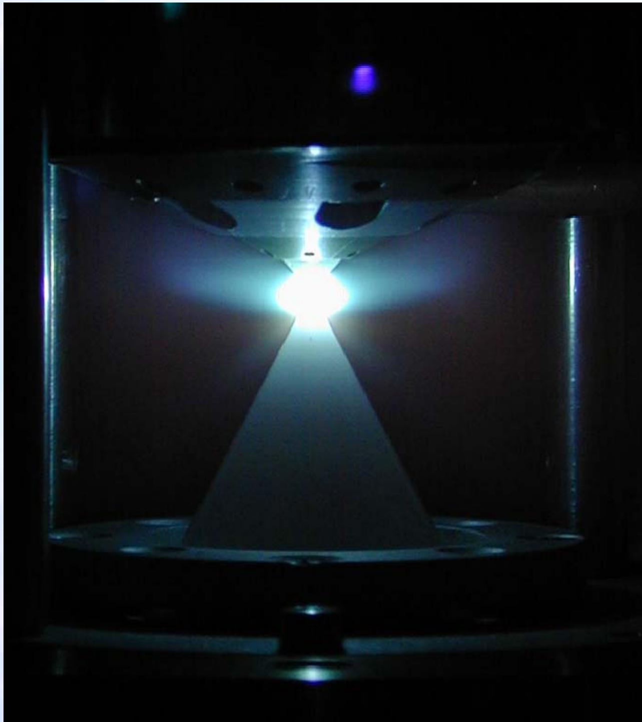
Modular Laser Produced Plasma Source For EUV Lithography



The Exulite Project Team:

Alcatel Vacuum Technology

B. Barthod, M. Davenet, B. Fay*, E. Véran and R. Bernard

THALES Laser SA

J. Skrzypczak, J. M. Barbiche, Ph. D'Aux, and E. Marquis

CEA-DSM/DRECAM/SPAM

C. Bonnefoy, F. Chichmanian, T. Ceccotti, D. Descamps, J. F. Hergott, P. Haltebourg, D. Normand, M. Segers, O. Sublemontier, and M. Schmidt

CEA-DEN/DPC/SPAL

Ph. Cormont, G. Cheymol, D. Farcage, M. Gilbert, J. M. Weulersse, P. Mauchien, and P. Y. Thro

*Presented by B. Fay (Consultant, Eurus Consulting)

EUV Source Workshop, Santa Clara, 23 February 2003

OUTLINE

- Introduction
- Goal of the EXULITE project
- Previous Work: PREUVE LPP source
- ELSAC LPP source
- Source Roadmap
- Summary

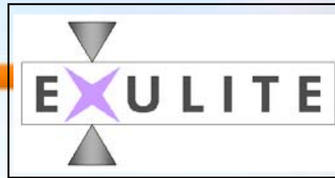
WITHIN MEDEA+ *

MEDEA+

- ALPHA TOOL
- EUV SOURCE
  - Laser produced plasma
    - MOPA concept XTREME Tech
    - N multiplexed oscillators (EXULITE)
  - Gas discharge plasma
- EUV MASK

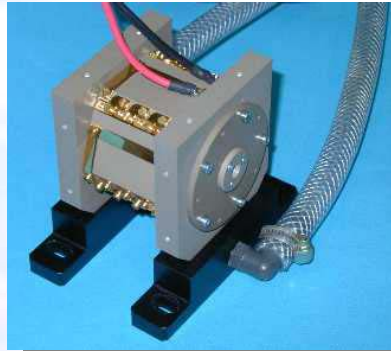
* MEDEA+ label obtained in May 2001

EXULITE Project Partners

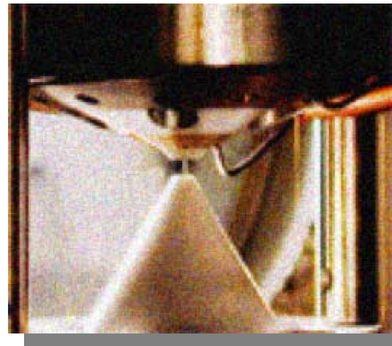


Coordinator : Alcatel

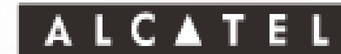
EXULITE Organization



Lower cost laser
High reliability



Process optimization
Characterization
Optical interface



Vacuum, Xe recycling
Monitoring
System integration,

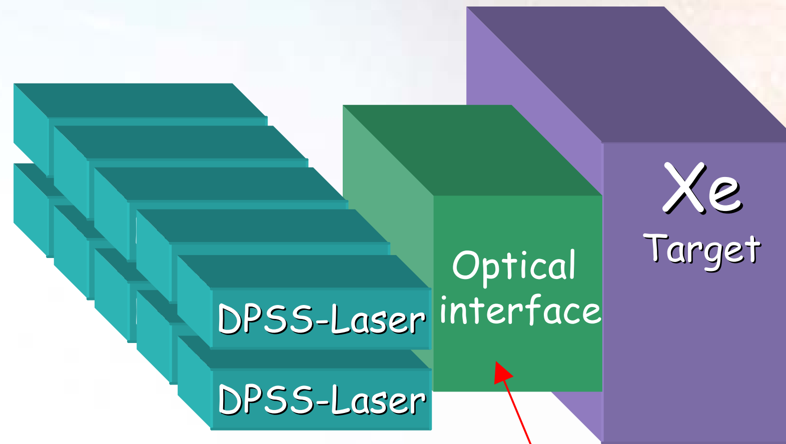
GOAL of EXULITE Project

- **Develop a High Performance, Modular LPP source for EUV Lithography**
  - EUV output power: 50W
  - Laser power: ≥ 5kW (N multiplexed oscillators)
  - Source rep rate : 10kHz
  - Target: Recycled Xe jet
  - Conversion efficiency: ≥ 1%
  - Availability: 2005

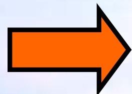
Technical Choices: Laser Produced Plasma and Xe target

- **Patent on Xe target (spray of droplets) and recycling**
  - Low debris (Xe)
  - Xenon recycling (reduction of C.o.O.)
  - Contamination control in order to increase the lifetime of optics
- **Patent on laser multiplexing**
  - Scalable power
  - Modular approach:
    - Optimization of development and manufacturing costs
    - Reliability
    - Easier maintenance
  - High pulse to pulse energy stability
  - Good beam quality for better focusability

Patented* Design of Modular LPP Source



N identical DPSS
(Diode pumped solid state)
laser units



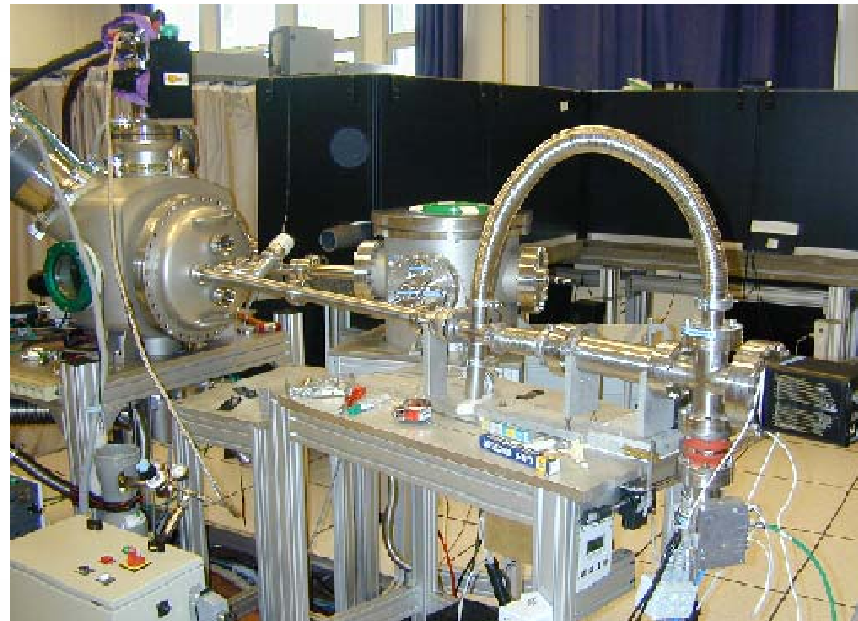
Advantages : efficiency, simplicity, compactness, reliability, reduced cost.

*WO 02/27 872

ALCATEL
cea
THALES

Previous Work: PREUVE LPP Source

- CEA/SPAM has developed a Xe LPP source for the EUV Test Bench (BEL) within the PREUVE program
- The BEL tool will be used within the “Excite project of MEDEA+”
- Thales has demonstrated in the second phase of the PREUVE program a 300W, 10kHz DPSS oscillator module



EXULITE

Performances of the ELSA (PREUVE) Source

- ✓ Performances of the ELSA source :

  35 W Nd:YAG pump laser power
  250 mW (EUV power in 2πsr*)
  CE = 0.71% (in 2πsr*)
  8.0 mW (useful EUV power in 0.2sr*)

- ✓ Exposure time with BEL : less than 1 sec

  assuming sensitivity of 100mJ/cm^2
  static exposure field of (100μm)^2
  and 2.5% EUV transmission of BEL

* 2.5% BW @ 13.5 nm

Today's performances of the modified ELSA source

- ✓ Modified ELSA prototype using a continuous cryogenic target
- ✓ Existing ELSA prototype and pumping system was not adapted to continuous operation, CE* = 0.20% (2.5% bw, 2πsr), optimization in process
- ✓ Present performances of modified ELSA is currently lower than expected because of strong EUV reabsorption (too high vessel pressure)
- ✓ Construction of the ELSAC prototype is underway to achieve optimized pumping

*This is an uncorrected value (with respect to the environmental pressure within the source chamber (CEx2 assuming 10^{-4} mbar))

cea

THALES

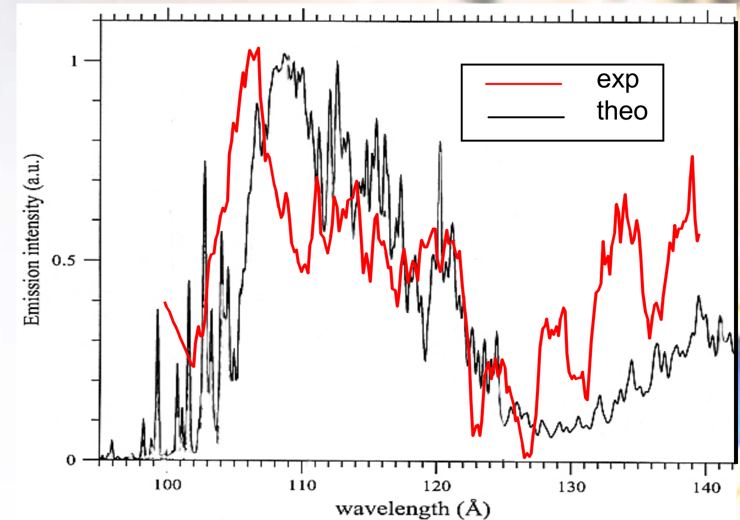
ELSAC System Architecture and Development

- ✓ Detailed functional analysis of the whole ELSAC system is completed
- ✓ Recirculated Xenon to keep costs reasonable (<500 l/h)
- ✓ EUV Chamber contamination control
- ✓ Vibration control
- ✓ Thermal management
- ✓ Debris mitigation
- ✓ Full scalability of the source architecture
- ✓ High speed target for high repetition rate laser operation (far above 10kHz possible)
- ✓ Properties of the ELSAC platform (modularity, redundant design and architecture)

EXULITE

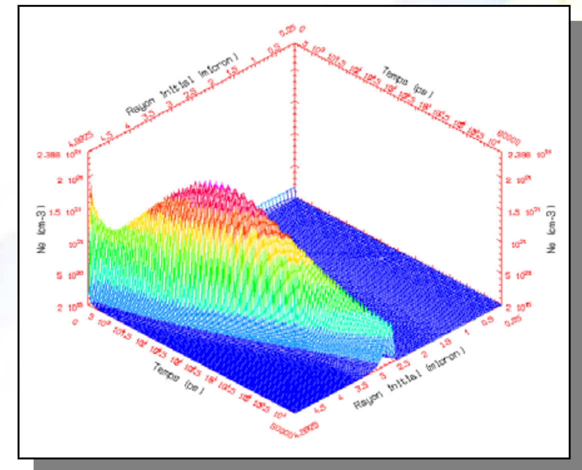
EUV Laser Plasma modeling at CEA

Numerical simulations at CEA to:



- enhance the plasma emissivity #
- improve the laser target coupling
- choose the best target material and composition

Approach: coupling a hydrodynamic code to collisional-radiative atomic physics code



CEA is a member of the Sematech EUV data workgroup

 # F. Gilleron, et al., J. Appl. Phys. (submitted 2002).

A complete set of Plasma and Source Diagnostics

- Space (and *time) resolved EUV spectrograph
- Plasma diagnostics (e.g. Thomson scattering and 4ω interferometry)
- Multi pinhole frame camera (CEA/DAM)
- *Streak camera (CEA/DAM)
- Angular distribution measurement device

ALCATEL

cea

THALES

Debris Characterization

- ✓ Ionic debris of ELSA are quite energetic (15keV mean energy)
- ✓ Ionic erosion (and thermal load) requires for very specific nozzle materials (e.g. hardness and thermal conductivity)
- ✓ Within MEDEA+ T405, consulting at Innolite and Xtreme for debris characterization in 2002

EXULITE

Complementary Experiments

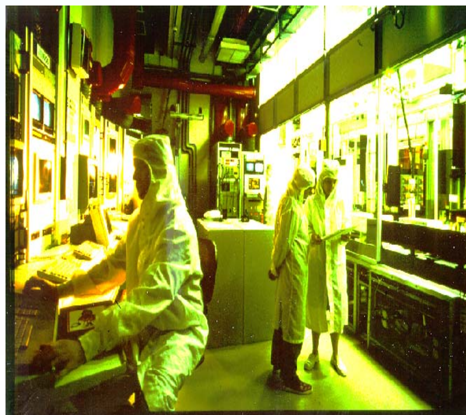
- ✓ Experiments on alternate target yields CE = 1.4 % (3Q 2002)
- ✓ In situ thermal studies on jet using 4 - 8 kW cw laser in 100 µm spot @ 1.064nm (1Q 2003)
- ✓ Test with 500W 10kHz laser module on continuous Xe target (3Q 2003)
- ✓ Experiments on improved alternate targets (4Q 2003)

ALCATEL
cea
THALES

Laser Development: Technical Background

- ✓ 10 years of experience developing complex optical systems (French AVLIS program)
- ✓ Patented design of high-power, diode-pumped solid-state-lasers

Patent on multiplexed laser for producing a EUV source



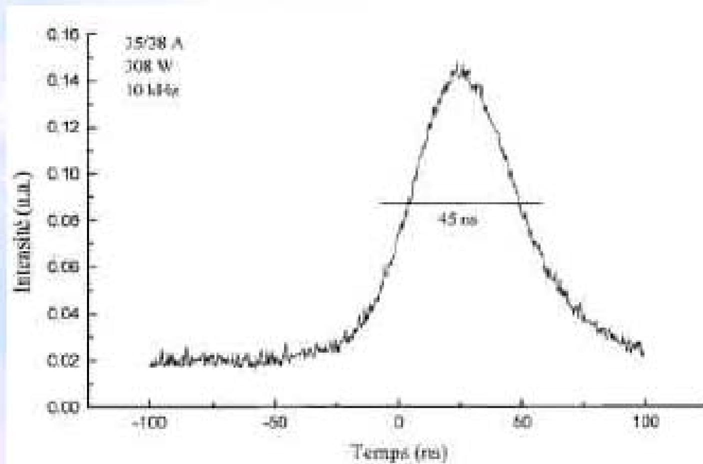
EXULITE

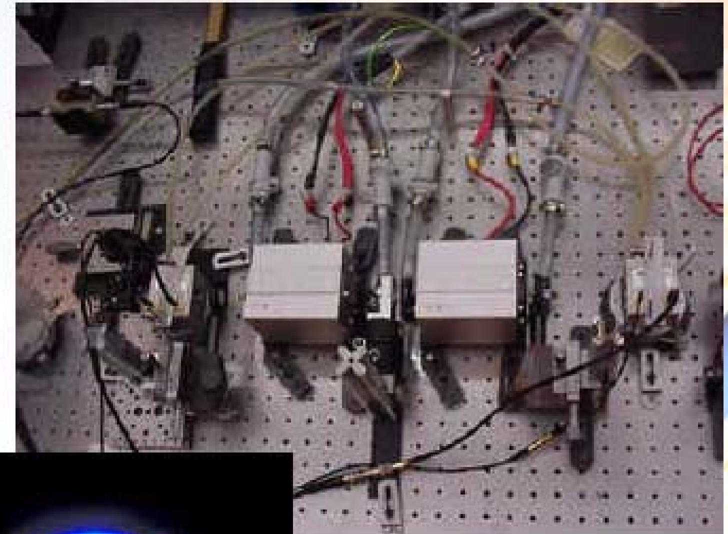
THALES Laser Involvement in the EXULITE Project

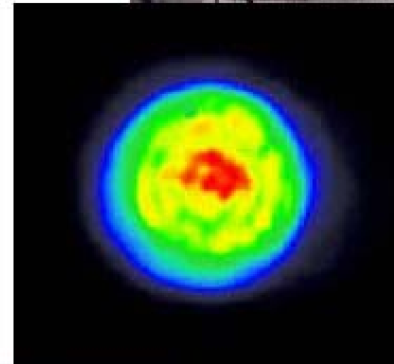
- Demonstration of 300W IR laser based on existing pumping chambers
- Development of 500W IR laser for EUV source based on more powerful pumping chambers: first prototype in August 2003
- Industrialization of ten 500W IR laser modules for the first quarter of 2004

300W IR Unit: Laser Demonstrator

λ	1064 nm
P_{AVG}	> 300 W
M^2	< 10
Repetition rate	10 kHz
Pulse duration	< 50 ns







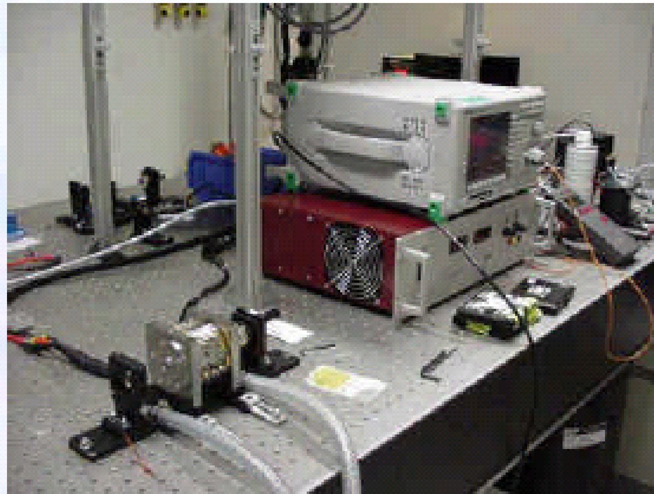
Laser Reliability Tests

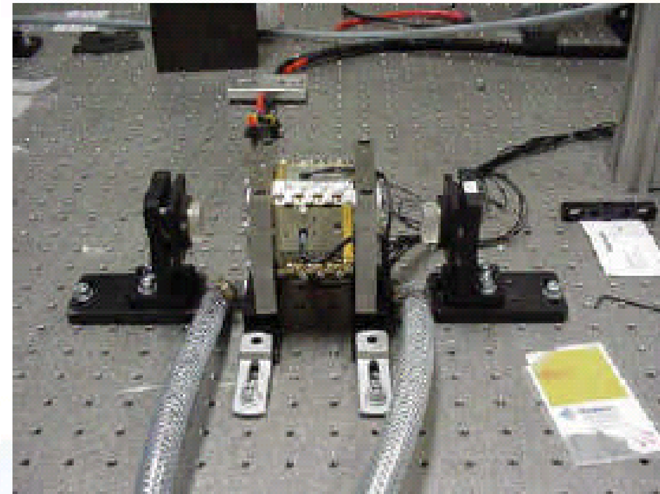
30 diodes heads under permanent operation at THALES

Laser laboratory

Up to now, 2000 hours of operation, inspection at 1200

Running till the end of the head

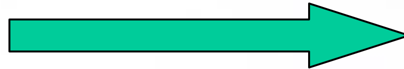




Development of the 5 kW Laser System

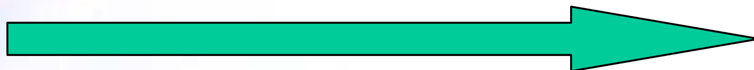
8/03 2/04 12/04

Development of the 500 W, 10 kHz, M^2 =10 laser module



Coupling 2 modules to EUV source

Coupling 10 modules (5 kW) to EUV source

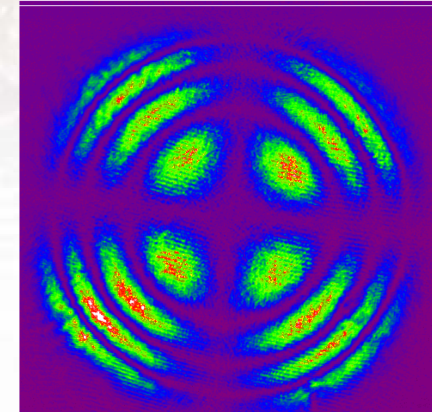


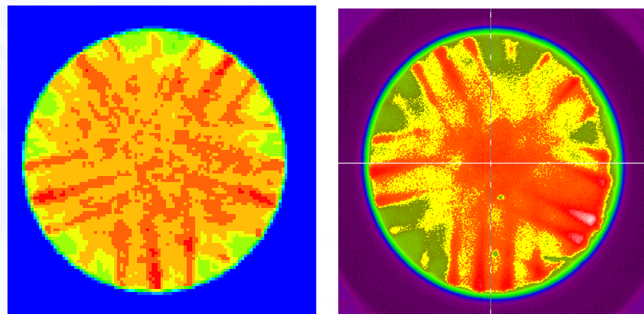
Design the multiplexing and focusing system

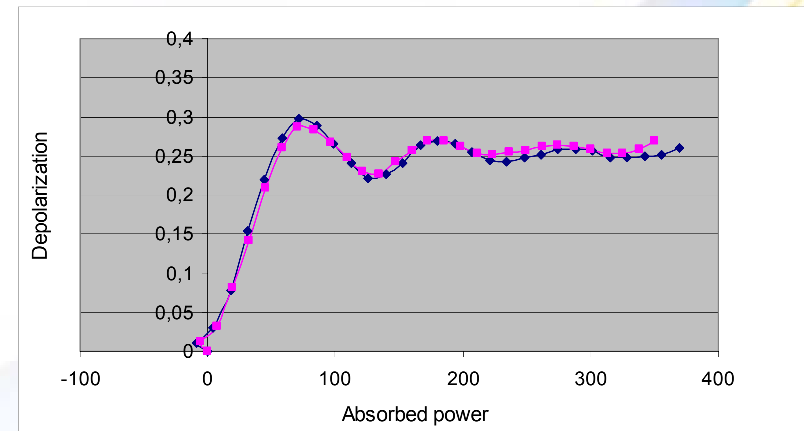
Challenges in Laser Technology

Filling the gap between 300 and 500 W :

- ✓ Modeling and minimizing thermal effects
- ✓ Optimizing the laser parameters (pulse length, beam quality, efficiency, …)
- ✓ Further improving reliability, reducing costs







Xenon Pumping and Recycling System

High pressure injected Xenon

Turbo Maglev.Pump

Turbo Maglev. Pump

Xenon injector

High Vacuum chamber

EUV

Laser

Low Vacuum chambe r

Xenon pumping, recycling and purifying system

Dry+ Roots pump

ALCATEL

Dry pump

ALCATEL

Low pressure Pumped Xenon

Xenon Recycling and Purifying Principle

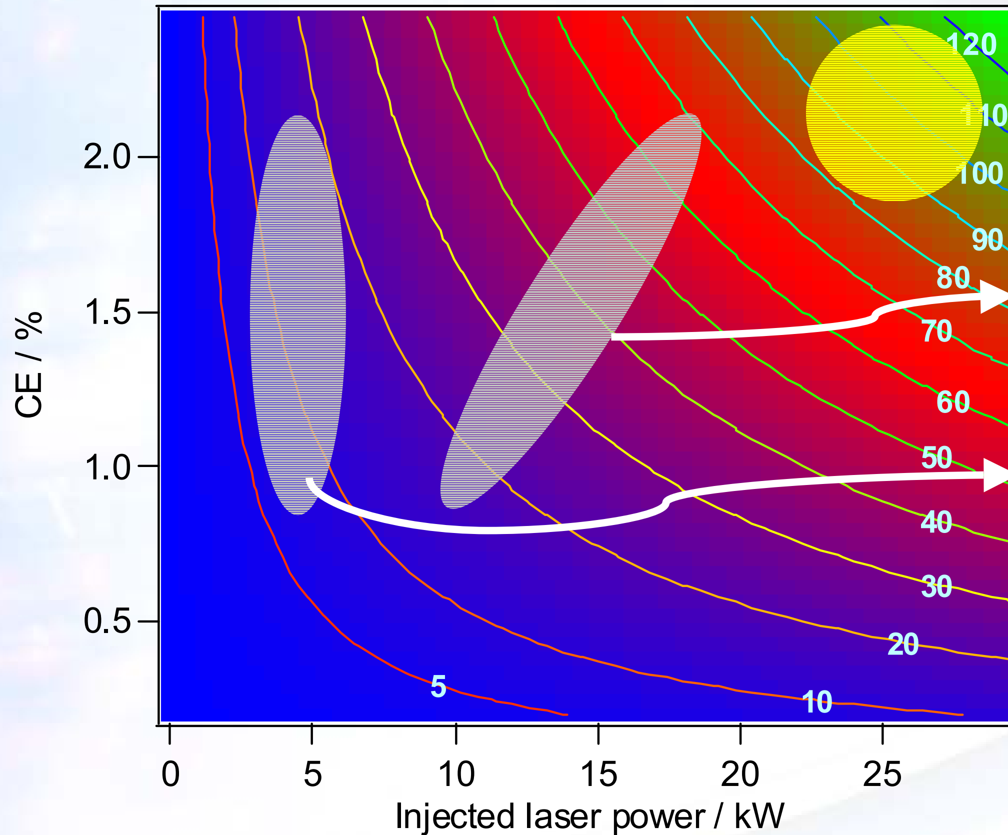
- **Flexible tank to stock Xenon**
- **Specific filter units to purify xenon**
- **Physical transformation:**
  - Cryogenic and heating means
  - Cycle is made continuous by using 3 identical tanks

Xenon Recycling System Capacities

	Today	Tomorrow
Xenon Flow	0.4 slm (3.10^{-4} mol.s^{-1})	8 slm (6.10^{-3} mol.s^{-1} / adjustable$<$1%)
Injected pressure	20 bar (+/- 10 %)	50 bar (adjustable from 1 to 50 bar)
Xenon purity	10 ppm H_2O 10 ppm O_2 10 ppm hydrocarbons	0.1 ppm H_2O, O_2 and hydrocarbons 10 ppm N_2 and rare gas 1 ppm other gases
Total xenon load	15 mol (~340L)	15 mol (~340L)

Development Roadmap of the ELSAC Laser-Produced Plasma Source

EUV in-band power in π sr @ intermediate focus #



Today's market request for industrial EUV steppers for 100wph

Source specs in 2006/07

Today's goal of EXULITE for 2004/05

#debris mitigation, spectral purity filter and gas transmission included

EXULITE Source Performance Roadmap

EXULITE Source Performance Roadmap

Metrics	Oct-00	Mar-01	Oct-01	Mar-02	Sep-02	Mar-03	Mar-04	Mar-05	Mar-06	Mar-07
Central wavelength (nm)	13	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
Demonstrated collectable EUV power in a 2% spectral bandwidth in the region between 13-14nm (W)	0.01	0.01	0.1	0.15	0.25	1	10	50	200	> 200
Available collection solid angle (sr)	1.5	1.5	1.5	2	2	π	π	π	2π	2π
Source emission area (mm^2)	0.2	0.2	0.2	0.03	0.03	0.01	0.01	0.01		
Etendue (mm2-sr)					0.06	0.03	0.03	0.03		
Demonstrated maximum repetition rate (kHz)	0.01	0.01	0.05	0.05	0.05	5	6-12	6-12	> 12	> 12
Demonstrated steady state repetition rate (kHz)										
Dissipated total power in source region at steady state (kW)		0.035	0.035	0.035	0.035	0.2	1	5	10	> 10
Source facing condenser lifetime (# of pulses to 10% reflectance loss										
Pulse-to-pulse spatial stability (um 3s)										
Pulse-to-pulse intensity stability (um 3s)										
Pulse-to-pulse angular stability (um 3s)										
Pulse-to-pulse pointing stability (um 3s)										
Key risk areas				nozzle	nozzle	nozzle	nozzle	CoO	CoO	CoO
Critical component lifetime (h)										

ALCATEL
cea
THALES

SUMMARY

- **Modular LPP source with N multiplexed laser modules**
- **Partnership between CEA, Thales and Alcatel Vacuum, with Alcatel Vacuum as system integrator**
- **Goal: 50W EUV (in 2π sr) in 2005 for alpha tool**
  - Xe flow target for first source
  - Study of higher CE target materials underway
- **Roadmap to higher power**

EXULITE