Beamline Design for the Energetiq EQ-10 EUV Source

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ABSTRACT

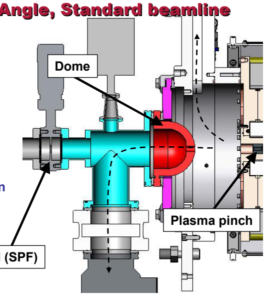
The beamline provides the interface between the EQ-10 EUV source and the first optical element in an exposure or inspection system. The function of the beamline is to transmit only the photons of interest, removing gas, particles, and out-of-band light.

Effective design of beamlines for the EQ-10 requires various compromises amongst composition and location of spectral filters, gas and vacuum management, and delivered in-band power. The spectral filters (typically, Zirconium or Silicon foils) must be thin (~ 200 nm) to maximize EUV transmission, and so are quite fragile. Furthermore, to access a maximum view angle, the filters must be mounted close to the source, which makes them susceptible to damage.

Data will be presented on performance of thin foil spectral filters placed within 20 cm from the Z-pinch. Also to be discussed are various methods of improving filter performance, including purging the beamline with buffer gas and the use of a vane trap.

Case 1 – Small Collection Angle, Standard beamline

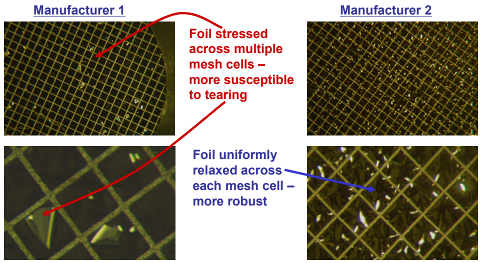
- Small dome aperture
- Pinch to dome aperture ~ 10 cm
- Pinch to foil ~35 cm
- Xenon pumped from source AND through dome and beamline
- Collection angle up to ~ 3 deg half angle
- Distances and small aperture minimize need for particle mitigation
- Long foil lifetimes observed



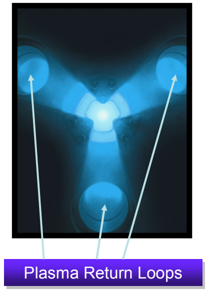
Measurement of Rate of Foil Damage

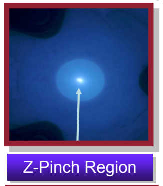
- **Leak Rate** is used as primary measure of foil damage (NEW foils have *initial* leak rates of ~ 10^{-5} mBar-L/sec)
- Required: Accurate and frequent leak rate measurements, taken over long timescales, for detailed analysis of foil damage rate
- Developed: Automated, computer controlled, measurement technique to capture leak rate through foils. Tests conducted over 24+ hours of continuous operation
- The time dependence of the SPF leak rate is determined using a rate of rise approach as described below:

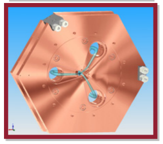
Comparison of Zirconium Foils:



Unique Source – Pinch Surrounded by Plasma:







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

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

Xenon plasma.

(Xe 10+)

Unique inductive design eliminates electrodes and electrode current

No electrodes → no electrode debris

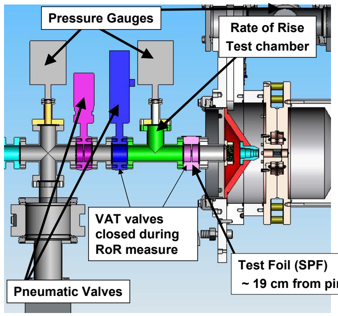
Larger collection angle requires larger dome aperture

To achieve larger collection angle, must –
- Increase diameter of aperture
- Move aperture closer to pinch
- Admits plasma into the beamline
- Introduces new physics –

Langmuir probe, thermocouple measurements indicate plasma invades beamline, causing heating and related damage.

Solution:
- Introduce vane trap
- Purge foil region (with appropriate gas!)
- Pump between vane trap and aperture

Primary Diagnostic Measurement Test Stand:

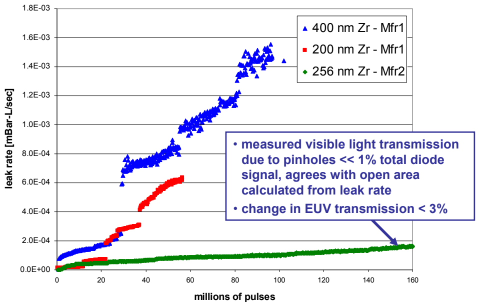


Completely automated test measurement apparatus measures Rate Of Rise (ROR) due to leak rate through foil.

LabView routine controls pneumatic valves and acquire signals from system

Consistent and reliable results

Test of Mitigation Method with various SPFs



Beamline design requires compromise and tradeoff

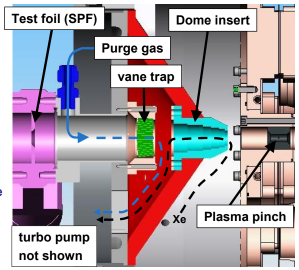
Source emits:
- In-band desirable photons (EUV)
- Out-of-band photons
- Xenon gas (attenuates EUV, reducing delivered power)
  - 20 cm beamline at 10 mT Xenon – 84% transmitted…
  - 20 cm beamline at 60 mT Xenon – 36% transmitted…
  - → Must remove Xenon from beamline!
- Fast ions (which can damage surfaces)
- Particles (from sputtered films, etc) which can damage beamline components

Interface between source and beamline must remove damaging debris and unwanted out-of-band photons, yet still transmit desired EUV → compromise

Requires collaborative design between source manufacturer and end user for cost-efficient result.

Case 2 - Large Collection Angle: (with mitigation)

- Mitigation gas flows between foil and vane trap, to low pressure pumped region
- Pinch to dome aperture ~ 1 cm
- Pinch to test foil ~ 19 cm
- Pumped region isolates source environment from beamline environment
  - Beamline protected from plasma, Xenon;
  - Source protected from purge gas
- Collection angle opened to ~ 8 deg half angle



Measurement Test Procedure:

- An SPF (test foil) is inserted into the beamline while the source is operating. This test foil remains in place over the course of the lifetime test.
- At fixed intervals of time, a known volume (shown in green) behind the SPF is isolated from the beamline turbo-pump by a gate-valve (shown in blue). This gate valve is controlled by the LabView routine.
- The LabView routine then records the signal from the pressure gauge at fixed time intervals. The background rate of rise in the test chamber is then automatically determined by finding the slope of the linear portion of the pressure curve.
- The volume of the test chamber is previously calculated from known dimensions.
- By multiplying the net rate of rise by the volume we have the effective leak rate through the SPF. The steps are repeated until leak rate is too large to measure.

Conclusions:

- The interface between source and beamline is a collaborative effort between Energetiq and the customer
- Unique design of the EQ-10 source requires application specific handling
  - good beamline design will allow more delivered power
  - good interface design will provide long optics lifetime
- A single SPF is adequate mitigation for a small collection angle beamline
- Large collection angle requires further mitigation techniques
- We have demonstrated effective use of a vane trap and gas purge for beamline mitigation to enhance the lifetime of optics in a prototype beamline interface.
  - SPF foil lifetime > 100 million pulses
  - minimal change in EUV transmission and out-of-band filtering

EQ-10 has some unique features

Pinch expanding into vacuum generates fast ions – escaping energetic electrons produce positively charged pinch region, which accelerates heavy, multi-charged ions to high energies. [Mora]

But – EQ-10 pinch is embedded in cold plasma – not vacuum.

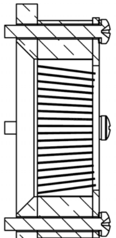
In "normal" pinch (vacuum case), adding light ions to gas feed helps neutralize field – positive light ions preferentially accelerated out of pinch region, reducing positive charge. [Ruzic]

Cold plasma surrounding EQ10 pinch provides source of cold electrons which fall into positively charged region– very efficient neutralization.

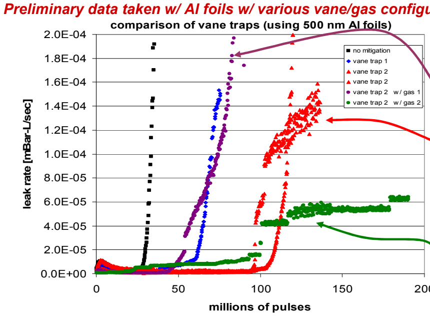
Recent measurements demonstrate EQ-10 electrodeless Z-pinch plasma yields lower energetic ion output than electrode sources.

Plasma in Beamline controlled by gas injection and vane trap

- Vane trap 2, no gas flow:
  - vanes: 240 deg C
  - beamline: 265
  - Rapid foil damage
- Vane trap 2, w/ Gas 1 flow:
  - vanes: 180
  - beamline: 200
  - More rapid foil damage
    - Worse than no purge!
- Vane trap 2, w/ Gas 2 flow
  - vanes: 180
  - beamline: 160
  - Acceptable foil lifetimes!



Preliminary data taken w/ Al foils w/ various vane/gas configurations



Surprising result – wrong purge gas worse than no purge!

Better choice gives improved results…

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