

Development of high conversion efficiency high power EUV sources for lithography

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TRINITI's EUV Prototype Machines

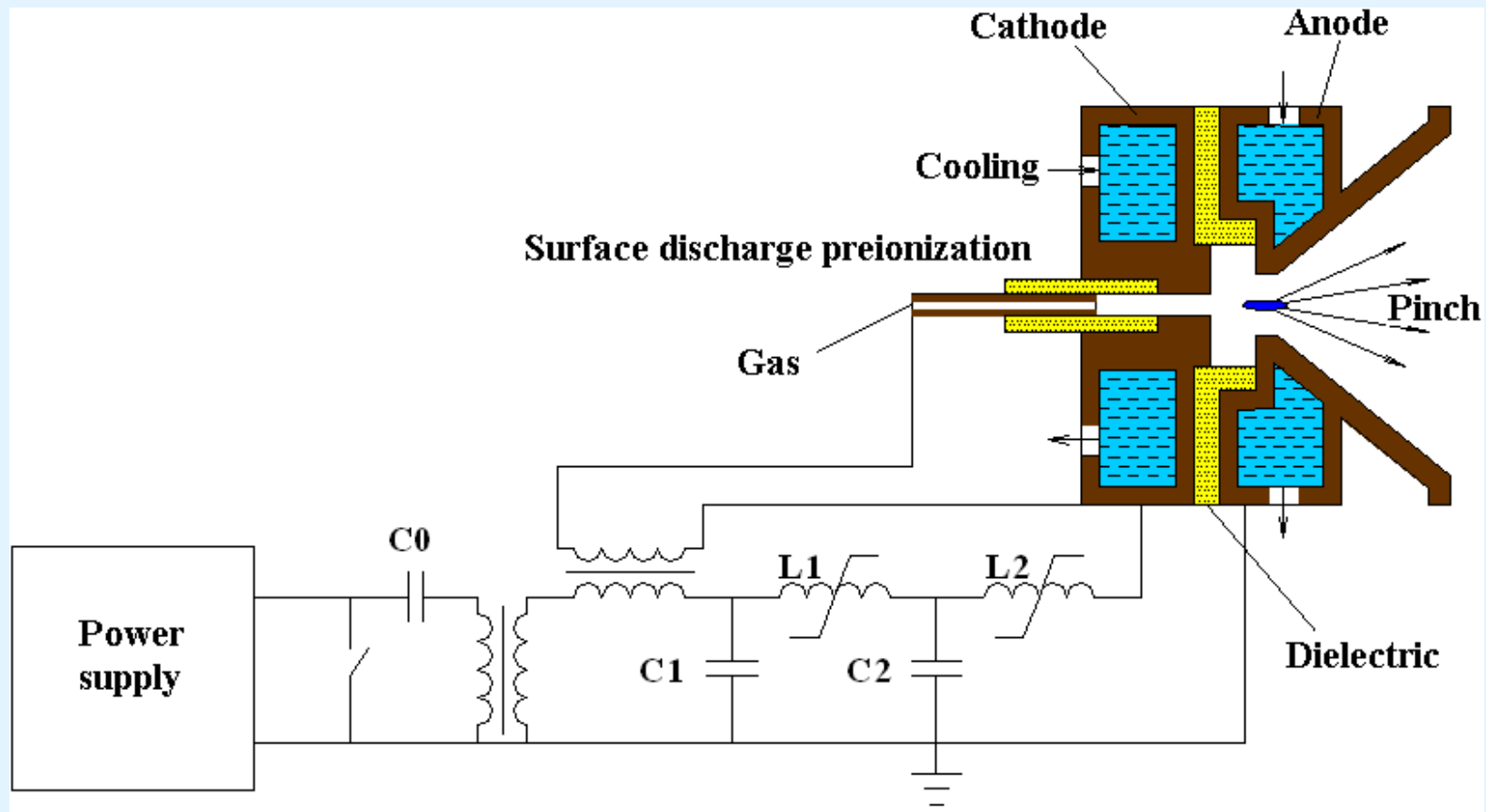
Parallel Development of Xe and Sn Sources



8 EUV sources with Xe and Sn have been built at State Research Centre of Russian Federation - Troitsk Institute for innovation & Fusion Research

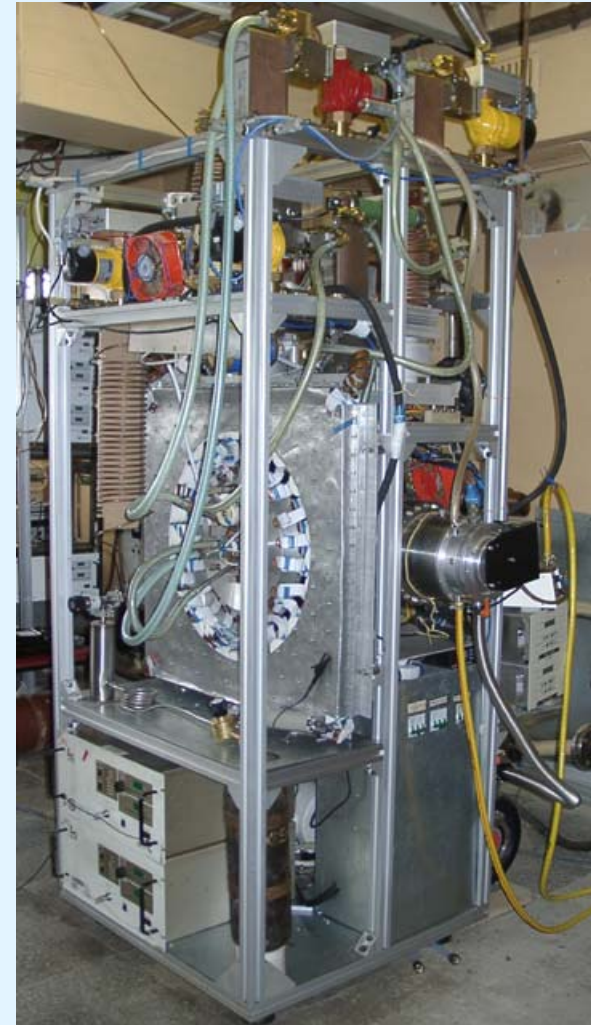
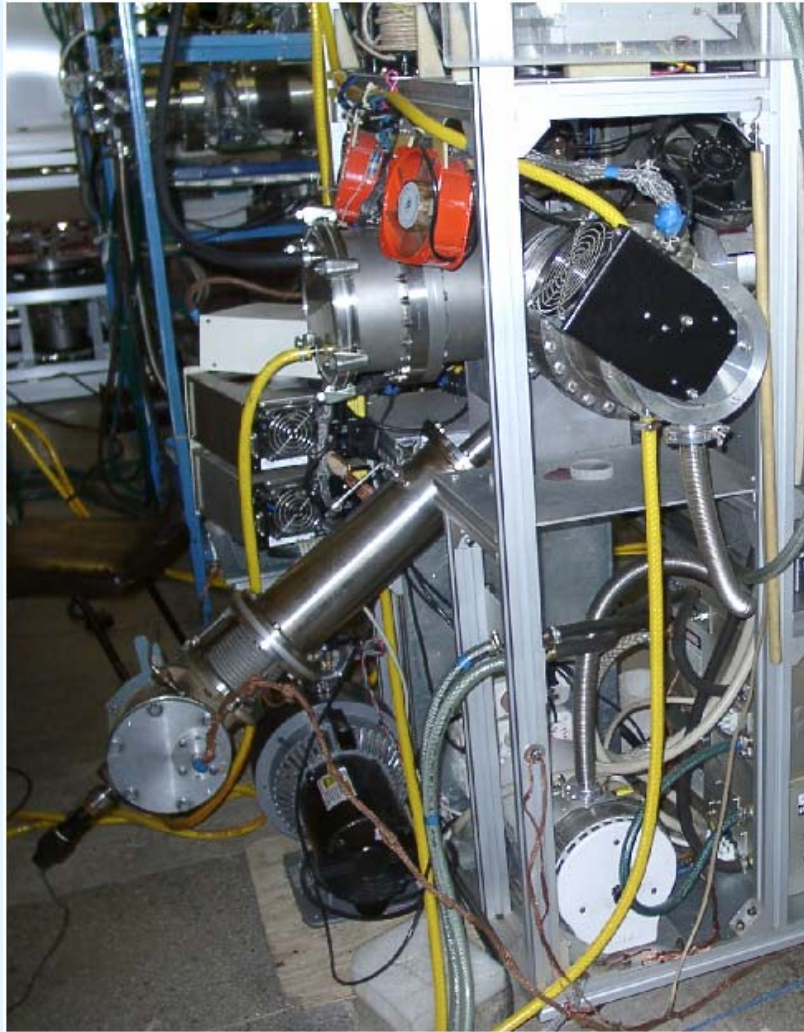


High power gas-discharge produced plasma EUV sources

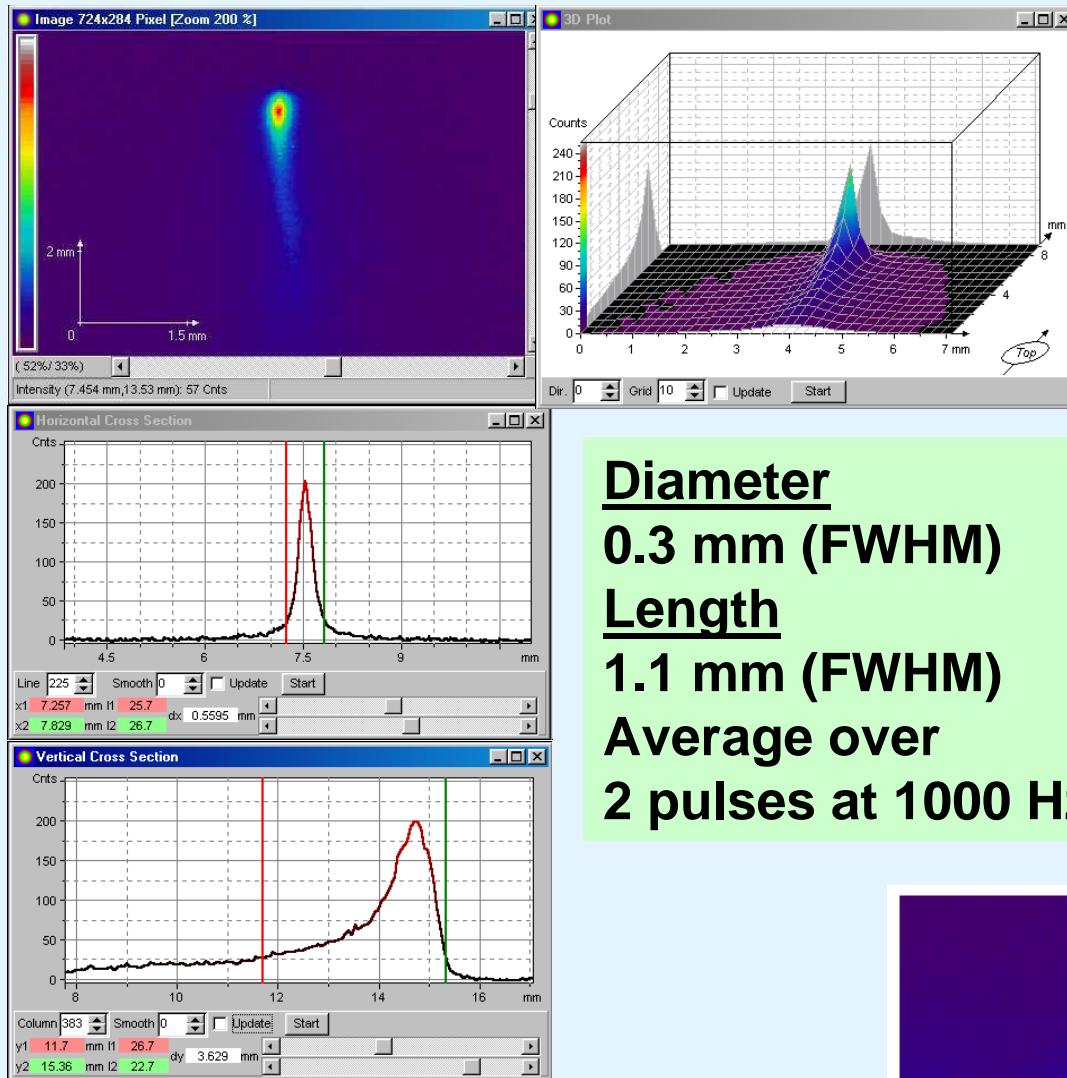


Schematic drawing of EUV source based on Xenon Z-pinch

Fourth Generation of the Xe Source



EUV plasma size in Xe



Diameter
0.3 mm (FWHM)
Length
1.1 mm (FWHM)
Average over
2 pulses at 1000 Hz

1) E_1, P_1, U_1

2) $E_2 < E_1$

3) $P_3 < P_2$

4), 4') $U_4 = -U_3$

EUV measuring instruments



Calibrated EUV energy measuring instrument

made in [AIXUV](#)

EUV-Technology

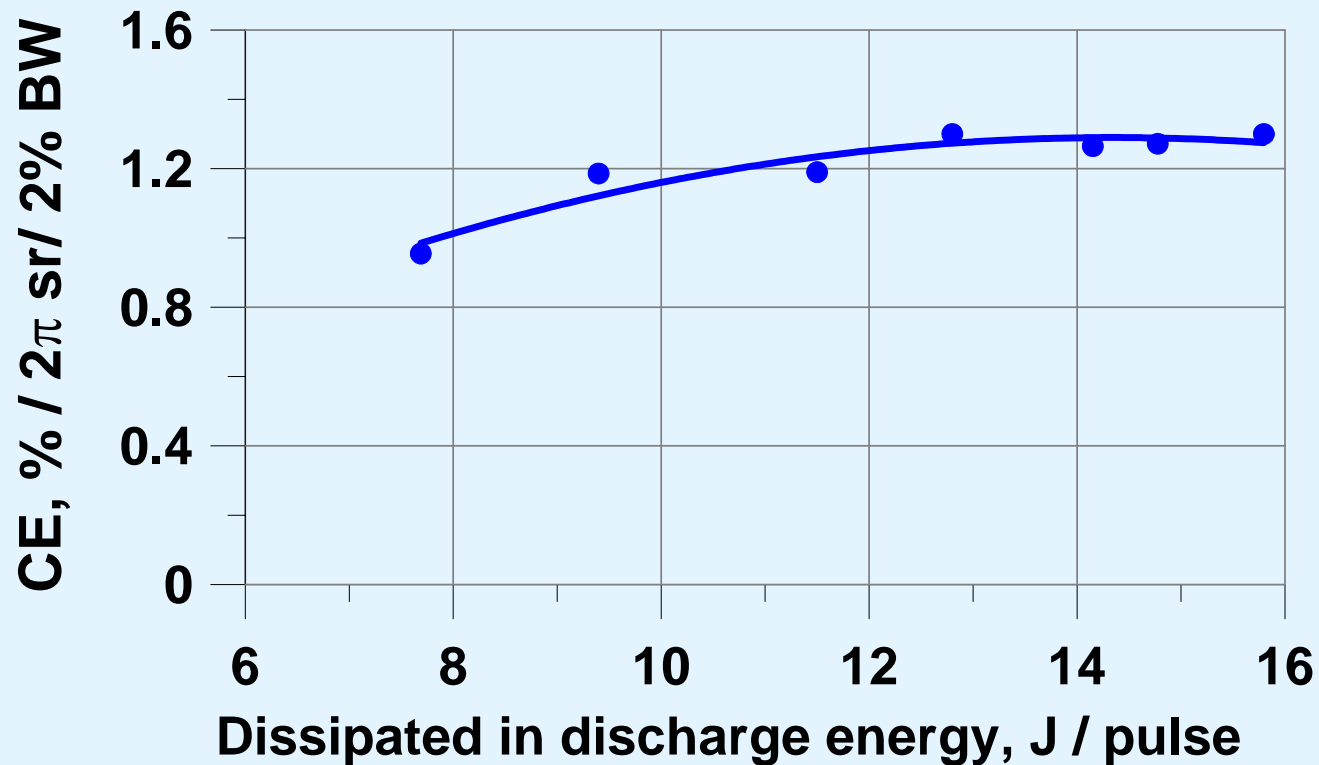


Pinhole camera developed in co-operation between XTREME technologies GmbH and Laser Laboratorium Göttingen to measure an image of the EUV pinch



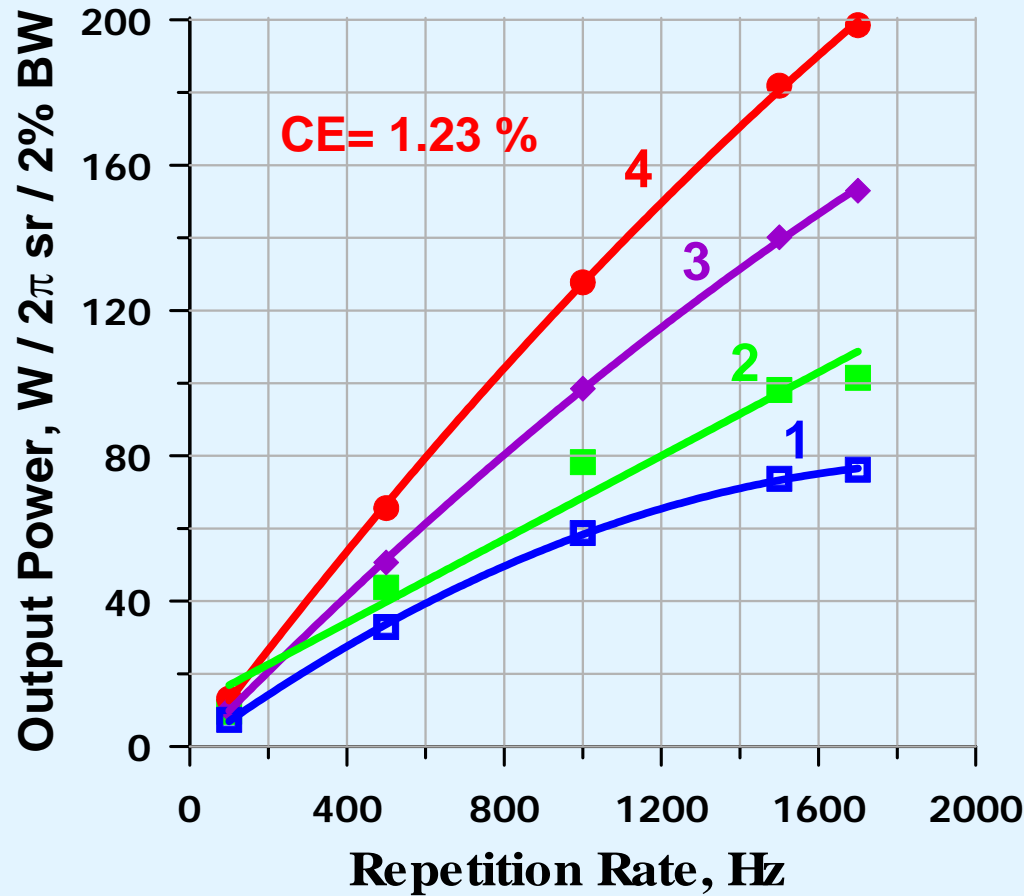
Intrinsic conversion efficiency for the Xe source

Intrinsic conversion efficiency (CE) is calculated as ratio of EUV energy just near the plasma (13.5 nm, BW=2%) into 2π sr (E_{EUV}) to dissipated in discharge energy (E_{in})



EUV source with Xe: output power

Burst mode



1- direct measurement when photodiode spaced 119 cm from pinch area

2- at distance 80 cm to pinch area

3- EUV radiation from pinch travels to photodiode through Xenon gas (20 cm) and then through a tube (60 cm) filled with Helium

4- Calculation taking the Xenon gas absorption into account

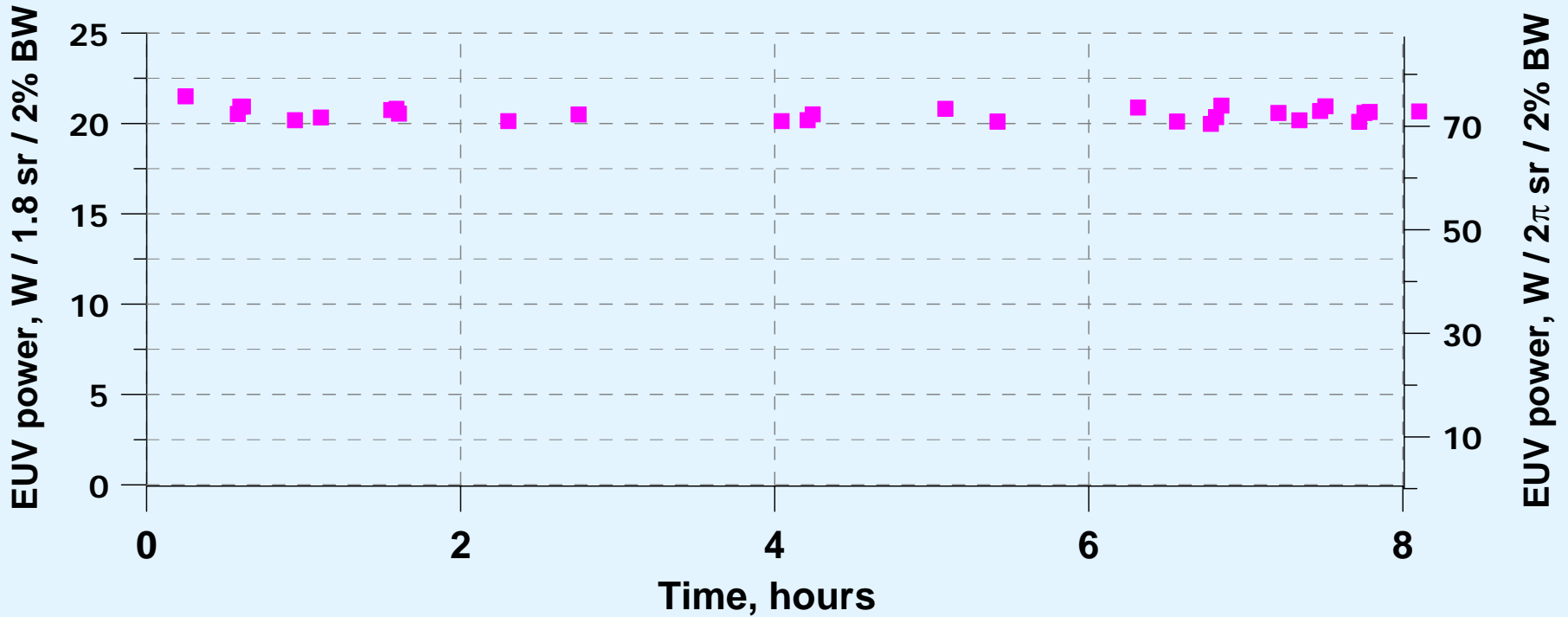
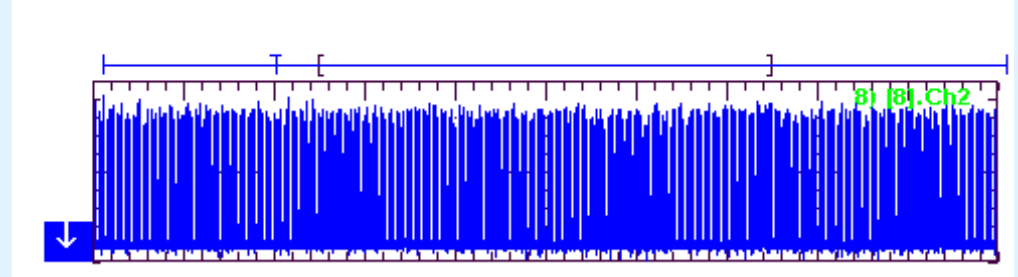
200 W at 13.5 nm wavelength (2% bandwidth) into 2π sr at a repetition rate of 1700 Hz is achieved



EUV source with Xe: long term test

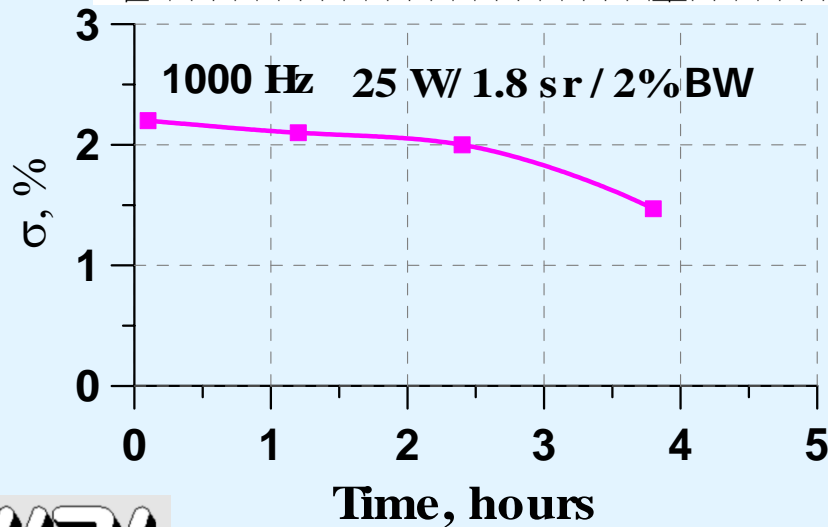
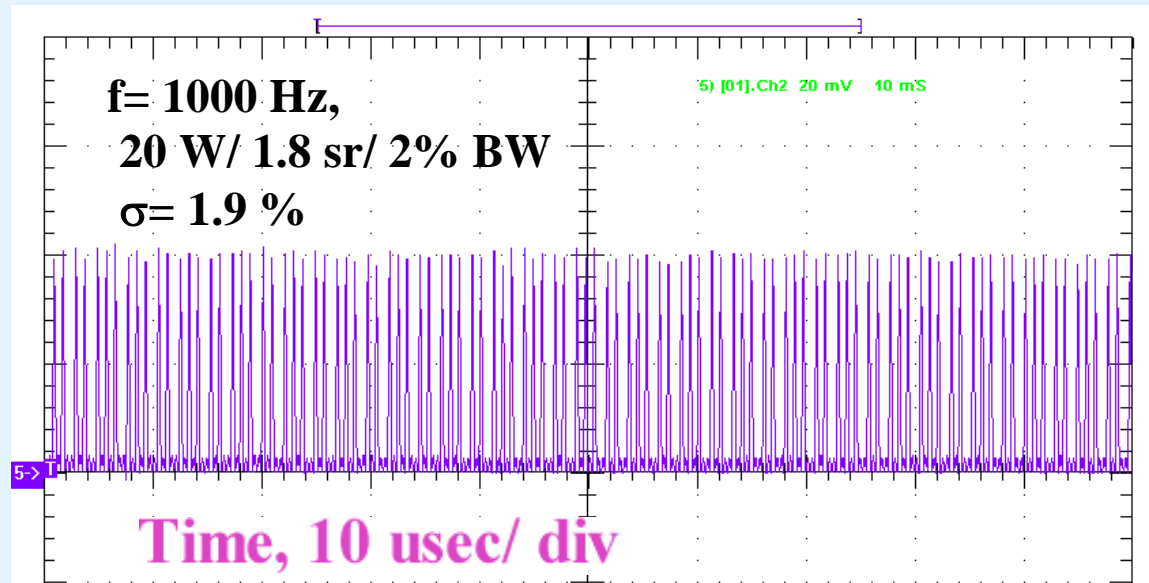
Continuous Operation

EUV Power 70 W at 13.5 nm wavelength
(2% bandwidth) into 2π sr at a repetition
rate of 1000 Hz during 8 hours

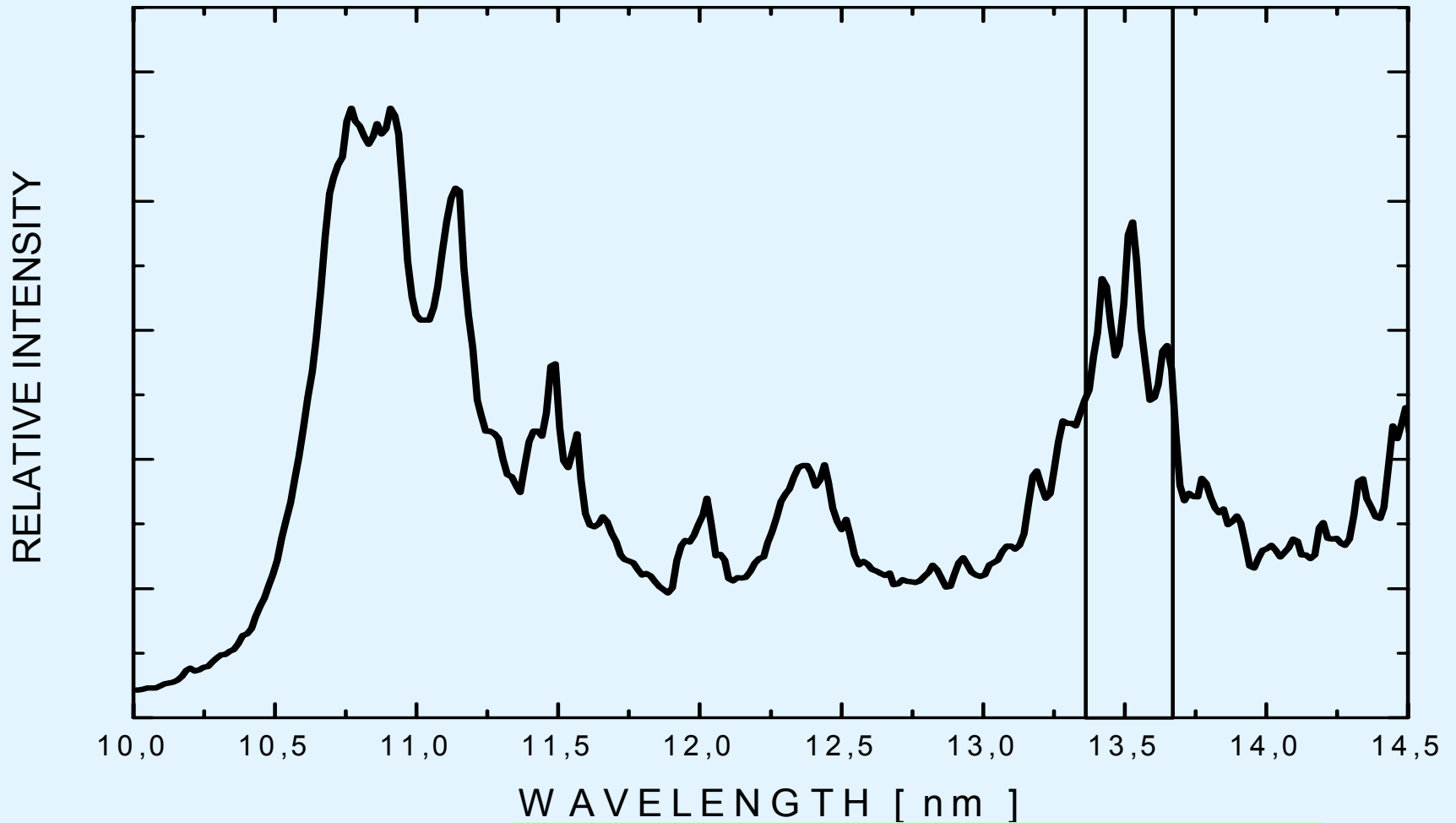


EUV source with Xe: Pulse to pulse repeatability

EUV signals



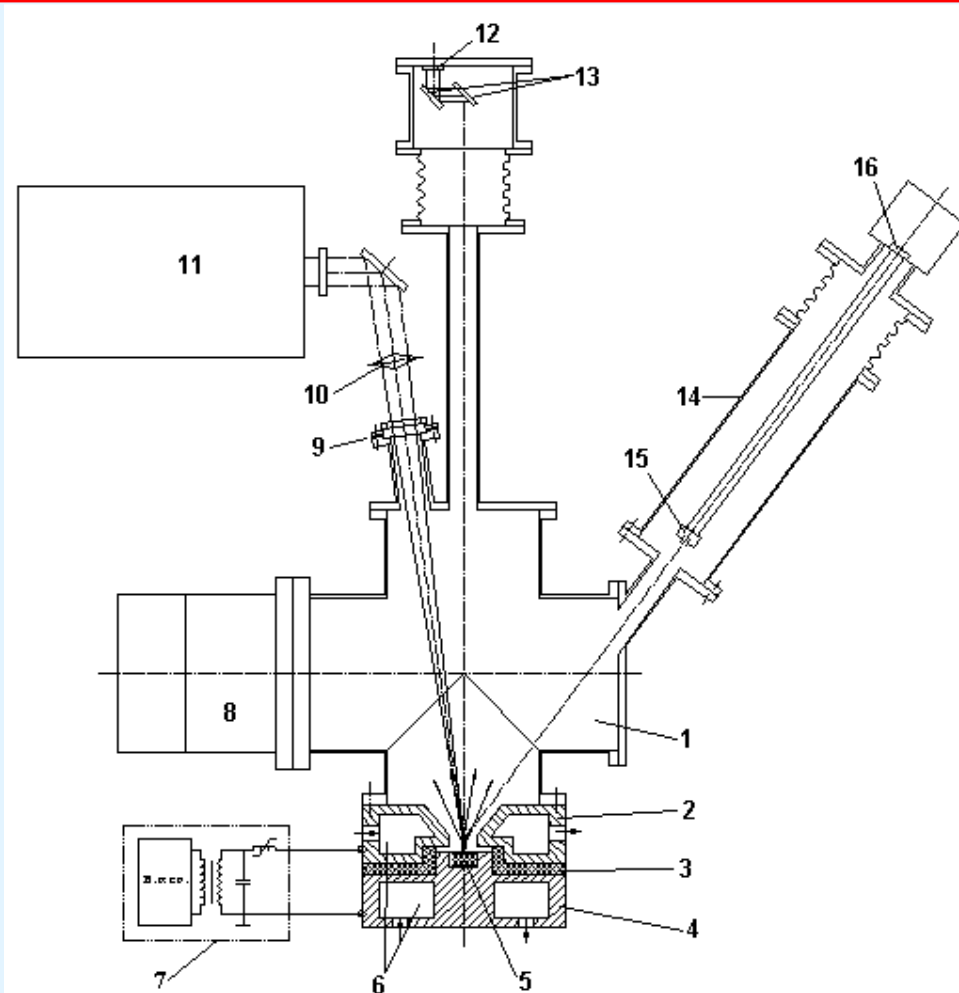
Xenon emission spectrum *



* Measured at XTREME Technologies GmbH



EUV source with Sn vapour



- 1 – vacuum chamber,
- 2 – grounded electrode,
- 3 – insulator,
- 4 – HV electrode,
- 5 – tin,
- 6 – cooling,
- 7 - electrical circuit,
- 8 – turbo molecular pump,
- 9 – window,
- 10 – lens,
- 11 – excimer KrF (248 nm) laser,
- 12 – photodiode AXUV – 100 with MoSi coating,
- 13 – MoSi mirrors,
- 14 – pinhole camera,
- 15 – diaphragm ($\varnothing 100 \mu$) with Zr coating,
- 16 – CCD camera.

EUV source with Sn vapour initiated excimer laser



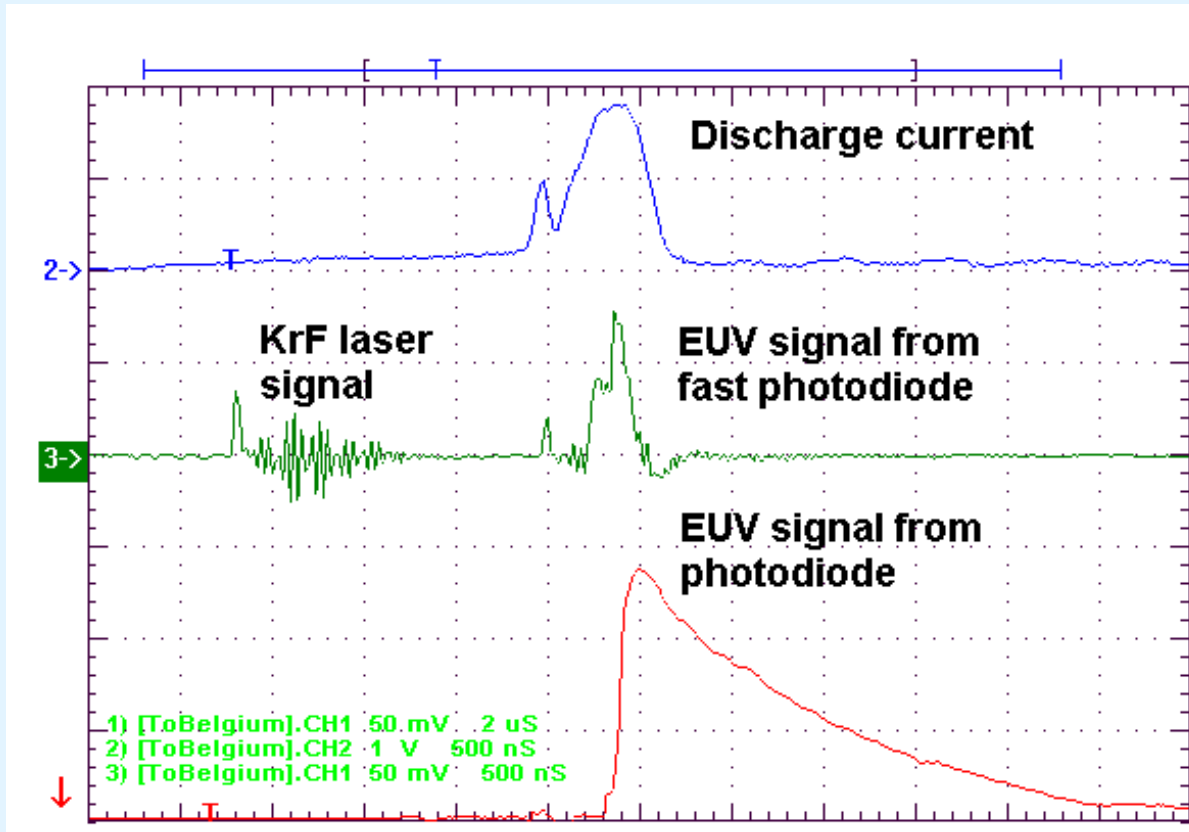
EUV source with Sn



5kHz KrF laser

EUV source with Sn vapour initiated by KrF laser

Intrinsic conversion efficiency **up to 2.2 % / 2% BW in 2π sr**
- unstable

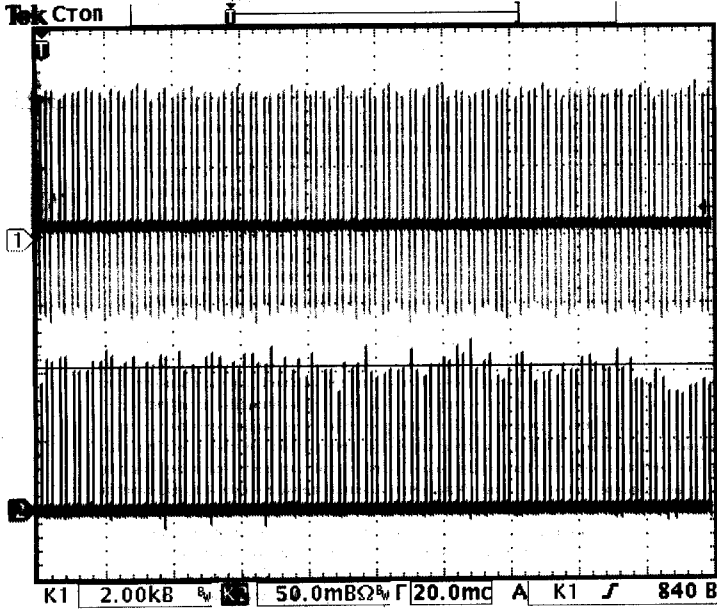


KrF laser beam density on Sn target $\sim 2 \cdot 10^7 \text{ W/cm}^2$

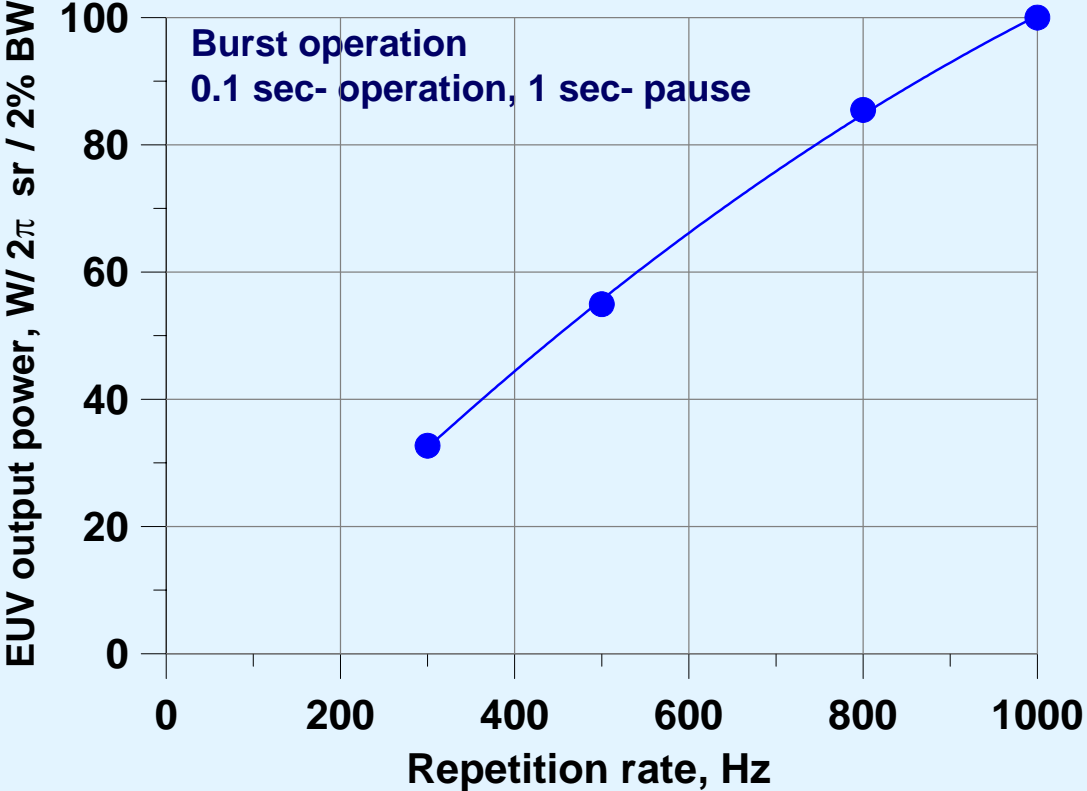
Pressure in the chamber $\sim 4 \cdot 10^{-3} \text{ Pa}$

EUV source with other methods Sn vapour initiation

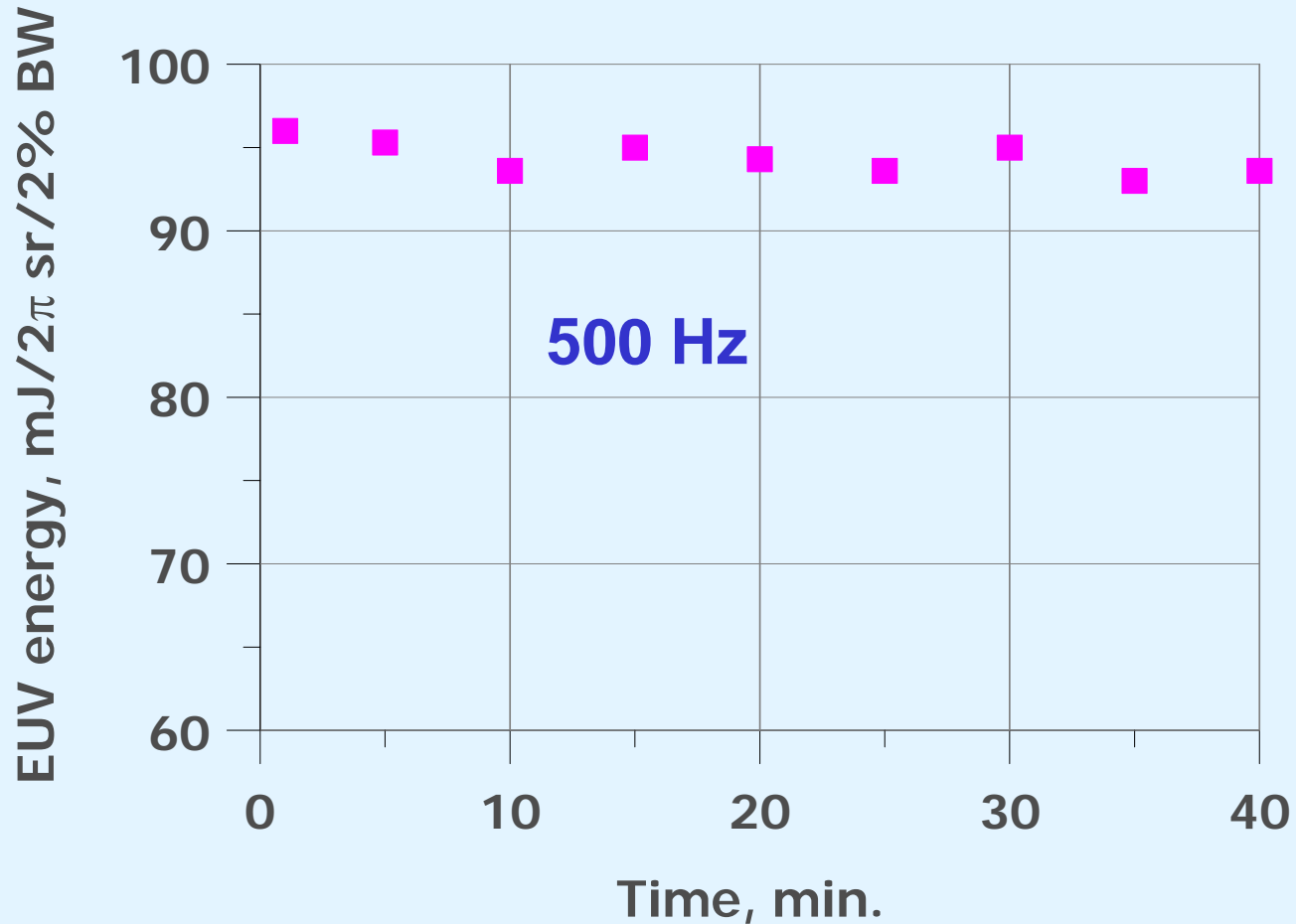
Intrinsic conversion efficiency
1,6% / $2\pi sr$ / 2% BW



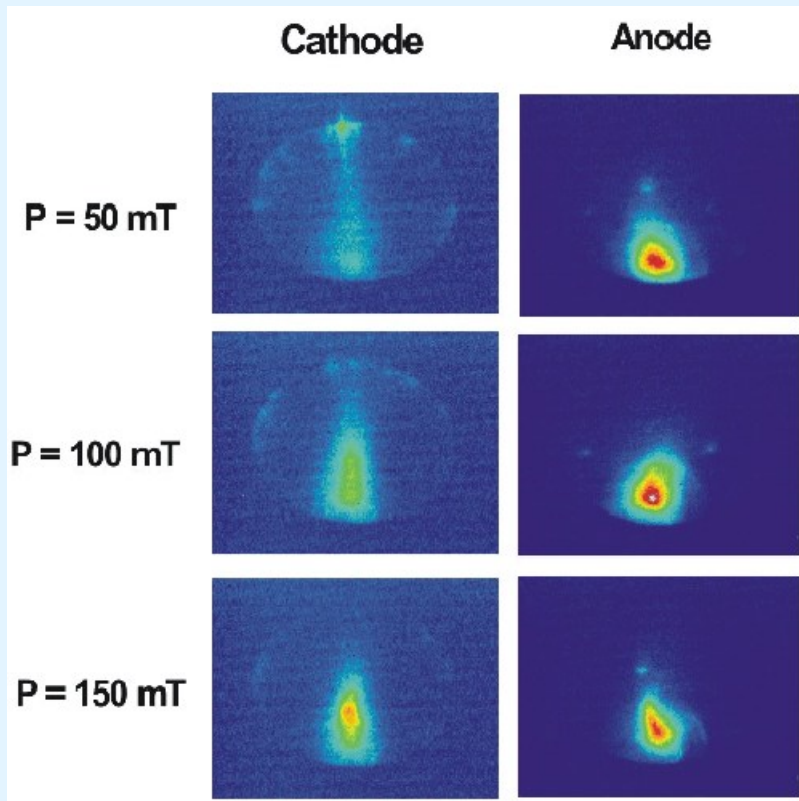
500 Hz



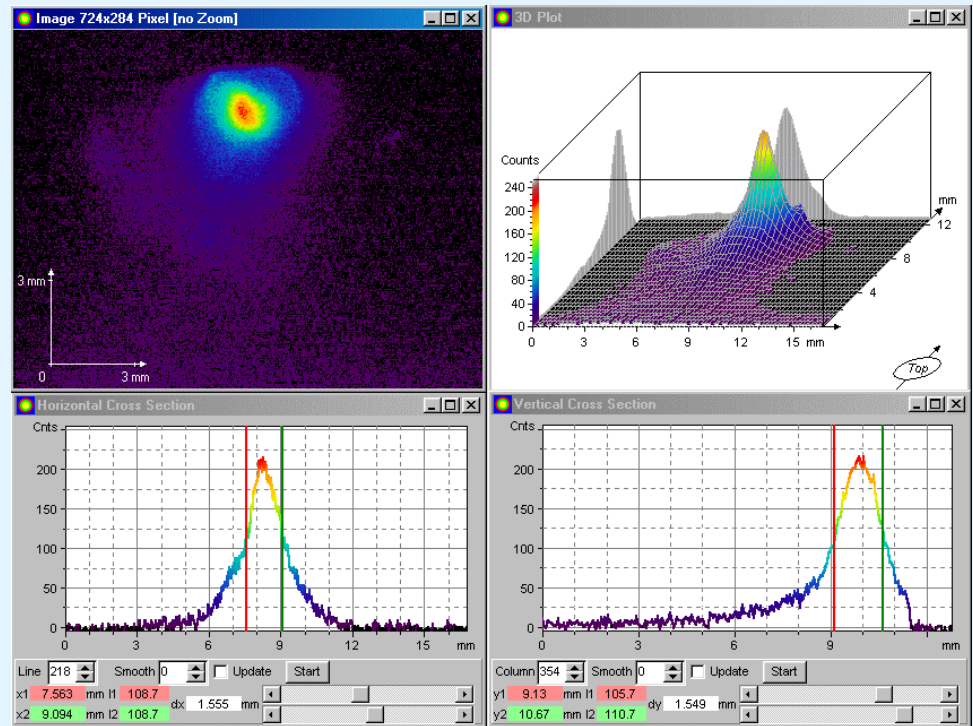
GDPP Z- pinch EUV source with Sn vapour : long term test



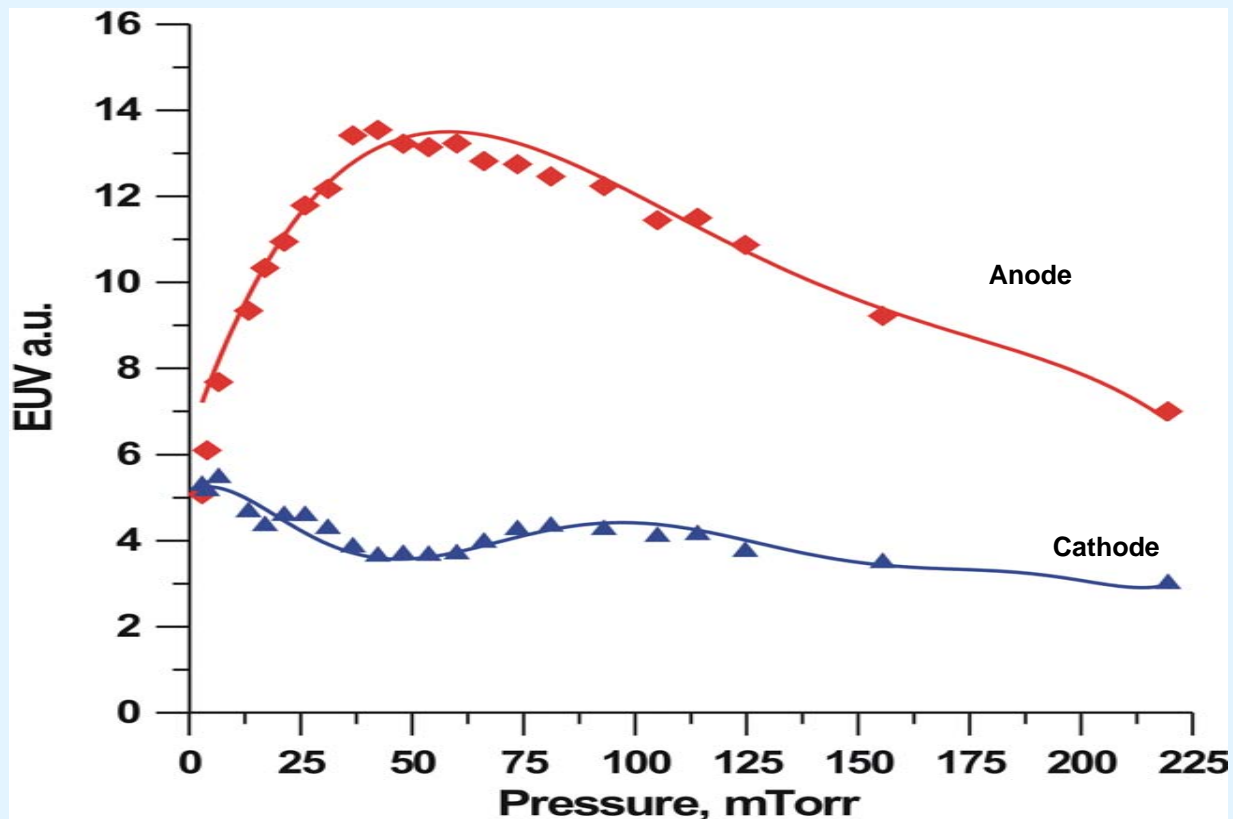
Sn plasma emission size at different polarity of HV electrode



Diameter: average over 16 pulses - 1.5 mm (FWHM)
Length: average over 16 pulses - 2.0 mm (FWHM)



Sn plasma EUV emission energy at different polarity of HV electrode



summary

Xe sources:

- Intrinsic conversion efficiency 1.2% (bw=2%) in 2π sr
- EUV output power 20W (bw=2%) in 1.8 sr or 70W (bw=2%) in 2π sr at 1000 Hz demonstrated during 8 hours continuous operation
- EUV output power more 200W (bw=2%) in 2π sr, burst at 1700Hz
- Energy stability 1.5% ...5% (sigma)
- Plasma size: diameter 0.3 mm (FWHM), length 1.1 mm (FWHM)
- Emission angle ≈ 2 sr ($\approx 45^\circ$ half opening angle)

Sn sources:

- Intrinsic conversion efficiency 1.4%...2.2% (bw=2%) in 2π sr
- EUV output power about 100W (bw=2%) in 2π sr, burst at 1000Hz
- Long-term test at 500 Hz demonstrated
- Plasma size: diameter 1.6 mm (FWHM), length 2.0 mm (FWHM)
- Emission angle ≈ 2 sr

