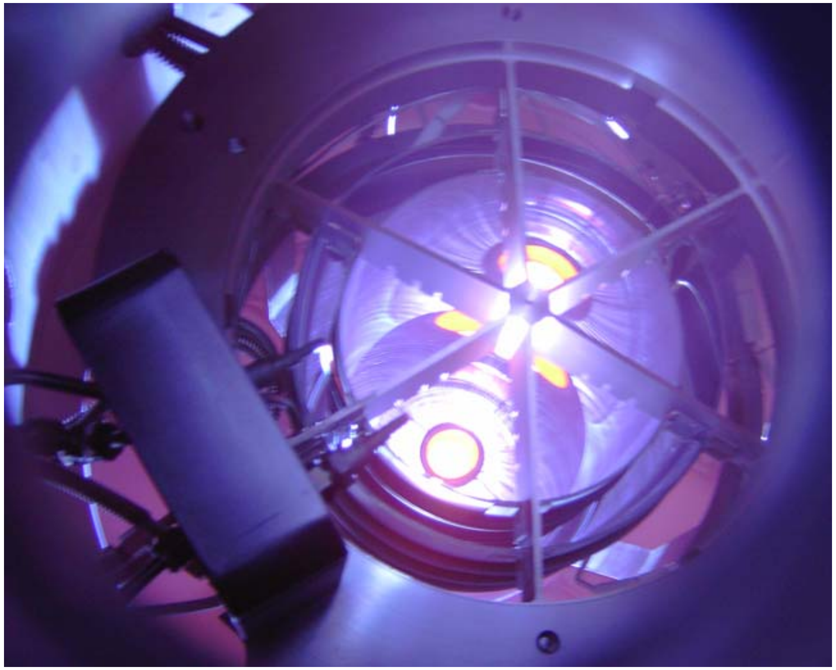
High power EUV source development for beta-level and high volume manufacturing lithography

Uwe Stamm

XTREME technologies



DPP EUV source with collector under operation

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Outline

1. Commercial EUV sources of today
2. High volume manufacturing EUV sources of tomorrow

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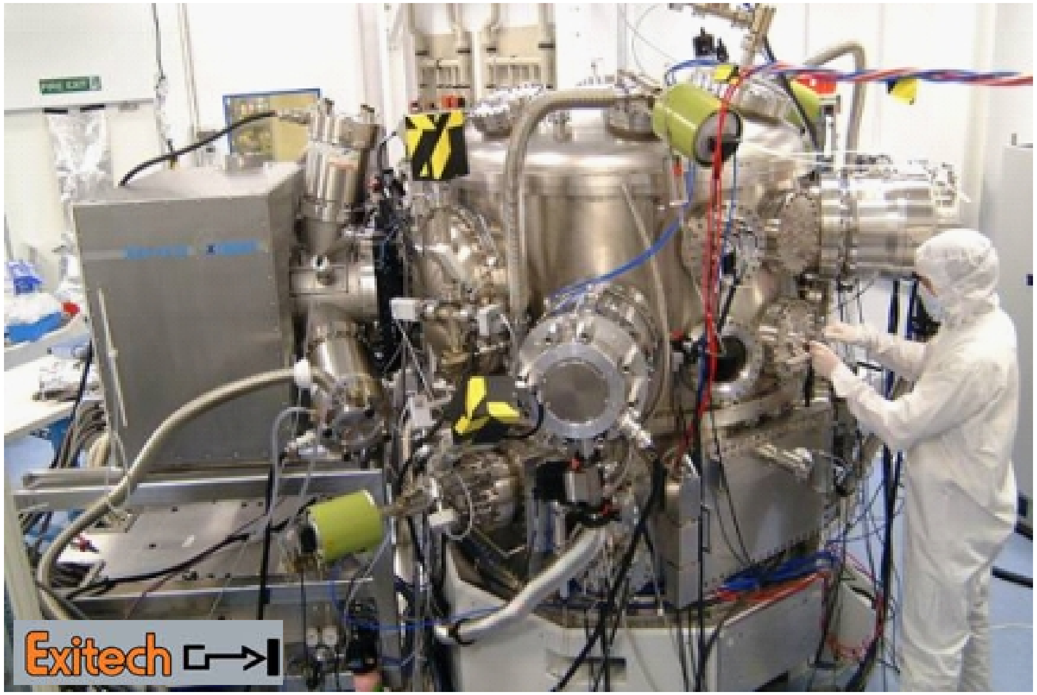
Commercial EUV Sources: XTS 13-35



XTS 13-35 source in EUV Microstepper at Exitech

Commercial DDP sources[1] for MET have been shipped already in 2003 → early learning

Main Specifications:

Power: 35 W / 2π sr

Nominal IF-power: 0.5 W

Optics lifetime: > 100 M pulses

1 w/o collector mirror

Commercial EUV Sources: XTS 13-75-IF

Commercial DDP sources with integrated collector mirror have been shipped in 2005

Main Specifications:

IF-power: > 3 W in 3.3 mm^2 sr

Optics lifetime: > 500 M pulses

EUV source XTS 13-75-IF with collector mirror

Commercial EUV Sources: XTS 13-150-IF

Next generation commercial DDP sources with integrated collector mirror have been developed[1]

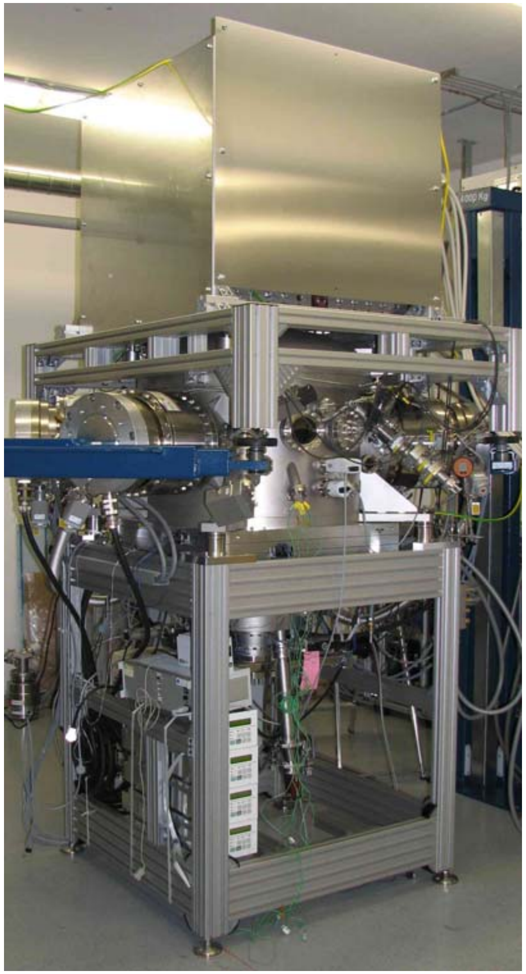
<u>Main Specifications:</u>

IF-power: > 10 W

Optics lifetime: > 10 G pulses
High energy particle sputtering completely stopped

Electrode system lifetime: > 2 G pulses

Shipment of first units will start in December 2006



Prototype of commercial 10 W EUV source XTS 13-150-IF with integrated collector mirror

1 see presentation of Bernd Nikolaus et al., …..

XTS 13-150-IF: Diagnostics and controlling

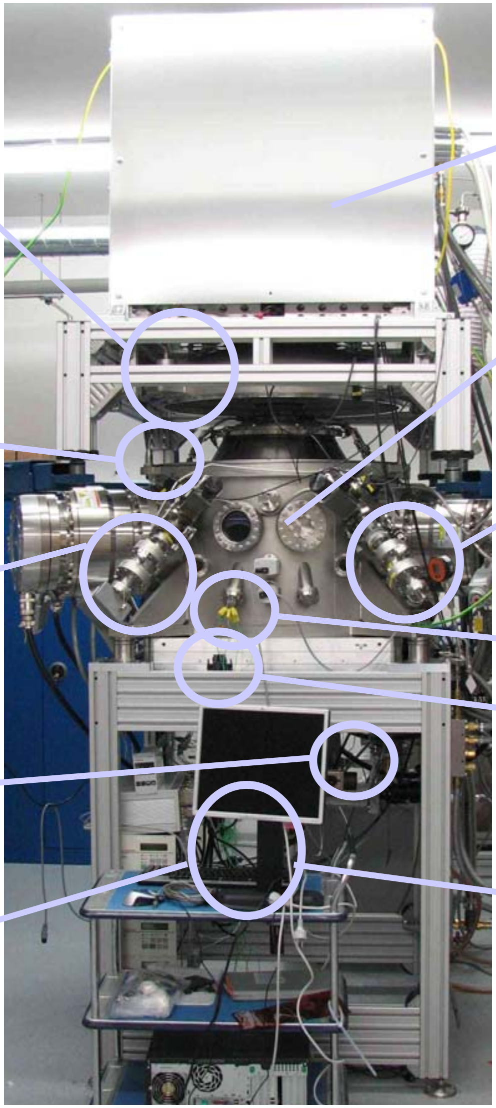
Coolant Power Control
Coolant flow
Temperatures

RGA
Gas impurities

EUV camera
Plasma size

Pressure gauges
Gas pressures

Power meter
Out-of-band radiation



DDP generator
EUV emission

Source Collector Module
DMT and collector mirror

Energy/Power monitor
EUV energy & stability

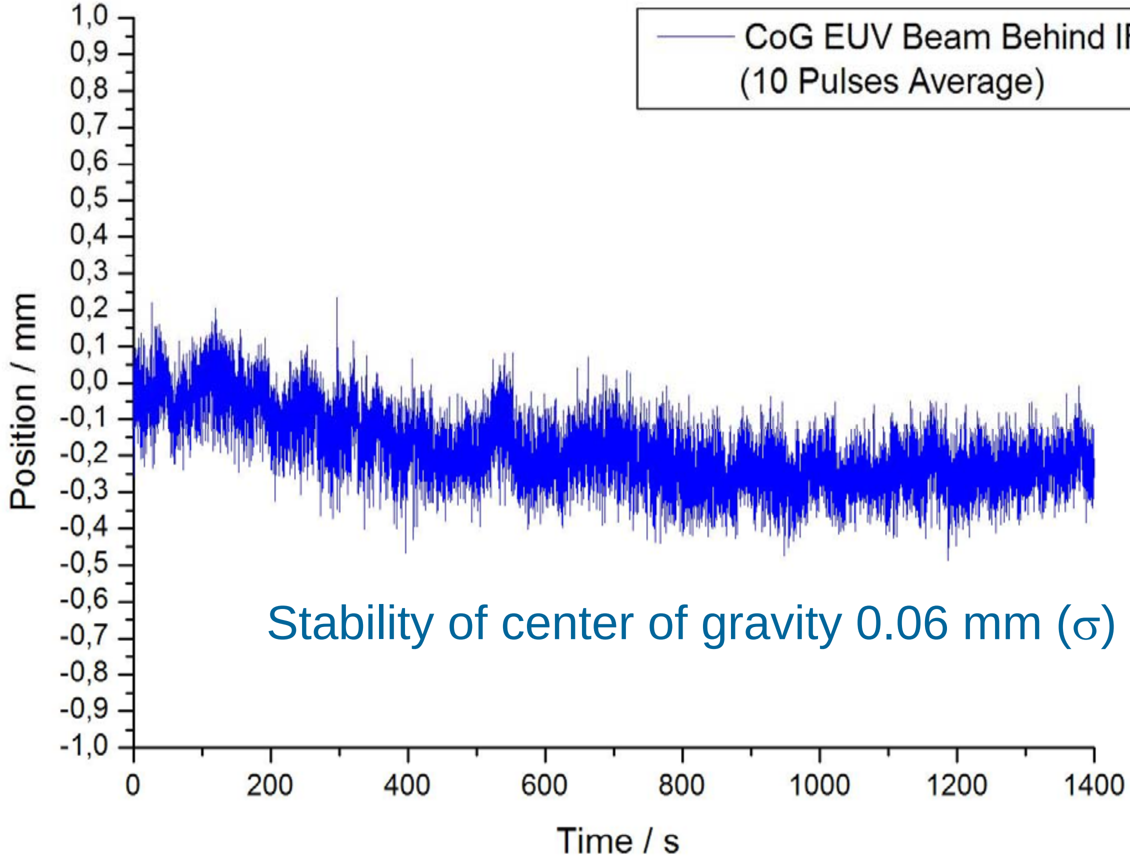
Thermocouples
Collector temperature

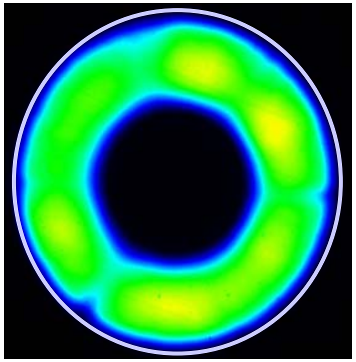
Stepper motors
Collector position

IF Screen tool
Power
Energy stability
IF size
Angular distribution

XTS 13-150-IF: Stability of intermediate focus distribution

Source – collector system shows 10 minutes warm-up phase
CoG shift of 0.2 mm of approx. 50 mm image size (0.4 %)





Intensity distribution behind IF: Outer diameter 50 mm

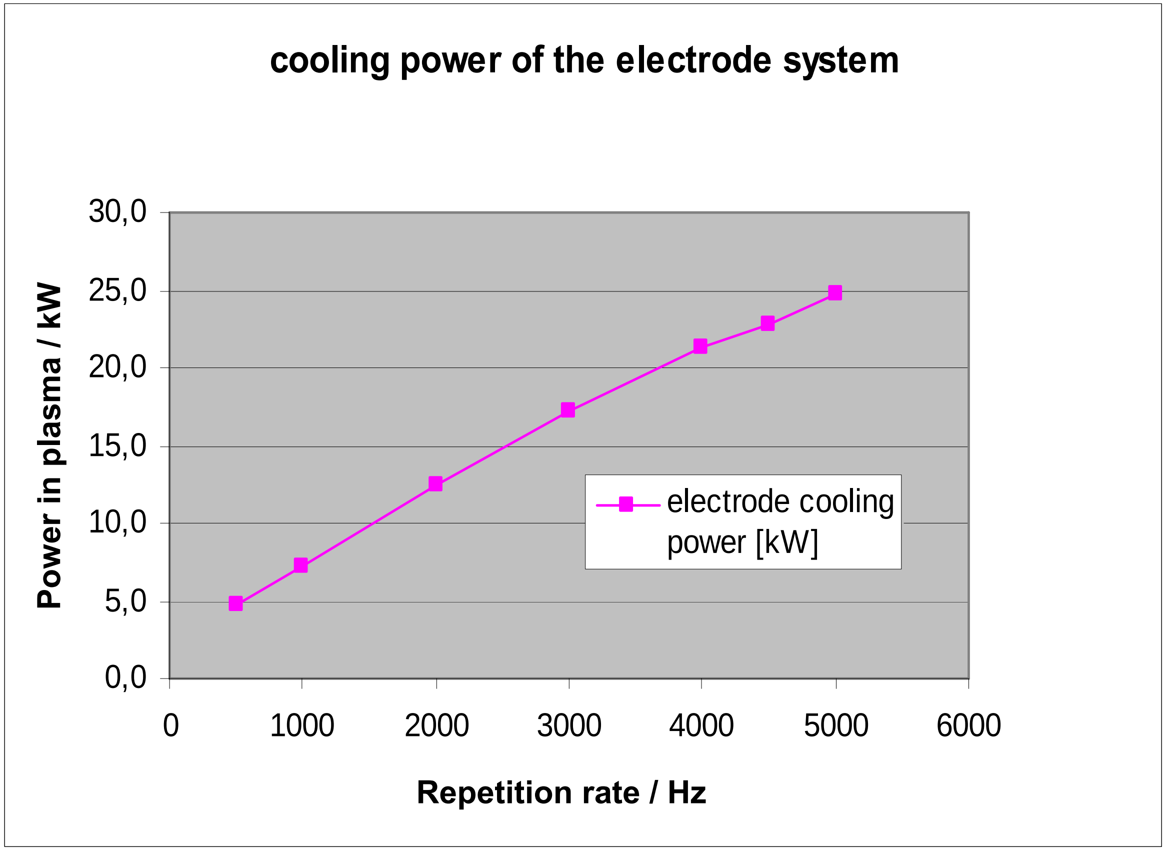
XTS 13-150-IF: Input power and heat removal

Continuous 5 kHz operation

- Electrode heat removal rises nearly linear with repetition rate:

  25 kW at 5 kHz, 2.2 kV

- Water inlet temperature max. 30 °C at 16 l/min



Taking light to new dimensions…

Outline

1. Commercial EUV sources of today

2. High volume manufacturing EUV sources of tomorrow

EUV Sources for HVM: Power requirements

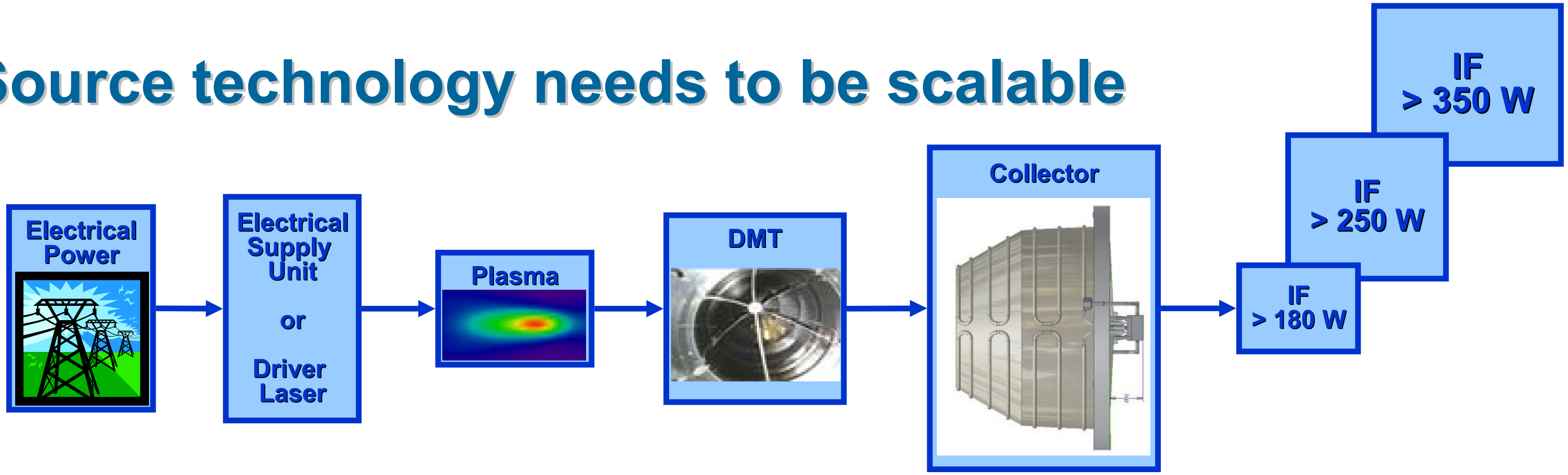
Source power requirement has been increased steadily to 180 W for 1st generation in HVM

- assumption: resist sensitivity 10 mJ/cm^2

Not meeting resist performance specifications with 10 mJ/cm^2 may lead to higher power requirement

Nodes below 22 nm may also need higher EUV power

→ Source technology needs to be scalable

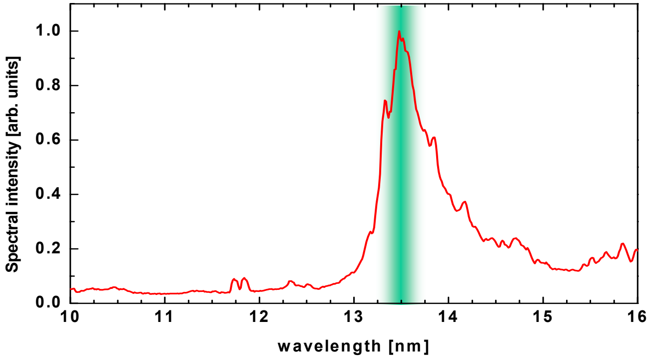


Taking light to new dimensions…

EUV Sources for HVM: Scalability options of DPP and LPP

HVM Power

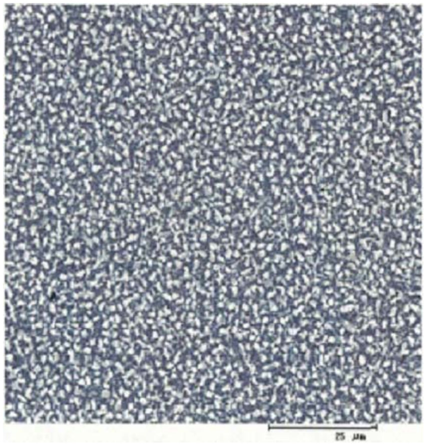
- increase input power to plasma (electrical / laser)
- improve heat removal from plasma, debris mitigation and collector mirror
- increase conversion efficiency of source fuel
  - xenon → tin
- increase overall collection efficiency
  - smaller plasma size
  - larger collection angle
  - higher collector reflectivity



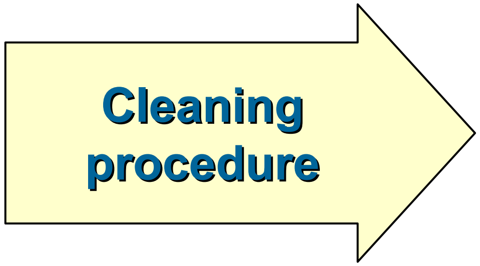
At the same time lifetime, reliability and CoO have to be met

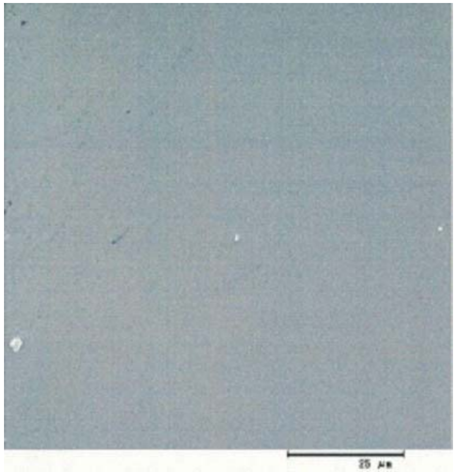
- Collector lifetime: > 3000 h

Tin Fuel and Collector Mirror Lifetime: Cleaning

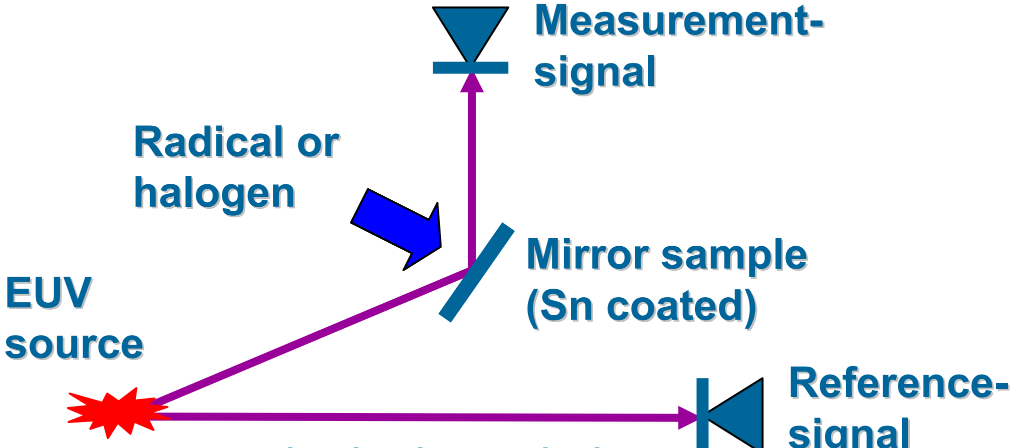


SEM images of tin coated mirror surface



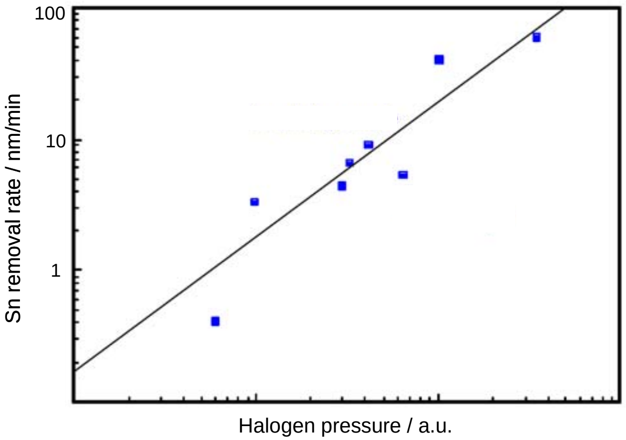


SEM images of cleaned mirror surface



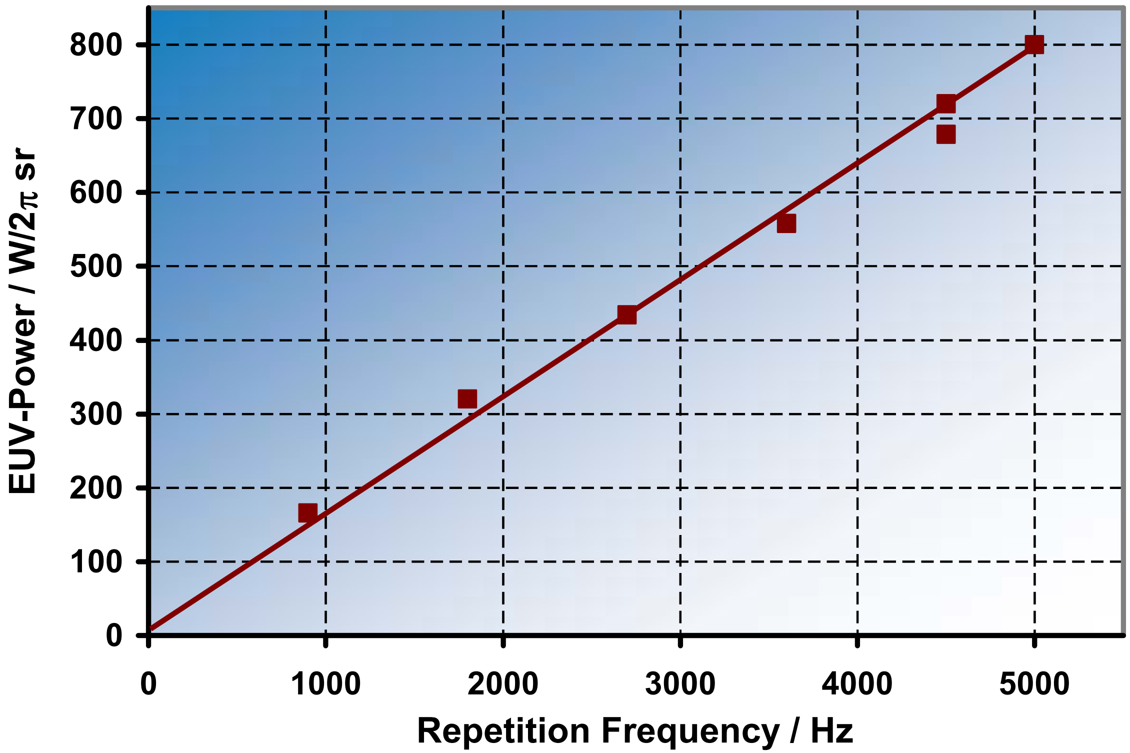
In-situ cleaning monitoring

High cleaning rate possible



Taking light to new dimensions…

DPP Power Scaling with XTS 13-150 Based Design Using Tin Fuel

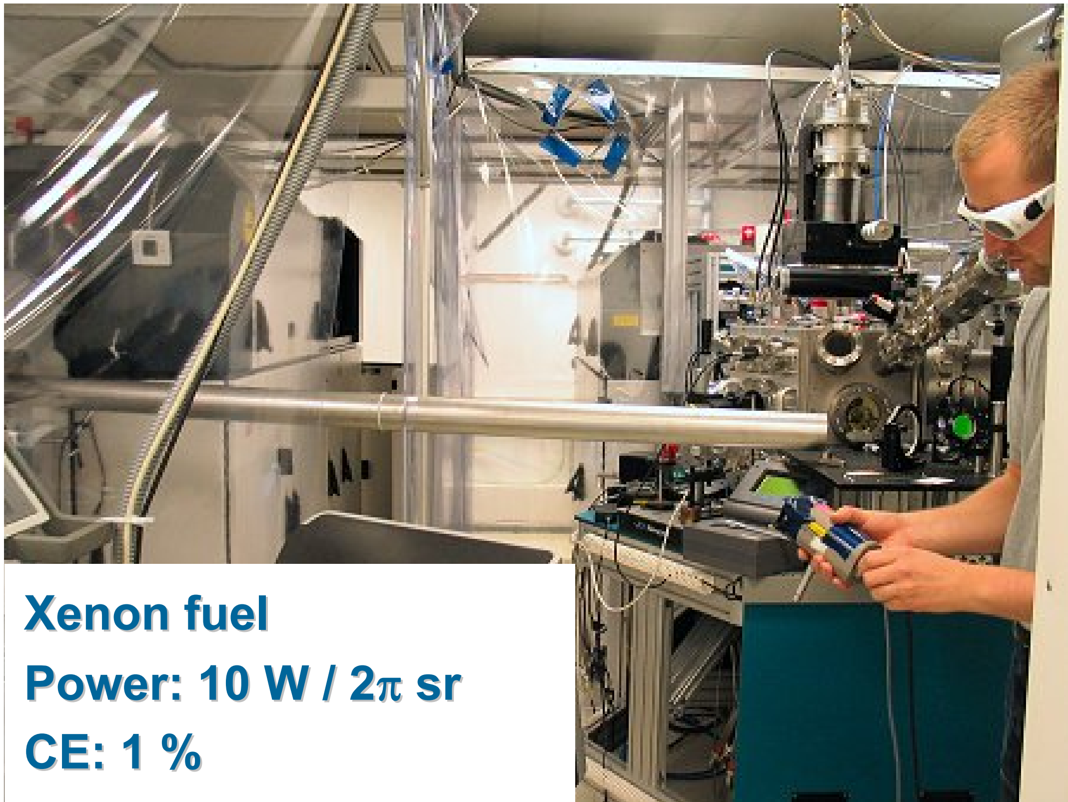


Power: 800 W / 2π sr
(in burst mode with
10 % duty cycle)
CE: up to 3 %
IF power: 70 – 120 W
(calculated)

Power scaling issues to be solved for HVM:

- electrode heat removal
- electrode lifetime
- power load on collector
- debris protection and cleaning of collector

LPP Power Scaling Using Tin Fuel



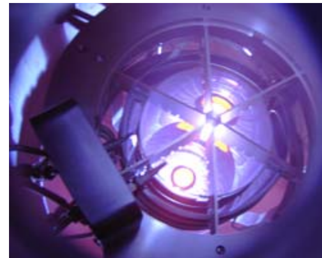
Xenon fuel
Power: 10 W / 2π sr
CE: 1 %
IF power: 3.3 W (calculated)

Tin fuel estimate
CE: up to 3 %
Power: 30 W / 2π sr
IF power: 10 W

Power scaling issues to be solved for HVM:

- driver laser
- heat removal from components
- power load on collector
- debris protection and cleaning of collector

Power 180 W: DPP versus LPP



DPP HVM status

240 kW supply unit
DPP current status

80 kW supply unit

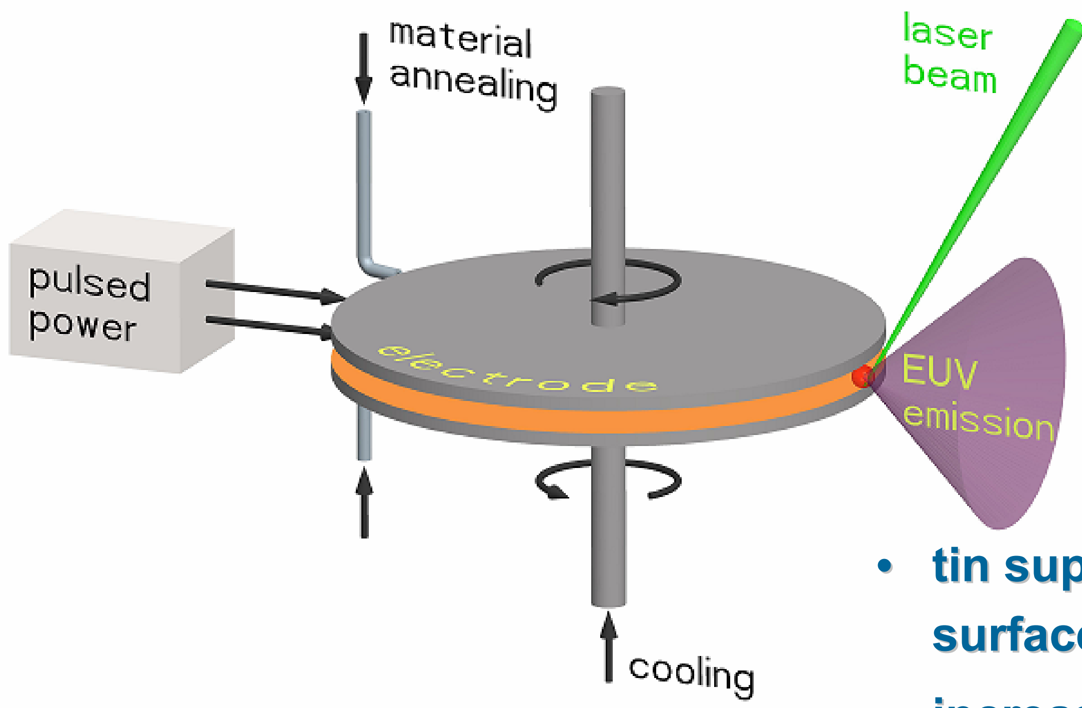
LPP HVM status

22 kW driver laser
LPP current status

1.2 kW driver laser

Power and Lifetime Scaling of Tin-Fueled DPP Sources

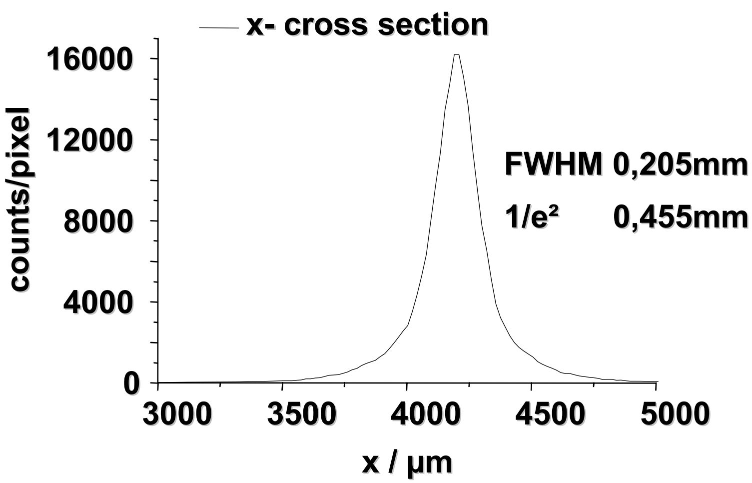
Laser assisted DPP with rotating disk electrodes (RDE)

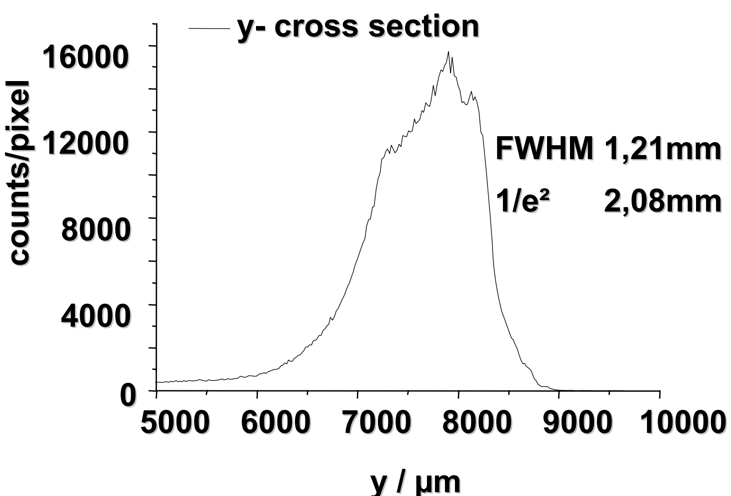


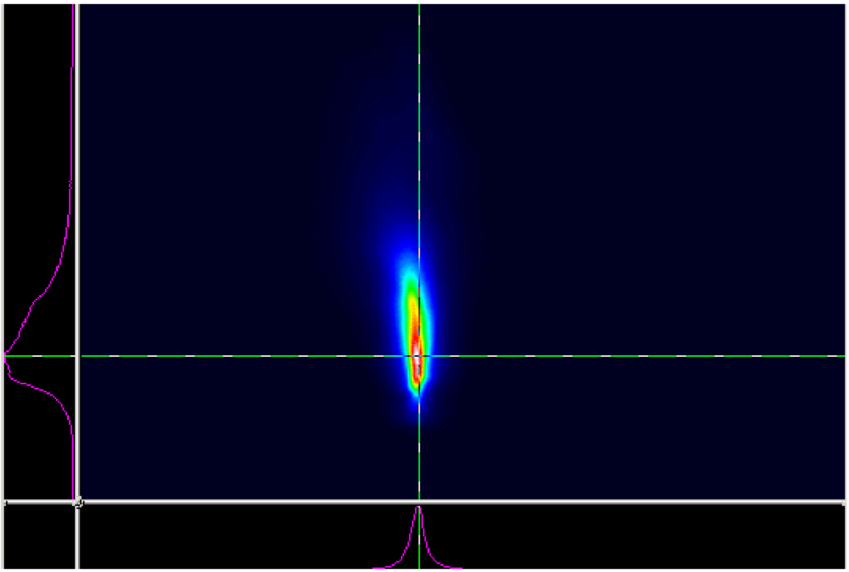
- **tin supply regenerates electrode surface and serves as fuel**
- **increases effective electrode area**
- **reduces heat load per area**

⟶ **increases electrode lifetime**

Laser Assisted RDE sources: Plasma size



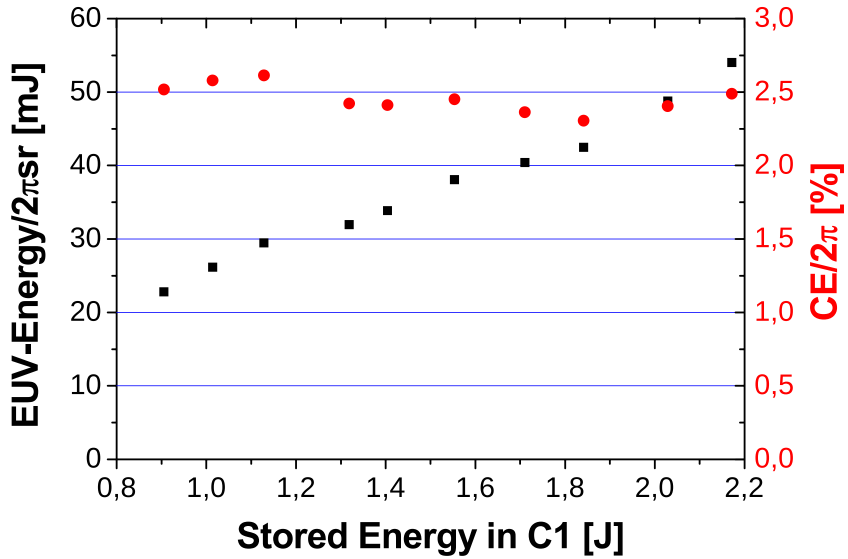


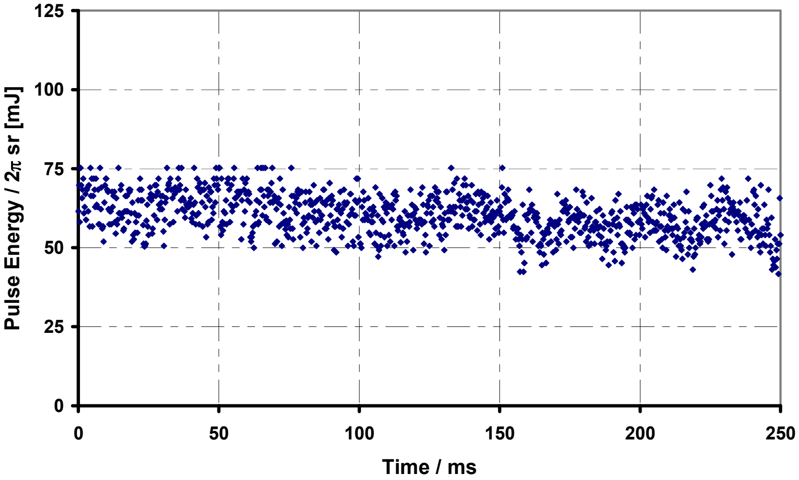


Plasma size: 2.1 mm x 0.5 mm (FW $1/e^2$)

Plasma size supports collection efficiency without significant etendue loss

RDE source: Power and stability





Power: > 200 W / 2π sr at 4 kHz

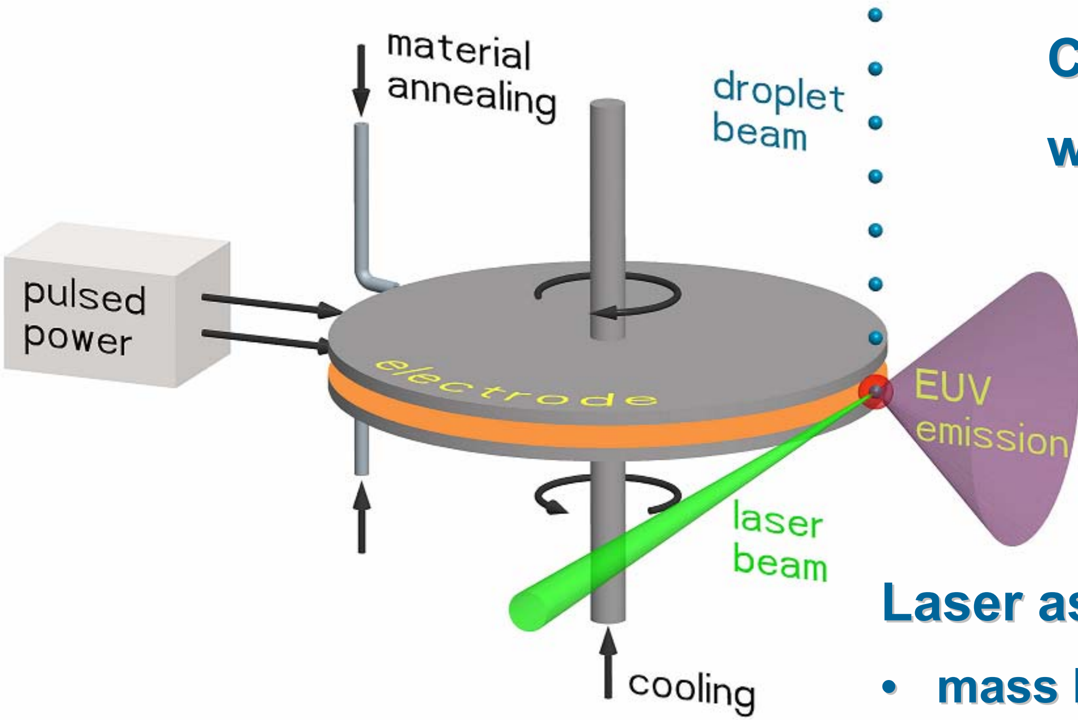
Conversion efficiency: up to 2.5 %

Critical equilibrium between

- tin supply
- tin evaporation
- output power

Better think about decoupling the system!

Laser Assisted Droplet RDE Source



Combines LPP advantages with DPP advantages

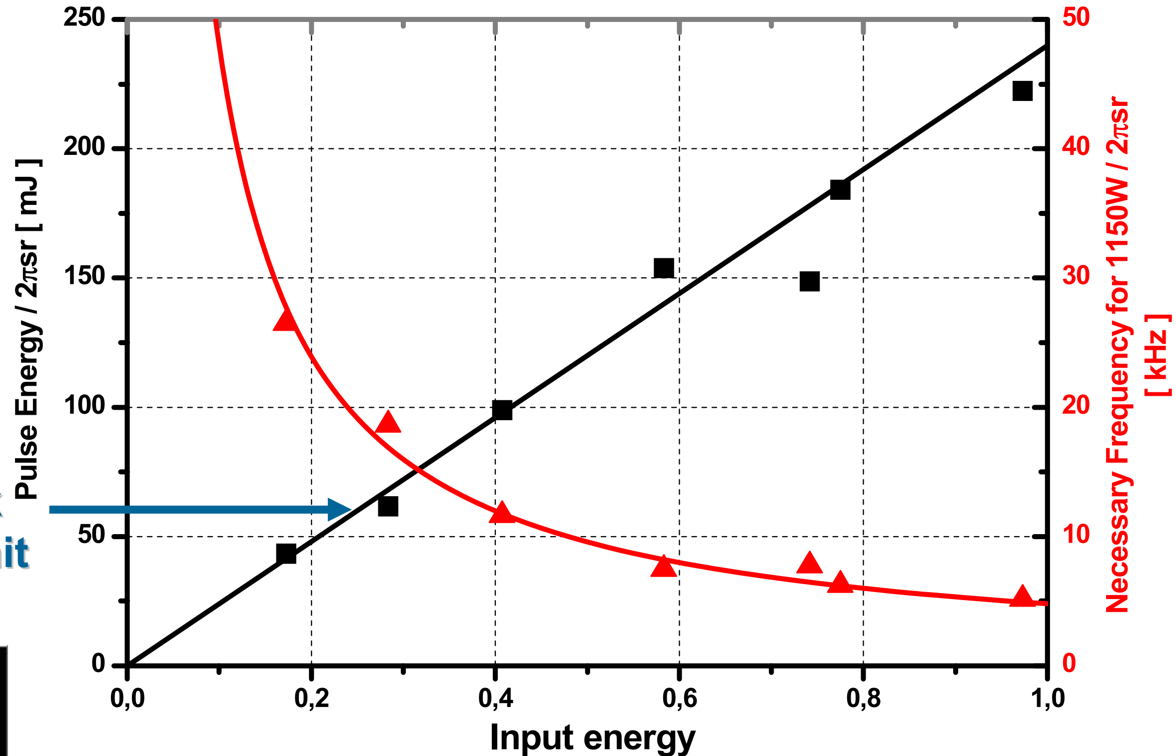
Laser assisted droplet RDE design:

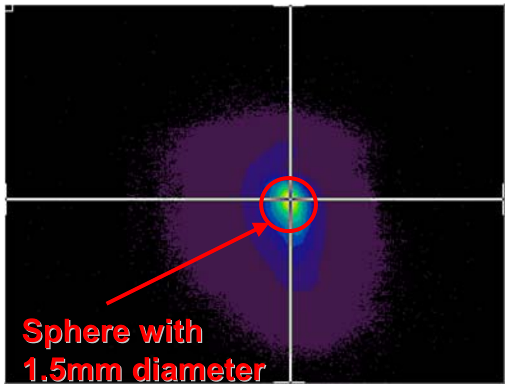
- mass limited fuel supply independent of electrode material and electrode surface regeneration
- higher brightness plasma
- better scaling possibilities
- debris direction control

Laser Assisted Droplet RDE Source: High pulse energy

Laser assisted droplet RDE approach delivers stable > 170 mJ in 2π sr

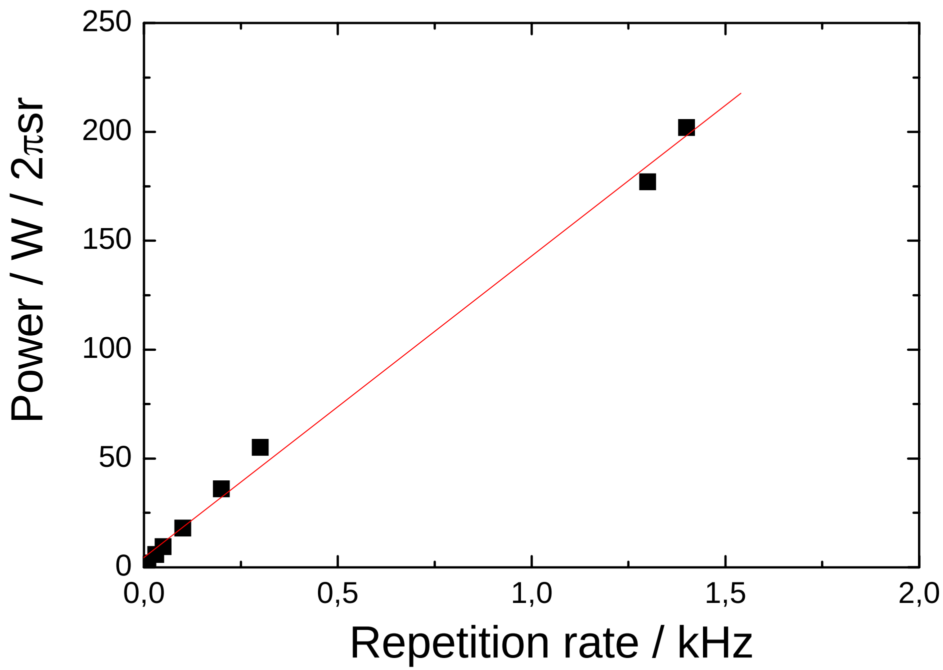
Conventional rotating disk electrode pulse energy limit

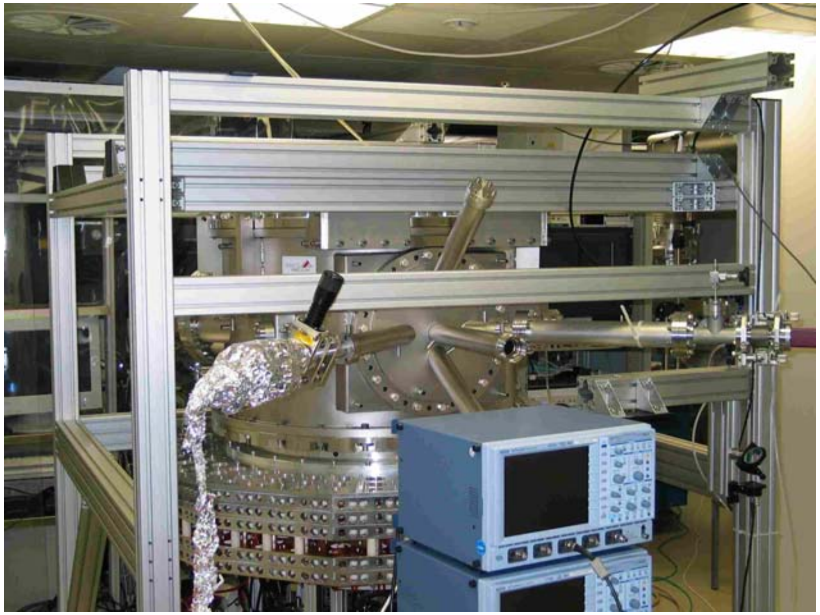




Small high brightness plasma

Output Power: > 200 W



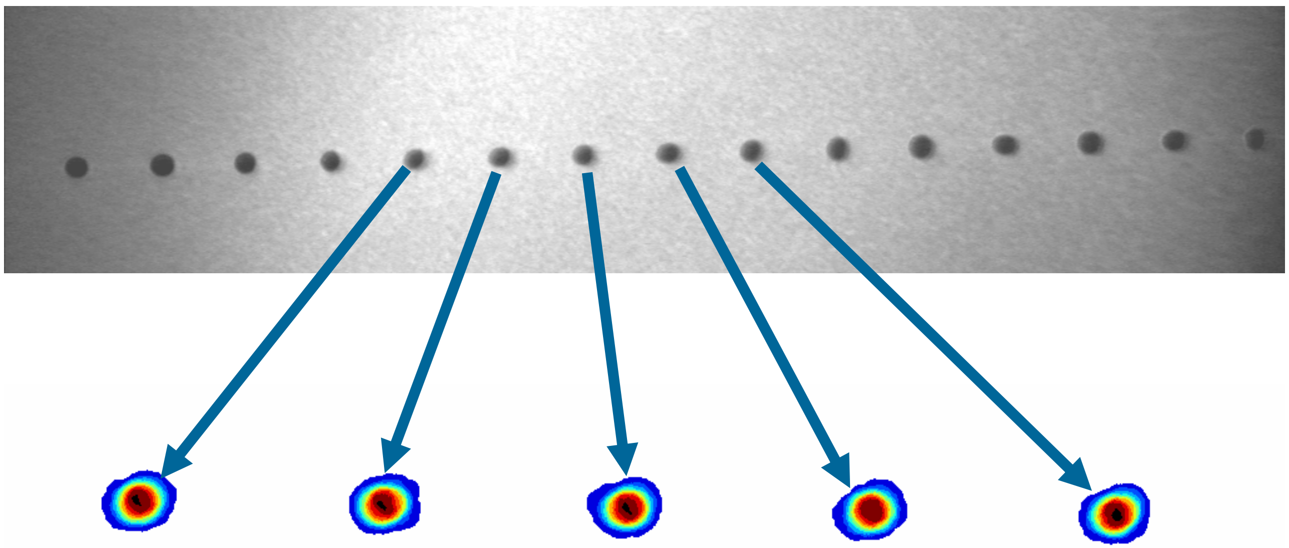


→ **Conversion efficiency is constant up to 1.4 kHz**

Experimental installation

Droplet Target Stability

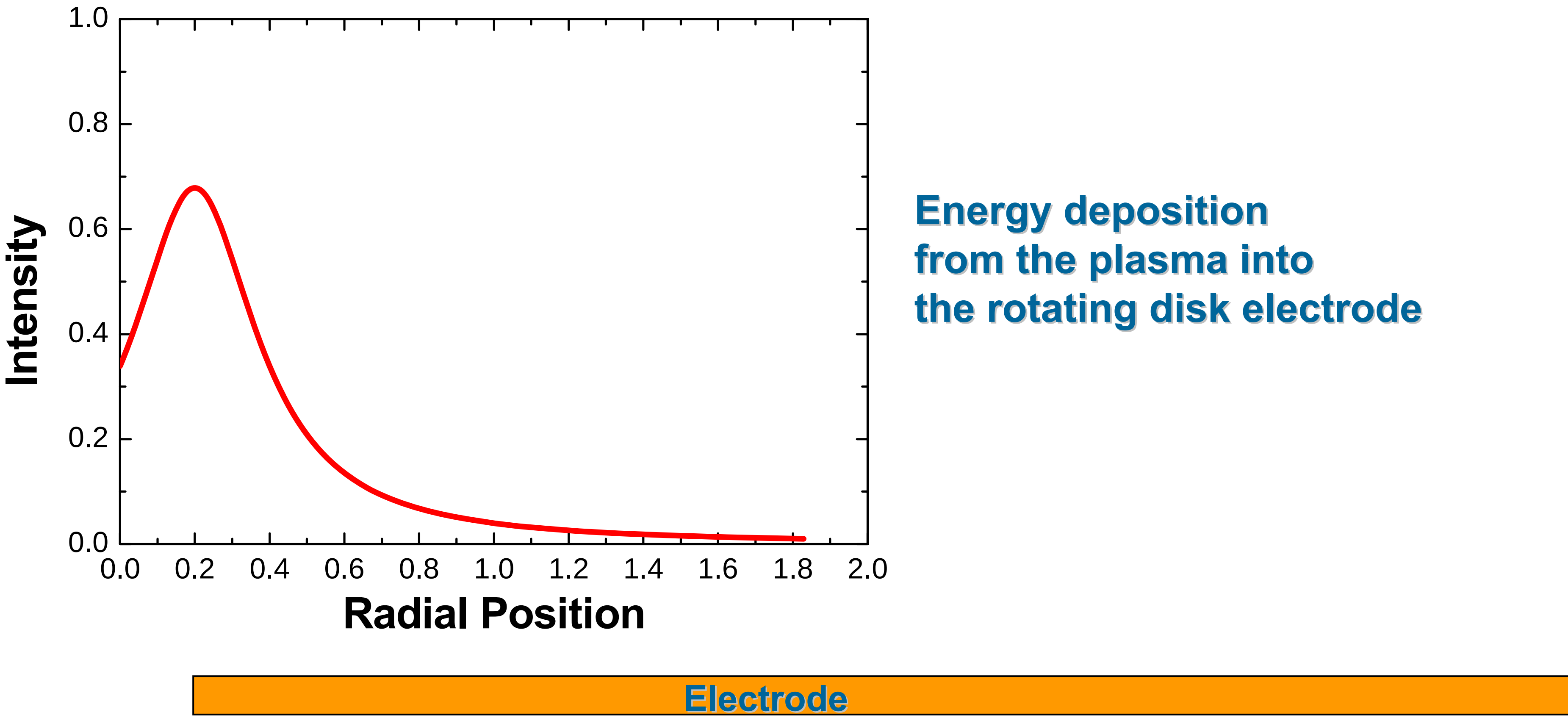
Image of droplet target



Probability distribution over 100 images

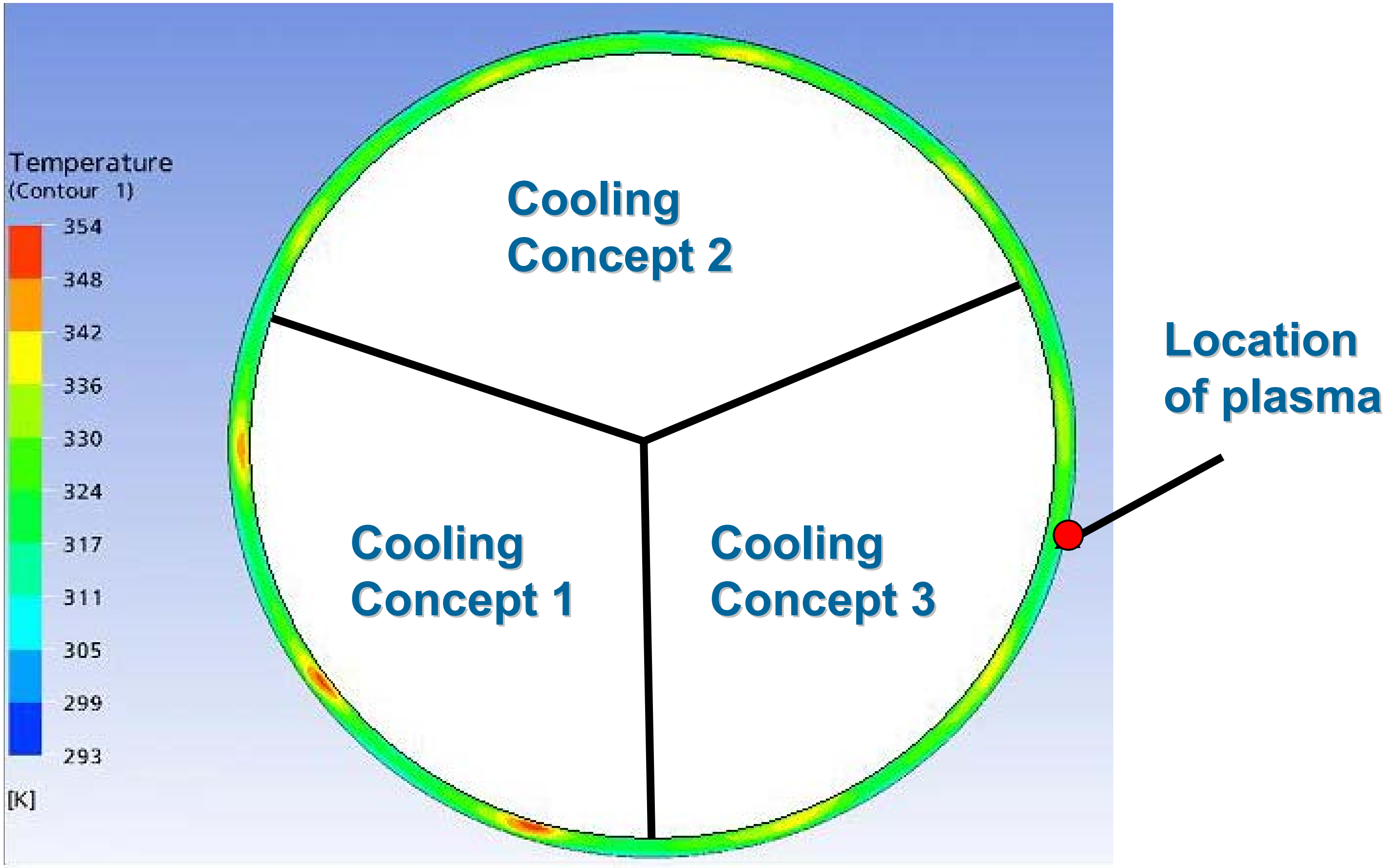
Distance to target nozzle: 75 mm
Droplet diameter: 130 µm
Spatial jitter: 16 µm

Laser Assisted Droplet RDE Source: Thermal simulation



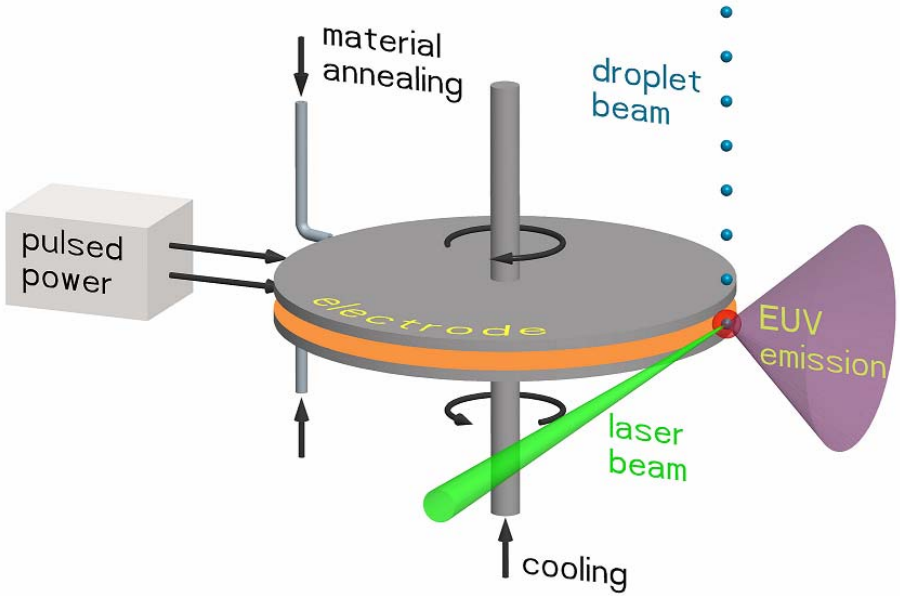
Energy deposition from the plasma into the rotating disk electrode

Laser Assisted Droplet RDE Source: Thermal simulation



FEM simulation of temperature of the laser assisted current RDE source for an input power of 75 kW and different cooling approaches

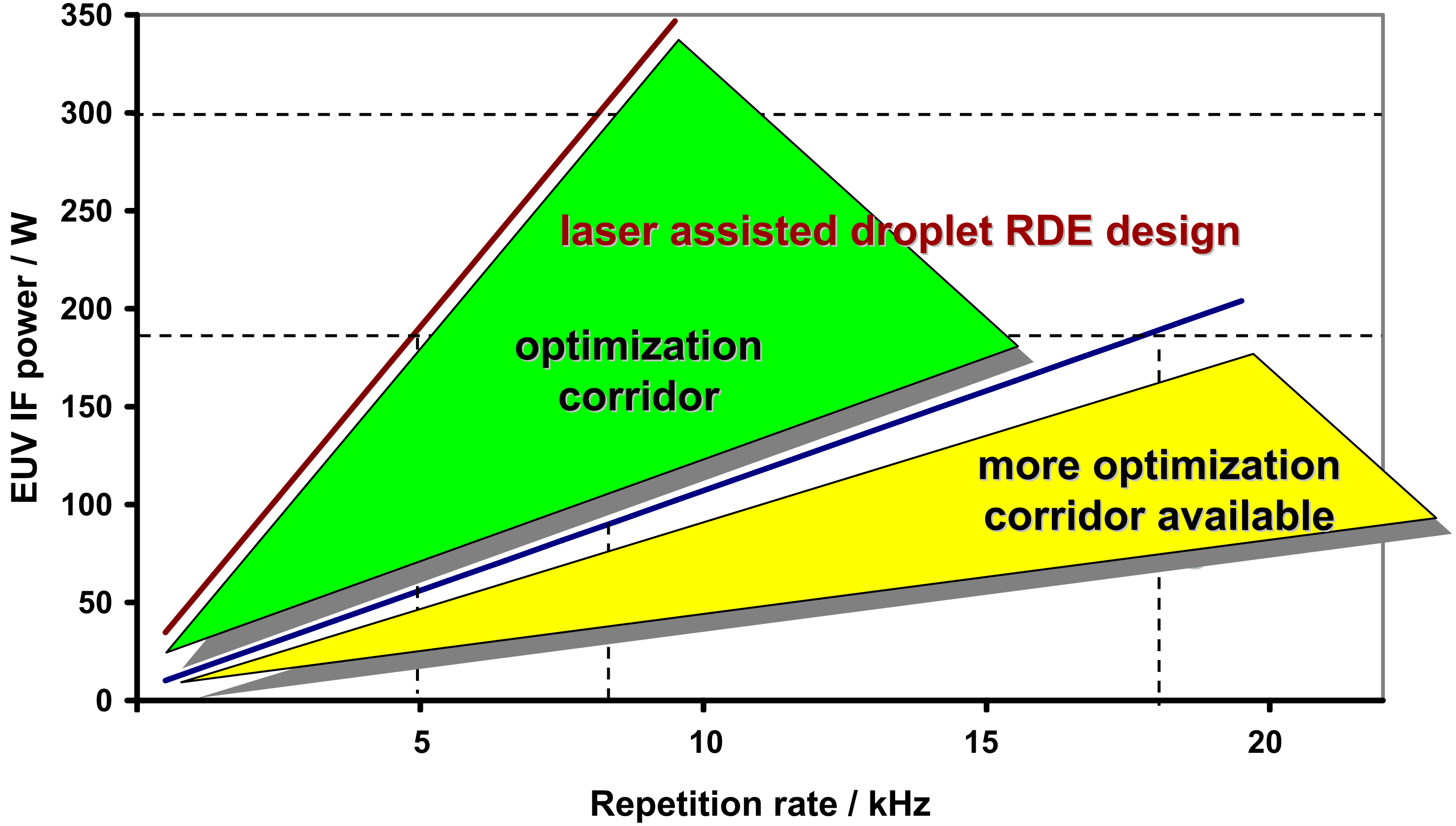
Laser Assisted Droplet RDE Source: Input power scaling



Current input power into the plasma: (limited by current cooling installation)	**10 kW**
Maximum input power with current design: (limited by repetition frequency of power supplies)	**50 kW**
Cooling capabilities with current design: (supported by FEM simulations)	**75 – 100 kW**

Heat removal of laser assisted RDE design scalable to above 100 kW

Laser Assisted Droplet RDE: Scaling potential over repetition rate



High pulse energy supports sufficient output power at reasonable repetition rates, higher repetition rates possible too

DPP EUV sources: Power status and HVM power roadmap

	Currently Status 10/2006	1st generation HVM	2nd generation HVM	3rd generation HVM
Electrical input energy into plasma (J)	> 6.7	4.5	4.2	4.9
Repetition frequency (kHz)	1.5	7	7	10
Power into plasma (kW)	> 10 (1)	31 (3)	29.4 (3)	49.0 (3)
Conversion efficiency (%)	2	2.5	3	3
Plasma Diameter ∅ (mm)	< 1	<1	< 1	< 1
EUV power (W/2π sr)	**> 200**	**780**	**880**	**1470**
Transmission of debris mitigation	0.8	0.8	0.8	0.8
Collection solid angle (sr/2π sr)	0.3	0.3	0.5	0.5
Average reflectivity of collector	0.63	0.63	0.6	0.6
Collection efficiency for point source (%)	18.9	18.9	30	30
Gas transmission in collector module	0.85	0.85	0.85	0.85
Intermediate focus power (W)	**28.9 (2)**	**100 (2)**	**180**	**300**

(1) in burst operation (2) calculated for existing collector mirror (3) 25 kW already realized continuously

Summary

Beta - tool sources

- Prototypes have been built based on xenon DPP sources
- IF power of > 10 W
- Collector sputtering has been stopped completely
- thermal heat extraction from electrodes of 25 kW already reached

HVM source development

- The new concept of
  laser assisted droplet RDE source
  has been tested experimentally
- Thermal management of
  RDE combined with droplet target supply
  supports the path to HVM
  (only 30 kW heat extraction are needed for 180 W IF power)