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

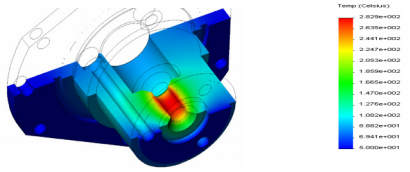
Foil transmission measured *in situ* – double foils.

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.

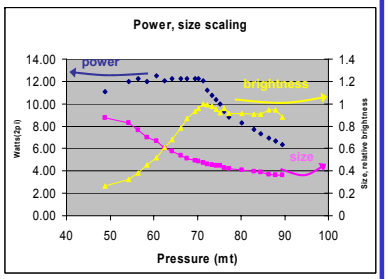


Experienced Semiconductor Product Developers

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

Two Zr foils used – insert each, then both – *in situ* foil transmission calibration

Glass window to verify foil integrity, measure instrumental offsets (all valves inserted)

Pinch location

Custom 85 degree mirror

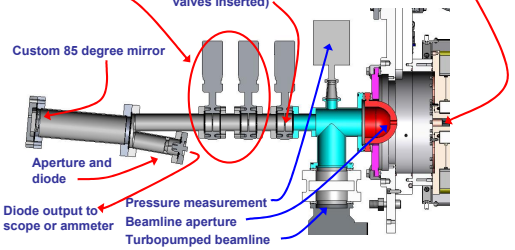
Aperture and diode

Diode output to scope or ammeter

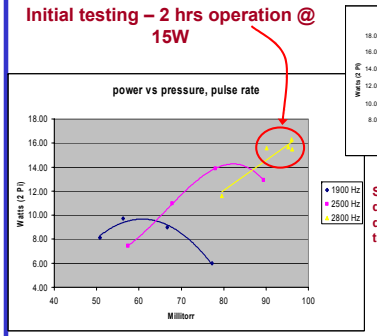
Pressure measurement

Beamline aperture

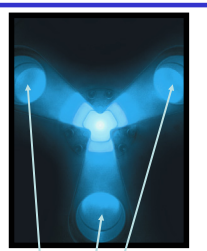
Turbopumped beamline

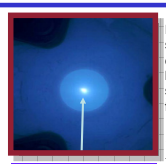


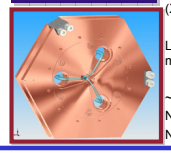
Initial testing – 2 hrs operation @ 15W



Significant development, qualification work still to be done!







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

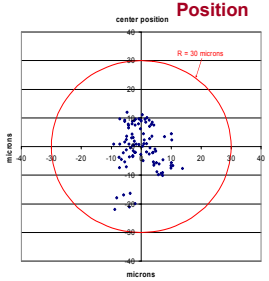
10 watts/2π, 13.5 nm, +/- 1% bandwidth.

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



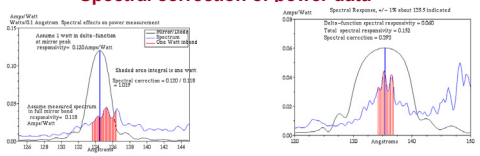
48 hrs continuous operation

One image every 30 minutes

Camera pixel size (referred to source) ~ 20 microns

Observed variation at/near measurement resolution limit

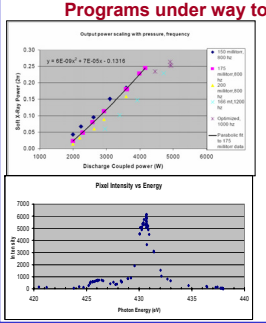
Spectral correction of power data



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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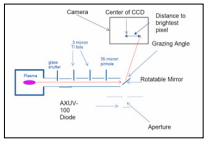
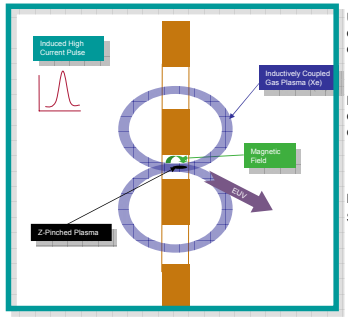




Unique inductive design eliminates electrodes and electrode current

No electrodes → no electrode debris

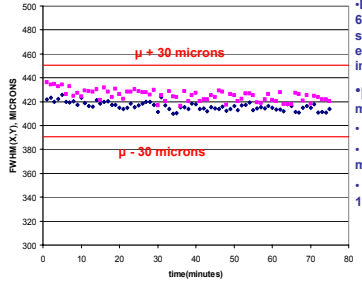
Plasma is magnetically confined away from source components

Reduces debris; allows higher power operation

Lower cost and complexity

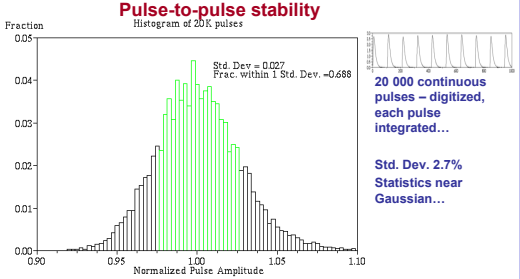
Six patent applications filed

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

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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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