High-radiance LDP source for mask inspection

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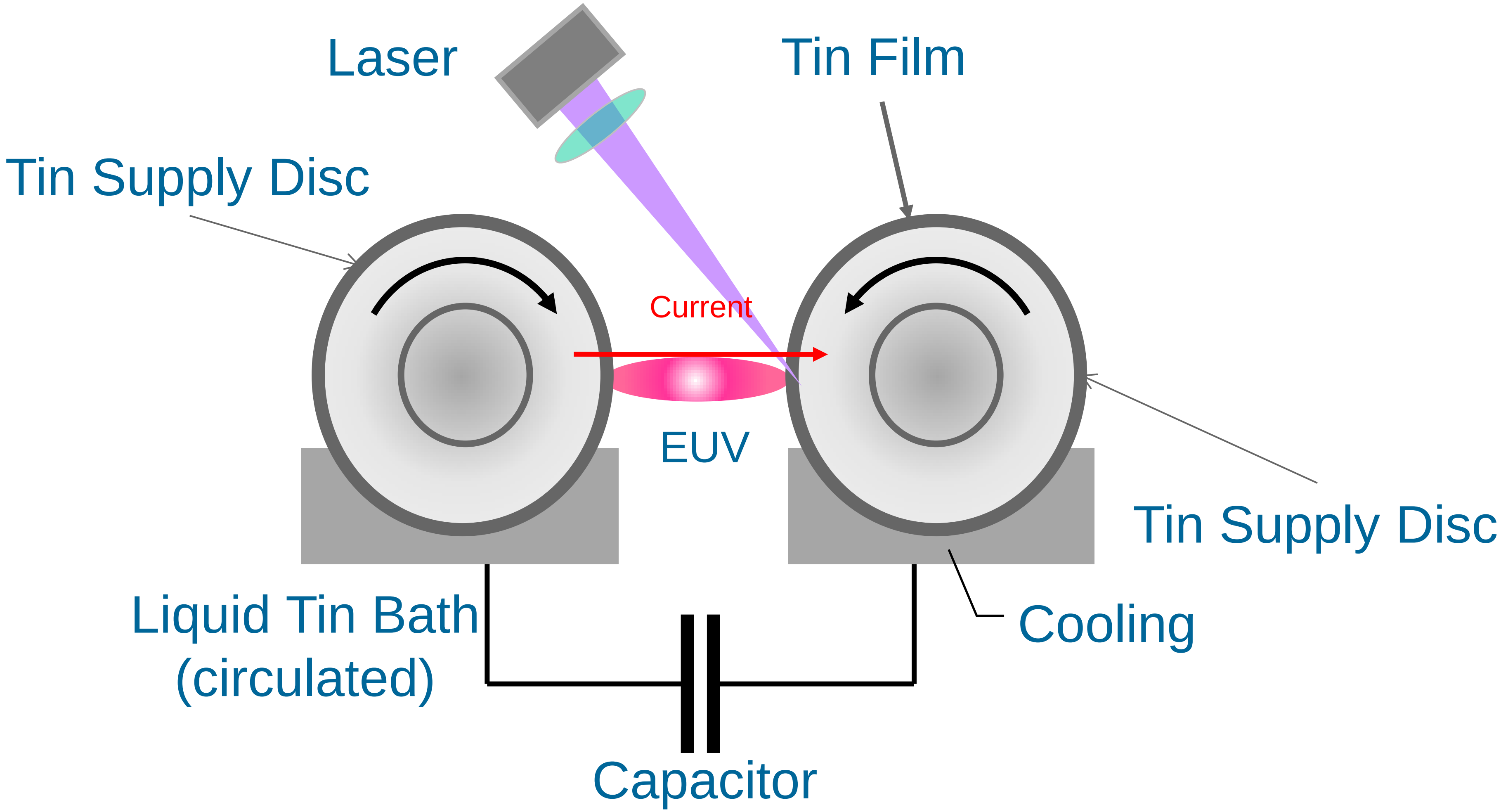
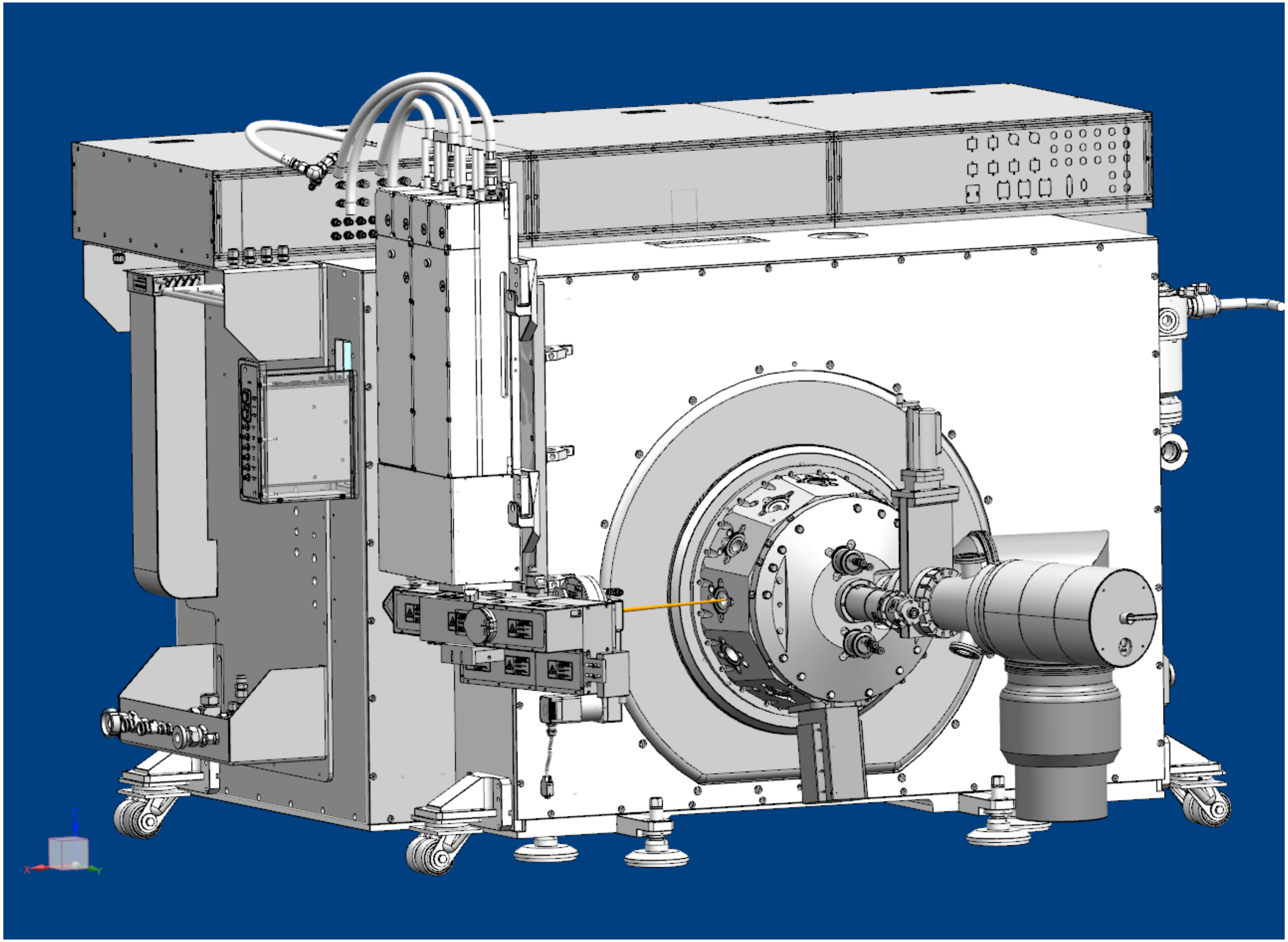
Laser-assisted Discharge-produced Plasma



Prototype LDP machine



High radiance, appropriate plasma size

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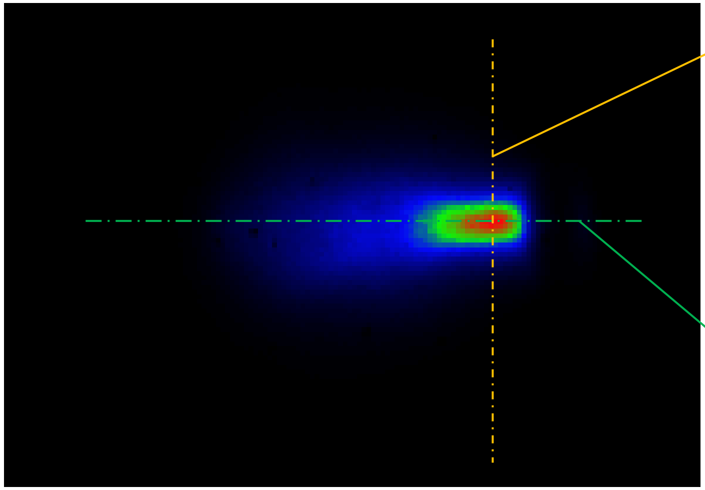
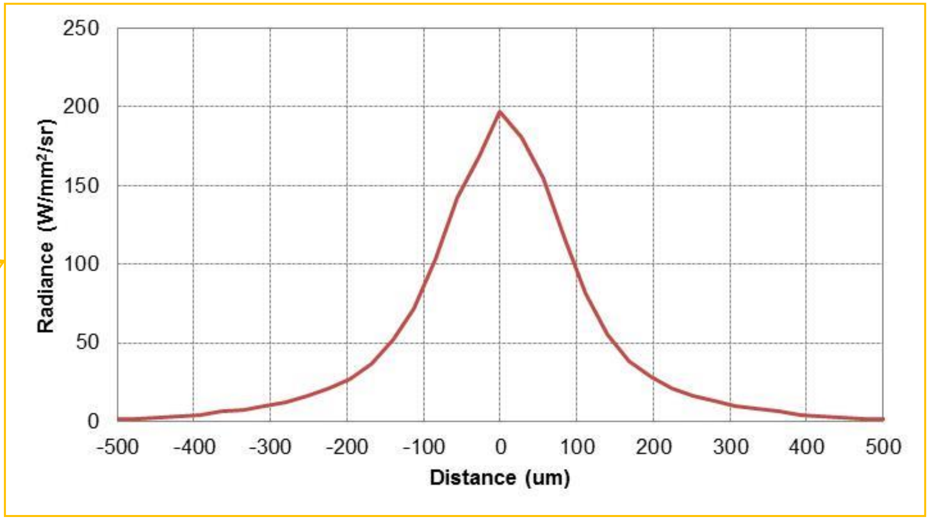
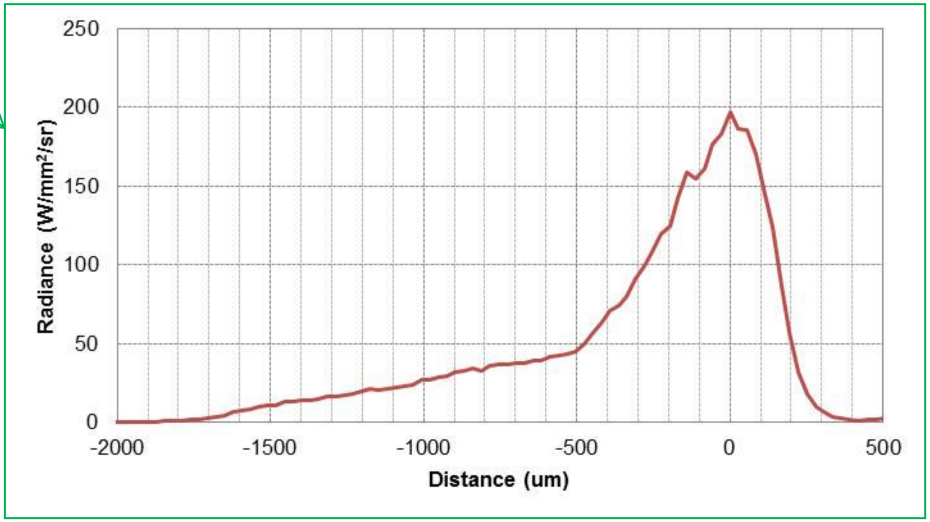
- ☐ Very high peak radiance at plasma
- ☐ Plasma size smaller than DPP, larger than LPP: good spatial stability







10 kHz, continuous operation

- ☐ Diameter: 200 μm (FWHM)
- ☐ Length: 450 μm (FWHM)

Nice Sn spectrum

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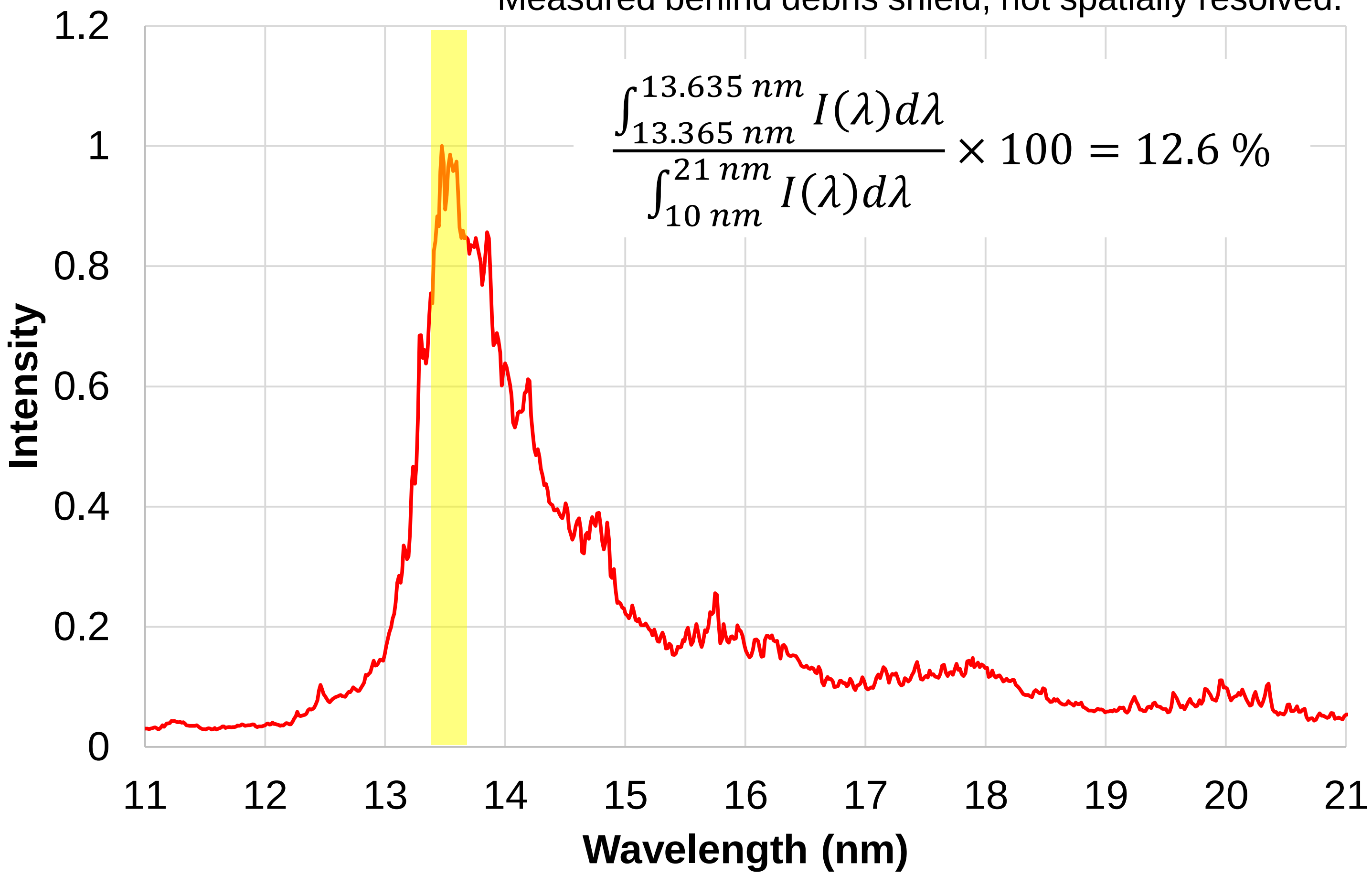
- Similar spectrum to Sn-LPP
- Beneficial in inspection and other applications

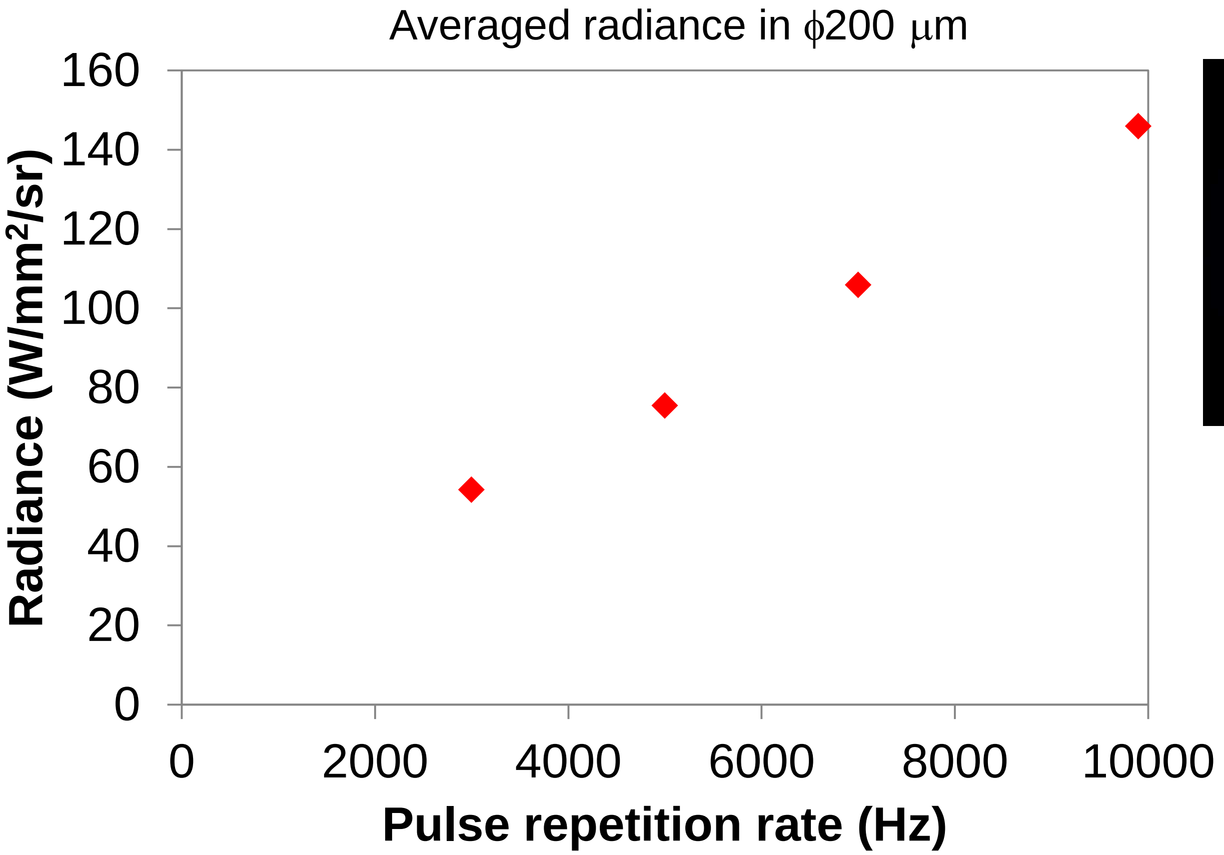
Measured behind debris shield, not spatially resolved.

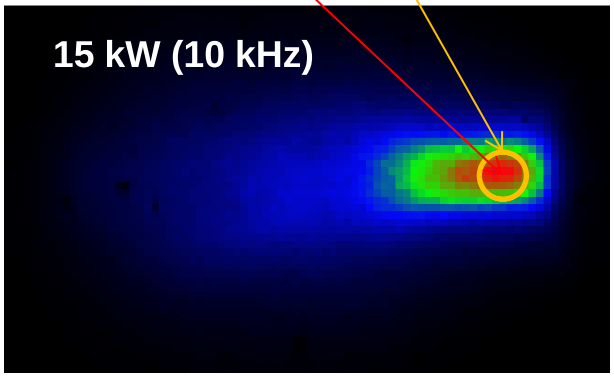


$$\frac{\int_{13.365\,nm}^{13.635\,nm} I(\lambda)d\lambda}{\int_{10\,nm}^{21\,nm} I(\lambda)d\lambda} \times 100 = 12.6\ \%$$

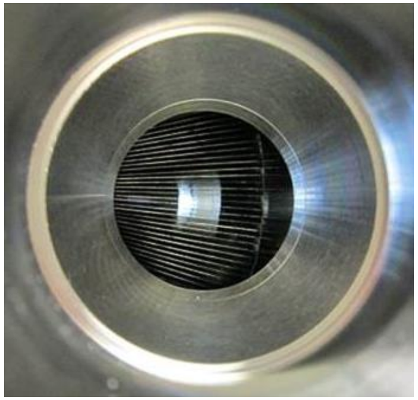
Radiance at plasma: 140 W/mm^2/sr

- Peak radiance: 180 W/mm^2/sr
- Area-averaged radiance: 140 W/mm^2/sr



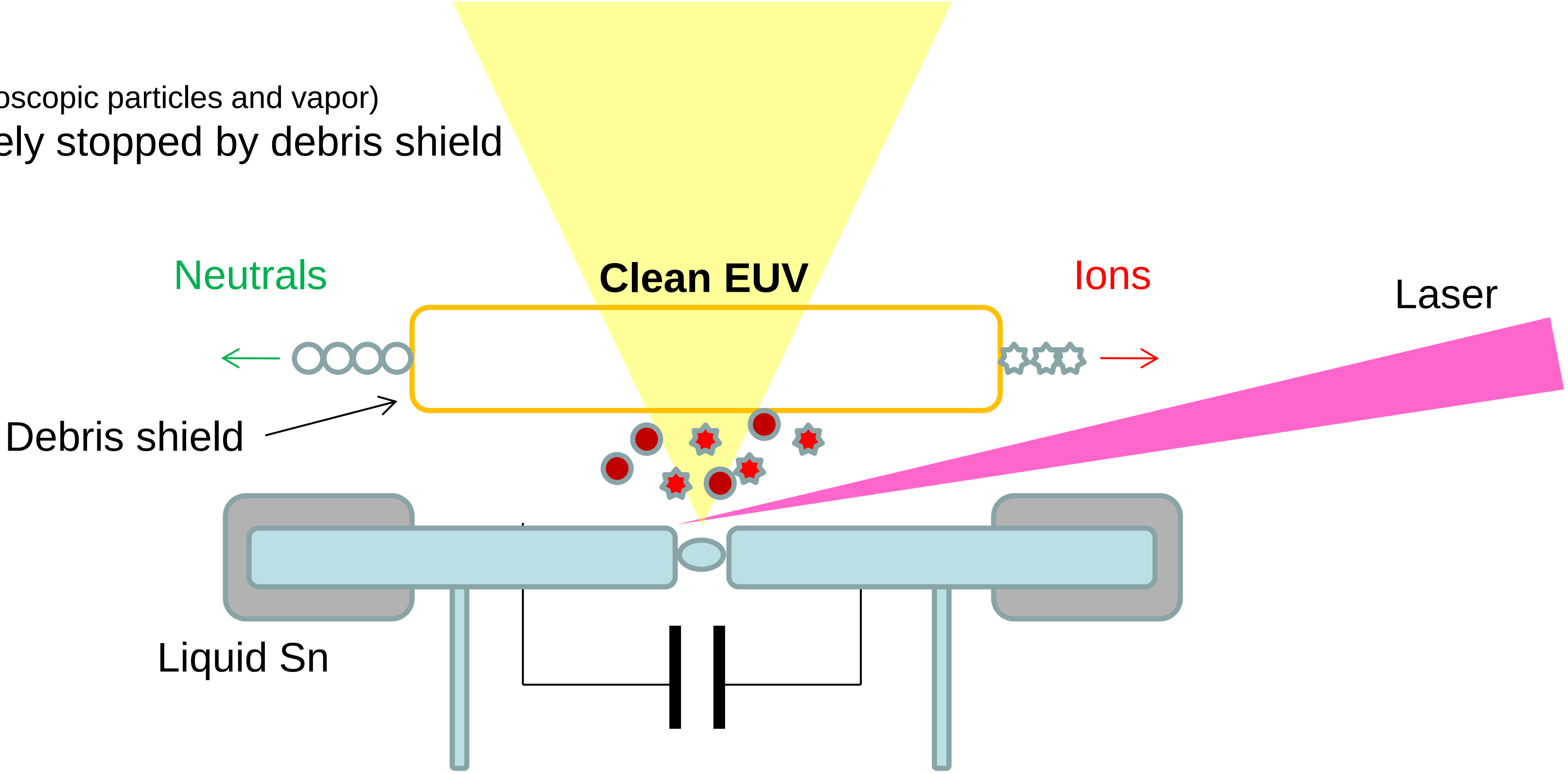


Mechanical debris shield concept



Charged particles (fast ions)
- Mostly stopped by debris shield
- Slows down in debris shield

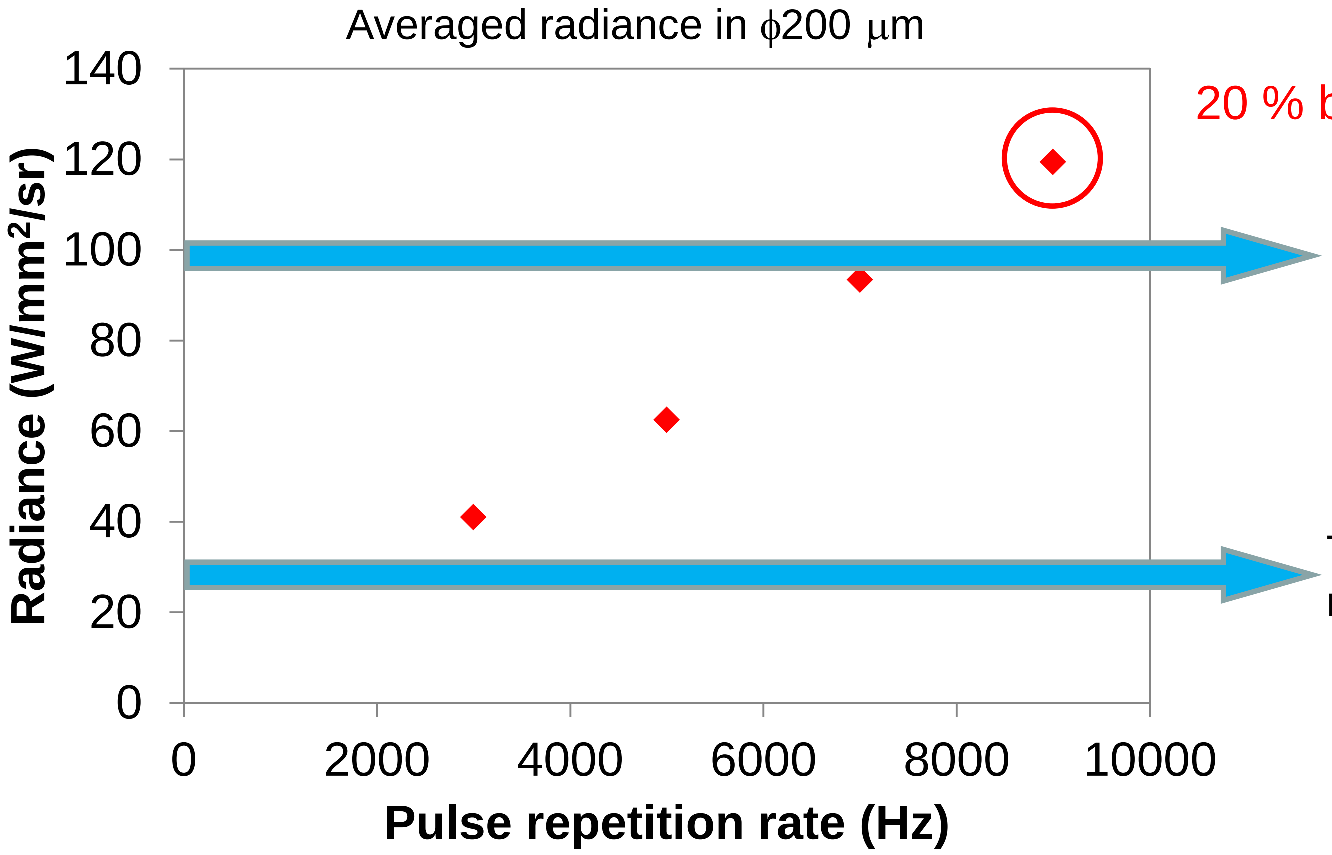
Neutrals
(Macro/microscopic particles and vapor)
- Completely stopped by debris shield



Radiance behind debris shield: 120 W/mm^2/sr

Measured behind debris shield as clean EUV photon

- ☐ Peak radiance: 145 W/mm^2/sr
- ☐ Area-averaged radiance: 120 W/mm^2/sr



20 % brighter than wanted

This is what the industry wants.

This is the need.

Energy stability: <10 % pulse-to-pulse

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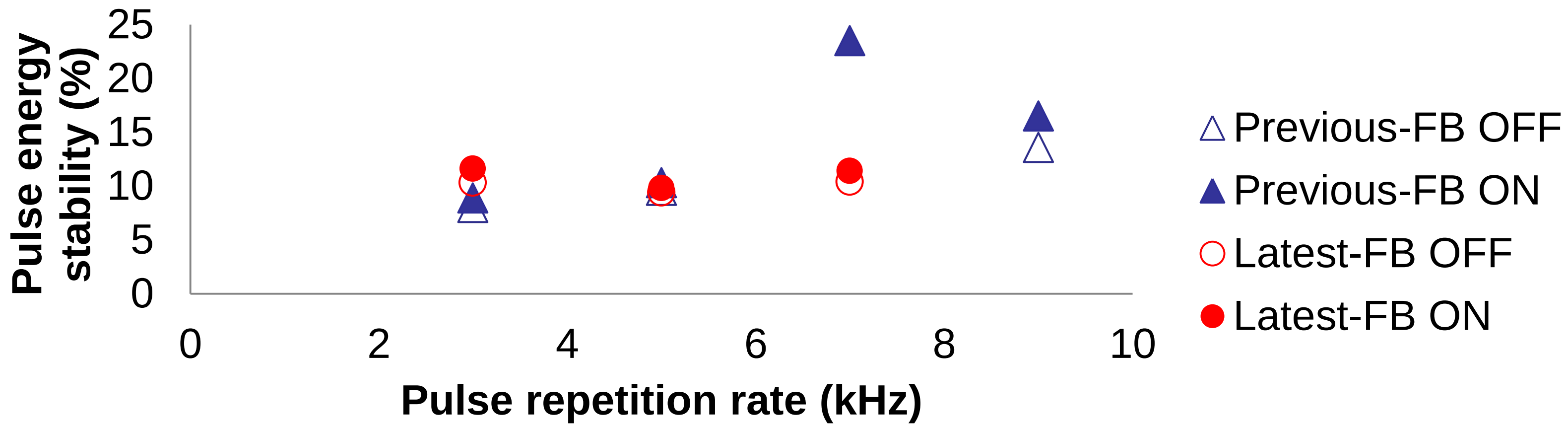

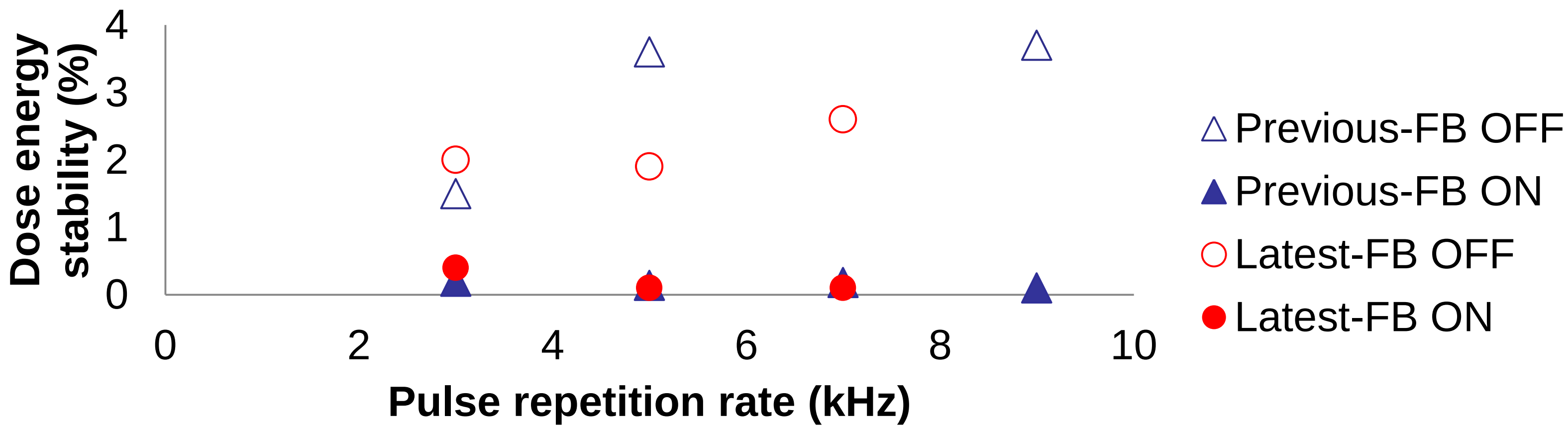

Position stability: ~6 μm

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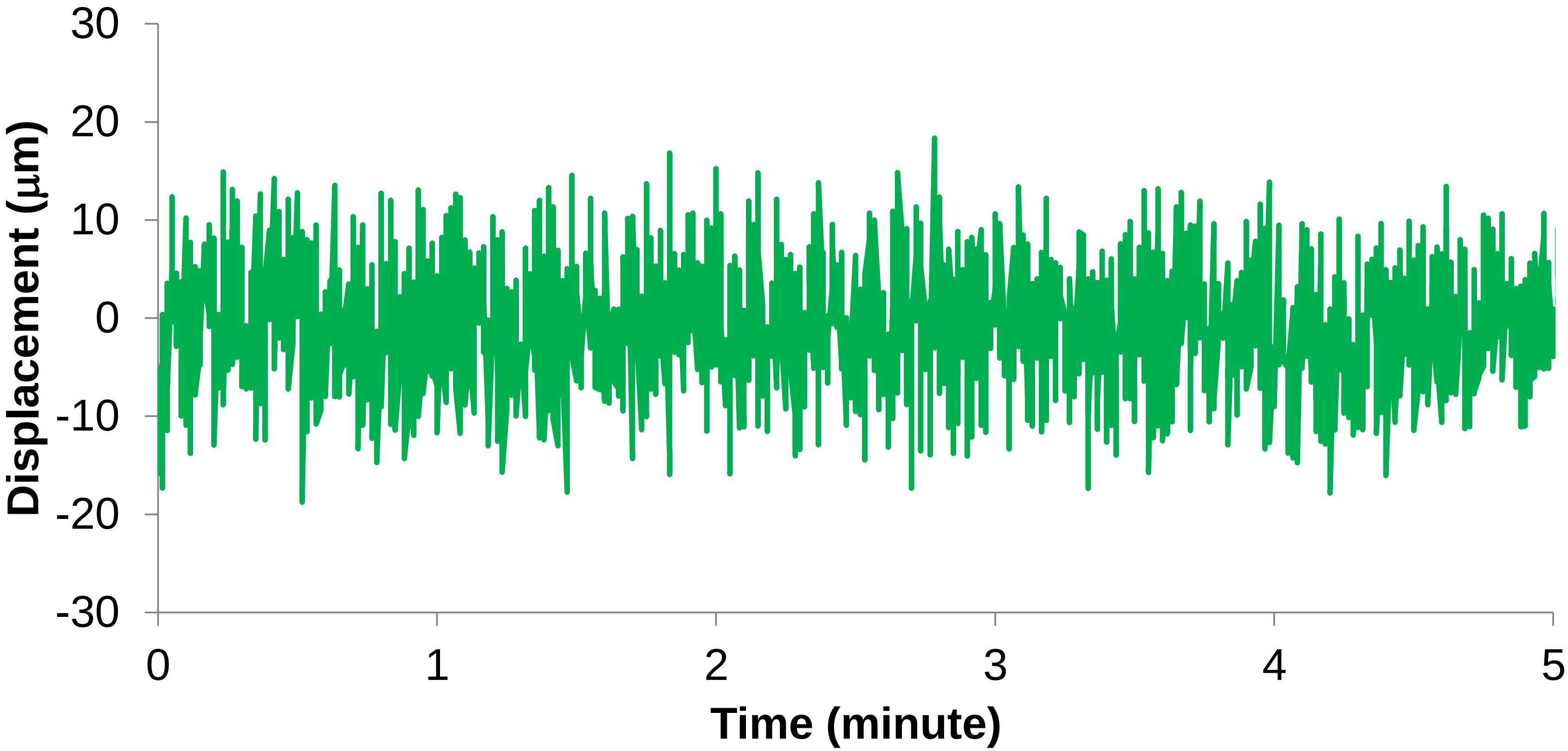
- ❑ Measured with camera placed on optical axis
  - ❑ Exposure time: 5 ms
- ❑ Standard deviation: 6.0~6.4 μm
  - ❑ <3 % of plasma FWHM (200 μm)



Reliability: tests ongoing

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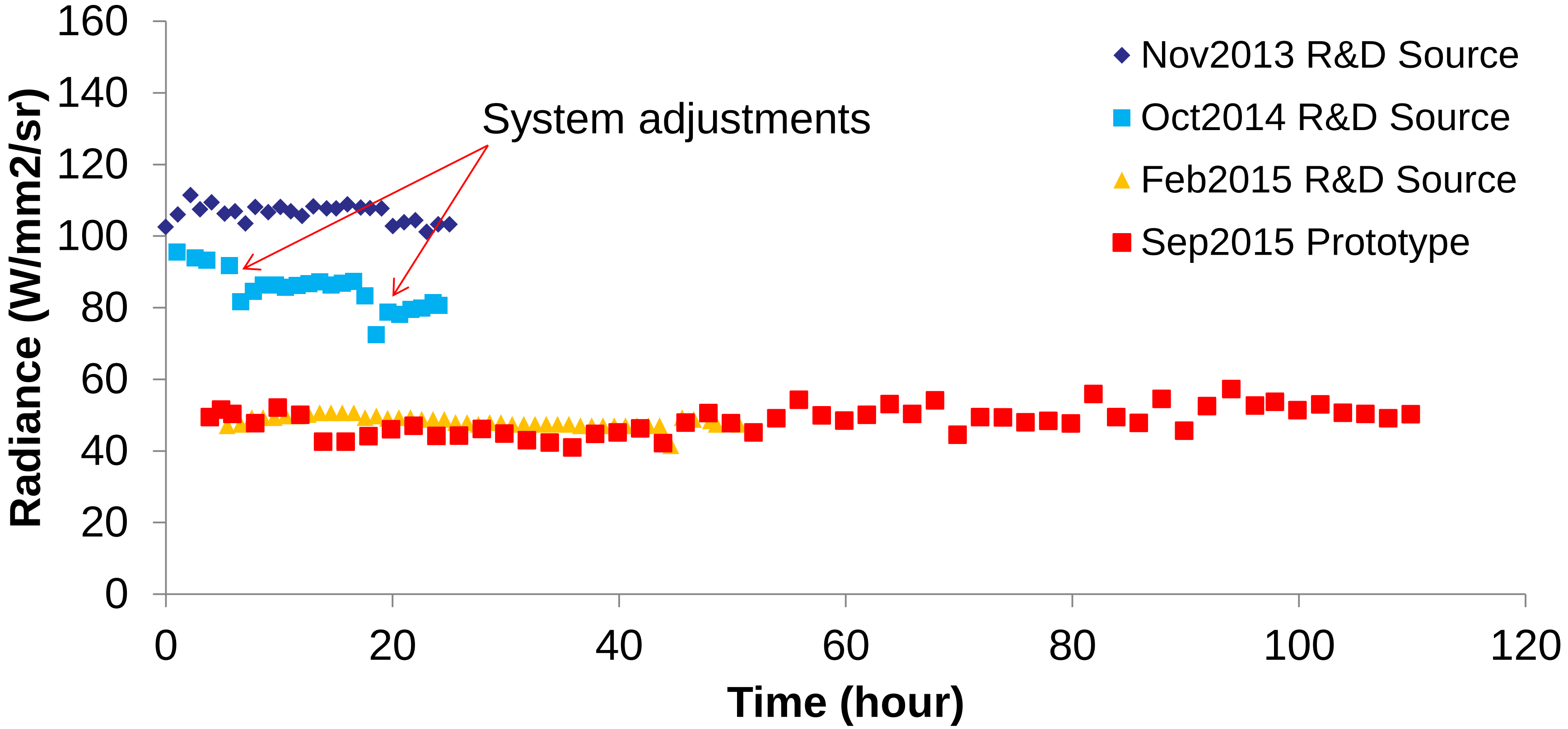
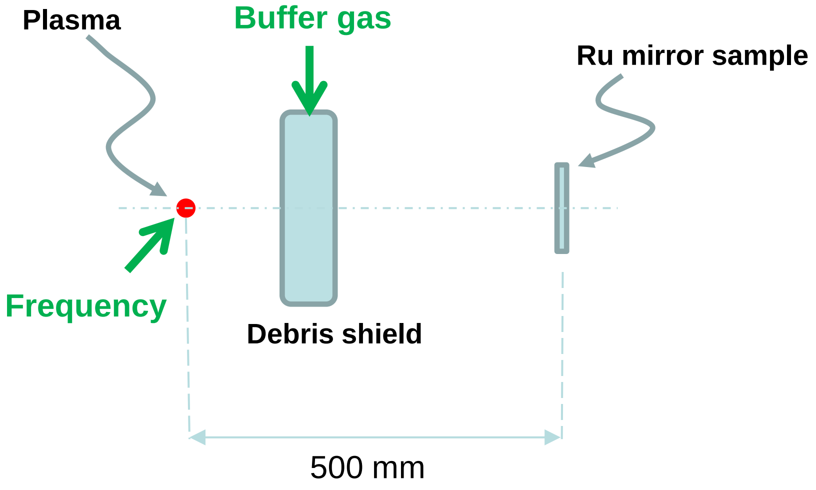
- ❑ The prototype machine is dedicated to days-long non-interrupted operation test.
- ❑ Several 5-day operations were carried out.
- ❑ Output radiance will be increased by (1) increasing operation frequency and (2) parameter optimization, and stabilized by (3) applying stabilization control.

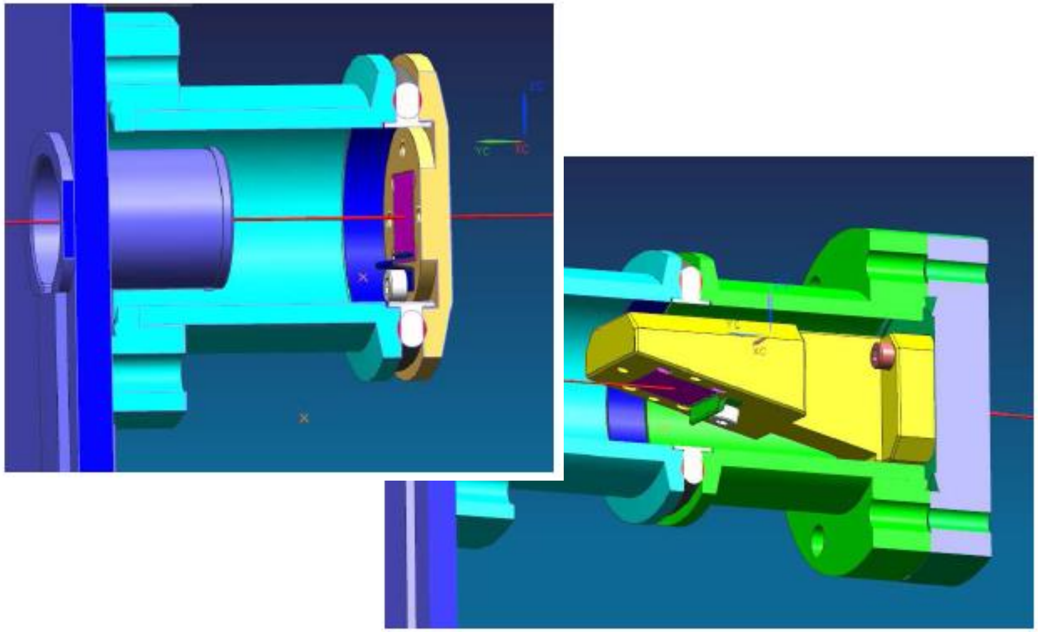


Cleanliness evaluation

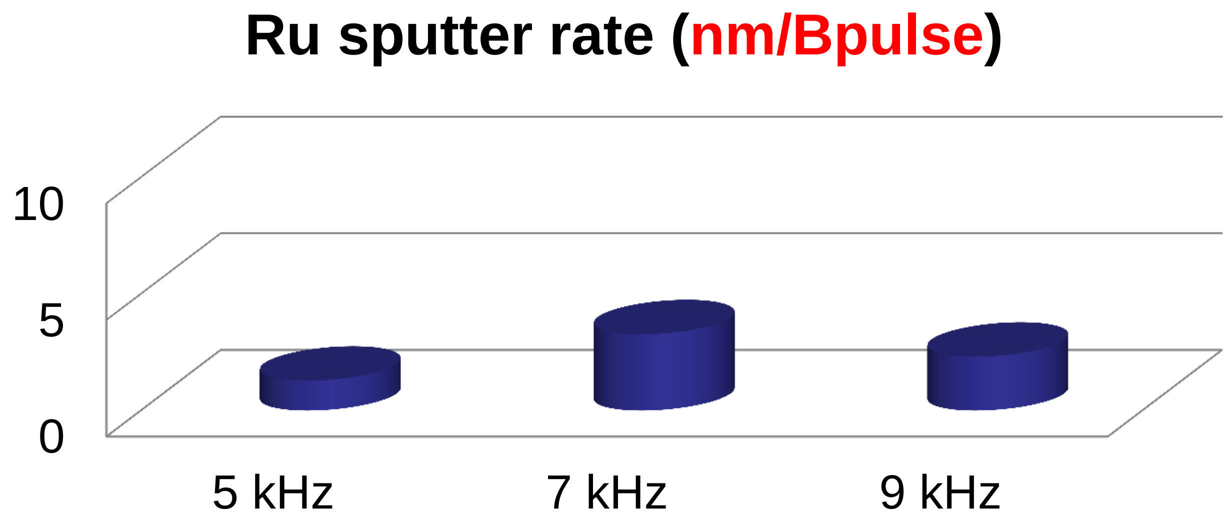


Discharge frequency:	5, 7 and 9 kHz
Buffer gas:	Variable
Sample:	8-nm-thick Ru on Si
Source-sample distance:	500 mm
Incidence angle:	90°, 15°
Analysis:	XRF

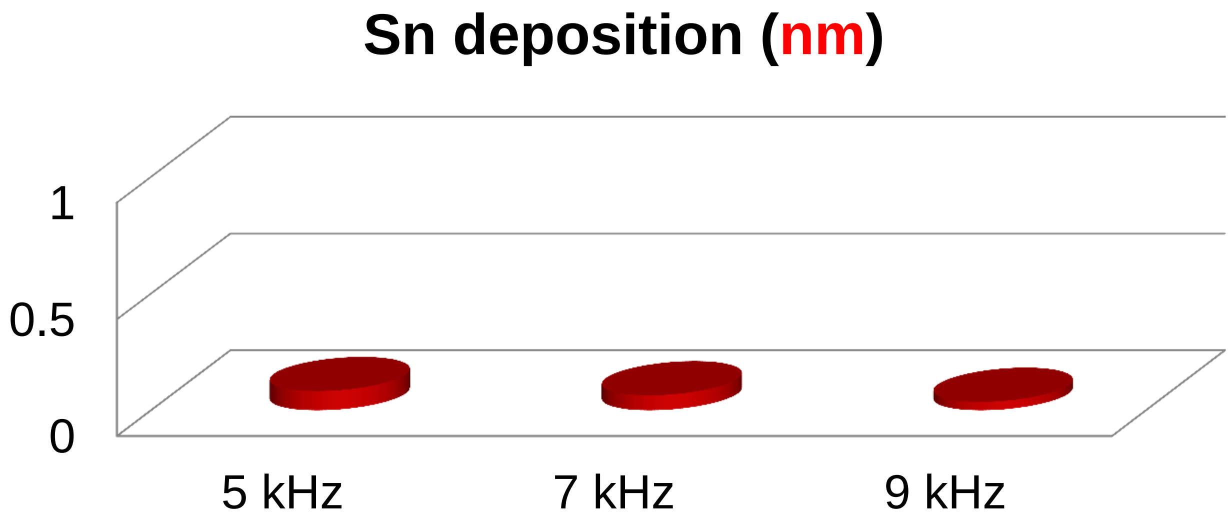
After 100~500M pulse



Cleanliness: influence of frequency



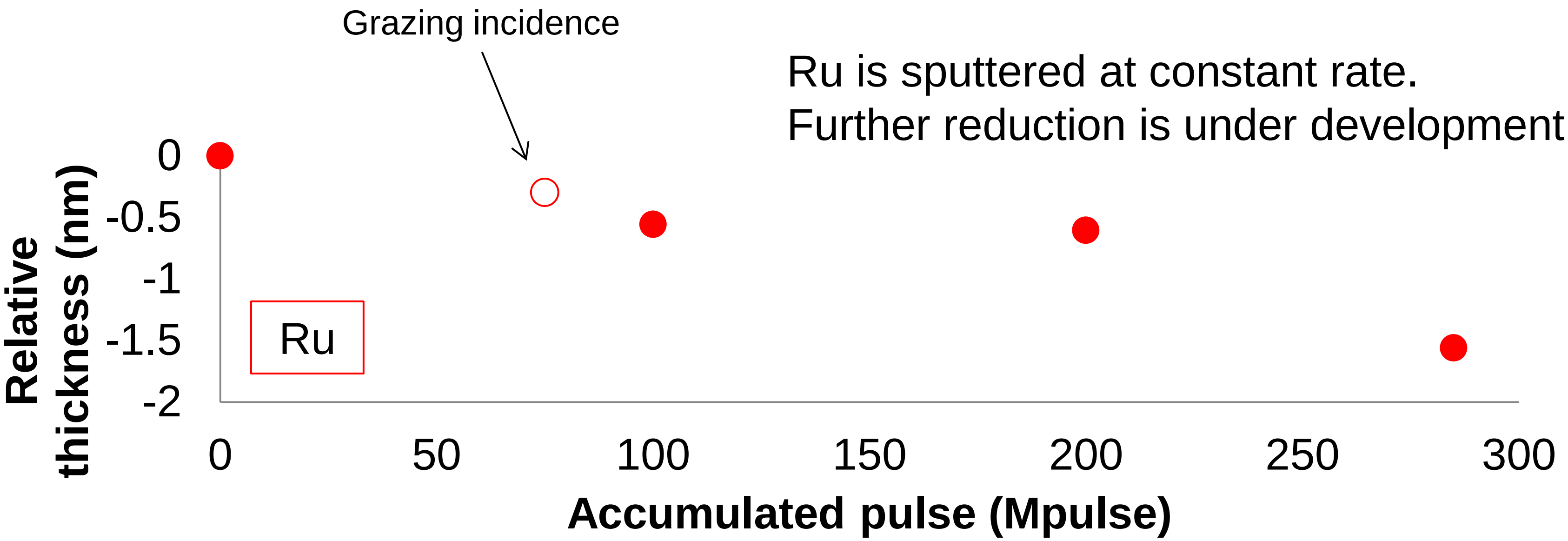
- There is erosion due to ions passing through the debris shield.
- There is a weak relationship between sputter rate and frequency.



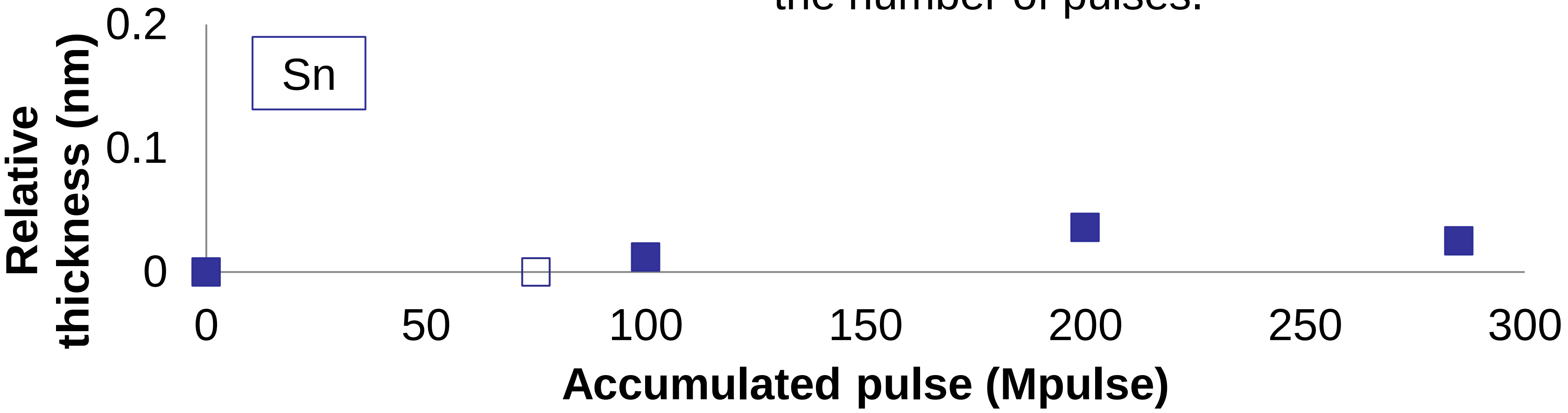
- There is a slight deposition of Sn.
- However, according to the experiments done so far, it does not grow and stops around at <0.1 nm.

Cleanliness: influence of number of pulses

Ru is sputtered at constant rate.
Further reduction is under development.



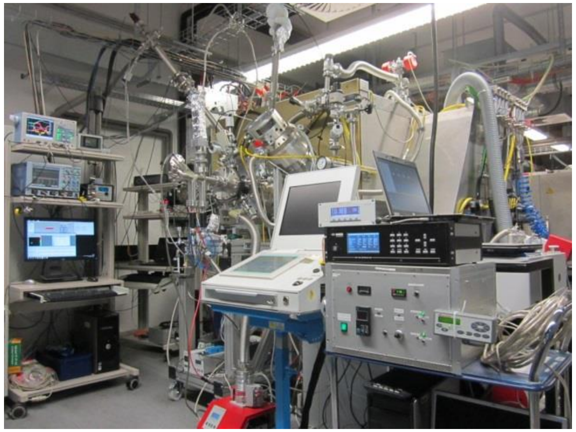
Sn layer does not grow in proportion to the number of pulses.



Summary

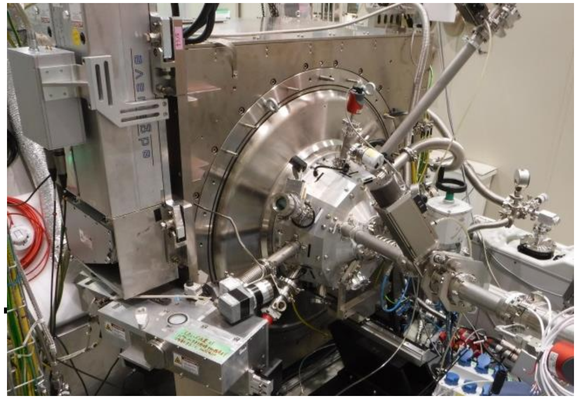
R&D source

- ☐ Energy stability and position stability have been improved.
- ☐ Sample exposure experiments are being performed.
  - ☐ Improved version of the debris shield has been designed and will be tested early 2016.
  - ☐ It has an improved gas distribution leading to better mitigation performance.



Prototype source

- ☐ 5-day non-interrupted operations have been carried out several times.
  - ☐ Successful 5-day-long non-stop operations.
  - ☐ Aiming at system/module reliability improvement.
  - ☐ Stabilization control will be implemented.



Performance summary

Item	Performance	Remark
Pulse repetition frequency	up to 10 kHz	variable
Duty cycle	100 %	
Input power	up to 15 kW	variable
In-band EUV power	up to 300 W/2πsr	at plasma
Radiance	**120 W/mm^2/sr*** * value measured behind debris shield	9 kHz 200-μm area averaged
Plasma size	200 × 450 μm	FWHM typical value
Energy stability	Pulse: ~10 % Dose: 0.1**~3 % ** with feedback control	
Radiance stability	5.8 %*** ***from 1.5-ms-exposure observation	10 kHz
Position stability	6~10 μm	