The Strongly Multiplexed Micro Plasma Pulse EUV Source Concept


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• EPPRA has demonstrated for the first time a high frequency photon collection and projection device based on a plasma structure.* The device is inherently damage resistant.

• The collimating structure demonstrates optical properties with equivalent focal point and enhanced photon delivery. The collimator designs can be tailored to provide different focal properties.

• This opens up the possibility of developing strongly multiplexed EUV source structure operating at > 10 kHz and delivering clean photons at the IF with a power level above 200 W in band power.

* WO2005038822- “PLASMA SOURCE OF DIRECTED BEAMS AND APPLICATION THEREOF TO MICROLITHOGRAPHY”
Collimator Performance

- Use Scanning Slit to measure illumination profile at given distance $Z$ from exit plane of collimator
- Slit scanned in X axis, orthogonal to Z axis
- Slit size 160 $\mu$m width, 5 mm height effective
- Use AXUV100 diode behind slit to measure radiation signal
- EUV band filter (Zr, 0.25 $\mu$m) mounted in front of diode
Collimator B Performance

- Collection efficiency > 1000 measured at 50 cm from source in 7-16 nm band at 2 kHz
- focal properties measured using 160 µm scanning slit over Zr filtered AXUV diode
- etendue at collimator exit (1st focus) ≈ 1e-3 mm²sr
- operating in admixture of 5 mTorr He and 0.2 mTorr Ar

\[ \text{angle} = \tan^{-1}(2.0/163) = 0.703 \text{ degree} \]

\[ \text{solid angle} = 4.72 \times 10^{-4} \text{ steradian} \]
Collimator C Performance

- Longer focal length structure developed
- focal properties measured using 160 μm scanning slit over Zr filtered AXUV diode
- larger focal spot size
- smaller etendue

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<thead>
<tr>
<th></th>
<th>Collimator B</th>
<th>Collimator C</th>
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<tbody>
<tr>
<td>FWHM measured (mm)</td>
<td>1.0 @ 50 mm</td>
<td>2.36 @ 200 mm</td>
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<tr>
<td>Source diameter = (2/ln2)^{1/2}.FWHM</td>
<td>1.70</td>
<td>4.01</td>
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<tr>
<td>Radiation half angle measured (deg)</td>
<td>0.703</td>
<td>0.258</td>
</tr>
<tr>
<td>Radiation solid angle (sr)</td>
<td>4.72*10^{-4}</td>
<td>6.36*10^{-5}</td>
</tr>
<tr>
<td>Etendue (mm^2.sr)</td>
<td>1.07*10^{-3}</td>
<td>8.03*10^{-4}</td>
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Collimator Performance

- Double ML spectrometer to provide inband imaging
- 400 µm scanning slit over Zr filtered AXUV diode to measure inband beam profile
- Narrower inband profile compared with EUV signal

Inband radiation at 330 mm optical path from collimator exit

EUV band (Zr filter) radiation at entrance to spectrometer, at 130 mm from collimator exit
Collimator Performance

- MPP radiation shows first collimation through dense plasma shell of pinch
- strong dependence on operating pressure gradient and energy input rate
- agreement with 3-D pinch compression demonstrated in Z*BME™ simulation

![EUV Emission from MPP at 470mm](image)

- *1.6 mm \( \phi \) 16 mm length alumina capillary
- 150 mJ stored energy
EUV Source Performance

3 kHz sustained operation

- MPP source lifetime exceeds $10^9$ discharges
- EUV radiation output shows long term stability without feedback control
- Feedback control through operating voltage possible
- Primary failure mechanism due to erosion of hollow cathode
- Alumina capillary not a limiting factor
MPP Source Roadmap

current activities

- Stored energy scale up from 40 mJ stored to 250 mJ
- Evaluate vacuum compatible electrical design
- Operating parametric scan
- Evaluate radiative cooling assisted compression
- Continue HCD optimization
- Evaluate electrode cooling issues and lifetime at higher operating power (> 1kW)
Collimator Roadmap

current activities

• Firm up design for 4 units MMPP evaluation
• Evaluate collimator properties at higher source power
• Continue collimator development
• Target 200 µJ inband delivered to first focal point
• Evaluate limitation of current design
Multiplexed MPP EUV Source

- Individual source running at 3 kHz
- Sequential operation for 12 kHz output
- Collimator provides photon collection and debris mitigation
- Vacuum compatible source design completed
Multiplexed MPP EUV HVM Source - HYDRA 60

60 units, 20 kHz design

• Individual source running at 5 kHz to provide 5 W out of collimator (1 mJ inband/pulse) at an input power of 8 kW
• 3.5 W projected to intermediate focus (0.7 ML transmission)
• single MoSi planar ML to redirect the beam to the IF
• gas column to provide long wavelength DUV filtering
• 12 source units to form 1 group with 42 W to IF
• sequential operation of 5 groups for 20 kHz (20% duty cycle)
• 210 W of inband available at entrance to PO Box from all units
Beam Steering & Wavelength Selection

ML collector assembly

Incident beam profile

Plan view
Multiplexed MPP EUV HVM Source - HYDRA 60

facts & figures

- Total electrical input of 480 kW
- Electrical energy to each source 8 kW @ 5 kHz
- Total anode surface area for thermal loading > 200 cm²
- Combined etendue from 60 sources, after wastage, is below 0.3 mm².ster.
- Failure of an individual source would not effect a shut down
- Sequential operation (20% duty cycle) overcomes problem with high frequency (>10 kHz) operation
- Radiation beam profiling in time and space possible to match downstream requirements
- Scalable HVM performance at an affordable cost
Acknowledgement

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