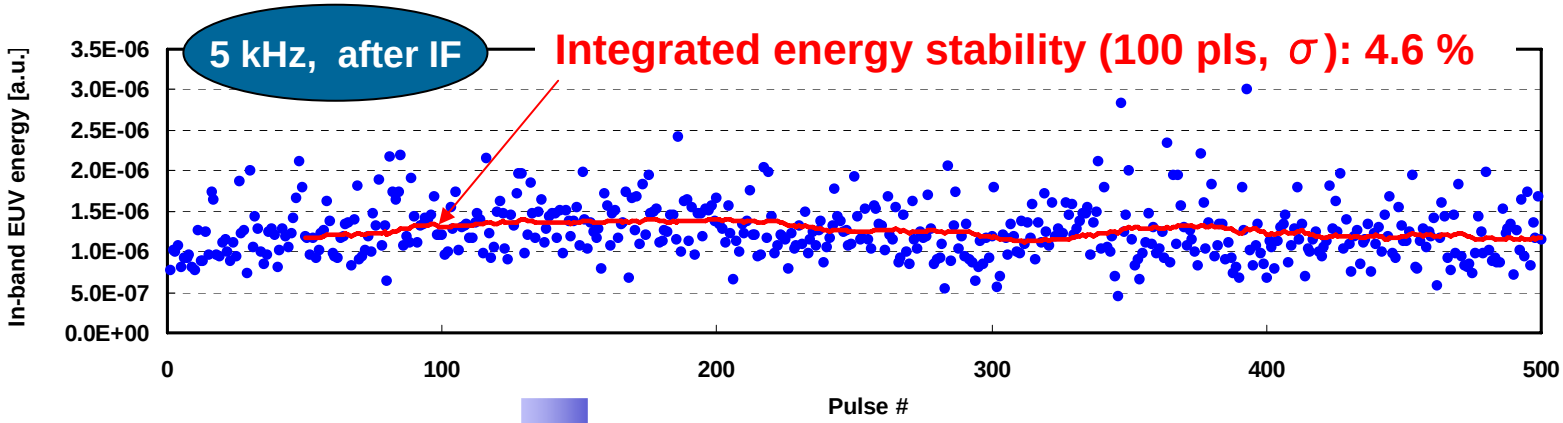


Angular distributions of simulation and measurement

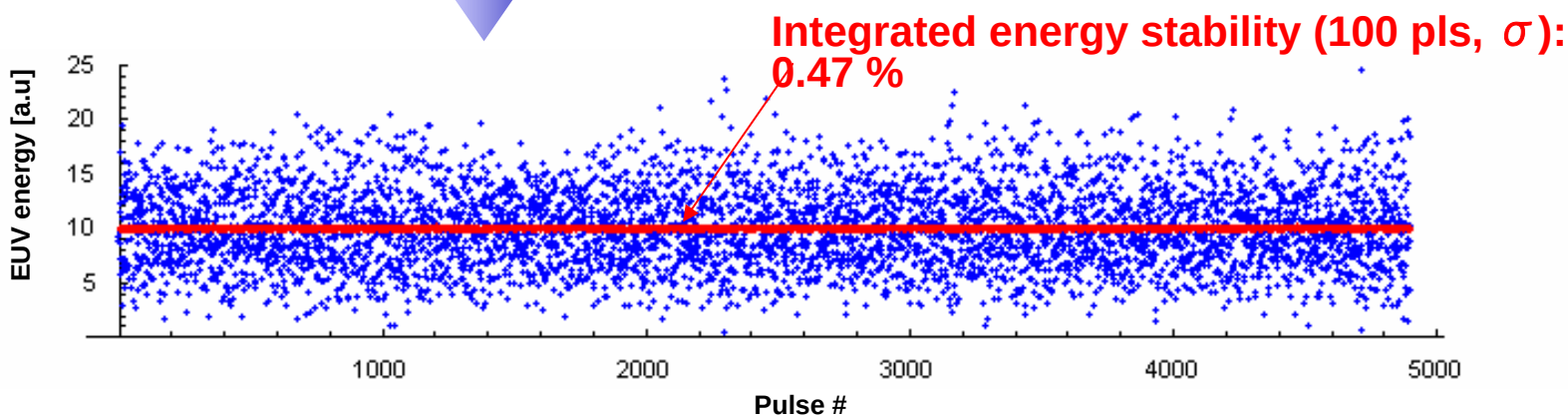


Output angle dependence of in-band energy after IF

In-band energy stability: <0.5 % achievable

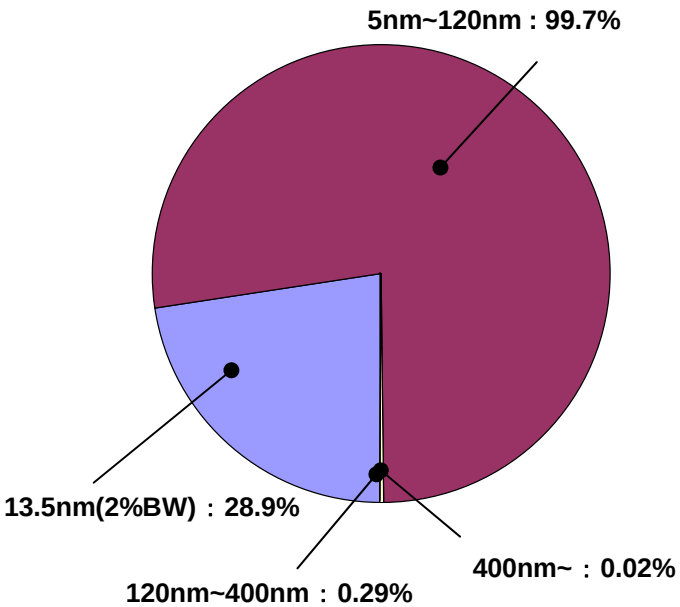


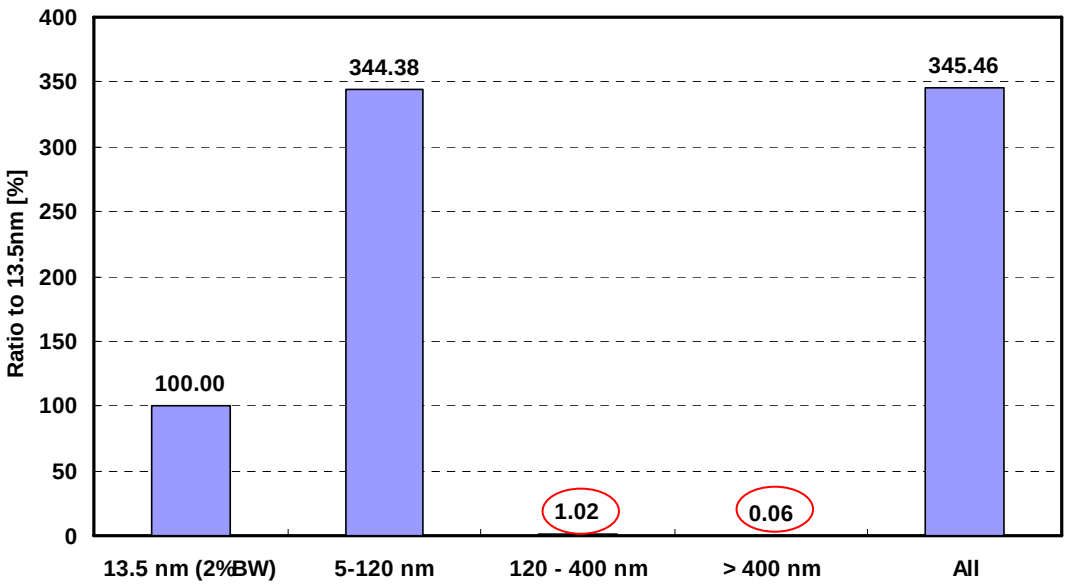
Feedback control (Simulation)



In-band energy stability at 5 kHz

Spectral purity at IF: DUV is ~1 % of in-band





Fraction of each wavelength band

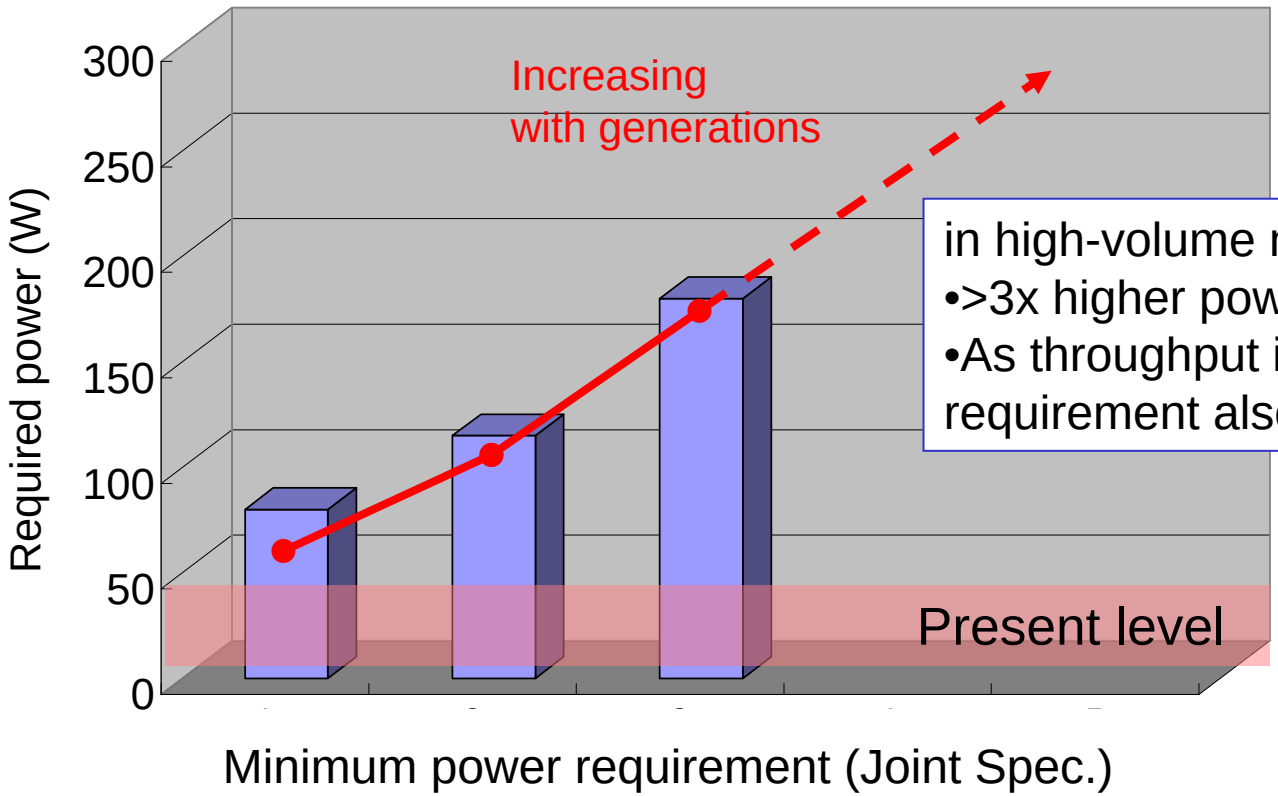
Ratio to 13.5nm radiation

Measured IF power: 19 W average

Evaluation item		Experimental result
Irradiance distribution at IF plane	EUV	Well consistent with simulation results
Approximate far-field image	EUV	Well consistent with simulation results
Angular distribution	Distribution profile (In-band)	Nearly consistent with simulation results
	In-band power	Average : 19.1 W / 3.3 mm^2sr @ 5 kHz
	In-band energy stability (Integrated over 100 pulses)	Free running : σ = 4.6 % @ 5kHz FB controlled : σ = 0.47 % [simulation]
Spectral purity	Energy ratio to 13.5nm ±2%BW	After 4.6mm aperture @ 5kHz 5 ~ 120 nm : 244 % 120 ~ 400 nm : 1.0 % 400nm ~ : 0.1 % All (w/o filter) : 345 %

- Source : Tin-fueled Z-pinch DPP source
- Collector : Multi-shelled grazing-incidence mirror (assembly with debris-shield)
- Metrology : All in-band energy detectors were cross-calibrated with “E-Mon”

HVM and beyond: constant increase of power required



in high-volume manufacturing
- >3x higher power than present level
- As throughput increases, power requirement also increases.

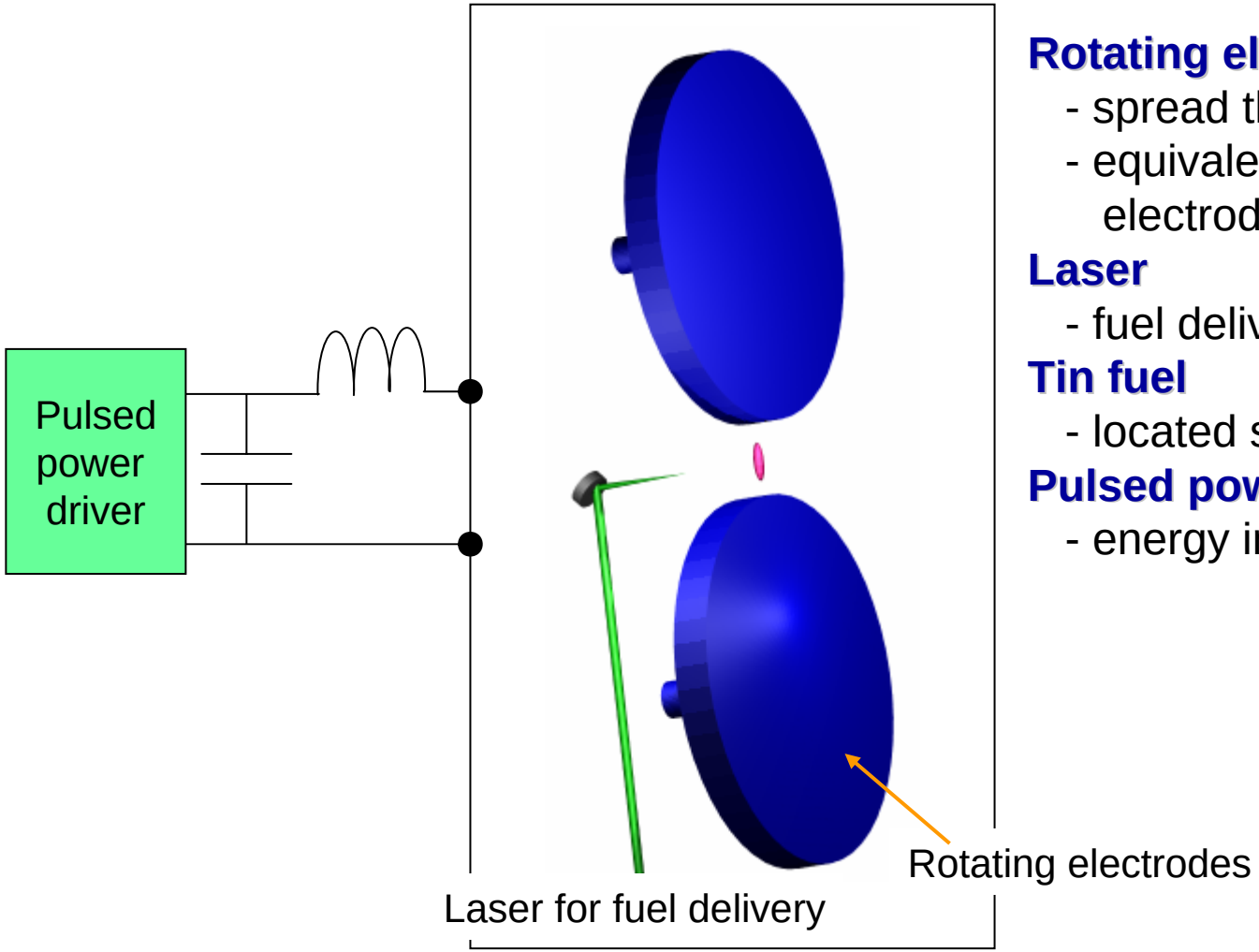
EUV power

Thermal load
Electrode lifetime

- Higher conversion efficiency
- Higher collection efficiency
- Higher input power (PRF and E/pulse)

~ Spread thermal load ~

A potential solution: Laser-Assisted DPP



Rotating electrode
- spread thermal load
- equivalent to large-surface-area electrode

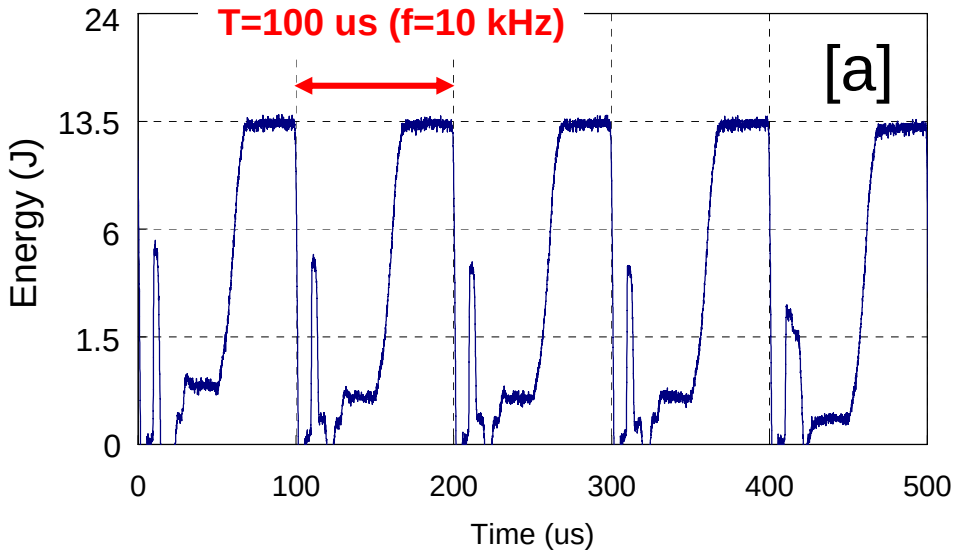
Laser
- fuel delivery to the discharge

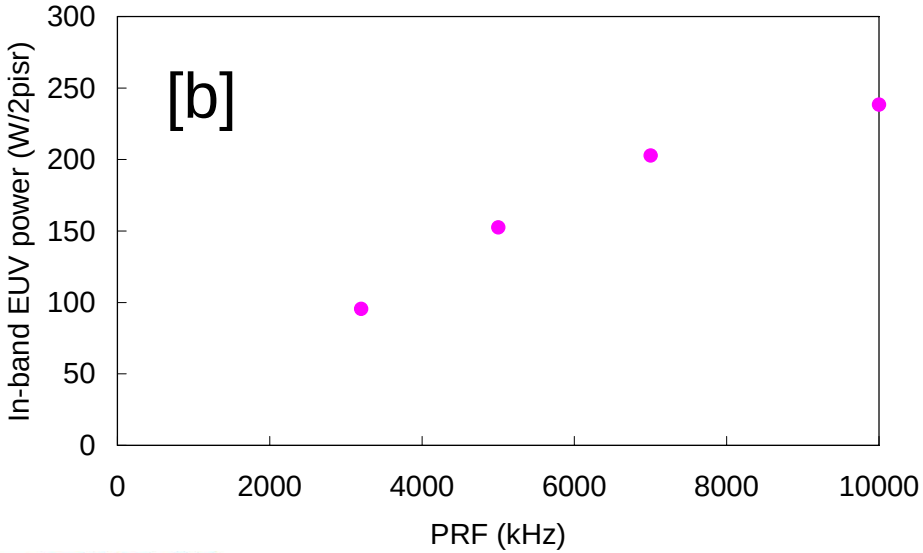
Tin fuel
- located somewhere in the source

Pulsed power driver
- energy input to the discharge

CONCEPTUAL diagram of laser-assisted DPP source

Scalability study: linear scaling up to 10 kHz confirmed



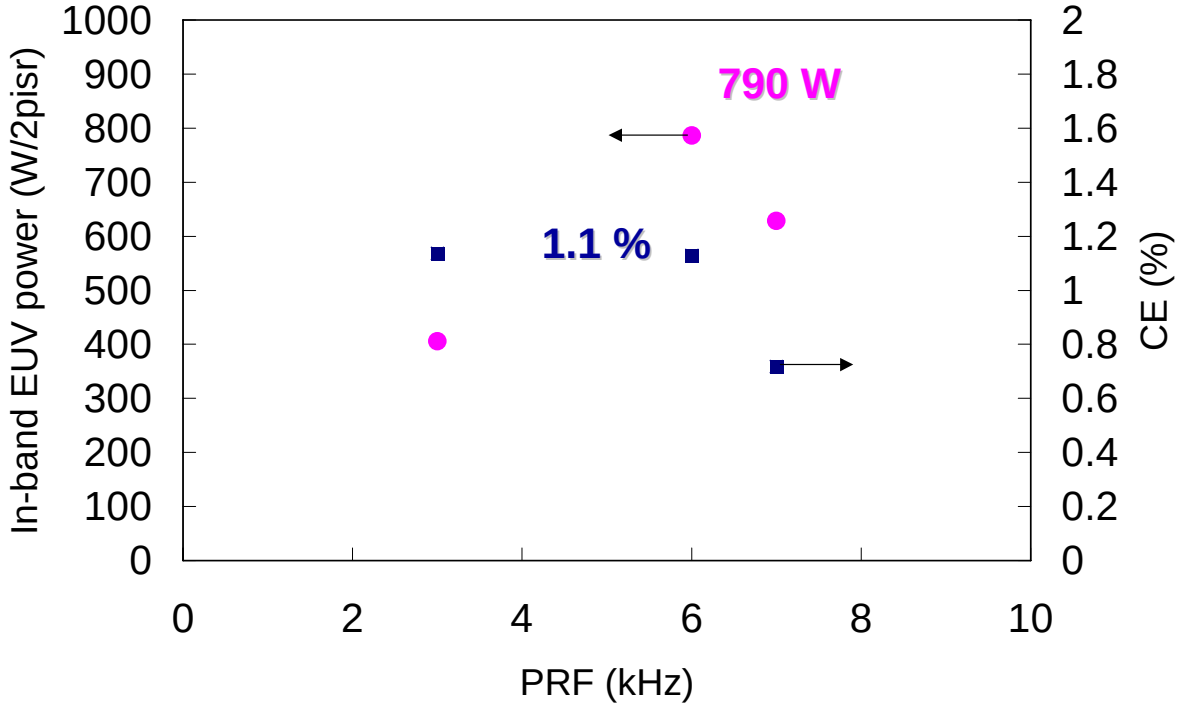


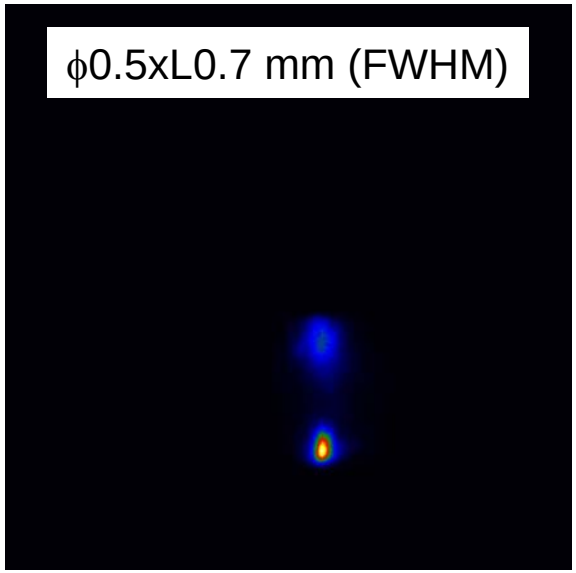
[a]10-kHz stable charge/discharge operation was confirmed on 150-kW system.

[b]Source power increases in almost proportional to PRF up to 10 kHz.

Construction of 20-kHz system in progress targeting 1~2 kW/2πsr of in-band EUV power.

Power-related study: 790 W achieved at 6 kHz





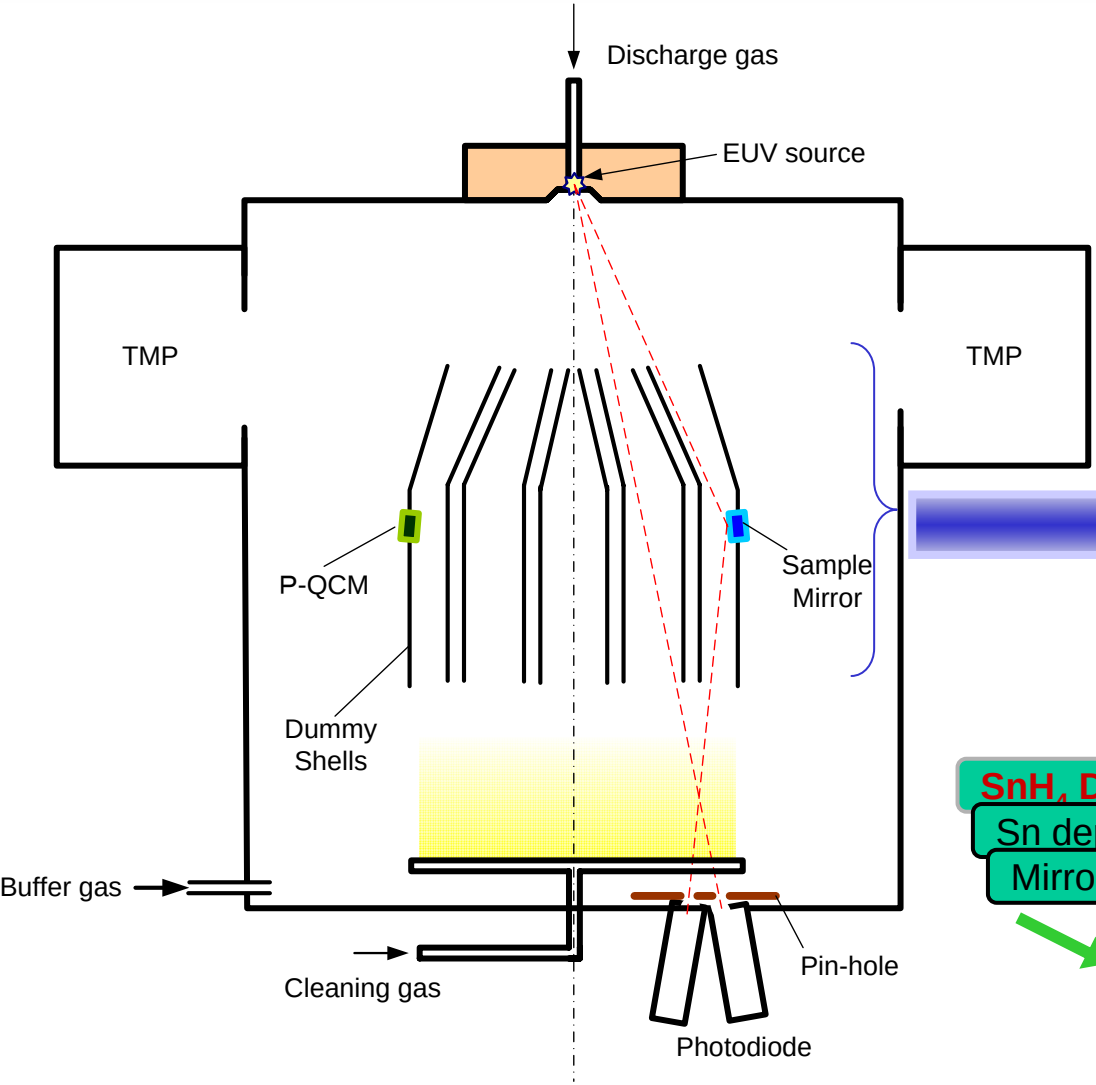
- **Stability**
- **CE**
- **Plasma shape**
- **Linearity at >7 kHz**

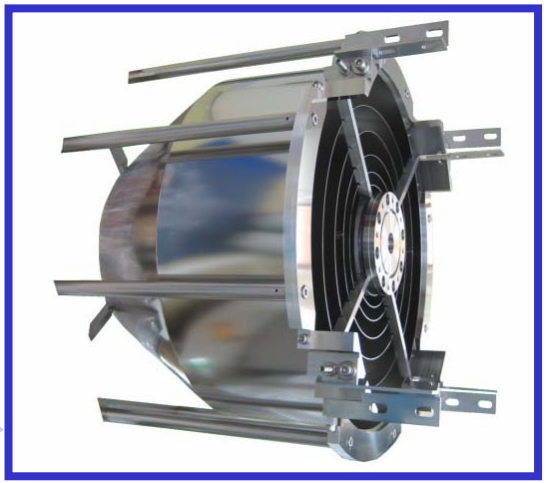
Improvement

Power input
Energy per pulse
Repetition frequency

HVM source power

Debris treatment: important in any types of source





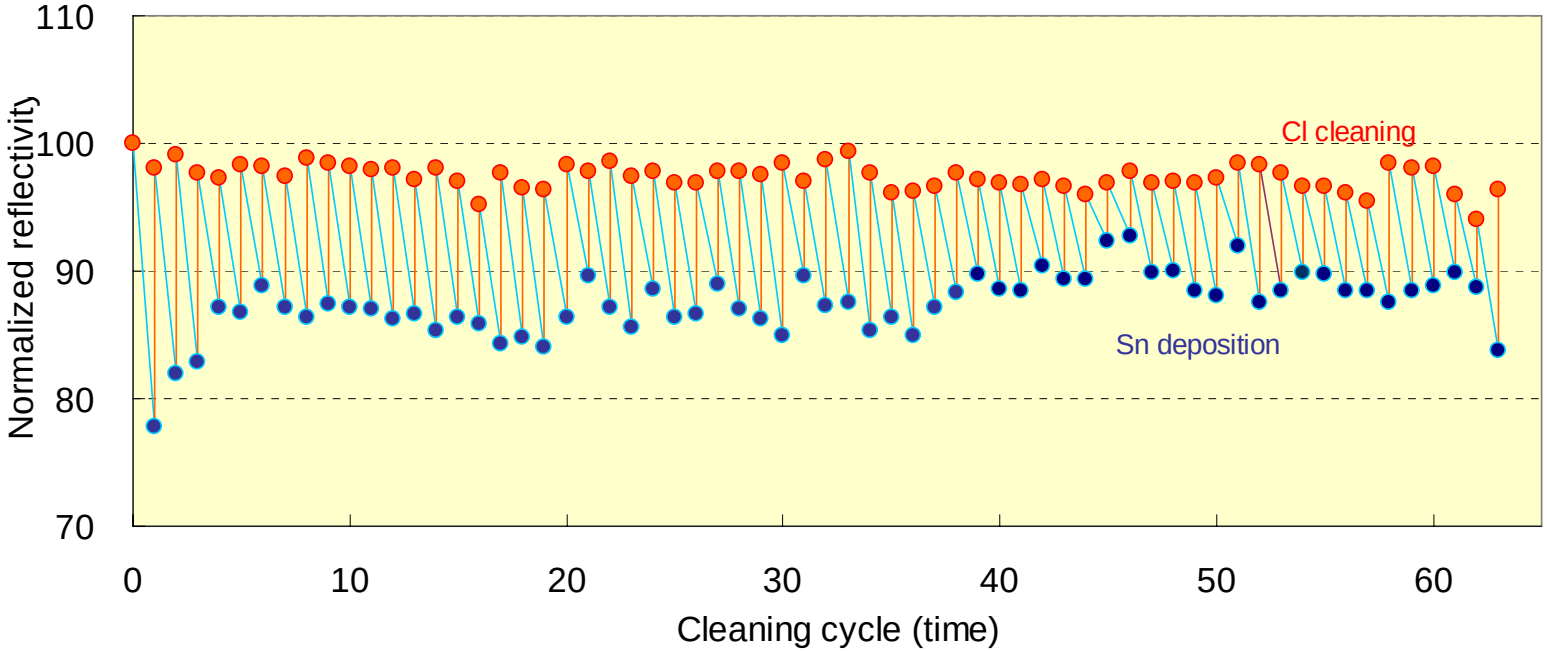
Collector mockup (12 dummy shells)

In-situ cleaning test cycle

SnH_4 DPP operation
- Sn deposition on mirror
- Mirror reflectivity measurement

Halogen Cleaning
- Sn removal from mirror
- Mirror reflectivity measurement

Debris treatment: cleaning works effectively



Cleaning of mirror samples on the dummy shell

After **63 cycles** of cleaning, relative reflectivity remains >90 %.

CC-P02: Debris mitigation and mirror cleaning for Sn-fueled EUV source

Summary and future works

Summary

•**Evaluation of intermediate focus on Sn-fueled source**

Power: 19 W confirmed.

Collection performance: experimental data consistent with simulation.

OoB: data showed enough less contribution of DUV.

•**Source development for >HVM**

Power: 790 W at 6 kHz.

Scalability: tested up to 10 kHz, resulted in good scalability.

Future works

•**Continuation of IF evaluation**

•**Development of 20-kHz discharge system**

•**Improvement of rotating-electrode DPP source performance**