EUV Lithography Source System

Abstract

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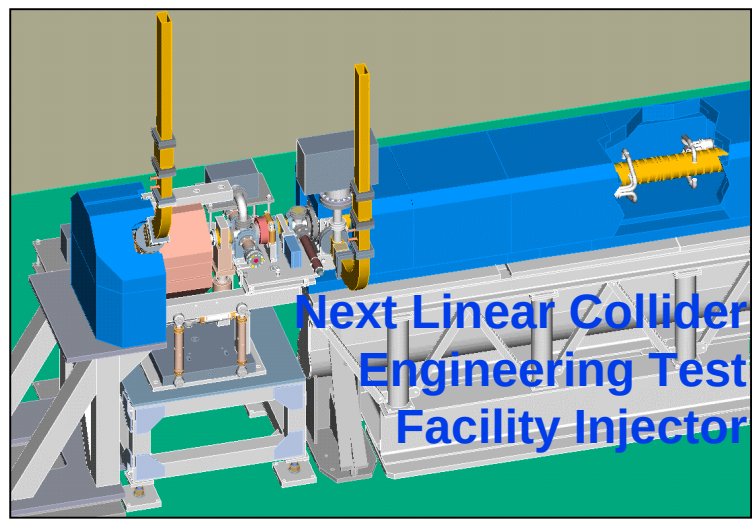
Advanced Energy Systems (AES) is developing Extreme Ultraviolet (EUV) light sources for lithography tools. A source test stand has been set up at the AES facility in Medford, New York, where the development program is centered. A top-level plan that addresses the requirements developed by the International Source Workgroup (ISWG) in March 2000 is presented. We also summarize the thermal analysis of full-power production systems and gas dynamics results from ongoing test stand experiments. A Cutting Edge Optronics (CEO) laser will be installed on the test stand shortly to enable EUV optimization and debris reduction development. It is planned to upgrade this laser to the kW level in 2001.

Part of this work was supported by the EUV LLC

Corporate Profile - AES

- **Privately held company incorporated in New York in September 1998 (formerly Northrop Grumman)**
- **Located in Medford, NY & Princeton, NJ**
- **Products:**
  - Advanced Radiation Sources
  - Turnkey Ion & Electron Beamlines
  - Accelerator Components
  - Engineering & Physics Services
  - Systems Engineering & Radiation Analysis
- **US & International Customers:**
  - Commercial
  - National Laboratories
  - Government
  - Universities
- **Markets:**
  - Semiconductor Manufacturing
  - Material Processing
  - Medical & Pharmaceutical Industries
  - Defense
  - Research & Development

TURNKEY SYSTEMS & COMPONENTS



AES Advanced Energy Systems, Inc.

AES Gas Jet Target System

Gas apparatus produces target for laser

US Patent # 6,133,577 & Published PCT Application: *Method & apparatus for producing extreme ultra-violet light for use in photolithography*

US Patent & PCT Applications Pending:

Holder assembly & method in an emitted energy system for photolithography

Emitted energy system for photolithography

Method & apparatus for adjustably supporting a light source for use in photolithography

Nozzle produces fluid flow

US Patent # 6,105,885 & PCT Application: *Fluid Nozzle System & Method in an Emitted Energy System for Photolithography*

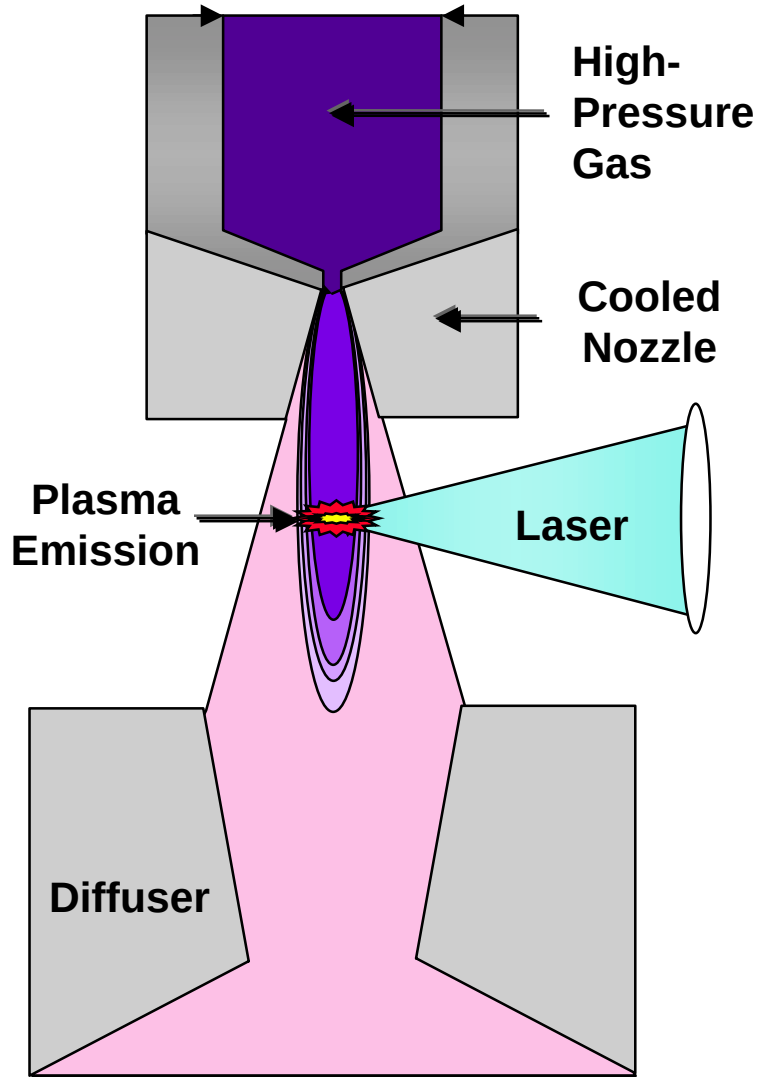
US Patent # 6,065,203 & PCT Application: *Method of Manufacturing Very Small Diameter Deep Passages in an Emitted Energy System for Photolithography*

Diffuser collects & recycles majority of flow

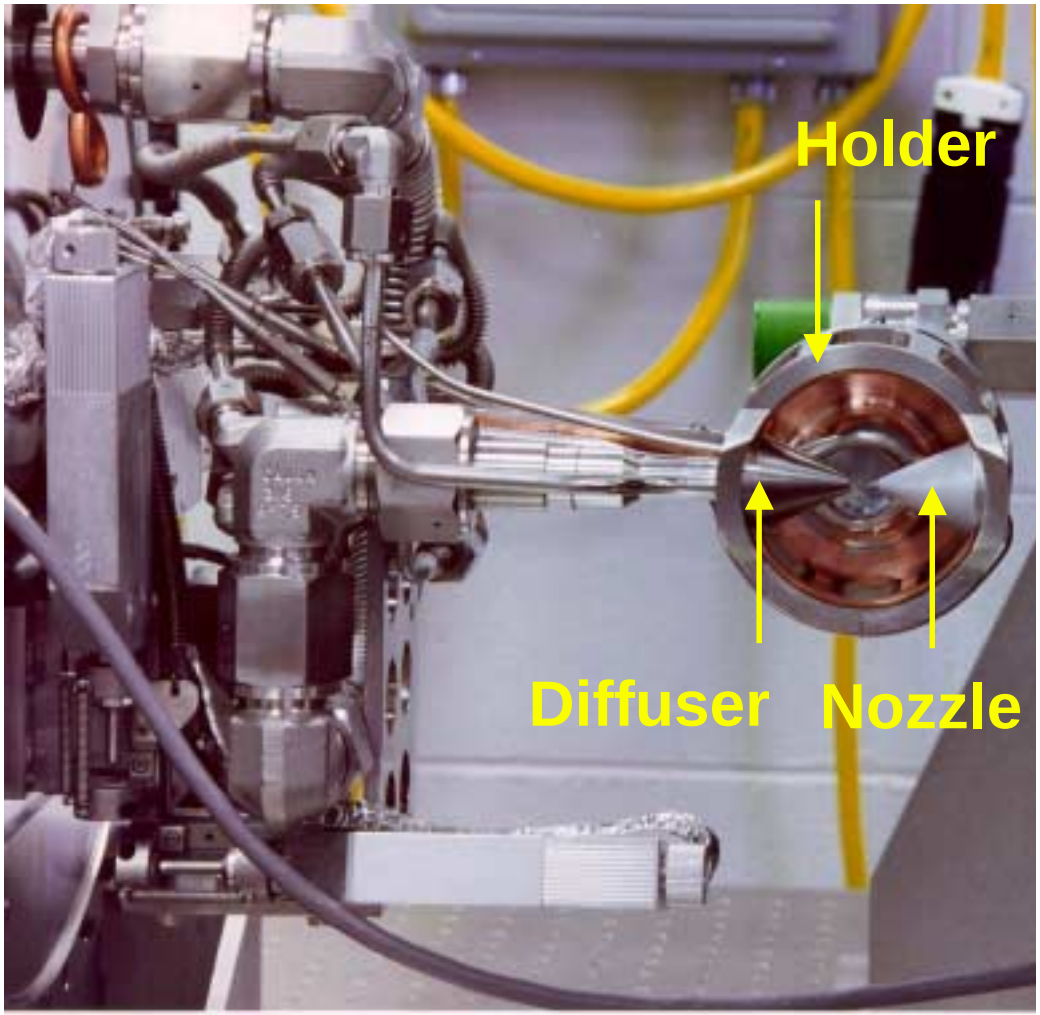
US Patent & PCT Application Pending: *Diffuser System & Method in an Emitted Energy System for Photolithography*

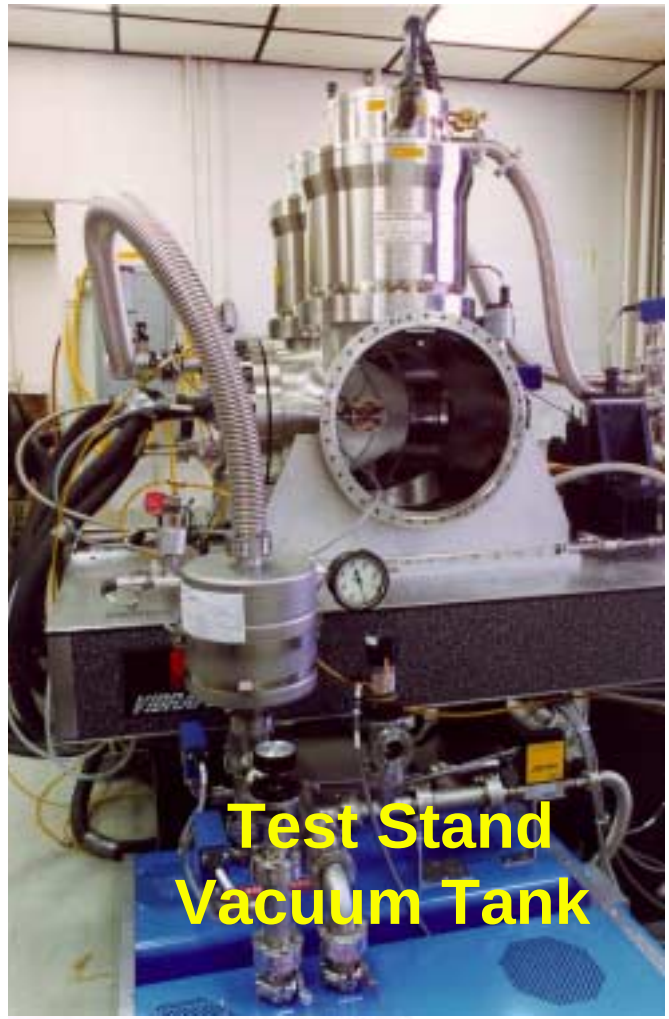
Coaxial nozzle delivers enhanced performance

US Patent & PCT Application Pending: *System & method for providing a lithographic light source for a semiconductor manufacturing process*



Test Stand Equipment Delivered to EUV LLC





Work supported by the EUV LLC

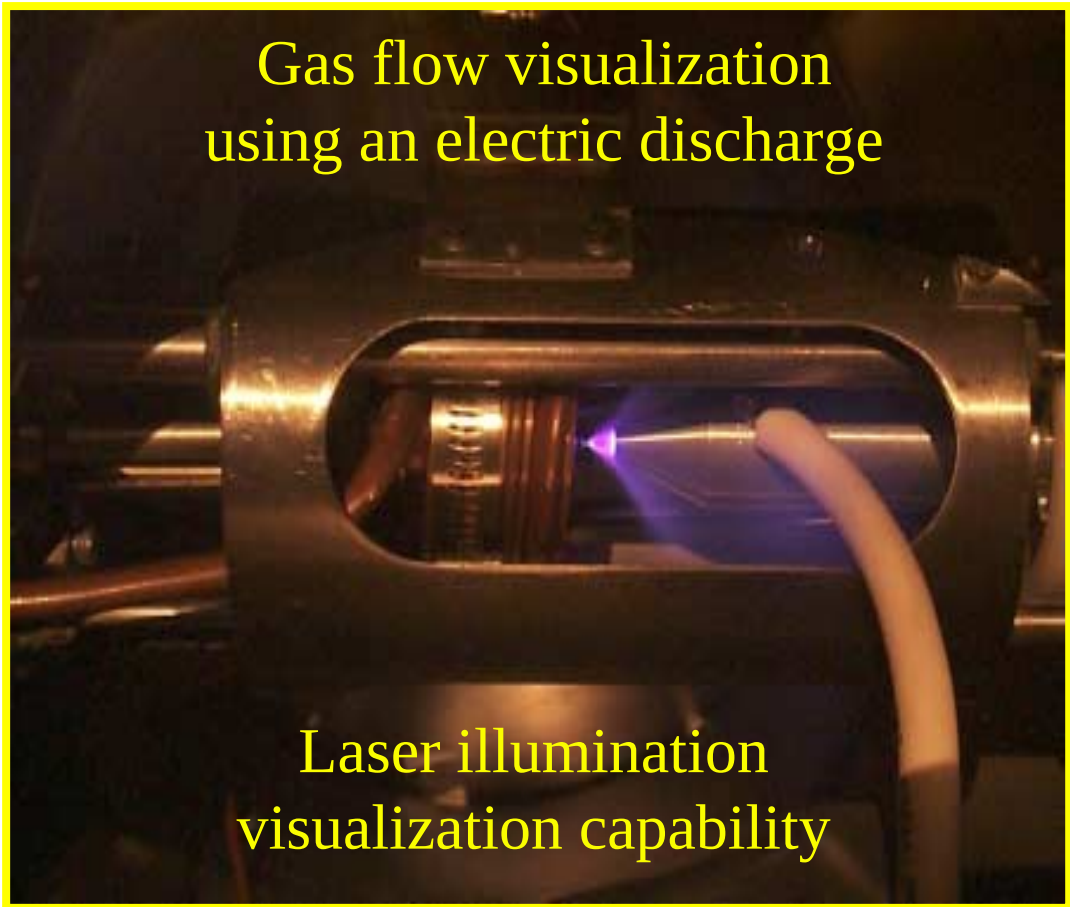
EUVL Source Test Stand at AES, Medford, NY

PAST & PRESENT

- Flow visualization & diagnostic development
- Comparison of pulsed & continuous operation
- Coaxial jet system & diffuser development

FUTURE

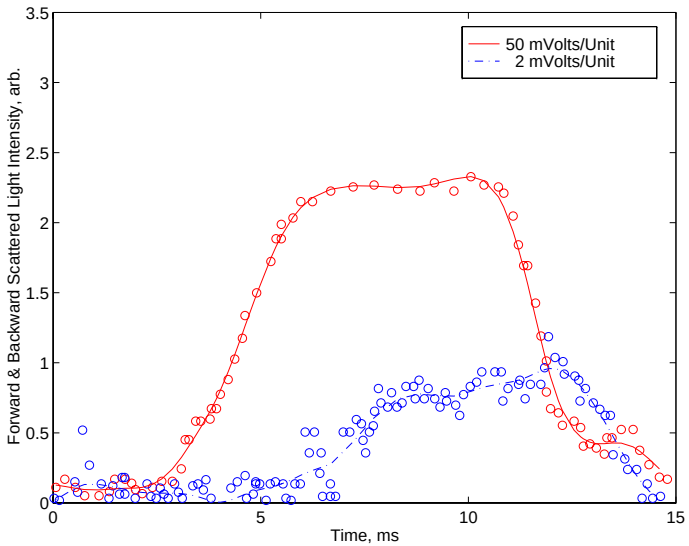
- EUV generation & measurement capability with near-term addition of a CEO laser
- Laser upgrade to 2 kHz & 1 kW in 2001 for debris & EUV optimization studies

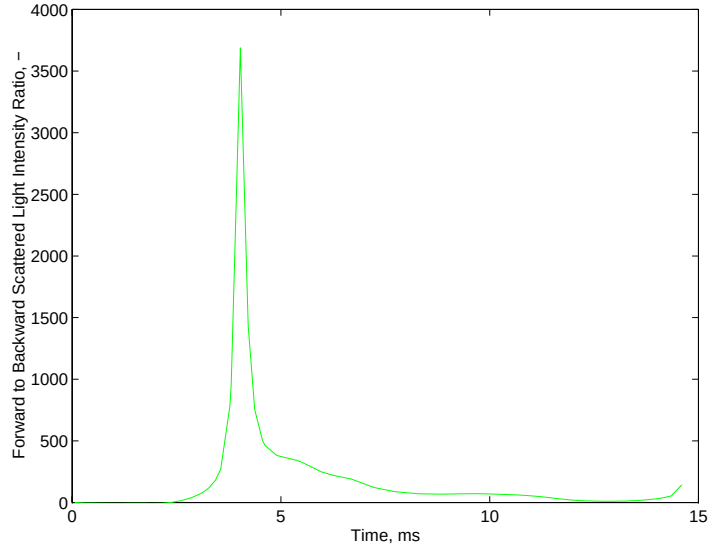


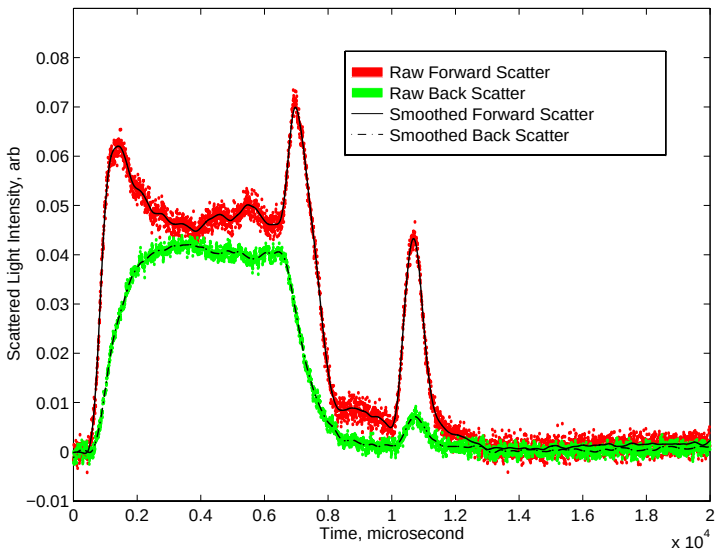
Initial CEO Laser Specifications:
1.064 μ Nd:YAG, 0.5 J @ 300 Hz, 6 nsec, $M^2 < 6$
single longitudinal mode, phase conjugated
quasi-cw diode pumped

AES Advanced Energy Systems, Inc.

AES Test Stand Data







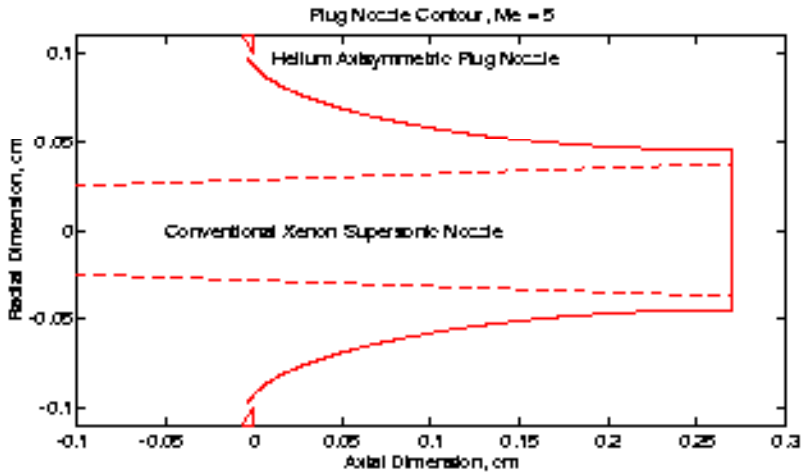
Mie Scattering Results

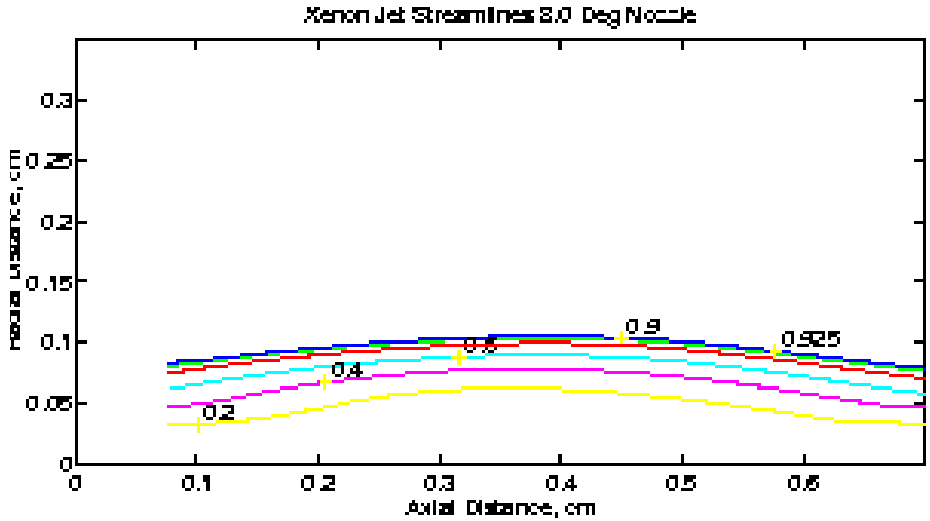
- Upper figures are for a piezo-electric pulsed valve
- Lower left figure shows solenoid valve behavior
- Left-hand figures are raw forward and backward signals
- Upper right figure shows the ratio of the two upper left signals
- A high forward/backward ratio indicates larger particle size

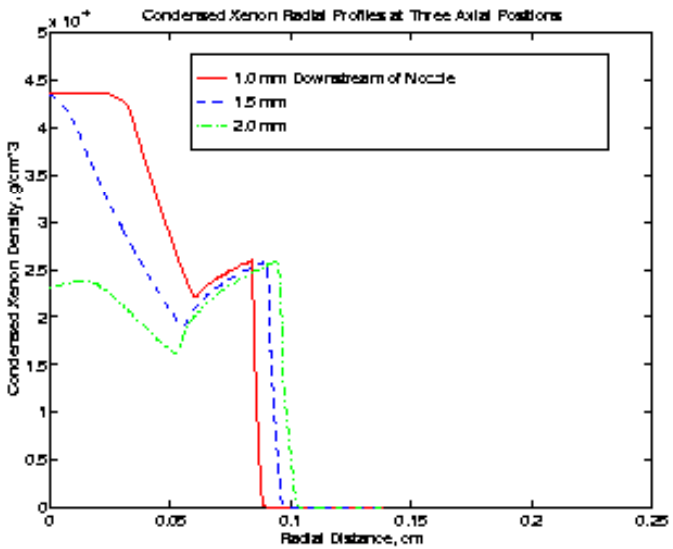
Work supported by the EUV LLC

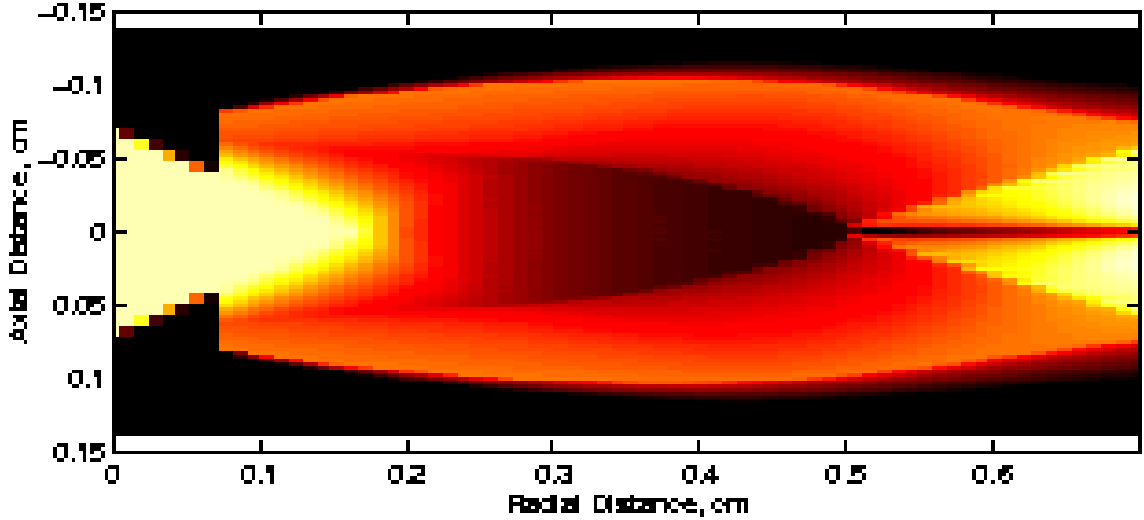
Coaxial Jet Flow Field

US Patent & PCT Application Pending: *System & method for providing a lithographic light source for a semiconductor manufacturing process*









Initial coaxial experiments are very encouraging with respect to the conformance of flow behavior with theoretical predictions and the observed effective nozzle/diffuser operation at large separation

ISWG Milestone Chart

	Now At EUV LLC	Soon At AES	In 1 year At AES	In 2 years At AES	Ultimo	Requirements for commercial tools [1]
Demonstrated collectable EUV power in a 2% spectral bandwidth in the region between 13-14 nm	4.0 W	1.2 W	8.0 W	34.5 W	69.0 W	50-150 Watt
Available collection solid angle	1.8 str	1.8 str	1.8 str	3.1 str	3.1 str	
Source emission volume dimensions (diameter)	300 µ	160 µ	160 µ	160 µ	160 µ	
Demonstrated maximum repetition rate	6000	500	2000	5000	10000	> 5000
Demonstrated steady-state repetition rate	6000	300	2000	5000	10000	
Dissipated total power (e.g. electrical or laser) in source region at steady-state repetition rate	1500 W	150 W	1000 W	3000 W	6000 W	
Source-facing condenser lifetime (pulses to 10% reflectance loss)	3×10^6 / 2×10^9 *	5×10^9	1×10^{10}	5×10^{10}	3.2×10^{11}	1 year or 1.6×10^{11} pulses
Pulse-to-pulse spatial stability [2]	50 µ	20 µ	15 µ	15 µ	10 µ	
Pulse-to-pulse intensity stability [3]	9 %	3 %	6 %	3 %	2 %	< 2%
Pulse-to-pulse angular stability [4]	9 %	5 %	10 %	10 %	10 %	
Pulse-to-pulse pointing stability [5]	-	100 µrad	75 µrad	50 µrad	50 µrad	
Key risk areas	EUV conversion efficiency, debris	EUV conversion efficiency	reliability, diode lifetime, debris	efficiency, cost, debris, in-band power	efficiency, cost, debris, in-band power	
Critical component lifetime	diode, nozzle & diffuser lifetime		2×10^9 pulse diode lifetime, nozzle & diffuser lifetime	20,000 hour diode lifetime, nozzle & diffuser lifetime	20,000 hour diode lifetime, nozzle & diffuser lifetime	

1 Requirements defined by international source workgroup in March 2000
2 3-sigma variation of EUV emission centroid position
3 3-sigma variation of in-band EUV flux
4 3-sigma variation of EUV radiant flux at widely separated angular positions
5 3-sigma angular variation of the principal EUV emission direction (if non-uniform)
* Not simultaneously achieved with power figure

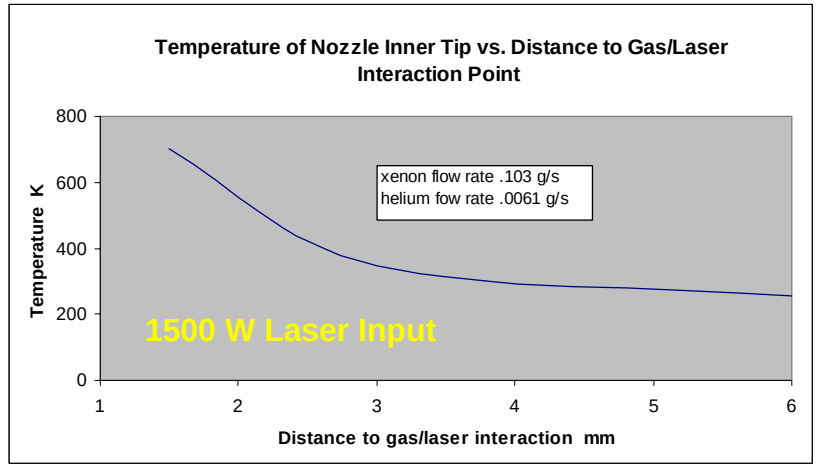
Desired Factor of Two Specification Relaxation: **Collectable in-band EUV power**

Thermal Analysis

US Patent & PCT Application Pending: *System & method for providing a lithographic light source for a semiconductor manufacturing process*

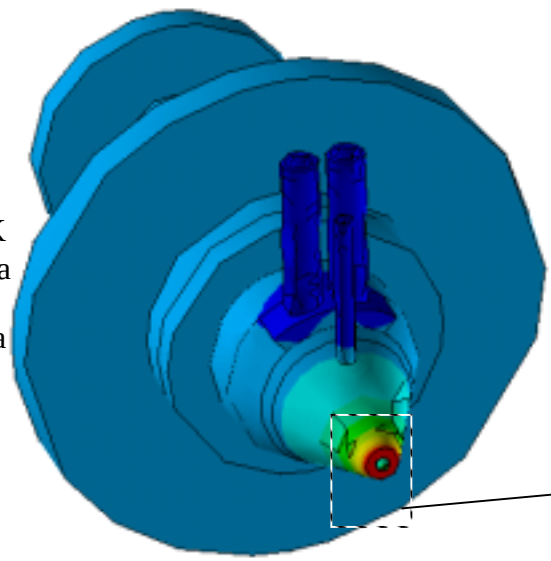
Temperature contours have been calculated for many input conditions

- 3000 W laser input is illustrated below
- to determine thermal load, 50% of laser power is assumed radiated, distributed evenly in solid angle
- remaining 50% of input power is assumed carried off in the laser-disrupted flow to the chamber walls
- laser spot positioned 3.0 mm from nozzle tip for lower results
- illustrated configuration is compatible with EUV LLC ETF but would be modified for a beta or production system (thermal results are conservative for expected Xenon conditions)



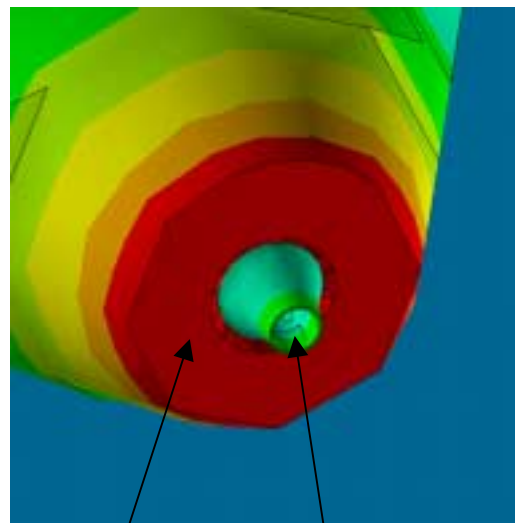
coolant - xenon & helium
inlet temperature 225 K
xenon outlet temperature 243 K
xenon plenum pressure 100 psia

helium plenum pressure 45 psia



Temperature
K

225.
257.
289.
320.
352.
384.
416.
448.
480.
511.



Inner tip temp 370 K

Outer tip temp 511 K

Summary

- AES has established a significant international IP position with respect to EUVL laser-plasma source technology
- We are continuing to develop improved EUVL light source components, such as miniature coaxial nozzle and diffuser configurations, at our Medford, NY, test stand
- The near term addition of a high-power laser system to the test stand will permit further development of optimized EUV production and debris reduction hardware
- A multi-kHz, kW-level AES source test stand will be in place in 2001
- EUVL source system development will proceed as indicated in our ISWG milestone plan response with key program CoO targets for production systems being: 10% laser wall-plug efficiency, 20,000 hour diode lifetime and near 1.2% in-band EUV conversion efficiency