Unique patented Electrodeless Z-Pinch™ EUV Source enables new applications

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Lasers & Electro Optics Seminar
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Agenda

• Why EUV
• EUV Technology
• Energetiq’s Technology
• EQ-10 Performance
• Applications and Data
EUV Lithography for next generation Chips

Extreme ultraviolet (EUV) lithography
The next enabler of the exponential growth of IC capabilities
$\lambda = 13.5 \text{ nm}$

- Multilayer-coated reflectors
  - $R \approx 70\%$
- Intermediate focus
- LPP Source
- Collector
- $\text{CO}_2$ laser

Reticle-stage
- Illuminator
- Projection optics
- Wafer stage

Total light transmission from JE in Wafer $T \leq 2\%$
How is EUV Made?

- By heating a gas e.g. Xenon, Tin Vapor to extremely high temperatures ~300,000°C!

- There are two ways to heat the gas
  - Heat with high power laser pulses (LPP, Laser Produced Plasma)
  - Heat by an electrical discharge or ‘arc’ (DPP, Discharge Produced Plasma)
Laser Produced Plasma

- Tin droplet generators are not yet reliable – low uptime
- Very difficult to hit each droplet with laser – poor EUV pulse-pulse stability
- Debris from Tin (Sn) is major contaminant for optics – high cost of ownership
Cymer EUV Source for EUV Lithography

LPP EUV Source Plasma Chamber

- Laser/Droplet
- Target Cameras (visible)
- Line scan (2) - high speed
- 2D Frame (2) - Video rate

- Droplet Generator
  - X, Y - steer
  - Z - steer (optional)

- EUV Sensor(s) (4)
- Internal Energy
- Angular Symmetry

- Elliptical Collector

- Turning Mirror
  - X, Y - steer

- Focusing Mirror
  - Z - steer

- Droplet Catcher

- Intermediate Focus
- Obscurations
- Turbomolecular Pump(s)

Primary Focus, Plasma
Traditional Discharge Plasma

- Electrodes and Tin Vapor are a major source of debris
  - Damaging to optics
- Electrodes require frequent replacement
  - Poor uptime
  - High Cost of Ownership
- Plasma position varies substantially
  - Poor EUV pulse–pulse stability
The Laser-assisted Discharge Plasma (LDP) Technology – Extreme Technology
LDP System for integration into EUV Scanner – Extreme Technology
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!
EQ-10 Product Family
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
## EQ-10 EUV Product Line

<table>
<thead>
<tr>
<th>Typical Performance*</th>
<th>EQ-10</th>
<th>EQ-10HR</th>
<th>EQ-10HP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power $2\pi$ (13.5nm±1%)</td>
<td>10W</td>
<td>2W</td>
<td>20W</td>
</tr>
<tr>
<td>Plasma Size (FWHM)</td>
<td>400um</td>
<td>1.6mm</td>
<td>400um</td>
</tr>
<tr>
<td>Maximum Brightness</td>
<td>5W/mm^2-sr</td>
<td>NA</td>
<td>8W/mm^2-sr</td>
</tr>
<tr>
<td>Repetition Rate</td>
<td>2kHz</td>
<td>10kHz</td>
<td>2kHz</td>
</tr>
<tr>
<td>Plasma Size Stability (σ)</td>
<td>&lt;4μm</td>
<td>&lt;4μm</td>
<td></td>
</tr>
<tr>
<td>Spatial Stability Position(σ)</td>
<td>&lt;6μm</td>
<td>&lt;6μm</td>
<td></td>
</tr>
<tr>
<td>Pulse-Pulse Stability</td>
<td>~2%</td>
<td>~2%</td>
<td></td>
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</tbody>
</table>

*Performance values are typical. Actual values depend on customer’s particular operating conditions which vary by application.
Field-Proven Reliability

- More than 20 sources operating in the field
- Installations in Japan, Europe and USA
- Systems operating 24/7 with minimal downtime
- Systems integrated into tools for R&D and pre-production
  - Actinic Inspection
  - Resist Outgassing
  - Mask Contamination
  - Optics Testing
EQ-10 Performance
Performance Characteristics

• Energetiq’s EUV Sources are very well characterized…
  – Power
  – Brightness
  – Plasma Size
  – Stability

• …as a function of their operating parameters
  – Xenon Pressure
  – Repetition Rate
  – Drive Voltage
Example of EQ-10 Spectrum

- 1.2kHz 325V, 80mTorr, corrected for Zr/polyimide filter, on-axis
EUV Power vs. Pressure

• In the EQ-10, for each combination of energy per pulse and repetition rate, (i.e. power input), there is an optimum pressure for maximum EUV power.
EUV Plasma Size vs. Pressure

- Plasma size generally decreases with increasing pressure
EQ-10 in-band EUV Image
Stable 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 $\sigma_y = 5.0 \, \mu m$

- Stable position means higher effective brightness
- This is open-loop stability: No feedback
Stable 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 $\sigma_{\text{FWHM}_y} = 3.6 \, \mu m$

- Plasma size remains constant
- This is open-loop stability: No feedback
EQ-10HP Increased Brightness

- $P = \frac{25.7 \text{ Watts}}{2\pi}$
- 13.5nm 2%BW
- $F = 0.440$ FWHM

Graph showing the relationship between brightness and radius.

Brightness ($r$) [W/mm$^2$/sr] vs. Radius ('$r'$) [mm]
Sample of Installations

- EUV Technology Outgassing Tool at IMEC
- Flood Exposure system at Osaka University
- Actinic Mask Inspection Tool at Selete
- LithoTech Outgassing Tool at Selete
Summary

- The Energetiq EQ-10 Electrodeless Z-Pinch 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 many years.
- Energetiq EUV sources are being used around the world for EUV infrastructure development.
- The recently introduced EQ-10HP source offers higher power and higher brightness operation
  - Brightness of up to 8W/mm^2-sr
  - 20W/ 2π
  - Improved pulse-to-pulse stability
  - Continued excellent plasma stability
EQ-10 Applications in Detail
Wavefront Metrology Tool for Optics Testing

MISTI experimental setup

EUV source (Energetiq)

Brightness
10 W / 2π / ±1%BW
≈ 10^{11} photon/mm²/mrad²/0.1%BW

Pinhole mask (MISTI mask)

Test optics (HiNA-3)
NA 0.3
mag. 1/5

Oct. 19, 2010  2010 International Symposium on Extreme Ultraviolet Lithography, Kobe, Japan
Figure 2 Actinic mask blank inspection tool built at MIRAI-Selete clean room and concept of its inspection optics using dark-field imaging.
Carbon Contamination of Masks at CNSE

FIG. 2. Layout of the EUV MiMICS at CNSE. Carbon-containing molecules were injected into the vacuum chamber to increase the contamination rate.

EUV Resist Outgassing at CNSF

- Multi-technique outgassing studies
  - Total Pressure (Ion Gauge)
  - Mass Loss (QCM)
  - Mass Spectrum (RGA)
  - Mass Spectrum (GC-MS)

- Broad band and in-band exposures
  - Faster exposures, higher throughput

- Includes mirror contamination testing
  - Denbeaux et al
    - U Albany
LithoTech Japan EUV Resist Outgassing Tool #1 at Selete

Figure 1. Photograph and schematic of resist outgassing evaluation tool used for pressure rise method.

EUV Technology EUV Resist Outgassing Tool at IMEC

I. Pollentier et al. Characterization of EUV optics contamination due to photoresist related outgassing SPIE 2010 (7636-69)

• EUV Dose Snake
Soft X-Ray Microbeam installed at Columbia University (RARAF)

- Study of “Bystander Effect” in biological cells
  - Cancer research
- Uniquely small probe beam, 1μm diameter

Optical Microscope
Sample Stage
Beamline with Focusing Optic
EQ-10SXR Soft X-Ray Source
Xradia nanoXCT-S220
Soft X-ray Microscope System

Microscope Chamber  Energetiq EQ-10SXR  Electronics Rack

X-ray Alignment System

Cryo Sample Transfer System Docked to Microscope

Variable Magnification Slide  CCD Camera
3D Tomography of Yeast Cell

Using Soft X-ray Microscopy
Thank You!