High Power Lasers for EUV Sources

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EUV Source Workshop

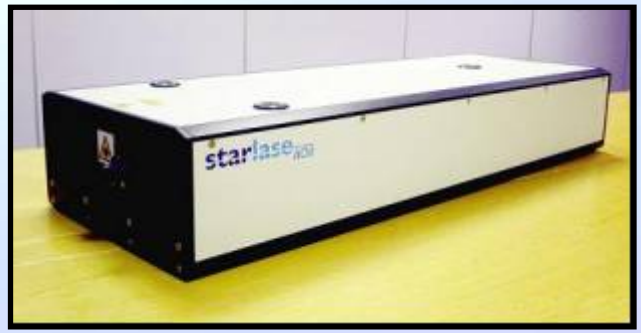
10th November 2005

San Diego, USA.

Presentation outline

- High power laser progress
- Available Starlase lasers
- Starlase shorter pulse applications
- Laser efficiency and cost
- Summary

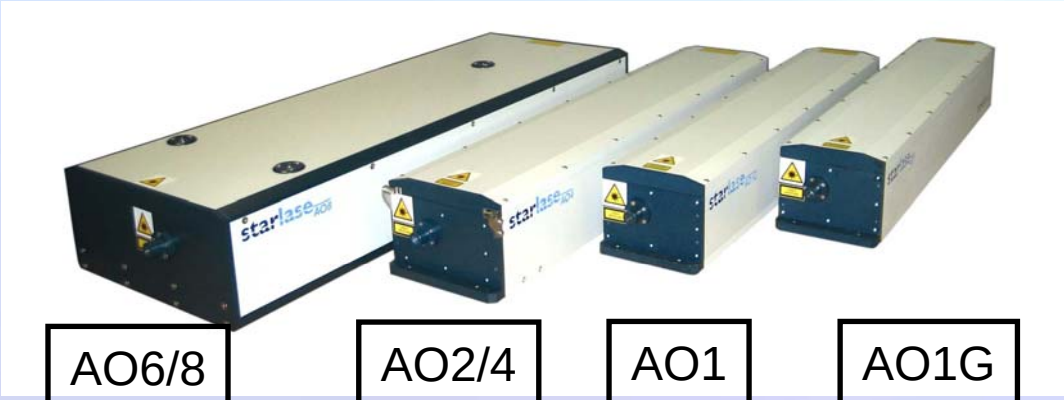
Progress of Powerlase High Power Lasers



- The development of the power scaling method has been completed. 1 kW class has been released.
  - Excellent overall power efficiency up to 10%
  - Compact modular design system
  - This is based on Powerlase already proven technology- currently used in industrial manufacturing.
  - Cost effective scale up of average power / cost per Watt.
- Up to 8 laser systems have been multiplexed and used in one single processing machine - 6 to 8kW of processing power is used.

Laser technology is ready for partnership with EUV source developers.

Available Starlase Lasers



AO6/8 AO2/4 AO1 AO1G

Gain modules

Core technology for all Starlase lasers

Industrially proven design

- High repetition rate- 3kHz to 50kHz
- Spread Powers 25W to 1kW
- AO Switch Pulse duration 28 - 200ns
- EO Switch Pulse duration 6 - 11ns
- M^2 values: 5 to >30

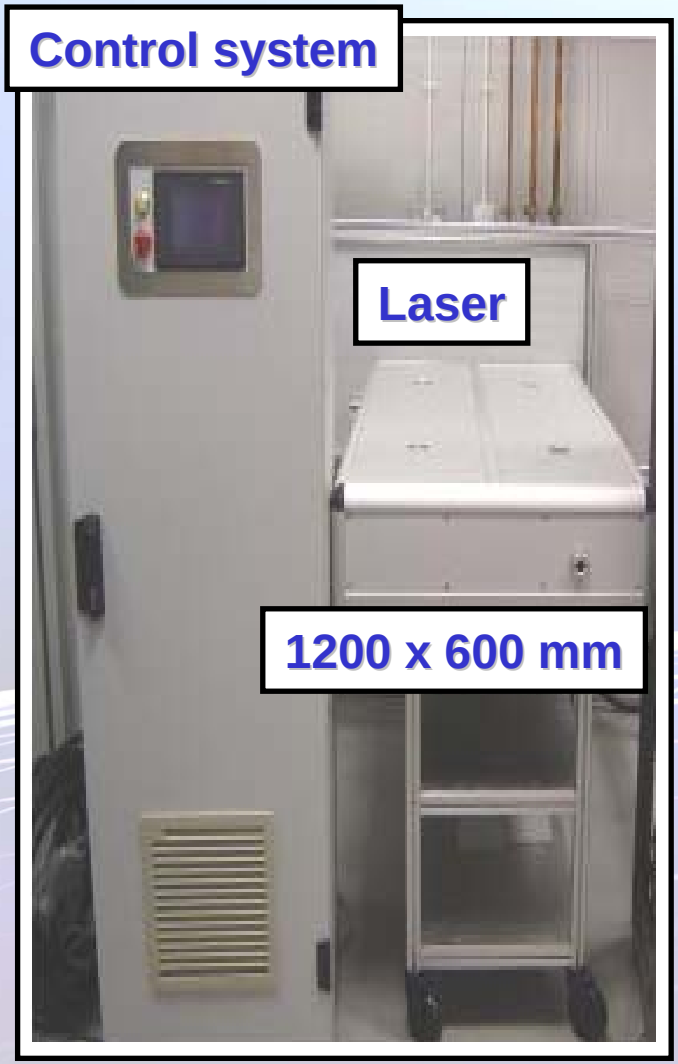
EO5/10

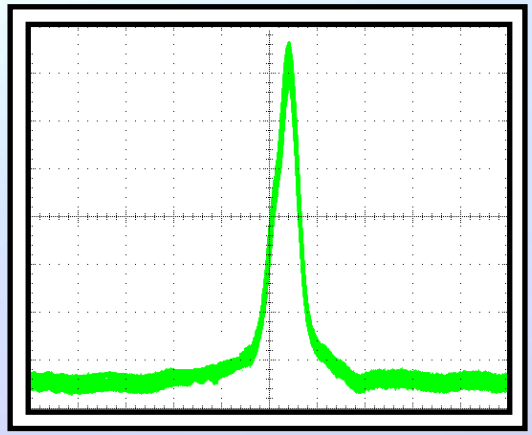
1kW class Starlase AO8 Laser System Released Q2 2005

Key features and characteristics

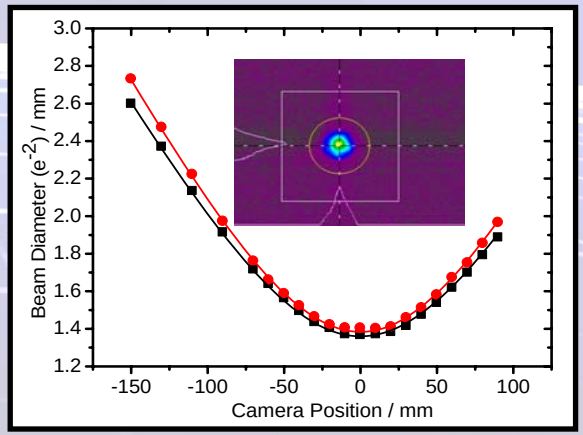
- Robust product based on Industrially proven 400W AO4 laser
- 800W to1kW
- Dimensions (L, W,H) (1250mm, 420mm, 235mm)
- Repetition rate range 5kHz to 20kHz
- Pulse energy varies with the rep rate (typically 100mJ per pulse)
- Pulse duration 28ns upwards

1 kW EO switched laser



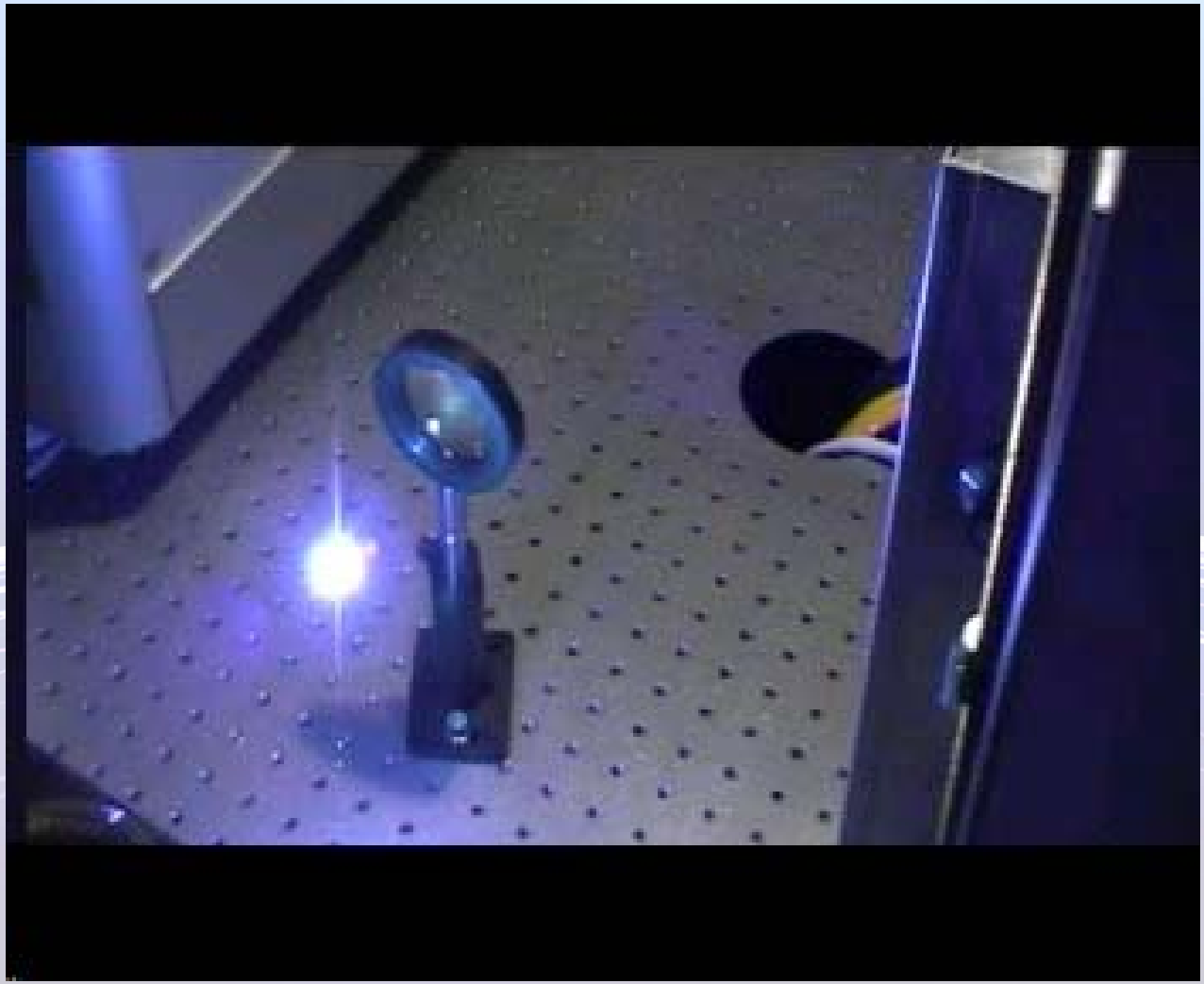


Pulse duration = 6 ns

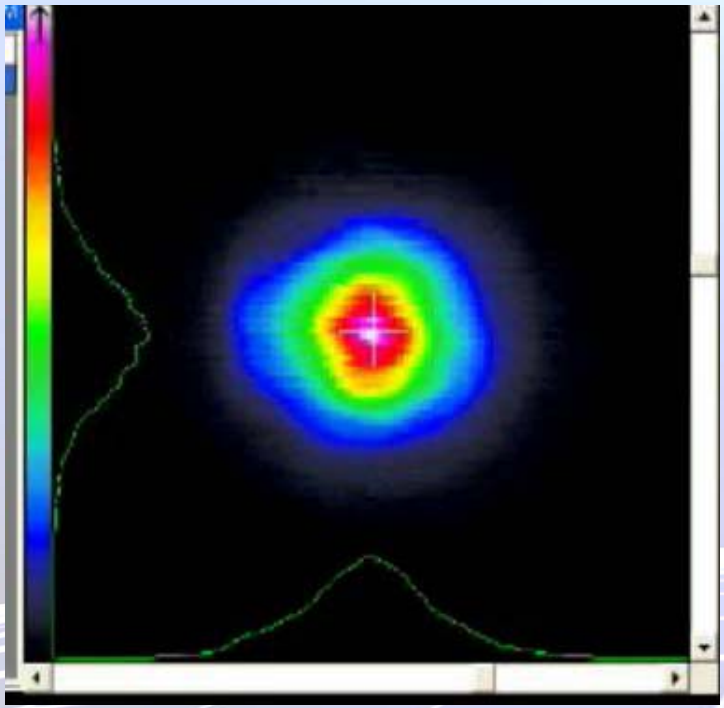


M^2 = 12

Air breakdown Starlase EO 1kW switched laser



EO 1kW laser stability



Excellent Power stability

Sigma
0.5% over 100 hrs

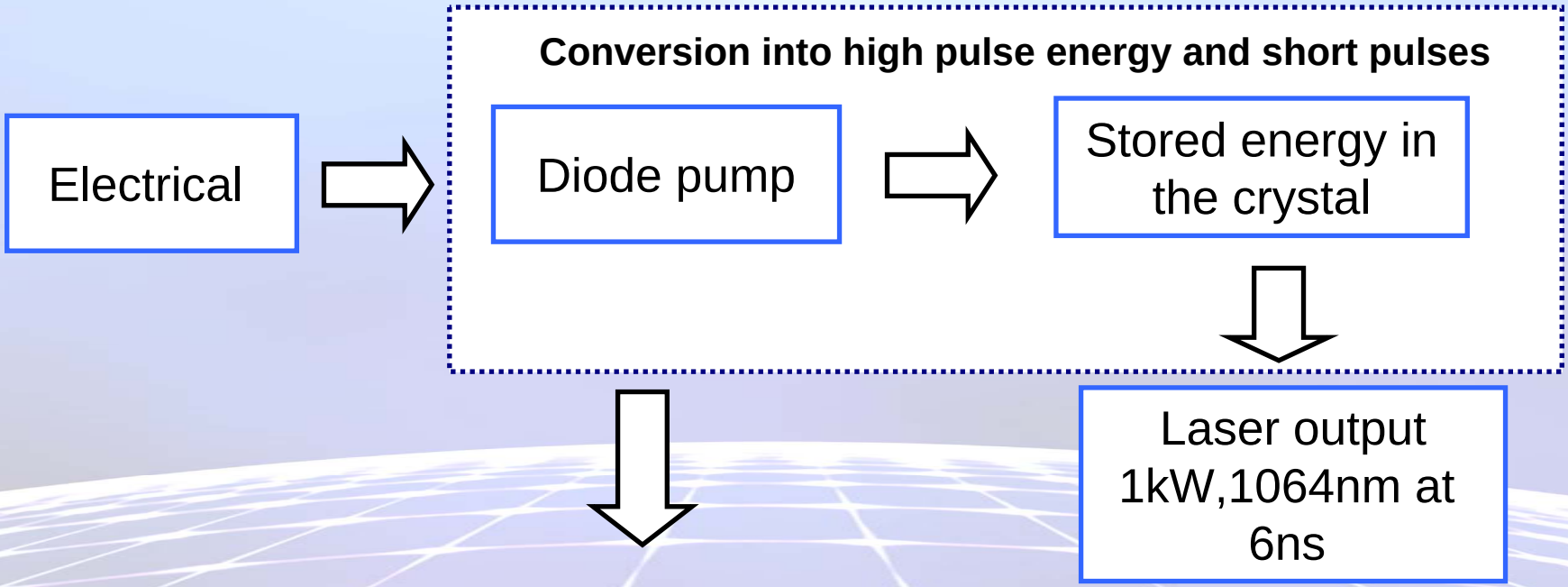
Excellent pointing stability

Sigma
0.4 μm over 100 hrs

Spot diameter
60 μm
Focal length
200 mm
Beam quality
$M^2 = 12$

Laser module service life- up to 10k hrs

Laser efficiency and cost effectiveness



Objectives:

- Conversion efficiency into short pulses
- Cost reduction

Achievements:

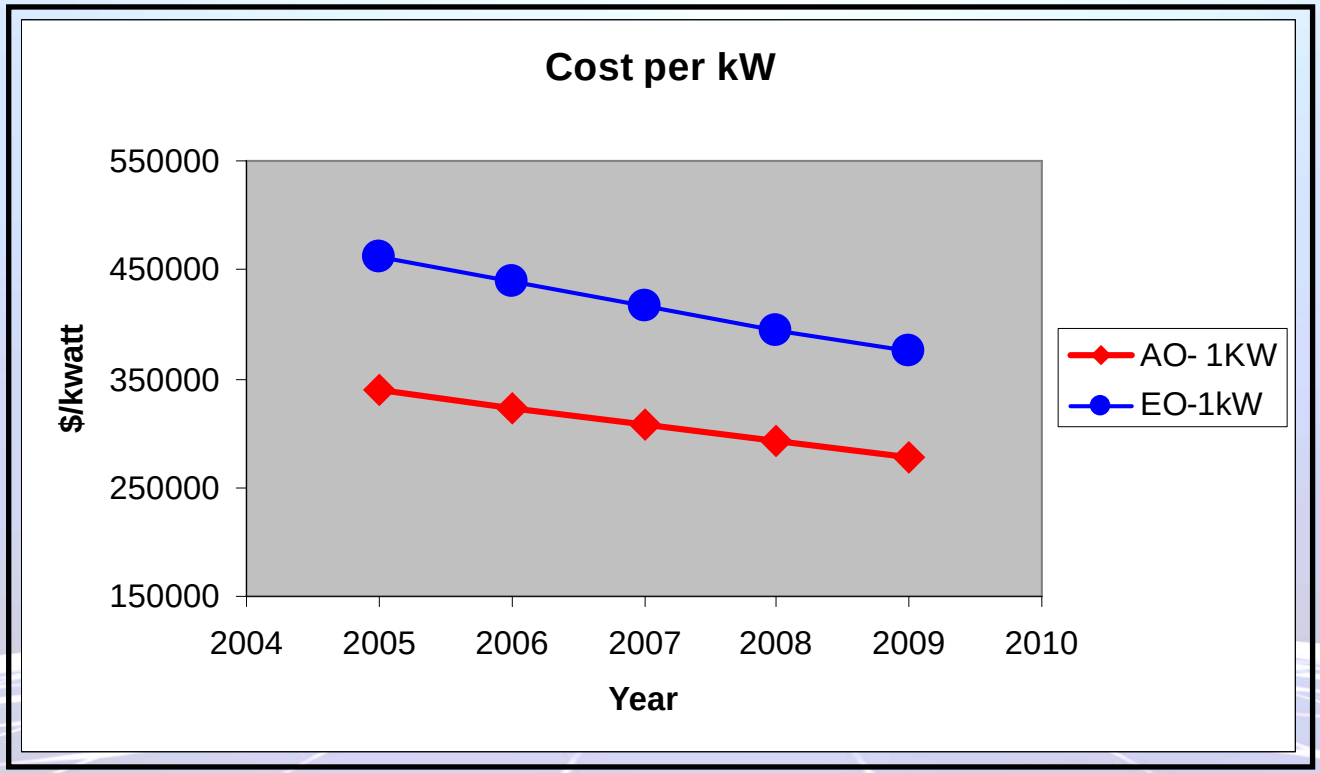
- Excellent coupling efficiency between the diode and the crystal
- Unique laser cavity design

1kW EO laser cost – 10ns, 5kHz, 200mJ and M^2=12

Cost per kW for <10ns	Year
$462k	2005
$439k	2006
$417k	2007
$395k	2008
$376k	2009

- This is based on current volume sales experience
- Consistent with our projection of the laser cost since we introduced our cost of ownership in 2003

Cost per watt



Cost influences

- Laser diode
- Laser efficiency
- Number of laser modules and components

Starlase Multiplexed laser products

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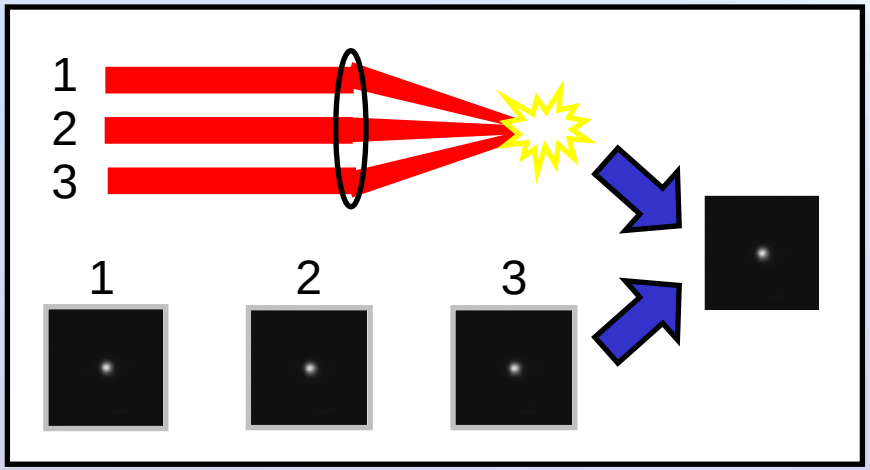
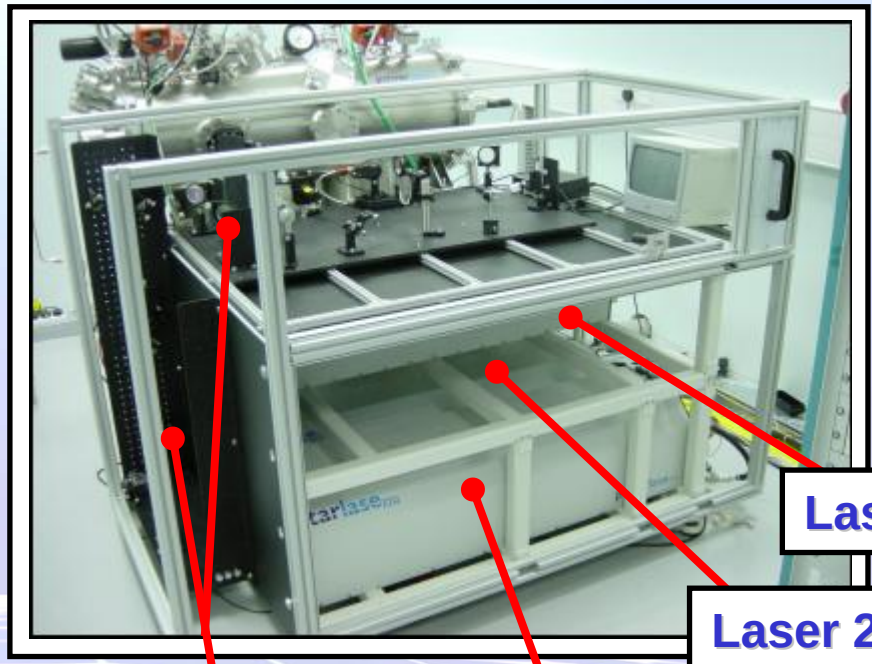
Spatial and temporal multiplexing on EUV target

e.g. single lens multiplexing 3 beams

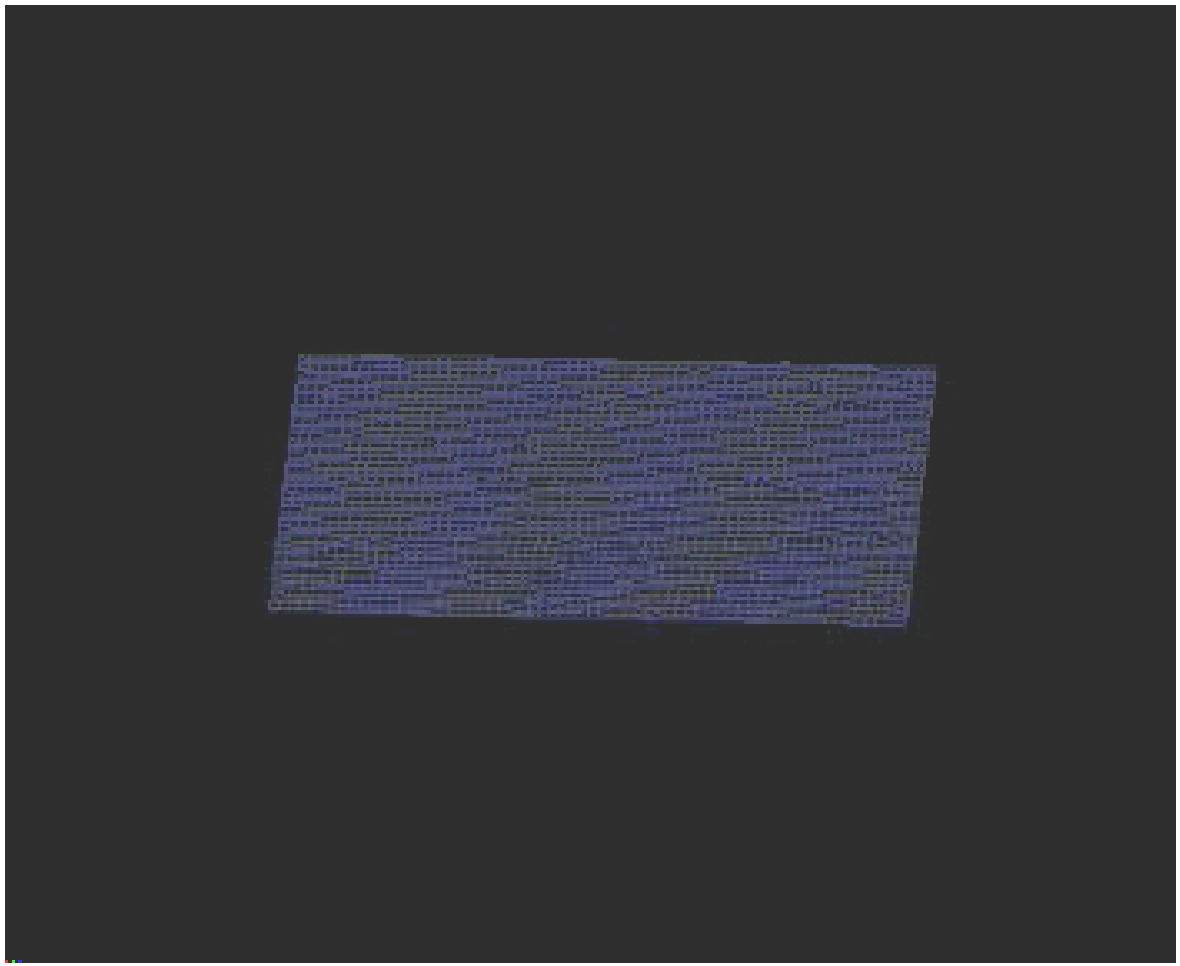




- Optimal EUV CE was achieved using different combinations of spatial and temporal multiplexing

Example of spatial multiplexing

Image of laser focus at target position



Diameter of Beam 1
57.8 μm
Diameter of Beam 2
61.0 μm

Multiplexed spot diameter
61.2 μm

Focal length
200 mm
Beam quality
$M^2 = 12$

Laser Performance using EUV targets

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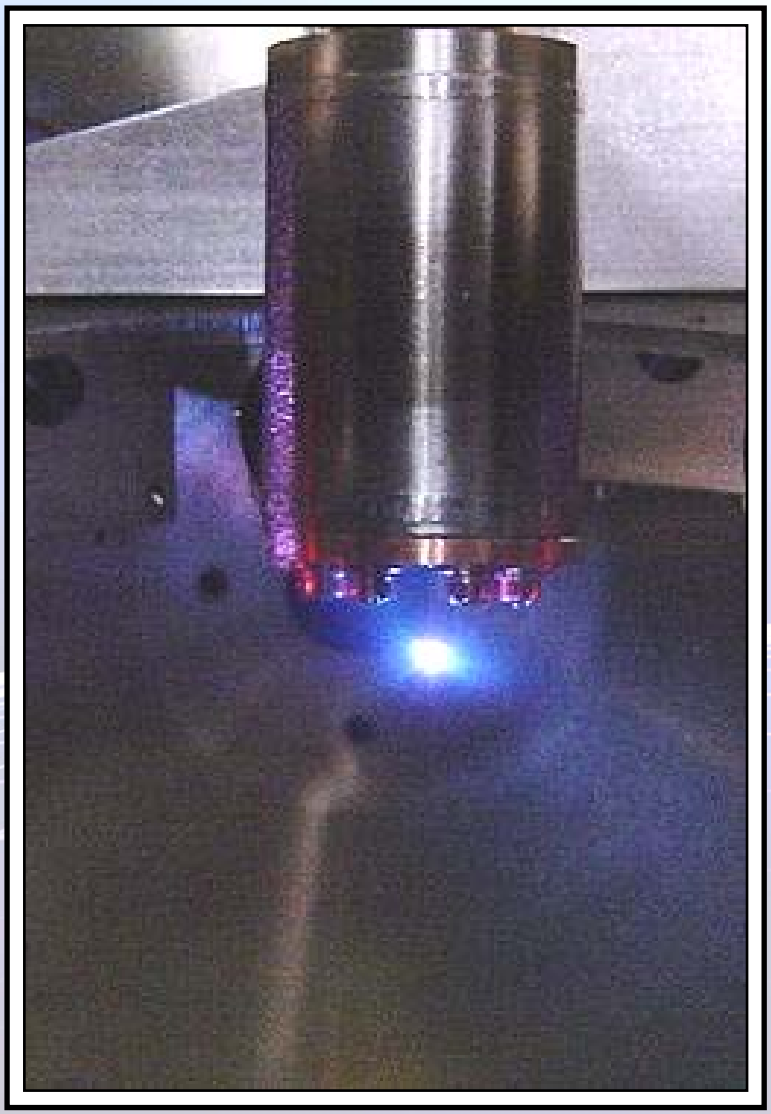
Laser test rig using Xenon & Tin targets



Highest CE achieved 0.8%
using Xe droplets
60 mm from nozzle
EUV power 8 W into 2π

Highest CE achieved 2.5%
using Sn target

Scale up strategy

1 kW laser power demonstrated **Q4 2004** ✓

10 x 1 kW lasers can be multiplexed to 50 μm spot

Total laser power 10 kW

2.5% CE demonstrated from LPP tin target

Assume 40% collection efficiency including mitigation

Gives ~240 W into 2π and **~100 W at IF**

Laser efficiency is 10% which translates to electrical power of 100kW if 10 kW of laser power is used.

High power lasers performance & cost summary

Powerlase Nd:YAG laser, today Performance	Single laser module average power (kW)	Pulse width (ns)	Single laser module rep rate (kHz)	Single laser module pulse energy (mJ)	CE-Wall plug to pulse laser light (%)	Capital cost (2005) ($m)	Expected date to meet HVM
	1	6	3.5-10	100-285	8-10	0.460	2006
	1	30	5-20	50-200	10	0.350	Already available
	1.5	30	5-20	75-300	10	0.450	2006
HVM Goal	**Multiplexed average power (kW)**	**Pulse width (ns)**	**Multiplexed rep rate (kHz)**	**Total pulse energy (mJ)**	**CE-Wall plug to laser light (%)**	**Capital cost (2005) ($m)**	**Expected date to meet HVM**
	10	6	5-50	Depends on the target used and the multiplexing architecture	8-10	4	2007
	10	30	5-50		10	3	Available

Note: All prices based on 50W diodes at 2005. Cost performance of diodes is improving

Summary

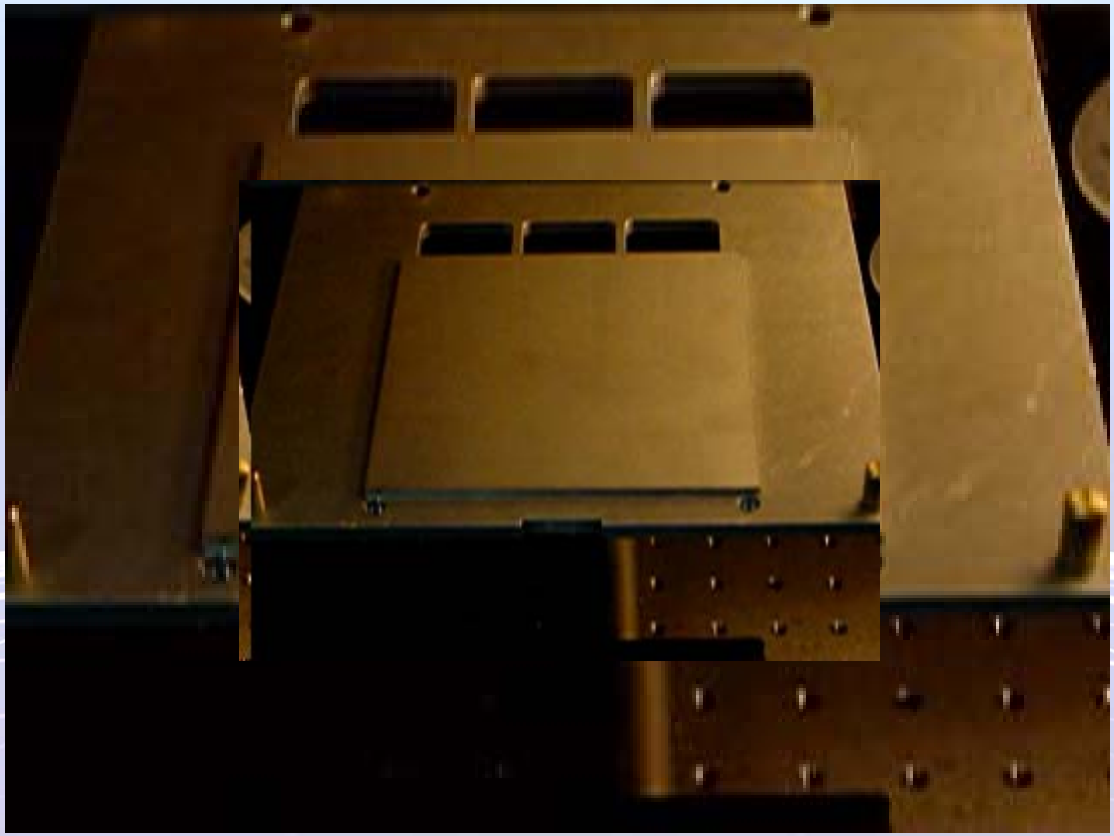
Current Roadmap task – improve power amplification scaling – completed successfully

Improved power efficiency, cost, performance and reliability of 1kW laser sources

Clear and effective method of power scaling using spatial and temporal multiplexing

Acknowledgements

Nick Hay, Ian Henderson, Steve Dabbs, Ben Fulford, Terry Nowell



Industrial Lasers Enabling Diverse Markets