ASML

Extreme ultraviolet sources for lithography applications

Vadim Banine - ASML,

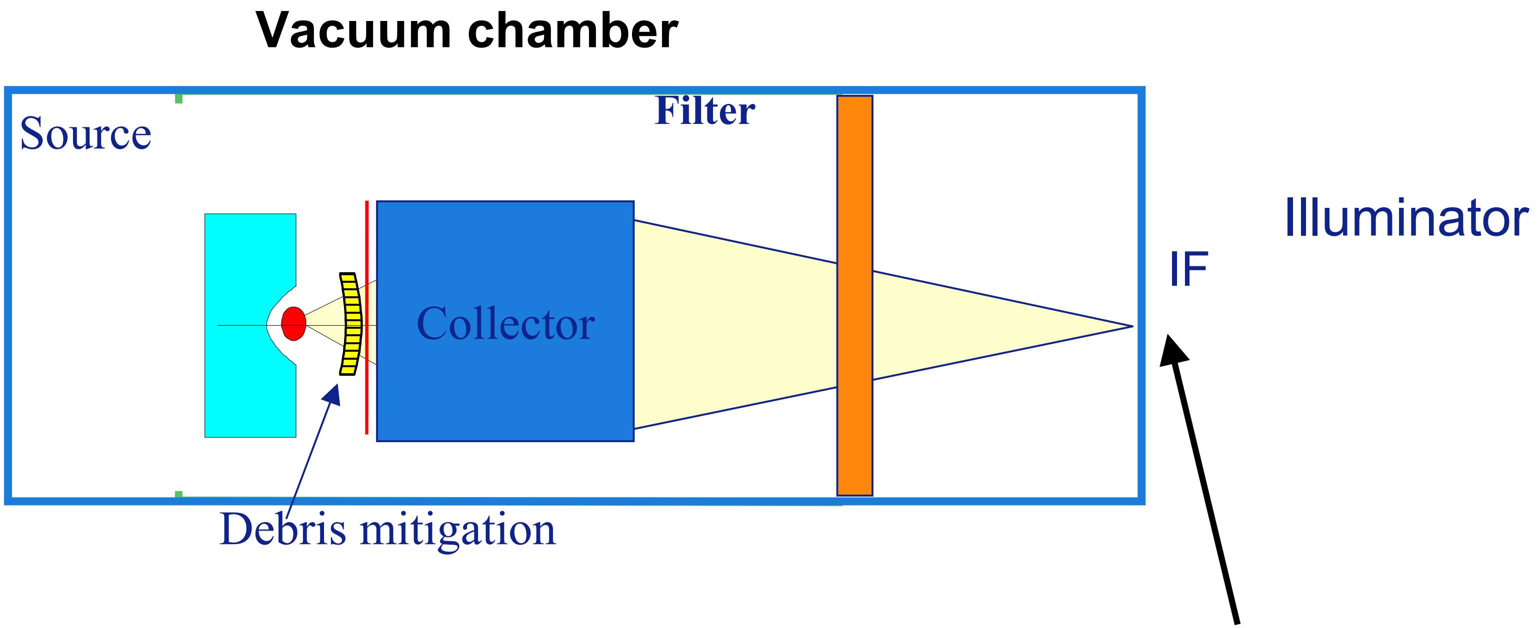
Konstantin Koshelev - Instiute of Spectroscopy of Russian Academy of Science,

Erik Kieft - Eindhoven University of Technology

Contents

- Power specification of EUV source for lithography
- High input power as a main technical challenge
- Possible solutions for power problem
- Conclusions

Definition of clean photon spot at intermediate focus (IF)



>100 W in2% BW
at 13.5 nm is required here
in order to support >100 wph tool

Evaluation of required input power for discharge sources

- >100 W at IF means about 500 W in 2π in-band (with π collector, 55% integral reflectivity, 10% gas absorption, 90% transmission of debris mitigation and spectral purity filter transmission of 100%, assuming SP conditions are met)
- presented CE about 0.5% (SPIE 2002, U. Stamm et al)
- Direct input power into discharge region about 100 kW (very high thermal load)

Why 100 kW input seems high

- **Permanent load**: It depends on configuration, but imagine that half of it going into a volume of a sphere with 0.5 cm radius. If walls are 1mm thick and perfectly cooled, the inside sphere temperature will rise to 1500-2000 C.
- **Pulsed load**: Due to the fact that the load is pulsed, only several μm's will be heated up during 200 ns of a pulse. This will bring the pulsed temperature to 4000-5000 K
- **Atoms of electrode material loss**: Under this temperature even for tungsten the saturated pressure is about 1 mbar. Thus about 10^{13} atoms/cm^2 per pulse will evaporate from the surface. This means that about 1 mm in 10^7 pulses will be lost changing the shape of the electrodes significantly for life time to be the limit.

Consequence of the high power input

- The upgrade to higher powers with Xe is questionable
- Possible improvements: Alternative materials with high CE and multiplexing

Challenges for Discharge based EUV sources related to high power operation

- Potential heat load control problem (electrodes close to the place of heat release)
- High component erosion (due to high current at electrodes)
- High debris production (due to electrode erosion)
- High fast ion flux

What can be done to obtain the required result

- Increase of CE by means of use of alternative materials such as Sn, In, …
- Multiplexing of the sources

Special attention should be paid to the fact that any alternative source configuration has to be compatible with optical requirements of the system

Comparison of an alternative source configuration with an established EUV Xe-based source

Current and alternative systems

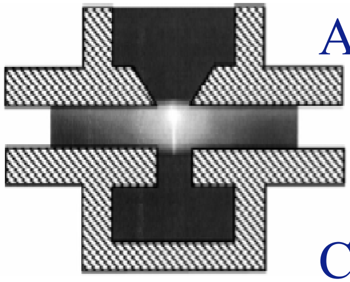
Extreme UV (Philips) EUV pinch source

RGA

Xe Discharge plasma

Flying circus

Experimental vacuum chamber



Anode

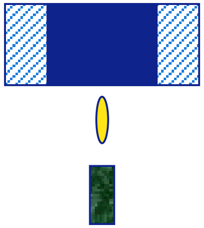
Cathode

Bergmann *et al.*, Microel.eng. 57-58, 2000, pp. 71-77

Source installed in ISAN and ASML

Pseudo spark

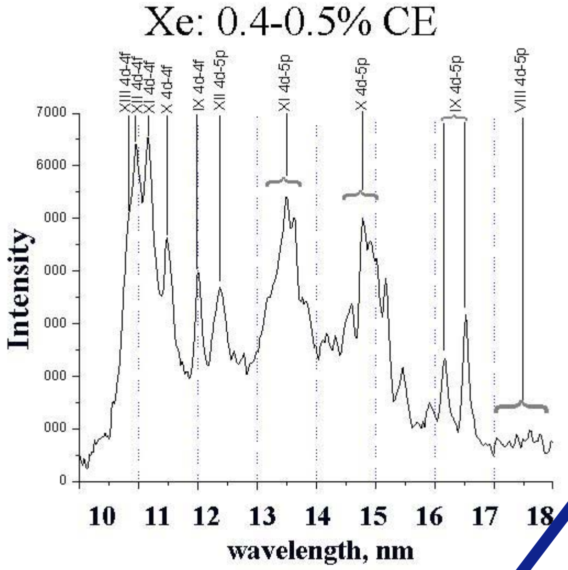
Anode



Cathode

Spectra and CE: choice of material (Xe, Sn, In, Li)

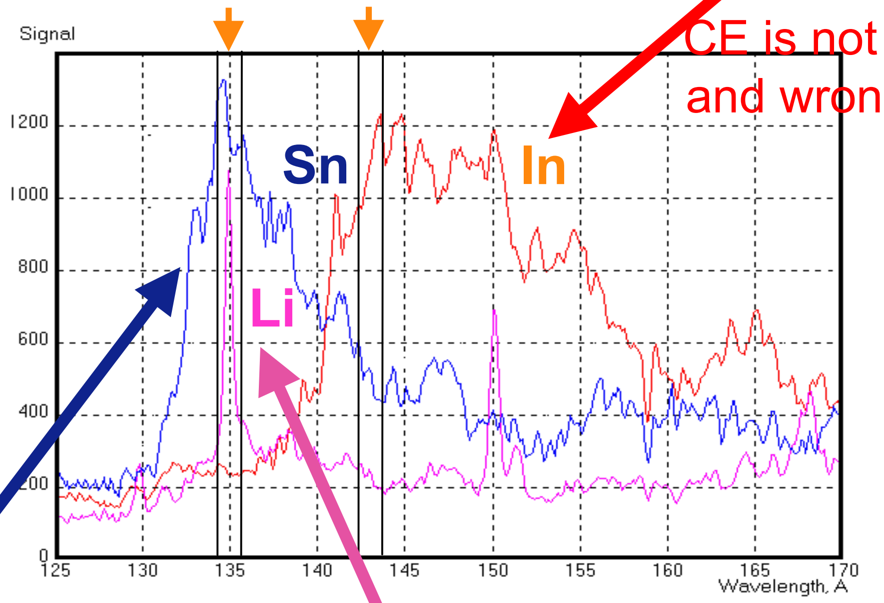
Hollow cathode



Pseudo spark

2 % BW @ 13.5

2 % BW @ 14.3



In: CE= 1% @ 14.3 nm

In is NO GO:
CE is not high enough
and wrong wavelength

Sn: CE= 2-3% @ 13.5 nm

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

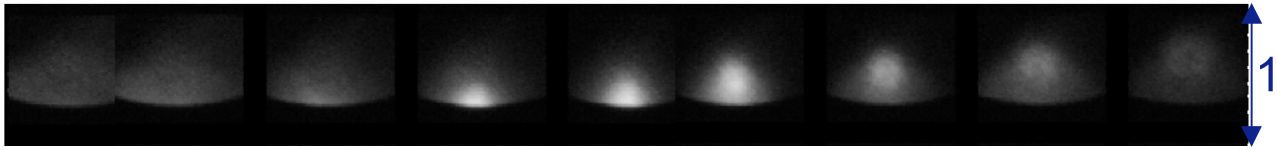
Li: CE=0.5% @ 13.5 nm

Li has a right wavelength but CE seems to be low at the current source configuration: Not a good choice.

Pinching time and size

Zippering effect in Xe pinch

Anode



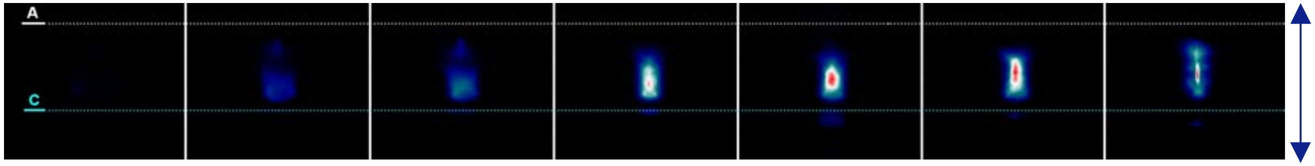
1.9 mm

Cathode

Pictures taken with fast EUV camera during pinching (each 10 ns)

Zippering effect in Sn pinch

Anode



5 mm

Cathode

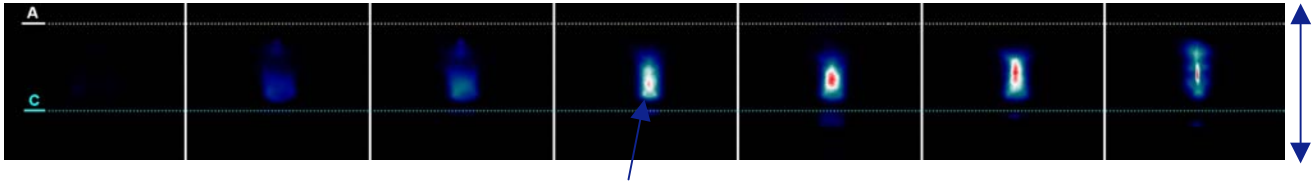
Pictures taken with fast EUV camera during pinching (each 10 ns)

Effect of pinching time as size are comparable

Theoretical prediction of zippering effect

Zippering effect in Sn pinch experiment and model

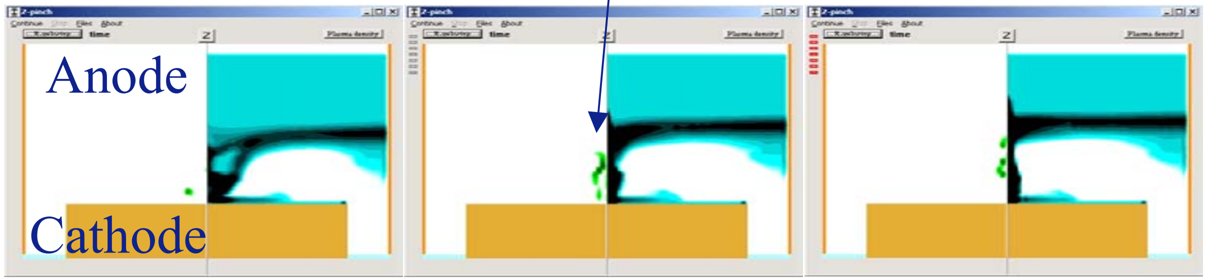
Anode



5 mm

Cathode

EUV spot



Anode

Cathode

The model is developed by V. Ivanov (ISAN)

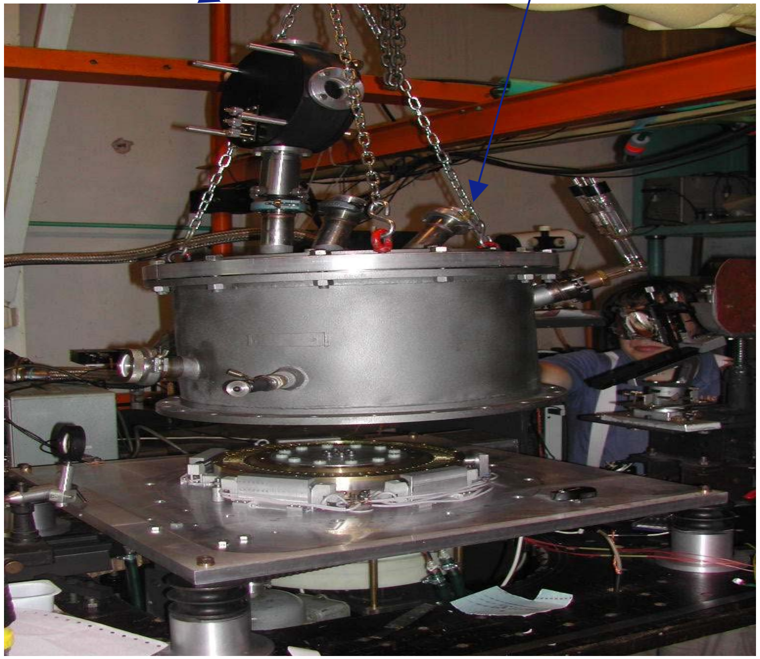
Independent on the pinch size physics of pinching seems to be governed by so-called “radiative collapse” model (K. Koshelev et al)

Another way to reach the required power is to multiplex

Multiplexed Sn source

power measurement tool

Experimental vacuum chamber



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

20 W in 2π in-band (about 2 W IF

Prospect:
- 3%
- 5000 Hz

>100 W in IF

Concluding remarks

- EUV source to support 100+ wph throughput tool is required
- To achieve required EUV power with Xe seems highly questionable
- Experiments with different alternative materials and multiplexing point at Sn as high potential candidate for EUV source material
- Together with high demonstrated CE with Sn multiplexing seem promising for high EUV output production (>100 W)
- Next challenge: debris