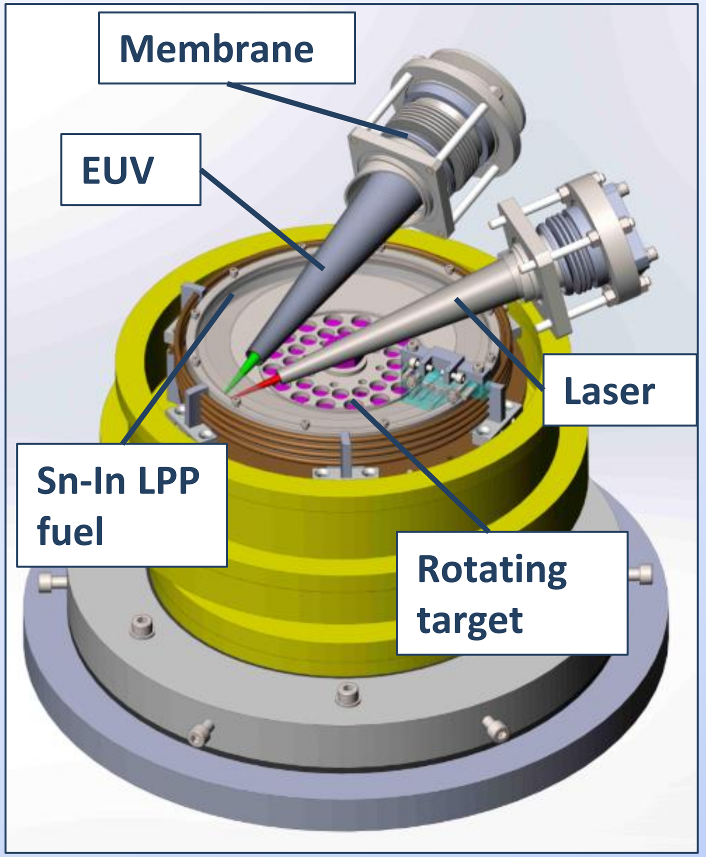
TEUS - high-brightness EUV LPP light source based on fast rotating target: product overview and specifications

TEUS light source: clean EUV (13.5 nm) photon production



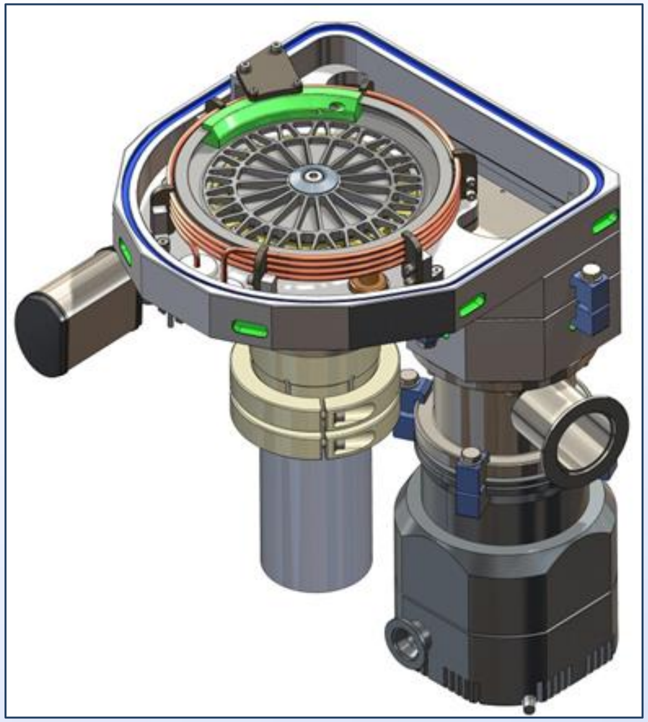
Innovative LPP target + conventional debris mitigation techniques
→ ultimate solution for clean photon EUV source

Advantages of fast rotating liquid metal LPP target.

Fast rotation target provides :

- ★ **Redirection of droplet debris away from input (laser) and output (EUV) windows**
- ★ **Undisturbed target surface for a high rep rate laser system (up to 1 MHz)**
- ★ **Minimum synchronisation required as the target is continuous**
- ★ **Excellent inherent source spatial stability**

TEUS product line



TEUS-S100

Average laser power, up to 1 kW

EUV radiation collection angle

S	0.05 sr	In production
M	0.15 sr	In production
L	0.3 sr	Production planned for 2022
XL	0.5 sr	Production planned for 2022

→ TEUS S(M)100, S(M)200, S(M)400 production started in 2020

→ 3 source modifications delivered to customers

TEUS sources in production

General characteristics and facility requirements	
Dimensions (LxWxH)	1.4x1x1.2 m^3
Electrical power	6.5-10.5 kW
Flow rate of running water	10-25 L/min
Ultra high purity Ar consumption	1e-1 slpm
Weight, including laser components	770 kg
Room cleanliness class	ISO7

TEUS source product specifications

Laser average power	100 W	200 W	400 W
Maximum pulse repetition rate	25 kHz	50 kHz	100 kHz
Solid angle of collectable EUV power (S/M)	0.05 sr / 0.15 sr		
Conversion efficiency in-band (13.5 nm±1%) radiation	2%@2π		
In-band EUV (13.5nm±1%) flux inside collection angle with account for debris mitigation system (S/M)	8.5 mW / 25.5 mW	17 mW / 51 mW	25.5 mW / 76.5 mW
In-band EUV (13.5nm±1%) brightness 'on plasma' with account for debris mitigation system (S/M)	90 $W/mm^2 \cdot sr$	180 $W/mm^2 \cdot sr$	360 $W/mm^2 \cdot sr$
Plasma size*	60 µm		
Intensity stability**	3% RMS		

*: defined as the diameter of the plasma intensity profile at $1/e^2$ level
**: pulse-to-pulse intensity stability over 60 seconds, mainly determined by the stability of the laser

For full-band (13.5nm ±2%) conversion efficiency is 4%@2π, giving double brightness and double the collected EUV power.

TEUS source product specifications

Laser average power	100 W	200 W	400 W
First mirror lifetime without using a CNT membrane filter in 24/7 mode of operation*	>12 month	>6 month	>3 month
First-mirror lifetime using a CNT membrane filter in 24/7 mode of operation*	>24 month	>12 month	>6 month
Exploitation time before maintenance	8 months	4 months	2 months
Uptime in 24/7 mode of operation**	4 months	2 months	1 month

*: the first-mirror lifetime is defined as the period of 10% degradation in reflectance
**: with shutting off the EUV beam for 5 minutes for membrane magazine replacement

For full-band (13.5nm ±2%) conversion efficiency is 4%@2π, giving double brightness and double the collected EUV power.

Debris mitigation

Debris types: droplets and plasma/vapor.

- **Magnetic field, gas counterflow, laser pulse profile optimization → plasma/vapor debris mitigation**

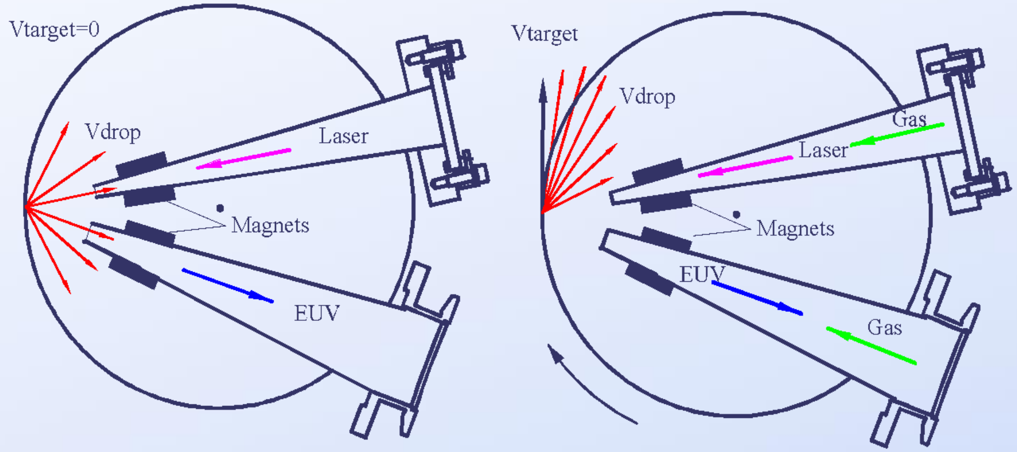
- **Fast target rotation → droplet debris mitigation**

- **EUV-transparent CNT* membrane → ultimate solution for both types of debris**

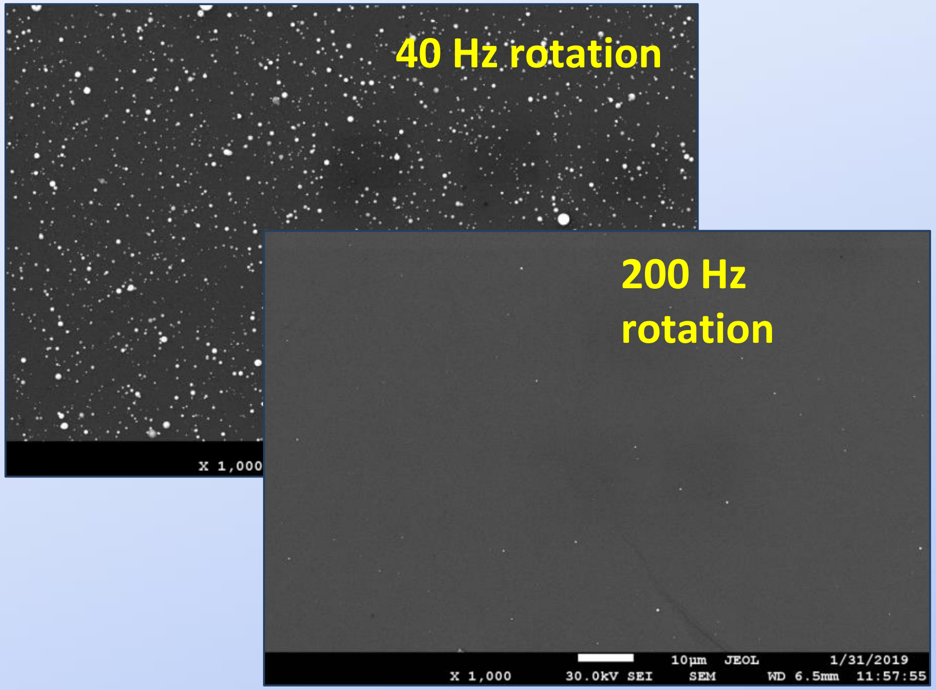
*CNT = carbon nanotube

Droplet debris mitigation: fast target rotation effect

Fast rotating target is used to change direction of the droplet debris, deflect them from input laser and output EUV windows



Demonstration of droplets mitigation effect due to high rotation speed



SEM images of the witness samples located in output window after the same exposure time

Droplet debris mitigation: optimal EUV output direction

Sample contamination analysis:

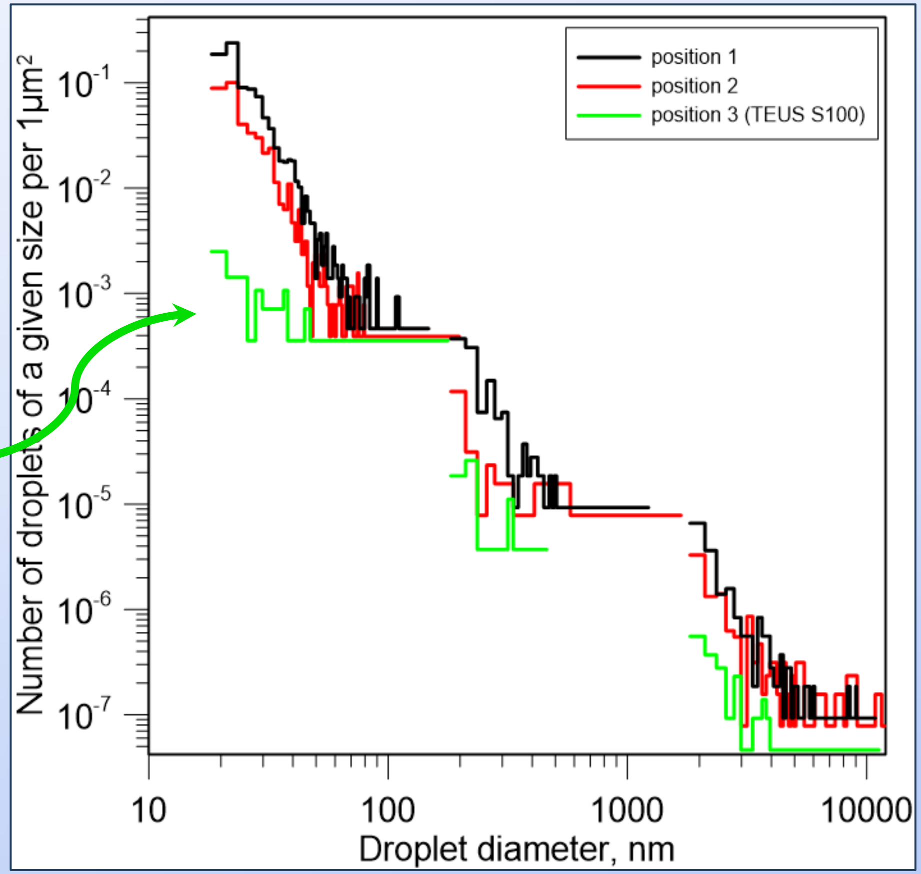
The number of droplets and their sizes were calculated from the SEM images of the Si witness samples.

The witness samples were located at different positions of the source chamber (experimental setups).

The amount of droplet debris significantly depends on the location of the output EUV window.

In TEUS-S100, the direction of the output cone is designed to minimize the amount of droplet debris.

Droplet debris size distribution



Number of droplets after 8 hours of sample exposure

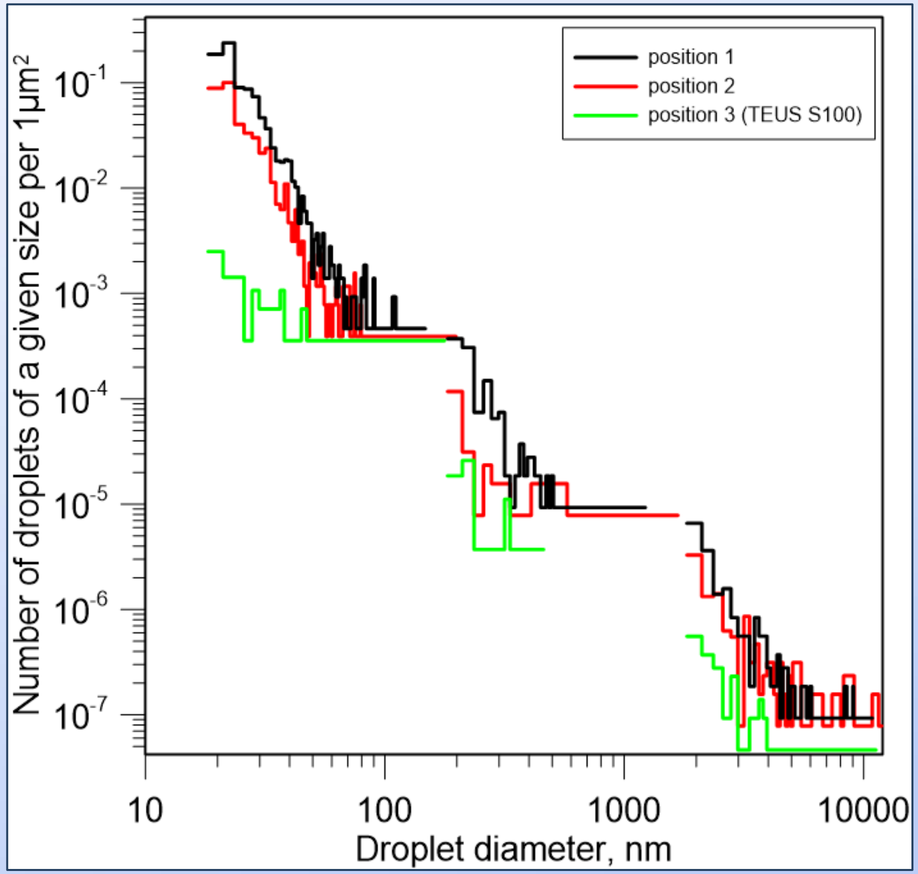
Droplet debris mitigation: optimal EUV output direction

TEUS S100 first mirror lifetime calculation based on experimental data:

➔ **First mirror lifetime is mainly limited by the fraction of the area covered with droplets.**

➔ **Data extrapolation: areal coverage with droplets is ~10% after one year of continuous operation.**

Droplet debris size distribution

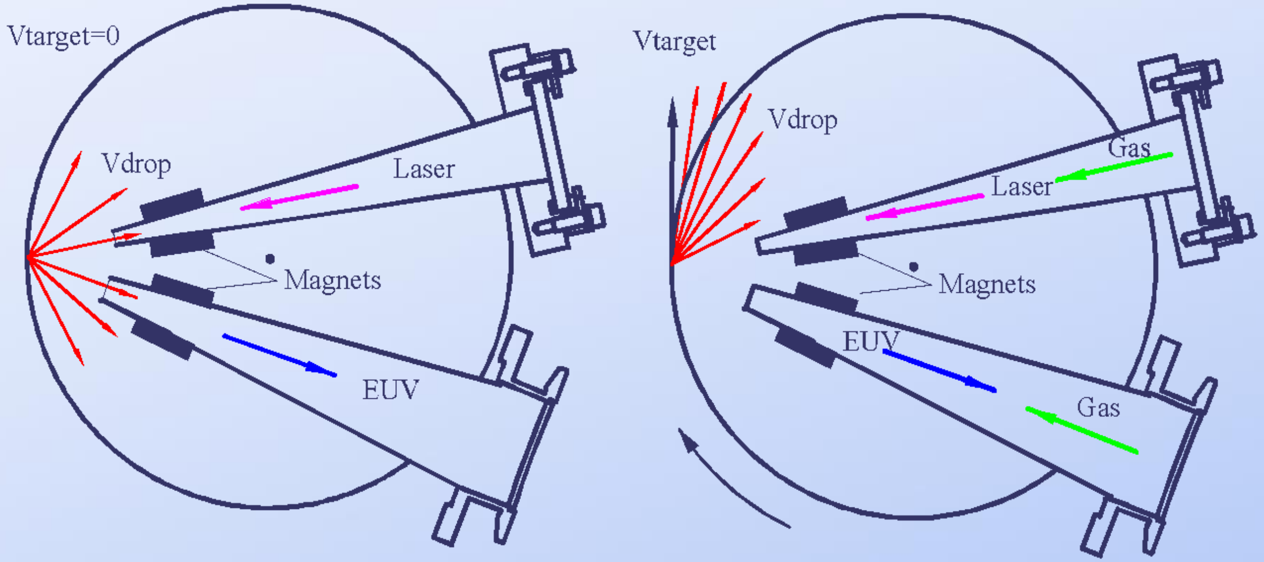


Number of droplets after 8 hours of sample exposure

Plasma\vapor debris

Magnetic field, gas counterflow and temporal profiling of a laser pulse

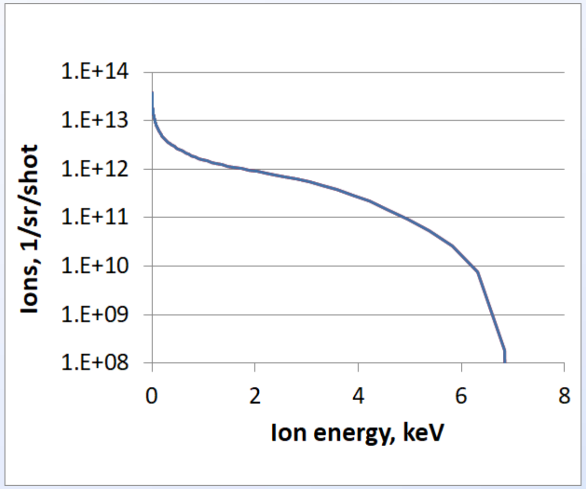
- ★ Gas counterflow → stopping of Sn/In vapors + ion deceleration
- ★ Magnetic field → ion deflection
- ★ Laser pulse profile optimization → lowering maximum ion energy for more effective ion mitigation by magnetic field



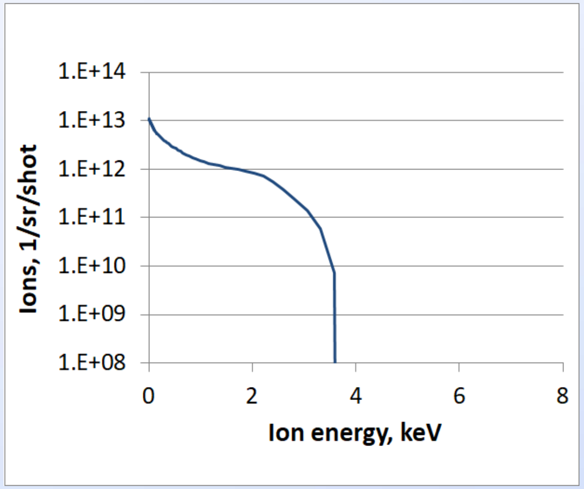
Plasma\vapor debris
Temporal profiling of a laser pulse

Max ion energy lowering via laser pulse optimization

Standard Gaussian pulse profile

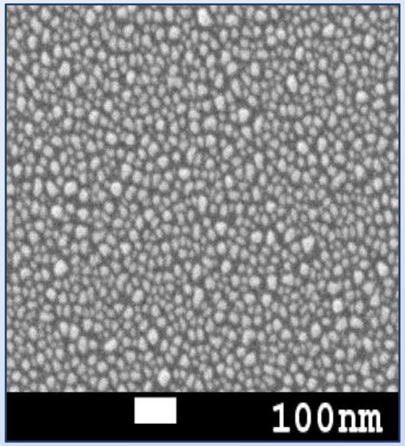


Optimized pulse profile

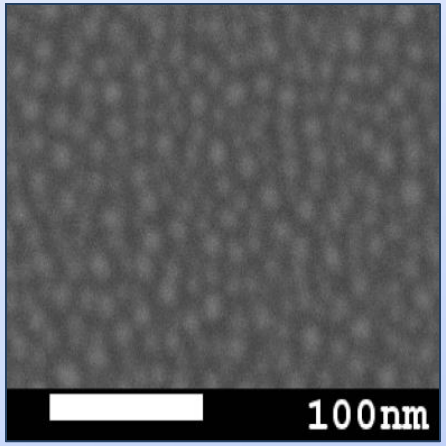


SEM images of the witness samples.
No magnets and no gas counterflow.
1 hour of exposure

Gaussian laser pulse



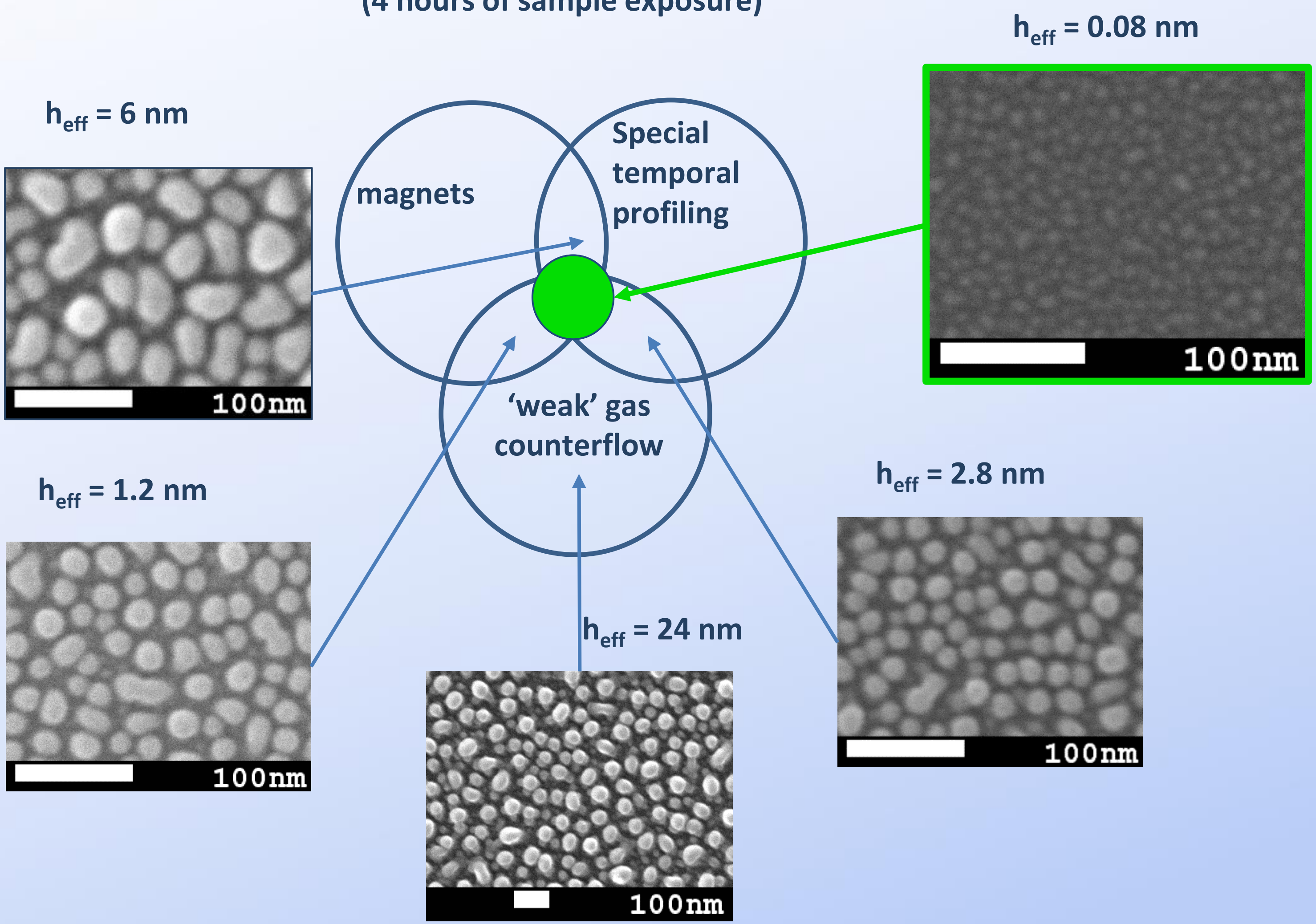
Optimized pulse



Laser pulse profile optimization → cut off high-energy ions and decrease the amount of ions

Plasma\vapor debris
Combination of mitigation techniques

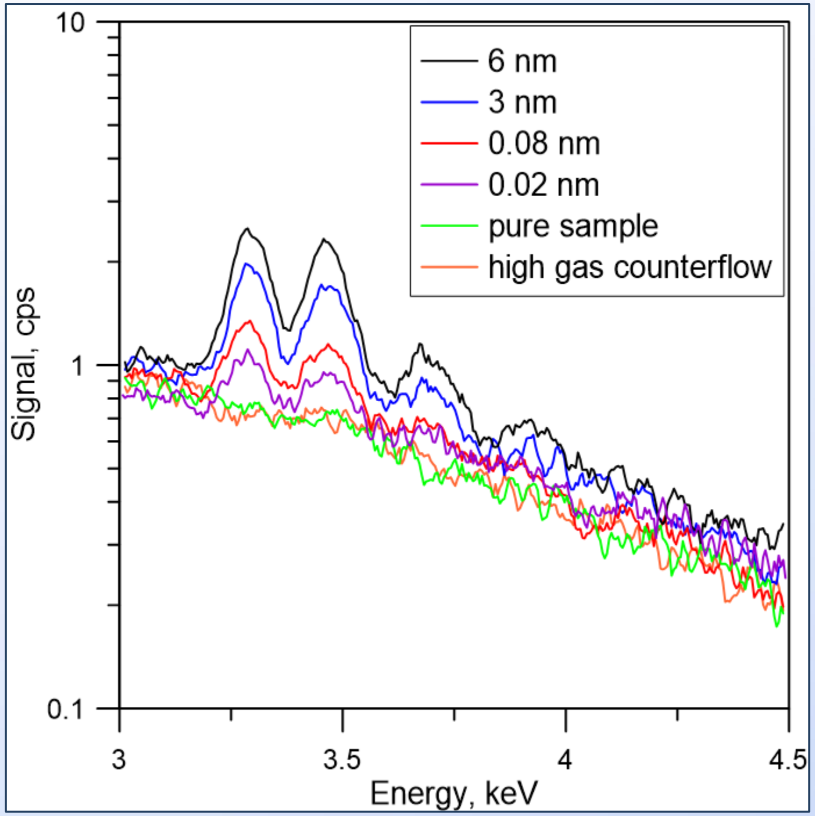
SEM images and effective thickness (4 hours of sample exposure)



Plasma\vapor debris

‘Strong’ gas counterflow and first mirror lifetime estimates

Averaged EDX signals were recorded from area ~100 µm^2



4 hours of sample exposure

In case “Strong gas counterflow” group of lines L_α, L_β, L_γ for In, Sn is not observed. If Sn and In are present on the sample, their amount not enough to detect them.
The detection limit of the effective thickness, determined experimentally, is ~0.005 nm.

40 hours of sample exposure

For the case “Strong gas counterflow” additional sample was prepared, sample exposure time was 40 hours. Again, the EDX signal is indistinguishable from the pure sample signal, i.e. film grow rate is **<10e-4 nm/hour**.

The time of growth of 1.5 nm thickness film (transmits ~90% EUV) is > 15000 hours or almost two years of continuous operation.

Longer tests are in progress.

TEUS sources: optics lifetime

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Contact us

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ISTEQ runs EUV Source program in close collaboration with

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