

TRW / Cutting Edge Optonics

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# **Laser Produced Plasma for Production EUV Lithography**

EUVL Source Workshop

October 29, 2001



# TRW/CEO Laser-Produced Plasma (LPP) EUV Source Development and Commercialization

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## OUTLINE:

- TRW / Cutting Edge Optronics
- Product development roadmap
- Technology development status
- Critical technology issues
- Thermal engineering and thermal management

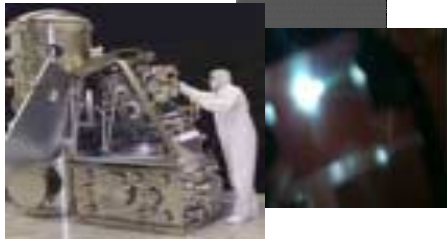


# TRW commitment to EUV source commercialization



## Demonstrated commitment to EUV source development

- TRW EUV source in operation at the ETS with EUV LLC  $\alpha$ -tool
  - EUV LLC source partner since 1997
  - 1700 W laser delivered to ETS in Q1, 1999
- TRW target developments implemented to augment ETS tool capabilities and accelerate  $\alpha$ -tool availability
- Over \$40M TRW investment (R&D, capital, facilities, personnel) in source development to date



## Executing strategic plan for EUV source commercialization

- Acquired Cutting Edge Optronics (CEO) in 2000 as foundation for launching EUV light source business
- Accelerating product development to meet industry schedules
  - Dedicated development/initial production facility (15,000 sq ft)
  - Demonstrating commercial high-power laser module in late 2001
  - Achieving significant cost reduction through focused design effort



**TRW expanding EUV source commercialization activities to address total market requirements**



# TRW/CEO Developing a Complete Offering

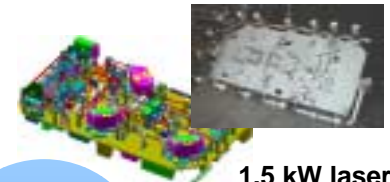
## Commercialized Product

Refining R&D achievements into a commercialized, exportable product

- Alpha-tool at the ETS (Sandia)
- Achieve required performance supporting 80 wph
- Simplifying and optimizing for cost, reliability and maintainability



1.7 kW laser at ETS



1.5 kW laser module in fabrication

## Efficient Manufacturing

Assuring successful EUV ramp

- Established scalable production process
- Initial capacity (~30 units/year) in place today, expand in 2004
- Develop supply chain to support ramp and cost reduction

4.5 kW beta source laser



## Global Development and Support Presence

Launch offices (2002) in Japan, Netherlands and Silicon Valley

- Focus on customer needs and expectations
- Support critical engineering and development phases
- Enable interaction at various levels of organizations

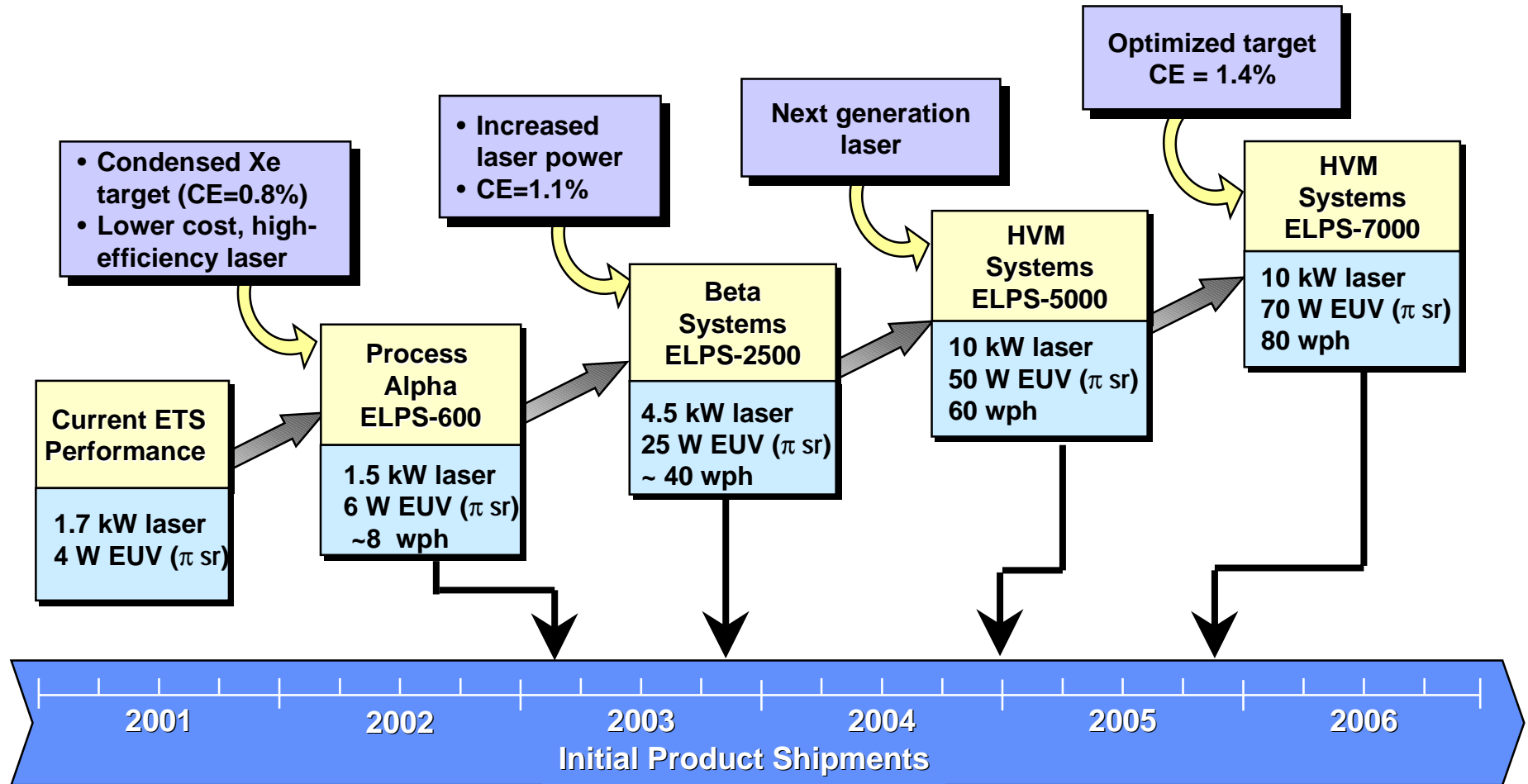
## Ramp Support and Product Integration

Expand offices with technical and operating personnel

- Facilitate integration of sources into tool production
- Establish global parts warehousing network
- Ensure rapid resolution of issues

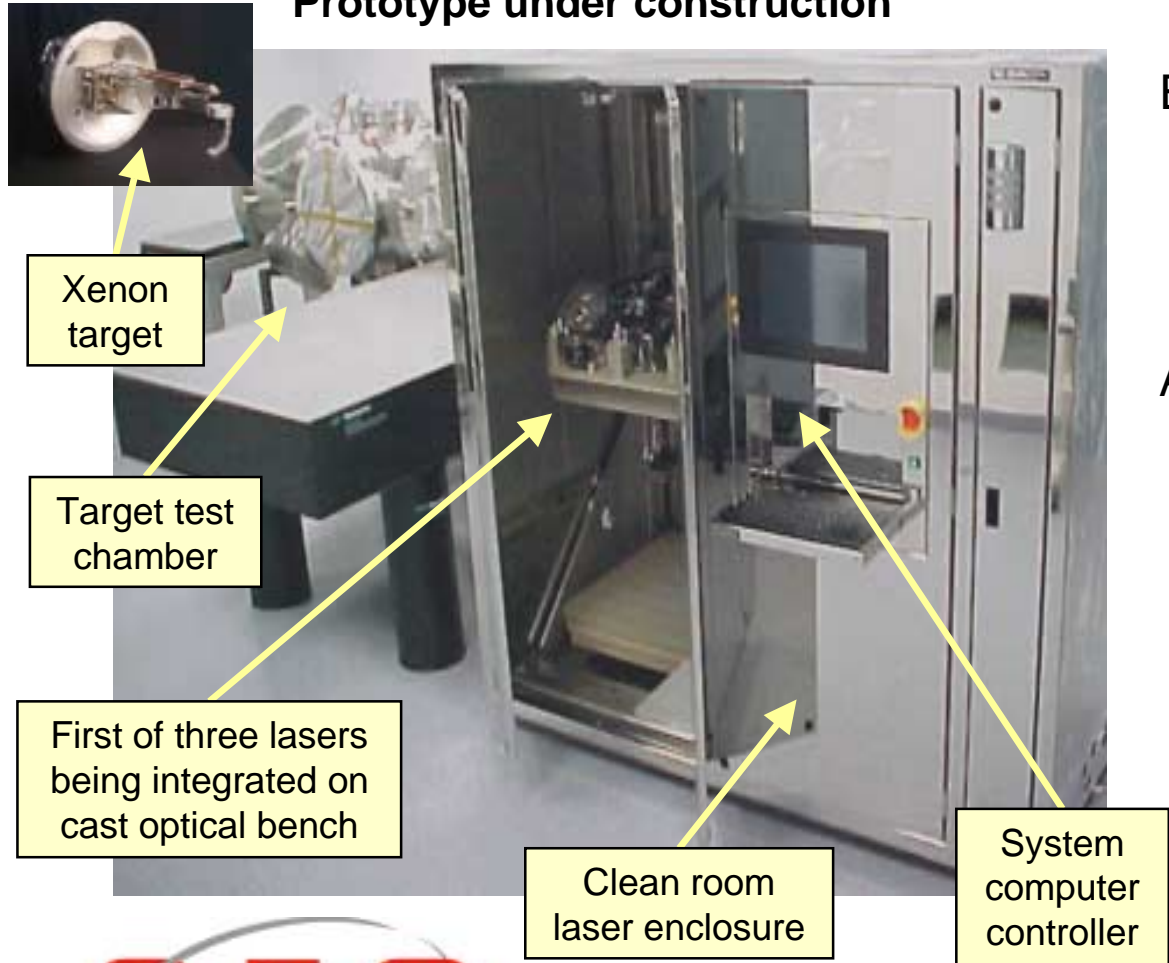


# EUV Source Product Development Roadmap and Shipment Schedule



# Prototype being assembled at new CEO laboratory

## Prototype under construction



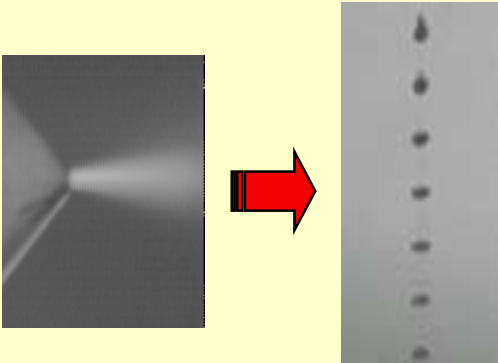
## EUV facility expansion

- 15,000 sq.ft dedicated to EUV development & manufacturing
- Capacity for 15-30 units per year

## Alpha prototype status

- 1.5kW laser assembled and begun testing
- Integrating with chamber and jet in Q1 2002

# Xenon target development achieving higher efficiency and intensity uniformity

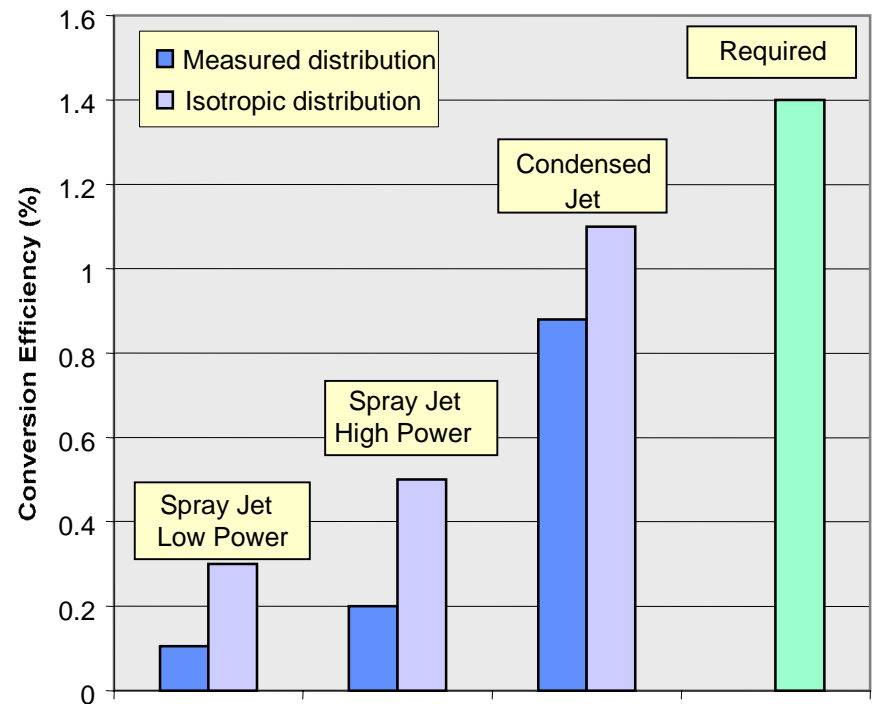


Xenon liquid spray jet

Condensed Xenon droplets

- Xenon targets minimize optics contamination
- Xenon droplet design improves efficiency through higher target density and reduced EUV absorption by local gas
- Extended streams permit laser focus far from nozzle, prolonging life of nozzle and optics
- **Preliminary laser tests show increased efficiency (~1%) and high uniformity — technical approach on right path**

Measurements show increased efficiency and improved emission isotropy from condensed xenon targets



# LPP Performance Overview

Plans and Status	CEO/TRW LPP EUV Source				Commercial tool requirement March 2001
	Now	In 1 year	In 2 years	Ultimo	
Demonstrated collectable EUV power in a 2% spectral bandwidth in the region between 13-14 nm, W	4	6	25	70	50-150
Available collection, solid angle, sr	$0.9 \pi$	$\pi$	$\pi$	$1.1 \pi$	
Source emission volume dimensions, mm	0.2-0.4	0.2-0.4	0.2-0.4	0.2-0.4	
Demonstrated maximum repetition rate, kHz	6	6	6	12	
Demonstrated steady state repetition rate, kHz	6	6	6	12	>5
Dissipated total power (e.g. electrical or laser) in source region at steady-state repetition rate, kW	1.3	1.5	4.5	10	

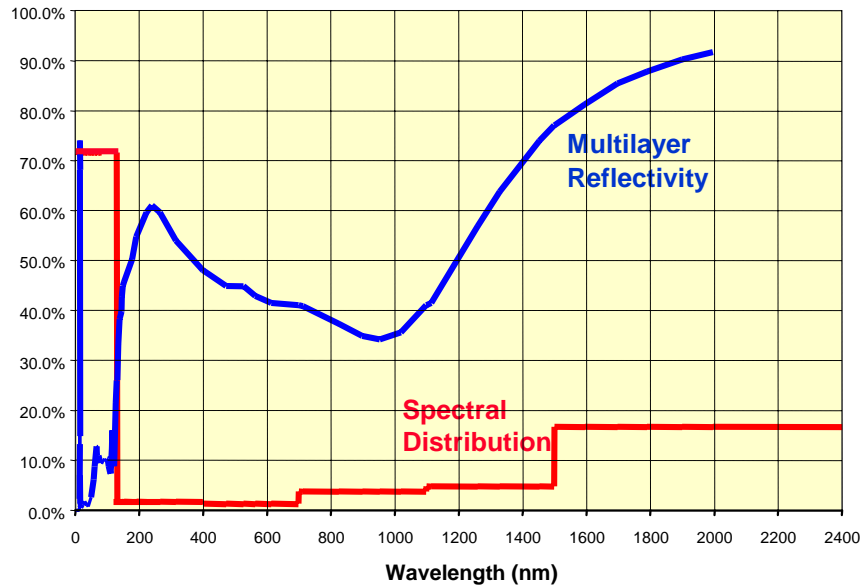
# LPP Performance Overview (Continued)

Plans and Status	CEO/TRW LPP EUV Source				Commercial tool requirement March 2001
	Now	In 1 year	In 2 years	Ultimo	
Source-facing condenser lifetime (pulses to 10% reflectance loss) # of pulses	3x10 <sup>8</sup>	1.6x10 <sup>9</sup>	1x10 <sup>10</sup>	>10 <sup>11</sup>	1 year or 1.6 x 10 <sup>11</sup> pulses
----- Environment requirements TBD					
Pulse-to-pulse spatial stability, μm (3σ)	50	10	10	10	
Pulse-to-pulse intensity stability (3σ)	15%	10%	3%	2%	< 2%
Pulse-to-pulse angular stability (3σ)	15%	10%	3%	2%	
Pulse-to-pulse pointing stability (3σ)	TBD	5%	3%	2%	
Key risk areas	Nozzle and diode life				

# Critical Technology Issues

Critical Issue	HVM Tool Requirement	Current Performance	Technical Approach to Resolve
Collectable EUV power ( $\pi$ sr)	50 – 150 W (80 w/ph)	4 W	<ul style="list-style-type: none"> <li>• Increase laser power (6x)</li> <li>• Solid xenon target (3x)</li> </ul>
Source-induced condenser lifetime	1 year ( $1.6 \times 10^{11}$ pulses @ 5kHz)	$1.6 \times 10^9$ (extrapolated)	Use of xenon provides non-condensing, non-reactive target material.
Repetition rate	>5 kHz	6 kHz	Demonstrated on Alpha laser at VNL. Higher rep rates planned for HVM.
Pulse-to-pulse repeatability	<2%, $3\sigma$	15%, $3\sigma$	Reproducible solid xenon target - droplets
Selling Price / Cost-of-Ownership	Meets industry CoO requirement	~4x less than Alpha laser at VNL	Transition from R&D to Commercial Product <ul style="list-style-type: none"> <li>• CEO vertical integration minimizes diode costs</li> <li>• Minimize parts count and expert labor</li> <li>• Transition to CW-pumped, pulsed laser technology</li> </ul>

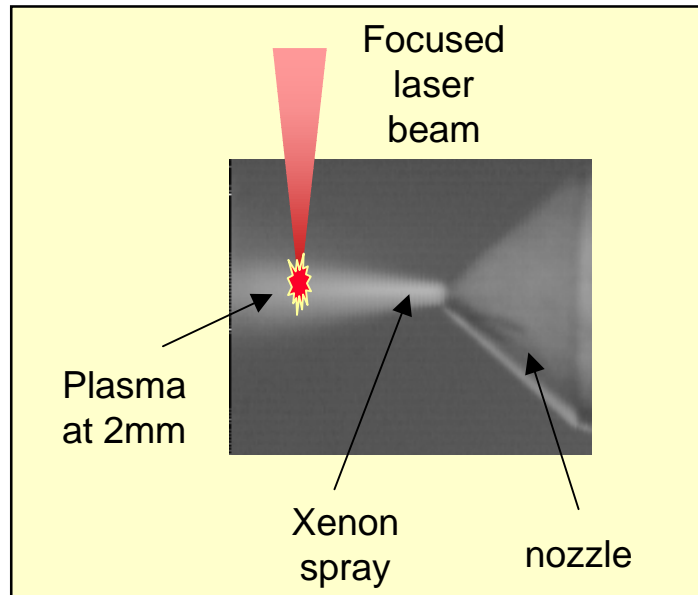
# LPP thermal loads on illuminator optical system determined by calorimetry



Spectral Band	Power Content
0 – 130 nm	71.6%
130 – 400 nm	1.8%
400 – 700 nm	1.3%
700 – 1100 nm	3.8%
1100 – 1500 nm	4.8%
1500 – 2500 nm	16.7%

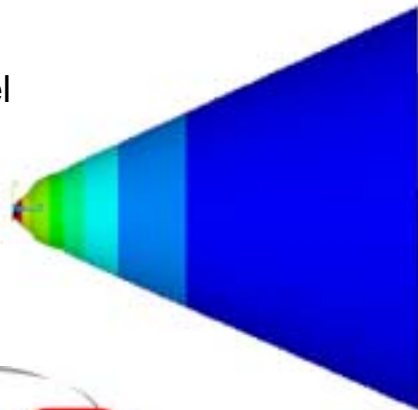
- Filtered calorimeter measurements show that about 72% of the broadband power from the plasma is particle kinetic energy and short wavelength radiation ( $\lambda < 130$  nm)
- Almost all of this power will be absorbed at the C1 mirror
- **For a C1 mirror collecting  $\pi$  steradian, the heat load will be ~180 W per kW of laser power**
- The remaining ~28% of the radiated power is reflected by the C1 multilayer mirror with an integrated R~70%.
- **The heat load on a spectral purity filter between C1 and C2 will be ~50 W per kW of laser power**

# Steady-state thermal analysis of liquid-spray xenon jet



- Jet thermal model assumes 1500 W average laser input power with plasma formed at 2 mm from nozzle tip
- Nozzle absorptivity  $\sim 1$
- Model predicts steady-state nozzle tip temperature of 200°C for tungsten nozzle and 450°C for graphite nozzle

Thermal model of nozzle



**Steady-state temperatures are well within material thermal limits for laser powers up to 1500 W**  
**Higher power lasers will use new target designs with increased stand-off distance**

# Summary

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- ✓ TRW / CEO committed to the needs of the industry
  - Combines the technology and financial resources of TRW with the commercial product capability of CEO
  - Responding to product manufacturing and support ramp-up expectations
  
- ✓ EUV power and cost issues are being addressed
  - Advanced laser architectures increase laser power
  - EUV efficiency shows continued improvement for xenon targets
  - Thermal management issues pose minimal development risk
  - Results in cost reduction per EUV watt
  
- ✓ Product plan delivers 25 W source in Q4 2003; 50 W source in Q4 2004, and 70 W source in Q4 2005.