Electrodeless Z-Pinch™ EUV Source for Metrology Applications for Today and Future

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Agenda

- Background on the EQ-10 Electrodeless Z-Pinch™ EUV source
- Characteristics of the EUV source
- Initial experiments for 6.7nm
EQ-10 Source

- Introduced in 2005
- 13.5nm ±1% Power in $2\pi$
  - 10W continuously
  - Now 20W
  - @2 kHz
- 10kHz operation also
- Operates continuously for days and weeks
**Detailed Operation:**

**Electrodeless Z-Pinch™ EUV Source**

- ‘Slow’ pulse from modulator
- Capacitor banks charge up
- Switch core saturates. Impedance $\Rightarrow 0$
- Capacitor discharges. (Pulse compression)
- Inner core couples current pulse to plasma loops.
- Pulse in plasma current $\Rightarrow$ Z-pinch!

![Diagram showing the operation of an Electrodeless Z-Pinch EUV Source](image)
System Reliability

- Shipped over 22 sources in the field
  - 4 High Brightness Sources already shipped
- Installations in Japan, Europe and US
- Systems being operated 24/7 with minimal downtime
- Systems integrated into tools for research and development
  - Actinic Inspection
  - Resist Outgassing
  - Mask Contamination
  - Optics Testing
Sample of Current Installations

EUV Technology Outgassing Tool Installed at IMEC

Flood Exposure system installed at Osaka University (Tagawa Lab)

Actinic Mask Inspection Tool at EIDEC

LithoTech Outgassing Tool installed at EIDEC
Recent Improvements in EQ-10 Brightness and Power
EQ-10 Product Family

EQ-10
- High-Reliability, High-Stability
- 10Watt EUV Source for EUV R&D

EQ-10HP
- High-Brightness 20Watt EUV Source for Metrology and Testing

EQ-10SXR
- Soft X-Ray Source for Water-Window Microscopy and 6.7nm R&D

EQ-10HR
- High Repetition-Rate EUV Source for Accelerated Optics Testing
Actinic Mask Inspection/ Metrology

- Actinic Blank Inspection, AIMs and Patterned Mask Inspection are critical to the success of EUV lithography
- Major OEMs are being funded and have programs for development of these tools
  - Funding by both Sematech EMI and EIDEC (Japan)
- There is no commercial source on the market to meet the “production” needs for these tools
- Minimum brightness specifications are 10 W/mm^2-sr for Prototype tools
**EQ-10HP Overview**

- Based on standard EQ-10 High Reliability Source
  - Utilizes new better cooling bore design
  - Improved modulator

- Design allows for up to 7kW input power
  - Improved cooling of source and modulator

- Specifications
  - >20 W of 13.5nm ±1% Power in 2π
  - ~8 W/mm^2-sr brightness
EQ-10HP EUV Power vs. Pressure

Power at 13.5 nm
Spectrally Corrected

- 300V 2200Hz
- 320V 2200Hz
- 340V 2000Hz
Optimizing Brightness with Power and Pressure

![Graph showing brightness vs. pressure]
Stability in EUV Plasma Position

- Image recorded once an hour for over 300 million pulses (~44 hours) of continuous operation. Position then extracted from images:
  - Position: $\sigma_x = 5.8 \, \mu m$ and $\sigma_y = 5.0 \, \mu m$

- Brightness remains constant
- This is open-loop stability: No feedback!
Stability in EUV Plasma Size

- Image recorded once an hour for over 300 million pulses (~44 hours) of continuous operation. Size then extracted from images:
  - Size: $\sigma_{\text{FWHM}_x} = 3.1 \, \mu m$ and $\sigma_{\text{FWHM}_y} = 3.6 \, \mu m$

- Brightness Remains Constant
- This is open-loop stability: No feedback!
EQ-10 for 6.7 nm for Resist Development
Selection of gas:

- NIST spectral database used;  
  [http://physics.nist.gov/PhysRefData/ASD/lines_form.html](http://physics.nist.gov/PhysRefData/ASD/lines_form.html)

- Search for lines with high relative intensity: The only gas which appears is Neon

<table>
<thead>
<tr>
<th>Ion</th>
<th>Observed Wavelength Vac (nm)</th>
<th>Rel. Int. (?)</th>
<th>$A_{ki}$ (s$^{-1}$)</th>
<th>Ac c.</th>
<th>$E_i$ (eV)</th>
<th>$E_k$ (eV)</th>
<th>Configurations</th>
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<tr>
<td>Ne VIII</td>
<td>6.5822</td>
<td>1000</td>
<td>3.50e+10</td>
<td>B</td>
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<td>1500$^*$</td>
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<td>-</td>
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<tr>
<td>Ne VIII</td>
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<td>1500$^*$</td>
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<td>0.0000</td>
<td>-</td>
<td>[183.9816] 1s$^2$2s - 1s$^2$4p</td>
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Diagnostic:

- Near-normal incidence ML Mirror
- AXUV100 Diode
- Dual Zr Foil
- Pumped Beam-Line
- Neon Plasma
- 1 cm Aperture
- Pump Port
**Diagnostic: Mirror**

- In-band measurement via custom mirror. Fwhm 0.75% (very narrow)

<table>
<thead>
<tr>
<th>R(peak), %</th>
<th>CWHM, nm</th>
<th>Lpeak, nm</th>
<th>FWHM, nm</th>
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<td>44.31</td>
<td>6.754</td>
<td>6.755</td>
<td>0.051</td>
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*Mirror made by Rigaku*
Foils: use Zr...

Zr Density=6.506 Thickness=0.2 microns

- Transmission at 6.7382 nm ~ 0.48
- On grid (82% transmission)
- Net transmission ~ 0.39
Zr has a problem at low energy...

- Need to check mirror reflectivity at low energy...~ 10%. Neon has many strong lines here. So need additional filtering....

Zr Density=6.506 Thickness=0.2 microns
**Gas filtering...**

- Argon works well. \( \sim 10^{-10} \) transmission 40-60 nm

- Transmission at 6.7 nm \( \sim 54\% \). (Neon also was used...)

\[ \text{Ar Pressure}=0.4 \text{ Path}=80. \text{ cm} \]
## Results:

Measurement with Ar filter gives reasonable foil transmissions. (theoretical ~ 0.4)

<table>
<thead>
<tr>
<th>foil</th>
<th>signal (na)</th>
<th>foil trans.</th>
<th>cm</th>
<th>Ar trans.</th>
<th>Diode</th>
<th>Pwr, mw</th>
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<td>0.296</td>
<td>81.9</td>
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<td>t2</td>
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<td></td>
<td>0.71</td>
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</table>

- Best 2pi pwr-- ~ 70 mW

- 430 V, 1100 Hz, 5.5 kW DC power, 400 mT process pressure
How can this be utilized?

- Integration into sensitivity Measurement tool
- Utilize Zr/B2 foil eliminates need for Ar mitigation gas
- Focusing optic at 6.7nm increases power density on wafer by more than 100x
- <30 sec/mj exposure time at wafer
Closing Remarks

- The Energetiq EQ-10 EUV source is a reliable and stable source of EUV photons.
- The system is being operated in the field 24/7 with consistent operation over years!
- Energetiq Sources are being used for infrastructure development globally.
- Redesign of the source offers higher power and higher brightness operation
  - Brightness of ~8W/mm^2-sr
  - 20W/ 2π
  - Continued excellent plasma and pulse-to-pulse stability
- The high power version of source is capable to running Ne for 6.7nm development
Acknowledgements

- The team at Energetiq…
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