Extreme ultraviolet sources for lithography applications

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People contributed to the presentation

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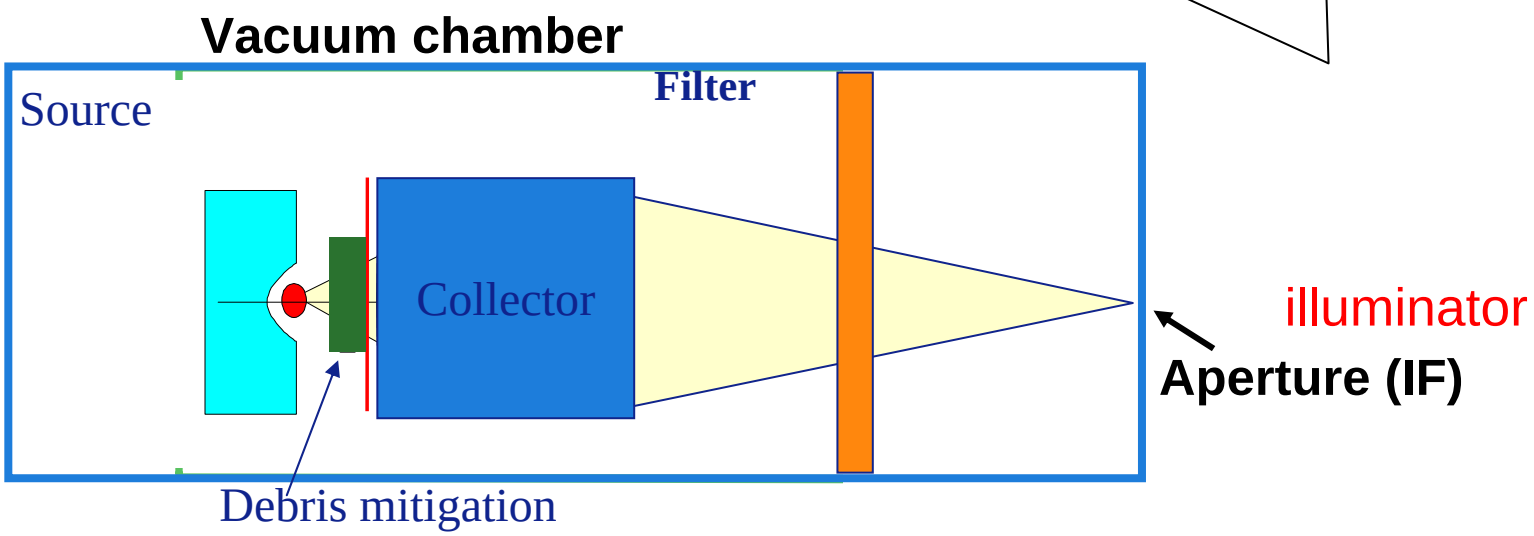
- Philips Research: D. Klunder, M. van Herpen

Contents

- Specifications of EUV source for lithography
- Achievement in power for EUV sources and technical solutions
- Debris mitigation:
  - micro particles,
  - atomic,
  - ions/ plasma,
  - EUV induced molecular contamination
- Conclusions

Definition of clean photon spot at intermediate focus (IF)

Source specifications are defined at intermediate focus (IF) which is illuminator entrance



Joint Requirements for EUV Source

Previous EUV symposium

SOURCE CHARACTERISTIC	REQUIREMENT
•Wavelength	13.5 [nm]
•EUV Power (in-band)	80 - 115 [W]
•Repetition Frequency	> 6000 Hz
•Integrated Energy Stability	±0.3%, 3σ over 50 pulses
•Source Cleanliness at IF	≥ 30,000 hours
•Etendue of Source Output	max 1 - 3.3 mm^2sr
•Max. solid angle input to illuminator	0.03 - 0.2 [sr] Spectral
Purity:	
130-400 [nm] (DUV/UV)	≤ 3 - 7%
≥ 400 [nm] (IRVis) at Wafer	TBD

Production of sufficient and “clean” power is a major challenge for EUV

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Challenges for EUV sources related to high power operation

For discharge sources:

- Heat load (electrodes close to the place of heat release)
- Component erosion (due to arc type of erosion at electrodes)

For LPP based sources:

- Required laser power (CoO)

For all sources:

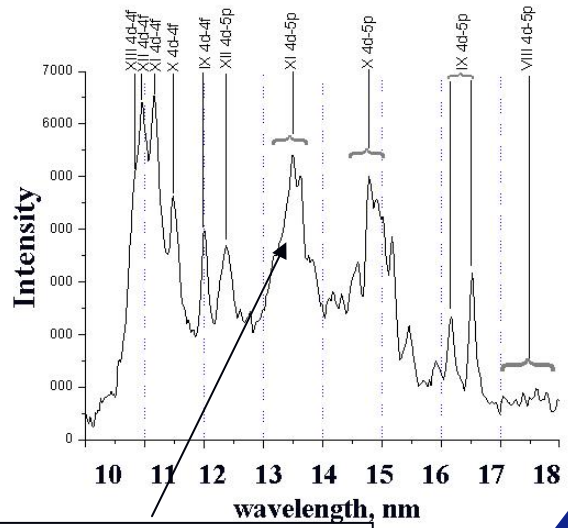
- High debris production

Solutions for the EUV source power

- Step from the current Xe based solutions with low CE (0.5-1%) to high CE (>3 %) materials, such as Sn, Li, …
- Source multiplexing
- Both of above

Use of alternative materials

Hollow cathode

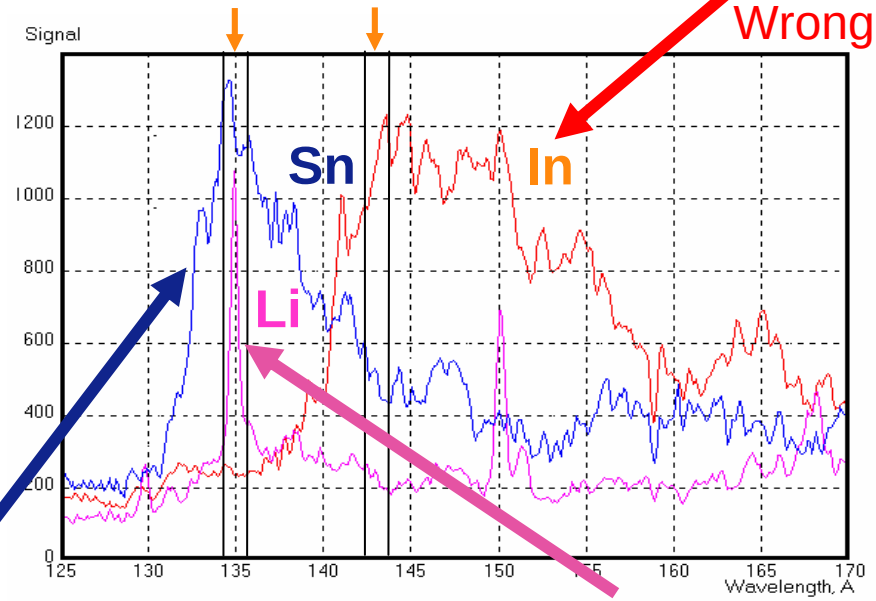


Xe: CE= 0.4-0.5%

Pseudo spark

2-3.5 % BW @ 13.5

2 % BW @ 14.3



In: CE= 1% @ 14.3 nm

In is NO GO: Wrong wavelength

Sn: CE= 2-3.5% @ 13.5 nm

Sn pseudo spark demonstrates much higher CE than Xe based source and at the right wavelength

Li: CE=0.5% @ 13.5 nm

Li has a right wavelength but CE seems to be low: For a time being is not preferred

The CE with Sn is 4-5x higher than that of Xe ! -> Lower Heat load.

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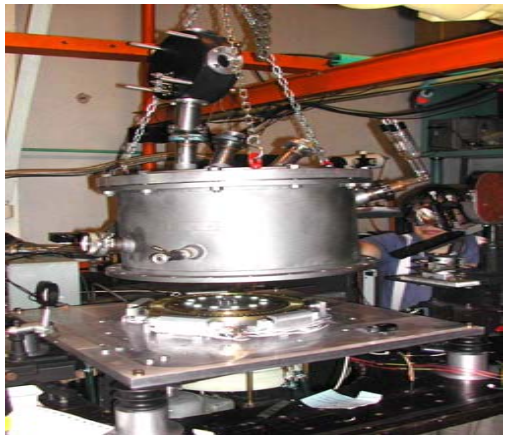
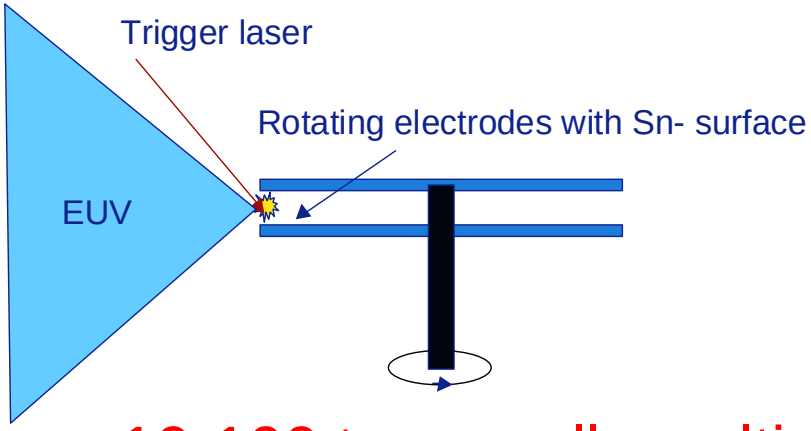
Laser triggered multiplexed Sn source



Achieved:

- 2 % CE
- 200 Hz (not power limited)

20 W in 2π in-band
(about 2 W IF)



Prospect:

- 3.5 %
- 5000 Hz

>100 W in IF

10-100 temporally multiplexed elementary sources !
-> Distributed Heat load

No significant electrode erosion

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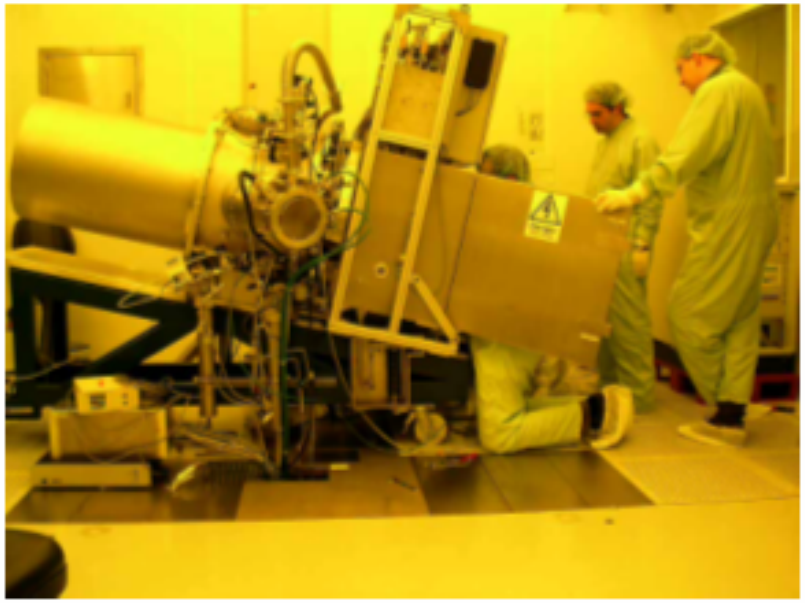
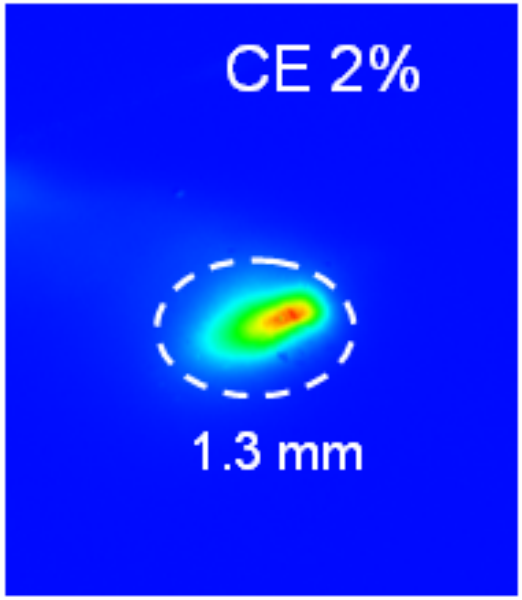
Philips' Source development:

This symposium

- Xe source as integration workhorse
- Sn source: 25 W@IF continuous operation (π collector)



Xe-source



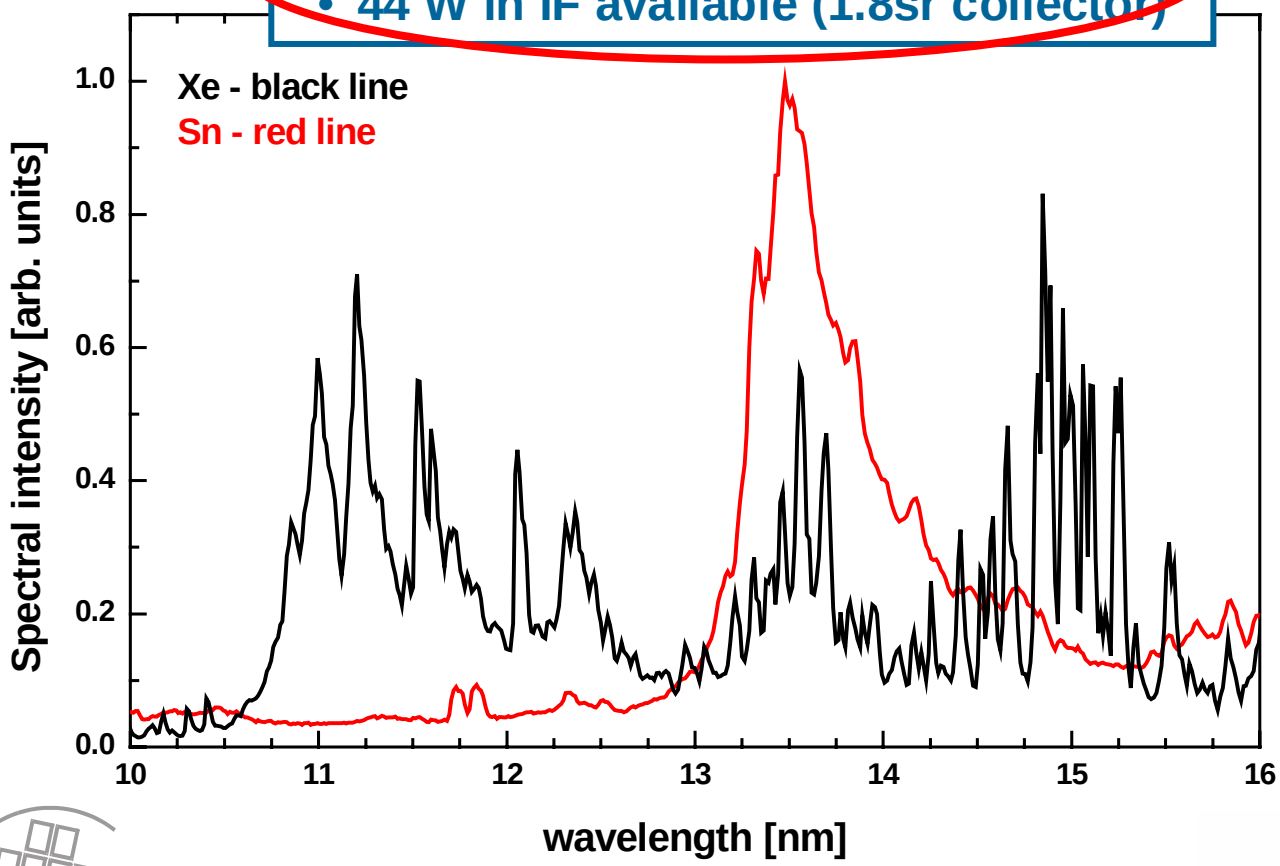
pinch of Sn-source

Status GDPP EUV Sources: Power scaling (II) - tin

MNE Rotterdam
Sep2004

Highest power from tin GDPP source in the world

- 400 W power in 2 π sr
- 44 W in IF available (1.8sr collector)

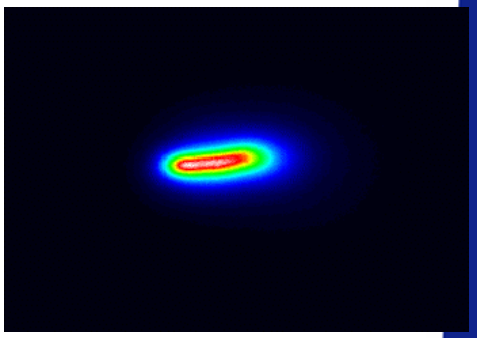


EUV Energy:

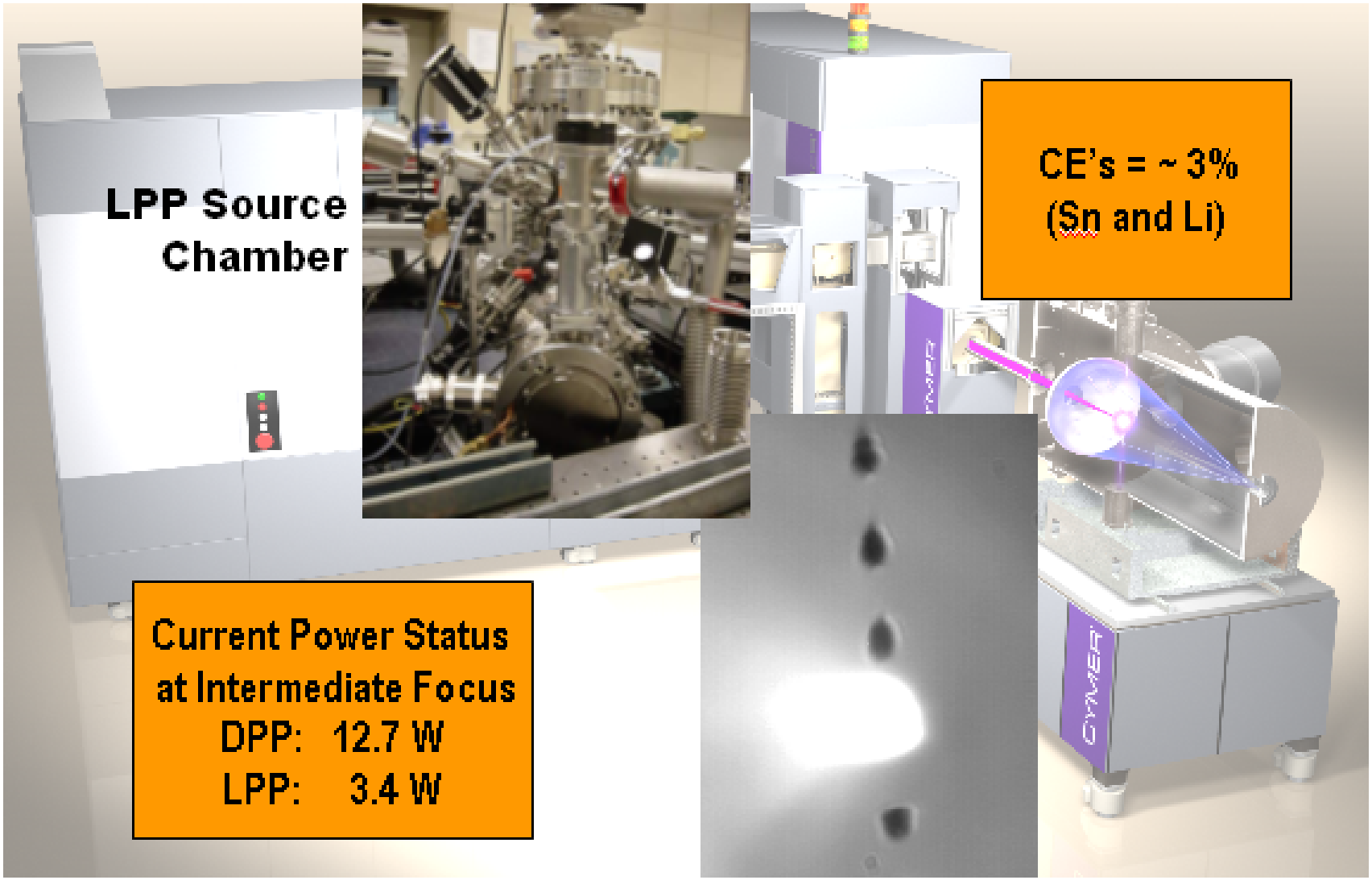
- 80 mJ/2π sr (tin)
  (40 mJ / 2πsr, xenon, for comparison)

Repetition rate:

- Up to 5 kHz



Cymer EUV Source Development Status



CYMER

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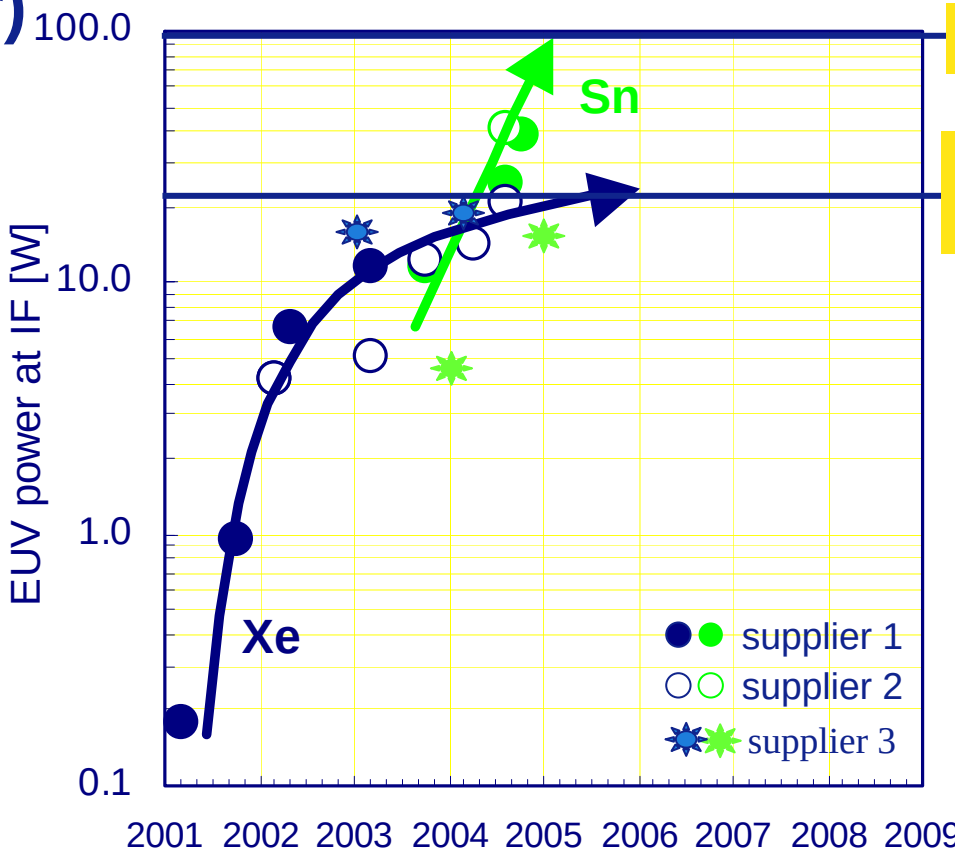
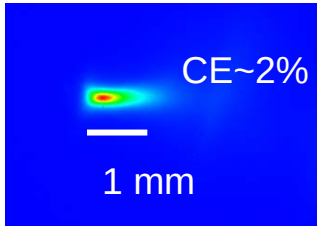
Fast progress on system productivity (source power)



Need >115W for >100 W/hr

Need 22W for Alpha Demo tool, 10 W/hr

Sn source



Best result:

- *39 W by supplier 1 and 42 W by supplier 2*

Conclusion

- ***Production tool source power requirement within 3x demonstrated by multiple suppliers.***

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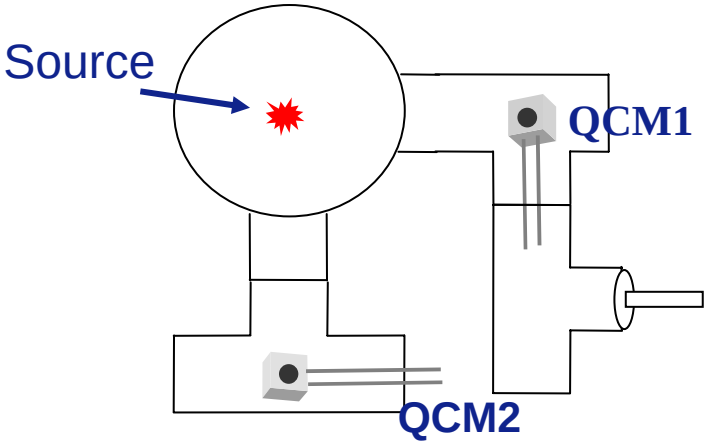
The scaling of power to production tool levels with alternative sources is feasible!

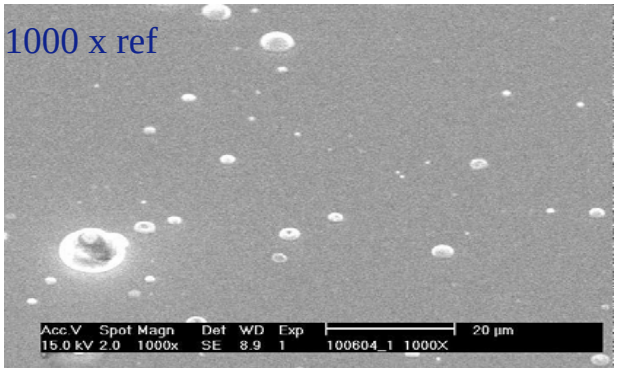
The major challenge is the debris mitigation

Debris characterization

- Total amount produced debris
  - Micro particles -> non-uniform collector surface coverage
  - Fast ions -> surface sputtering
  - Atomic/ ionic debris -> uniform collector surface coverage
  - EUV induced molecular contamination -> surface coverage (see presentation of Bas Mertens at this symposium)

Total amount of Sn debris





- Total amount of Sn debris as measured with QCM: about 10^{15} 1/pulse (the number of atoms to mitigate)
- 10% reflection loss corresponds to 10^4-10^5 pulses (< 1nm deposition)
- Amount of micro-particles as calculated from SEM photo's is about equal to amount of atomic debris.
- The theoretically required minimal number of atoms in pinch should be $1 \cdot 10^{14}$ 1/pulse, K.Koshelev, EUV source workshop 2003

Improvement in debris production x10 is still possible

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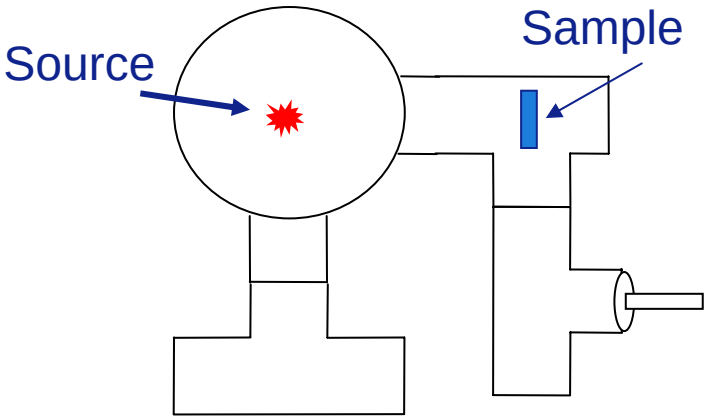
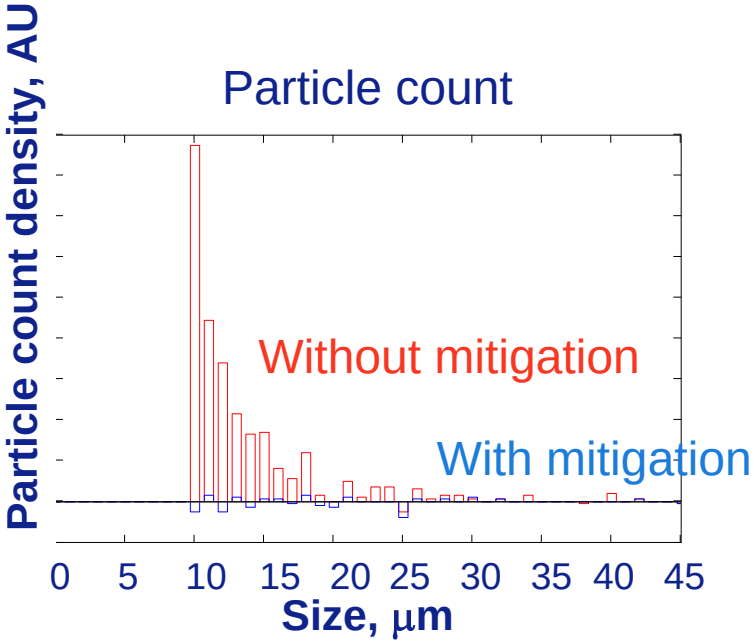
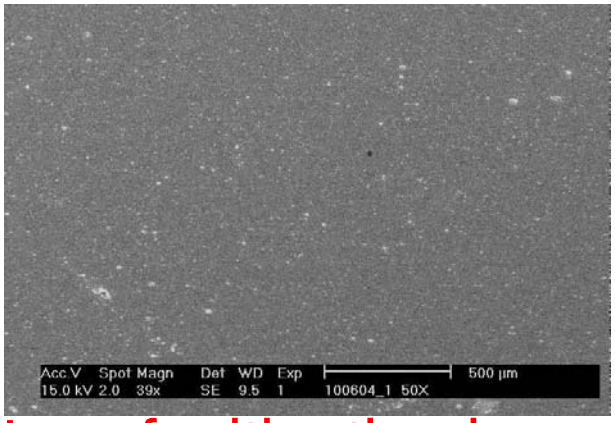
Micro-particles

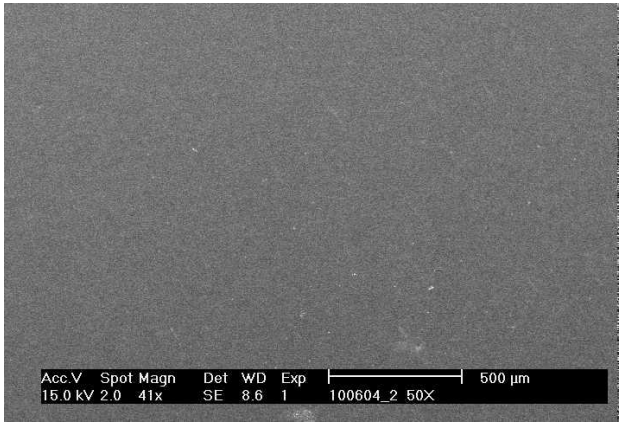




SEM measurements



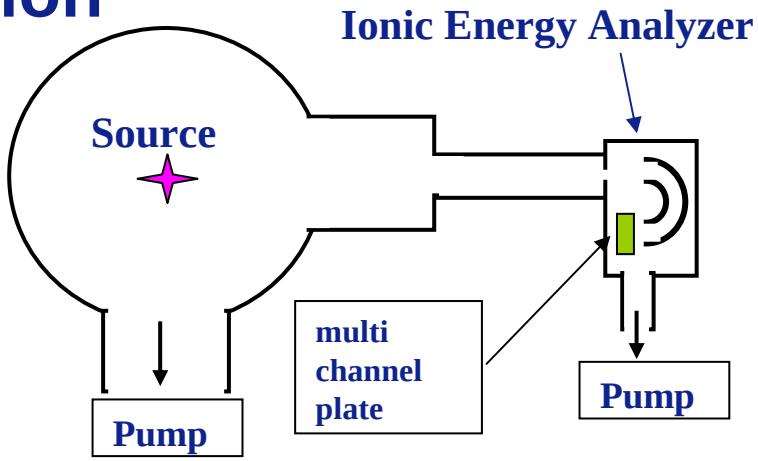
Mitigation

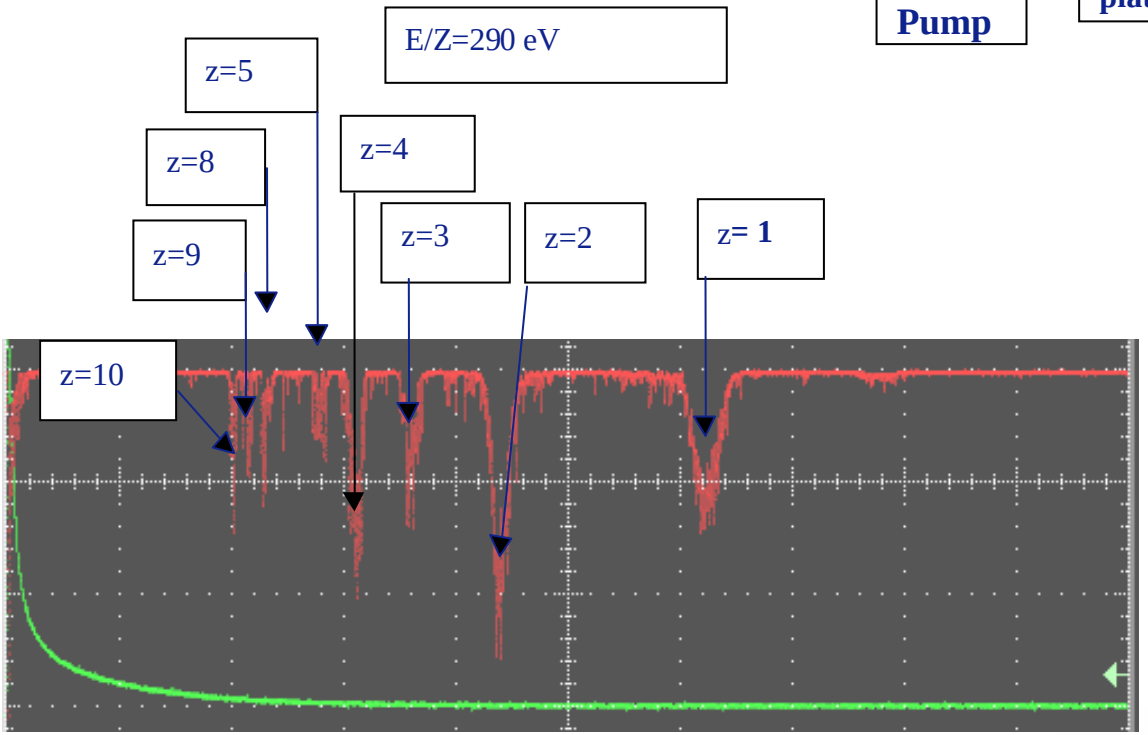


Use of mitigation improvement brings particle count on the background noise level (projected lifetime at least 10^9 pulses determined by detection limit)

Ionic debris characterization

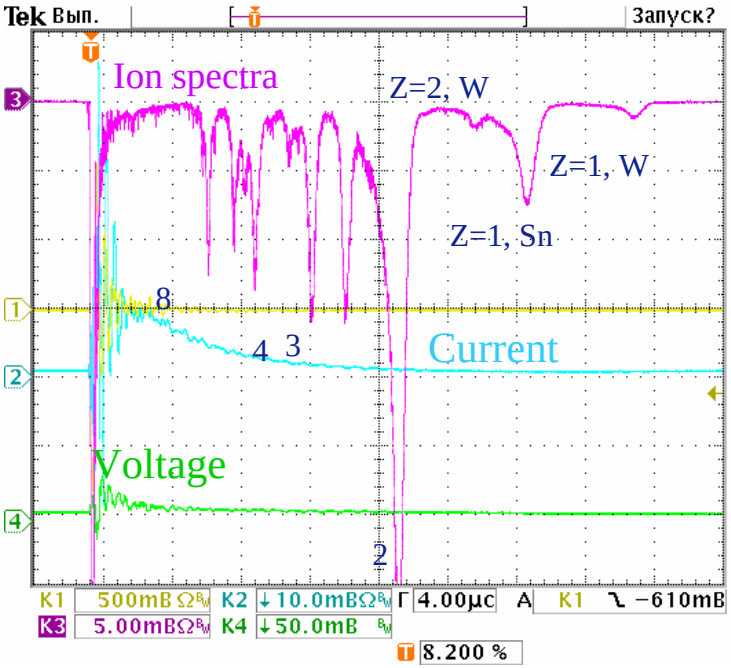
Ions form z=1 to z=10 are present in the ionic debris



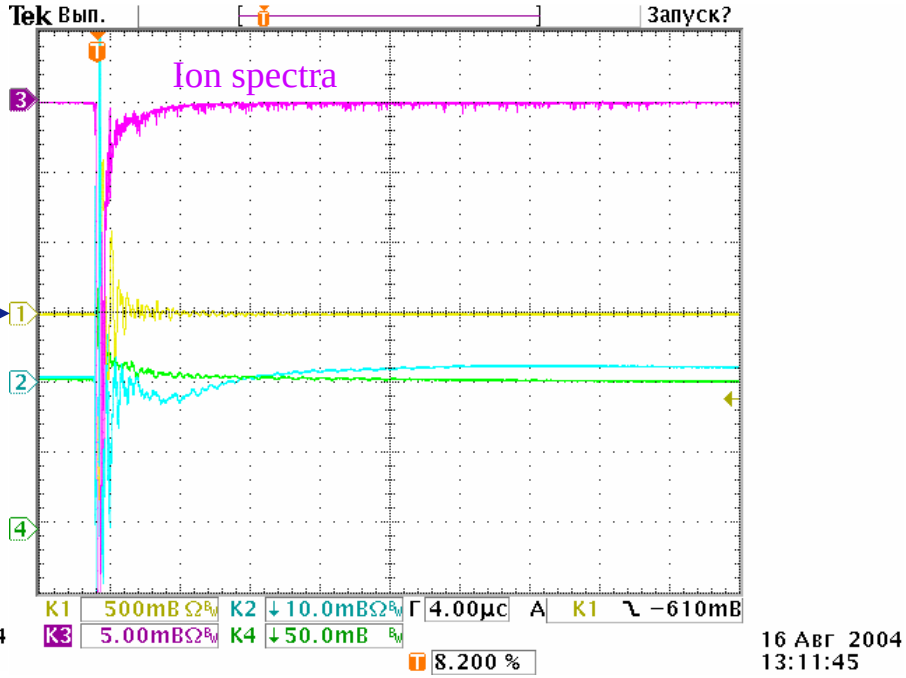


Ionic debris mitigation

No mitigation applied



Mitigation applied



As measured with witness samples no fast ion induced damage has occurred with an equivalent 10^7-10^8 pulses of lifetime (determined by the detection limit)

Ionic debris can be successfully stopped by applied mitigation

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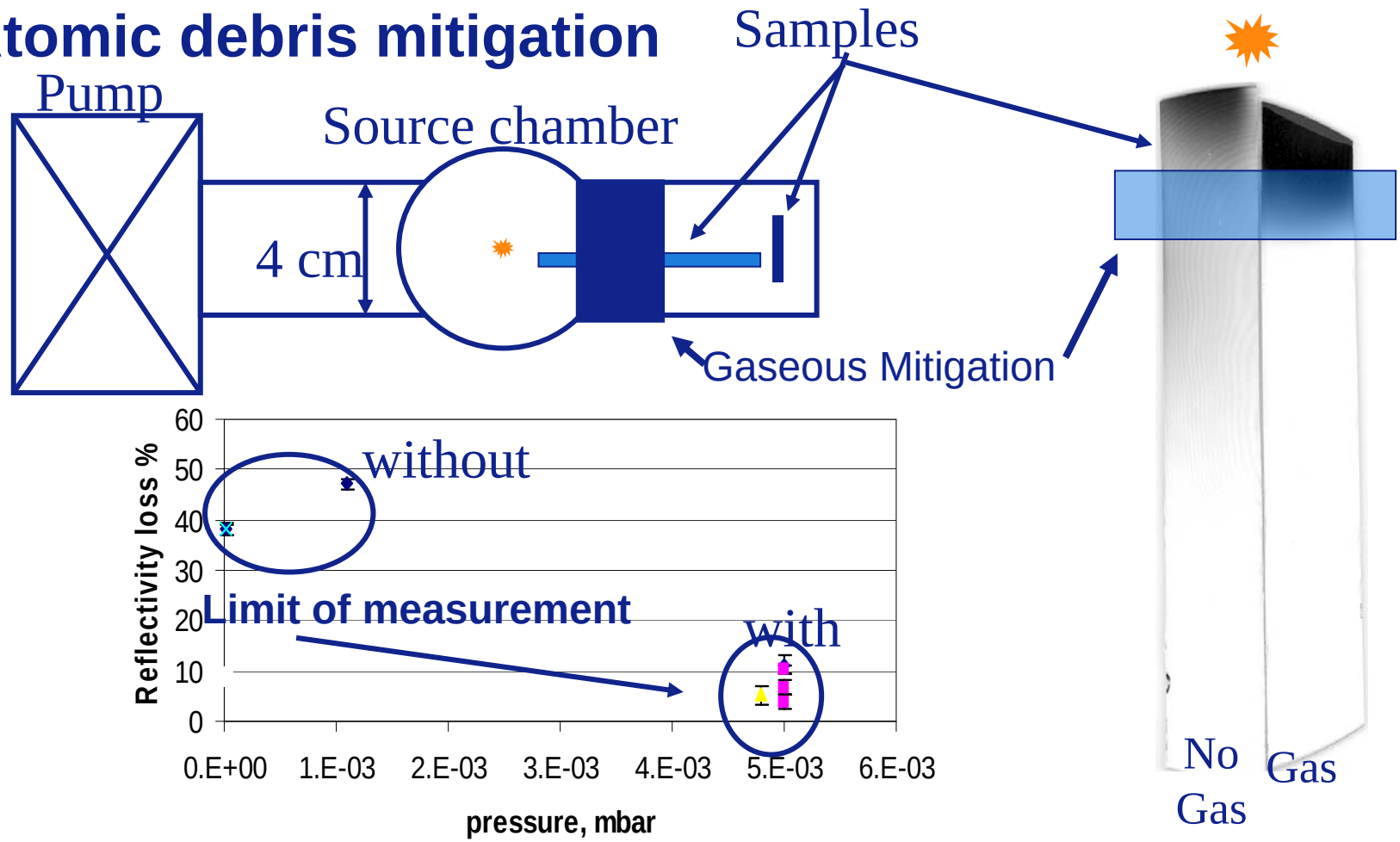
Atomic debris mitigation



As analyzed with witness samples no atomic Sn component has been found at equivalent lifetime of 10^7 pulses with approximation with extended mitigation of 10^8 pulses (determined by detection limit)

Atomic debris can be efficiently stopped by gaseous mitigation

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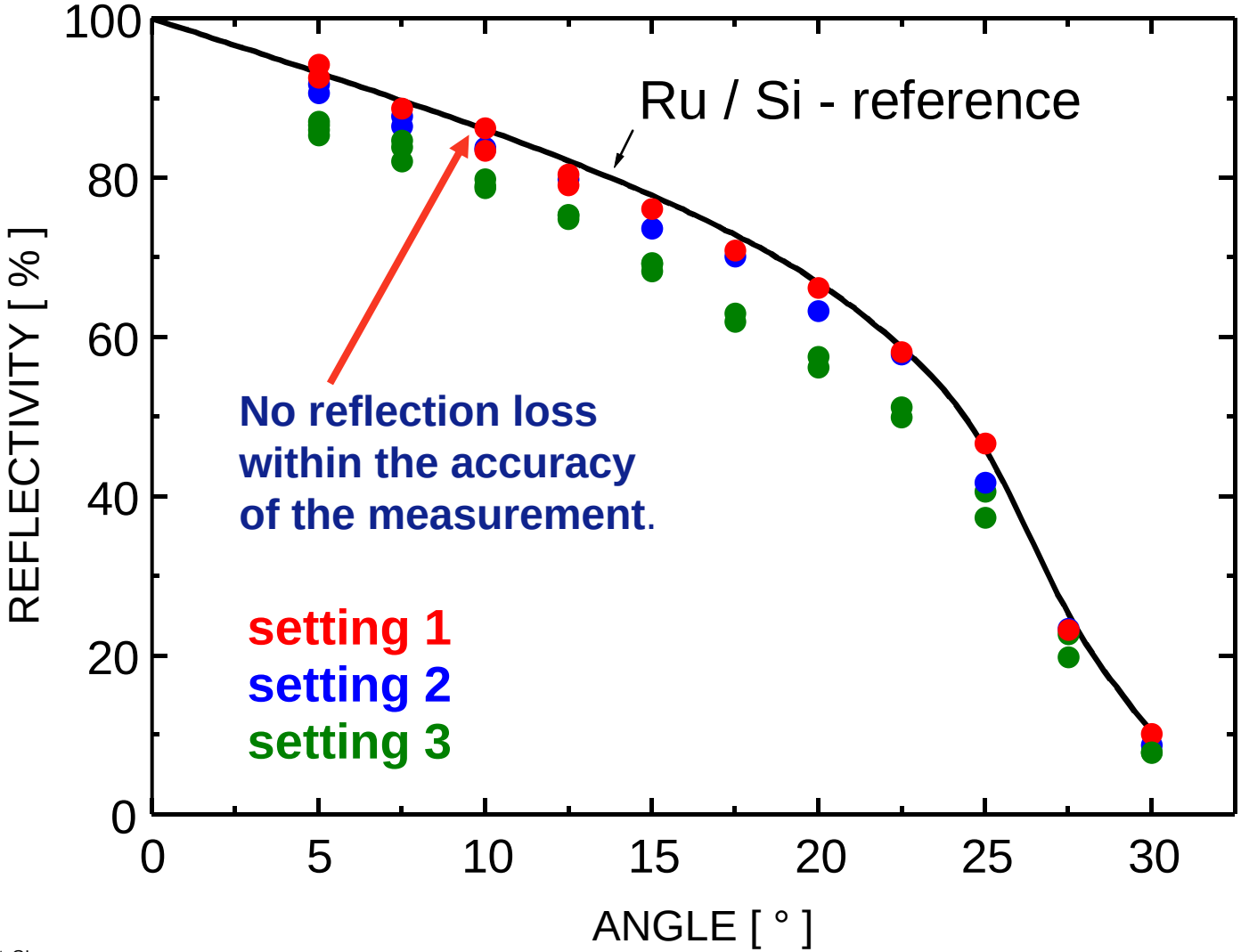
Variation of mitigation parameter (Grazing Incidence, 5 M shots)



Plot : GreflectivityGI
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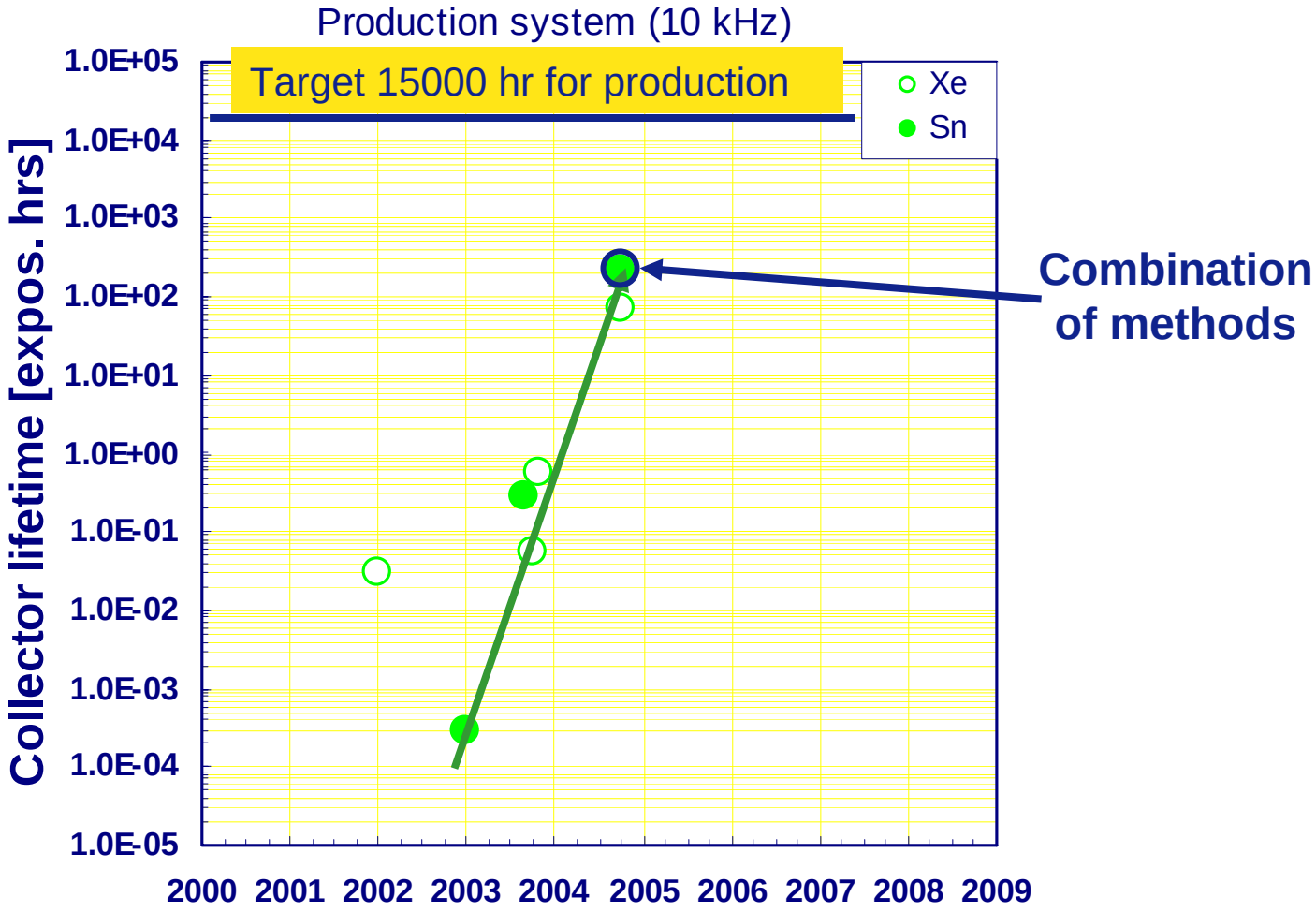
Collector lifetime combining a number of methods



Up to 200 hours of the collector lifetime combining a number of mitigation methods is feasible.

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Concluding remarks

- >115 W EUV source to support 100+ wph throughput tool is needed
- Sources working with alternative materials and/or multiplexing show that there is no potential show stopper in power scaling (up to 40 W already now against >115 W needed in production tool)
- Experiments with debris mitigation show no collector damage based on the accuracy of the measurements (up to about 10^8 shots)
- Combining a number of mitigation methods 200 hr of colletor lifetime seems feasible
- A scaling method to demonstrate collector lifetime of several thousand hours (for production tool) is needed

Acknowledgements

Thanks for help at…

- ASML
- Philips Extreme UV
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- Cymer
- …and many others

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