EUV Source Development at XTREME technologies - An Update

Uwe Stamm

XTREME technologies

3rd International Symposium on

Extreme Ultra-Violet Lithography

Miyazaki, Japan, 02 November 2004

Outline

1. Critical issues and development strategy

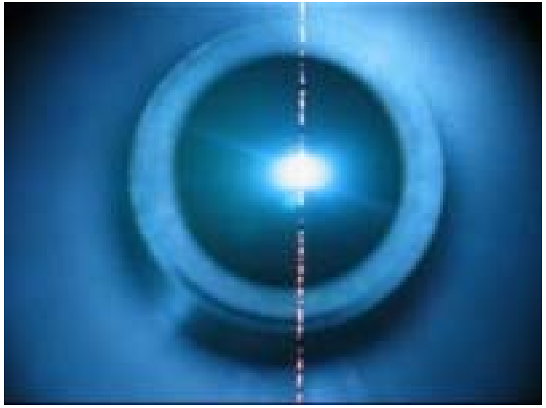
2. EUV source power in intermediate focus –
   some definitions and clarifications

3. Laser Produced Plasma EUV Sources

4. Gas Discharge Produced Plasma EUV Sources

   - XTS 13-35 for Integration in EUV Microstepper
   - High power source development

5. Summary and remaining critical issues



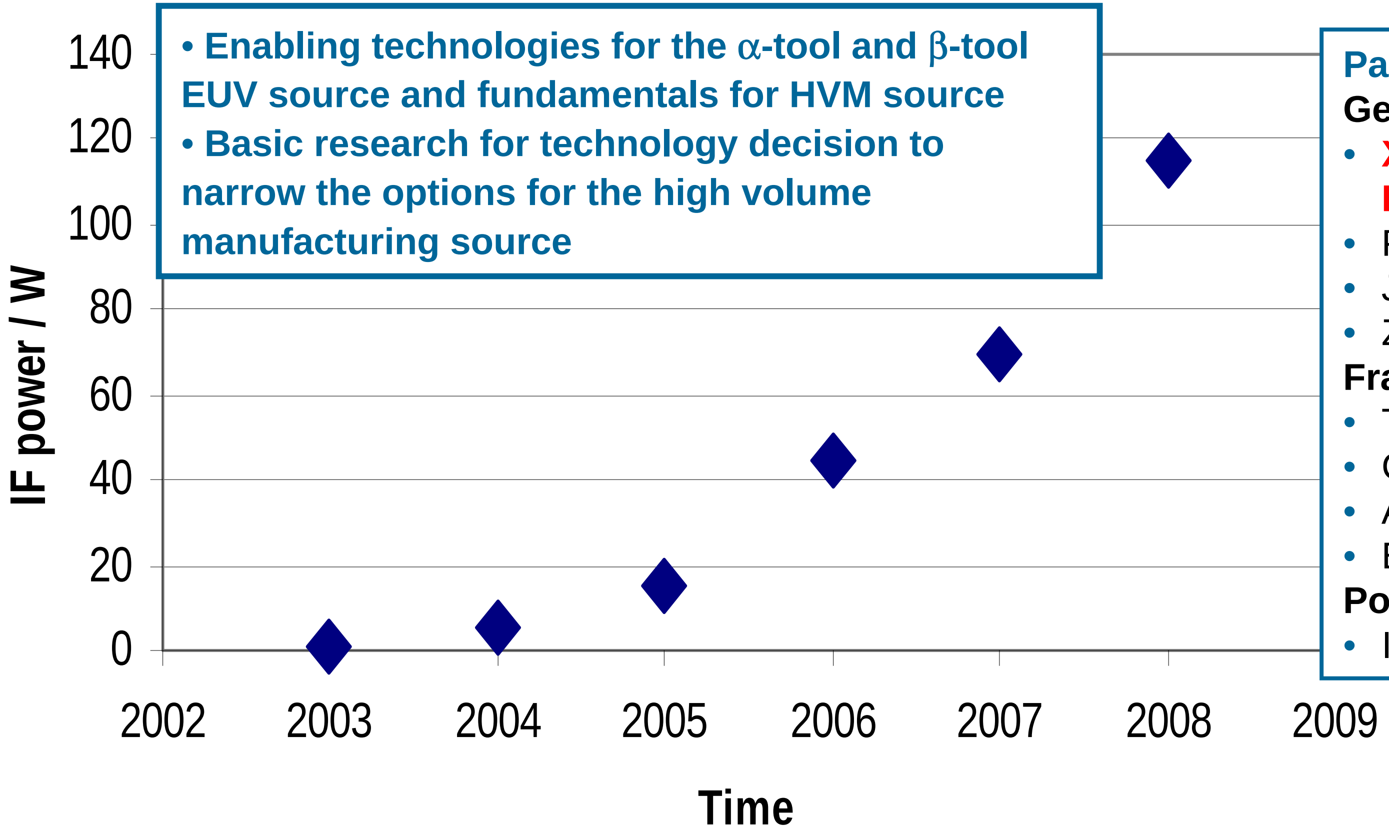
Most Critical Tasks in Source Development today

Table presented in the IEUVI Source TWG Progress Report, Presentation to the IEUVI Board July 16, 2004, San Francisco, CA, USA

	Topic	Feb 04		June 04	
		Ranking	Vote	Ranking	Vote
(*)	**1. Source power**	2	21 %	**1**	**36 %**
(*)	**2. Lifetime optics & source components**	1	29 %	**2**	**22 %**
	3. Spectral purity	7	3 %	**3**	**16 %**
	4. System reliability	4	15 %	**4**	**10 %**
	5. Tool footprint, total power consumption (CoO9	3	18 %	**5**	**8 %**
(*)	**6. Thermal management**	5	12 %	**6**	**4 %**
(*)	**7. Conversion efficiency**	6	3 %	**7**	**2 %**
(*)	**8. Etendue requirements (source size)**	8	0 %	**8**	**2 %**
	9. Source stability	9	0 %	**9**	**0 %**

(*) Focus of the EUV source development program at XTREME technologies

MEDEA+ Project T405 “EUV Source Development“: Goals



- **Enabling technologies for the α-tool and β-tool EUV source and fundamentals for HVM source**
- **Basic research for technology decision to narrow the options for the high volume manufacturing source**

Participants:

Germany

- **XTREME technologies Project Leader**
- Philips Extreme UV
- JENOPTIK Mikrotechnik
- Zeiss

France

- Thales
- CEA
- Alcatel
- EPPRA

Poland

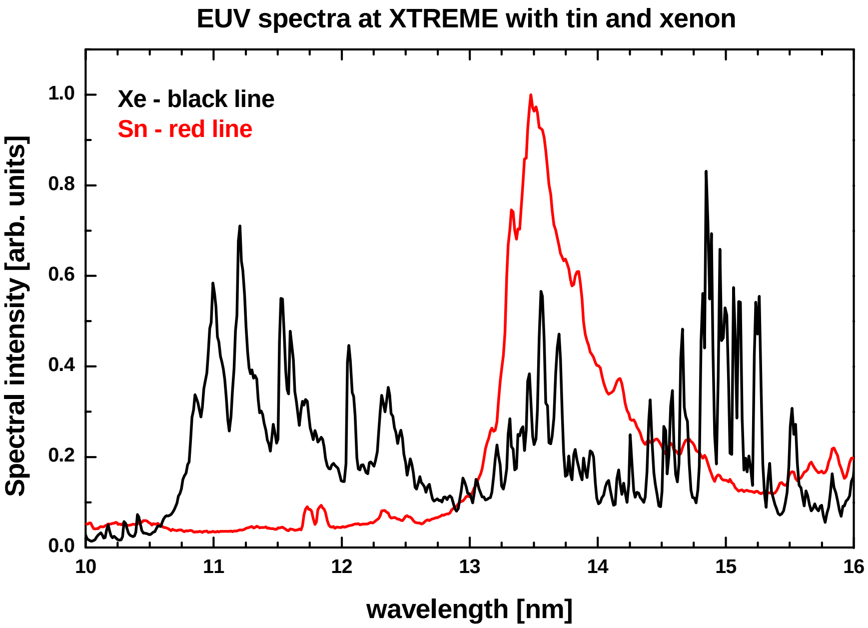
- IOE

XTREME technologies is project leader of the MEDEA+ project T405 „EUV source development“
Project duration June 2001 – March 2005

XTREME technologies is funded by the German BMBF under contract no. 13N8131

XTREME technologies: Project “more Moore” within FP6

XTREME technologies is project partner of the „more Moore“ project within the 6th Frame Program of the European Community


EUV spectra at XTREME with tin and xenon

Project leader:

ASML, NL

Project duration:

Jan. 2004 – Dec. 2006

Funded by the European Community under contract no. IST–1-507754-IP

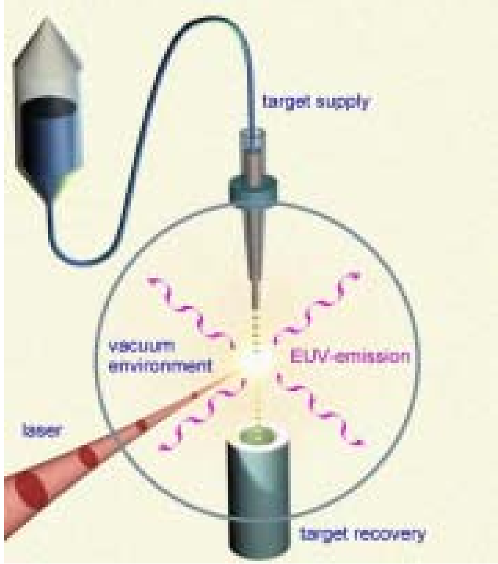
XTREME‘s tasks within the project:

Development of gas discharge produced plasma sources based of tin fuel

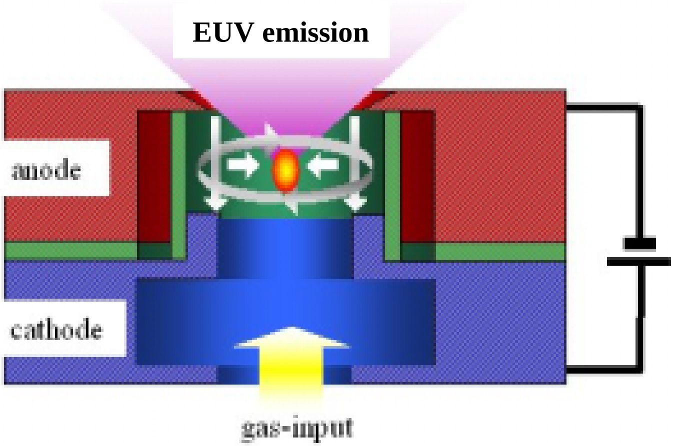
Taking light to new dimensions…

XTREME technologies: EUV Source development strategy

Laser Produced Plasma Source

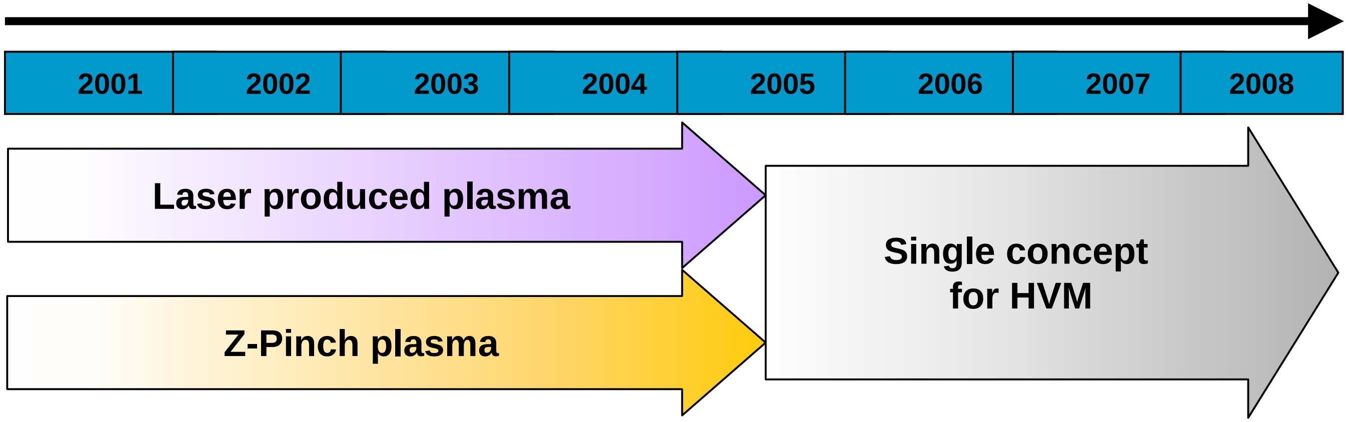


Gas Discharge Produced Plasma Source



Double Technology
&
Minimize Risk

EUV Source development technology roadmap



Laser produced plasma

Z-Pinch plasma

Single concept for HVM

Outline

1. Critical issues and development strategy

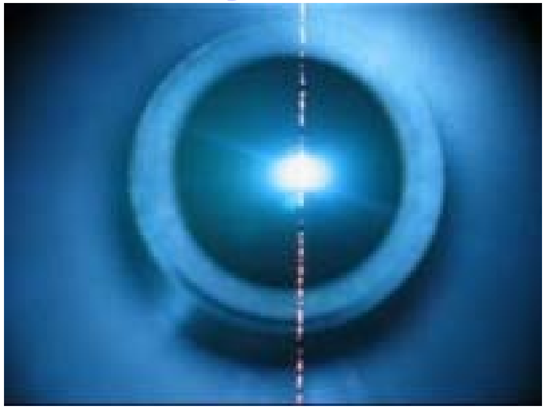
2. EUV source power in intermediate focus –
some definitions and clarifications

3. Laser Produced Plasma EUV Sources

4. Gas Discharge Produced Plasma EUV Sources

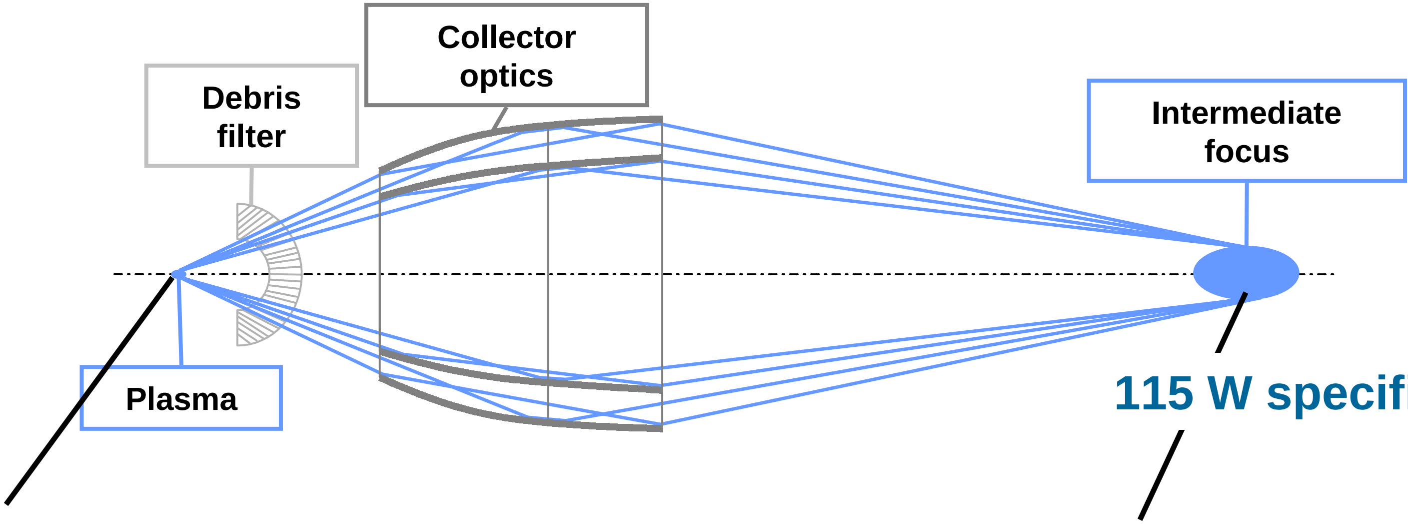
- XTS 13-35 for Integration in EUV Microstepper
- High power source development

5. Summary and remaining critical issues



Taking light to new dimensions…

Power in IF: High volume manufacturing (HVM) specification



115 W specification

EUV in-band power
in 2π sr solid angle

No HVM specification
but good to compare
between different sources

EUV intermediate focus power

HVM specification
but not good to compare
between different sources

Power in IF: Definitions

How to compare intermediate focus power values?

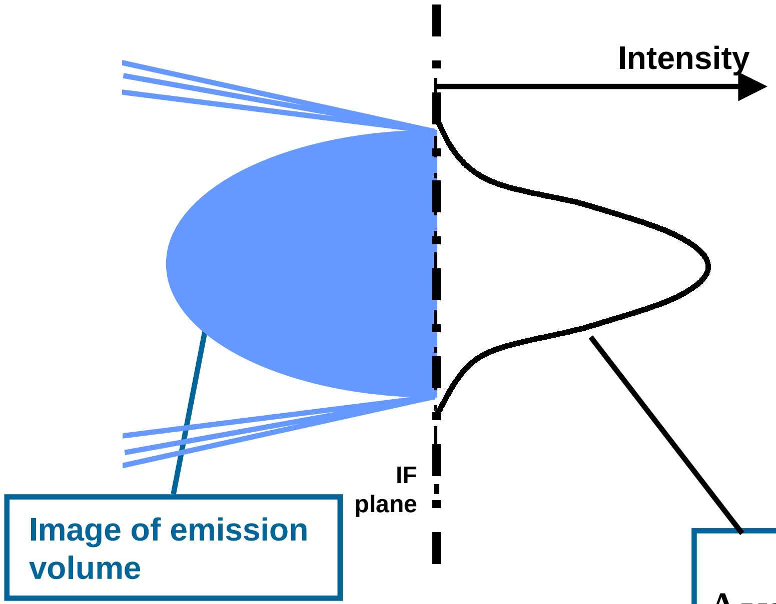


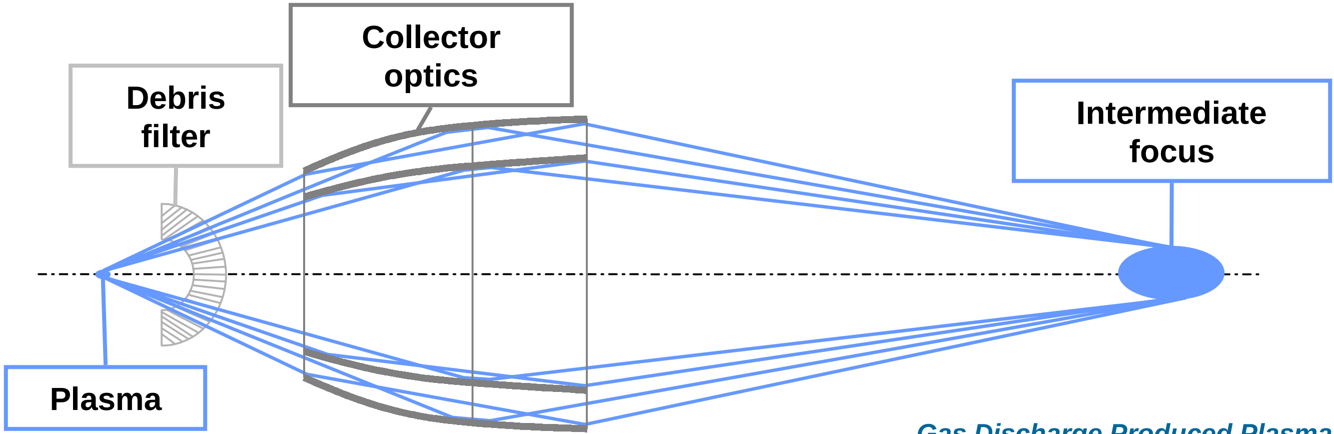
Image of emission volume

Because of the spatially extended plasma
the IF is also spatially extended according to the collector magnification

$$\text{Available IF power} = \int_0^{2\pi}\int_0^{\infty} I\,(r,\varphi)\; r\,dr\,d\varphi$$

The “Available IF power” is only dependent on the source and the source collector module.
It is independent of the etendue of the exposure tool.

Available Power in IF: HVM collection efficiencies

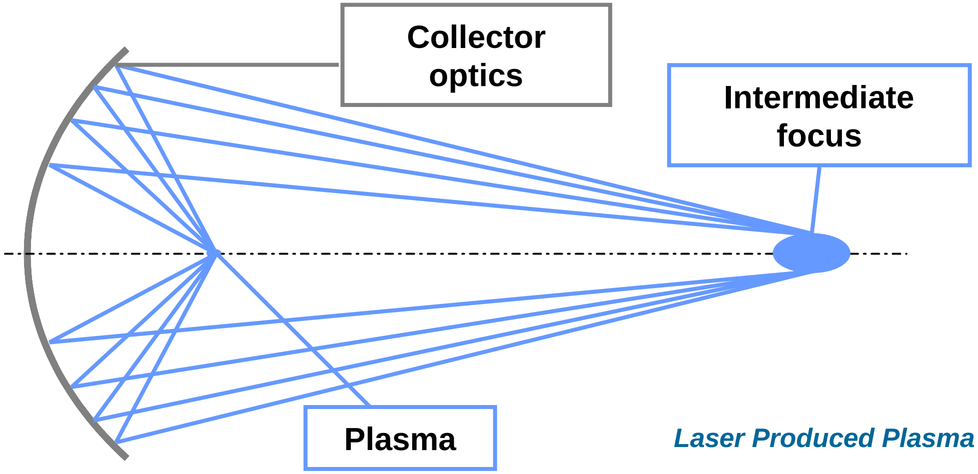


Gas Discharge Produced Plasma

Available IF power:

HVM collection efficiency, including losses by gas and debris filter:

Up to 20% w.r.t. 2π sr



Laser Produced Plasma

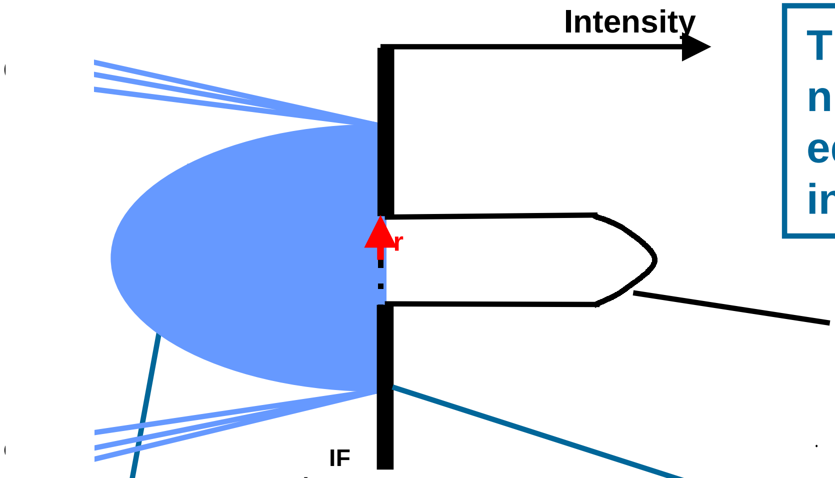
Available IF power:

HVM collection efficiency, including losses by gas and debris filter:

Up to 33% of 2π sr

Power in IF: Definitions

$$E = \int_{A}\int_{\Omega} dA\ \cos\alpha\ \ d\Omega = const\ .$$



The etendue E of the scanner and the numerical aperture in IF result in an equivalent aperture with finite radius r in the IF plane

$$\text{Usable IF power} = \int_{0}^{2\pi}\int_{0}^{r} I\ (r,\varphi)\ \ r\ dr\ d\varphi$$

Image of emission volume

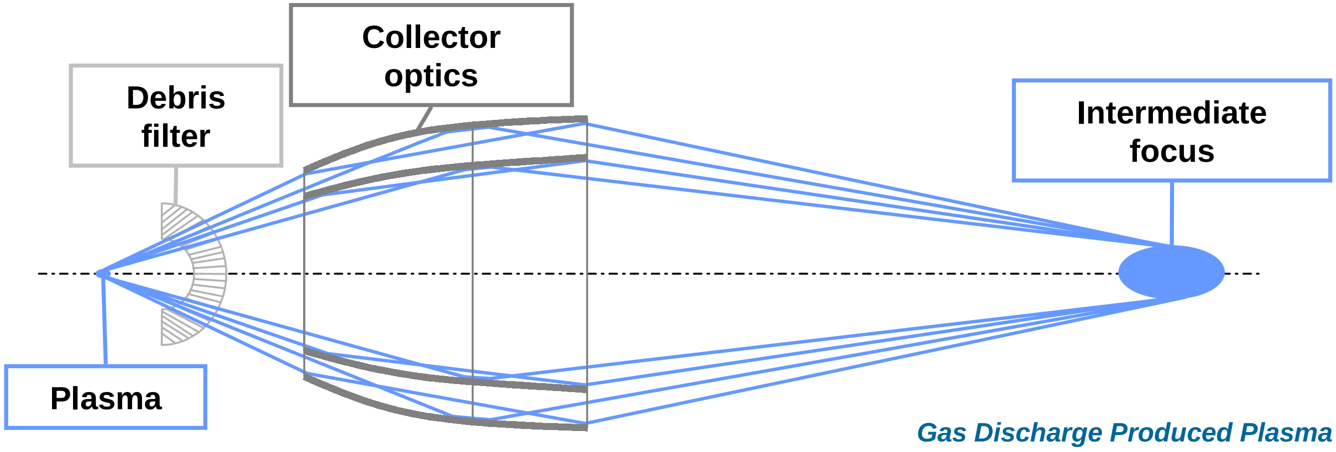
Aperture equivalent to etendue and NA

If the plasma image is larger than the IF aperture only a part of the available IF power is transmitted through the aperture – the "Usable IF power"

We define:

$$\text{Etendue}\ \ \ \text{acceptance}\ \ \ \text{factor}\ = \frac{\text{Usable}\ \ \text{IF power}}{\text{Available}\ \ \ \text{IF power}}$$

Power in IF: Conclusions from definitions



Gas Discharge Produced Plasma

- The „Available IF power“ can be quoted knowing the collector design

- The „Usable IF power“ can be quoted only knowing the collector design and the etendue of the exposure tool

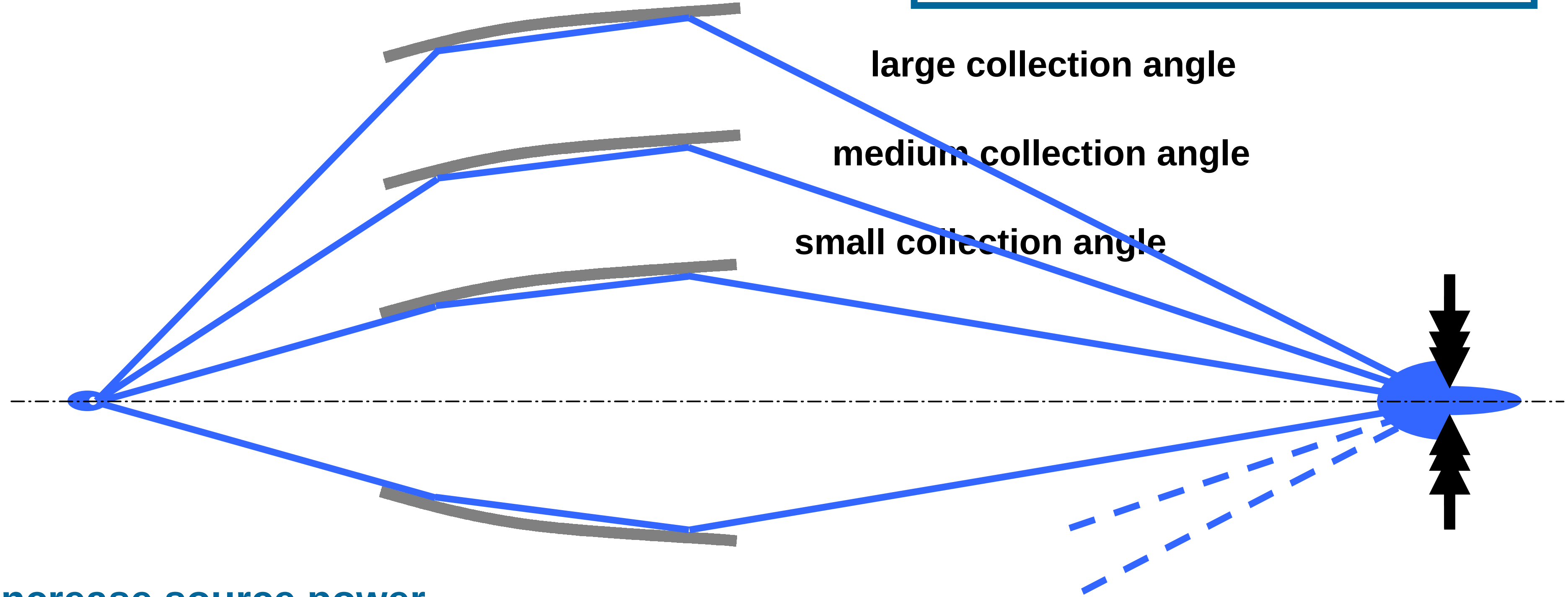
- Etendue specification for HVM has currently a range from 1 mm^2sr to 3.3 mm^2sr

- The “Usable IF power” can be 1.8x higher for etendue values of 3.3 mm^2sr compared to 1 mm^2sr

Taking light to new dimensions…

How to increase Usable IF Power: Input power and collection angle

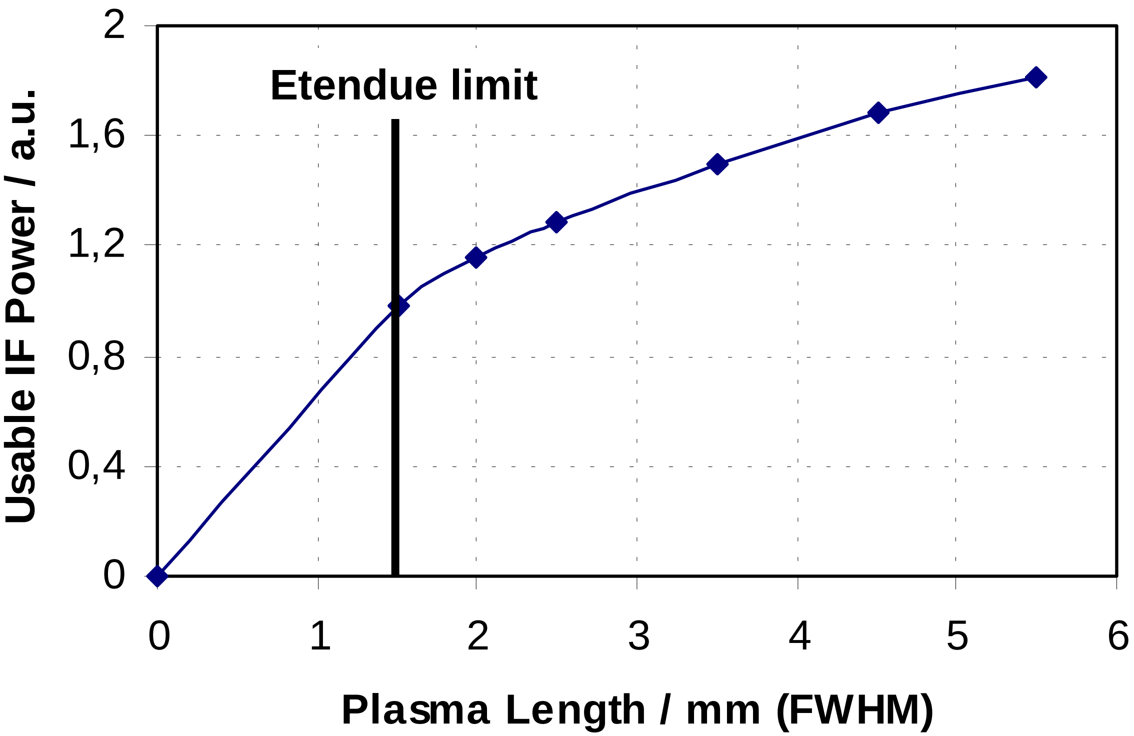
$$E = \int_A \int_\Omega dA \cos\alpha \; d\Omega = const\,.$$



Increase source power

Effective IF aperture decreases with increasing collection angle

Usable and Available Power in IF: Plasma size and collection angle



Etendue = 3.3 mm^2sr
1.8 sr collector

The usable IF power increases with plasma length

To achieve higher usable IF power it may be better to increase the plasma size above the equivalent etendue limit.

This is also better for illumination uniformity.

Taking light to new dimensions…

Usable and Available Power in IF: Conclusions

- LLP sources have typically smaller plasma size than GDPP sources which results in a potential Etendue acceptance factor of = 1
- Because of the small plasma size LPP sources tend to have higher collection efficiencies than GDPP sources
- The usable IF power increases with plasma size which may favor high power GDPP sources as HVM solutions

➡ XTREME technologies is working in both technologies

Outline

1. Critical issues and development strategy

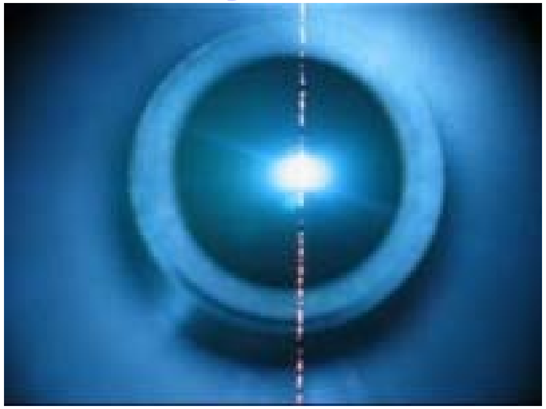
2. EUV source power in intermediate focus –
   some definitions and clarifications

3. Laser Produced Plasma EUV Sources - Update

4. Gas Discharge Produced Plasma EUV Sources

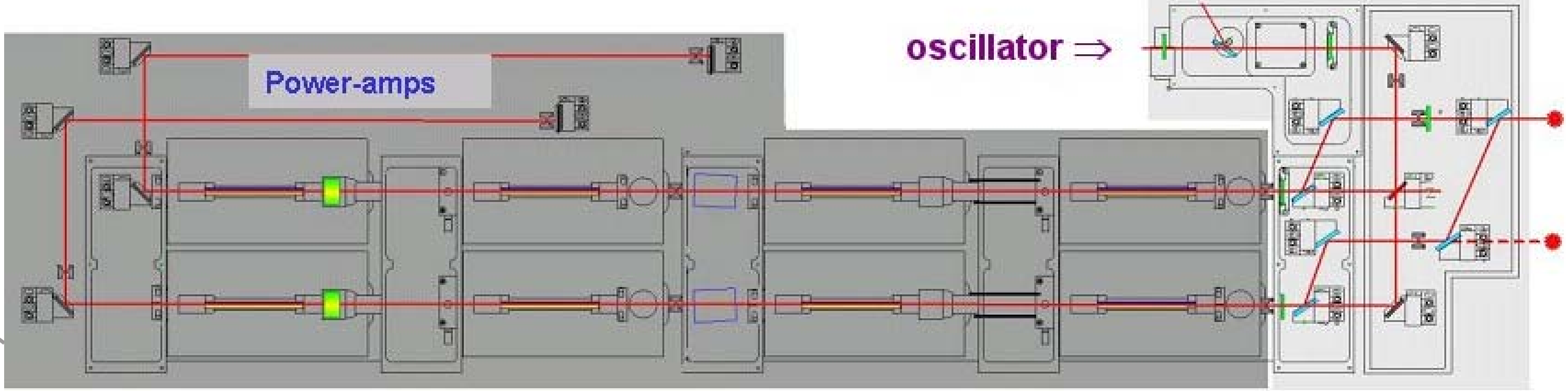
   - XTS 13-35 for Integration in EUV Microstepper
   - High power source development

5. Summary and remaining critical issues



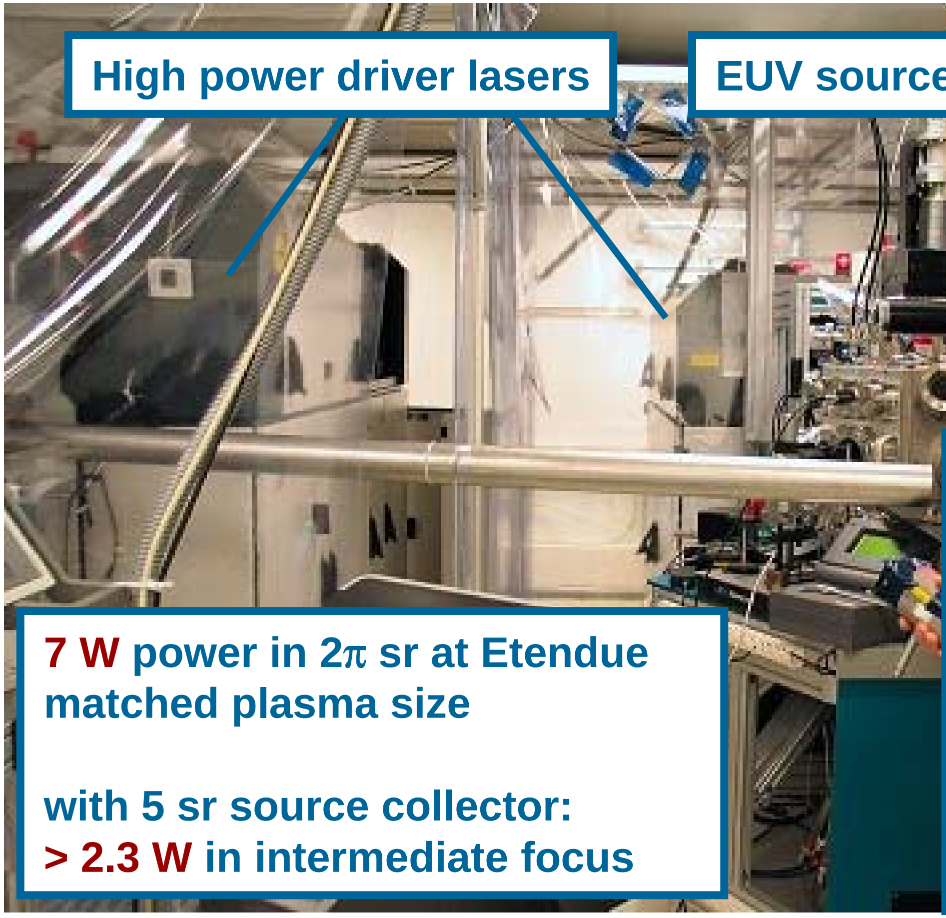
LPP EUV Sources: Industrial 1.2 kW driver laser

- oscillator + pre-amp
  + two identical 4 head power-amp chains
- 1.2 kW @ 10 kHz, $M^2 = 10$, 16.5 ns pulse width



Taking light to new dimensions…

LPP EUV Sources: EUV power



High power driver lasers

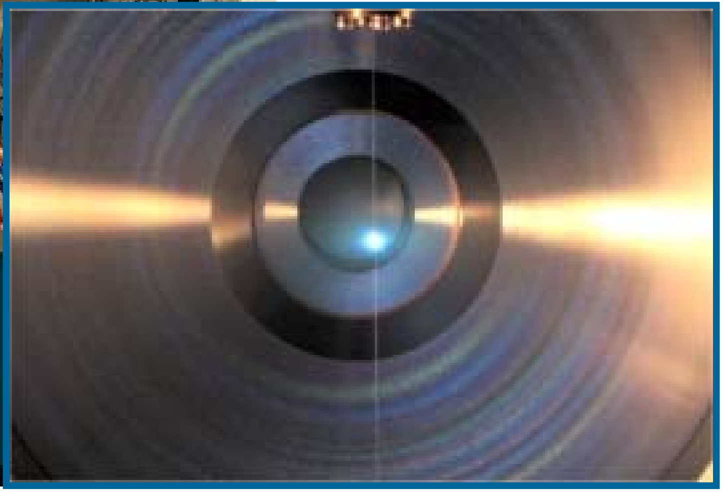
EUV source chamber

7 W power in 2π sr at Etendue matched plasma size

with 5 sr source collector:
> 2.3 W in intermediate focus

Conversion efficiency 1% with xenon

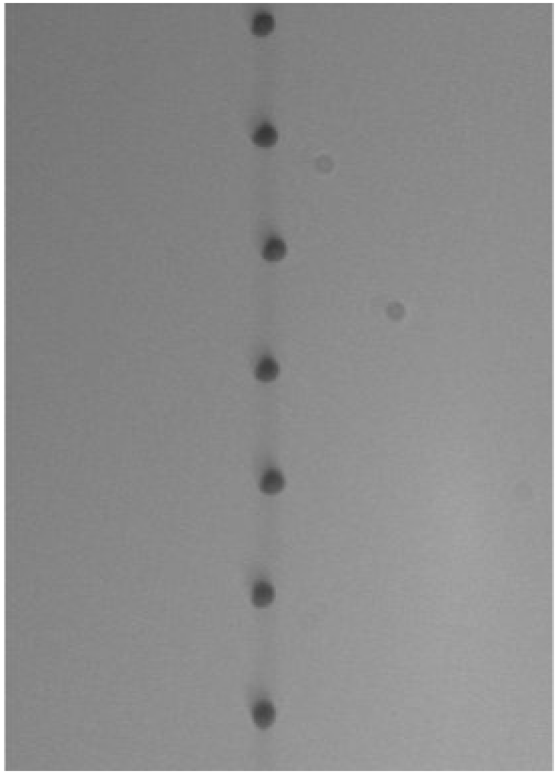
Xenon LPP EUV-source



Driver laser: 1.2 kW industrial solid state laser

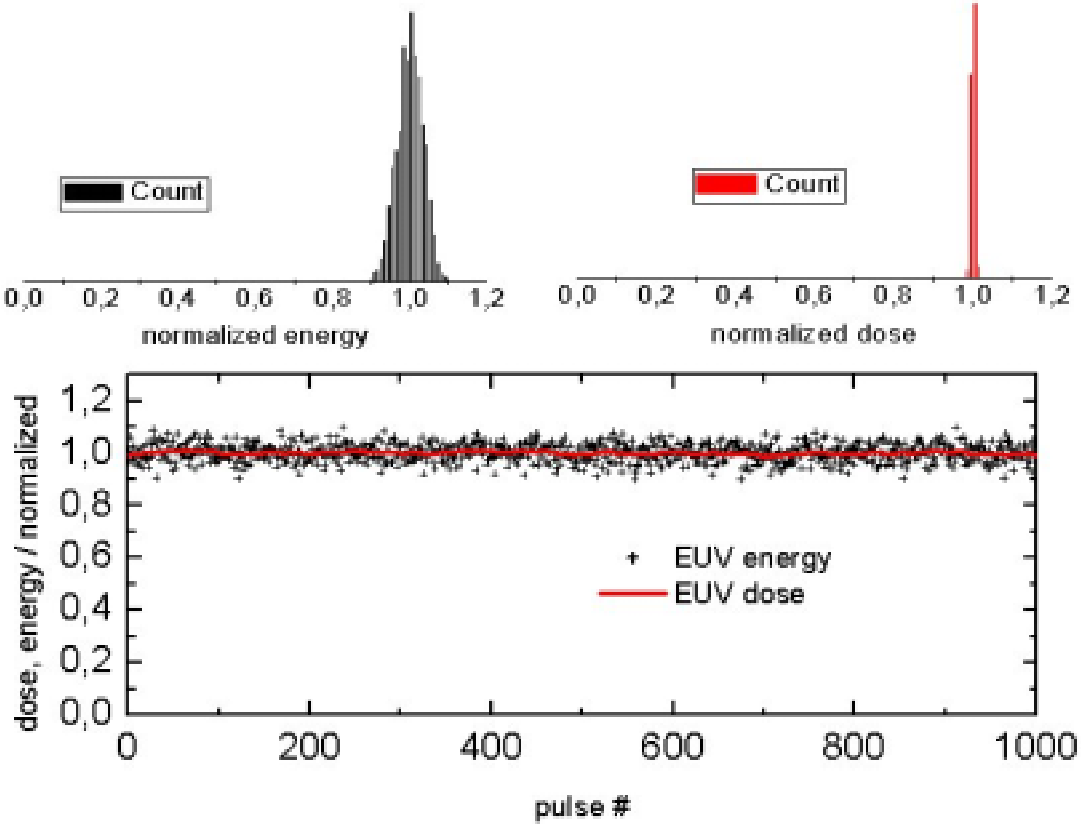
LPP EUV Sources: Xenon droplet target development

A new injector system delivers equidistant Xenon-Droplets in vacuum with high positional stability



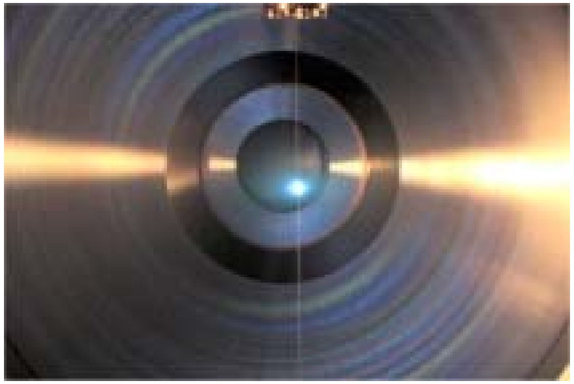
Xenon droplet train at 5 cm distance from the nozzle

LPP EUV Sources: EUV energy and dose stability



σ (energy) = 3%

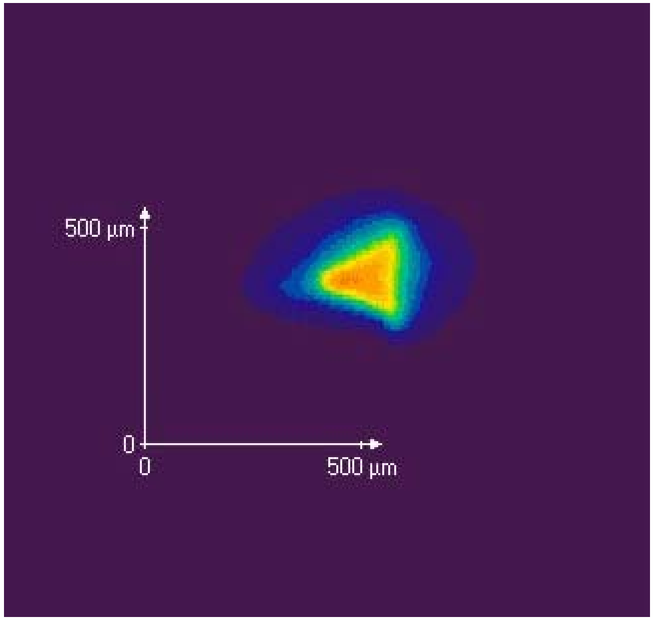
σ (dose) = 0.45 %
50 pulses moving average



Results achieved without any active stabilization

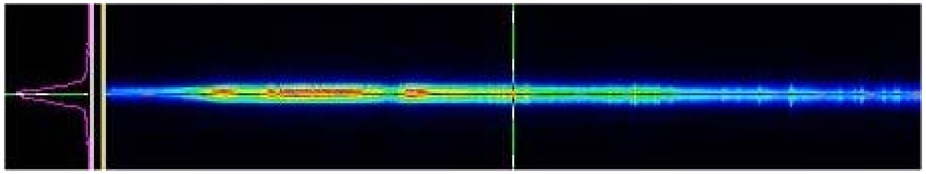
LPP EUV Sources: HVM energy and plasma size

- **LPP source size @ 13 mJ EUV energy (75% of HVM energy):**



Pinhole camera image of source distribution at 13 mJ

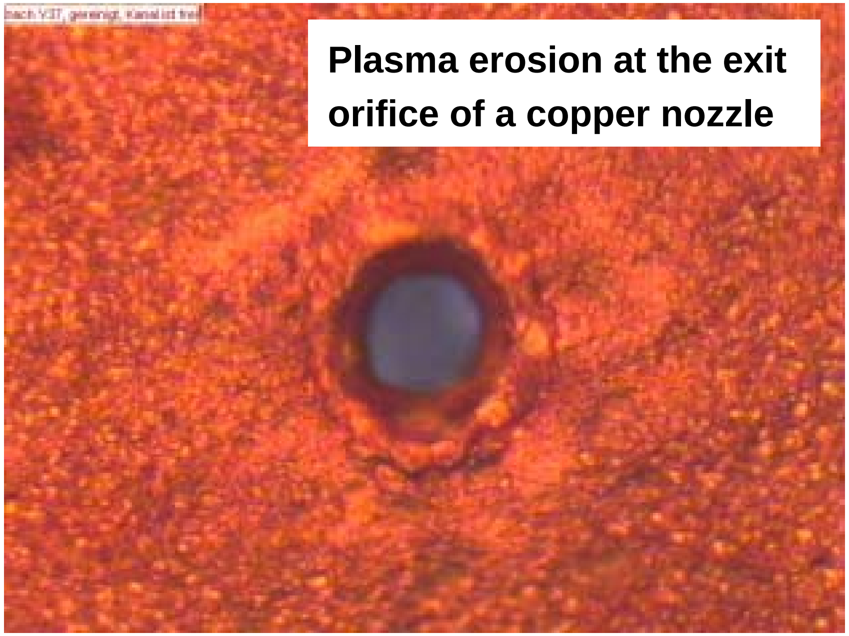
- **source diameter ($1/e^2$) is smaller than 0.5 mm**
- **etendue acceptance factor = 1 for a 5 sr collector optics**



- *1-D spectrally resolved source size at 13.5 nm agrees with pinhole camera within 20%*
- *diffraction is negligible*

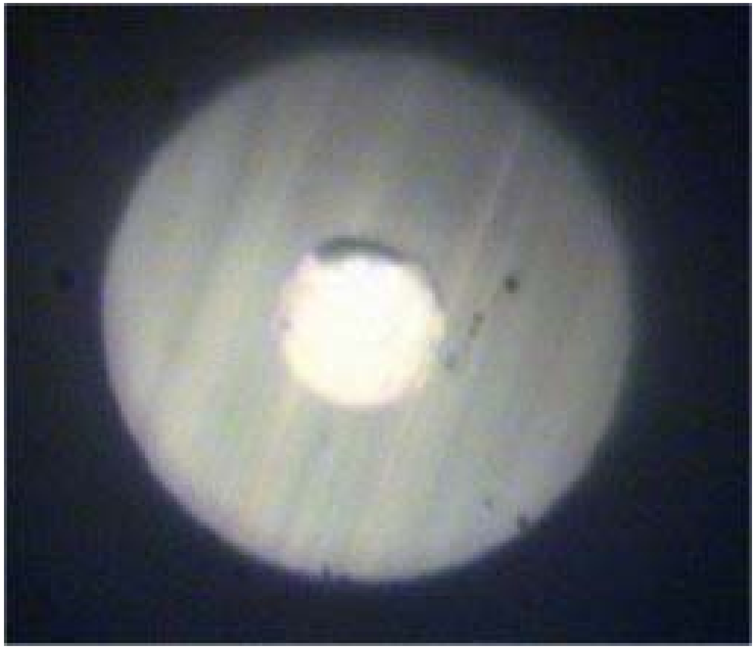
Taking light to new dimensions…

LPP EUV Sources: Critical component lifetime - Injector nozzle



Plasma erosion at the exit orifice of a copper nozzle

Old nozzle design after 10 Mio shots



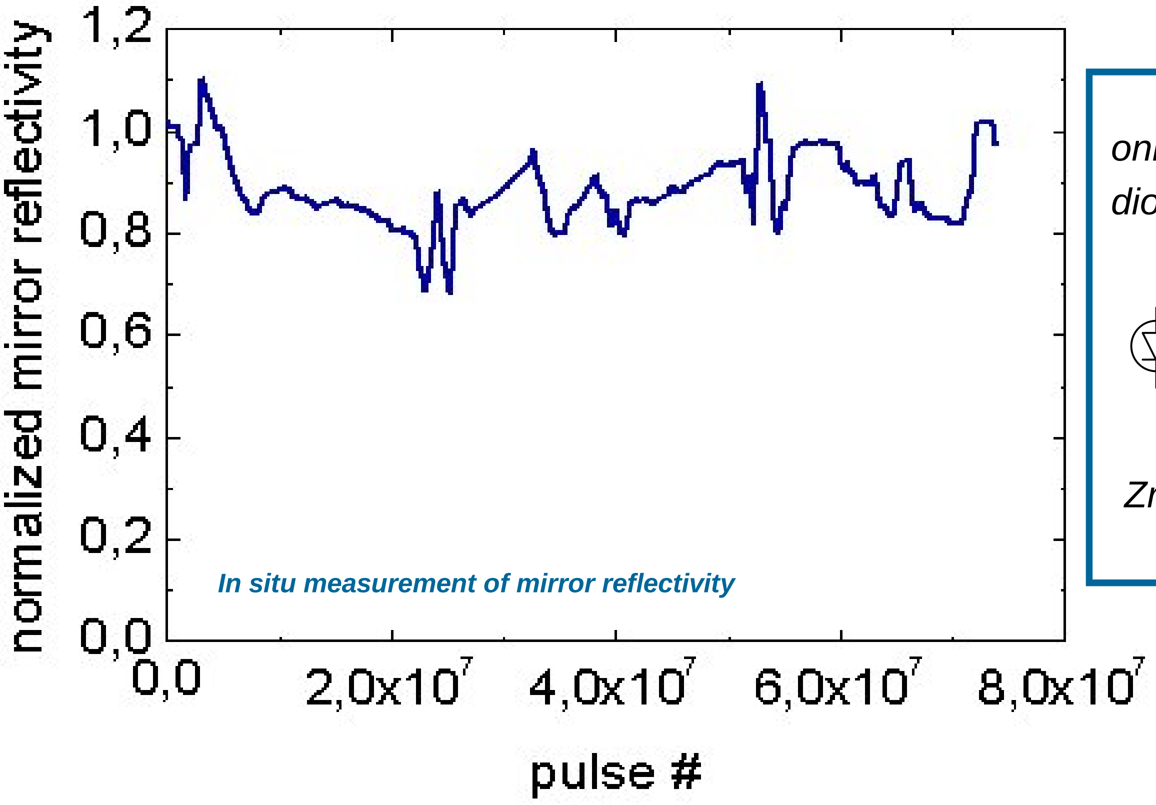
new nozzle design after 10 Mio shots

- new materials are used for nozzles
- additional potection is implemented
- ➢ **More than $1.5\cdot10^9$ pulses** were accumulated without noticeable degradation

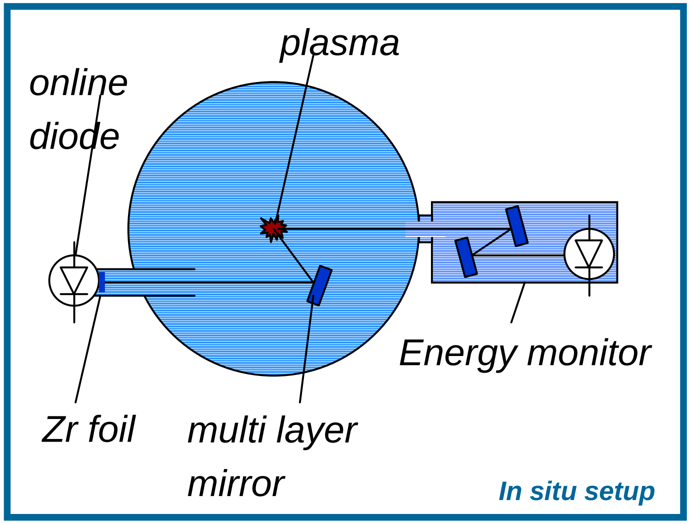
LPP EUV Sources: EUV optics lifetime

With erosion protection:

- **Mirror reflectivity stays constant over 75 Mio pulses**
- **In-situ and ex situ evaluation of erosion rate yields a mirror lifetime of 5·10^9 pulses at 7W/2π and 5kHz (280 hours)**



In situ measurement of mirror reflectivity

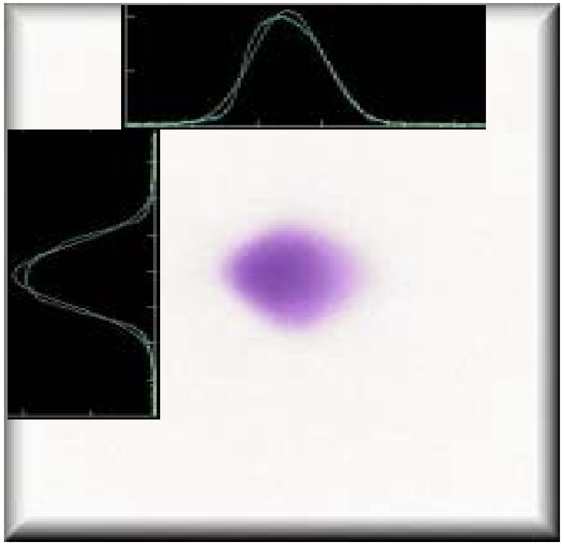


In situ setup

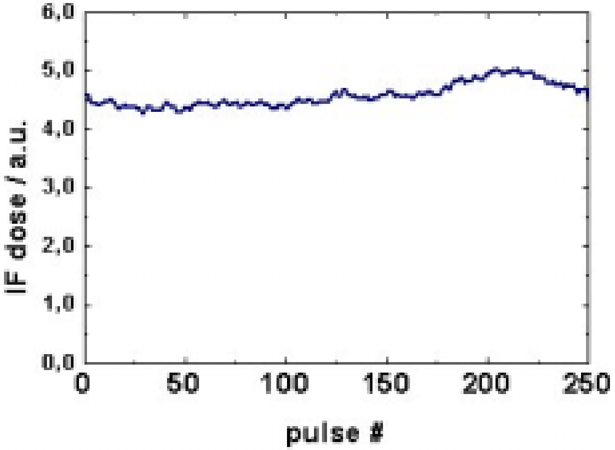
LPP EUV-sources: intermediate focus measurements, 0.35 sr aspherical collector

Mirror in EUV-source

IF diagnostics unit



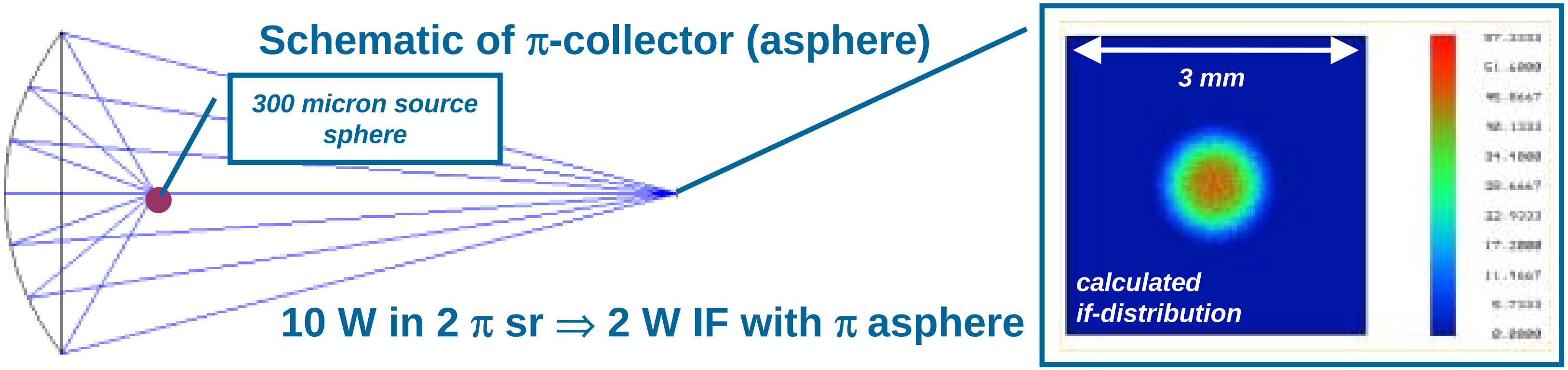
Single pulse inband source distribution



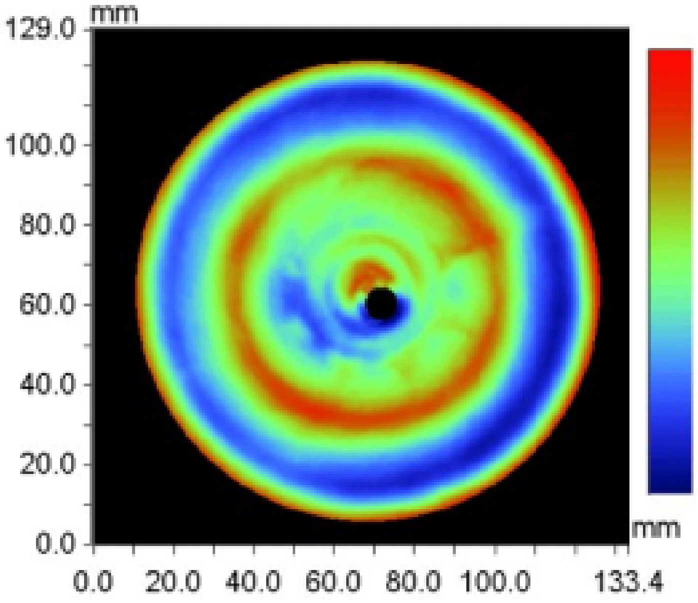
Measured dose in interm. focus

- Inband source size 1/e^2 : 500 μm x 380 μm
- Mirror reflectivity exceeds 60%
- No noticeable mirror degradation after 100 Mio pulses
- Postional stability: 16% of diameter

LPP EUV-sources: π EUV-collector optics



π collector substrates manufactured and measured in spec, will be coated this month

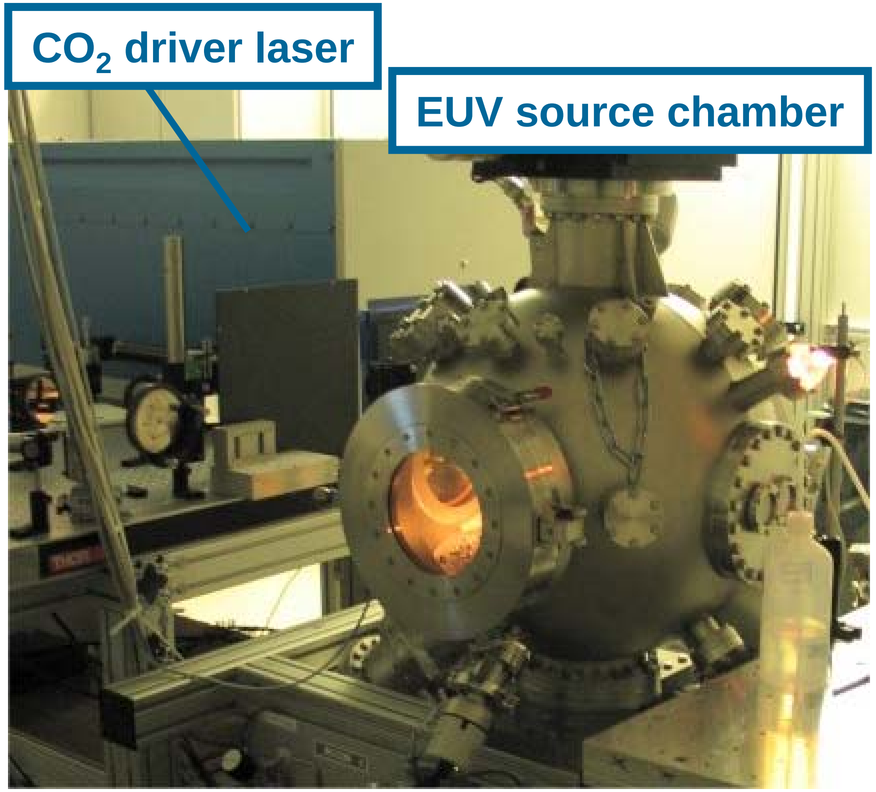


Interferometric data of π substrate

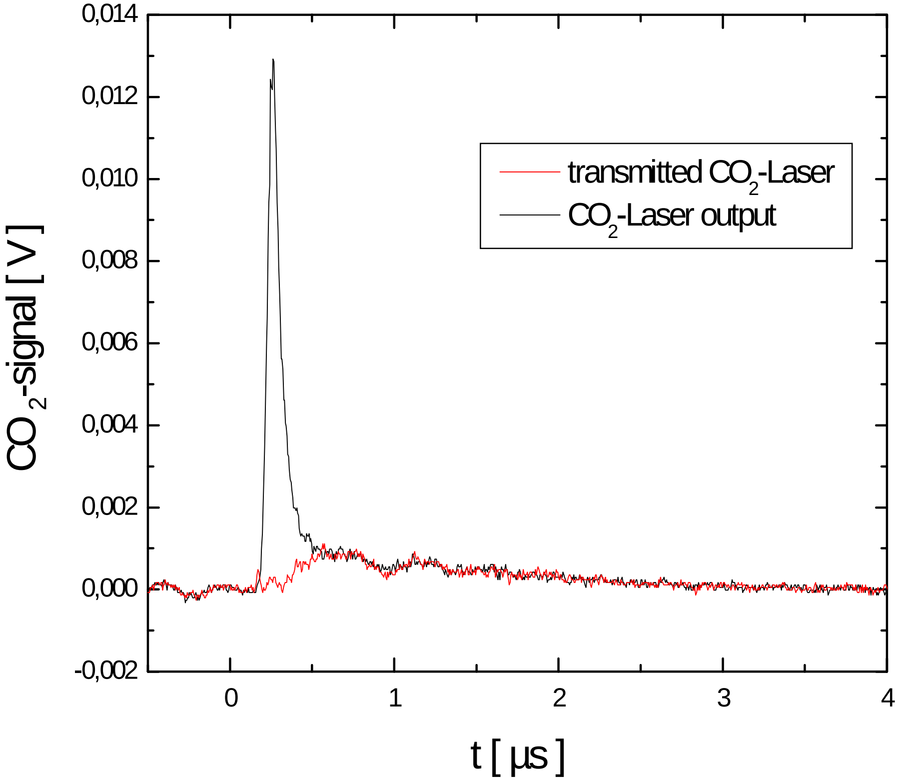
Taking light to new dimensions…

LPP EUV sources: CO_2 laser driven EUV source

CE = 0.7 % achieved with Xe-target & CO_2 laser



CO_2 laser driven, Xe-fueled EUV-source



LPP EUV Sources: Power status and HVM power roadmap

Fuel	xenon status 09/2004	tin expected with current status	xenon on the roadmap	tin on the roadmap
Laser power on target (kW)	0.7	0.7	34	11
Conversion efficiency (%)	1.0	3.0	1.0	3.0
EUV power (W/2π sr)	7	21	340	340
Transmission of debris mitigation	0.9	0.9	0.9	0.9
Collection solid angle (sr / 2π sr)	0.8	0.8	0.8	0.8
Average reflectivity of collector	0.55	0.55	0.55	0.55
Gas transmission in collector module	0.85	0.85	0.85	0.85
Available IF power (W)	**2.3**	**7.0**	**115**	**115**
Etendue acceptance factor	1.0	1.0	1.0	1.0
Usable IF power (W)	**2.3**	**7.0**	**115**	**115**

Outline

1. Critical issues and development strategy

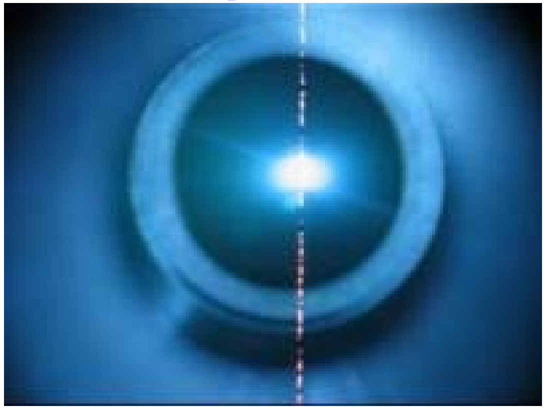
2. EUV source power in intermediate focus –
   some definitions and clarifications

3. Laser Produced Plasma EUV Sources

4. **Gas Discharge Produced Plasma EUV Sources**

   - **XTS 13-35 for Integration in EUV Microstepper**
   - **High power source development**

5. Summary and remaining critical issues

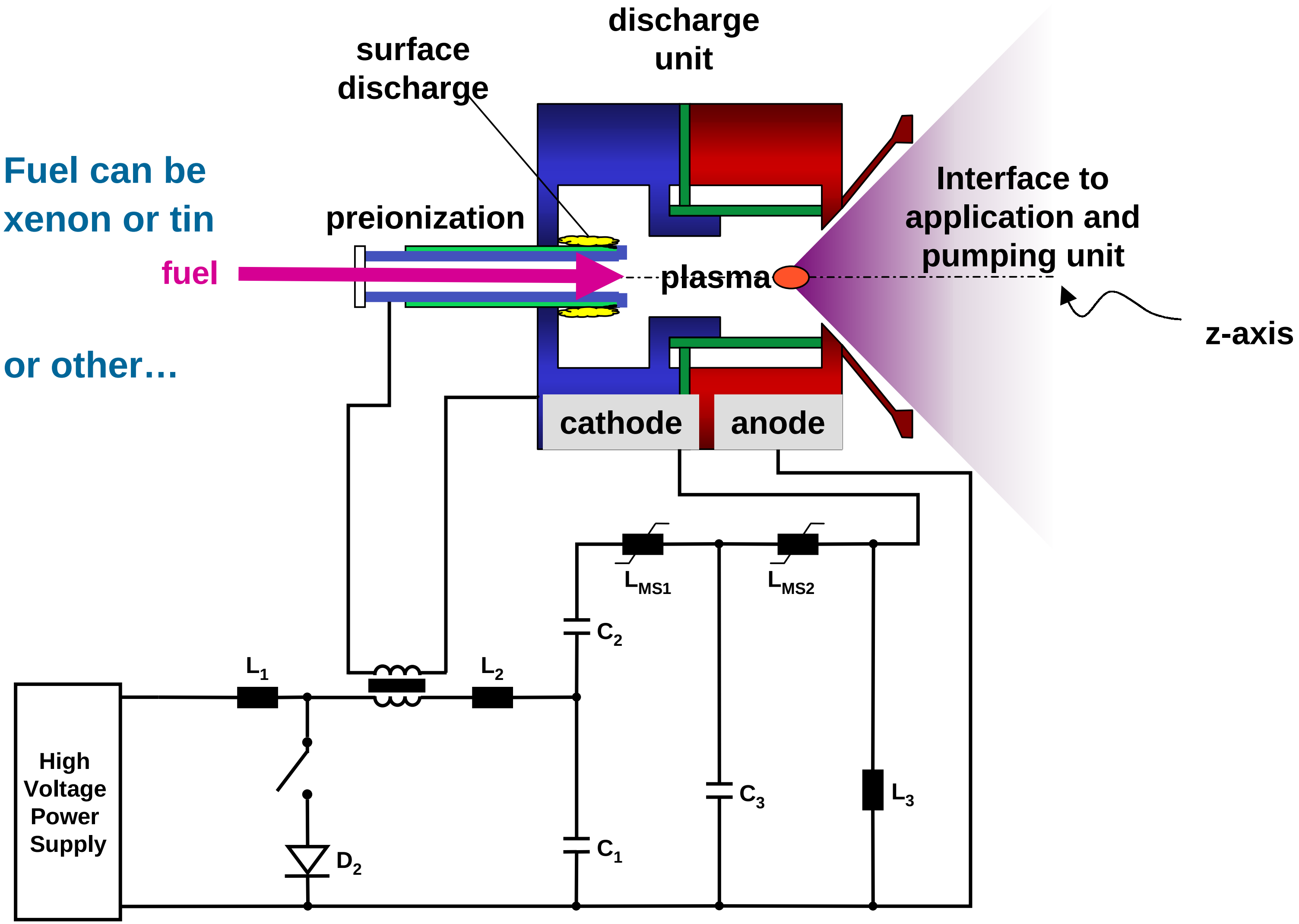


Taking light to new dimensions…

XTREME GDPP EUV Sources: Z-pinch discharge

Fuel can be xenon or tin

or other…



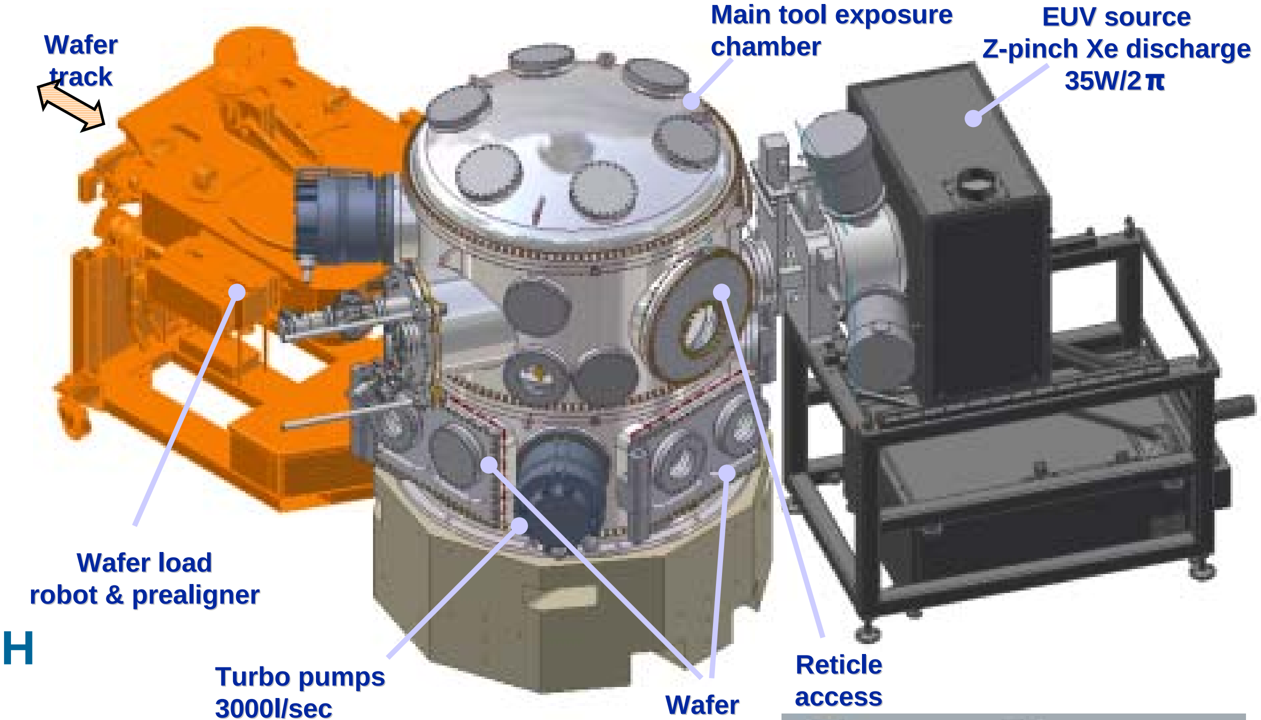
Taking light to new dimensions…

XTREME GDPP EUV Source in MS-13 EUV Microstepper

- XTS 13-35 for EUV Microstepper:
  - EUV sources with 35 W in 2π sr at 1000 Hz delivered and integrated
  - Optics lifetime (10 % Reflectivity decrease) with debris filter > 100 million pulses

- Equipped with debris mitigation and integrated with collector optics from Zeiss, Germany

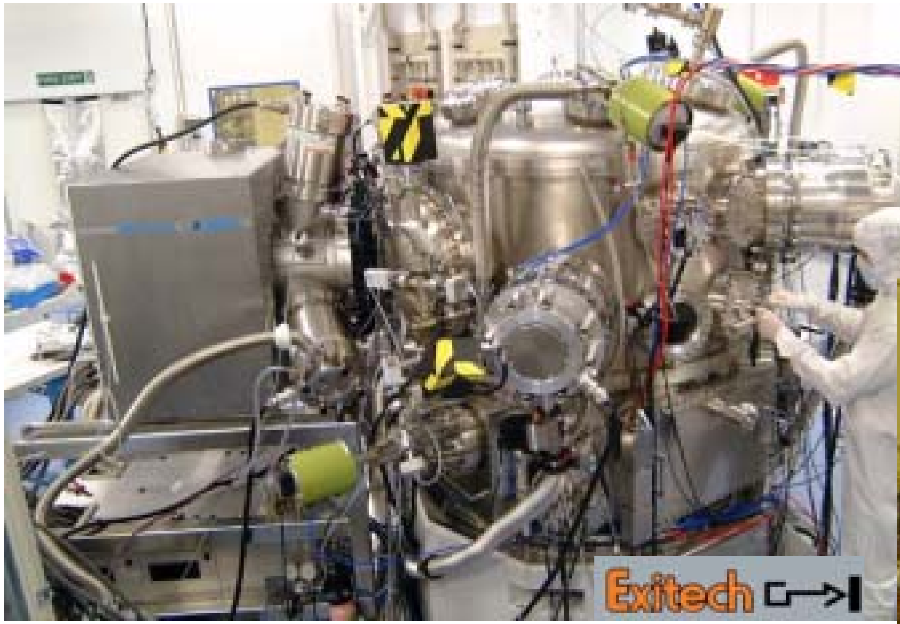
- MS-13 microstepper as pathfinder tools for semiconductor industry at intel and International SEMATECH



See Eric Sohmen, Zeiss, this conference

Taking light to new dimensions…

XTREME GDPP EUV Source in MS-13 EUV Microstepper

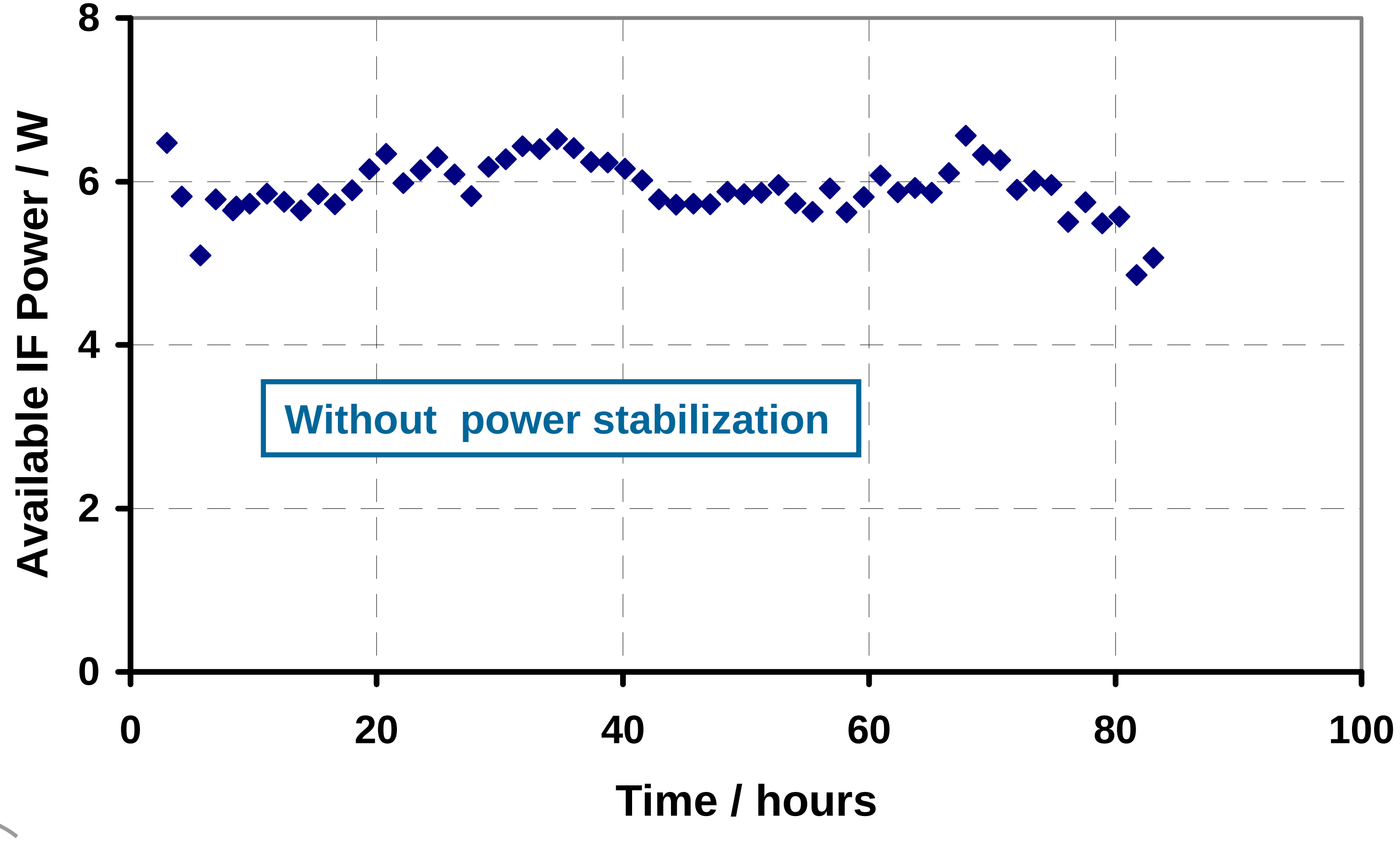


GDPP EUV source from XTREME technologies at microstepper at Exitech (Source: Exitech)

World's first commercial EUV lithography tool installed at Intel (Source: Intel)

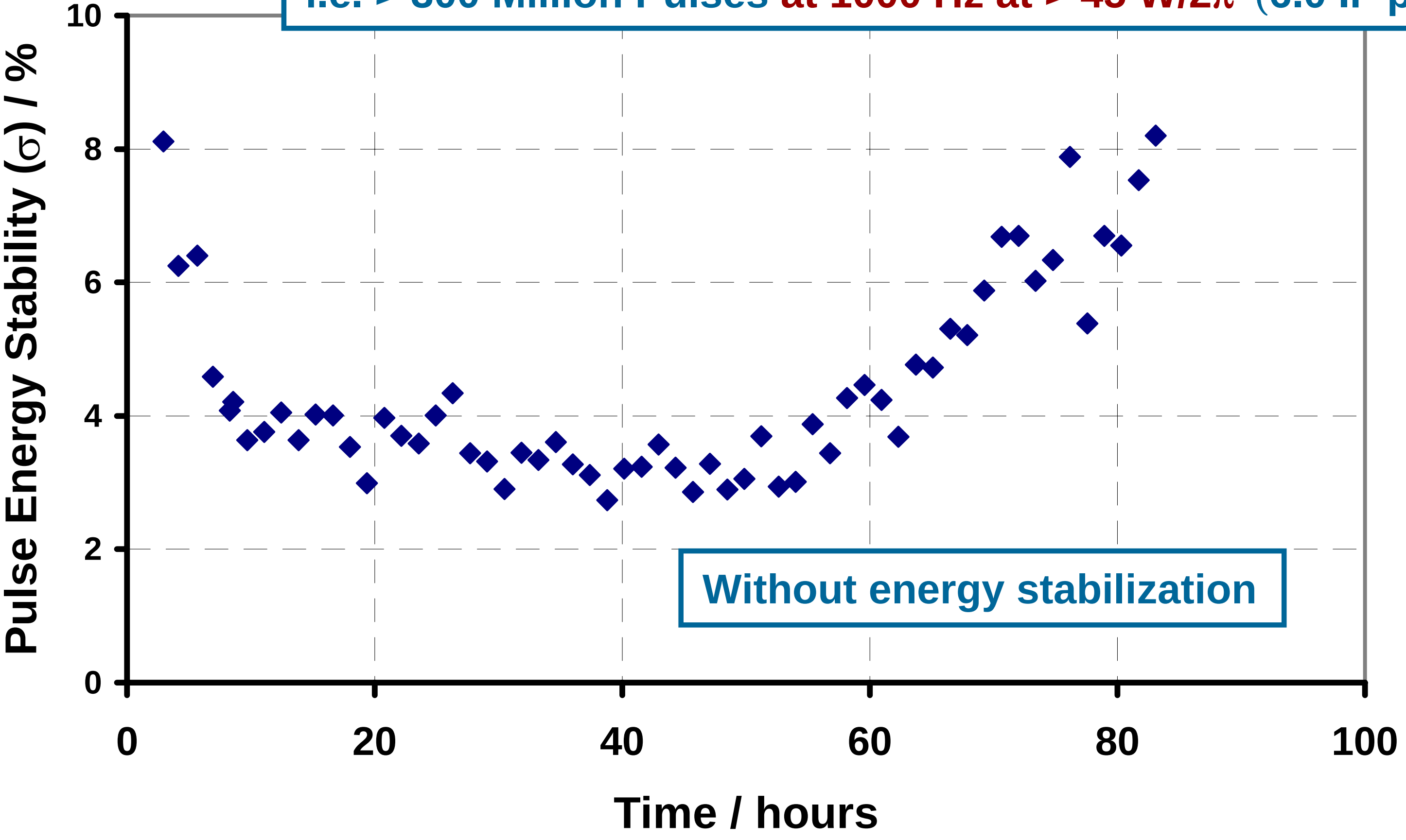
GDPP EUV Sources: component lifetime - power

Discharge electrode lifetime > 80 hours,
i.e. > 300 Million Pulses at 1000 Hz at > 45 W/2π (6.0 IF power)



Without power stabilization

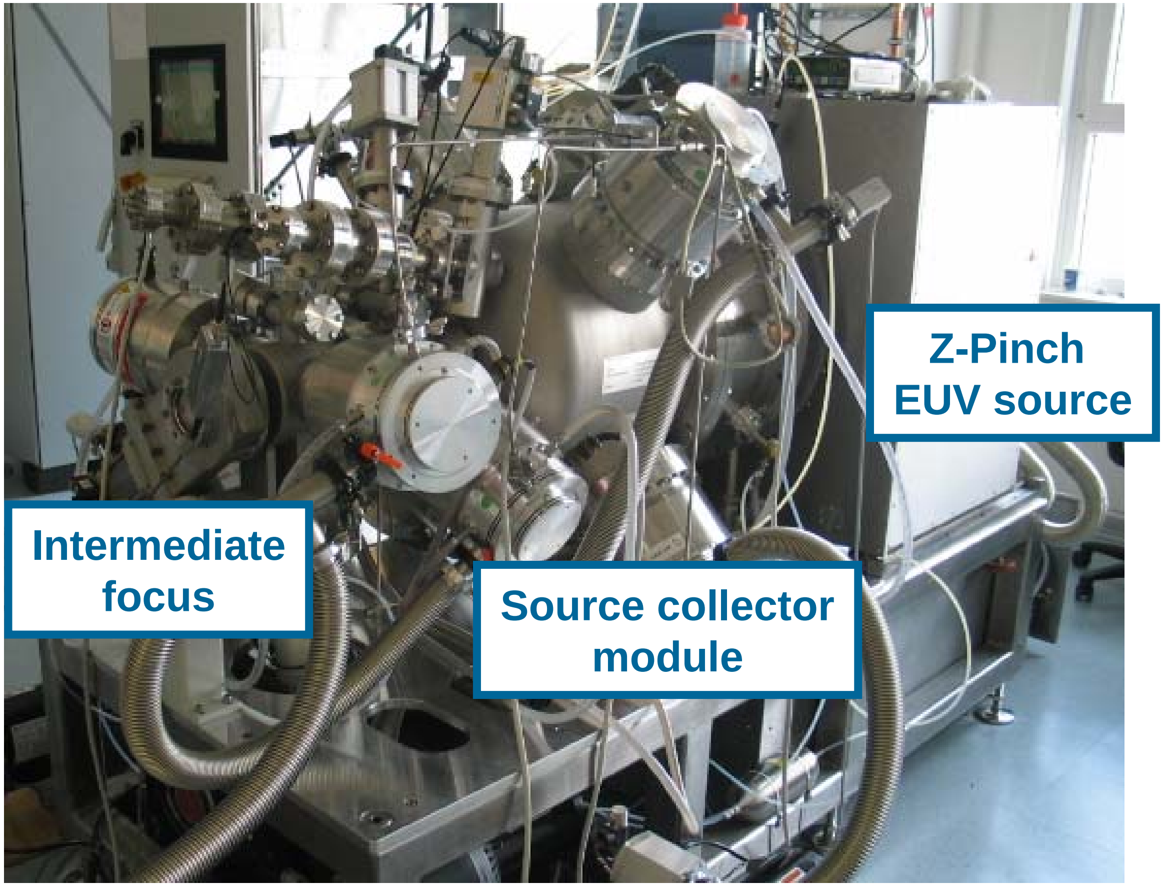
GDPP EUV Sources: component lifetime – energy stability

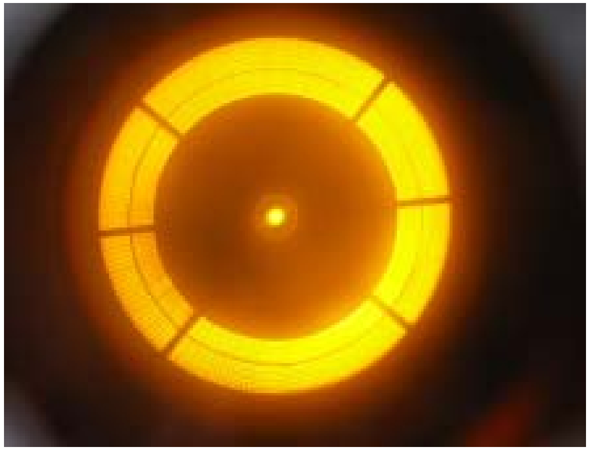


Discharge electrode lifetime > 80 hours,
i.e. > 300 Million Pulses at 1000 Hz at > 45 W/2π (6.0 IF power)

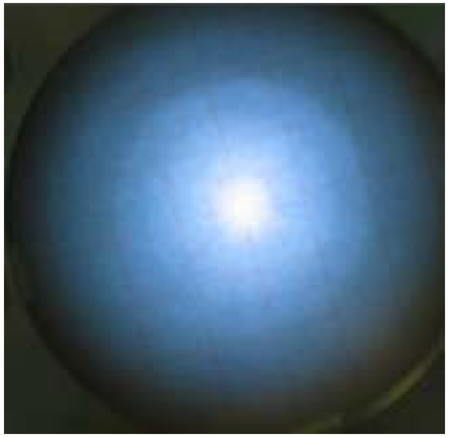
Without energy stabilization

GDPP EUV Sources: Integration of collector mirror





View from IF

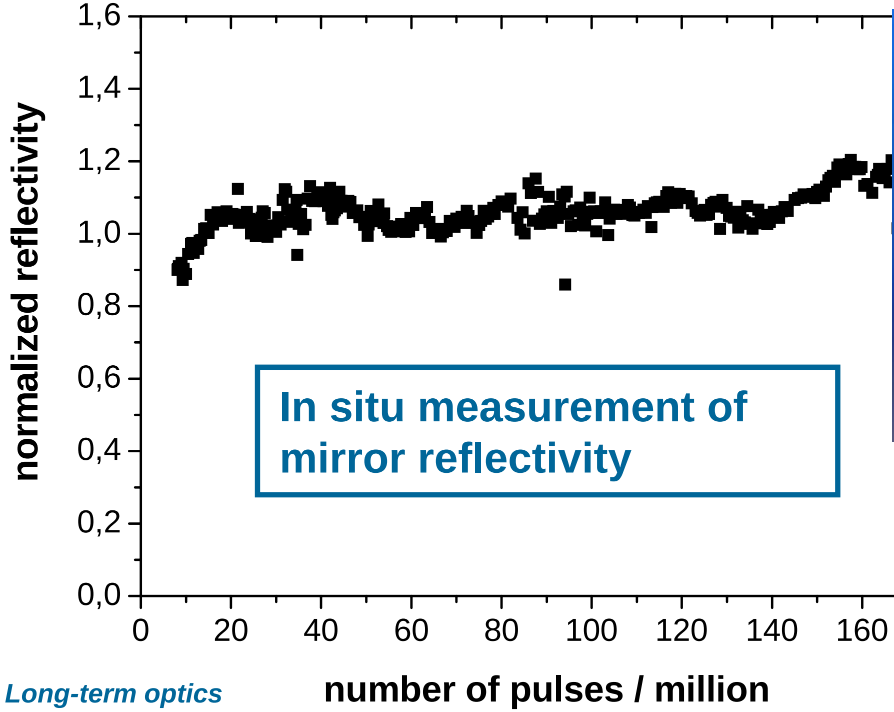


Visible light at IF

Determination of source collector efficiency
High power collector exposure
Development of IF metrology

See Piotr Marczuk, Zeiss, this conference

GDPP EUV Sources: collector optics lifetime



In situ measurement of mirror reflectivity

Long-term optics reflectivity test

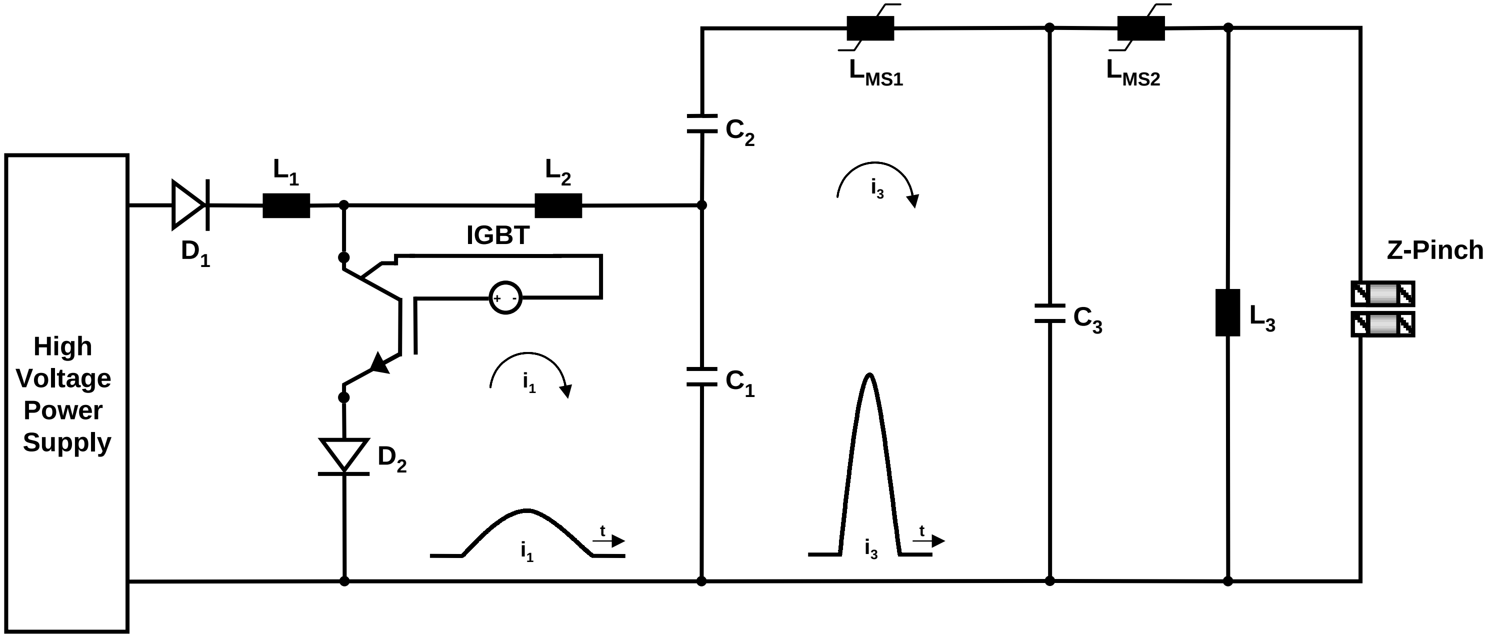
Debris filter

Zeiss collector optics

In-situ and ex situ evaluation of erosion rate yields:

- **Mirror lifetime of 0.5-1.0·10^9 pulses at 35-50W / 2π and 1kHz, i.e. 140 - 280 hours**

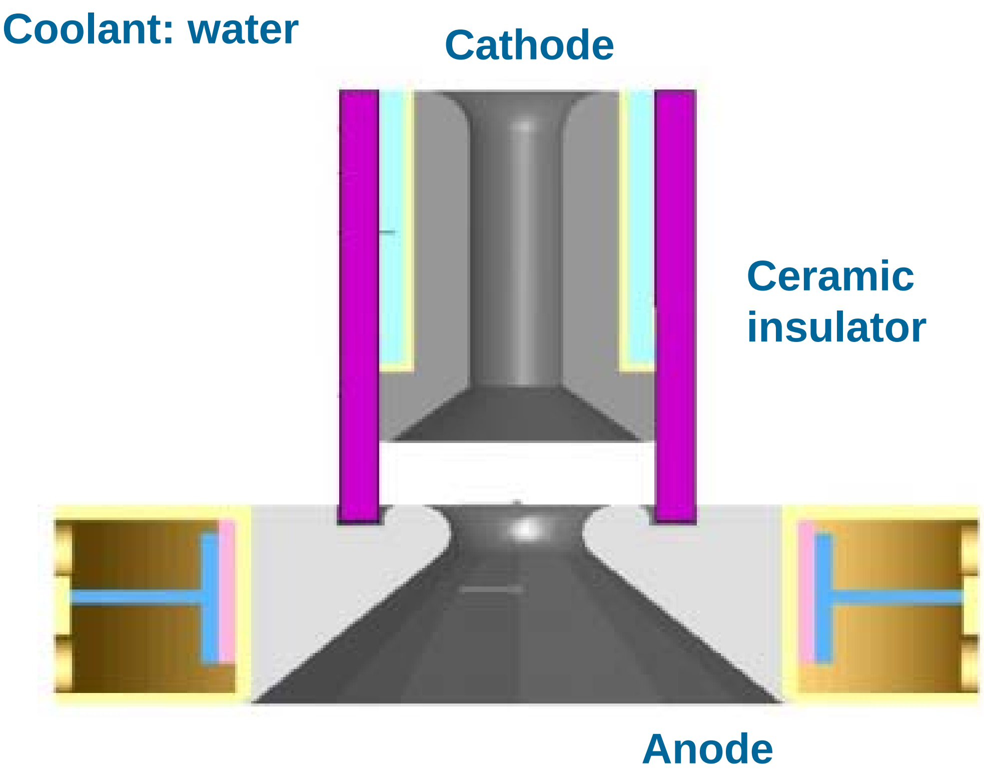
GDPP EUV Sources: Pulsed power supply



Improvement in pulsed power circuit efficiency and cooling:

Pulsed power supply can deliver
50 kW electrical power to the source

GDPP EUV Sources: Heat removal with porous metal cooling



Standard cooling design
(cooling fins)
Maximum heat removal
≥ 5.2 kW

1st porous metal cooling design (10/03)
Maximum heat removal
≥ 15.2 kW

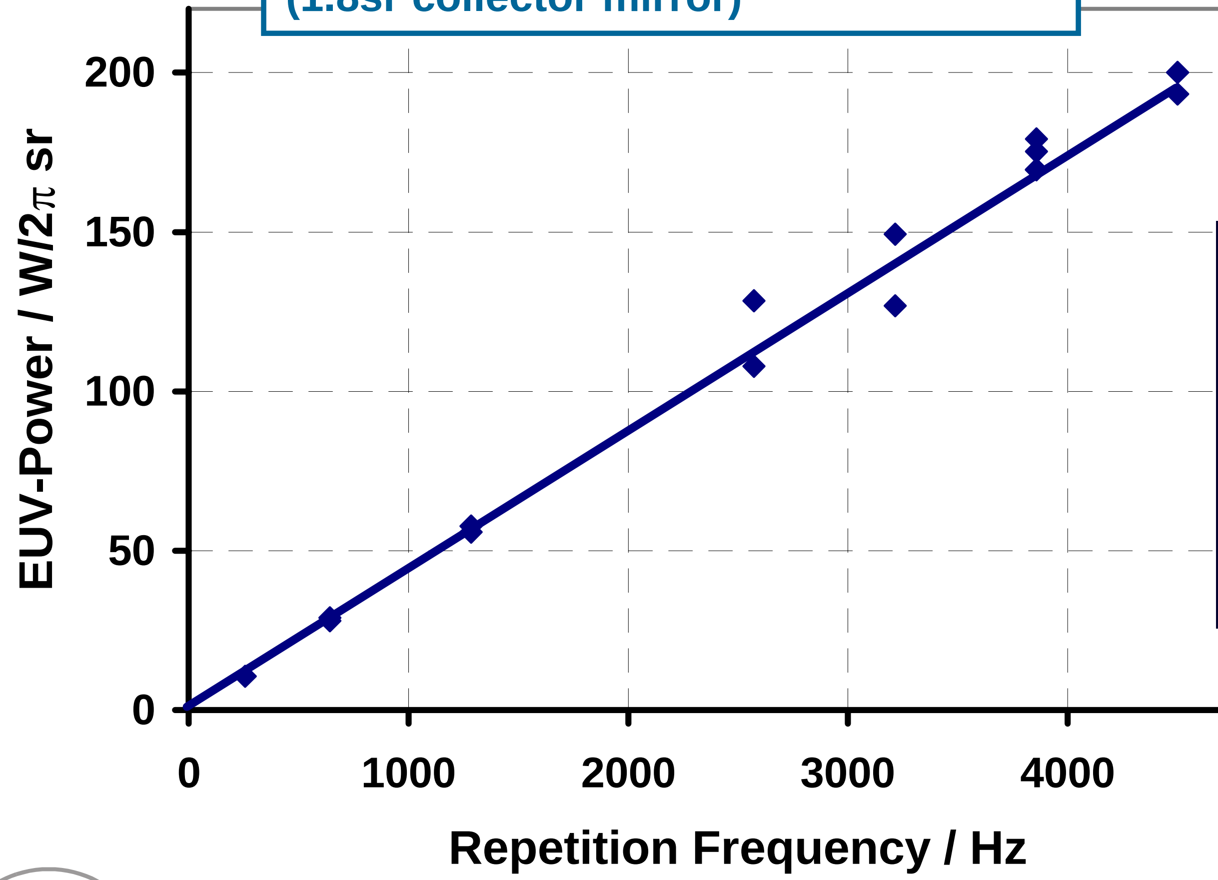
2nd porous metal cooling design (02/04)
Maximum heat removal
≥ 18 kW

3rd porous metal cooling design (06/04)
Maximum heat removal
≥ 20 kW

Status GDPP EUV Sources: HVM power scaling (I) - xenon

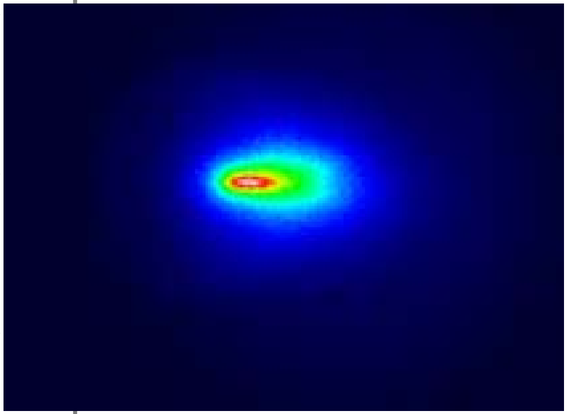
Available IF power: 25 W

(1.8sr collector mirror)



EUV power
at 4500 Hz:

200 W / 2π sr



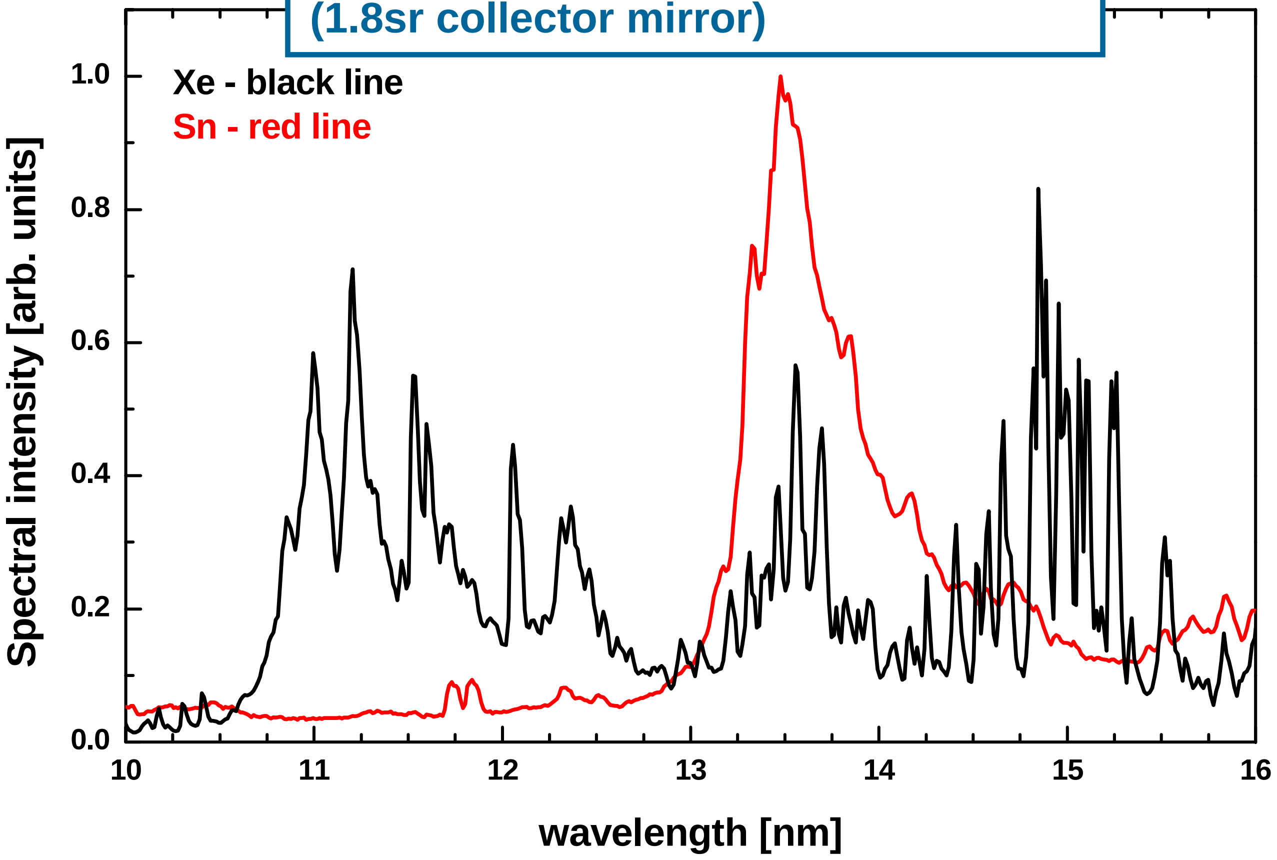
Plasma Image

Taking light to new dimensions…

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

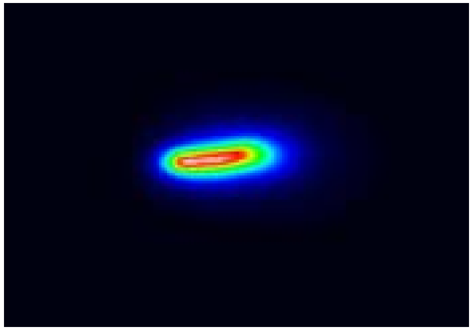
Available IF power: 50 W

(1.8sr collector mirror)



EUV power at 4500 Hz:

400 W / 2π sr

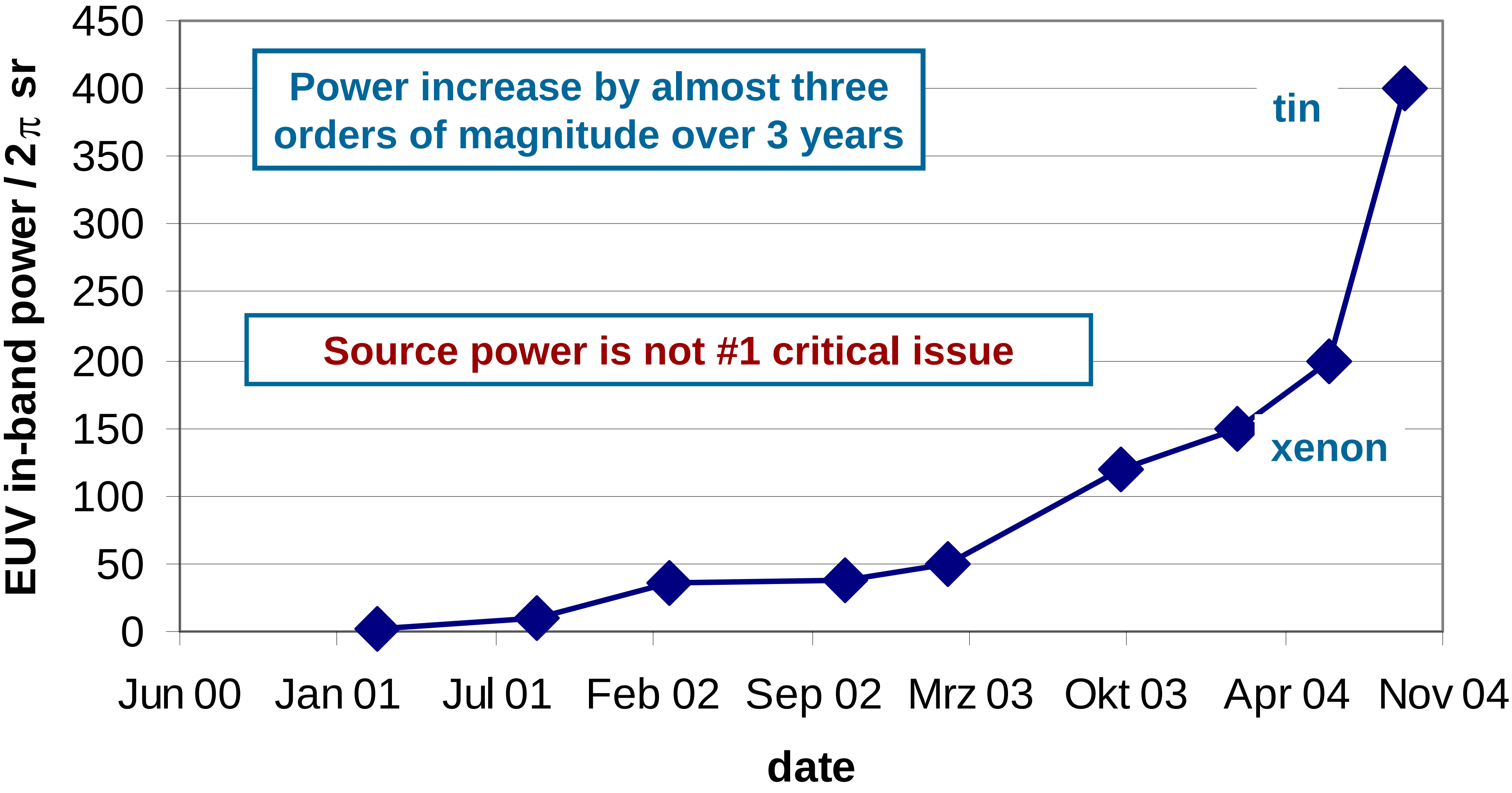


Plasma Image

50 W IF power is nearly half of HVM specification.
Source power is not #1 critical issue anymore.

See Jens Ringling, XTREME, this conference

Status GDPP EUV Sources: Power scaling (III) - history



Power increase by almost three orders of magnitude over 3 years

Source power is not #1 critical issue

Taking light to new dimensions…

GDPP EUV sources: Power status and HVM power roadmap

Fuel	**xenon status 09/2004**	**tin status 09/2004**	**tin on the roadmap with collector of today**	**tin on the roadmap with improved collector**
Heat removal from discharge (kW)	20	20	40	40
Conversion efficiency (%)	1.0	2.0	3.0	3.0
EUV power (W/2π sr)	200	400	1200	1200
Transmission of debris mitigation	0.8	0.8	0.8	0.8
Collection solid angle (sr / 2π sr)	0.3	0.3	0.3	0.5
Average reflectivity of collector	0.63	0.63	0.63	0.55
Gas transmission in collector module	0.85	0.85	0.85	0.85
Available IF power (W)	**25.7**	**51.4**	**154.2**	**224.4**
Etendue acceptance factor	0.5-1.0	0.5-1.0	0.5-1.0	0.5-1.0
Usable IF power (W)	**12.8-25.7**	**25.7-51.4**	**77.1-154.2**	**112.2-224.4**

The source power is not a critical issue

Taking light to new dimensions…

Summary: EUV source status

LPP EUV Sources:

- EUV power of 7 W in 2π sr continuous operation demonstrated corresponds to 2.3 W @ IF with 5 sr collector
- Optics lifetime (10 % reflectivity decrease) 280 hours
- Nozzle lifetime larger than 80 hours

GDPP XTS 13-35 for EUV Microstepper:

- EUV sources with 35 W in 2π sr at 1000 Hz delivered and integrated corresponds to 3.8W @ IF with 1.8 sr collector
- Optics lifetime (10 % reflectivity decrease) with debris filter 140-280 hours
- Discharge electrode component lifetime > 80 hours

High Power GDPP EUV Sources:

- EUV power of 200 W in 2π sr continuous operation demonstrated with xenon source corresponds to 25W @ IF with 1.8 sr collector
- EUV power of 400 W in 2π sr continuous operation demonstrated with tin source corresponds to 50W @ IF with 1.8 sr collector

Remaining most critical source issues

EUV source power is not critical issue #1

Most critical issues remaining:

- **Tin handling and related contamination issue**
- **Source collector optics lifetime**
- **Electrode discharge system lifetime**

Taking light to new dimensions…

Thank you for your attention !!!

Acknowledgement

Thanks to all my colleagues for their excellent contributions
to the progress we have made

H. Ahlbrecht, I. Ahmad, D. Ahrens, I. Balogh, H. Birner, D. Bolshukhin,
J. Brudermann, J. Bürger, R. de Bruijn, L. Dippmann, G. Dornieden, H. Ebel,
A. Eickhoff, S. Enke, F. Flohrer, F. Friedrichs, K. Gäbel, A. Geier, S. Götze, B. Grote,
G. Hergenhan, A. Hoang, A. Keller, J. Kleinschmidt, D. Klöpfel, V. Korobochko,
B. Mader, M. Möritz, R. Müller, J. Ringling, G. Schriever, B. Tkachenko, D.C. Tran,
M. Wegstroth, C. Ziener

Parts of the work were supported by the BMBF under
contract no. 13N8131 and by the European Community within the
FP6 project „more Moore“, IST-1-507754-IP