EUV Source Concept: Scalable DPSS Laser and Contained Target Generator

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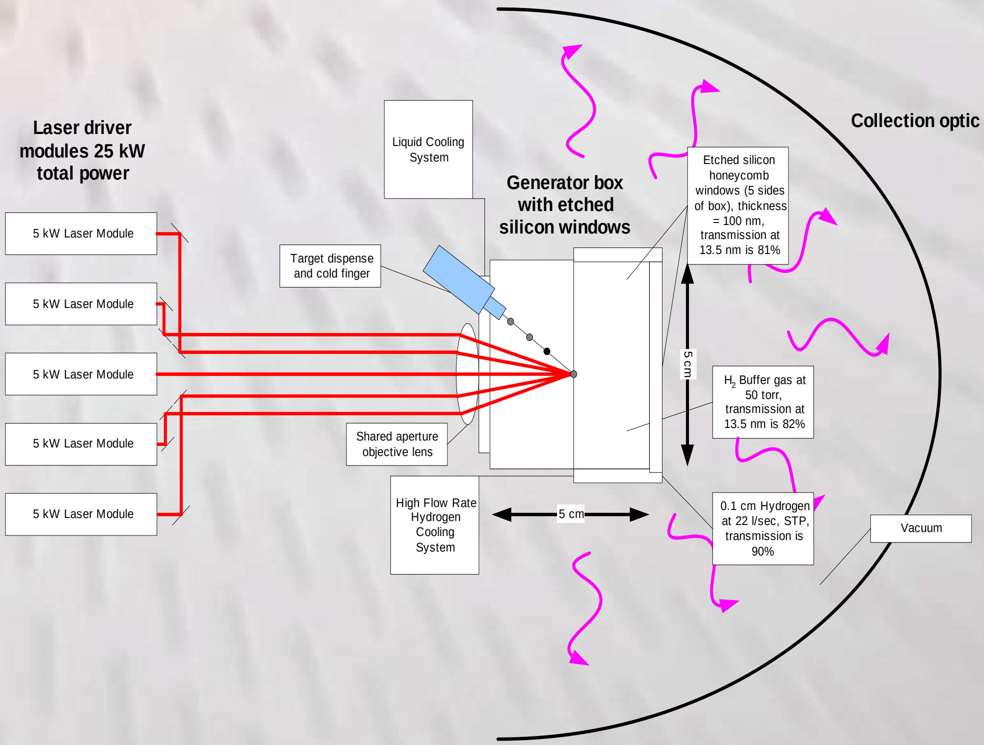
Agenda

- Introduction
- System Conceptual Design
- EUV Link Budget to IF
- Laser Design and Hardware
- Generator Conceptual Design
- Summary

Introduction

- Realize that Tin (or Lithium) needed to get a C.E. of at least double Xe
- Have devoted limited funding to Debris Management
- 3 Methods reviewed for Tin: Supersonic Flow & E/B Field Deflection
  - Results to date indicate all 3 may not be sufficient
  - Believe different approach may be needed

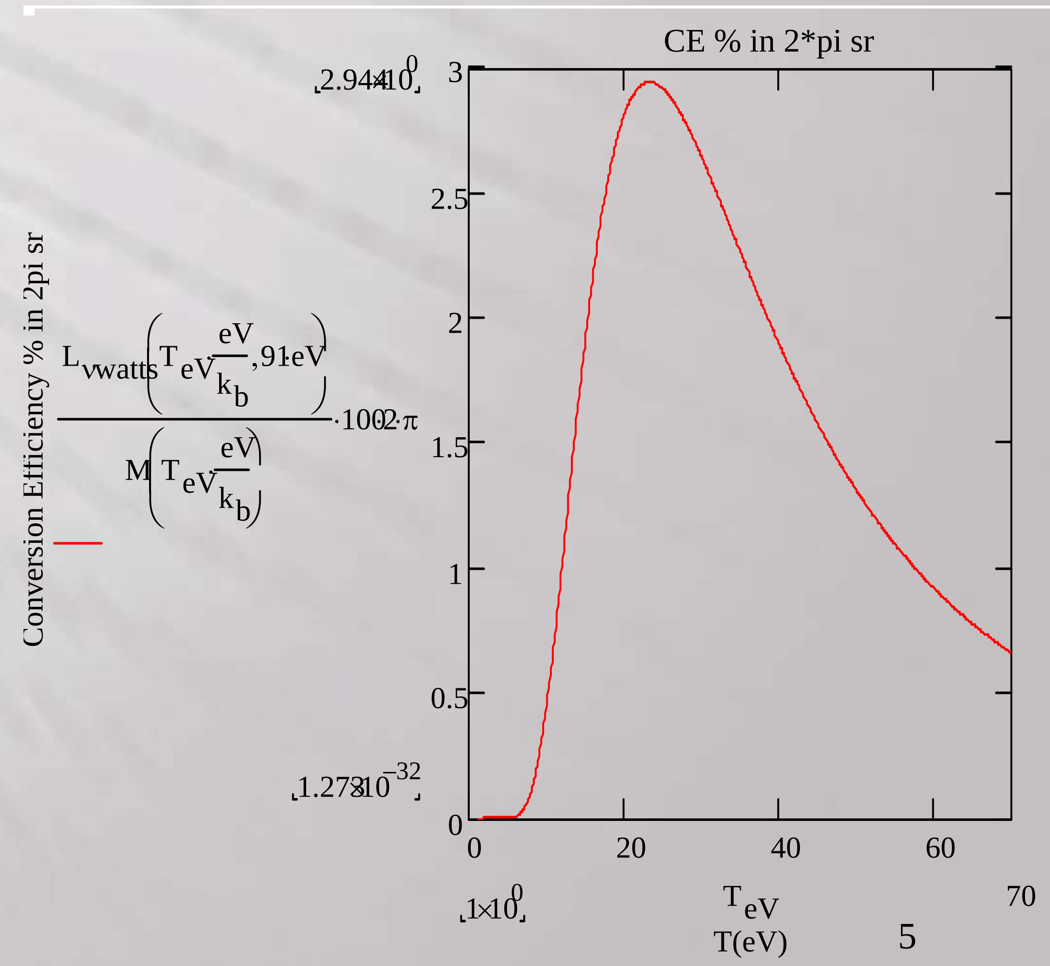
EUV Light Source System



- Sealed target chamber with EUV transparent windows
- Recycled micro-targets
  - Lithium
  - Tin
- High power DPSSL driver

Planck Fundamentals for EUV

- Assumes 2 J in 5 ns focussed to 500 micron spot
  - 5 x10^5 K maximum plasma temperature
- CE limit is less than 3%
  - This implies CE will probably be lower than this number
- FYI for x-ray source limit is >50% CE (due to large acceptable BW)



System Design Point Calculations

Source Parameter	Assumed Value	Notes
Average Laser Power	25000	W optical
Laser-Plasma Coupling Efficiency	80%	Range may be 70-90%?
Conversion Efficiency	3%	Sn or Li target (Skeptical)
EUV 2% BW, 2π sr	600	
Collection Efficiency	50%	2π sr, OK with LPP
Collector Efficiency	70%	Mirror reflectivity
DM Window Inner	80%	CXRO data on Silicon
DM Window Outer	80%	CXRO data on Silicon
Gas Transmission (buffer)	82%	CXRO data on Hydrogen (H2)
Gas Transmission (cooling)	90%	CXRO data on Hydrogen (H2)
EUV @ IF	99.1	W optical
Required Wallplug Power	62500	W electrical

Laser Requirements: EUV vs. X-Ray

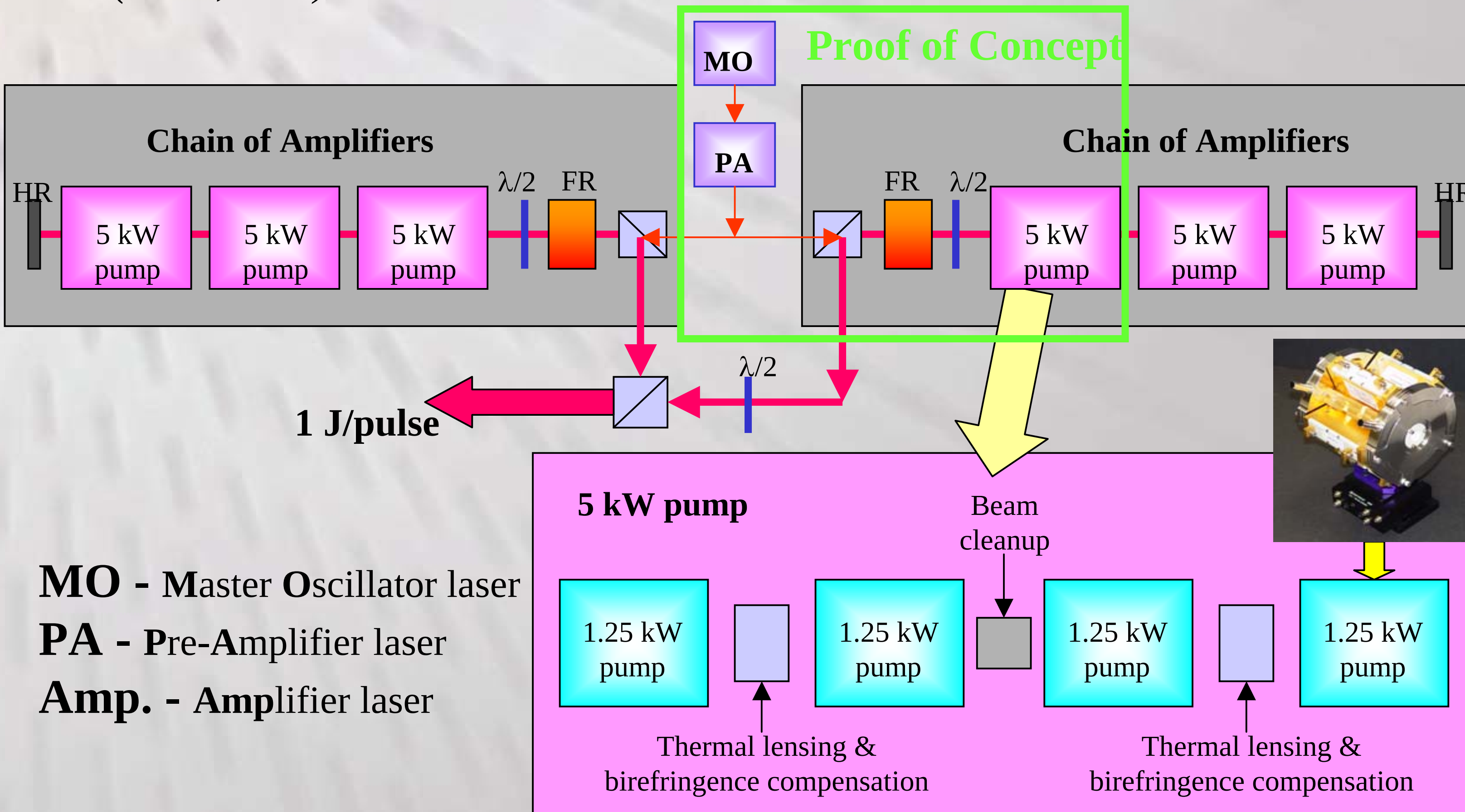
Parameter	EUV	XRL
Brightness (W/cm^{2})	10^{11}	10^{15}
Pulse Duration (ps)	~5000	700
Beam Quality	~5X DL	< 2X DL
Power (W)	25,000	300 –1,000
Rep. Rate	5kHz-30kHz, CW	300 Hz-1000 Hz, QCW

- EUV laser is less challenging in brightness and therefore time and space parameters can be relaxed
- EUV laser is much more challenging in average power

EUV Source Laser Architecture

CW Pumped Nd:YAG Laser System

(5 kHz, 5 kW)



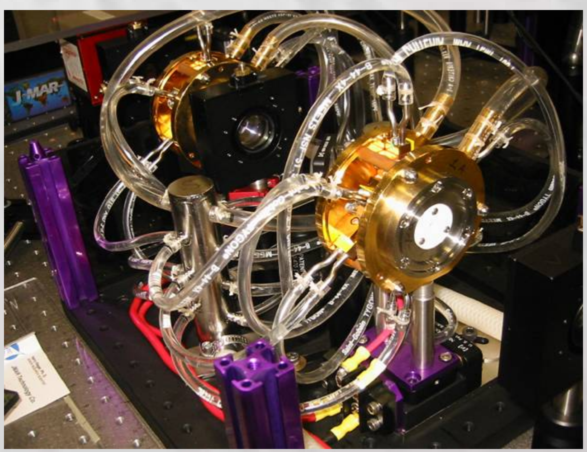
MO - Master **O**scillator laser

PA - Pre-**A**mplifier laser

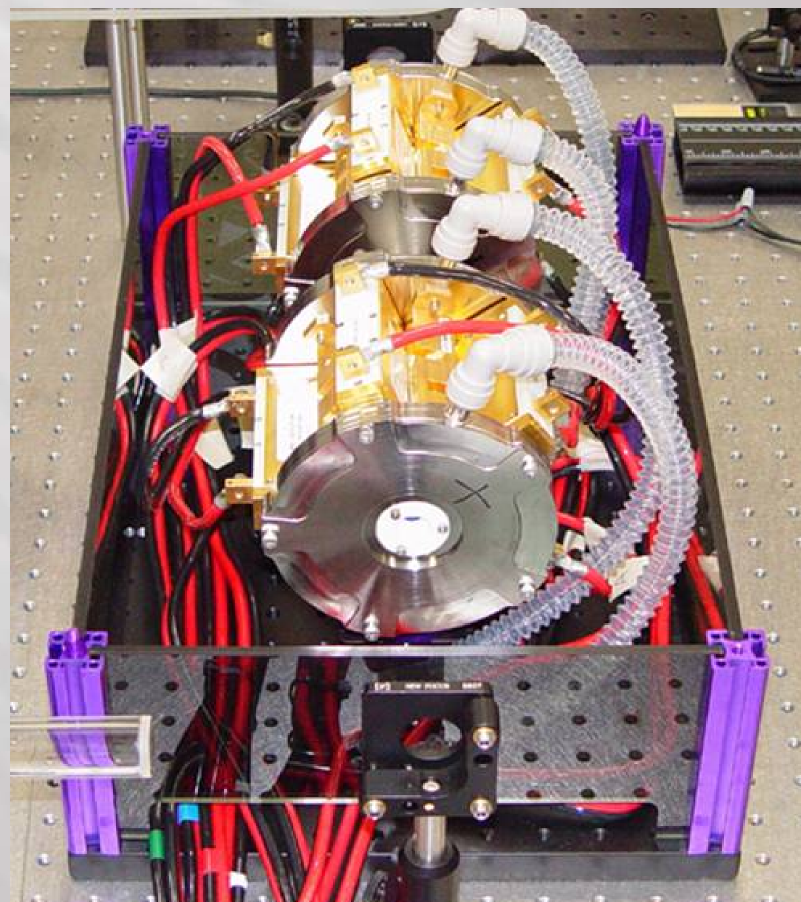
Amp. - Amplifier laser

Laser Subsystem POC Hardware

120W Pumped MO Head



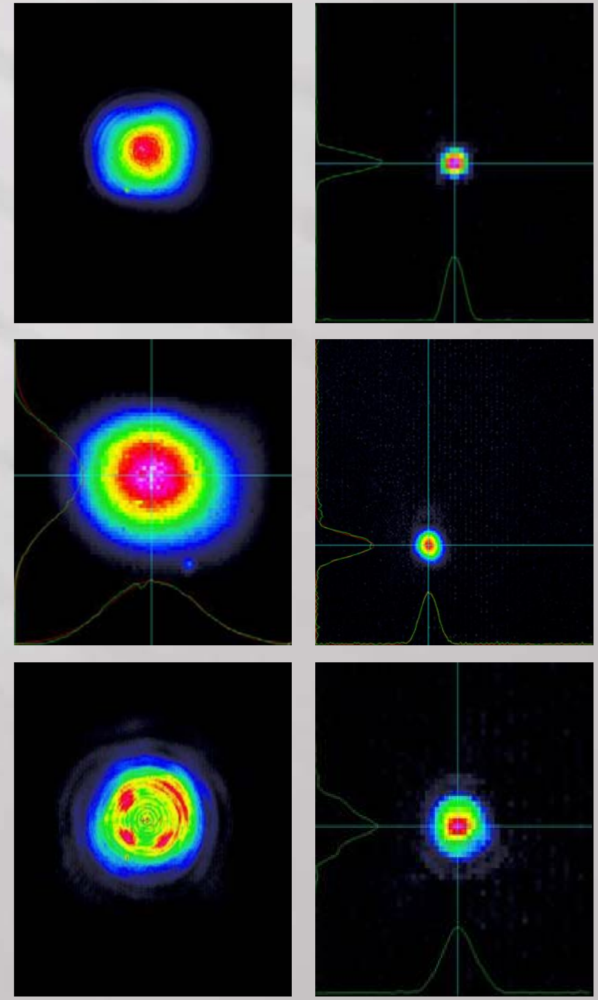
Two 240W Pre Amp Pump Heads



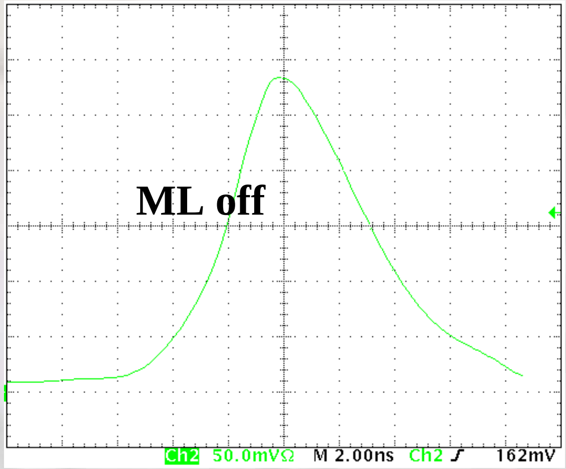
1.25 kW Pumped Amp. Head

Laser Performance: Spatial Quality

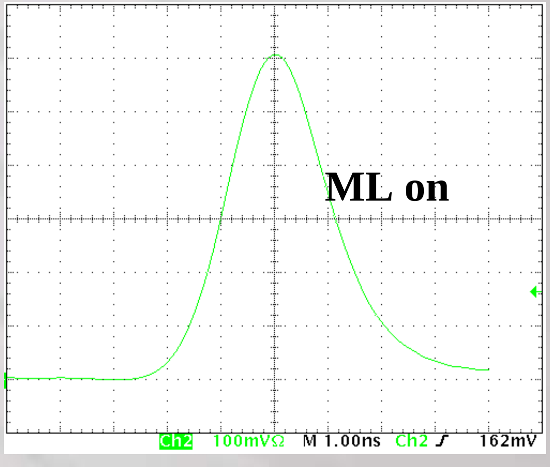
- Master Oscillator near and far fields approximately diffraction limited
- Pre Amplifier near and far fields approximately diffraction limited
- Amplifier near field ringing, yet far field is approximately diffraction limited



Laser Performance: Temporal Quality



5.5ns FWHM



2ns FWHM

- Mode locker allows pulse to be short and therefore high intensity
- Pulse width is selectable from 1-9 nsec

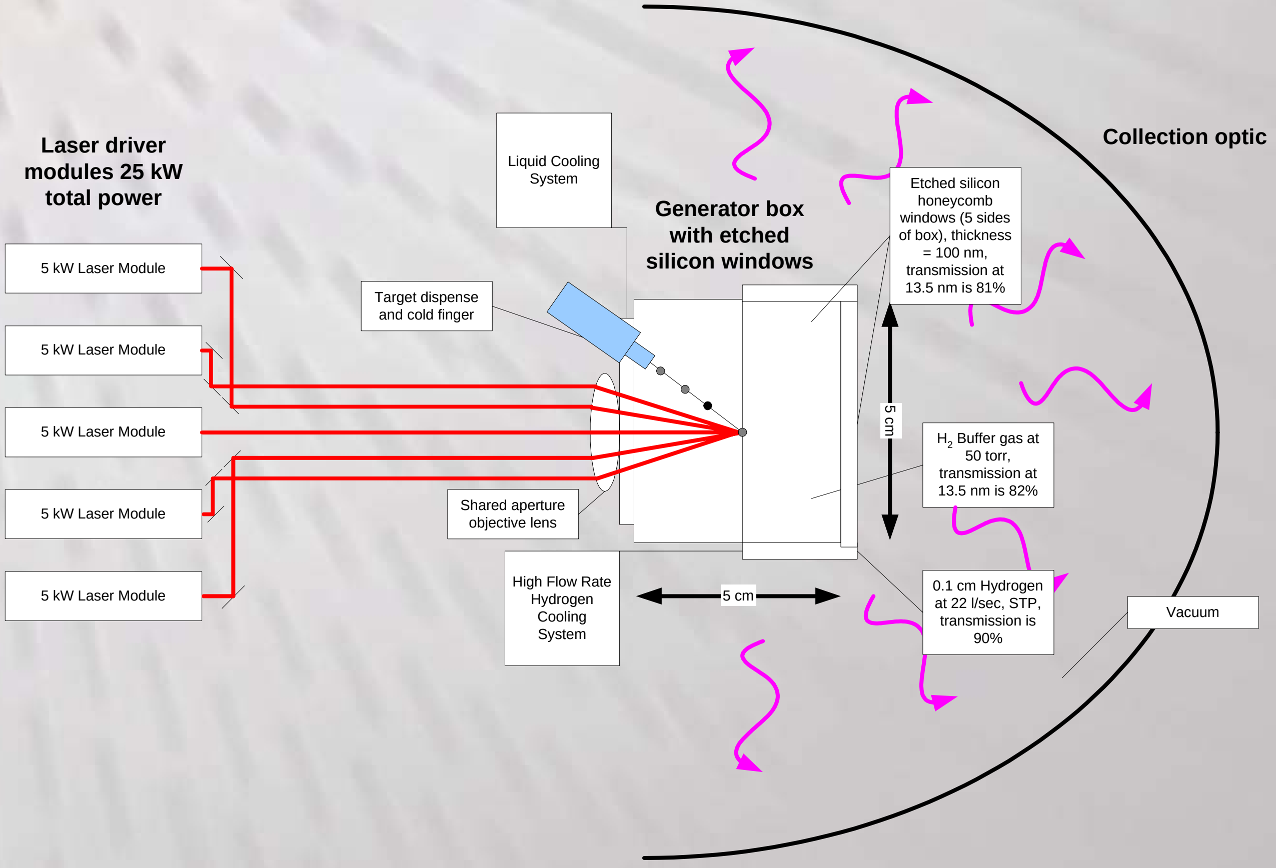
Laser Status

- MO completed successfully
- Pre-Amp completed successfully
- Design, fabrication, and assembly of Amplifier completed
  - Initial characterization of Amplifier met expectations:
    - Gain/head = 1.4,
    - Slope efficiency > 40%
    - Perfect thermal lensing compensation
    - Excellent polarization compensation
    - Single pass beam quality < 1.3xDL
  - Currently working on aligning thermal lens with optical axis, they are not coaxial making alignment difficult

Laser Scaling to High Power

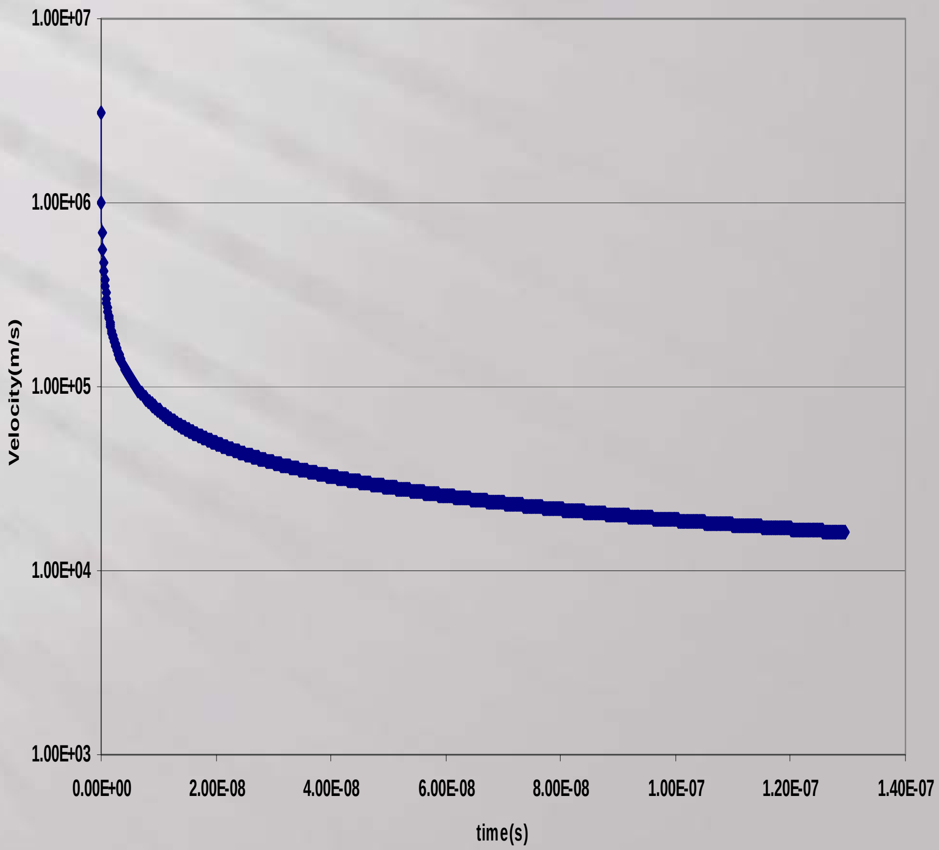
- Requires several amplifier chains, implies a beam clean up system will need to be employed
  - Difficult at high power
- If the system assumptions on earlier slide are used implies 25 kW laser. Geometry is five amplifier subsystems each producing 1J at 5 kHz (5kW)
- Beams can illuminate target simultaneously or time multiplex

Generator Concept



Snowplow Model for Debris and Buffer Gas

- Assumes:
  - 100 torr of H_2, (T=66% at 2.5 cm path length)
  - All debris and buffer gas is swept up in shock front
- "Final" velocity is 10^4 m/s
- Energy of debris or gas molecules is about 0.5 eV
- Silicon surface binding energy is about 4.7 eV
  - Should not be much sputtering of Silicon windows (Gaussian dist gives 1 in 10^9)
- Current x-ray system uses 0.2-0.4 micron polyamide windows for collimator protection and pressure hold-off



Thermal Calculations

- Gas cooled side
  - C_v for H_2 is 20.4 J/mol/K
  - Thermal resistance of Si window is nearly zero
  - For heat load of 25/2 kJ (half goes to liquid cooled side), $\Delta T = 500$ K, implies about 1 mole/sec of gas flow or about 1200 l/m
- Liquid cooled side
  - C_v for water is about twice H_2 , all scales linearly

Thermal Issues

- Laser heating
  - Cooling silicon windows with high flow rate hydrogen
    - Very high pump rate 1200 l/min
    - Inner windows still heat up to 500K
      - Bonding issues, CTE mismatch on window seal, others?
- Target material evaporation rate from walls > deposition rate on walls
  - Limits target materials (Maybe lithium only)
  - Lithium has very low vapor pressure at its melting point (10^{-10} torr), low vapor absorption

Source Roadmap*

EUV Source Development Milestones			
	Q105	**Q106**	**Q107**
Central wavelength	13.5 nm	13.5 nm	13.5 nm
EUV power in 2% bw (W)	40 W/2π	40W IF	115W IF
Collection solid angle	NA	2π	2π
Source emission area (mm^2)	0.01	0.01	0.01
Etendue(mm^2*sr)	0.06	0.06	0.06
Rep.rate (kHz)	0.3	5	5
Dissipated power in source region (kW)	0.3	5	25
C1 lifetime(shots to 0.9R)	2.00E+08	2.00E+09	2.00E+11

* Contingent on funding

Summary

- Generator is an engineering challenge, but no apparent showstoppers…….and would eliminate debris issues
  - Thermal management flow rates for hydrogen
  - Micro-target delivery/targeting recycling system
- Laser scaling to 5kW average power is within reason
  - Beam clean-up for few ns pulse is the challenge area
- A CE much less than 3% will significantly increase technical/cost issues