Advanced LPP Architecture for an EUVL SoCoMo

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Executive summary

With proven optical, lifetime and thermal management performances, the Grazing Incidence Collector (GIC) reduces the EUVL Source Collector Module challenge and risk for HVM

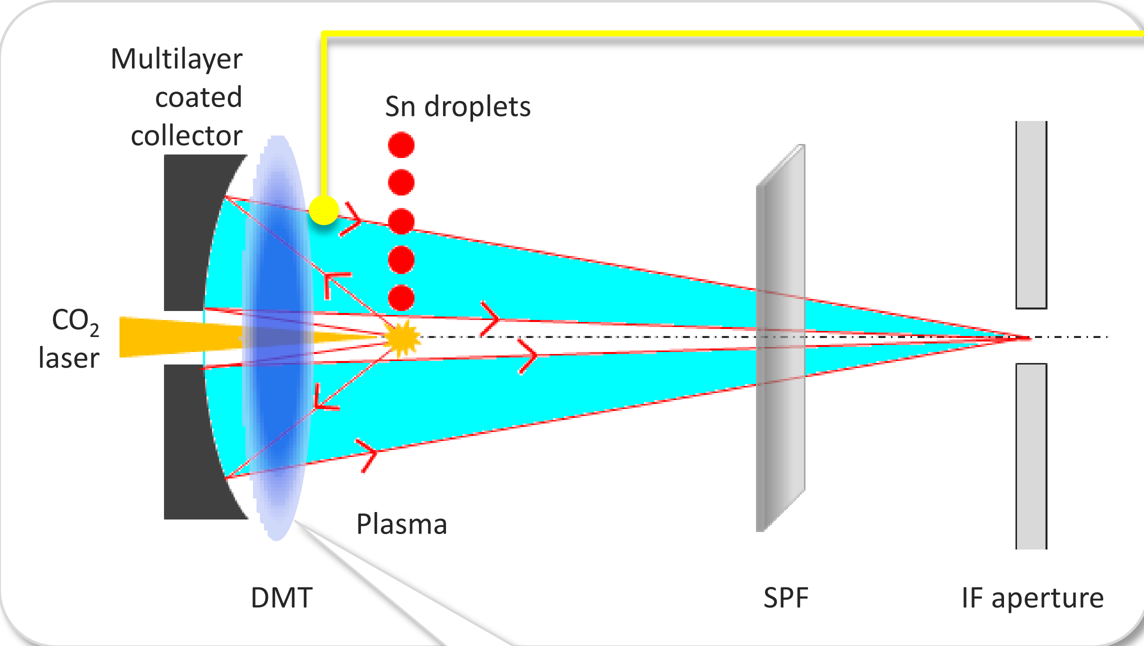
- In its current embodiment, the LPP architecture is overly constrained by the use of an “elegant” optical design
  - The multilayer coated collector creates a “double pass source” requirement that limits the spectrum of usable debris mitigation technologies
  - In this configuration, the need to protect the multilayer has constrained the plasma within the debris mitigation strategy
  - The multilayer lifetime challenge will be harder at HVM because it needs a debris-control that is 99.9999% effective
- EUVL adoption in HVM needs a new SoCoMo paradigm that eliminates the multilayer driven challenges and enables the full potential of LPP
  - Prioritize collector robustness over optical design elegance by integrating GIC into LPP as the low tech, least demanding, most reliable collector technology
  - Use the “unconstrained” LPP knobs to maximize EUV power and mitigate the reflected IR problem
- Our customers’ requirements have guided the development of GIC which has become the field proven enabler of DPP EUVL sources
  - With tailored optical designs and customized ruthenium coatings, our GIC’s have maximized the efficiency of diverse DPP and LDP sources
  - Media Lario’s manufacturing processes meet the optical performance requirements for HVM grazing incidence collectors
  - GIC >1-year lifetime has been field proven for the LDP source architecture
  - We have demonstrated GIC thermal management over to the full span of the source power roadmap, up to 500 W_{IF} peak power
    - With the Advanced Cooling Architecture, we have further increased and homogenized the heat transfer capability from optical surface to coolant
    - Tests on shell prototypes operated at 500 W_{IF} equivalent power demonstrate that ACA effectively minimizes thermal gradients across the shell to < 5 °C
    - We have also proven that ACA maintains this low-thermal-gradient performance also on larger shells
    - Low thermal gradients result in superior optical stability performance up to an equivalent 500 W_{IF} operation power (15 kW absorbed by GIC)

Contents

- The LPP challenge
- The LPP-GIC solution
- Proven GIC features

The multilayer coated collector creates the "double pass source" requirement that limits the choice of usable DMT options

Multilayer Reflector LPP SoCoMo



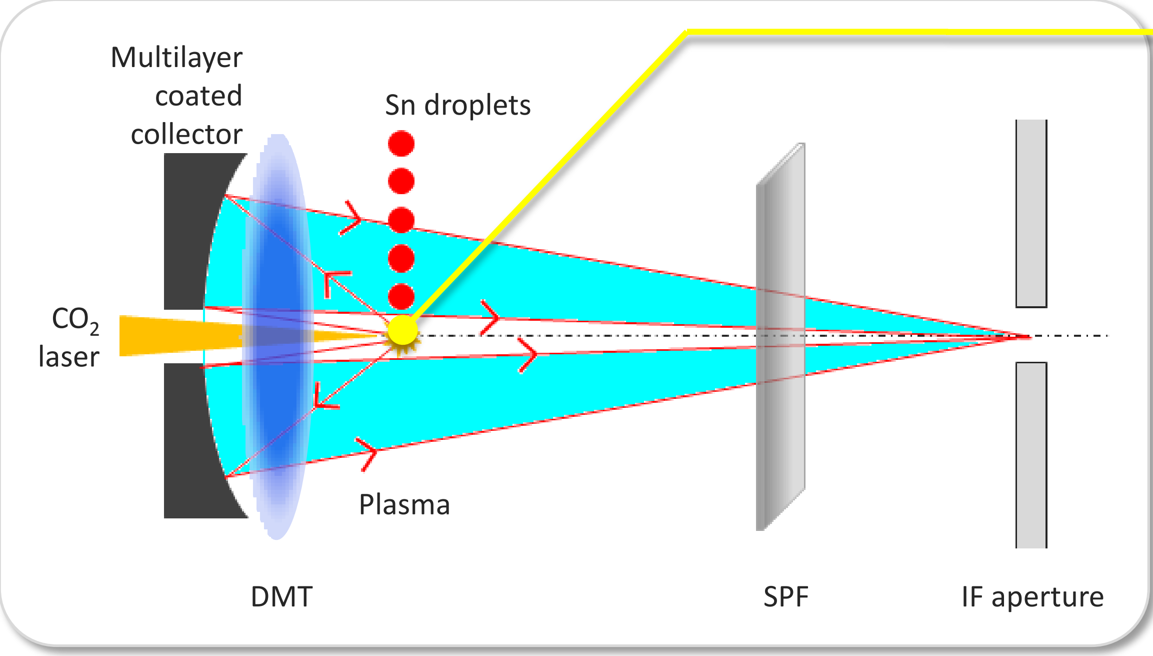
Requirement

"Double pass" of the EUV radiation through the source region

Only "soft" DMT options based on
- Gas
- Magnetic field

In this configuration, the need to protect the multilayer has constrained the plasma within the debris mitigation strategy

Multilayer Reflector LPP SoCoMo



Constraint

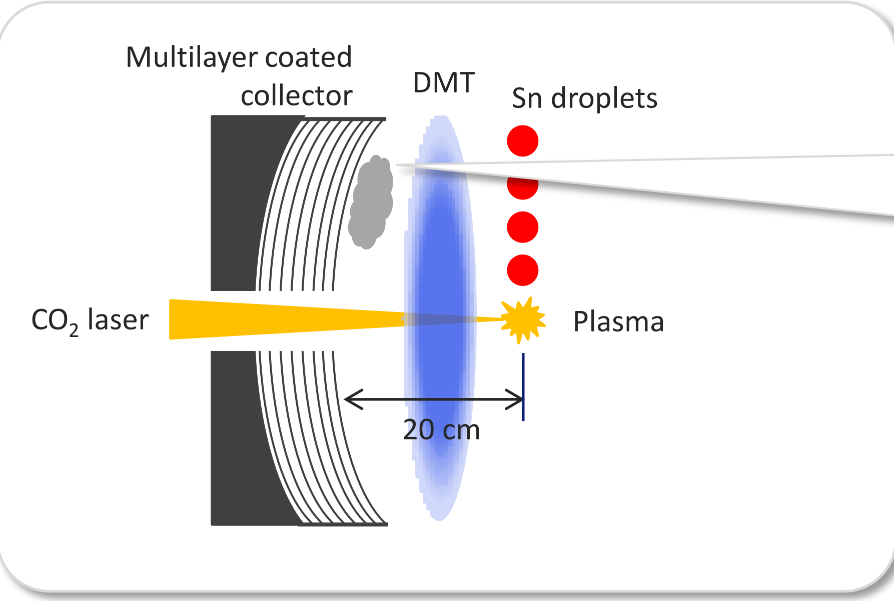
In order to minimize Sn debris, plasma has to be generated from mass limited targets

Resulting architectural complexity

- Droplet generator for mass limited targets (< 30 µm droplets)
- Synchronizations of two lasers with 30 µm droplets at very high rep rate (10^4 Hz for HVM)
- Complex and demanding debris mitigation systems
- SPF and/or other “innovative” developments to “disperse” reflected IR radiation

The multilayer lifetime challenge will be harder at HVM because it needs a debris-control that is 99.9999% effective

Multilayer Reflector LPP SoCoMo at HVM



Multilayer lifetime challenge at HVM

- 50% reflectivity drop caused by 5 nm Sn deposition
- 6 seconds to deposit 5 nm Sn

Assuming a 2-month collector lifetime requirement

DMT must be 99.9999% effective

EUVL adoption in HVM needs a new SoCoMo paradigm that eliminates the multilayer driven challenges and enables the full potential of LPP

1. Prioritize collector robustness over optical design elegance by integrating GIC into LPP as the low tech, least demanding, most reliable collector technology

2. GIC places virtually no demands on source, which can be as simple as it needs to be for enhanced reliability

3. Use the "unconstrained" LPP knobs to maximize EUV power and mitigate the reflected IR problem

Prioritize collector robustness over optical design elegance by integrating GIC into LPP as the low tech, least demanding, most reliable technology

Grazing Incidence Collector LPP SoCoMo

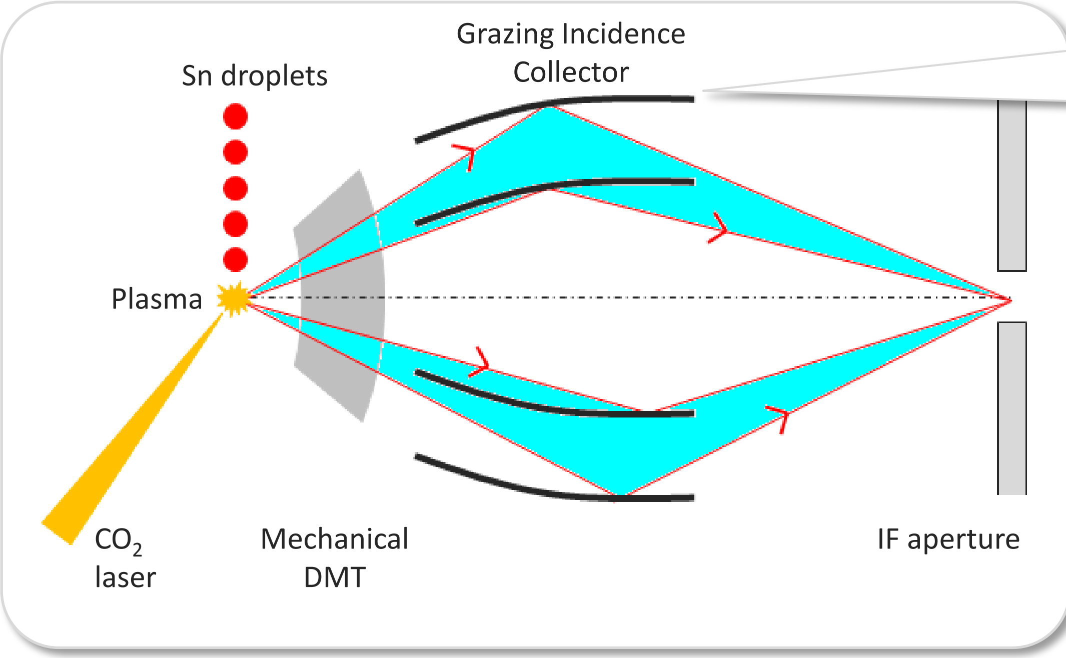


Figure of merit: Survival

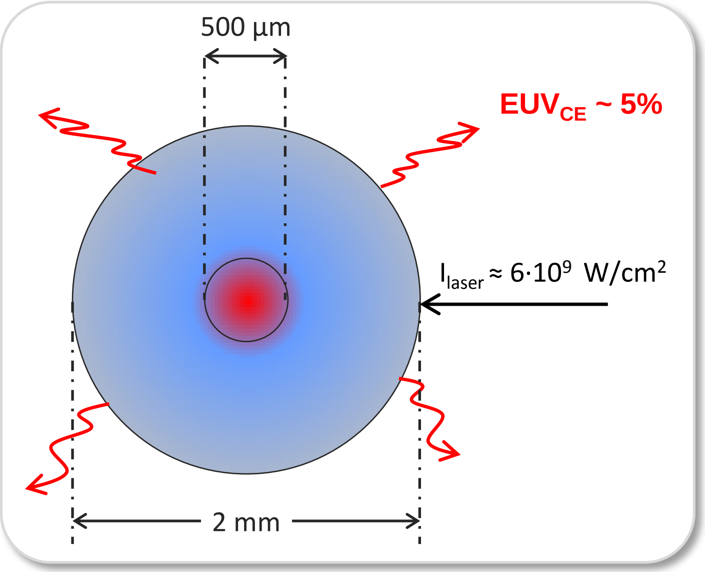
GIC is the low tech, least demanding, most reliable collector technology

Architectural solution features

- Simple and robust grazing incidence reflection mechanism
- Thermally managed GIC up to 500 W_{IF}
- Unidirectional light path (no “double-pass source” requirement) allows utilization of mechanical DMT
- GIC places virtually no demands on source, which can be made as simple as it needs to be for enhanced reliability

Use the "unconstrained" LPP knobs to maximize EUV power and mitigate the reflected IR problem

LPP sweet spot for the elimination of reflected IR and maximization of EUV efficiency*



Laser-target initial conditions

- Under dense: $N_{ion} \approx 0.05\ n_{critical}$
- Plasma ∅ = 2 mm
- Long scale length: IR absorption > 98%
- $I_{laser} \approx 6{\cdot}10^9$ W/cm^2

EUV Performance

- Conversion Efficiency ≈ 5%
- EUV source ∅ ≈ 500 µm
- EUV opacity ≈ 10% (i.e. 90% transmission)
- IR reflection ≈ small ($n_e < n_{critical}$)

* Simulated results of sub-critical mass plasma target

Our customers' requirements have guided the development of GIC which has become the field proven enabler of DPP EUVL sources

The LPP challenge

The LPP-GIC solution

Proven GIC features

Optical performance

Lifetime

Thermal management

2005

Galvanic → PVD Ru
500 W cooling
Sn-DPP source proto


PHILIPS

2006

PVD Ru
1 kW cooling
Sn-DPP source
ADT (ASML)

PHILIPS ASML

2007

PVD Ru
3 kW cooling
Xe-DPP source
EUV1 (Nikon)

XTREME Nikon Selete

2008

Galvanic Ru
Xe-DPP source
SFET (Canon)

XTREME Canon EIDEC Selete

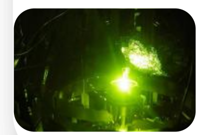
2010

PVD Ru
6 kW cooling
Sn-DPP source
NXE3100 (ASML)

XTREME ASML imec

2012

Collector proto
PVD Ru
15 kW cooling (500W_{IF})



Media Lario Technologies

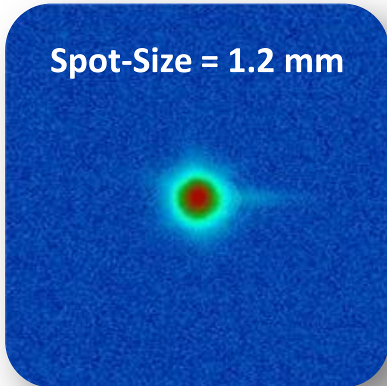
With tailored optical designs and customized ruthenium coatings, our GIC's have maximized the efficiency of diverse DPP and LDP sources

		Collection solid angle	Collection efficiency
SFET		1.7 sr	13%
ADT		1.6 sr	14%
EUV1		2 sr	17%
NXE:3100		3.7 sr	25%

Media Lario's manufacturing processes meet the optical performance requirements for HVM grazing incidence collectors

Experimental visible light optical measurements of a 2-shell HVM collector prototype

Image at intermediate focal plane



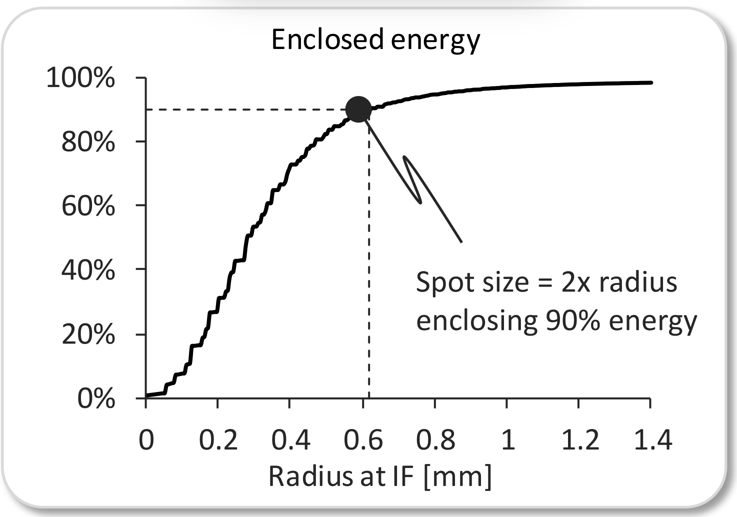
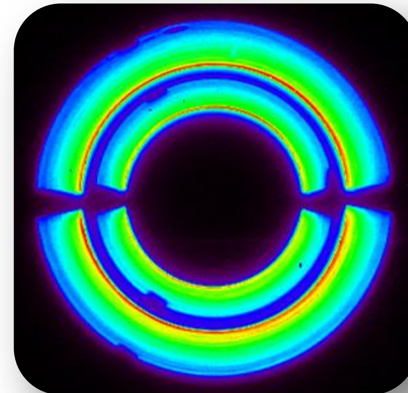
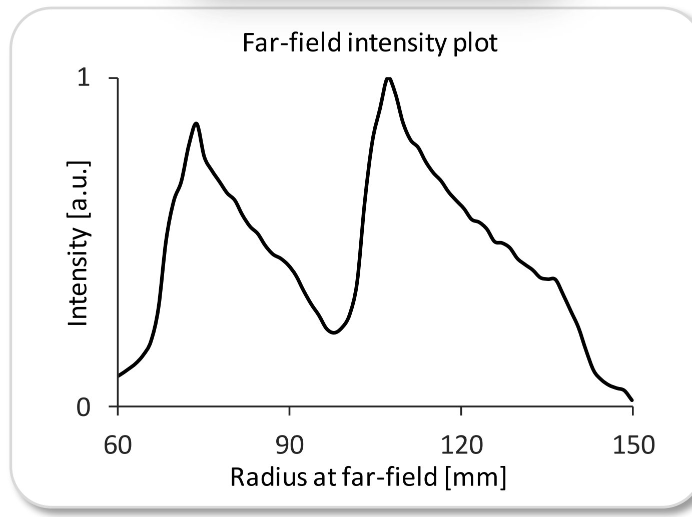


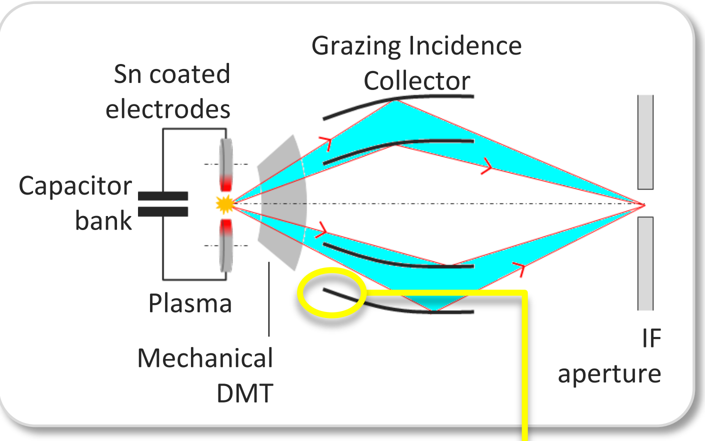
Image at far-field plane (1 m past IF)



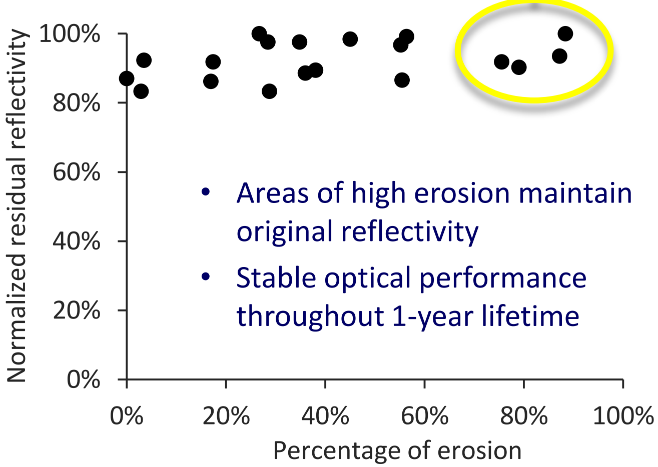


GIC >1-year lifetime has been field proven for the LDP source architecture

Grazing Incidence Collector LDP SoCoMo



Reflectivity / lifetime measurements



- Tolerance of Ruthenium layer to erosion experimentally characterized on Sn-LDP source prototype
- Several GICs operated in ADT at IMEC and Albany since 2007 with >1-year lifetime
- GICs operated in NXE:3100 at IMEC since 2010
- 1-year projected lifetime at HVM operation

We have demonstrated GIC thermal management over to the full span of the source power roadmap, up to 500 W_{IF} peak power

The LPP challenge

The LPP-GIC solution

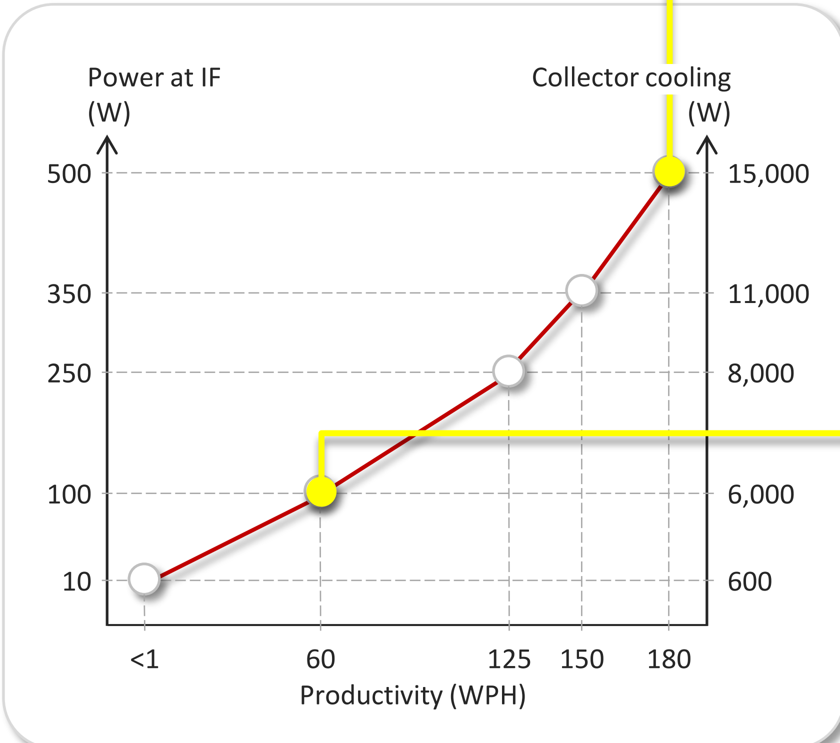
Proven GIC features

Optical performance

Lifetime

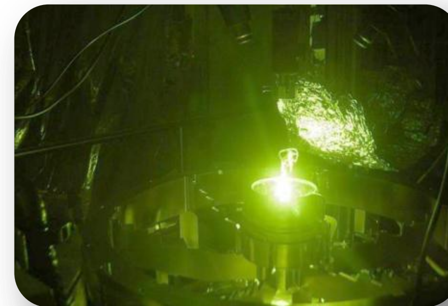
Thermal management

Collector cooling as a function of source power and scanner throughput (illustrative)



Advanced Cooling Architecture (ACA) prototype

- 6% far-field stability (RMS) at 500 W_{IF} power



Mirror Cooling Assembly (MCA) installed in NXE:3100

- Shell integrated cooling lines
- 6% far-field stability (RMS) at 100 W_{IF} power

With the Advanced Cooling Architecture, we have further increased and homogenized the heat transfer capability from optical surface to coolant

The LPP challenge

The LPP-GIC solution

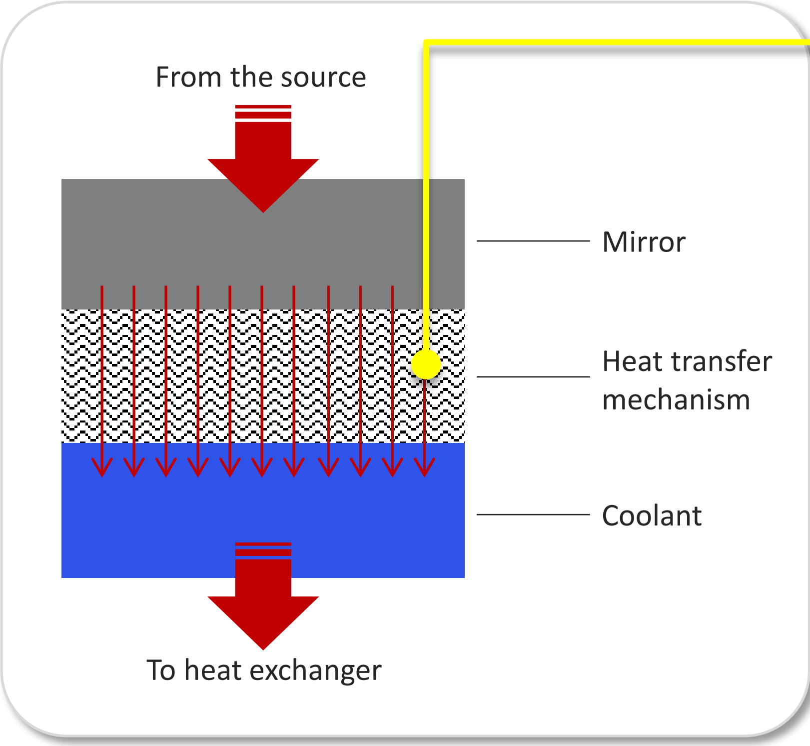
Proven GIC features

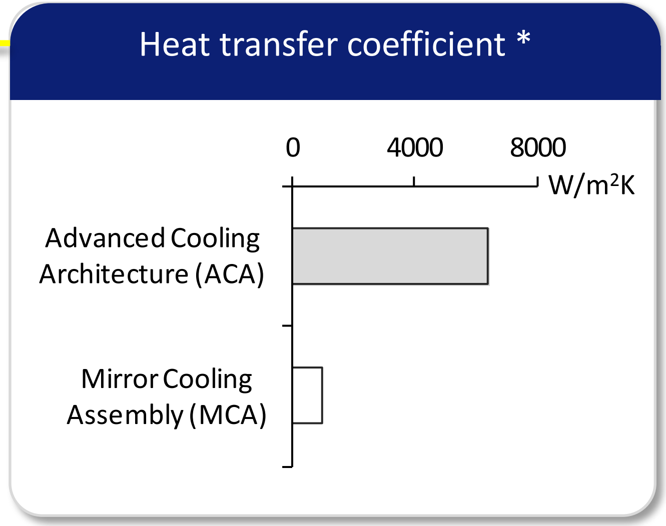
Optical performance

Lifetime

Thermal management

Heat transfer concept in a cooled mirror

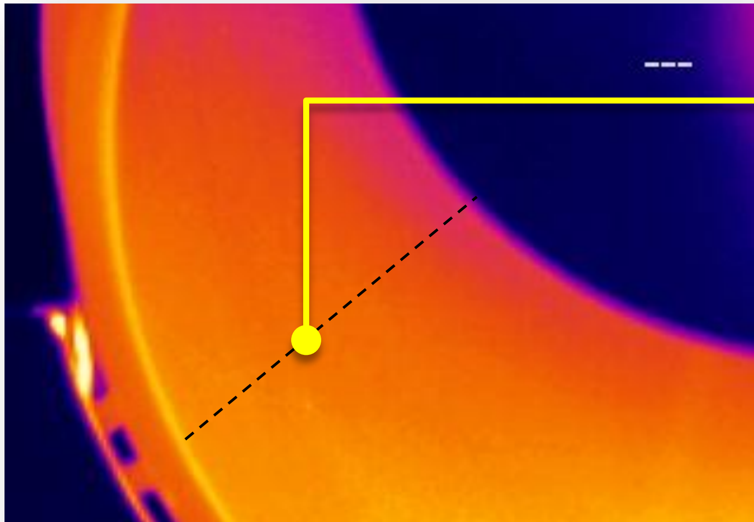




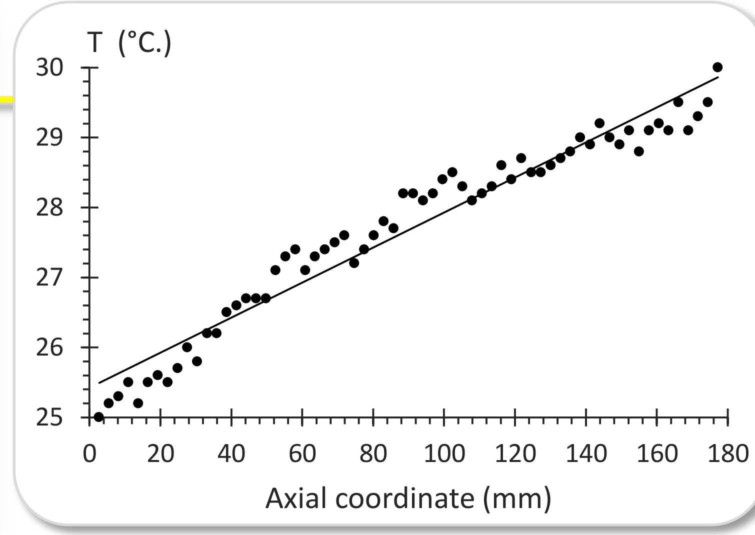
* Experimental measurement on ACA cooling sample

Tests on shell prototype operated at > 500 W_{IF} equivalent power prove that ACA effectively minimizes thermal gradients across the shell to <5°C

Thermal image of optical surface of the shell operated at > 500 W_{IF} equivalent power *



Temperature profile of optical surface of shell



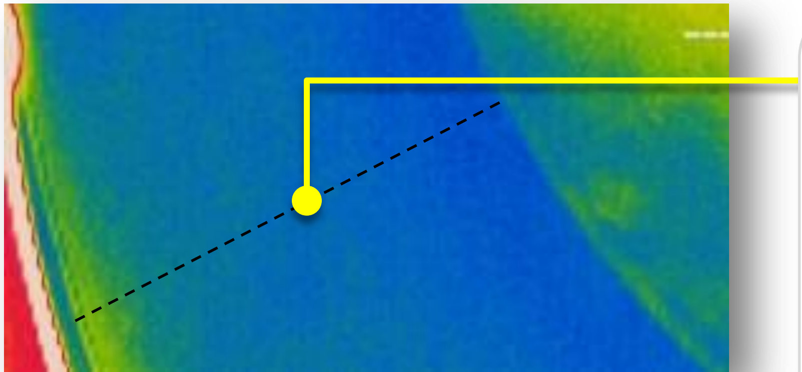
- Temperature gradient across shell < 5 °C
- No print-through of cooling structure

* Test conditions

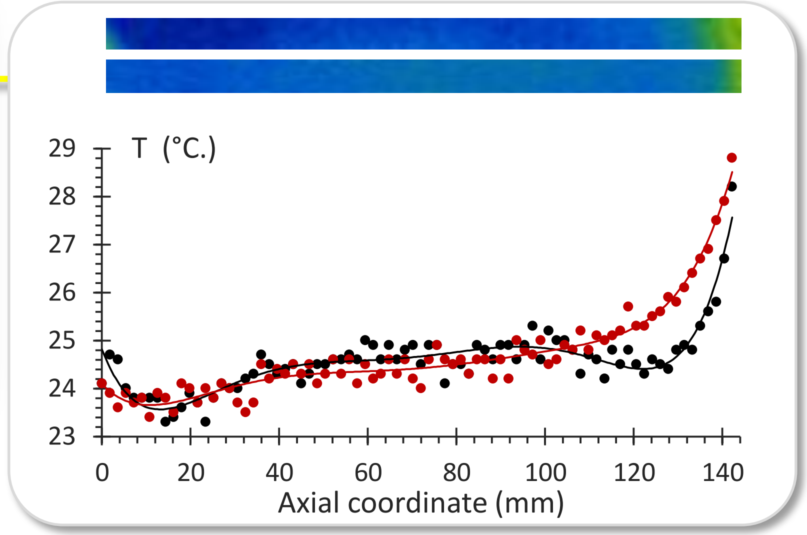
- ACA shell prototype (∅ 140 mm x L 180 mm) with IR lamp mounted on optical axis
- Water flow = 12 l/min; ΔT_{WATER} = 2.5 °C; Absorbed power = 2 kW (equivalent to > 500 W_{IF} operation)

We have also proven that ACA maintains this low-thermal-gradient performance also on larger shells

Thermal image of optical surface of the shell operated at 500 W_{IF} equivalent power *



Temperature profiles of the optical surface of the shell at 120° apart azimuthal positions



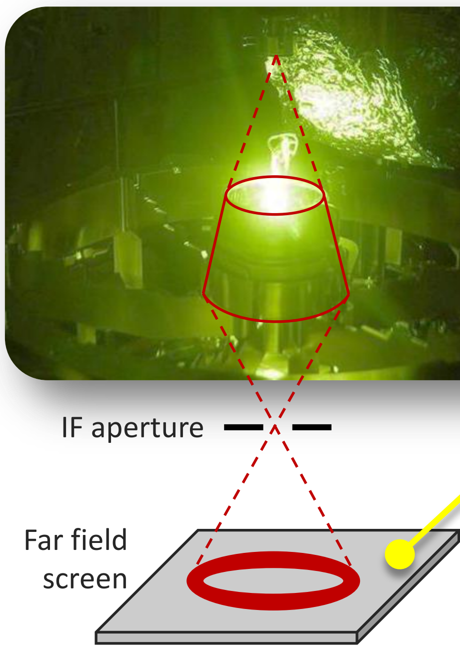
- Temperature profile gradient across shell < 5 °C
- Temperature gradient in azimuth direction < 1°C
- No print-through of cooling structure

* Test conditions

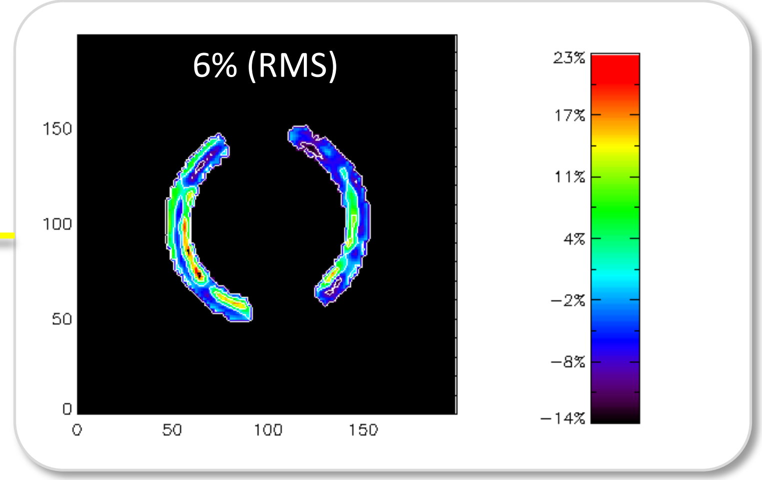
- ACA shell prototype (∅ 330 mm x L 140 mm) with IR lamp mounted on optical axis
- Water flow = 14 l/min; ΔT_{WATER} = 1.8 °C; Absorbed power = 1.8 kW (equivalent to 500 W_{IF} operation)

Low thermal gradients result in superior optical stability performance up to an equivalent 500 W_{IF} operation power (15 kW absorbed by GIC)

Experimental setup of thermo-optical tests on ACA prototype operated at 500 W_{IF} equivalent power *



Far-field optical stability



- 6% optical stability (RMS) at far-field

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* Test conditions

- ACA shell prototype (∅ 140 mm x L 140 mm) with IR lamp mounted on optical axis
- Water flow = 15 l/min; ΔT_{WATER} = 0.8 °C; Absorbed power = 0.8 kW (equivalent to 500 W_{IF} operation)

Summary

1. In its current embodiment, the LPP architecture is overly constrained by the need to protect the multilayer

2. The LPP-GIC architecture eliminates the multilayer driven challenges and enables the full potential of LPP, thus reducing the risk towards EUVL adoption at HVM

3. GIC is the low tech, least demanding, most reliable collector technology with proven optical, lifetime, and thermal management performance for HVM