ENERGETIQ

EUV Source Development at Energetiq Technology

Matthew J. Partlow, Stephen F. Horne, Matthew M. Besen, Donald K. Smith, Paul Blackborow, Deborah Gustafson

Energetiq Technology, Inc.

ABSTRACT

Commercially available since 2005, the EQ-10 is a medium-power (10 W/2π, 13.5nm +/- 1%, Xenon) EUV source suitable for a variety of mirror testing, resist exposure, and defect inspection applications. The range of customer applications for the EQ-10 continues to evolve, to meet the increasingly challenging requirements driven by the quickening pace of development in EUV lithography. Over the years, significant field experience and customer feedback have accumulated as more sources are used in a wider range of applications. In response, development programs are ongoing to re-engineer and optimize the EQ-10 source to better match market requirements as they have evolved over time, as well as more rigorously characterize the operating characteristics of the current design. Parameters being addressed include power, stability, pinch size, and component lifetime. Results will be presented on the effect of varying source frequency, materials, geometry, and input power. Recent source stability characterization data will be shown. Lastly, new source operation upgrades will be described, including improved high voltage pulse delivery.

Current Applications -- Installed Sources

- Open frame exposure (both in-band and broadband)
  - Resist sensitivity measurements
  - Resist development (chemistry)
- Resist out-gassing
  - Qualification of resists for alpha tools
- Mirror contamination
  - Simulate stepper environment
- Mirror characterization
  - Reflectivity, bandwidth
- Inspection
  - Actinic Mask

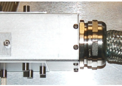
Metrology – Detector Calibration

Accurate Output Power characterization is critical to customers

- Use custom 85 degree multilayer mirror and IRD photodiode to obtain all in-band EUV power measurement
- Energetiq maintains Reference Standard power monitor
  - Regularly calibrated by NIST Gaithersburg
  - Used ONLY for cross-calibrating testing power monitors
- Spectral Correction:
  - Responsivity corrected for shape of source output spectrum relative to mirror reflectivity
- Cross-calibration of test detectors:
  - Calibration of test detectors performed in situ with Reference Standard
  - Test detectors re-calibrated regularly

Recent Source Improvements:

NEW & Improved High Voltage Cable



- Designed for lower temperature and higher reliability.
- Old strap ran at ~ 90˚C, new strap runs at 45˚C
- Additional benefits are a longer and more flexible cable.

Pressure Control

- Successfully implemented closed loop control of Xenon pressure for greater stability of process conditions.

Experienced Semiconductor Product Developers

Short Wavelength Light Source Development

The LDLS™ Principle of Operation

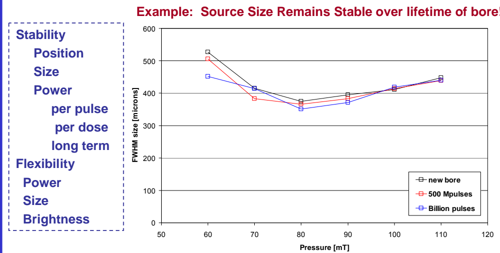
EUV Light Sources

DUV Light Sources

Customer requirements drive source development

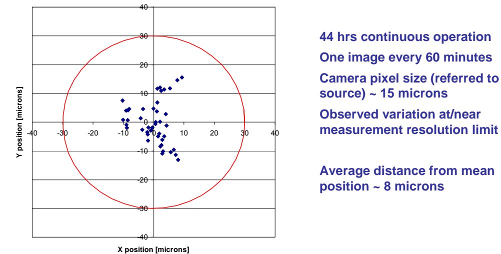
- Stability
  - Position
  - Size
  - Power
    - per pulse
    - per dose
    - long term
- Flexibility
  - Power
  - Size
  - Brightness

Example: Source Size Remains Stable over lifetime of bore!



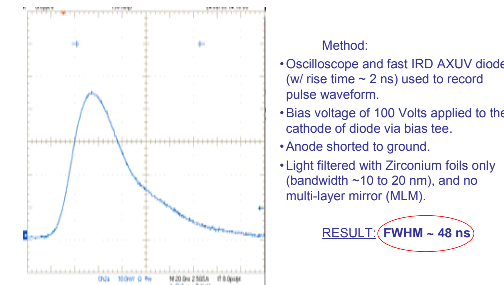
Various measures of pinch stability….

Long Term Position Stability – 300 Million Pulses



- 44 hrs continuous operation
- One image every 60 minutes
- Camera pixel size (referred to source) ~ 15 microns
- Observed variation at/near measurement resolution limit
- Average distance from mean position ~ 8 microns

Characterization of Light Pulse Duration



Method:

- Oscilloscope and fast IRD AXUV diode (w/ rise time ~ 2 ns) used to record pulse waveform.
- Bias voltage of 100 Volts applied to the cathode of diode via bias tee.
- Anode shorted to ground.
- Light filtered with Zirconium foils only (bandwidth ~10 to 20 nm), and no multi-layer mirror (MLM).

RESULT: **FWHM ~ 48 ns**

Electrodeless Z-pinch source developed to enable EUV lithography for semiconductor fabrication.

Plasma Return Loops

Z-Pinch Region

10 watts/2π, 13.5 nm, +/- 1% bandwidth.

Xenon plasma.

(Xe 10+)

Leverage our R&D for medical applications:

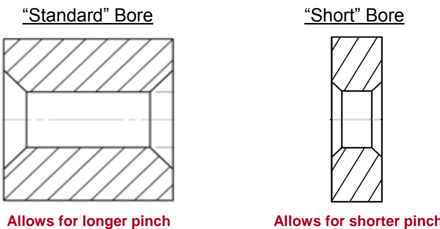
~ 0.2-0.5 W, 2.88 nm,

Nitrogen plasma

N 7+ (Helium-like N)

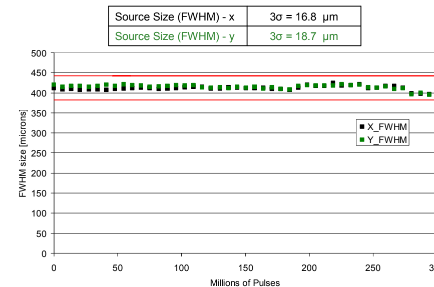
Reduction in plasma length

All pinch dimensions can be tailored by adjusting bore size/shape and process conditions



Allows for longer pinch | **Allows for shorter pinch**

Long Term Size Stability – 300 Million Pulses



Program under way to raise operating frequency

- Growing interest in sources for metrology that operate near HVM frequencies → optics degradation/contamination may have dependence on pulse frequency!
- Factor of 5+ increase in operating frequency required basic redesign of source components to re-optimize EUV emission, including thermal, electronic, and magnetic effects.
- Promising initial results with patchwork prototype:
  - Operation at 7 kHz
- First 10 kHz source to be shipped by end of calendar year 2008. More results to be presented at SPIE 2009.

Induced High Current Pulse

Inductively Coupled Gas Plasma (Xe)

Magnetic Field

EUV

Z-Pinched Plasma

Unique inductive design eliminates electrodes and electrode current

- No electrodes → no electrode debris

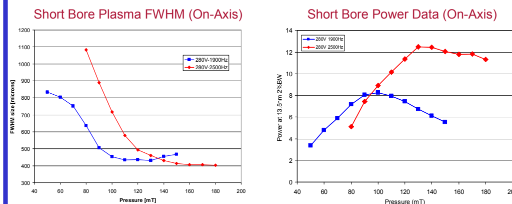
Plasma is magnetically confined away from source components

- Reduces debris; allows higher power operation

Lower cost and complexity

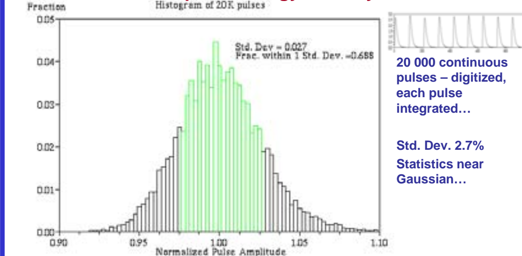
Six patent applications filed

Short Bore Performance: Results



Plasma length reduced from ~11mm to 3 mm

Pulse-to-pulse Energy Stability



- 20 000 continuous pulses – digitized, each pulse integrated…
- Std. Dev. 2.7%
- Statistics near Gaussian…

Obtain similar results when capturing 10 hours of pulses with gated box-car integrator

References

- P. A. Blackborow, M. J. Partlow, S. F. Horne, M. M. Besen, D. K. Smith, and D. S. Gustafson, "EUV Source Development at Energetiq," in *Emerging Lithographic Technologies XII*. Edited by Schellenberg, Frank M. *Proceedings of the SPIE*, Volume 6921(1), pp. 692121 (2008).
- Blackborow, Paul A.; Gustafson, Deborah S.; Smith, Donald K.; Besen, Matthew M.; Horne, Stephen F.; D'Agostino, Robert J.; Minami, Youichi; Denbeaux, Gregory; "Application of the Energetiq EQ-10 electrodeless Z-Pinch EUV light source in outgassing and exposure of EUV photoresist" in *Emerging Lithographic Technologies XI*. Edited by Lercel, Michael J. *Proceedings of the SPIE*, Volume 6517, pp. 65171W (2007).
- S. F. Horne, M. M. Besen, D. K. Smith, P. A. Blackborow, and R. D'Agostino, "Application of a high-brightness electrodeless Z-pinch EUV source for metrology, inspection, and resist development," in *Emerging Lithographic Technologies X*. Edited by Lercel, Michael J. *Proceedings of the SPIE*, Volume 6151, pp. 201-210 (2006).