Lithium Discharge EUV Source

Malcolm W. McGeoch

PLEX LLC
Brookline, MA
617-277-4480
mcgeoch@xuv.com

The Star Pinch plasma source of 13.5nm radiation has achieved excellent power and life scaling with xenon as the working gas, but lithium offers higher EUV production efficiency and the most pure spectrum for ease of use in lithography. Additionally, lithium should extend the discharge life by orders of magnitude over xenon because its low-energy product ions have very small sputtering rates on the walls of the discharge chamber. The use of metals in EUV sources is very difficult, but it appears that the use of lithium vapor in equilibrium with lithium metal at 700C will reliably generate the desired vapor density for the star pinch type of discharge. We have constructed and operated a star pinch discharge in lithium using a heat pipe configuration so as to prevent lithium migration out of the discharge chamber, or onto the discharge insulators. Tests have been performed with argon or helium as the heat pipe containment gas and higher EUV production efficiency has been achieved using helium. Results will be reported from these and additional experiments and projections will be made for the ultimate scaling of this type of EUV source.

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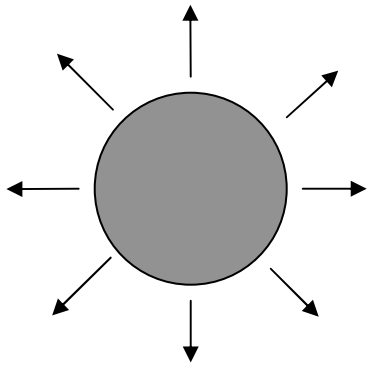
Lithium plasma only produces low energy particles



IP (LiI) = 5.392 eV

IP (LiII) = 75.641 eV

LiIII = radiating species

Electron temp = 15eV = ion temp

Asymptotic ion energy = 126eV

Contrast with tin or xenon which have 1keV asymptotic energy

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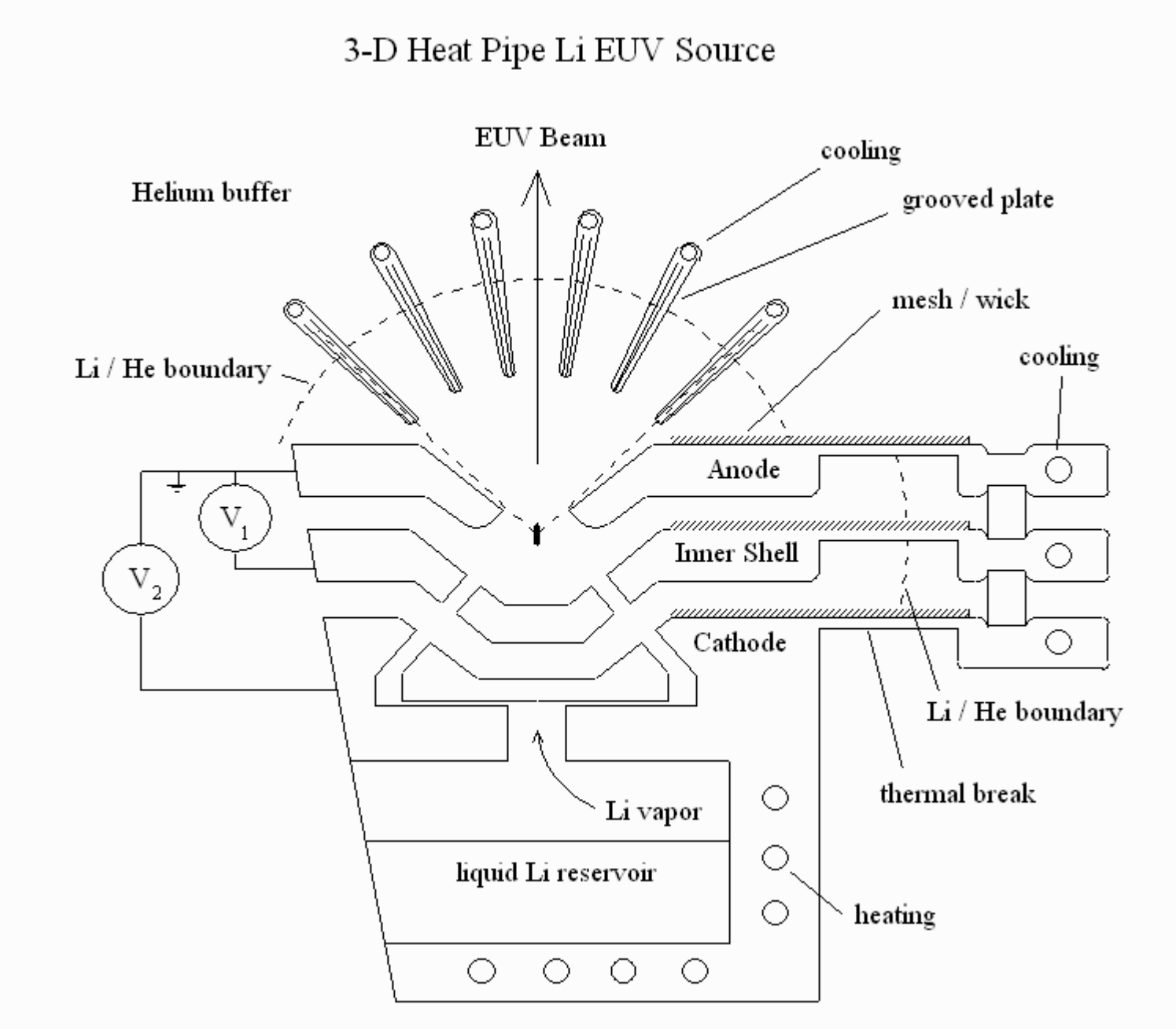
3-D Heat Pipe Li EUV Source
EUV Beam
cooling
Helium buffer
grooved plate
mesh / wick
Li / He boundary
cooling
Anode
V_1
Inner Shell
V_2
Cathode
Li / He boundary
thermal break
Li vapor
liquid Li reservoir
heating

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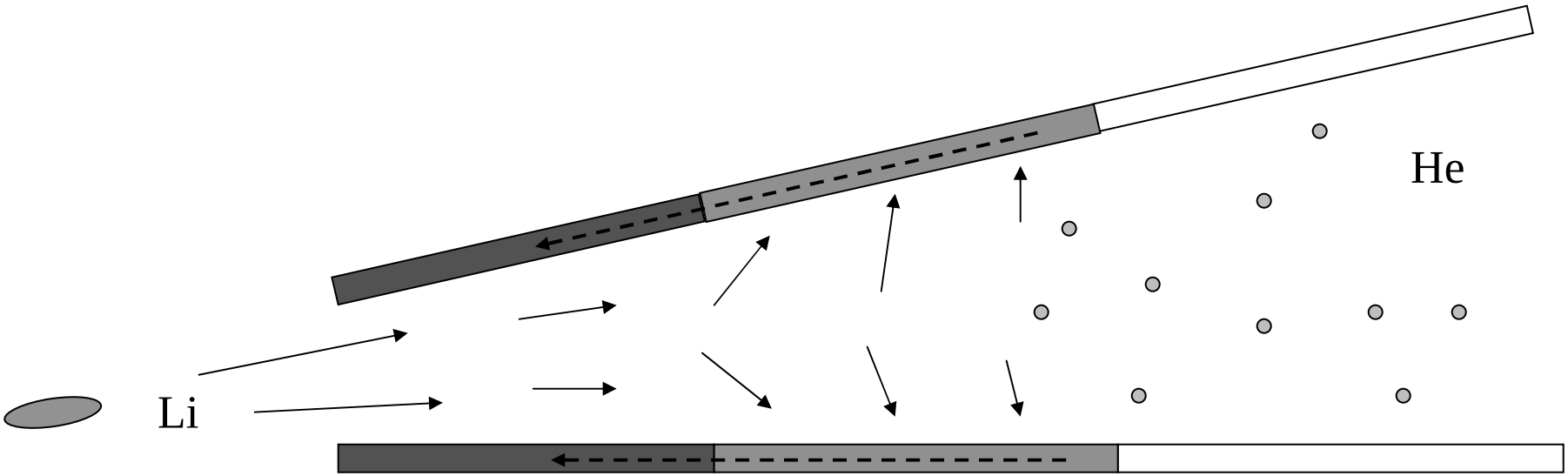
The heat pipe is a “debris” barrier!

Problem is measured by momentum per ion $\sqrt{2E_i M_i}$

Li momentum per ion = 0.086 x Sn momentum per ion



Li is recycled!

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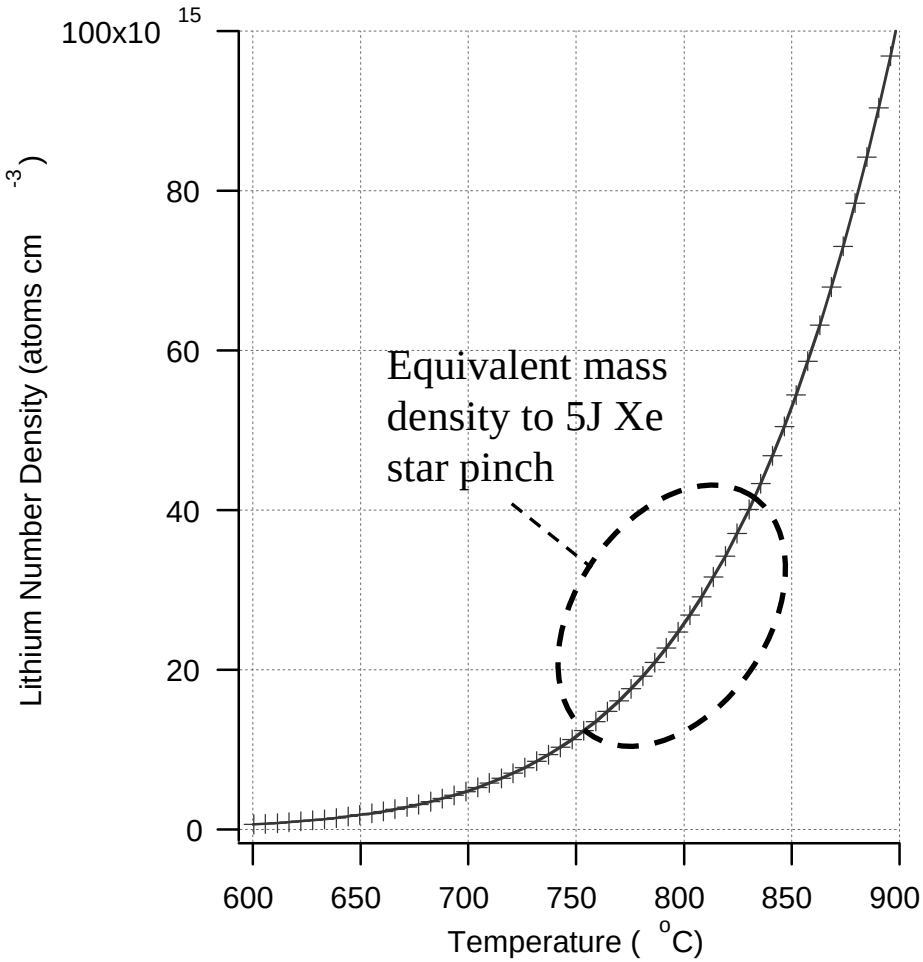
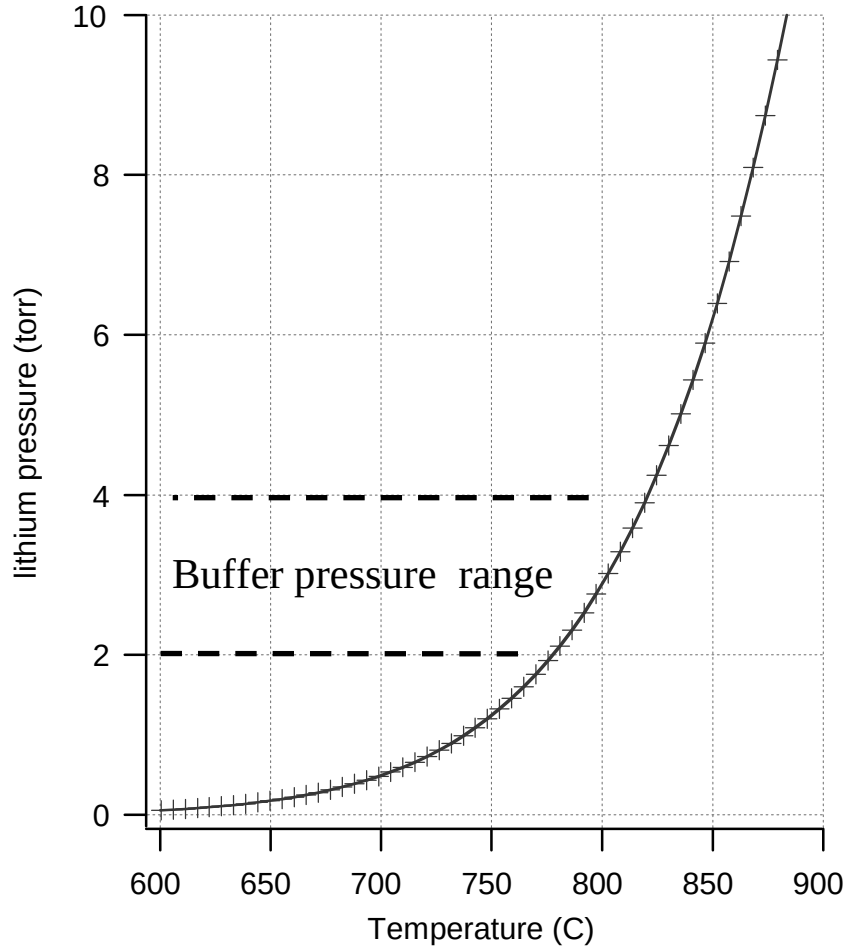
Lithium density requirement sets temperature





=> Li star pinch expected to be optimum at 800C

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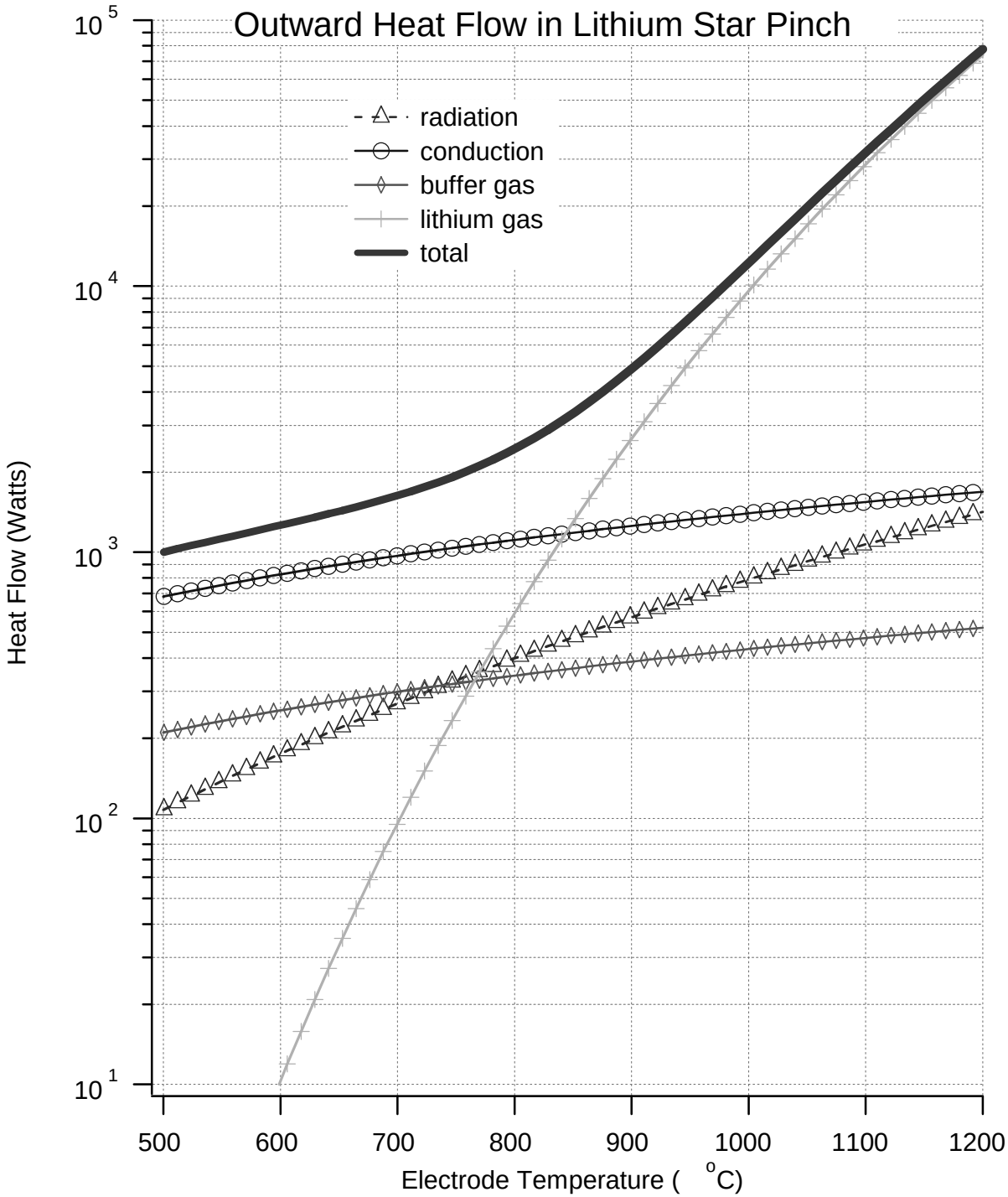
Outward Heat Flow in Lithium Star Pinch
radiation
conduction
buffer gas
lithium gas
total
Heat Flow (Watts)
10 5
10 4
10 3
10 2
10 1
500
600
700
800
900
1000
1100
1200
Electrode Temperature (oC)

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Thermal Management (50kW)

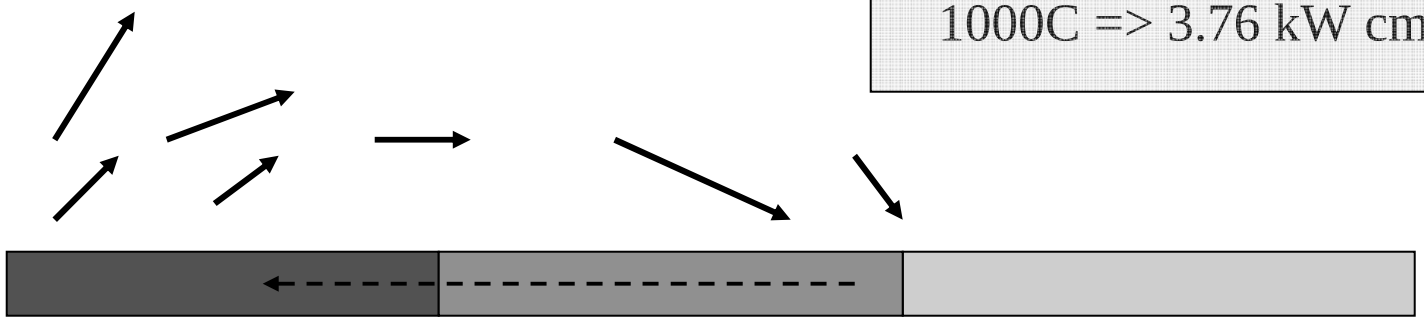
Li evaporation rate $G = 3.5 \times 10^{-8} \dfrac{\exp\left(1.5 \times 10^{-2} T\right)}{\sqrt{T}}$ g cm^{-2} sec^{-2}

Latent heat of evaporation = 19.6 kJ g^{-1}

800 C => 204W cm^{-2}

900 C => 877 W cm^{-2}

1000C => 3.76 kW cm^{-2}



Heat removal by Li itself!

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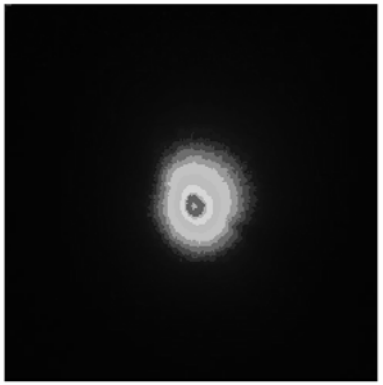
Results as of 11-1-05

1. Li star pinch operated to 700C
2. Not optimized: >4mJ/sr/pulse “in band” at 13.5nm
3. Efficiency >0.6%, is already greater than Xe efficiency
4. 100% Li containment
5. Proof of principle established
6. If 2%, Li star pinch offers scaling to >200W for HVM
7. Low sputter rate offers $>10^{10}$ life for HVM

PLEX xenon and lithium EUV source models

	EUV-125-Xe	EUV-625-Li (*)	
13.5nm energy /pulse	4.0	20	mJ/sr/2%band
Max. rep. rate	5.0	5.0	kHz (0.5 sec burst, duty factor 20%)
Max. in-band power	125W	625W	2π sr at 5kHz
Life to electrode change	$>10^8$	$>10^9$	pulses
Equivalent IF power	17W	80W	(assuming 2sr collection, at 5kHz)

(*) available 2006



XAPPER, Xe high energy irradiation system focal spot
1 Jcm^{-2} $pulse^{-1}$
Image courtesy LLNL

3.3kHz star pinch
test bed for Li and Xe development

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