

Development of a High Average Power Extreme-Ultraviolet Electric Capillary Discharge Source

Status:

- Produce 14 mJ in-band EUV over π sr
- Short-term operation at 1 kHz to produce 14 W
- 1 kHz steady-state operation testing in progress

Advantages:

- Direct and efficient electric discharge EUV production
- Simple and compact footprint
- Scalable to multi-kHz operation
- Low Xe pressure at source output region
- Etendu well-matched to β -machine requirements
- Pulse-on-demand

Disadvantages:

- Capillary erosion and required replacement
- Debris mitigation required to eliminate condenser contamination
- Materials experience high temperatures in vacuum environment

Supported by EUV, LLC and International Sematech under LITH 114



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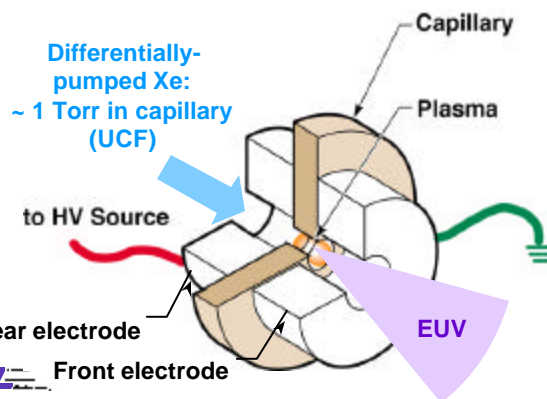
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1

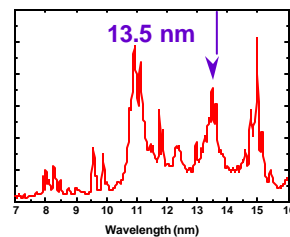
Capillary Discharge Source Overview

Approach

- Concept originated by Silfvast & Klosner/UCF
- Direct electrical \rightarrow EUV energy conversion
- 1 kHz, 14 W source in development
- 5 kHz, >50 W source needed for b-tools
- Lifetime improvements being developed



EUV Output Spectrum



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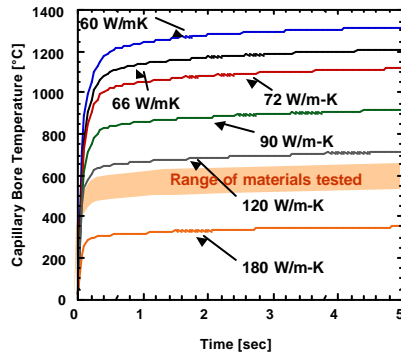
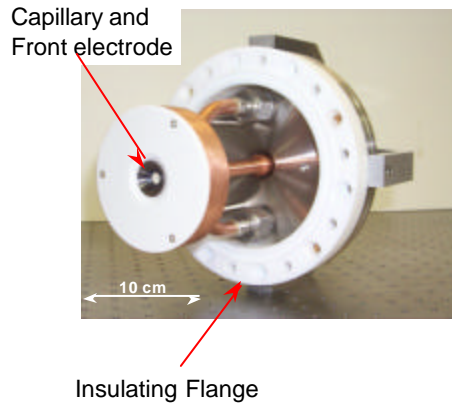


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2

Fabrication of first generation high-repetition rate lamp complete

Thermal analysis predicts lamp capable of continuous operation at 1 kHz



- Estimate 1500 W absorbed power into the capillary (~half of applied pulse energy).
- Nominal measured radial conductivity ~140 W/m-k.



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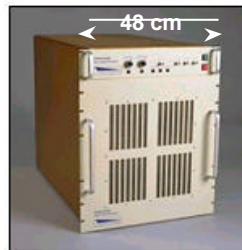
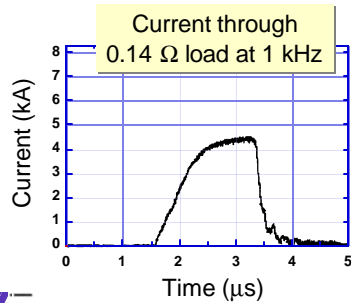
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Testing of high-repetition-rate pulser in progress

- Operation at repetition rates up to 1 kHz
- 5000 A at 1500 V output
- Selectable pulse duration from 0.5 - 4 msec
- Pulsed and simmer pre-ionization for improved stability and reduced lamp erosion
- Total power dissipation ~7.5 kW at 1 msec pulse duration



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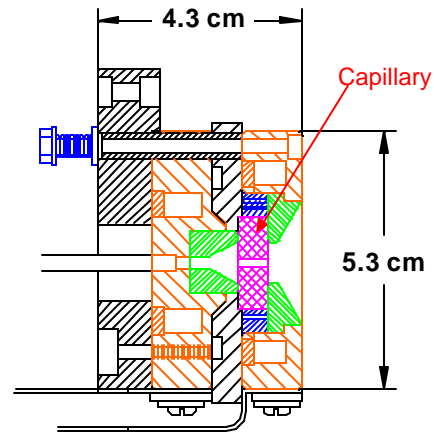
4



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Lower Inductance achieved with second generation high-repetition-rate lamp

- Faster current rise-time
- Reduced power dissipation in pulser
- Better cooling of capillary and electrodes
- Smaller footprint to avoid obscurations in existing large-angle condenser designs



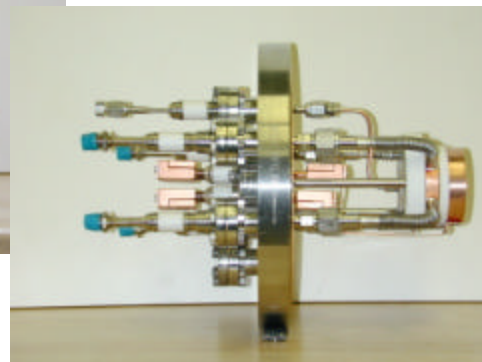
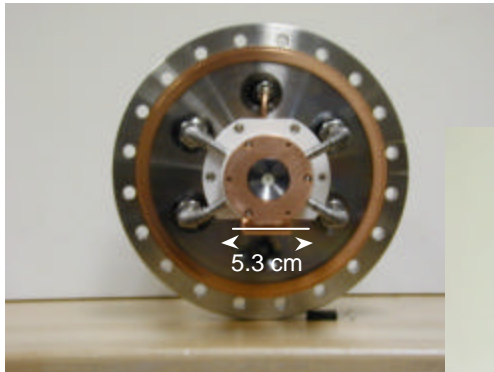
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5



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Second generation high-repetition-rate lamp assembly completed



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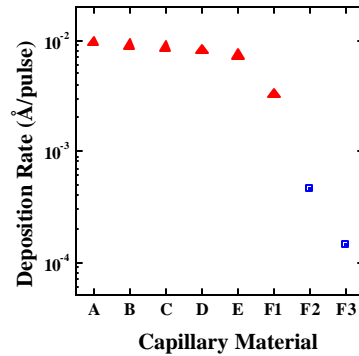
6



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Debris generation has been reduced by ~70x

- Analyzed debris on witness plate after 100,000 shots at 20 Hz
- Three important breakthroughs
 - Capillary material
 - Electrode design
 - Electrode material



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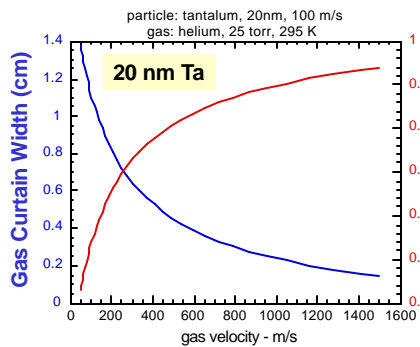


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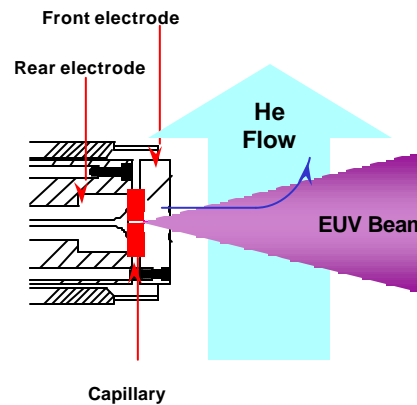
7

Gas curtain being developed to block lamp debris

Flowing, EUV-transmissive gas used to sweep debris out of EUV beam path



Plot of calculated "gas curtain" width for a fixed 60 degree deflection of 20 nm particle



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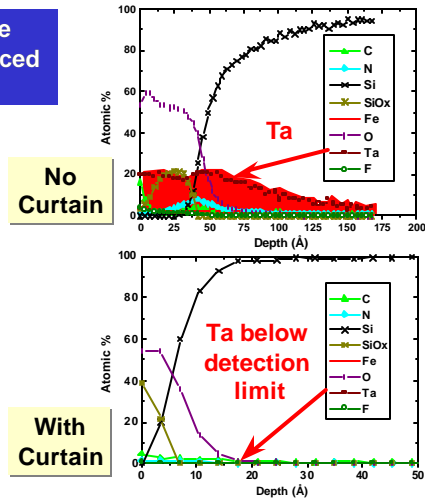
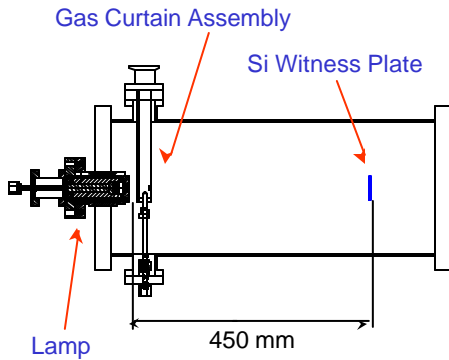


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8

Significant debris reduction obtained using prototype gas curtain

With gas curtain and 190 mTorr He background, Ta deposition rate reduced >40x after 10⁵ pulses



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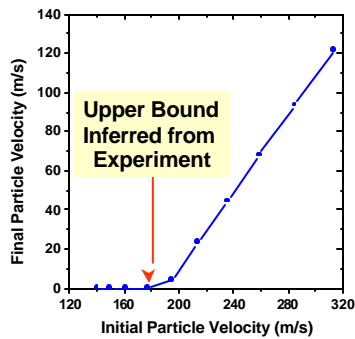
9



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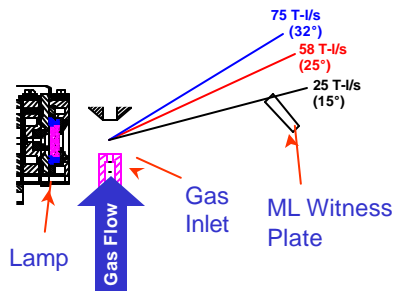
Estimates of Ta particle initial velocity and resulting deflection by 2nd generation gas curtain

Inferred Initial Velocity



Velocity of a 20 nm Ta particle in 190 mTorr He after traveling 450 mm

Predicted Deflection



Trajectory of a 20 nm Ta particle with an initial velocity of 175 m/s as a function of He flow rate



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10



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2000 → 2002 improvement path

Issue	Improvement path
Power scale-up and thermal management	Higher conductivity capillary materials Improved heat extraction Multiplexed lamps - 4 lamps at 1.5 kHz each
Condenser lifetime improvements	Preionization Electrostatic deflection Higher conductivity capillary materials
Capillary replacement	Improved materials Rapid replacement engineering
EUV output stability	Preionization Dynamic pulse compensation



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11



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Summary

- Capillary discharge power scaling in progress to 1 kHz and 14 W; multiplexed sources likely to be required for >50 W operation
- Debris *production* reduced 70x from material improvements and its *deposition* reduced additional >40x with gas mitigation
- Challenges remain in additional capillary and condenser lifetime improvements (~10x/yr) and thermal management

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12



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13



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