ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

LEC
Laboratory for Energy Conversion

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High brightness EUV source for EUVL applications

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Outline

- Laboratory for Energy Conversion, ETH.
- Applied Laser Plasma Science (ALPS) Facility.
- Droplet Dispenser.
- Computational Studies of Droplets.
- Droplet Stability Measurements.
- Droplet-by-Droplet Triggering.
- Pinhole camera and spotsize measurements.
- High Brightness Collector and I.F. measurements.
- EUV radiation measurements and results.
- Adlyte Ltd. Products: Debris mitigation results from HPS.

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Laboratory for Energy Conversion

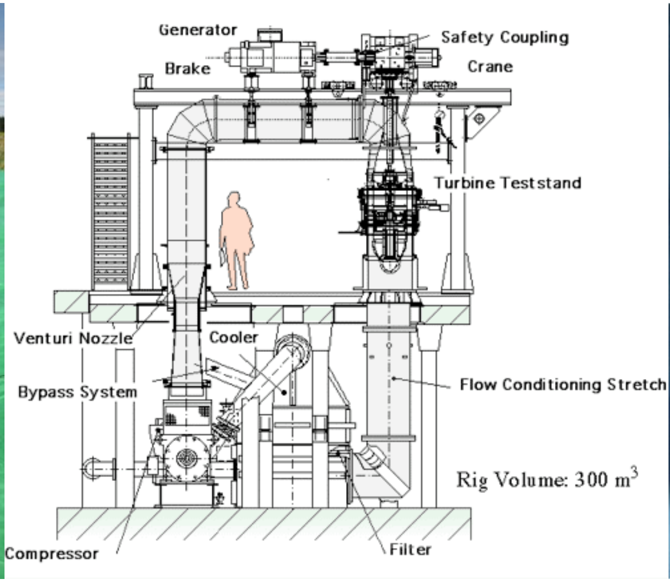

Figure 1:2 Sensor FRAP Probe with 1.8mm tip outer diameter of LEC.

<u>People:</u>

- 64 members of staff including PhD students, post-docs, Msc students, Electrical engineers and Workshop technicians.

<u>Fields of Research:</u>

- Power, Energy and Turbomachinery
- Applied Laser Plasma Science
- Environmental and Renewable Energy
- Instrumentation

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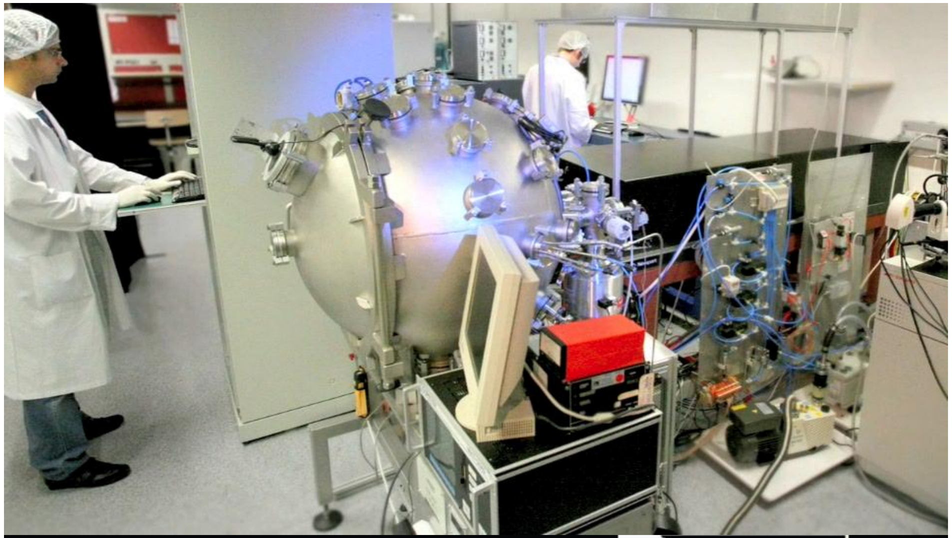
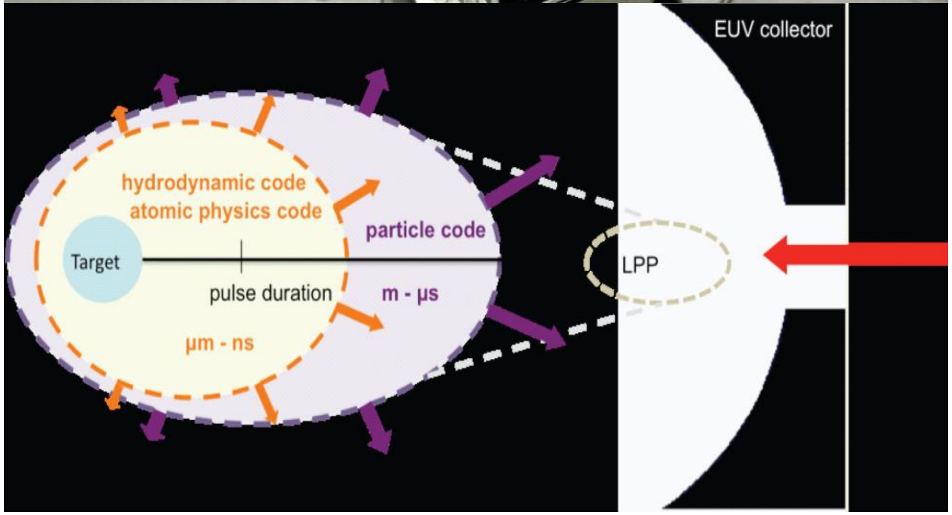
Applied Laser Plasma Science (ALPS) Facility





<u>Laboratory:</u>

•AO16 Nd:YAG Laser, 1064 nm, 20 kHz, 1.6 kW.

•Entire system automated from a single control unit.

<u>Computational studies:</u>

•2-D/axisymmetric hydrodynamic-particle code used to model plasma expansion from laser-droplet interaction up to the collector optic.

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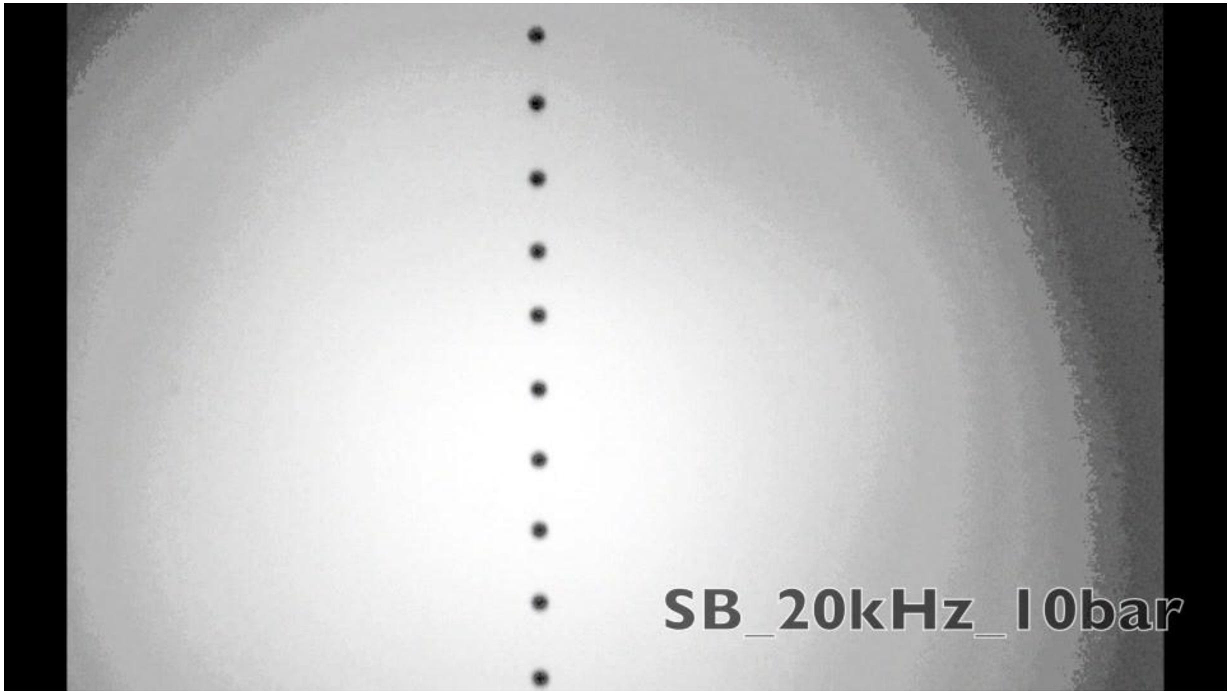
Droplet Dispenser



- Images recorded using Xe flash and macroscope.
- Single droplet exposure.
- Measurements recorded at 5 Hz.

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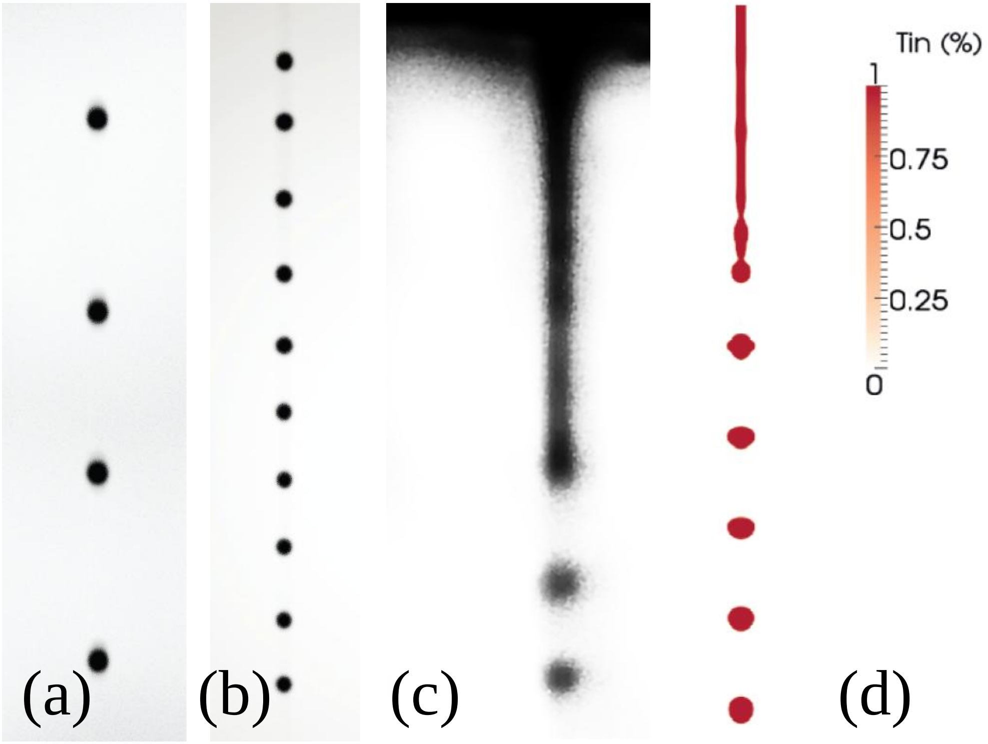
Computational Studies of Droplets

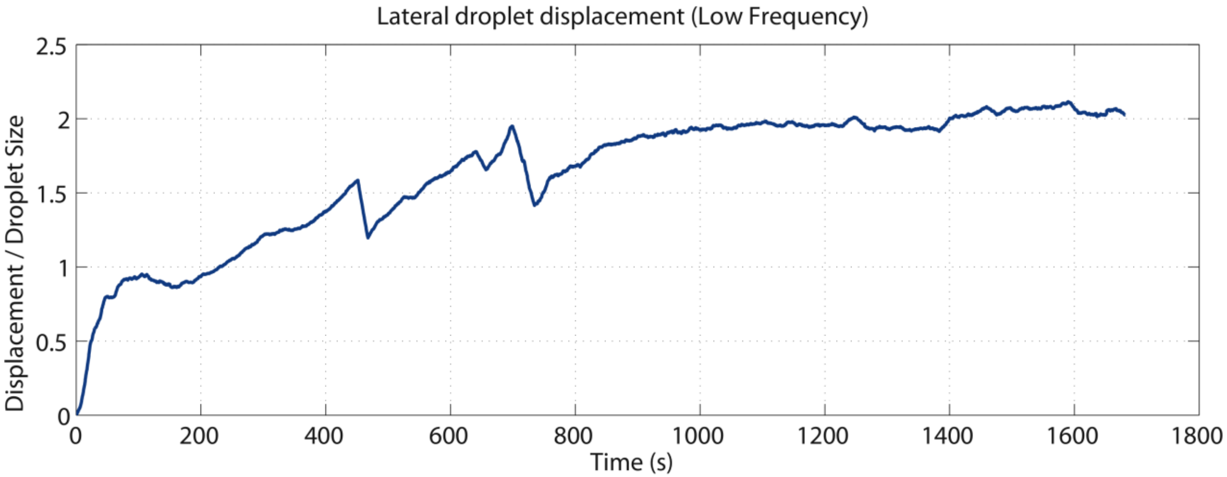
Droplet generator development is supported by experimentally validated computational simulations of droplet formation.

100 kHz droplet validation			
	Experiment	Simulation	Dev
Diameter	38um	43um	13%
Velocity	12.1m/s	11.1m/s	9%



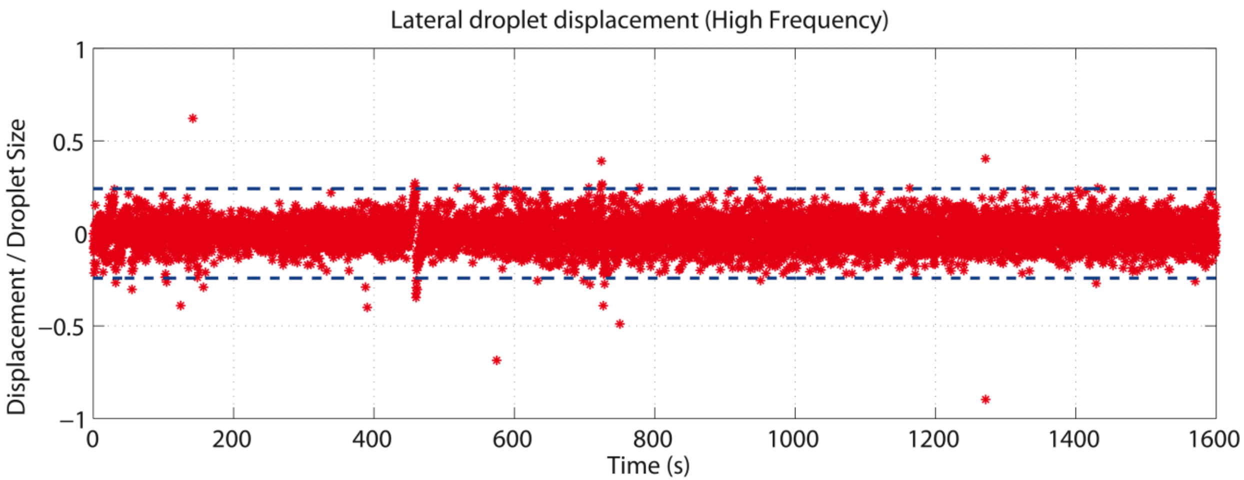
(a) Droplet train at 18 kHz, diameter 58 µm.
(b) Droplet train images at 50 kHz, diameter 43 µm.
(c) Rayleigh break-up observed at nozzle exit.
(d) Computational simulations of the Rayleigh break-up at nozzle exit.

Droplet Stability: Results from droplet imaging



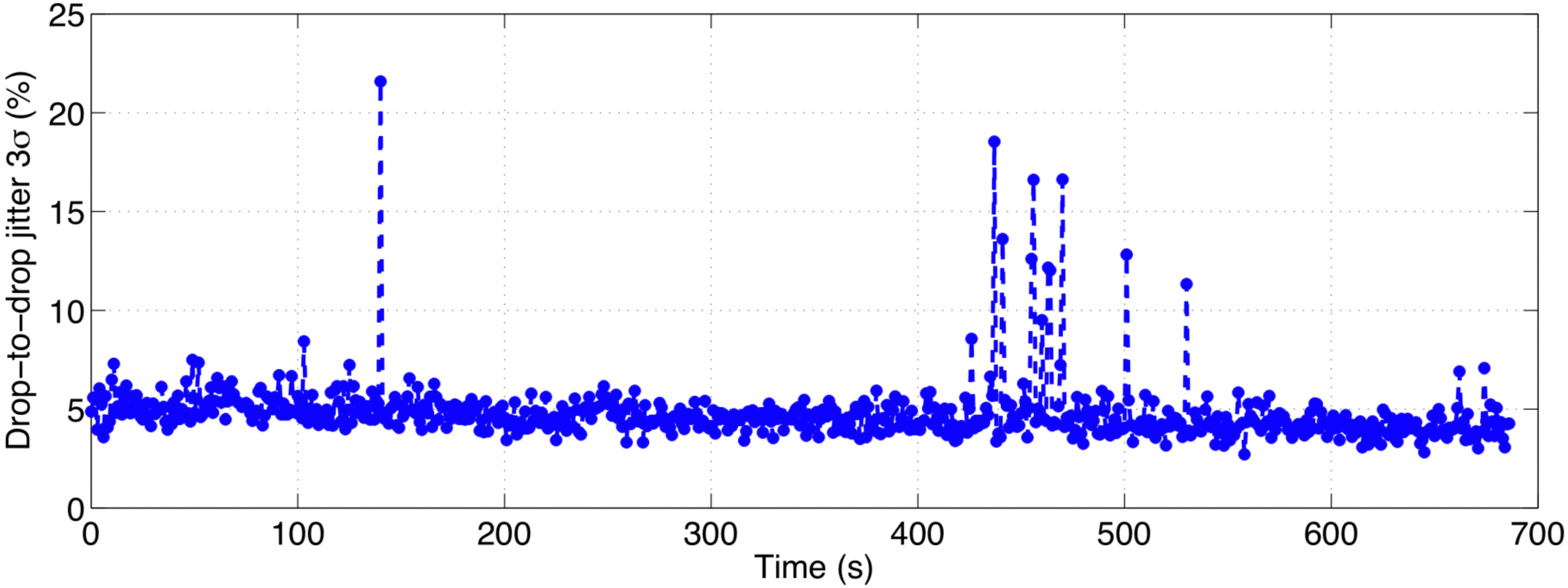
Results derived from droplet imaging.

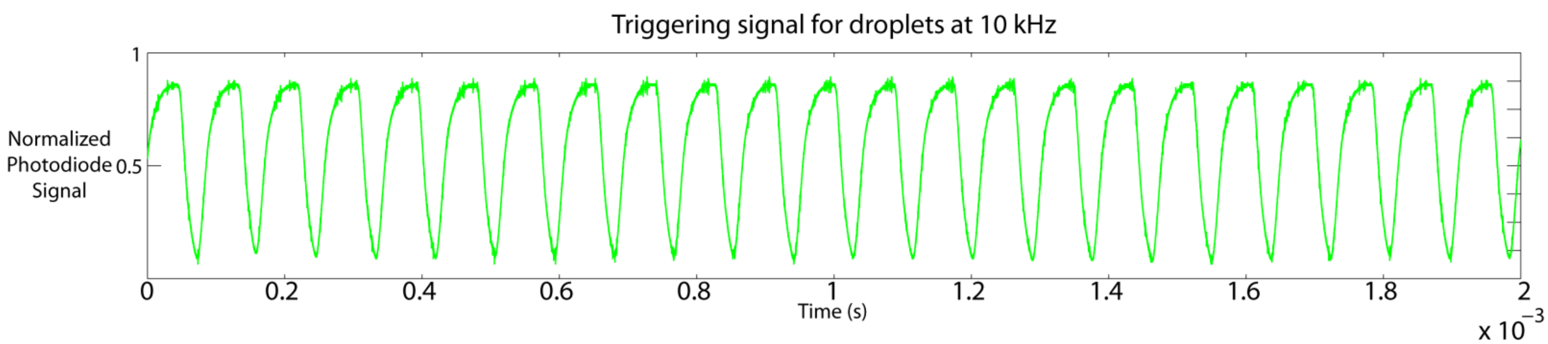
(A) Low frequency content (Hz scale) of lateral displacement.



(B) High frequency content (kHz scale) of lateral displacement.

Droplet Stability: Laser/Photodiode measurements





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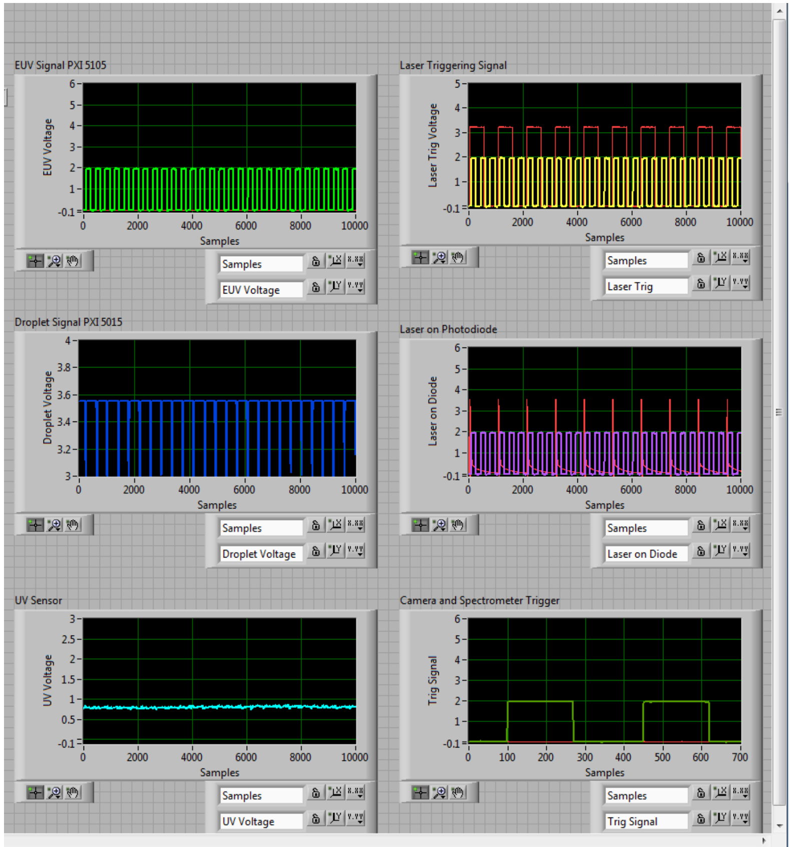
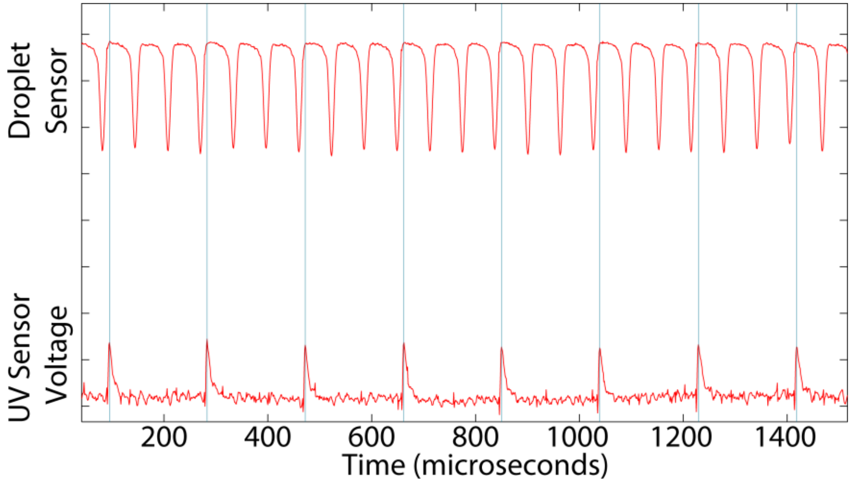
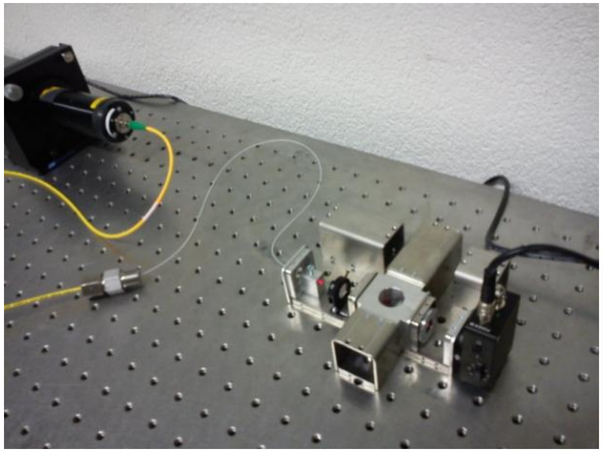
Droplet by droplet triggering





- Laser triggered to hit every third droplet.
- 100% hit-rate.



- All signals simultaneously recorded by the control system.
- Droplet Signals are used to directly trigger the laser to compensate for temporal Jitter.

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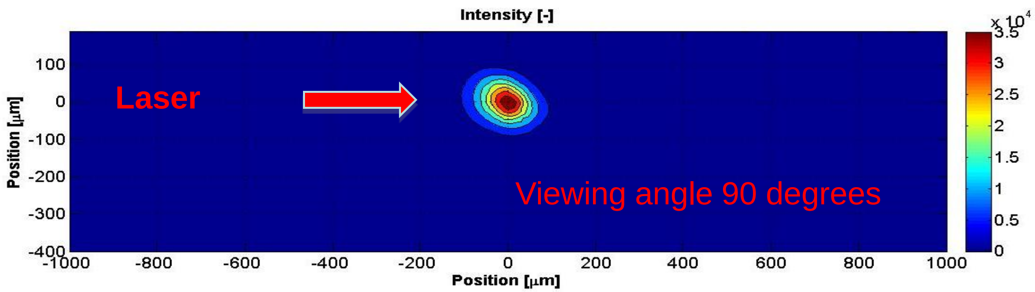
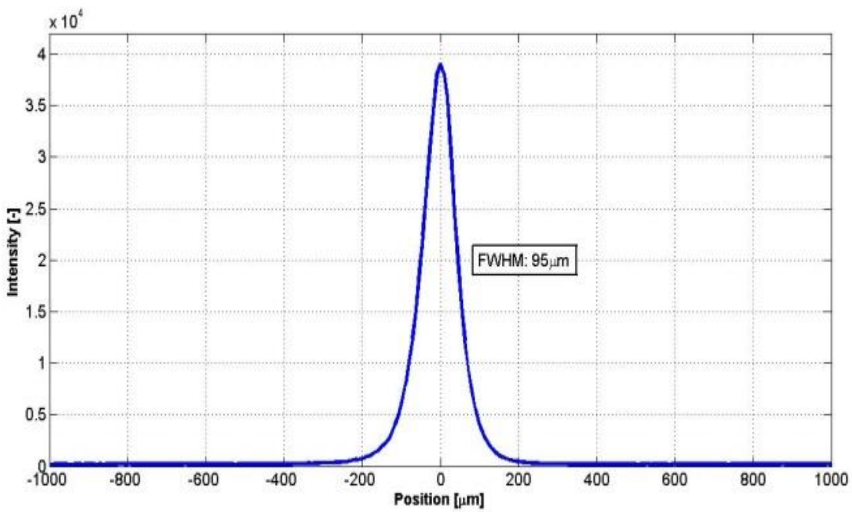
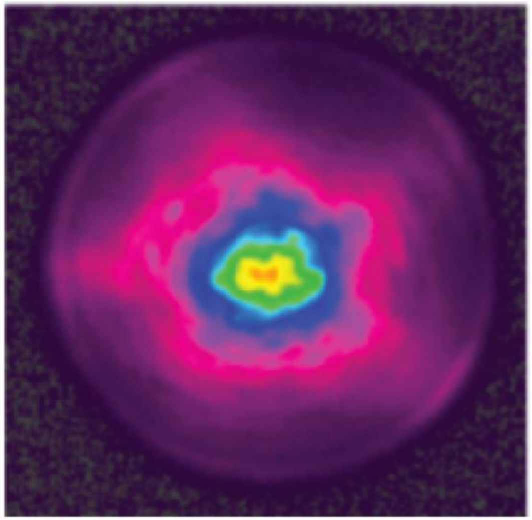
Pinhole Camera and Spotsize Measurements

EUV source size: 95 micron FWHM





Laser spot at focus



Focused laser spotsize:
78 micron.
Spiricon Image of the AO16 laser pulse.

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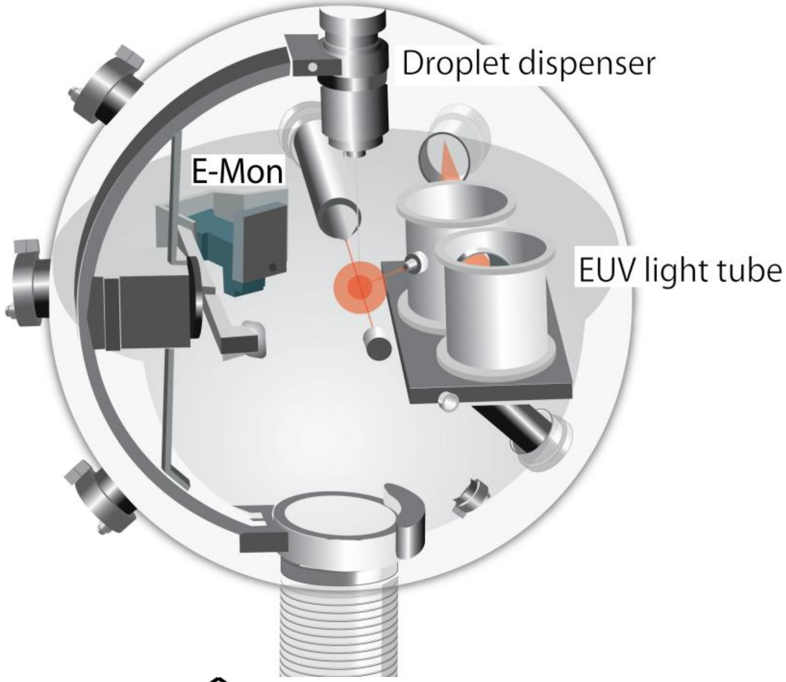
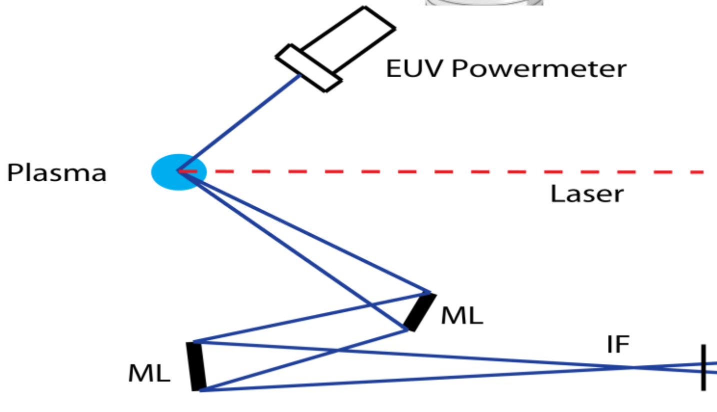
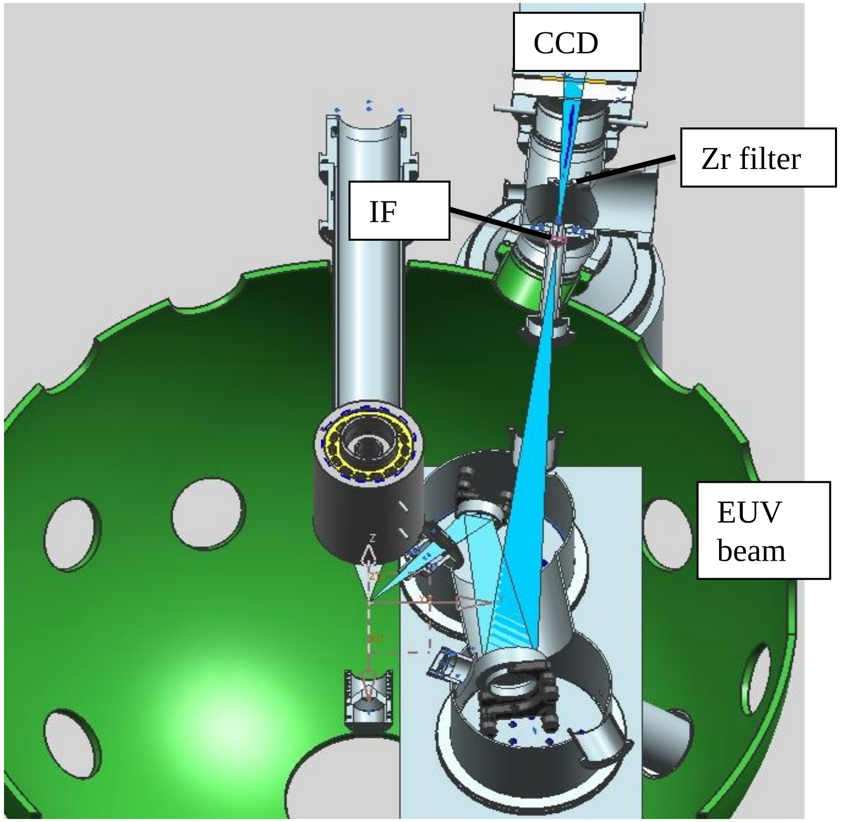
High Brightness Collector







CCD Camera is used to measure the radiation pattern after the IF.

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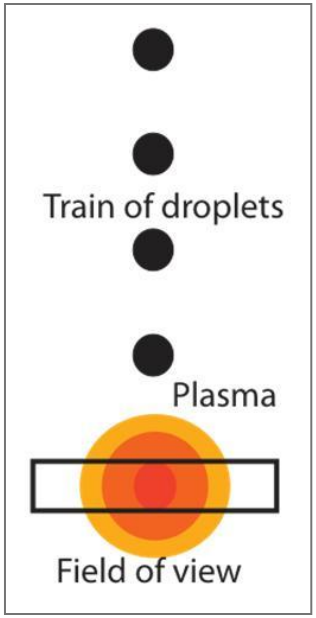
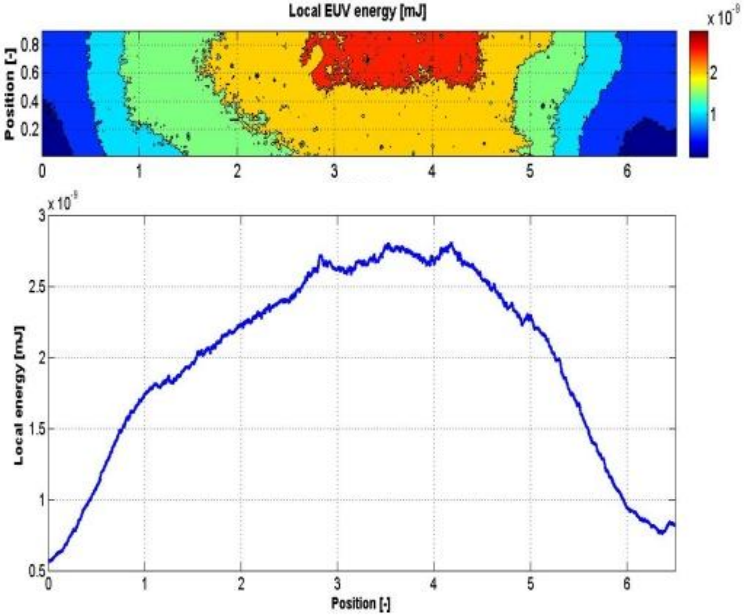
Collector Optics Module





- CCD positioned at a distance from IF to maximize spatial resolution of recorded EUV signals.
- Reflectivity of mirrors, transmission of filter and Quantum Efficiency of CCD are used to determine EUV power at IF.
- EUV Power measurements at the IF are cross calibrated with Energy Monitor measurements.

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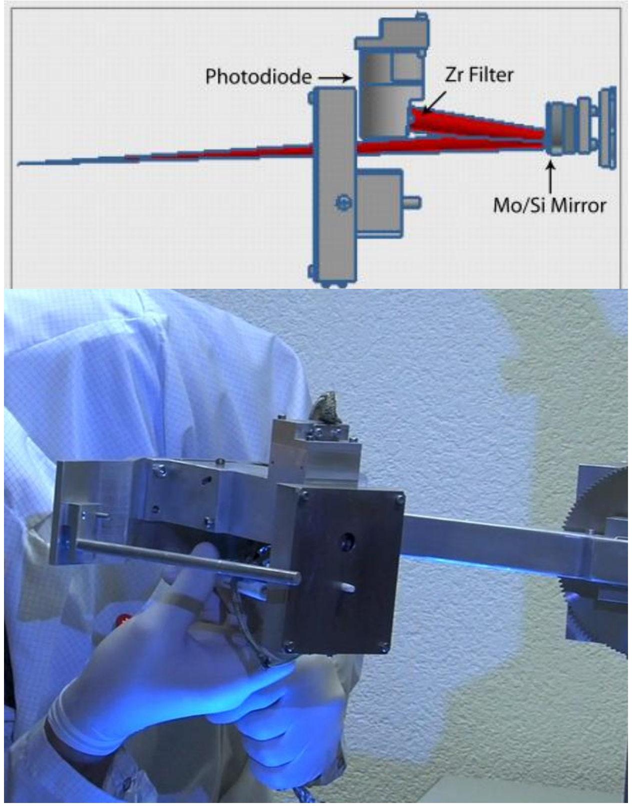
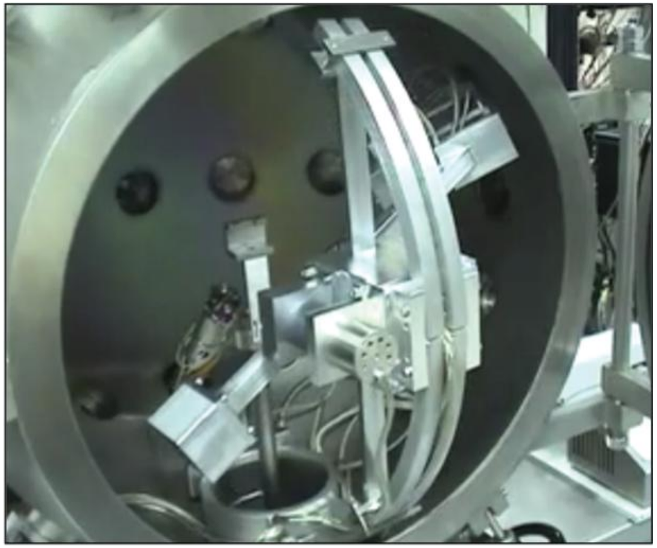
EUV Radiation Measurements

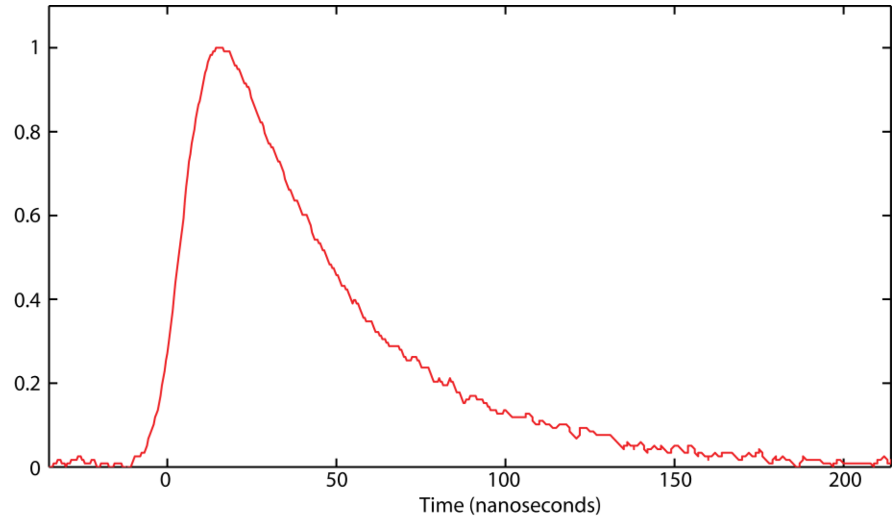
- EUV source power measured with a calibrated energy monitor.
- Measurements recorded at 45 deg w.r.t. laser axis to complement acceptance angle of LPS entrance aperture.





Energy Monitor mounted on robotic arm for 2 pi sr measurements.

EUV Radiation Measurements



EUV Source Measurement:
Conversion Efficiency:1.05%

Parameters	Measured
Laser power on target (W)	1100
Laser Frequency (kHz)	6
Laser focal spot size (µm)	78
EUV source size (µm)	95 at FWHM
Average Conversion efficiency (%)	1.05%
Source brightness (W/mm^2/sr)	≈ 259

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Ongoing Work

- Present Science and Technology Development continuing.
- To commercialize, an ETH spin-off company called Adlyte Ltd was formed in 2009.
- Currently Adlyte is working with customers in the metrology and inspection fields.

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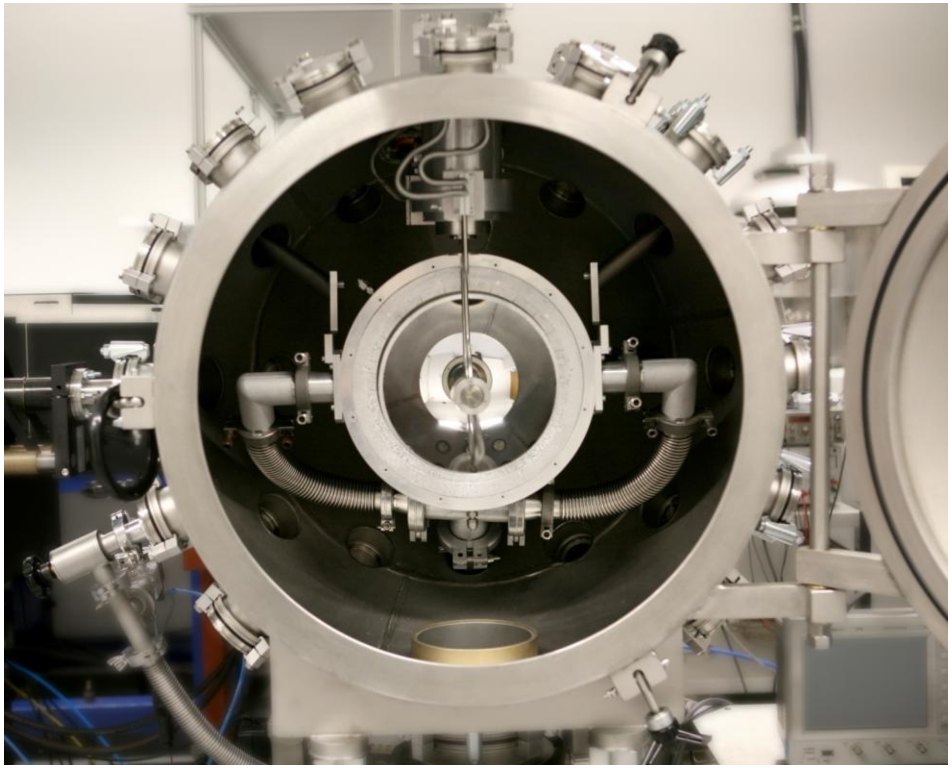
High power EUV source (HPS)



- Integrated debris mitigation system.
- Integrated collector cooling.
- Large solid angle, 4 sr.
- High IF power.

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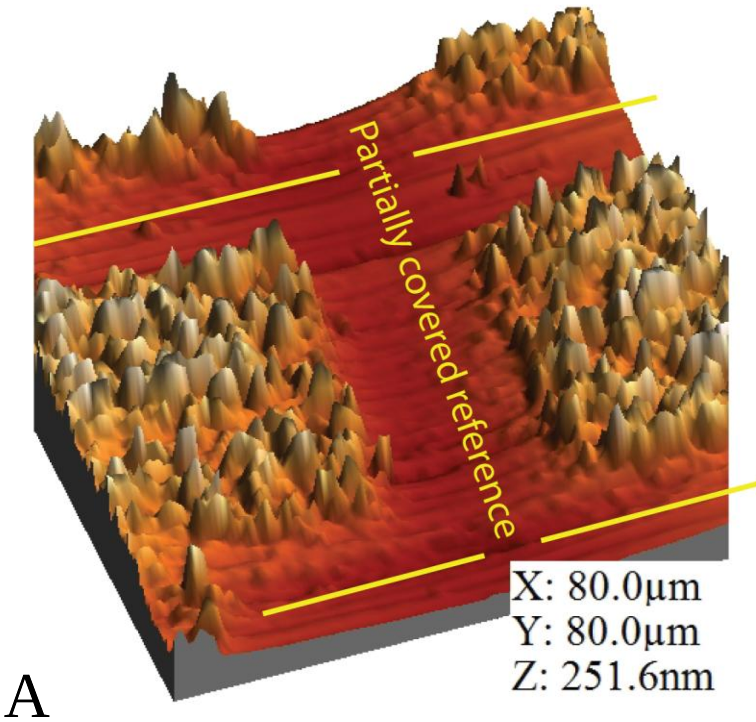
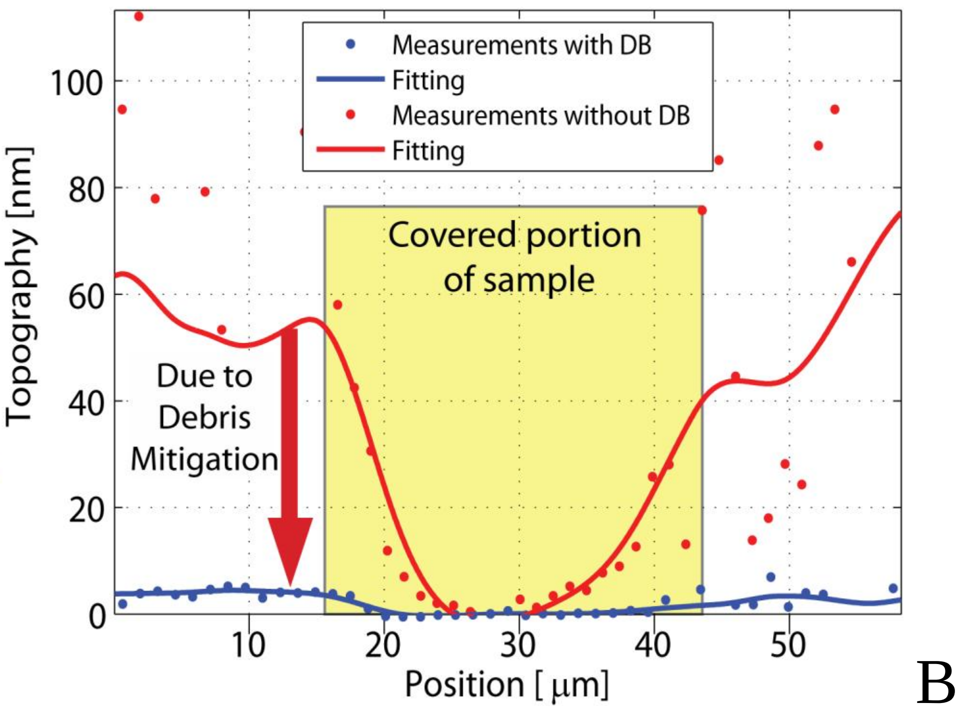
Debris Mitigation





A: AFM measurement sample without debris mitigation.

B: Comparison of samples with and without debris mitigation.

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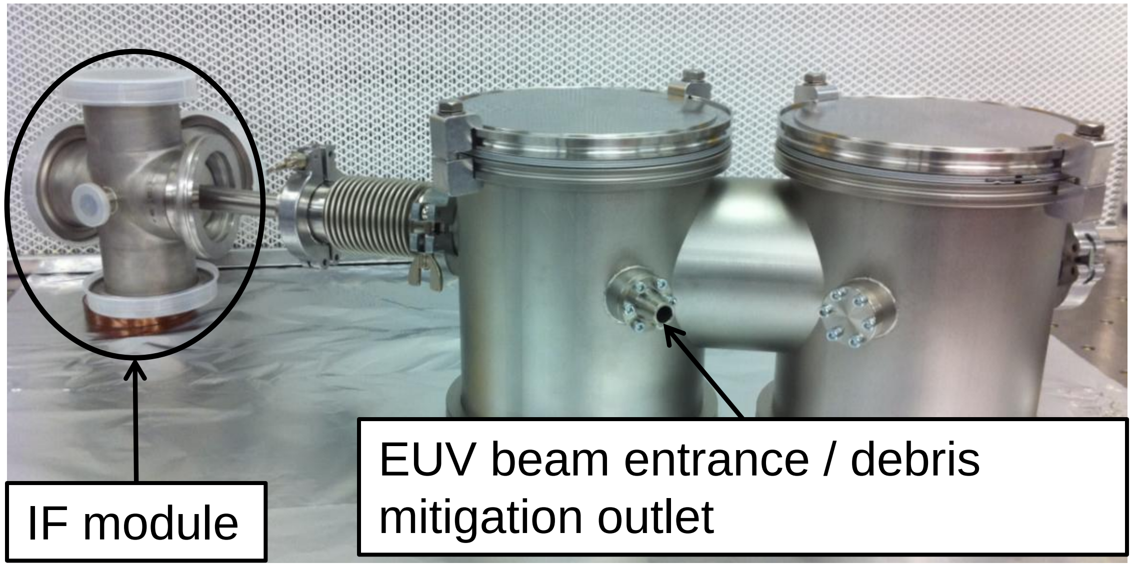
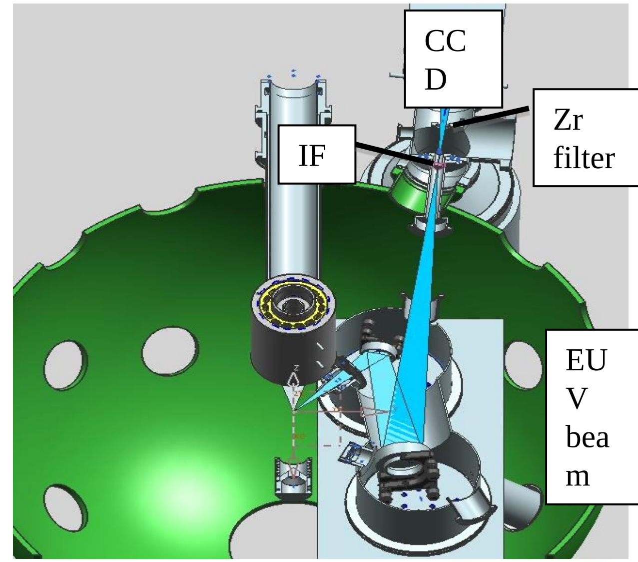
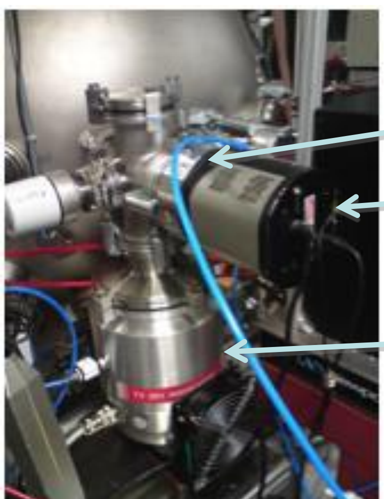
Low power EUV source (LPS)







IF tube exit port

CCD

Turbo Pump

Low power EUV source:
O.1 Sr Collector

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Questions

- **Thank you for your time.**

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