ENERGETIQ

EUV Source Development at Energetiq Technology

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Abstract

The EQ-10 is a commercially available, medium-power (10 W /2 pi,13.5nm +/- 1%, Xenon) EUV source suitable for a variety of resist exposure, mirror testing, and inspection applications. Since the launch of the product in 2005, significant field experience and customer feedback have accumulated. In response, a development program is under way to re-engineer and optimize the EQ-10 source to to better match market requirements as they have evolved over time. Parameters being addressed include power (a 15 W version is under development), source size, and stability. Data will be presented on the effect of varying source geometry, materials, frequency, and input power on these parameters.

A related program on beamline design and optimization is also underway, focused on improving the efficiency of EUV power delivery. Results from this program will be summarized; details will be presented in a separate paper.

Current applications -- installed sources

- Open frame exposure (both inband 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

Metrology

Basic measurement: Watts in 2pi at 13.5 nm +/- 1% bw (=P)

No "perfect" measurement device possible. Must always infer P based on imperfect measurements.

Approach – definitions: (all in Amperes/Watt)

- Instrument Responsivity: Amps/Watt/nm assuming line source. (standard mirror/diode curve, NIST traceable)
- Peak Responsivity: Above value, at peak of response.
- Spectral Responsivity: Assume power distributed according to some measured spectrum, with normalization set to yield 1 watt inband. Calculate expected current.

Define Spectral Correction = Instrument responsivity / Spectral responsivity

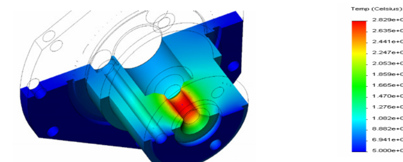
Foil transmission measured *in situ* – double foils.

Attenuation by residual Xe in beamline… Pumped beamline so correction is small; use absolute pressure measurement.

15 Watt Development

Must address thermal, reliability issues.

Thermal modeling (and temperature measurements) imply cooling is adequate.

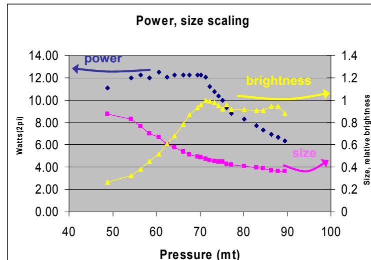


Experienced Semiconductor Product Developers

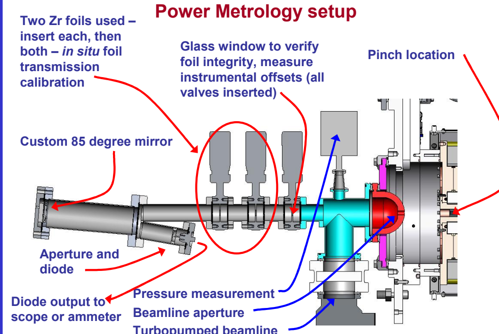
A track record of putting high power plasma devices into production

Customer requirements drive source development

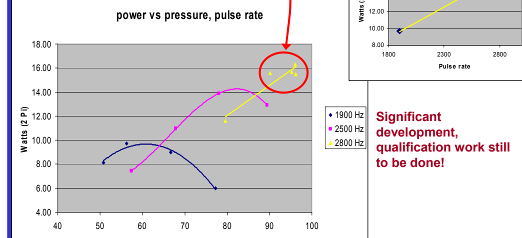
- Stability
  - Position
  - Size
  - Power
    - per pulse
    - per dose
    - long term
- Flexibility
  - Power
  - Size
  - Brightness



Power Metrology setup

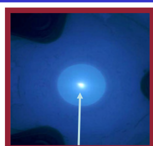


Initial testing – 2 hrs operation @ 15W

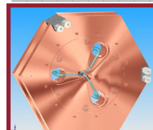


Significant development, qualification work still to be done!

Plasma Return Loops



Z-Pinch Region



Electrodeless Z-pinch source developed to enable EUV lithography for semiconductor fabrication[1].

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

Xenon plasma.

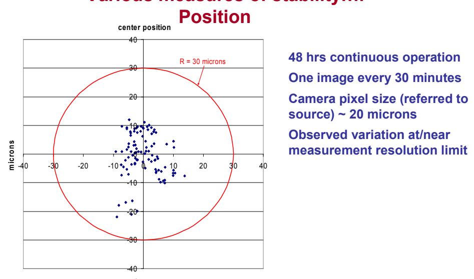
(Xe 10+)

Leverage our R&D for medical applications:

~ 0.2-0.5 W, 2.88 nm, Nitrogen plasma

N 7+ (Helium-like N)

Various measures of stability…. Position



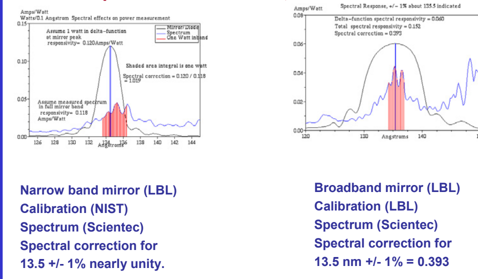
48 hrs continuous operation

One image every 30 minutes

Camera pixel size (referred to source) ~ 20 microns

Observed variation at/near measurement resolution limit

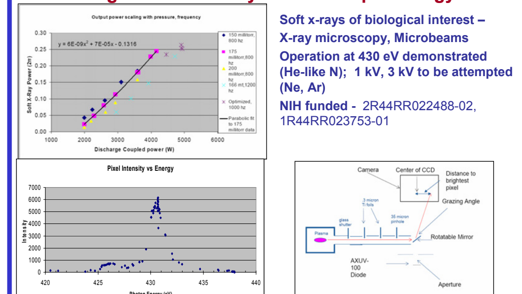
Spectral correction of power data



- Narrow band mirror (LBL)
- Calibration (NIST)
- Spectrum (Scientec)
- Spectral correction for 13.5 +/- 1% nearly unity.

- Broadband mirror (LBL)
- Calibration (LBL)
- Spectrum (Scientec)
- Spectral correction for 13.5 nm +/- 1% = 0.393

Programs under way to raise output energy



Soft x-rays of biological interest – X-ray microscopy, Microbeams

Operation at 430 eV demonstrated (He-like N); 1 kV, 3 kV to be attempted (Ne, Ar)

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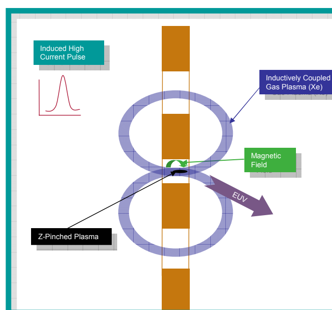


Unique inductive design eliminates electrodes and electrode current

- No electrodes → no electrode debris

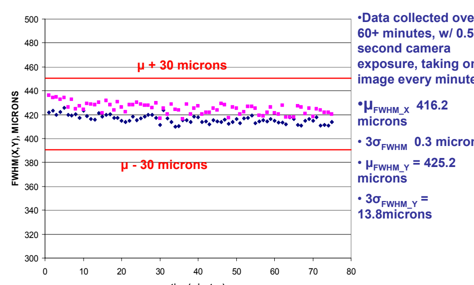
Plasma is magnetically confined away from source components

- Reduces debris; allows higher power operation

Lower cost and complexity

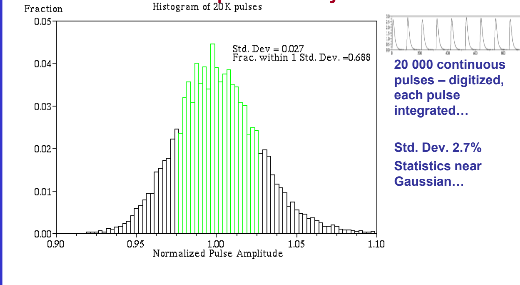
Six patent applications filed

Size…



- Data collected over 60+ minutes, w/ 0.5 second camera exposure, taking one image every minute.
- μ_{FWHM_X} 416.2 microns
- $3\sigma_{FWHM}$ 0.3 microns
- μ_{FWHM_Y} = 425.2 microns
- $3\sigma_{FWHM_Y}$ = 13.8microns

Pulse-to-pulse stability



20 000 continuous pulses – digitized, each pulse integrated…

Std. Dev. 2.7%

Statistics near Gaussian…

References

- 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).
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- .D. Sayre, J. Kirz, R. Feder, D.M. Kim and E. Spiller, "Potential Operating Window for Ultrasoft X-ray Microscopy of Biological Materials", *Science* 196 1339 (1977).
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