Collector Optics Integration Into Medium Power EUV Source Systems

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Outline

- **Objectives**
- **From electrical to EUV power at IF**
- **Collector's thermo-optical design**
- **Test stand and test equipment**
  - *Test objectives and conditions*
  - *Source test stand*
  - *Collector EUV reflectometer*
  - *Tests setup*
- **Test results**
  - *Power budget validation*
  - *Finite element model validation*
  - *Collection Efficiency validation*
  - *IF stability*
- **Conclusions and future work**

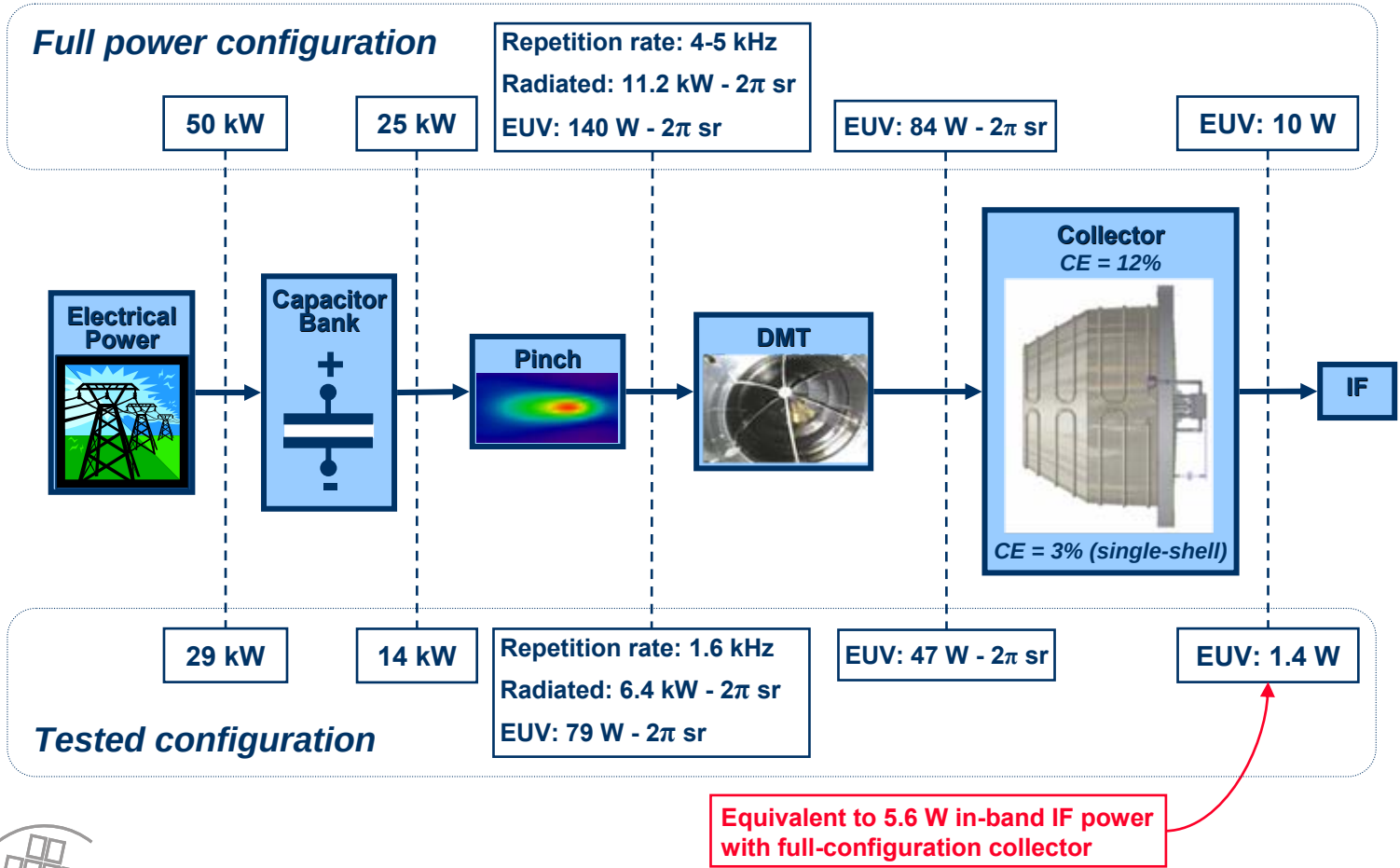
Objectives

- The dose uniformity requirements on wafer translate into tight spatial beam uniformity behind the IF plane, thus accurate control of all deformation effects caused by the high thermal load generated by the plasma source.

- Corresponding design challenges imply controlled cooling concepts for electrodes, debris mitigation system, and multi-shell collector.

- The verification of the overall source-DMT-collector module requires systematic experiments in combination with theoretical modeling.

From Electrical to EUV Power at IF



Collector Thermo-Optical Design

Assumptions / Data

Source Emission Data (2π sr)
- Total radiated power: 11.25 kW
- EUV radiation: 140 W
- Out-of-band radiation

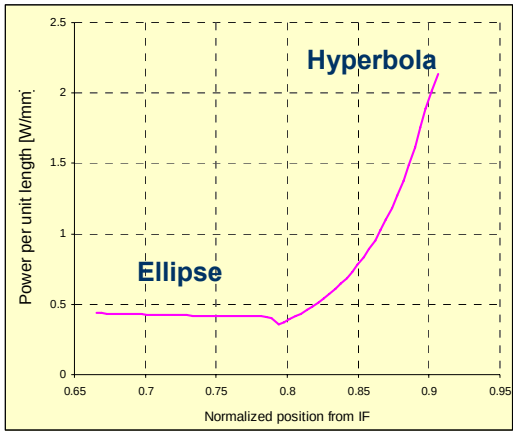
DMT assumptions
- Transmission
- Infrared radiation

Collector's optical design
- Collection angle
- Obscurations
- Equations of profiles

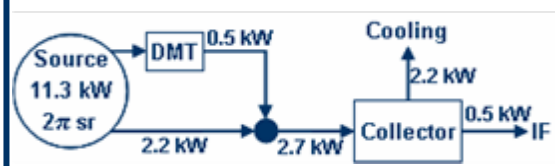
Reflectivity assumptions
- EUV ⇒ PVD Ru (measured)
- 9-20 nm ⇒ 80% of theoretical Ru
- 20-130 nm ⇒ 80% of theoretical Ru

Calculated Values

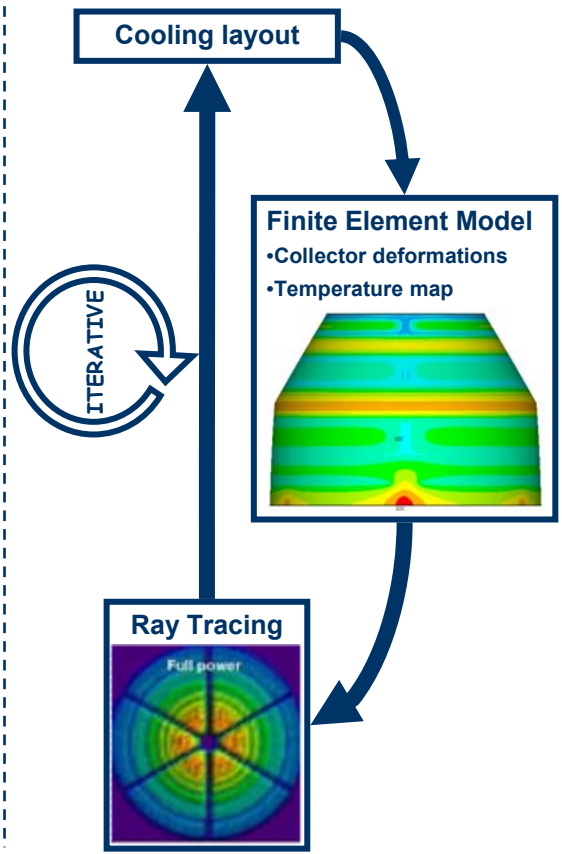
Absorbed Power Distribution on Shells



Power Budget



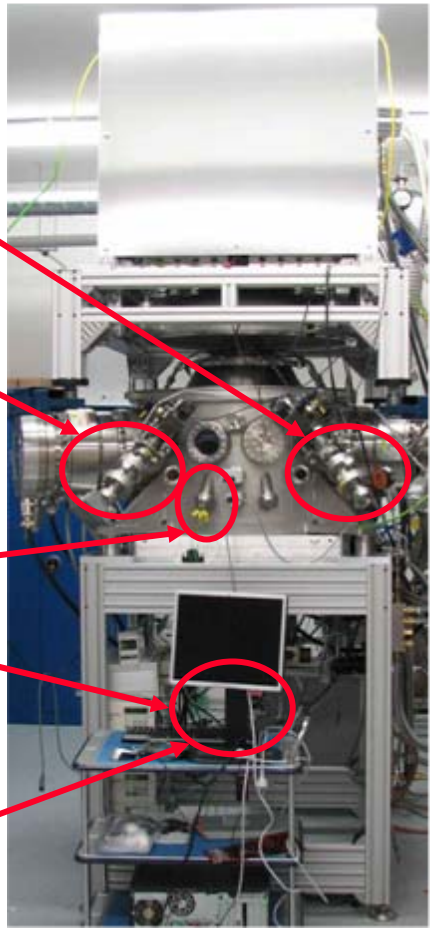
Thermo-optical simulation



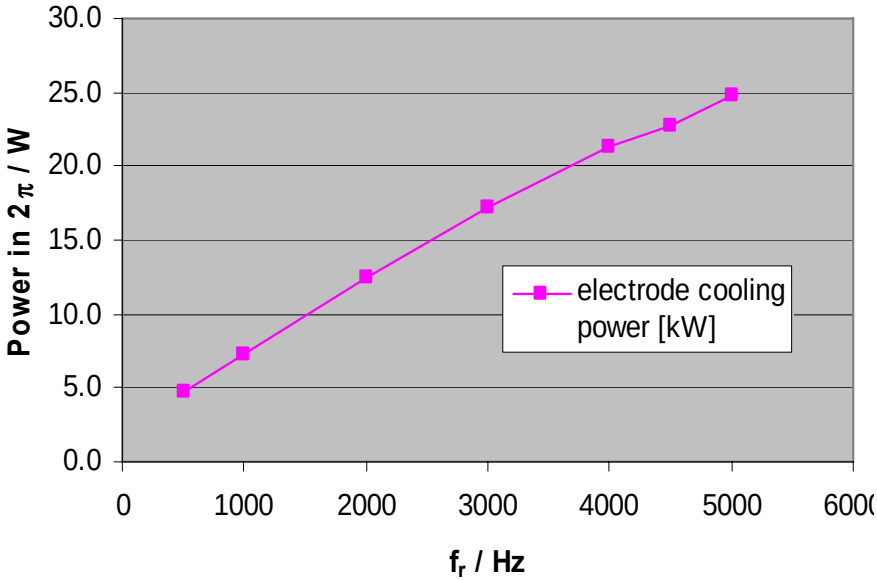
Test Objectives and Conditions

- **Quantification of DMT infrared radiation**
  - *DMT temperature measurements at 1.6 kHz repetition rate, steady state*
  - *No collector mounted*
- **Validation of the power budget and finite element model**
  - *Steady state operation at 1.6 kHz repetition rate for about 2 hours*
  - *Single shells collector with cooled obscuration disc*
    - Obscuration disc allows the integration of the single-shell collector with the production configuration DMT by blocking the radiation of the inner (missing) shells
- **Verification of the collection efficiency of the collector**
  - *Source test stand at low power, without DMT and IF aperture*
  - *Collector EUV reflectometer*
- **Verification of source-DMT-collector stability**
  - *Source test stand with DMT and IF aperture*
  - *Conversion screen located behind IF*

Source Test Stand

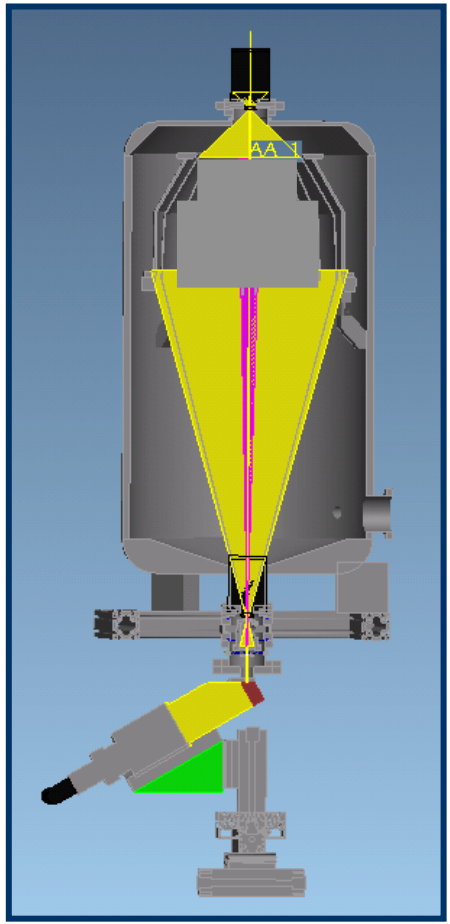


- **Source characterized up to:**
  - *5 kHz repetition rate*
  - *50 million pulses*
- **Electrode cooling power increasing almost linearly with repetition rate**
  - *25 kW at 5 kHz, 2.2 kV*
- **Overall satisfactory source thermal response**



Collector Reflectometer Description

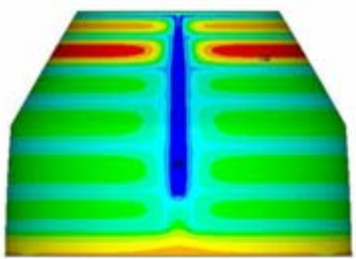
- **EUV source module**
  - *EUV tube (Phoenix EUV)*
  - *Silicon target used to produce stable (±0.5%) broadband EUV radiation*
  - *Zr filter to block UV and visible emissions*
  - *Schwarzschild objective to filter EUV in-band 13.5±1 nm radiation and to increase source NA to >0.25*
- **Detection system**
  - *XUV 16-bit back-illuminated CCD camera*
  - *Same detector used to measure input and output EUV energy*
- **Collection efficiency calculation**
  - *CE = (Et/ E0)· Ω0/2π*
- **Calibration**
  - *Gold coated, singe-shell collector used as reference*
  - *Initial data show good agreement, but further calibration is in progress*



Tests Setup

- Validation of the power budget and thermo-structural finite element model used in the design phase
- Verification of safe thermal operating window under medium and full power EUV exposure
- Verification of collection efficiency

1. Finite Element Analysis



2. 20 thermocouples installed in strategic locations

3. TC connections in vacuum

4. Connections in atmosphere

7. Datalogger reading

Steady state at 2000 Hz 1 - Notepad

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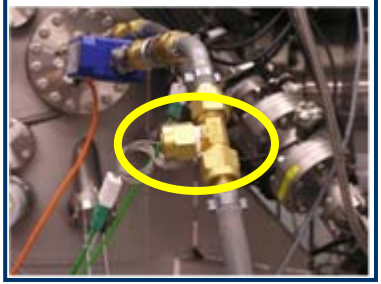
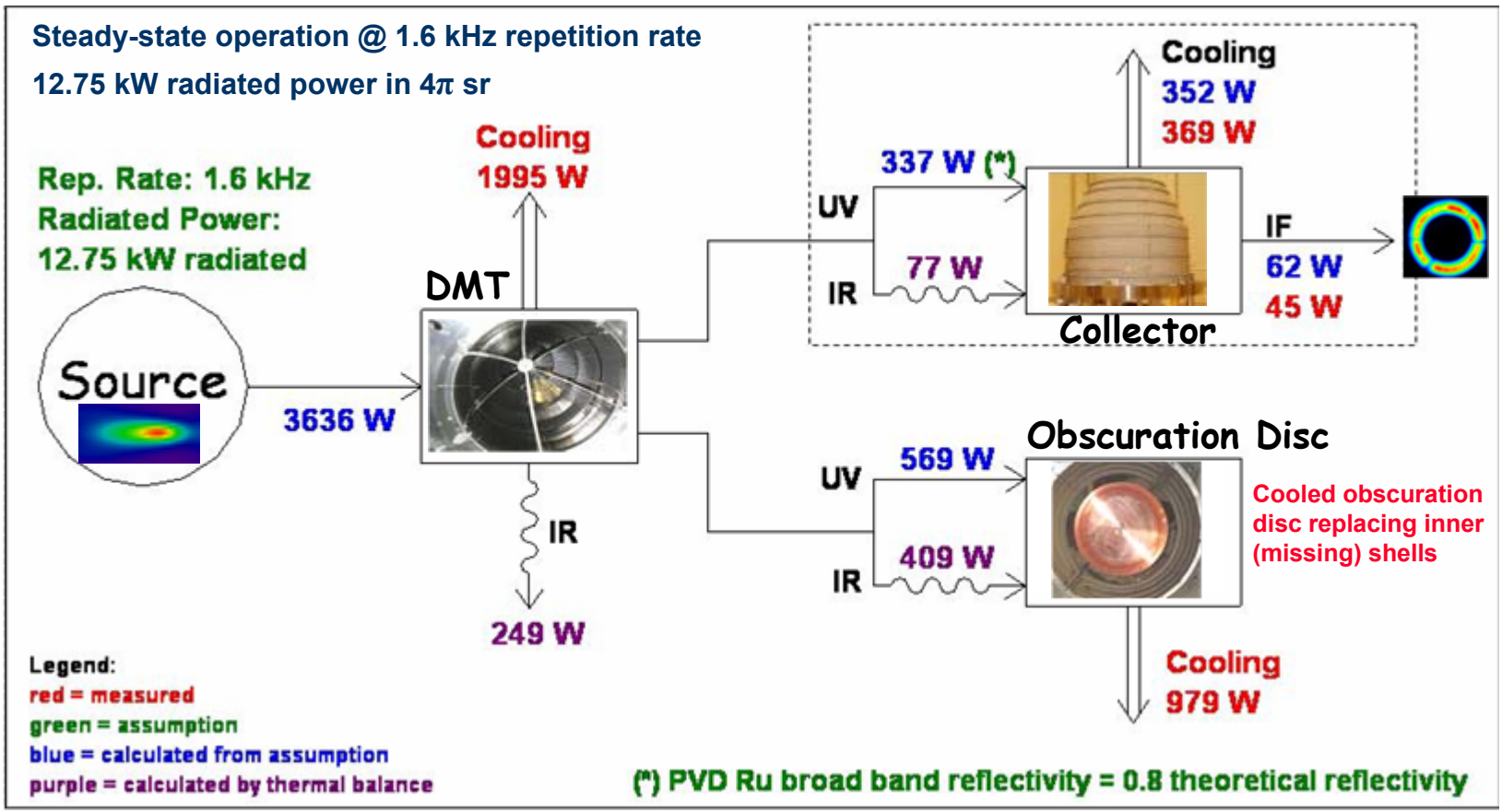
0	17.63	17.47	17.26	16.91	16.43	16.87	17.00	17.
500	17.63	17.47	17.26	16.91	16.43	16.87	17.00	17.
1000	17.64	17.47	17.25	16.91	16.43	16.87	17.00	17.
1500	17.64	17.47	17.25	16.91	16.43	16.87	17.00	17.
2000	17.63	17.46	17.25	16.92	16.43	16.87	16.99	17.
2500	17.63	17.46	17.25	16.92	16.43	16.87	16.99	17.
3000	17.63	17.46	17.25	16.91	16.43	16.87	17.00	17.
3500	17.63	17.46	17.25	16.91	16.43	16.87	17.00	17.
4000	17.64	17.47	17.26	16.92	16.42	16.87	16.99	17.
4500	17.64	17.47	17.26	16.92	16.42	16.87	16.99	17.
5000	17.63	17.47	17.26	16.92	16.43	16.87	16.99	17.
5500	17.63	17.47	17.26	16.92	16.43	16.87	16.99	17.
6000	17.63	17.47	17.25	16.91	16.43	16.87	16.99	17.
6500	17.63	17.47	17.25	16.91	16.43	16.87	16.99	17.
7000	17.62	17.47	17.26	16.92	16.42	16.87	16.99	17.
7500	17.62	17.47	17.26	16.92	16.42	16.87	16.99	17.

6. Flow meter

5. Thermocouples in the inlet and outlet flow



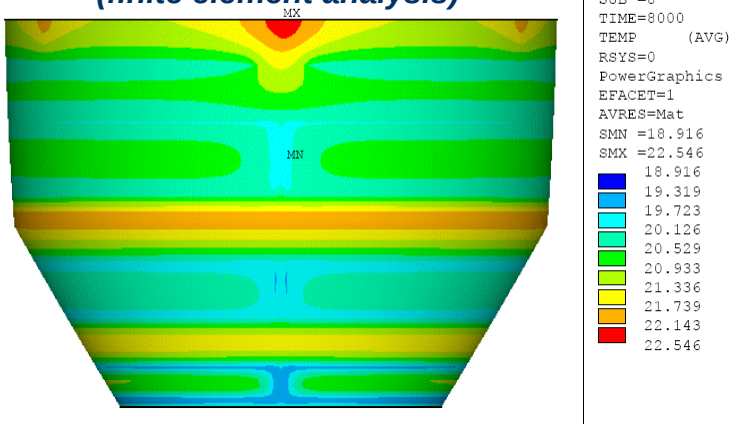
Power Budget Validation



Finite Element Model Validation

Steady-state operation @ 12.75 kW radiated power in 4π sr (1.6 kHz)

Predicted temperature map
(finite element analysis)



Sensor	Temperature [°C]	
	Analysis	Measured
T02	20.9	21.0
T03	20.9	21.0
T05	21.8	21.0
T06	21.3	21.0
T07	21.8	21.0
T08	21.3	21.0
T09	19.9	22.5

- Shell at thermal equilibrium ⇒ **370 W** heat load removed by cooling
- Temperature of the shell remains in the low 20°C range
- Temperature map in agreement with FEM prediction ⇒ FEM validated

COOLING IS EFFECTIVE AS PER DESIGN

Collection Efficiency Validation

- **Source test stand conditions**
  - *Low power*
  - *No DMT*
  - *No IF aperture*
  - *Source modeled from EUV camera image*
- **Collector EUV reflectometer**
  - *CE theoretical value based on point source*

Collection Efficiency Measurements	Source Test Stand		Collector Reflectometer	
	Measured	Calculated (1)	Measured	Calculated (2)
Single-Shell collector, Gold			2.37%	2.34%
Single-Shell collector, Galvanic Ru	3.72%	3.86%		
Single-Shell collector, PVD Ru	4.74%	5.18%		
Dual-Shell collector, PVD Ru			7.8-8.1%	9%
Full configuration collector, Galvanic and PVD Ru			16.4-17%	17.1%

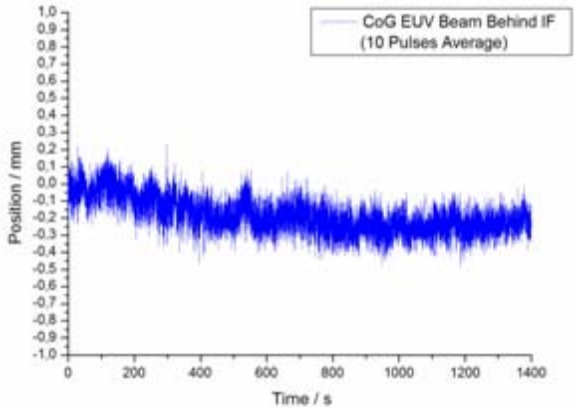
(1) Calculated value based on extended source model (Fitting Error = 2.83% - RMS)
(2) Calculated value based on point source

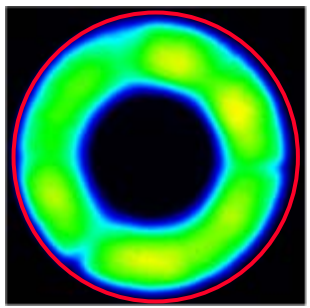
27% CE improvement with PVD Ru reflective coating

Verification of IF Stability

CoG stability

- Source-DMT-collector system shows 10-minute warm-up phase
- Initial CoG shift is approximately 0.2 mm calculated on a 50-mm extra focal image (0.4%)
- Stability of CoG after warm-up phase is 0.06 mm (1σ)

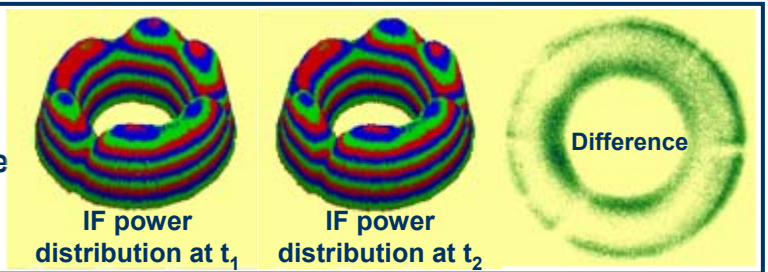




Diam. 50 mm

Thermal stability (IF power distribution)

- RMS variation after warm-up < 2%
- Good thermal stability of source-DMT-Colle system



Conclusions and Future Work

Conclusions

- **Cooled collector successfully tested for thermal load of 5.6 W in-band IF system**
  - *Experimental data show comfort level of meeting requirements of 10 W IF system*
- **Collection Efficiency validated by EUV optical measurements**
- **Integrated source-DMT-collector system meets the stability requirements**
- **Confirmed 20% *CE* improvement with PVD Ruthenium with respect to Galvanic Ru**

Future Work

- **Experimental test campaign ongoing under high power regime (10 W IF system)**
- **Full lifetime test at high power load to verify multi-billion pulses collector lifetime**
- **Extended measurements and simulations to evaluate far field characteristics**

Acknowledgements

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