



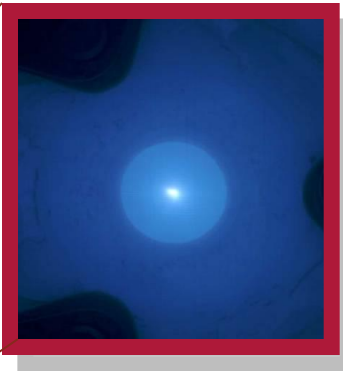
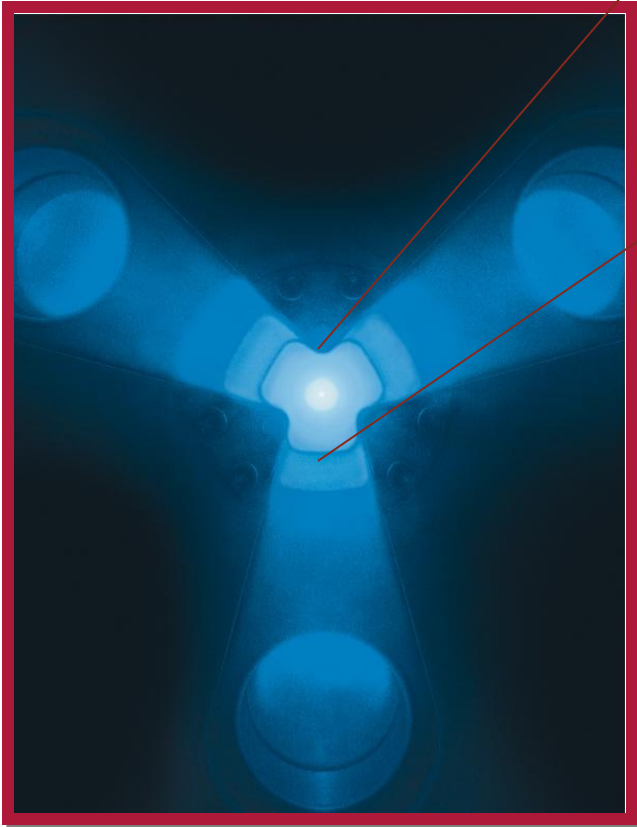
EQ-10 EUV Source High Brightness Metrology Source

*Debbie Gustafson, Matt Partlow,
Paul Blackborow, Steve Horne,
Matt Besen, Don Smith*

Agenda

- Background on the EQ-10 Electrodeless Z-Pinch™ EUV source
- New Metrology
- Improvements of source to gain high brightness source

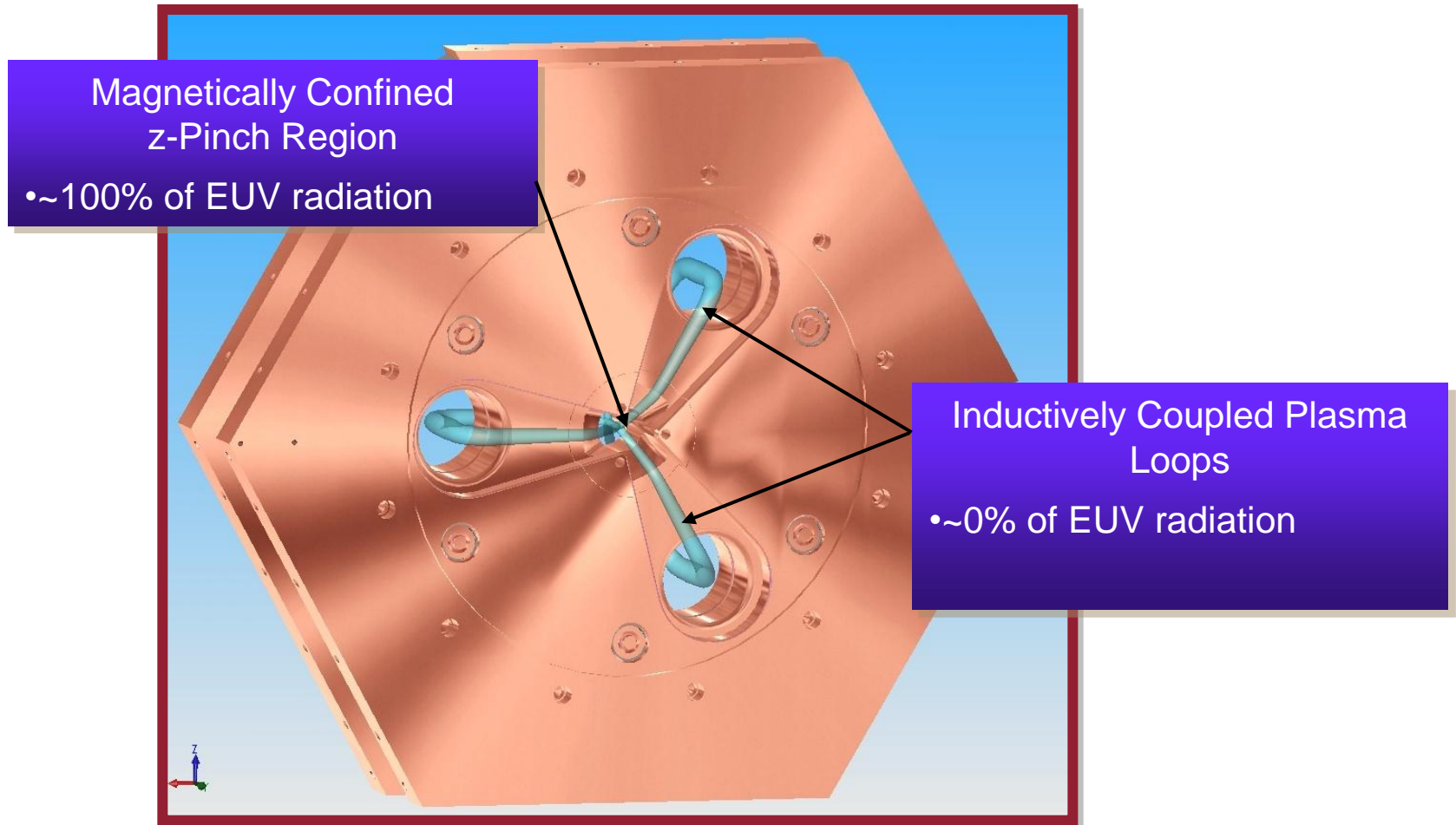
EQ-10 Source



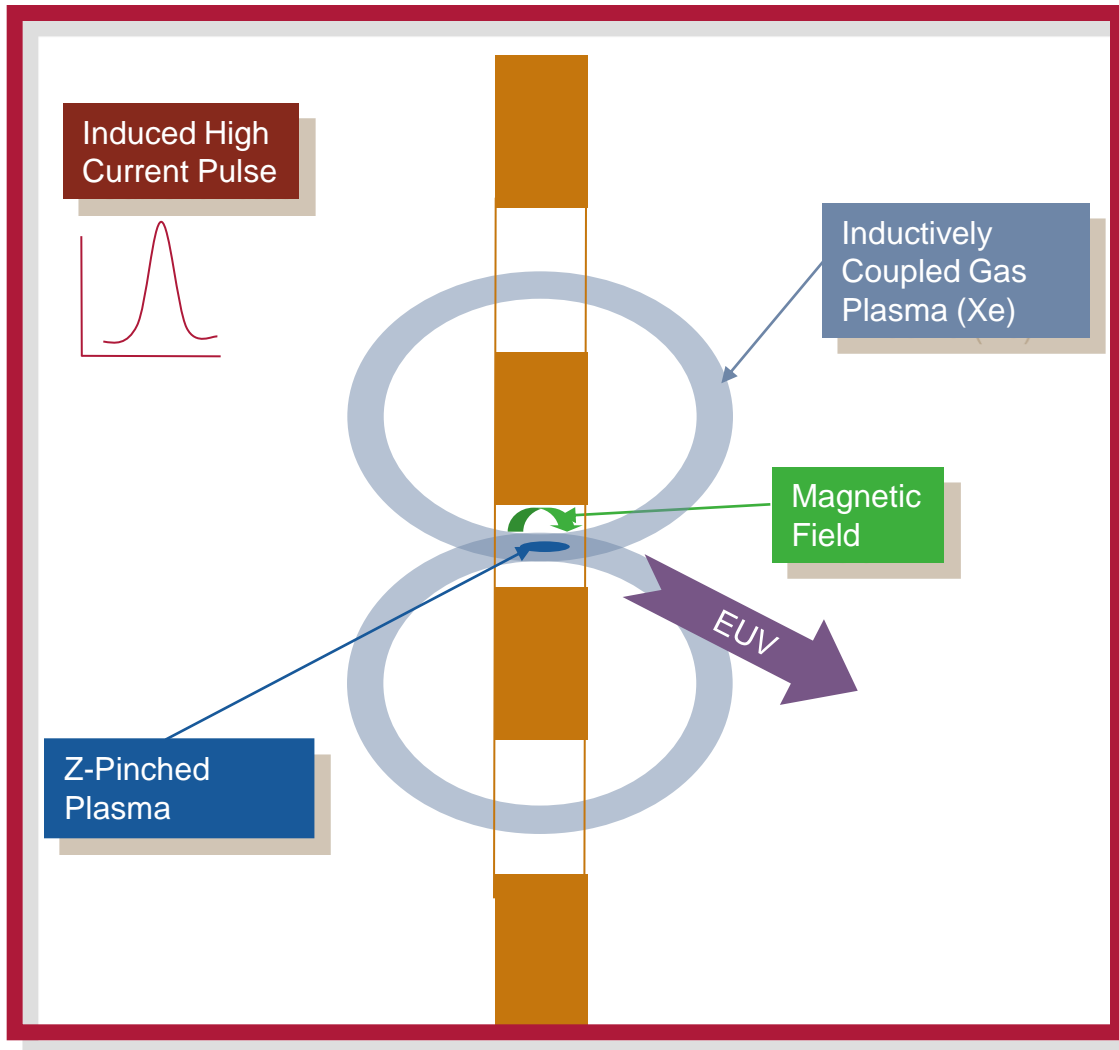
- Introduced in 2005
- 13.5nm \pm 1% Power in 2 π
 - 10W continuously
 - Now 20W
 - @2 kHz
- 10kHz operation also
- Operates continuously for days and weeks



Electrodeless Z-Pinch EUV Source



Electrodeless Z-Pinch



- Inductive design eliminates electrodes and electrode current
- Plasma is magnetically confined away from source components and 'pinned' electromagnetically to the geometric center of the bore

System Reliability

- Shipped over 18 sources in the field
- Installations in Japan, Europe and US
- Systems being operated 24/7 with minimal downtime
- Systems integrated into tools for research and development
 - Actinic Inspection
 - Resist Outgassing
 - Mask Contamination
 - Optics Testing

Sample of Current Installations



EUV Technology Outgassing Tool Installed at IMEC



Flood Exposure system installed at Osaka University (Tagawa Lab)

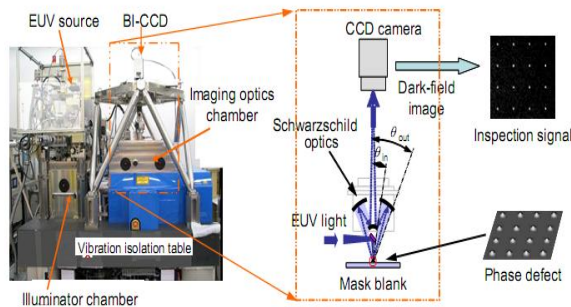


Figure 2 Actinic mask blank inspection tool built at MIRAI-Selete clean room and concept of its inspection optics using dark-field imaging.

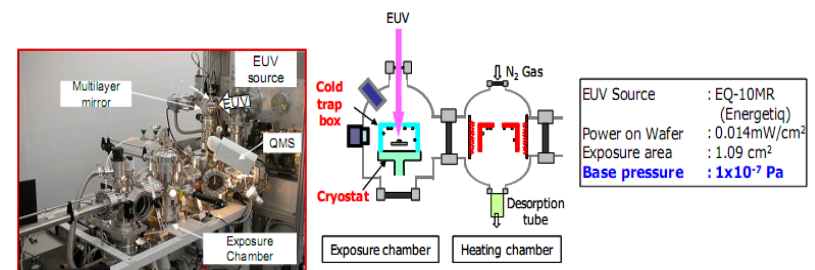


Figure 2. Photograph and schematic of resist outgassing evaluation tool used for GC-MS method.

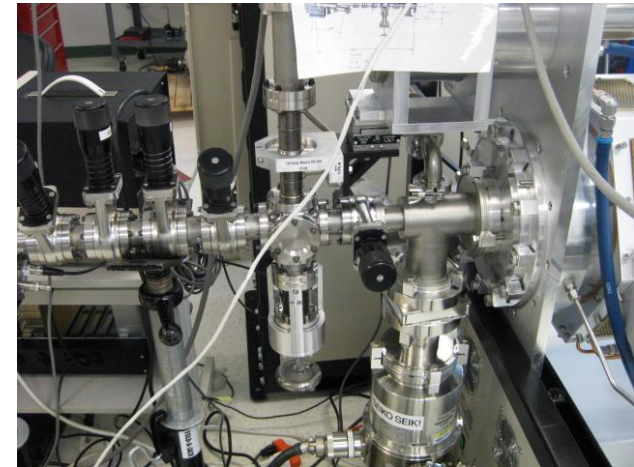
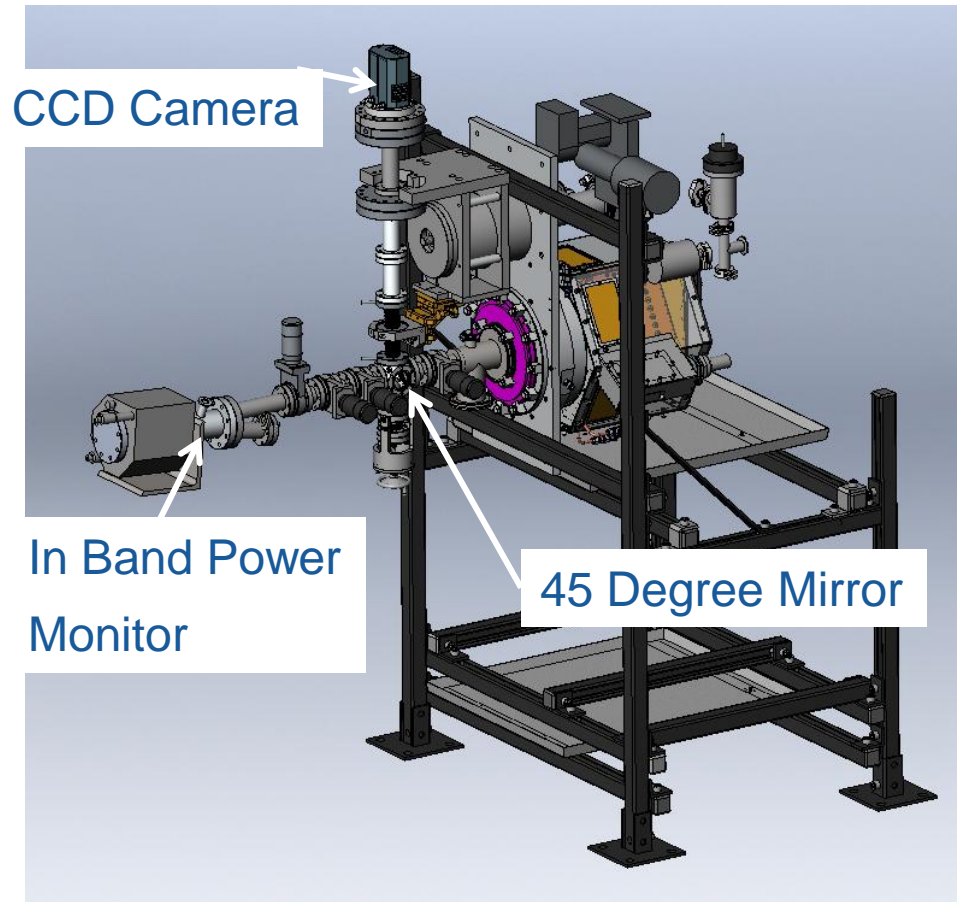
Actinic Mask Inspection Tool at Selete

LithoTech Outgassing Tool installed at Selete



Recent Improvements in EQ-10 Brightness and Power

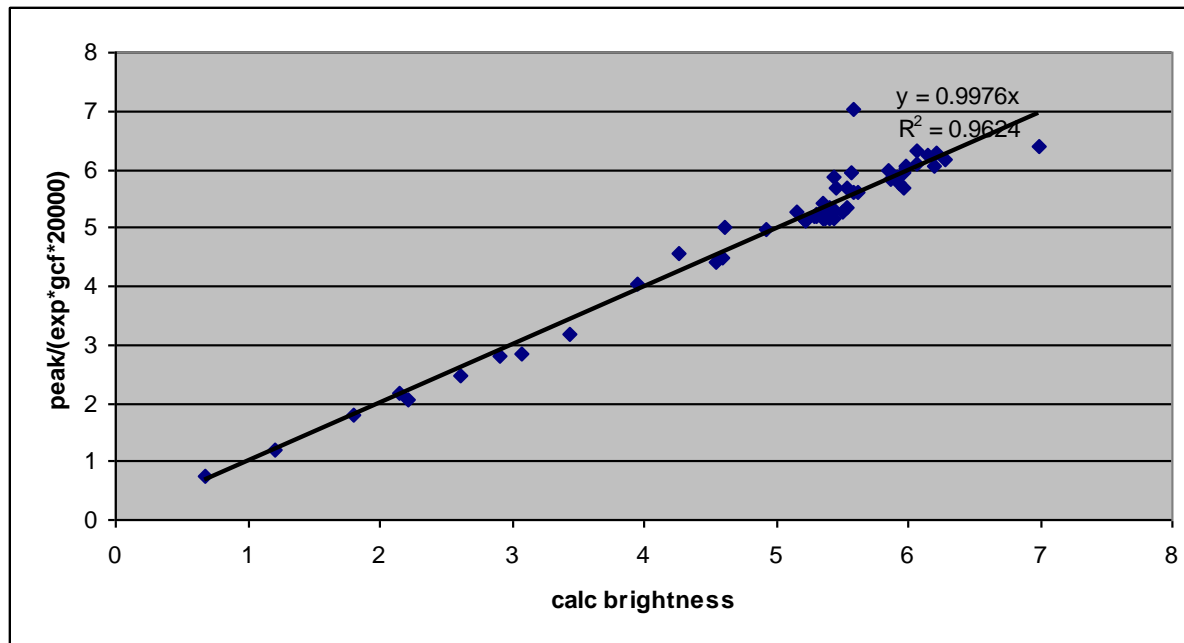
New Dual Diagnostic Brightness Measurements



- EUV Power Monitor is Calibrated at NIST

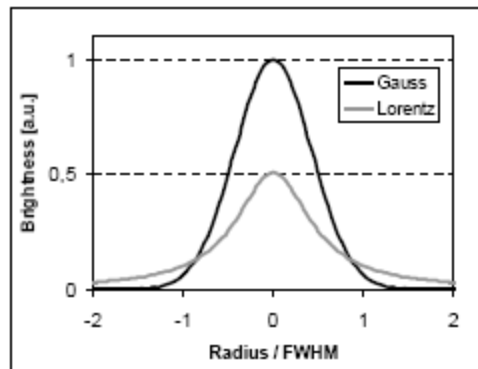
Better correlation for Brightness

- Allows brightness estimate by camera image
- Can optimize source while operating to find brightest plasma



Brightness Estimations

- *we have experienced in our concept & feasibility study that simplified estimates can lead to brightness numbers which are far from reality*



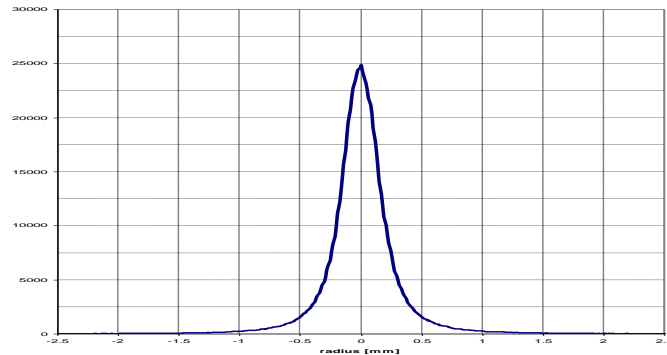
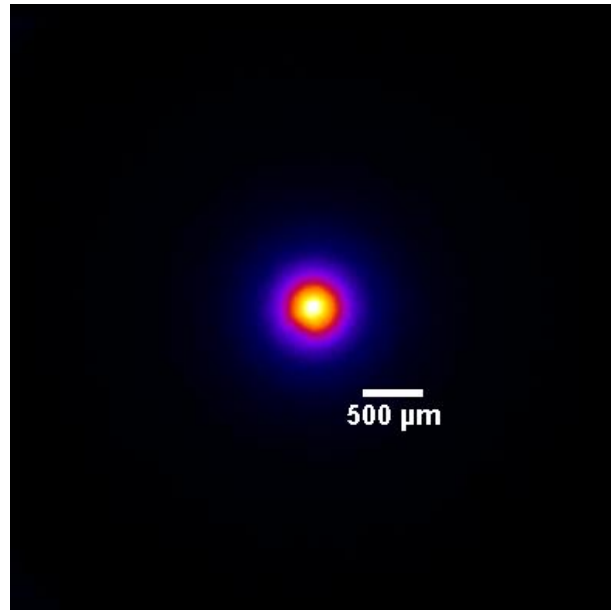
$$B_{MAX}(Gau\beta) = \frac{P_D}{\Delta\Omega_D} \cdot \frac{\ln(2)}{\pi \cdot (FWHM / 2)^2}$$

$$B_{MAX}(Lorentz) = \frac{P_D}{\Delta\Omega_D} \cdot \frac{1}{\pi \cdot (FWHM / 2)^2 \cdot [\ln(1 + (2R / FWHM)^2)]}$$

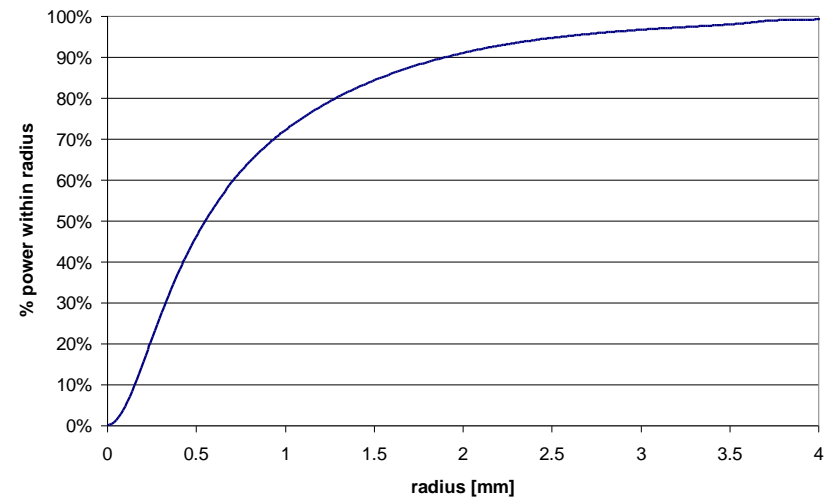
Figure 5: Comparison of a Gaussian source shaped and a Lorentzian source with the same FWHM and same (integrated) power leading to substantial different peak brightness. This demonstrates that the source shape needs to be known for an accurate determination of the peak brightness.

SPIE 7969-15 AIMS™ EUV - the actinic aerial image review platform for EUV masks Dirk Hellweg et al Carl Zeiss SMT

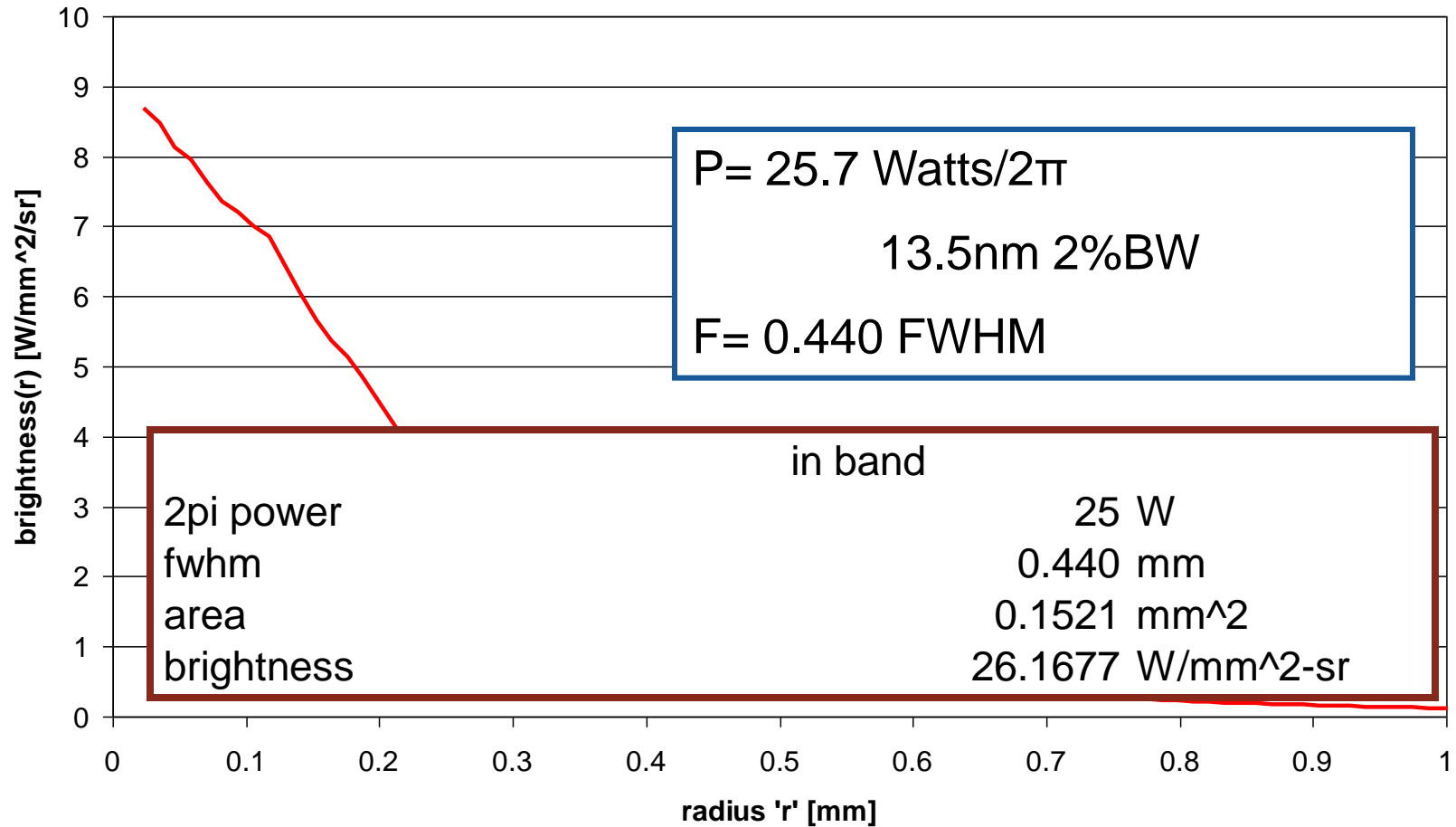
EQ-10 in-band EUV Brightness



- Brightness is a function of power and radius



EQ-10 HP Brightness



Actinic Mask Inspection/ Metrology

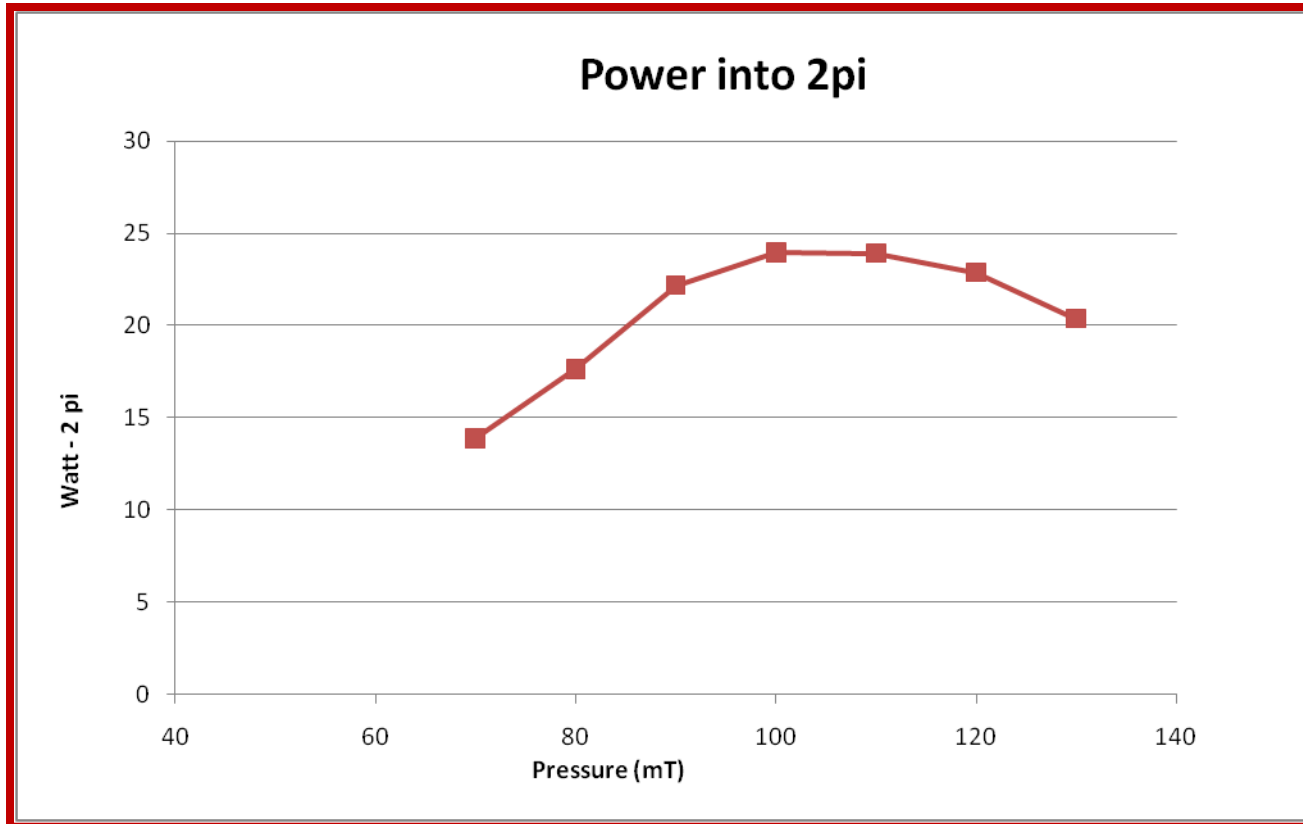
- Actinic Blank Inspection, AIMs and Patterned Mask Inspection are critical to the success of EUV lithography
- Major OEMs are being funded and have programs for development of these tools
 - Funding by both Sematech EMI and EDEIC (Japan)
- There is no commercial source on the market to meet the “production” needs for these tools
- Minimum brightness specifications are $10 \text{ W/mm}^2\text{-sr}$ for Prototype tools

EQ-10HP Overview

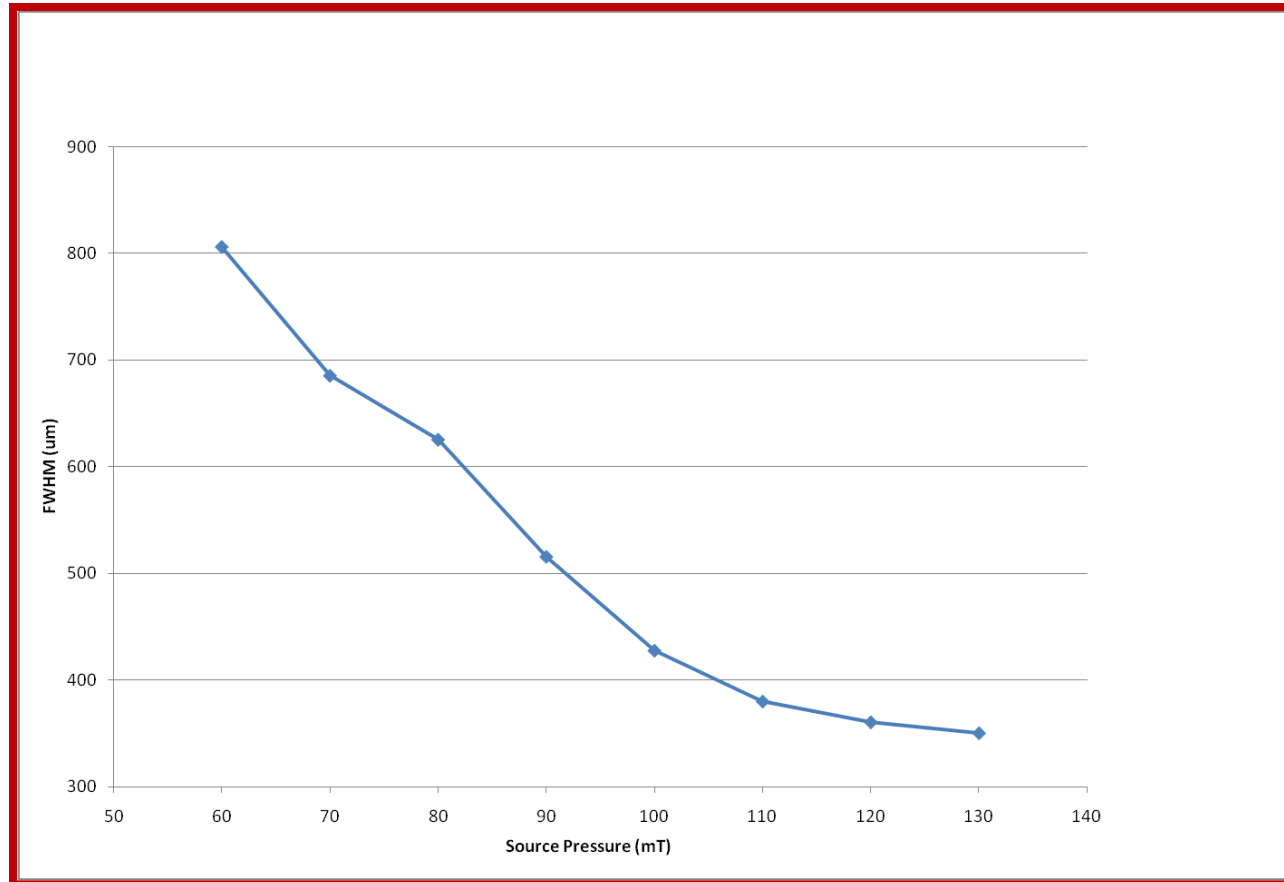
- Based on standard EQ-10 High Reliability Source
 - Utilizes new better cooling bore design
 - Improved modulator
- Design allows for up to 7kW input power
 - Improved cooling of source and modulator
- Specifications
 - >20 W of 13.5nm $\pm 1\%$ Power in 2π
 - ~ 8 W/mm²-sr brightness



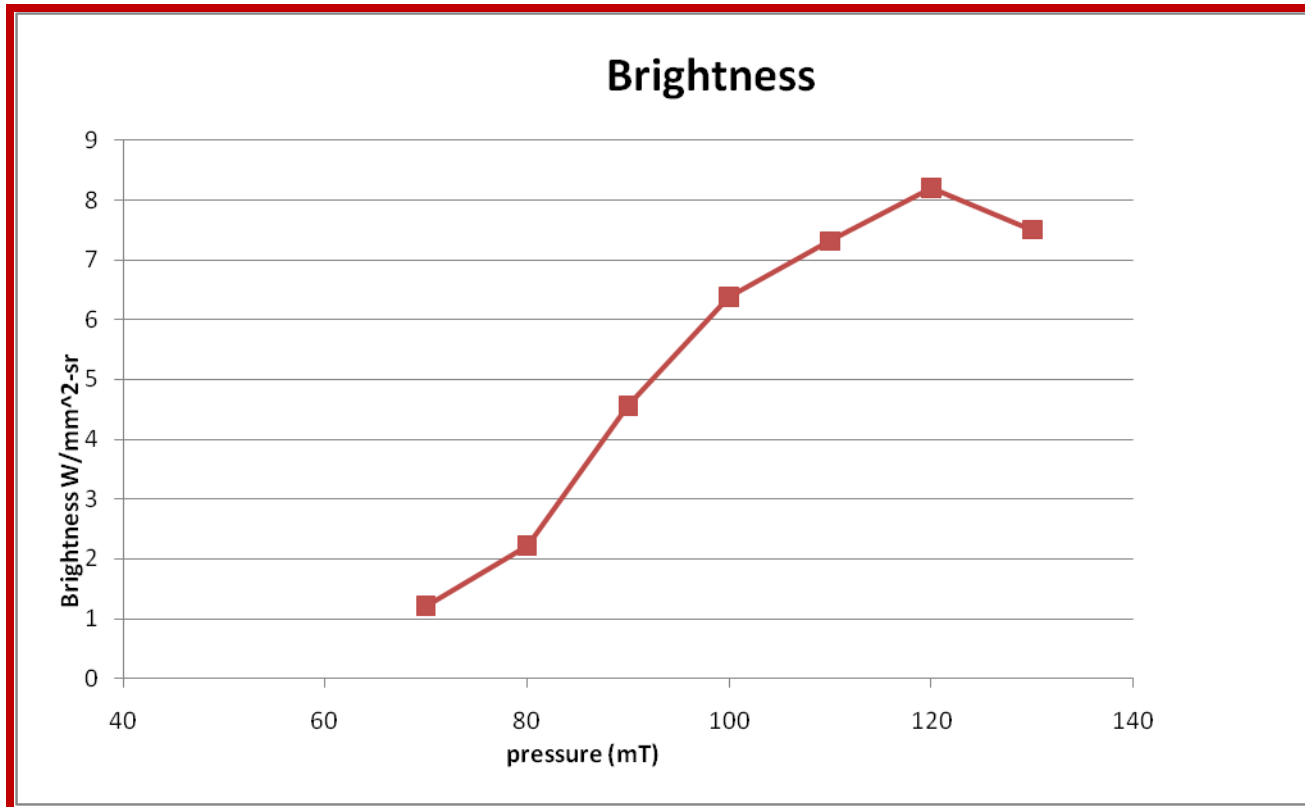
Power vs Pressure



Size optimized with Pressure



Optimizing Brightness with Power and Pressure

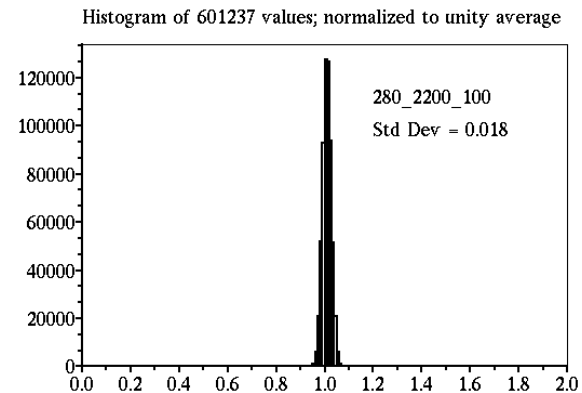
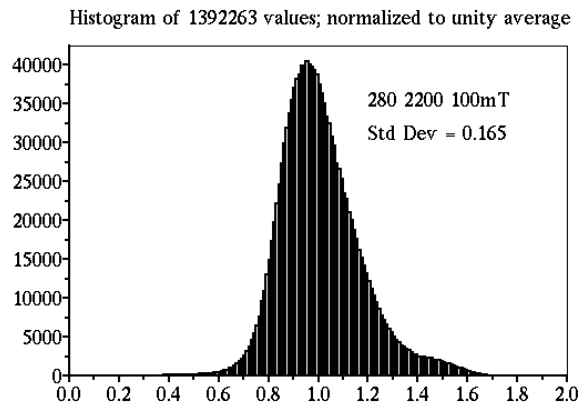


Improvements to Pulse Modulator

- The modulator was recently redesigned to improve power handling and stability.
- The redesign is to force the compression stages to a well-defined state prior to each charging cycle, thus reducing or eliminating this source of variability

•Pulse to pulse stability with Original Modulator – ~16%

•Pulse to pulse stability with redesigned Modulator ~2%

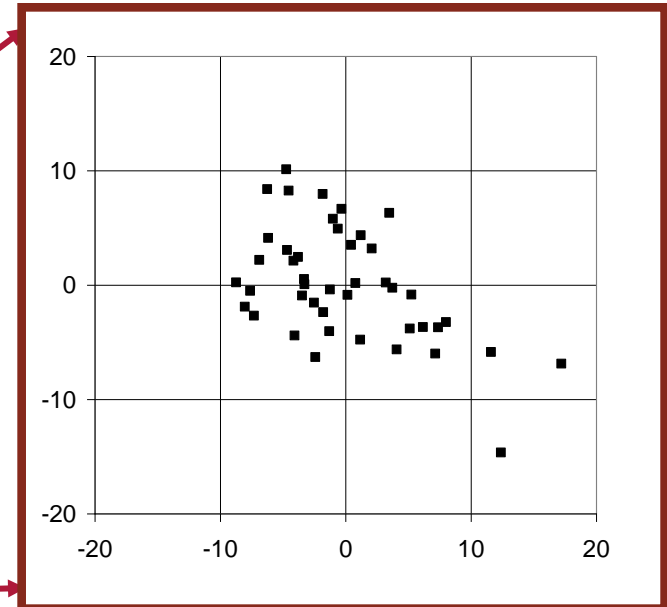
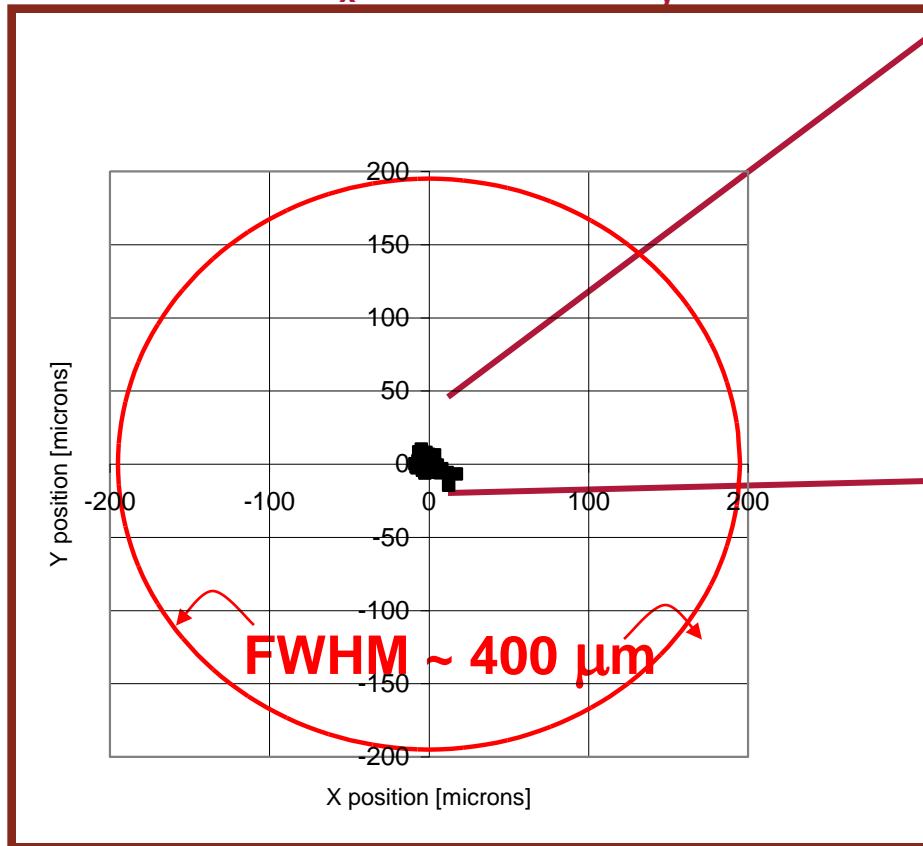


•Conditions: 280V,2200Hz,100mT

Stability in EUV Plasma Position

- Image recorded once an hour for over 300 million pulses (~44hours) of continuous operation. Position then extracted from images:

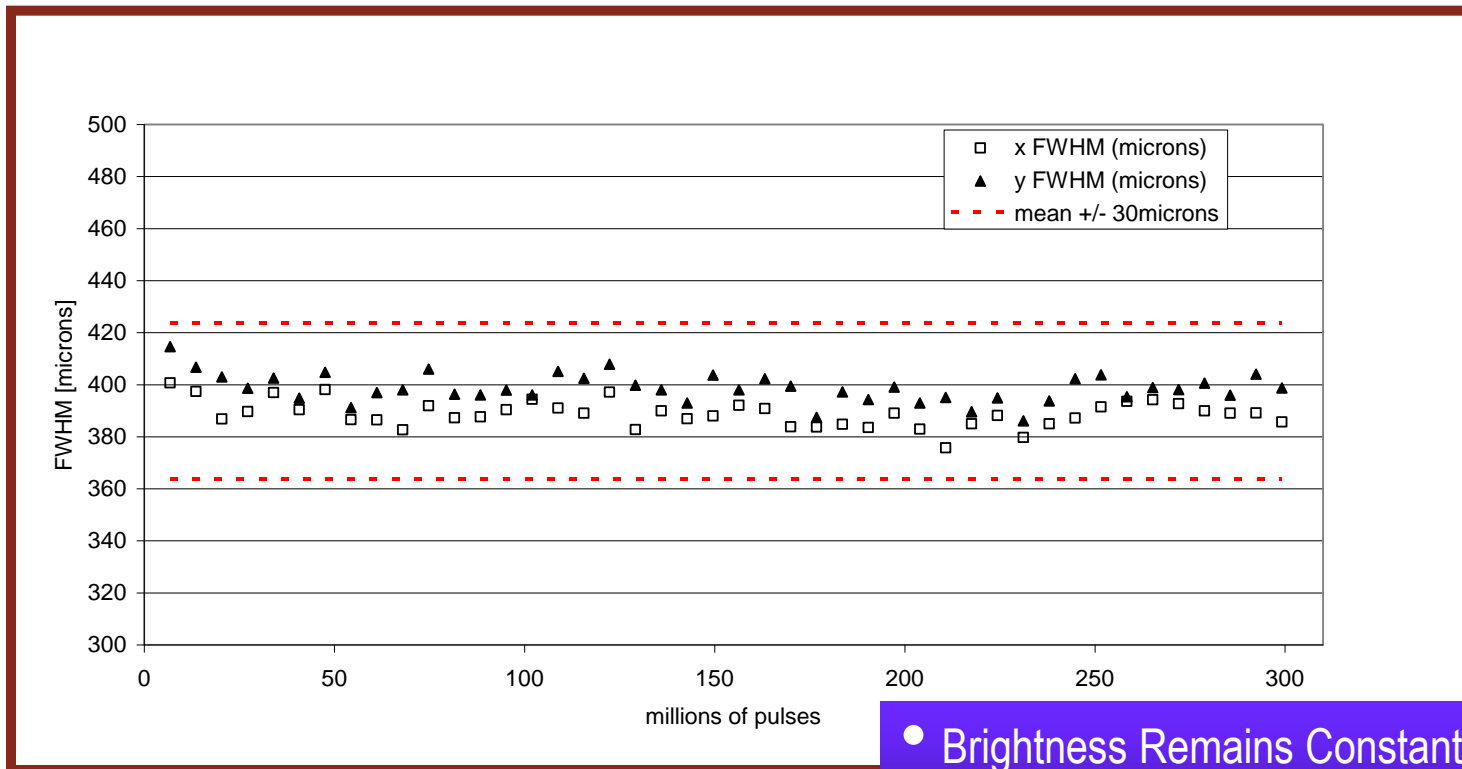
– Position: $\sigma_x = 5.8 \mu\text{m}$ and $\sigma_y = 5.0 \mu\text{m}$



- Brightness remains constant
- This is open-loop stability: No feedback!

Stability in EUV Plasma Size

- Image recorded once an hour for over 300 million pulses (~44hours) of continuous operation. Size then extracted from images:
 - Size: $\sigma_{FWHM_x} = 3.1 \mu\text{m}$ and $\sigma_{FWHM_y} = 3.6 \mu\text{m}$



- Brightness Remains Constant
- This is open-loop stability: No feedback!

Closing Remarks

- The Energetiq EQ-10 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 years!
- Energetiq Sources are being used for infrastructure development globally.
- Redesign of the source offers higher power and higher brightness operation
 - Brightness of $\sim 8\text{W}/\text{mm}^2\text{-sr}$
 - $20\text{W}/2\pi$
 - Continued excellent plasma and pulse-to-pulse stability

Acknowledgements

- The team at Energetiq...
- Our valued customers...
- Our excellent partners and collaborators...



Thank You

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