Light source for HVM Mask and Wafer Inspection

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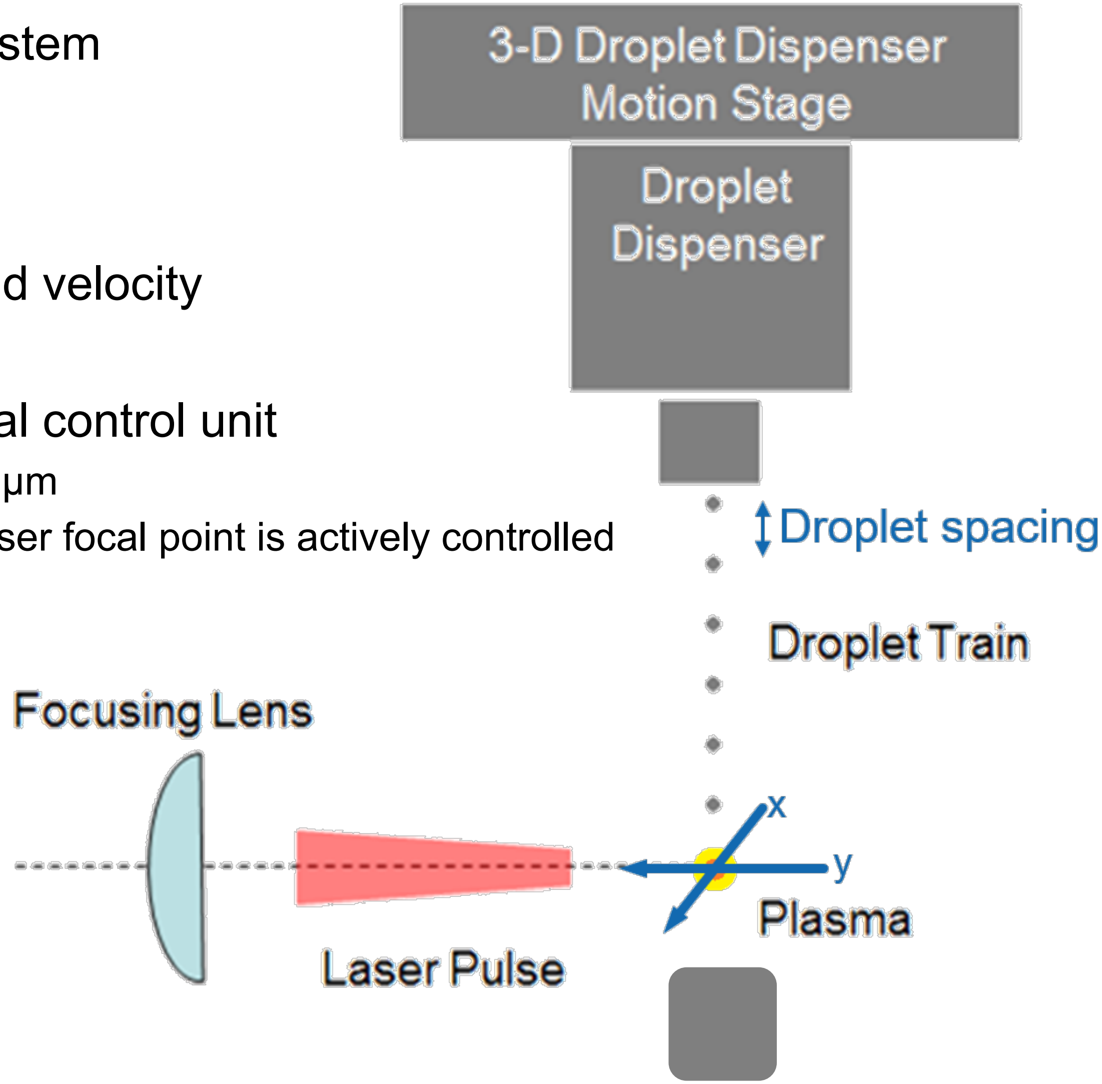
2019 EUV Source Workshop
November 4-5-6, 2019
Amsterdam Science Park

Source system overview

- Automated laser triggering system
  - frequency from 8 kHz to 20 kHz
- Adjustable droplet frequency
- Adjustable droplet spacing and velocity
- Automated feedback positional control unit
  - Tracking system resolution < 0.2 µm
  - Relative droplet position to the laser focal point is actively controlled
  - Input control parameters
    - E-Mon signals
    - Tracking signals
  - Automated alignment



EUV Source Technology at ETH Zurich

- Research & Development of **droplet-based LPP sources** since 2007
- Fully automated functioning system tested for over hundred of hours of operation
- Main application in EUV photomask inspection, such as AIMS^{TM}, actinic blank and pattern inspection
- Potential application for Wafer Inspection & Metrology

Historic perspective

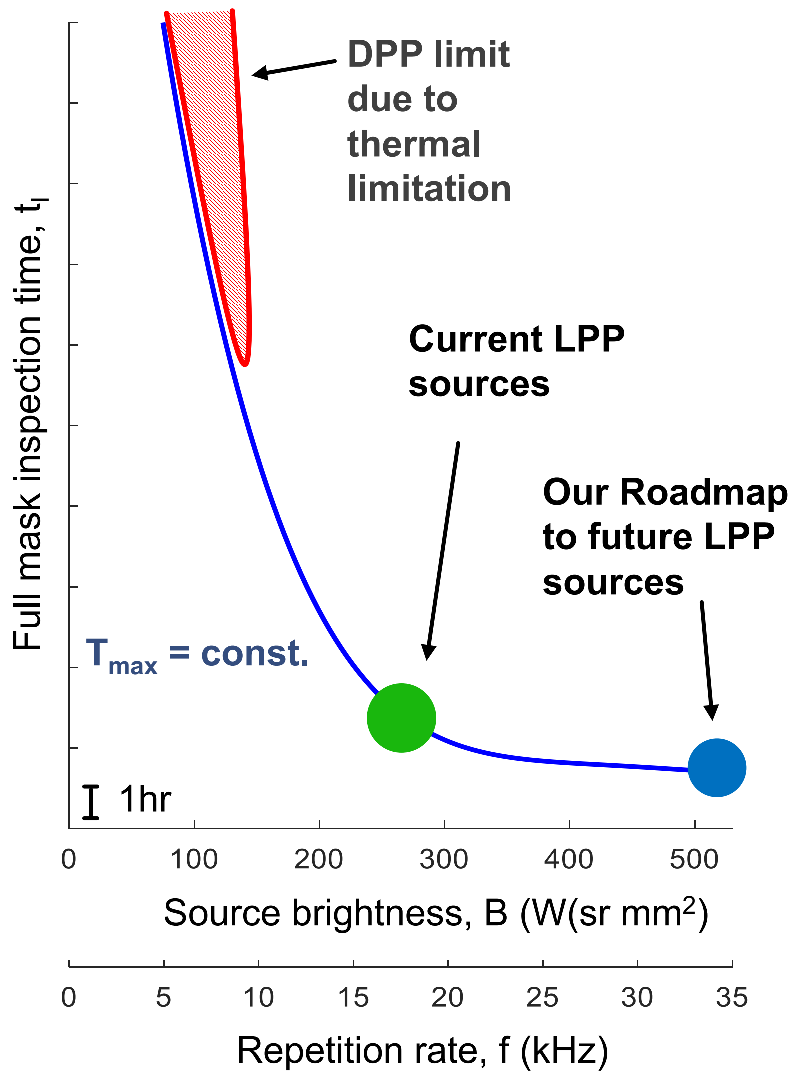
- Introduction of Alpha tool	(2013)
- Introduction of Beta Tool	(2014)
- Debris mitigated EUV collector	(2014)
- Cleanliness validation of tin-based LPP source after IF	(2015)
- Cleanliness validation of first bounce optics	(2016/17)
- HVM EUV light source development for APMI	2018/19
▪ **Infrastructure Expansion**	2019/20
▪ HVM production by Adlyte	2020/2021+

Full HVM Mask Inspection Requirements

- **Factors determining the mask throughput**
  - Thermal load
  - Data throughput (EUV CCD)
  - Calibration and mechanical alignment

- Throughput is a function of available EUV power on the mask or brightness for constant source size

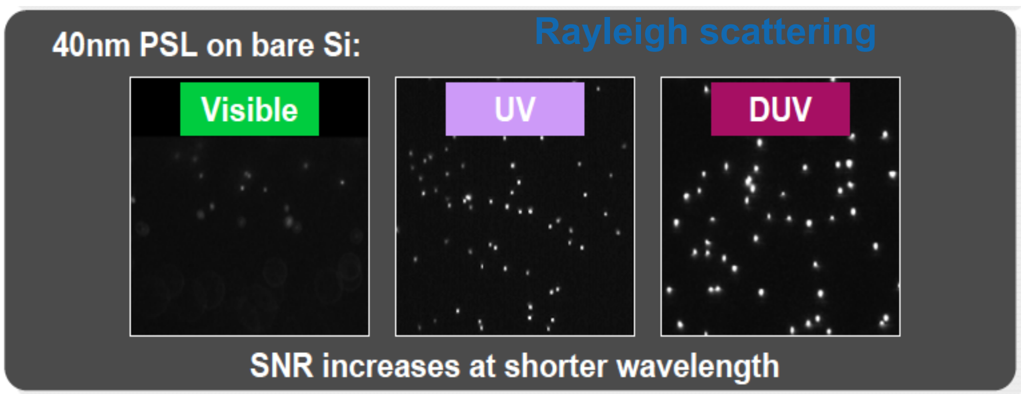
- Two options for scaling EUV power
  - Increasing frequency or
  - Increasing pulse energy



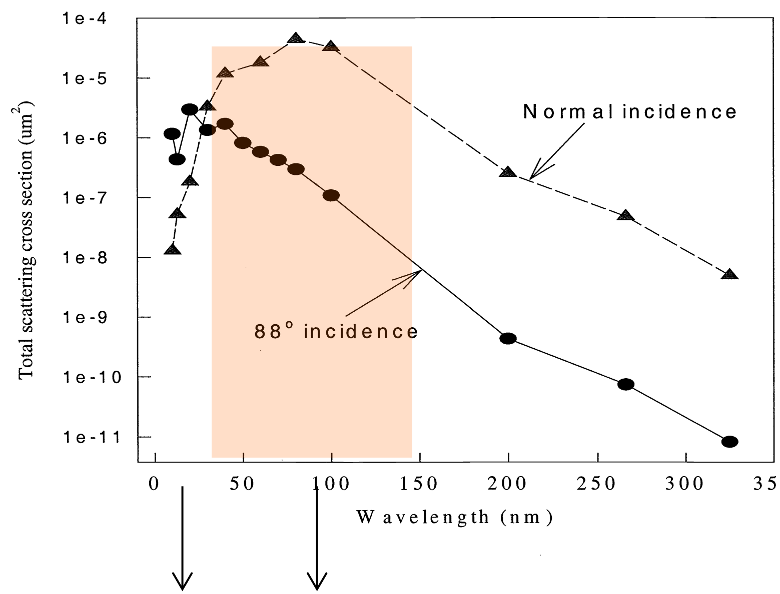
Particle Detection through DUV light for Wafer Inspection & Metrology

Particles detection mainly based on light scattering:

- laser at 193 nm or 266 nm (dark field and bright field illumination, with defect smaller than optical resolution, fast)
- Plasma for broadband illumination for bright field illumination (wider wavelengths, wider range of applicability and defect type detection)



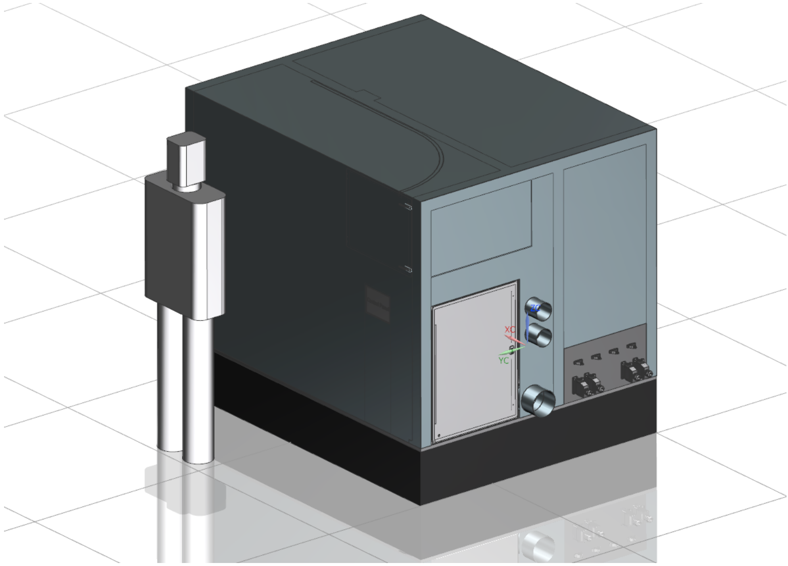
Simulated total scattering cross section of 20 nm polystyrene particle over silicon wafer vs. wavelength.



EUV VUV

D. Bucknera et al. Proc. SPIE Vol. 4182 (2000)

Adlyte's light source for APMI – Key nominal numbers

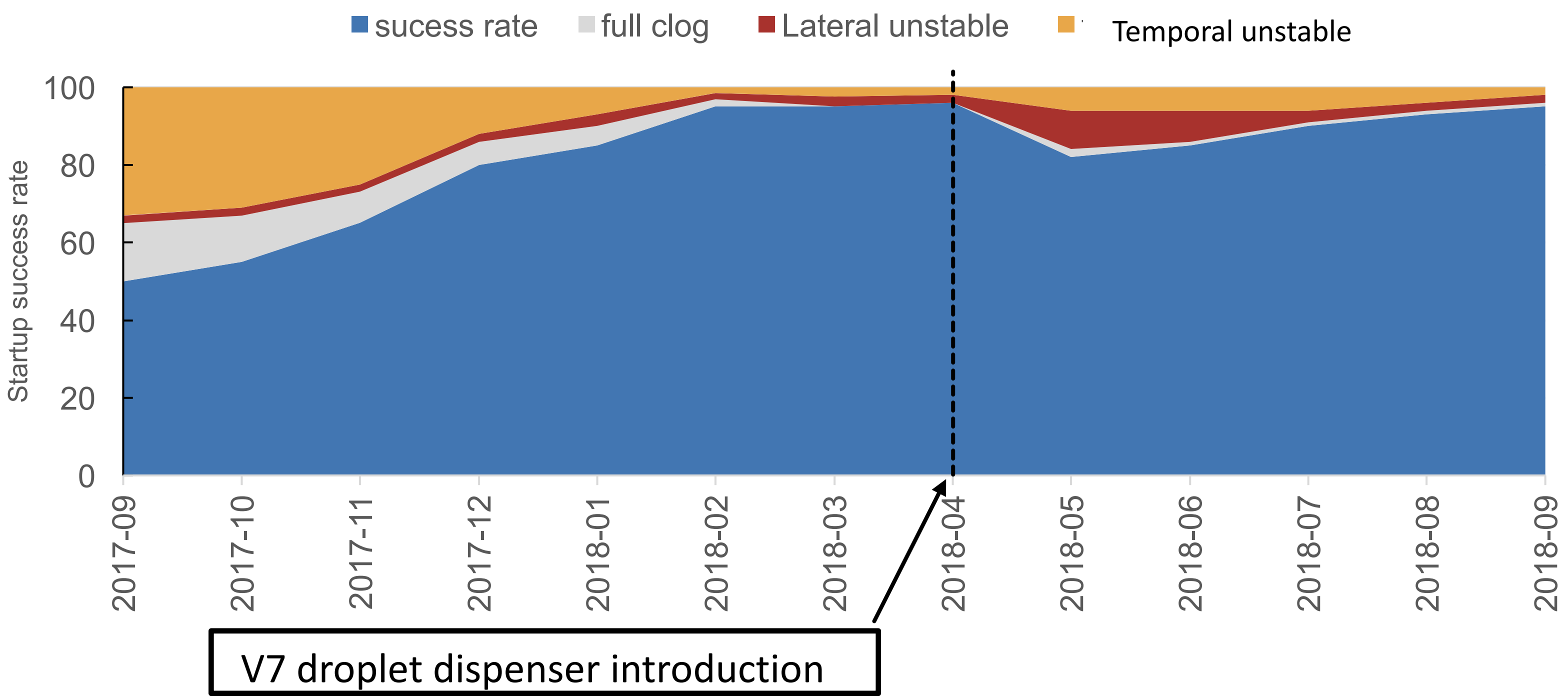


Parameters	Value	
Laser power on target	1300	W
Laser frequency	10-20	kHz
Laser focal spot, FWHM	75	µm
Conversion efficiency	>1	%
Source power at the source	>13	W
Peak source brightness	350	W/mm^2sr

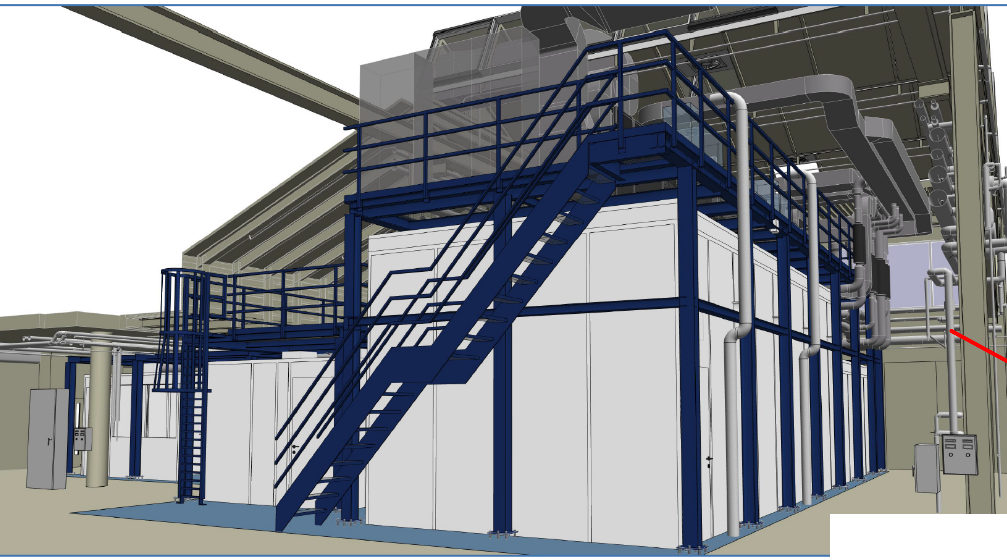
- Nd:YAG laser: average power of 1.6 kW, λ = 1.064 µm,10-20 kHz rep. rate, typically *Irradiance* = 80 - 200 GW/cm^2
- In-house droplet dispenser with >30 µm tin droplet generation
- Closed loop droplet tracking system with laser triggering on individual droplets enables droplet-laser alignment within <10% of droplet diameter.
- Debris mitigated grazing incidence collector, including clean IF module with imaging capability.
- Compatible with various collector configurations
- Full diagnostic including in-band energy monitors and out-of-band spectroscopy

Continual Improvements of Availability

- Continual improvement in droplet disperser, control system and thermal management allows availability rate of 95+ %



Extensive Infrastructure Expansion- Construction completion Target Date 1Q 2020



9 x increase in floor space

3 different facilities for source development

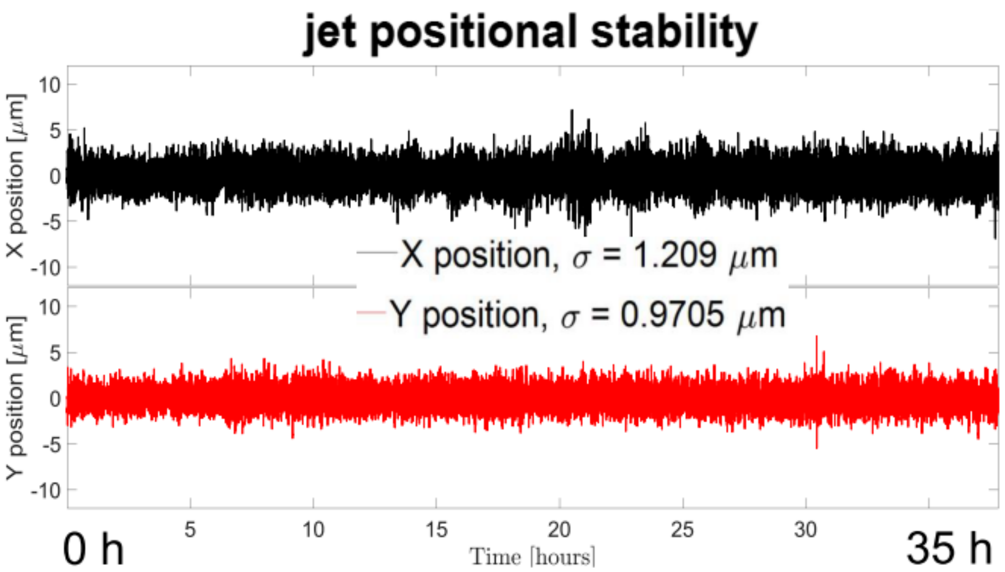
Various source platforms
ISO 3 cleanrooms

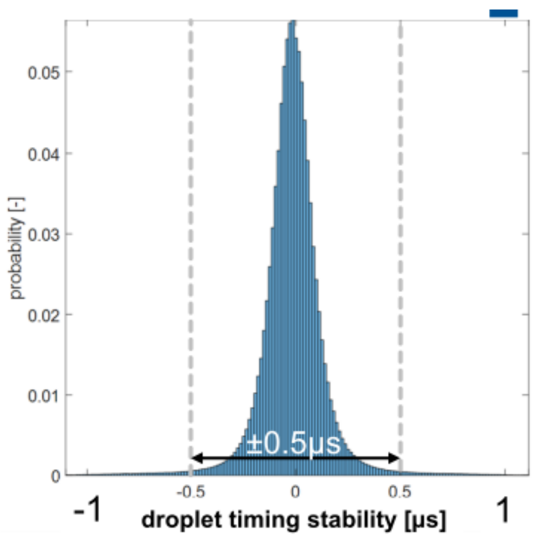
Recent Technical Progress

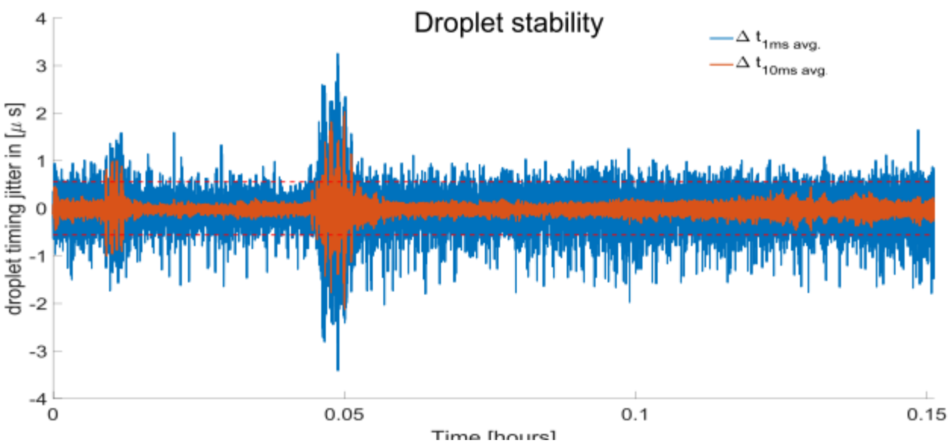
Droplet generation capability and run time

- V7 droplet generator tested
- > 35 hour continuous runtime
- Proven positional stability
- Stable droplet frequency

- Droplet timing stability:
  - Champion data
    - 1 ms avg. = 0.55 µs (3σ)
    - 10 ms avg. = 0.34 µs (3σ)

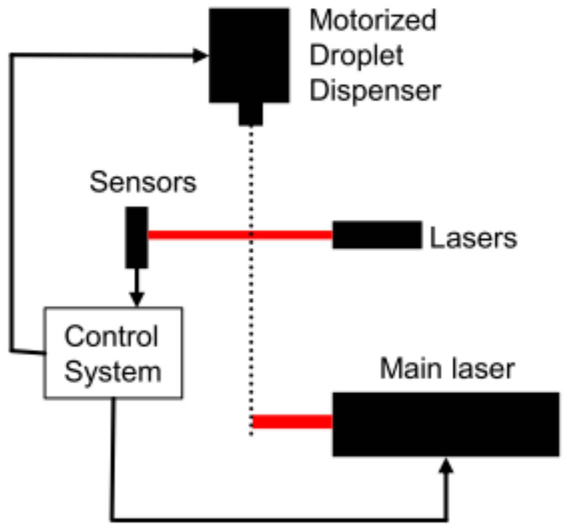


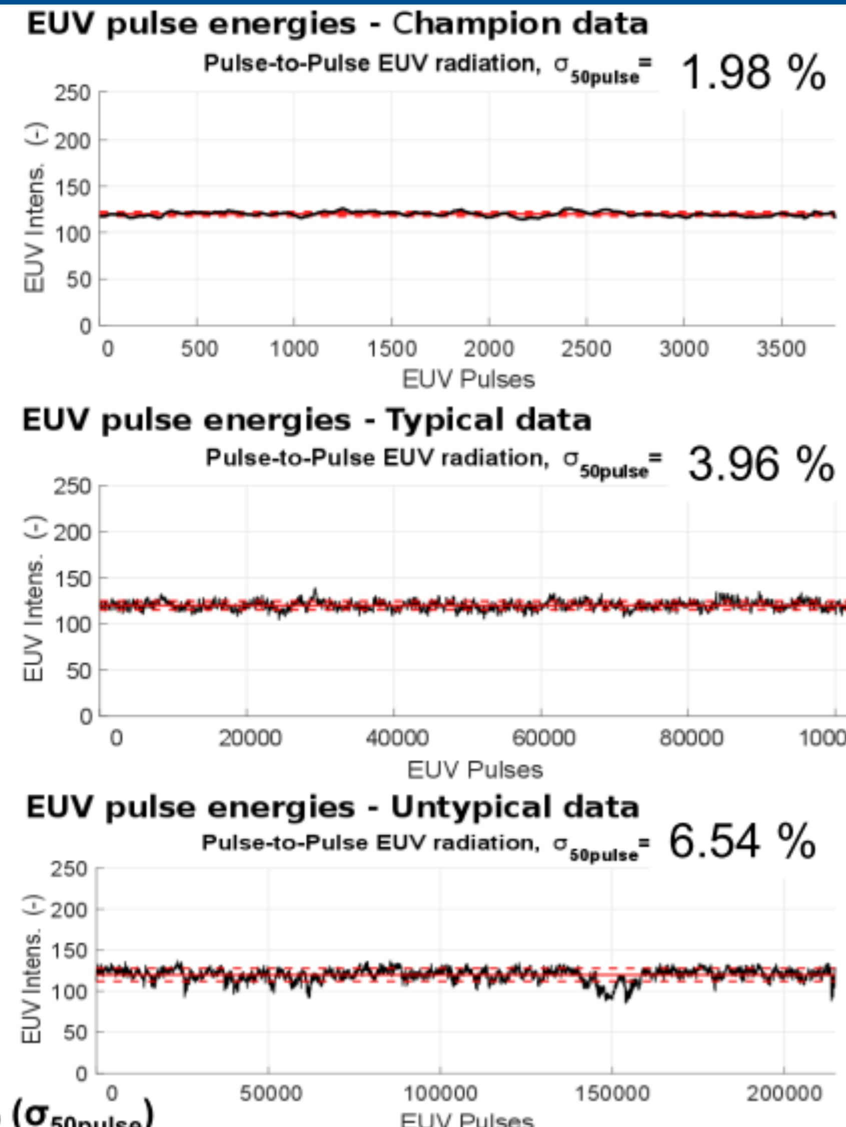




EUV Pulse Energy Stability

- EUV energy monitor (ML, Zr filter) and gated hardware integrator.
- standard source operation rate is 11 kHz





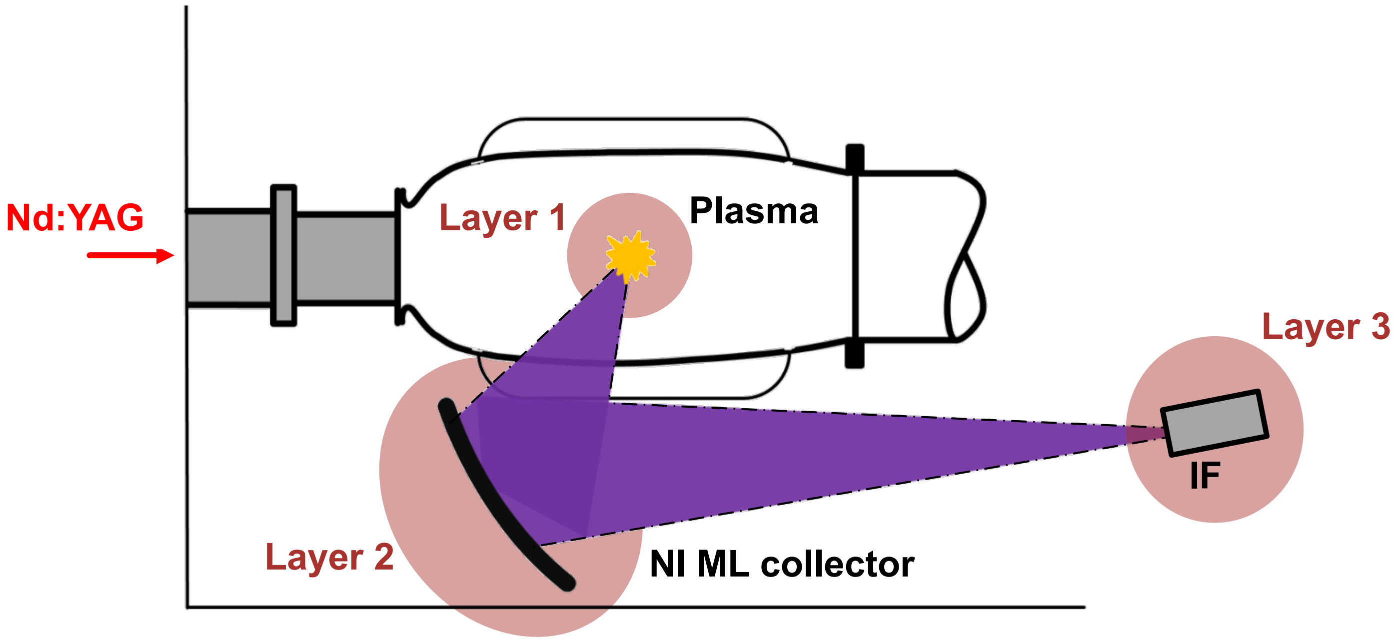
- **Pulse-to-pulse stability of EUV energy of 1.98% ($\sigma_{50pulse}$)**
- Strong dependence between EUV pulse-to-pulse stability and trigger / droplet tracking performance

Cleanliness through reduced Debris Formation and Debris Mitigation

A. Limit debris formation

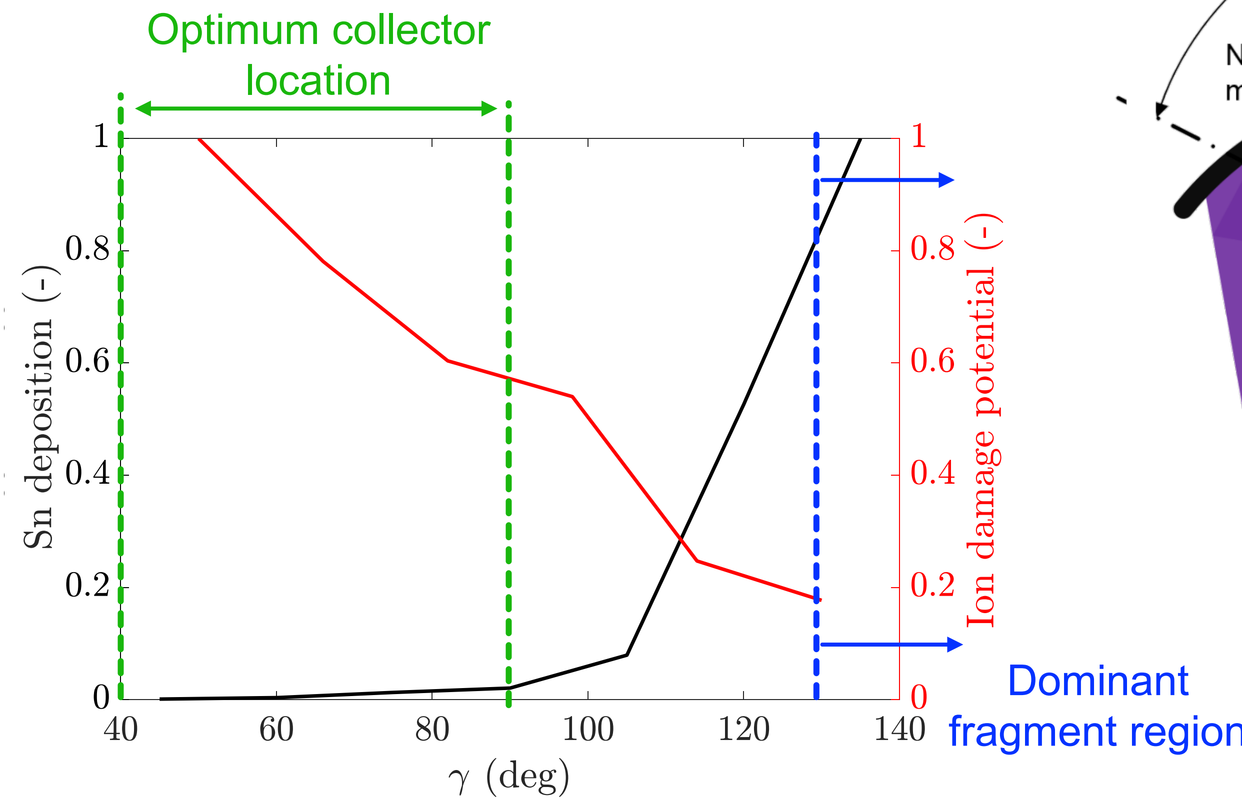
B. Mitigate debris

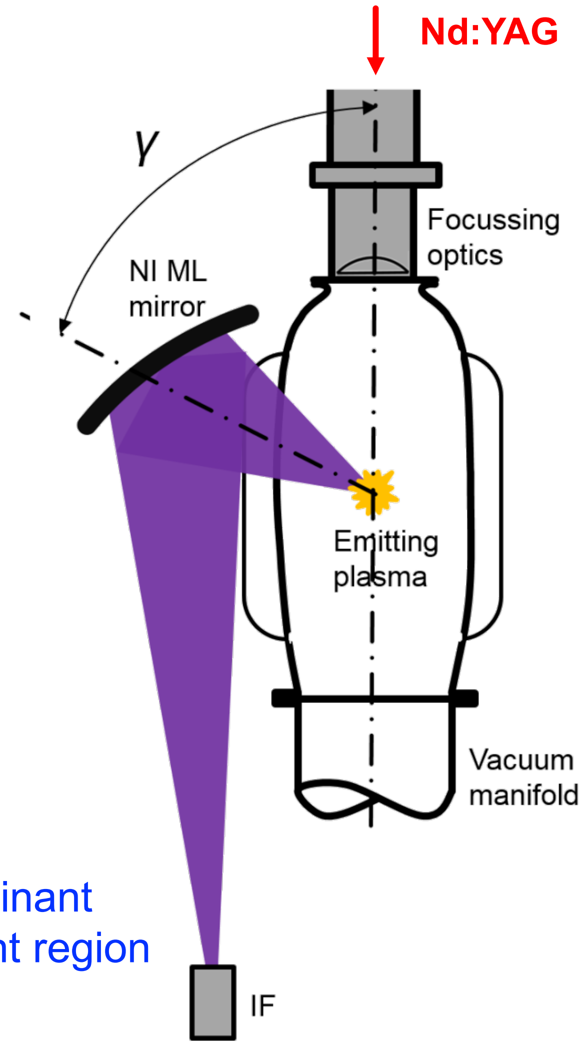
LAYER 1. Control debris around plasma
LAYER 2. Control debris in the collector module
LAYER 3. Control debris at IF



EUV collection optics placement

- Normal incidence collector (NI) placement for diagnostics and imaging

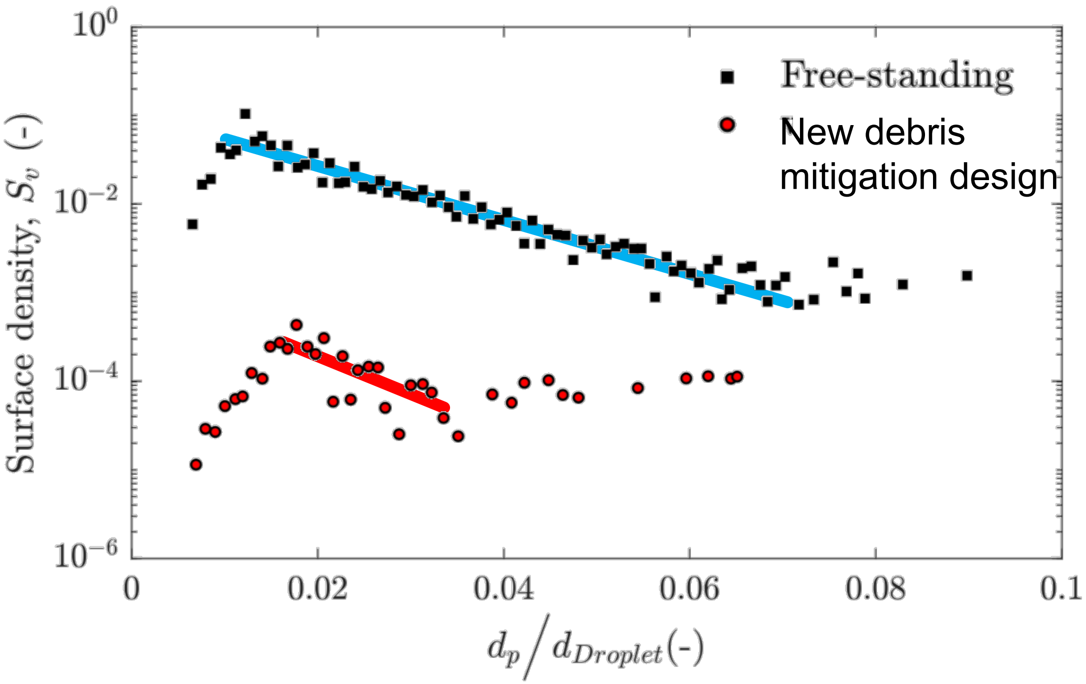




Trade-off between ion exposure and tin deposition: optimum betw. 40 – 90°
Larger neutral cluster dominant region narrows optimum collector location

First layer debris mitigation efficiency

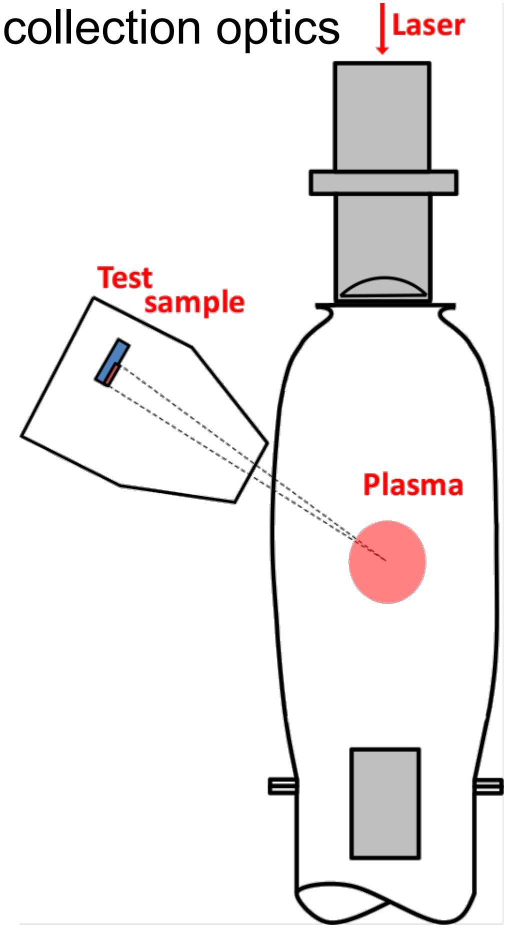
- Comparative study between free-standing plasma operation and debris mitigated source setup by means of high momentum buffer gas flow and debris mitigation design



- **Significant improvement** in terms of particle area coverage through application of high momentum flow versus freestanding operation, while maintaining source stability specification

Lifetime assessment of first bounce EUV collection optics

- Measurement set-up for grazing incidence collection optics
  - **EUV source operation conditions**
    - Long term operation of 14 hours
    - 6 to 20 kHz repetition rate
    - Nominal debris mitigation settings
    - Monitoring of EUV radiation
  - **Exposure of 1" test samples**
    - At nominal collector distance
  - **Sample contamination was analyzed Zeiss with**
    - Microscopy
    - Scanning electron microscope (SEM)
    - EUV reflectometry
    - X-ray photoelectron spectroscopy (XPS)

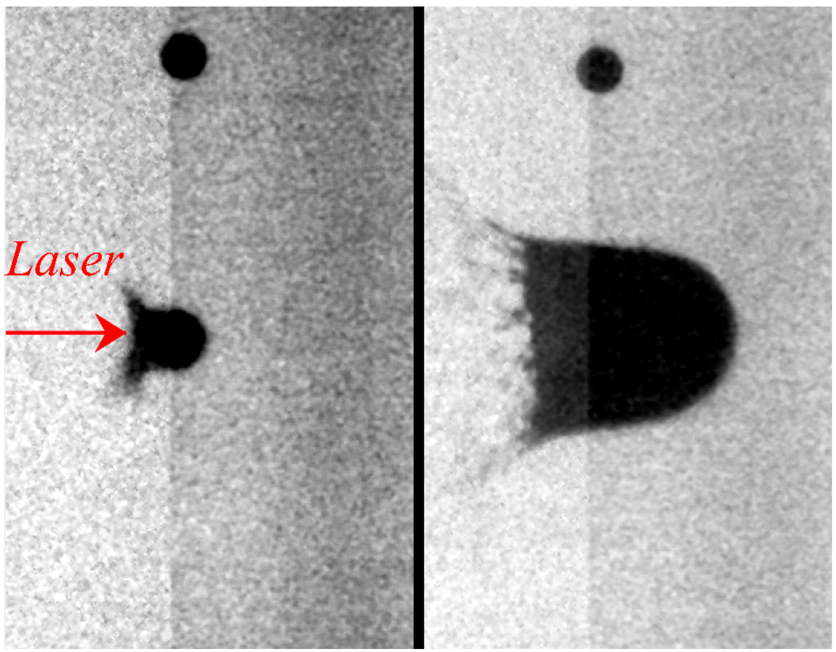


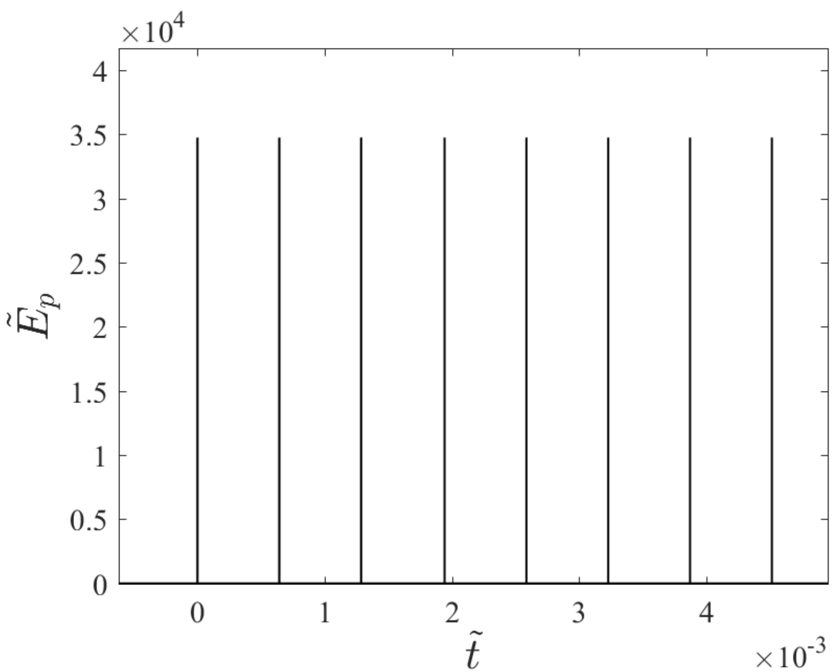
No reflectivity loss after 14 hours of exposure, Total particle area coverage 0.035 % on mirror dummy after 14 hours of continuous operation

Advanced target shaping by picosecond laser bursts

- *Bursts of picosecond laser pulses allow for high order degrees of control of target shape*

$$\tilde{E}_p \equiv \frac{E_p}{\sigma \cdot d_0^2}$$

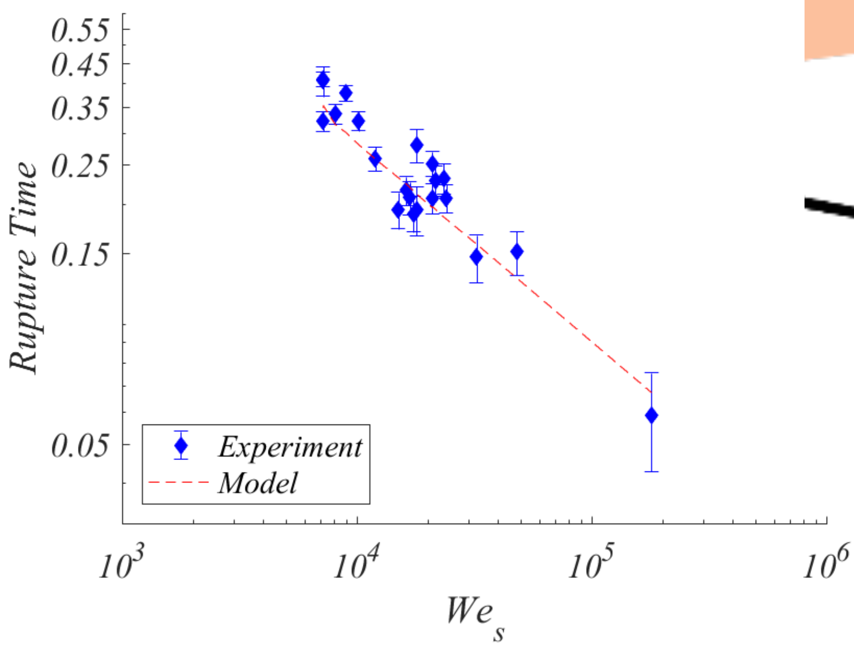


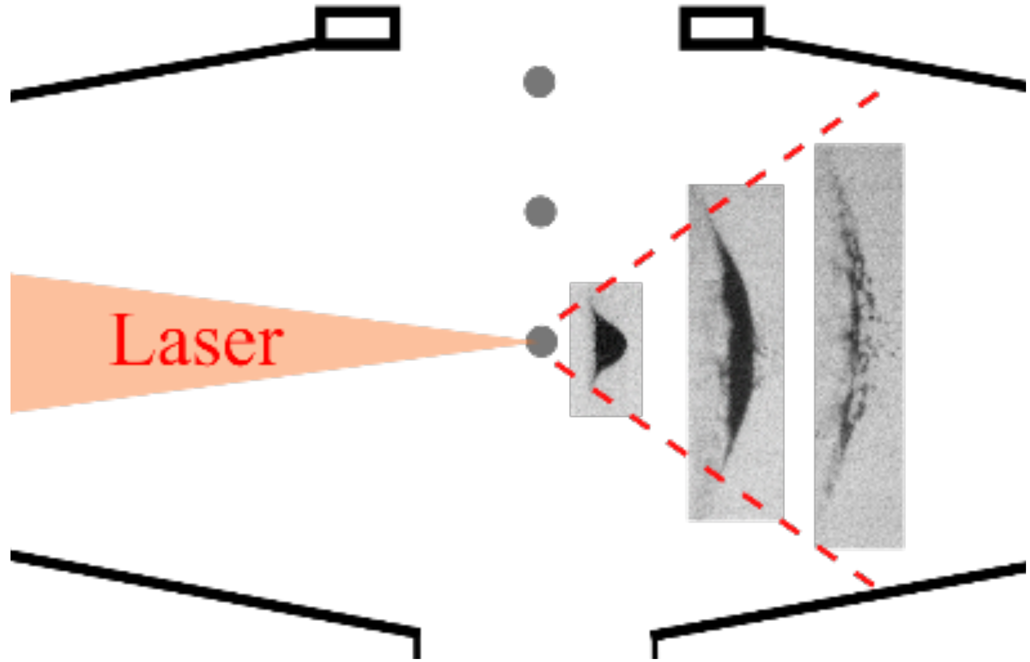


*figures: from submission D. Hudgins et al., 2018 Phys. Rev. E

Physically based model of debris field to maximize collector life

- *Modeling of droplet rupture dynamics identifies laser parameters that can reduce:*
  - *Dominant neutral cluster region*
  - *Neutral cluster fragment size*





$$We_s = \frac{\rho \cdot d_0}{\sigma} \cdot \left(\frac{dR}{dt} \right)^2$$

*chart: from submission D. Hudgins et al., 2018 Phys. Rev. Lett.

Summary and Conclusions

- Repetition rates in the range of 10-20 kHz necessary to further scale brightness to HVM requirements while reducing thermal load on pellicle and mask
- Our light source enables lowest cost of ownership (cost per photon) with high brightness and small foot print
- Technical performance such as stability, high brightness, source cleanliness, and others have been demonstrated and validated
- Beta light source operated as over the last 3 years, producing clean EUV for actinic inspection
- Major Facility and infrastructure expansion near completion

Acknowledgments

- Carl Zeiss SMT for collaboration and agreement to publish
- Swiss National Science Foundation (SNF R'Equip grant 2-77592-12)