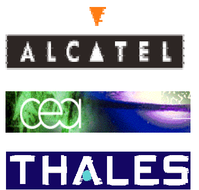
Modular Laser plasma EUV power source for micro-lithography



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Abstract

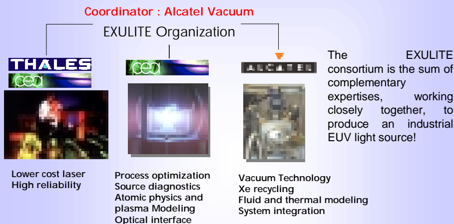
Within the frame of the European MEDEA+ initiative, Alcatel develops an EUV high power source for next generation lithography in collaboration with Thales Laser and the French national laboratory CEA Saclay.
The goal of this contribution is to show the study results and achievements to solve the technical key issues for the EXULITE LPP source. Conversion efficiency is the key element for the successful source. For laser produced plasma sources, it demands for identifying the best laser – target matching. Measurements have been done with long pulses in nano-second range. Moreover, plasma coupling has been modeled and a dedicated characterization tool has been developed for in-situ debris monitoring.
Our concept is based on ***10 identical laser oscillators spatially multiplexed and synchronized***. This implies that focusing and collecting optics are other key issues. We have analyzed precisely the optical configuration and studied a specific multi-element collector.
Due to the high power plasma, thermal management is a critical issue. To evaluate the thermal dissipation from all elements in the vacuum chamber, a thermal modeling using finite elements have been achieved. Parallel experiments have been done with a 3.5 kW continuous Nd:YAG laser.
The EXULITE LPP source uses a ***high speed xenon jet target***, consisting of high density micro-droplets. A continuous flux of approximately 2.10^{-3} $mol.s^{-1}$ is required with a pressure below 10^{-1} Pa in the vacuum chamber in order to avoid the re-absorption of the emitted light. We have achieved a complete fluid dynamic modeling of the vacuum chamber and designed an ***optimized pumping system*** and arrangement with original chamber in order to manage xenon evacuation. We have also developed ***a xenon purifying and recycling system***, which collects a majority of the xenon flux and delivers a high quality liquid to the injector. This system is reliably working in continuous mode.

The EXULITE project

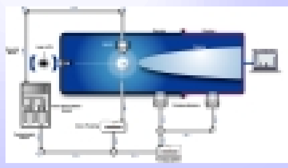
The EXULITE project is a close collaboration between two industrial companies: Alcatel Vacuum and Thales, and two French Laboratories of the CEA, with Alcatel Vacuum as the final supplier.

Coordinator : Alcatel Vacuum

EXULITE Organization



The EXULITE consortium is the sum of complementary expertises, working closely together, to produce an industrial EUV light source!



Goal of the project is to develop a highly powerful, Modular & Industrial LPP source for EUV Lithography.
ELSAC will run at the end of the year with two 500W laser modules and in 2004 with more than 5KW laser power @10 kHz with a fully recycled Xe target, in order to obtain 50W EUV output power in 2005.

Laser - target interaction

Laser plasma interaction:

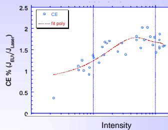
•Previous results with the first prototype and **Xenon target :**

CE = 0.71% (in 2πsr*) (with Xe target), 8 ns laser pulse.

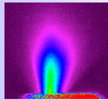
35 W Nd:YAG pump laser power

250 mW (EUV power in 2πsr*)

•Typical CE around 2% obtained **with Tin target**, 20 ns laser pulse



Xe target



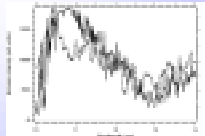
Xenon target is optimized to obtain a strongly confined jet target, stable for best laser/target interaction, and for limiting EUV reabsorption.

We realized high rep rate experiments with a 200W laser unit @10 KHz. Our Xenon target shows high stability with high repetition rate.

EUV Plasma modeling* at CEA:

CEA has a very long experience in atomic physics, theoretical plasma physics and numerical plasma simulations.

We use EUV laser plasma modeling to enhance the target emissivity, to improve the laser target coupling and to choose the best target material and composition.

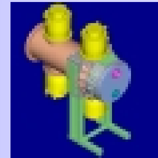


We obtained good accuracy between modeling and experiment as shown on the following figure that presents Xe plasma emission (dotted line for experiment and full line for modeling).

** CEA is member of the SEMATECH EUV data workgroup,*

See also EUV source Modeling Workshop, Dr.Poirier.

ELSAC prototype



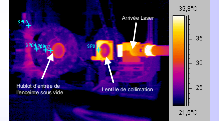
Design of ELSAC

The EXULITE consortium designed a new prototype EUV source taking into account optimized LPP EUV source characteristics as well as all thermal effects and management, optics contamination problems, foot print & industrial constraints.

ELSAC offers wide EUV power scalability. It is compatible with metrology tools for beam analysis, & with other collector systems.

Thermal management

Thermal management is an important issue for the industrial prototype as injected power is extremely high and all physical parameters have to be stabilized. We did simulations as well as experiments to optimize the industrial design of ELSAC



Optical collector for EUV source

CEA has designed an optimized collector for our LPP EUVsource using optical ray tracing software.

A novel multi-elements collector design provides an increase in transmission of more than 70% over that of an optimized elliptical collector, as shown on the following tab.

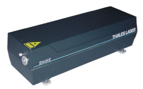
	Ultimate performances required	Optimized Elliptical collector	Optimized design for LPP source
Ideal Geometrical collection efficiency	50%	36%	80%
Reflectivity	65%	61%	46%
Transmission	32%	22%	37%

> +70% Transmission !

5 KW Laser developments

ELSAC EUV source strategy is to use a modular laser source architecture with 10x500W spatially multiplexed CW-diode pumped laser unit, developed jointly by Thales Laser and CEA lab., in order to achieve 5KW laser power.

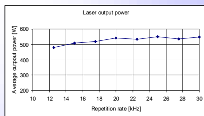
Such an architecture does present many industrial advantages to the classical MOPA approach. In particular, we use many identical, simple and compact lasers. Cost of Owner ship is thereby reduced while reliability is increased and maintenance rate is lower.



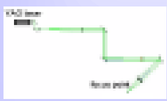
Thales Laser and CEA have developed an **industrial 300W CW-diode pumped Laser Unit**, with high beam quality (M² = 10), @ high frequency (10 KHz).

Industrial Laser Units are compact and extremely reliable (currently running with more than 4500H of operation)

High power 500W laser units @1064 nm, @ high repetition rate and with good beam quality are under developpement. We obtained laser power between 500 and 550W, and repetition rate can be varied from 10 to 30 KHz , with a pulse width from 35 ns to 75 ns.



Spatial multi Laser Beam multiplexing:



CEA has designed an actively close-loop feedback controlled focusing system to concentrate 10 laser beams on a 50µm diameter spot, with a very accurate stability (5µm for each beam).

This modular approach allows for scalable power, for optimization of development and manufacturing costs. It increases the reliability through the redundancy of pumping laser sources

System optimization and integration

Alcatel advanced pumping system

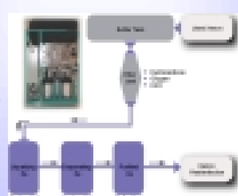
Vacuum Technology is a key element in EUV source to limit reabsorption and pressure of vacuum contaminants.

Alcatel Vacuum has optimized advanced vacuum technology for Xenon pumping, with low thermal conductivity and high mass, to fit with EUV sources requirements. AVTF has performed complete fluid modeling as well as experimental tests & measurements on the system in CEA lab.

Alcatel Xenon recycling & purifying system

Xenon recycling and purifying system can deeply improve C.o.O for industrial source.

Alcatel Vacuum developped a Xenon recycling system, with a prototype in operation since 2001 at CEA labs.



Xenon load: 340L
Injected pressure: 50 bar
Xenon flow: 8 slm

Inlet Xenon purity:
100 ppm for H_2O, O_2, Hydrocarbons

Outlet Xenon purity:
1 ppm for H_2O, O_2, Hydrocarbons
1 ppm for NH_3, Cl_2, F_2
10 ppm for N_2 and rare gases

Goals of the project & EUV source 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) *	7	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	10	> 10	>10	> 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)										

* Extrapolated value

Conclusions

- **Program Objectives:**
  - Modular LPP source with 10 multiplexed laser modules in 2005
- **EXULITE consortium strengths:**
  - Many industrial and technical advantages
  - Close Partnership between CEA, Thales and Alcatel Vacuum, with Alcatel Vacuum as system integrator
  - All parts had been deeply studied (modeling & experiment)
- **Roadmap:**
  - 50W EUV (in 2π sr) in 2005 for source alpha tool
  - 5KW laser system in progress
  - Xe flow target for first source
  - Study of higher CE target materials underway
  - Roadmap converging towards higher EUV power...

2nd International EUVL Symposium Antwerp, Sept 2003