HIGH POWER LITHIUM DISCHARGE EUV SOURCE

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PLEX HAS MADE MAJOR PROGRESS ON A LITHIUM EUV SOURCE

IT HAS DEVELOPED WAYS TO RELIABLY CONTROL LITHIUM

IT HAS PRODUCED HIGH POWER EUV IN LITHIUM AT HIGH EFFICIENCY

THE EFFICIENCY IS HIGHER THAN ACHIEVED FROM ANY OTHER SOURCE

THE POTENTIAL FOR USING LITHIUM IN HVM IS NOW VERY HIGH

STATUS OF LITHIUM SOURCE DEVELOPMENT

The Li Z-Pinch can be a target for laser heating or a source in its own right
This presentation will not discuss laser heating

Pinch optimization is in process, within the following parameter range:

Pinch length	1.5mm --> 6mm
Pinch diameter	< 1mm
EUV emission duration	> 1μsec (quasi-steady)
Repetition rate	20Hz --> 2kHz
Continuous run duration	200 sec --> 2000 sec

Achievements:

70mJ (13.5nm) / 4πsr / 1mm length / pulse @ 200Hz for 600sec

160mJ (13.5nm) /4πsr / 1mm length / pulse @ 1kHz for 300sec

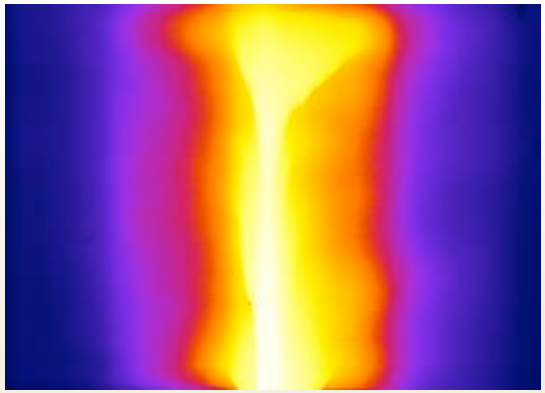
Steady operation at 15mJ, 20Hz for > 2000 sec

The 1kHz demonstration with 2π collection and 33% transmission would give **27W** at IF for 300 sec.

PINHOLE CAMERA IMAGES of LITHIUM Z-PINCHES

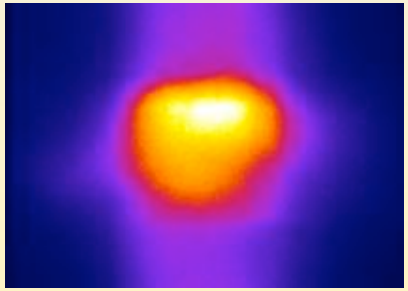
300nm Zr filter, 0.25mm dia. pinhole, Roper Scientific camera (courtesy Cymer)

1kHz, 50 pulses superimposed



Pinch length 4.5mm

200Hz, 20 pulses superimposed



Pinch length 1.5mm

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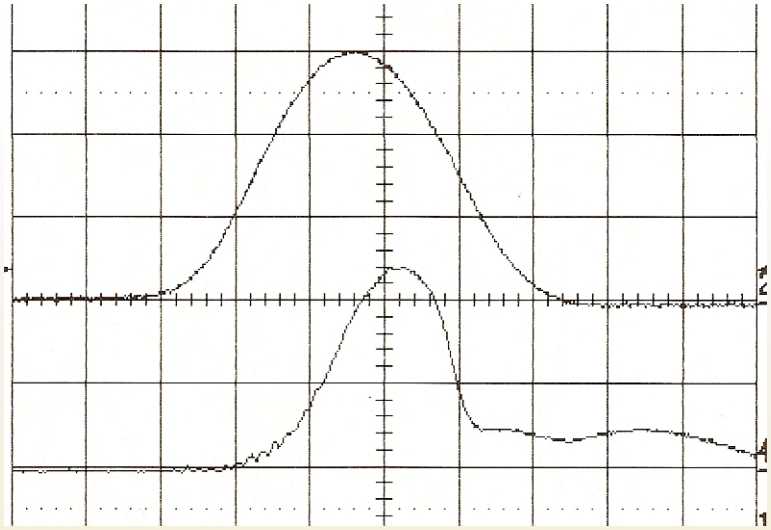
EUV DIODE WAVEFORM of LITHIUM Z-PINCH

Diode: SXUV 100 Si/Zr (IRD) Pinch: 200Hz, 70mJ/mm
Diode "window" approx. 12nm (decreasing) to 20nm

Pinch current
(arb. units)

EUV signal



Time (500 nsec/div)

Diode response < 50nsec, EUV "tail" is a saturation effect

The lithium Z pinch has demonstrated >10% efficiency (2π sr, electrical to 13.5nm).

EUV emission is quasi-steady for 1μsec

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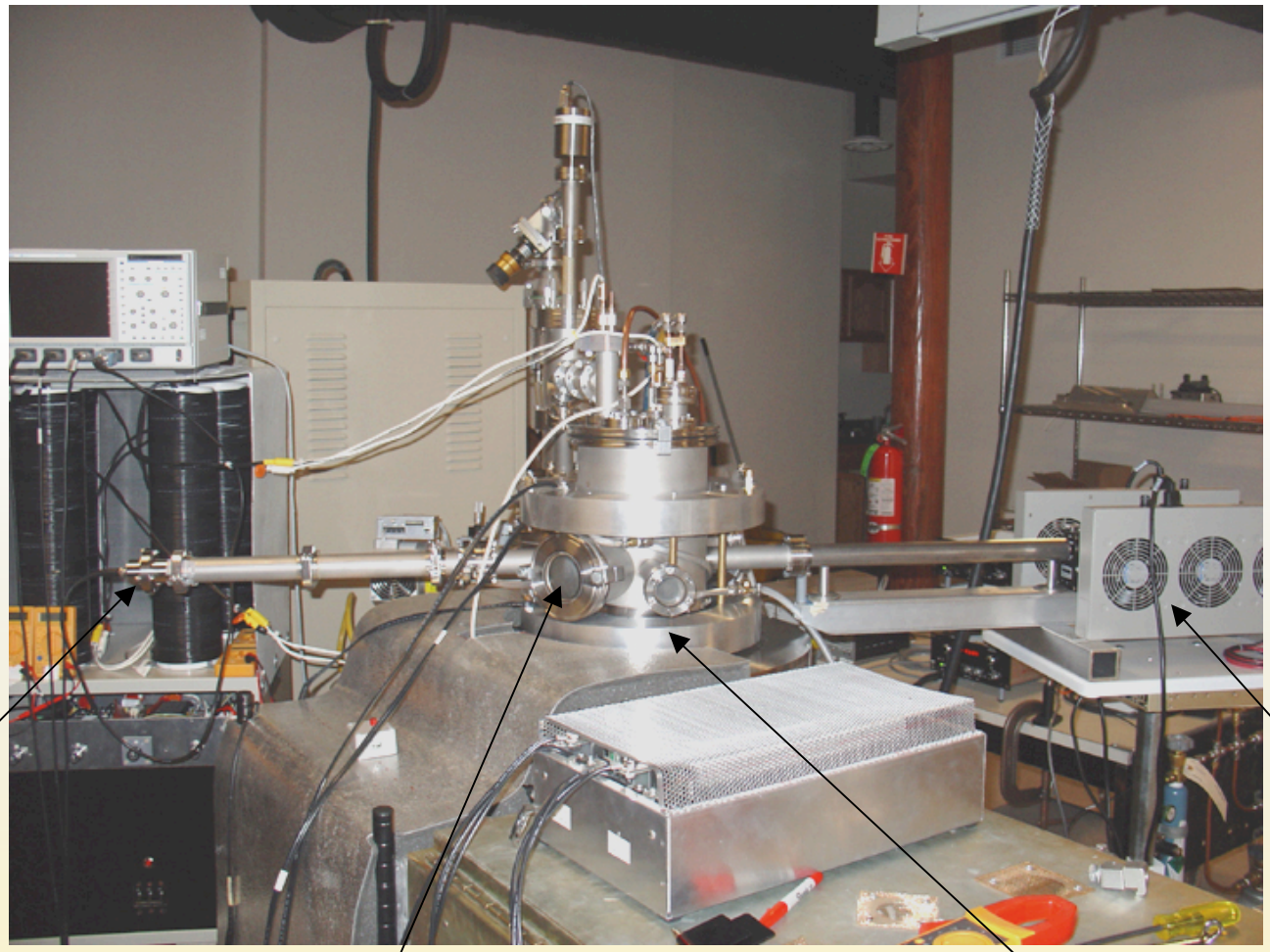
Absorption measurement of plasma density and pinch duration



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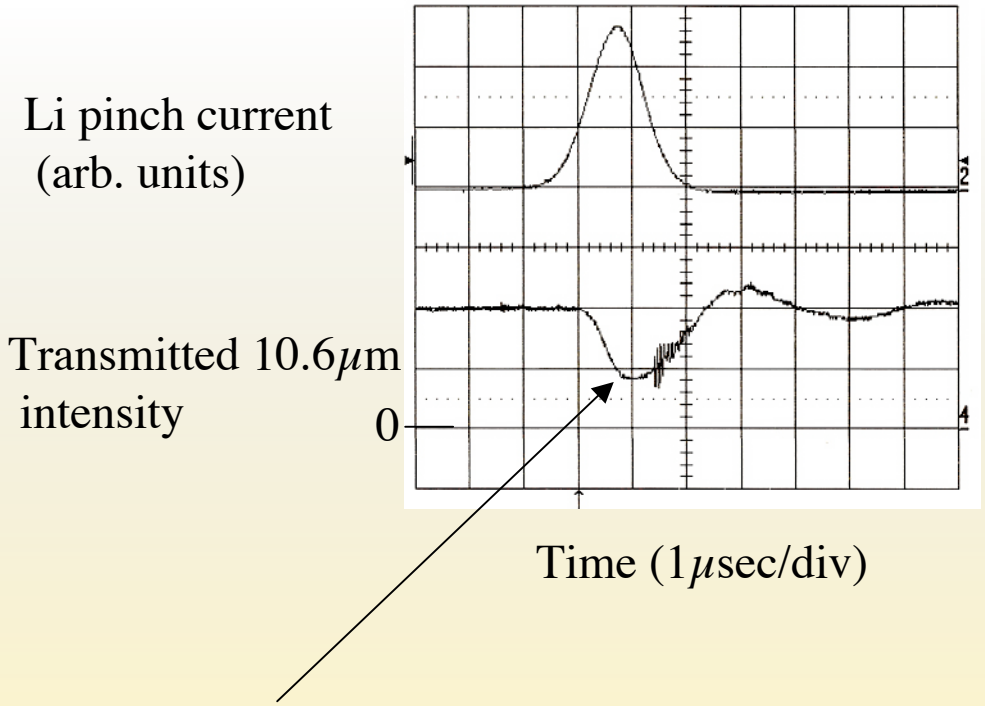
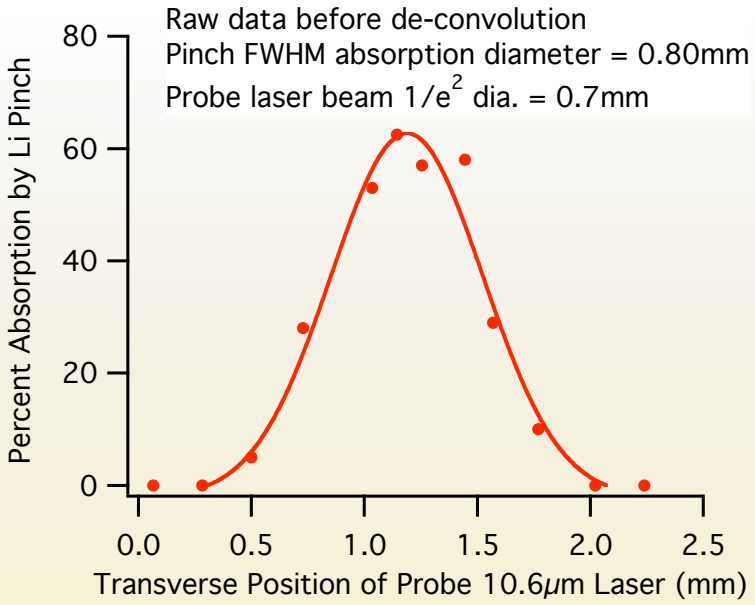
Data on Plasma Radial Profile in Z- Pinch

Conditions: 2kHz Li pinch, perpendicular CO_2 10.6μm laser, spot size 0.7mm (1/e^2 dia.).
Polarization parallel to pinch

Time Dependence of Absorption



Transverse Scan



60% absorption stable for approx. 1μsec, terminated by disruption

Lithium Containment

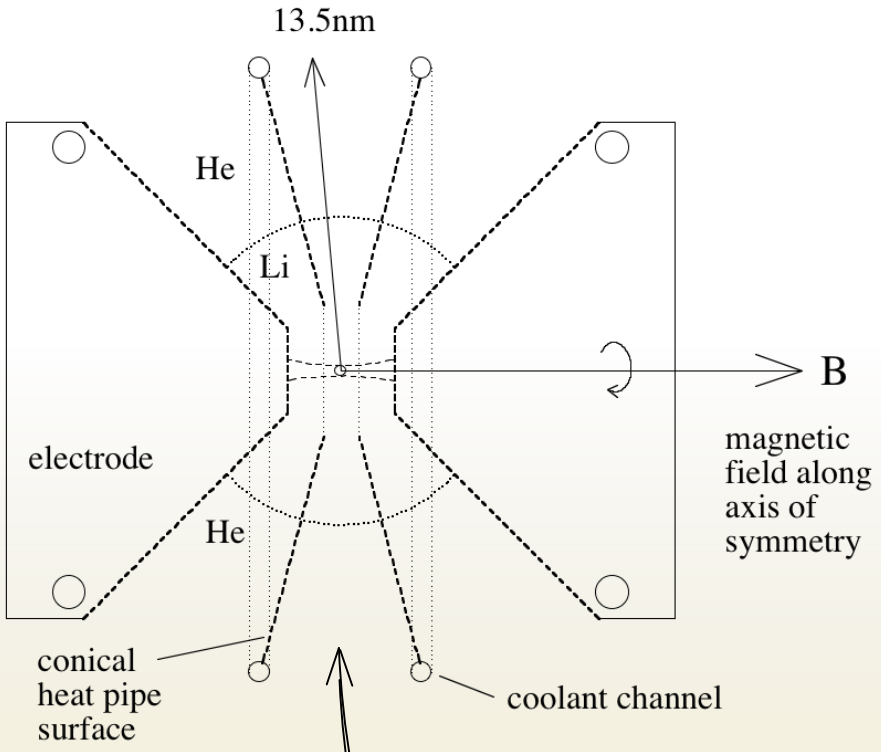
This difficult problem has been solved via the "Wide Angle Heat Pipe"

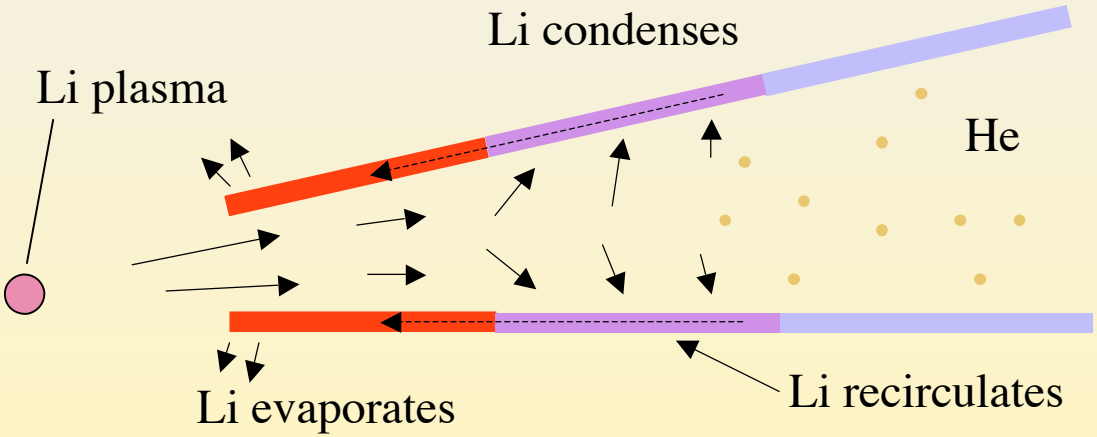
a) Recirculates Li. Total inventory 1g

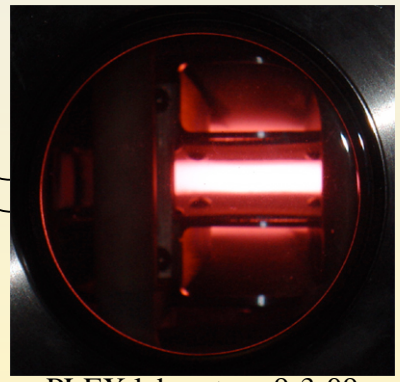
b) Blocks plasma exit (aided by B field)

c) Provides > 5sr collection

d) Prevents Li reaction: Mo and He only







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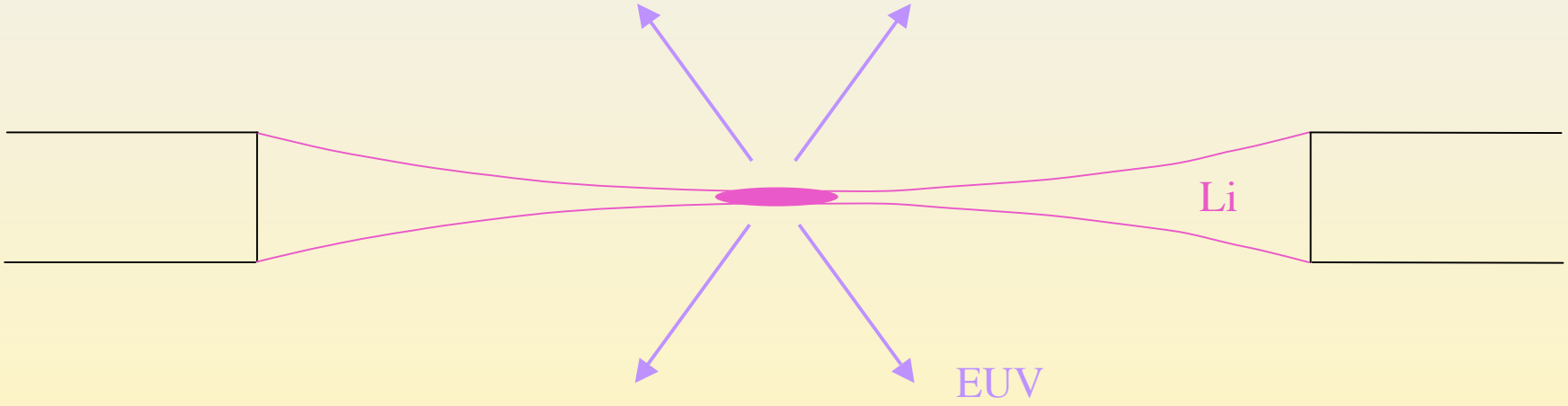
Z-Pinch Physics: Stability, Repetition Rate and Life

a) Stability: Symmetrical ignition scheme ensures < 0.3mm positional stability
Parallel magnetic field stabilizes "run down"
Experimental stable pinch duration >1 μs

b) Electrode Life: Sputter threshold Li^+ on Mo is 35eV. Cathode fall with Li is < 15eV (dependent on electrode design). Consequently, negligible sputter erosion.

c) Maximum Hz: Acoustic velocity in exhaust gas at 2000K is 1.5 x 10^5 cm sec^{-1}
25mm typical dimension with 3 transits => 20kHz.

d) Dissipation: Heat input to Pinch (mainly Ohmic) < 2J/pulse.
< 1kW cm^{-2} on surrounding surfaces, dominated by EUV.



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Planck Limit to Source Radiative Power

a) Electron excitation is not the limiting rate

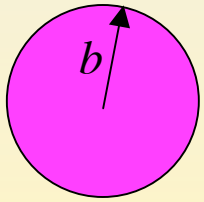
b) At the typical source dimension the Planck black body spectrum *P* limits power

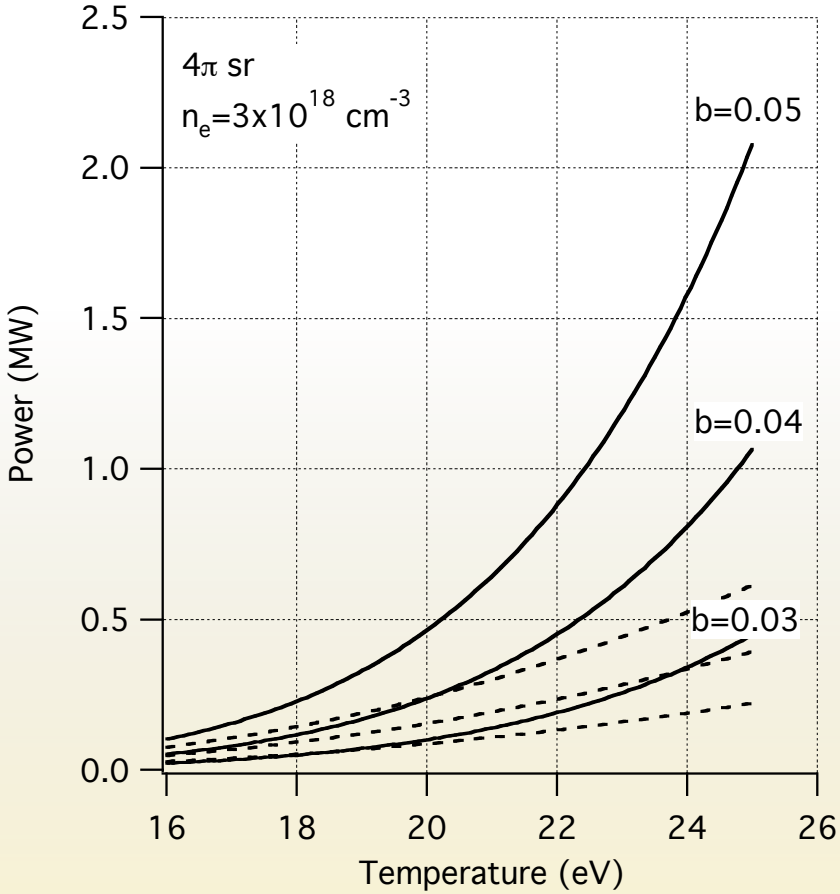
For a source sphere of radius *b*:

$$P_{\Delta\lambda}(b,T) = \frac{2\pi hc^2}{\lambda^5} \frac{4\pi b^2 \Delta\lambda}{\left[e^{\frac{hc}{\lambda kT}} - 1\right]}$$

c) Calculated bandwidth $\Delta\lambda = 9\text{x}10^{-3}$ nm
Doppler + some collisional broadening
Optical depth > 100

Source sphere, radius *b*





Excitation 13.5nm power (solid lines) and Planck radiative power (dashed lines) for source of radius *b (cm)*

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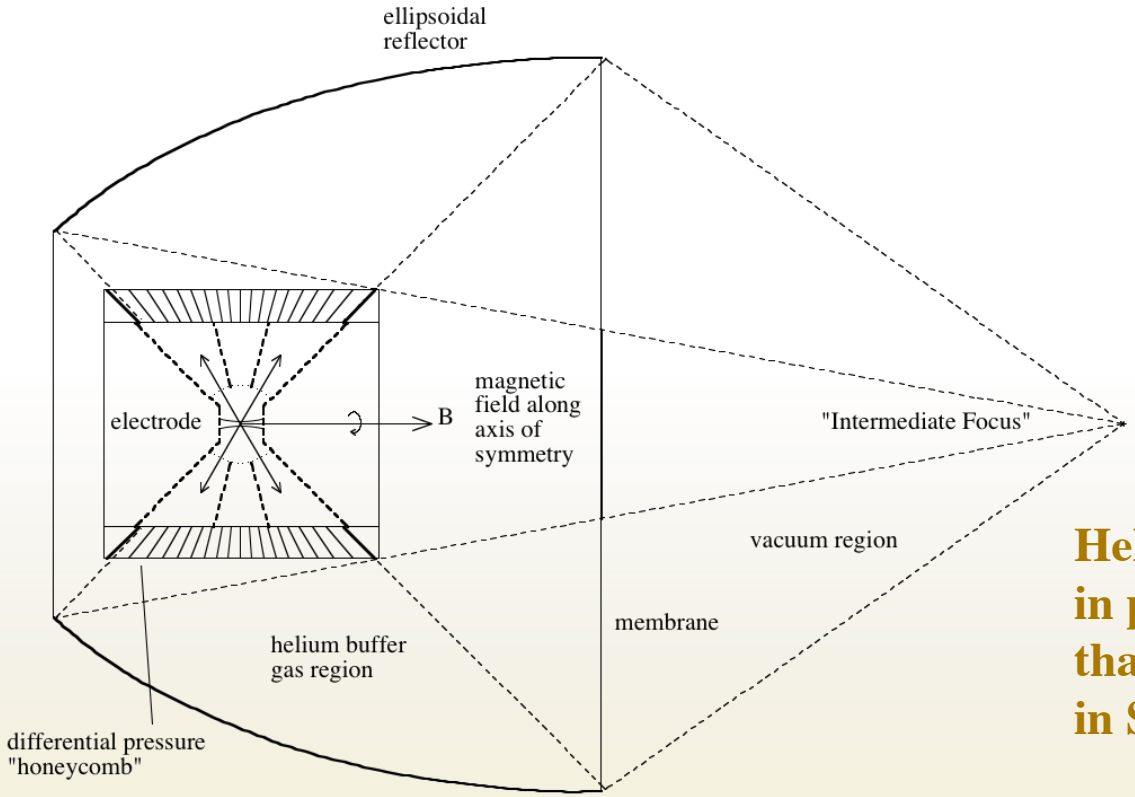
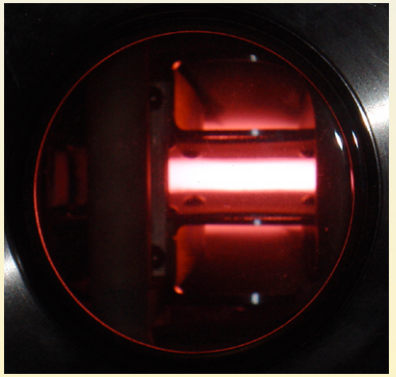
Proposed SoCoMo Design for Lithium Discharge Source



Helium buffer protects window in present experiment showing that multilayer will be protected in SoCoMo design

Optical element/medium	Transmission
1*cm* Li vapor at $3x10^{16}cm^{-3}$	0.95
5*cm* helium at an average of $6x10^{16}cm^{-3}$,	0.85
"honeycomb" differential pressure screen	0.8
15*cm* helium at an average of $2x10^{16}$ cm^{-3}	0.85
Multilayer mirror	0.6
Membrane	0.75
Total transmission	**0.25**



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SUMMARY

- **The lithium Z pinch has demonstrated >10% efficiency (2π sr, electrical to 13.5nm).**
- **The pinch has operated at 1kHz emitting 160mJ/mm for >300sec.**
- **The 1kHz result extrapolates to 27W at IF, multiplexing to >200W at IF.**
- **Future work will test laser heating of a small region within the lithium Z pinch to enhance EUV production.**
- **The source is relatively simple.**

A lithium source will provide the power needed for HVM