Integration and design optimization for the EXULITE LPP source

B. Barthod, J. Cassard, M. Chagneau, H. Kambara, H. Rouch, M. Davenet, E. Véran, and R. Bernard* (**ALCATEL VACUUM TECHNOLOGY - FRANCE**, 98 Avenue de Brogny, BP 2069, 74009 Annecy Cedex, France)
T. Ceccotti, D. Descamps, J. F. Hergott, O. Sublemontier, and M. Schmidt (**CEA-DSM/DRECAM/SPAM**, Saclay, Bât. 462, 91191 Gif s/Yvette Cedex, France)
* INOPRO. 2, rue du Tour de l 'eau, 38400 Saint Martin D 'Hères, France.
Corresponding author : benoit.barthod@an.cit.alcatel.fr

This work is supported by the European MEDEA+ T405 project and by the MINEFI (French Ministery of finances & industry)

Abstract

Within the frame of the European MEDEA+ initiative and with the support of the French MINEFI, ALCATEL VACUUM TECHNOLOGY FRANCE (AVTF) develops an industrial EUV high power source for next generation lithography in close collaboration with THALES LASER and the French national laboratory CEA Saclay, in a so called EXULITE consortium. This consortium is working on innovative and modular LPP concept with ten high frequency 500 W laser systems focused on a xenon target.

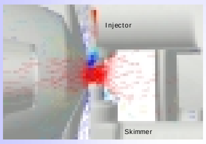
ALCATEL is working on the ***optimization and integration of the ELSAC prototype*** in close collaboration with EXULITE partners.

On one hand, in order to get a high conversion efficiency, the target is ideally a xenon jet with dense droplets leading to a high flow in the chamber. Since any re-absorption of the emitted EUV light can reduce the EUV output power, it is crucial to maintain a very low pressure in the chamber. However, pumping issues due to the particular physical properties of xenon gas. ALCATEL has designed a ***very innovative pumping system***, optimized for the EUV high power source and especially dedicated for xenon pumping. This system is based on the results of ***complete gas flow modeling*** and on experimental results on the first EUV source prototype. In particular, ALCATEL has also conceived an original arrangement for the chamber geometry and specific pumps adapted for Xenon.

The cost of ownership is a main industrial issue. So far, ALCATEL has developed a new ***xenon purifying and recycling system*** to maintain the C.o.O of the EUV source as low as possible. This system is designed and optimized for EUV source: a large xenon flux treatment (2.10^{-3} mol.s^{-1}), continuous supply mode for industrial application, a very high quality recycled liquid xenon delivered to the injection system. This system has been qualified on the EXULITE EUV source.
On first hand, ALCATEL has a great expertise in the simulation and modeling fields, especially in thermal and fluid dynamic modeling using finite elements simulation for theoretical study.
The high power EUV source will use several ultra compact diode laser modules, with a total power >5 kW. The high concentration of the laser power will result in rapid heating of the vessel and associated elements, up to few thousand Kelvin. Therefore an efficient evacuation of excess thermal energy is a crucial issue. ALCATEL has achieved complete ***thermal modeling studies*** using numerical simulation and modeling analysis for the EUV source system.

Fluid modeling

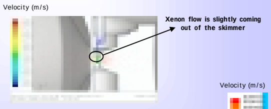
Maintaining a high vacuum level in the chamber is a key issue to avoid the re-absorption of the emitted EUV light. A fluid dynamic modeling using finite element simulation tool has been achieved. It enables to optimize the design chamber parameters as well as the optimal pumping configuration.



Velocity vectors in the chamber

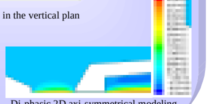
The figure on the right shows the gas flow dynamic of the injection. It clearly indicates that the injection system (injector and skimmer) is vertically blocking the xenon flow so that it expands in an horizontally.

The left figure shows that the gas flux is slightly coming out of the skimmer, which indicates a xenon back flow in to the chamber.



Velocity vectors in the vertical plan

However, with a di-phasic 2D axe-symmetrical modeling taking the existence of liquid xenon into account, it shows that the liquid xenon has an inertia effects that oppose to the xenon back flow in the chamber.



Di-phasic 2D axi-symmetrical modeling, indicating the velocity field

Pumping system

ALCATEL has a long experience in xenon pumping for EUV light source: in 1998, the first dry pumps dedicated to xenon pumping were running at TRW. Today, ALCATEL dry and maglev pumps are successfully operating at CEA laboratories on the EXULITE light source prototype (since end 2001) and at CEA LETI on the EUV Illuminator prototype BEL (since end 2002).

ALCATEL has conceived an original pumping system for the EXULITE LPP source. This system allows the use of compact maglev pumps by reducing the xenon flow rate in the "collecting chamber". Thus, standard size maglev pumps are convenient to maintain the vacuum level required to avoid the re-absorption of the emitted light.

ALCATEL maglev pumps are specially designed to pump high flow rates of heavy gases (like SF_6) used in harsh semiconductor processes. This explains why standard maglev pumps are successfully used in EUV light sources.


ATH2300M maglev pump

Xenon has very particular physical properties (high molecular mass, very poor thermal exchange coefficient, high miscibility in mineral greases).

ALCATEL has successfully developed specific versions of dry pumps dedicated to xenon pumping.

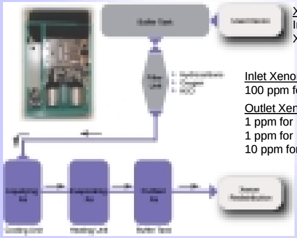

ACP28 dry pump

Xenon recycling system

ALCATEL xenon recycling and purifying system is the necessary tool to reuse xenon gas and reduce the processing costs of its application. Return on investments is inferior to one month for R&D application!

It offers:

- High performances
- Low cost process
- Recycling a rare resource
- Multi-process
- Continuous reliable supply of Xenon
- High degree of purity gas



<u>Xenon load:</u> 340 L
Injected pressure: 50 bar
Xenon flow: 8 slm

<u>Inlet Xenon purity:</u>
100 ppm for H_20, 0_2, Hydrocarbons

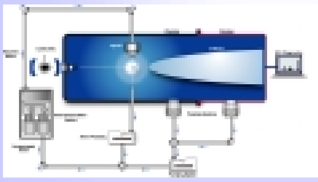
<u>Outlet Xenon purity:</u>
1 ppm for H_20, 0_2, Hydrocarbons
1 ppm for NH_3, Cl_2,F_2
10 ppm for N_2 and rare gases

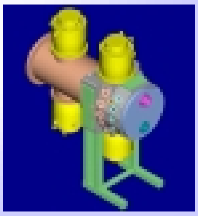
ALCATEL has developed a Xenon recycling system, with a prototype in operation since 2002 at CEA labs.

ELSAC integration

ALCATEL has a great expertise in the simulation and modeling field, especially in thermal and fluid modeling, using finite elements simulation.

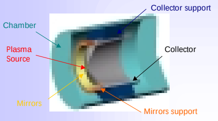
In close collaboration with all partners of the EXULITE project, ALCATEL has optimized the design of the LPP source, so called ELSAC, with particular attention to the thermal effects and to the pumping system, for the industrial integration of the EXULITE LPP source.


Schematic of the EXULITE LPP source


3D view of the ELSAC prototype

Global thermal study

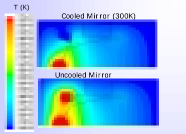
Thermal management has a strong influence on ELSAC conception. Indeed, concentration of very high laser power results in very high temperature, up to a thousand Kelvin and rapid heating of the different elements of ELSAC. Schematic of the system is presented below: we have paid special attention to thermal effects on optical elements. Modeling have been achieved, in parallel to experimental measurements, for optimum ELSAC design to manage thermal effects.



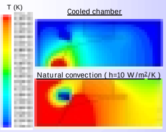
2D axi-symmetrical representation of the chamber

Modeling shows with evidence that mirrors and chamber needs cooling system.

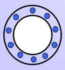
The modeling presented below shows that the absence of cooling system for the mirrors results in a strong thermal effect (temperature higher than 650 K) and optical deformation of the focused beam. Chamber and collecting optics need a similar cooling system to maintain standard conditions.

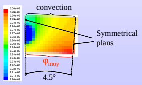


Temperature distribution in the chamber with and without mirror cooling system



Temperature distribution in the chamber with and without chamber cooling system

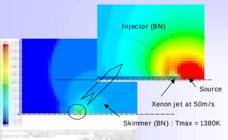

Water circulation in the chamber walls



Temperature distribution (in K) in the water cooled chamber walls

Based on the thermal modeling, we have optimized the cooling system for the ELSAC LPP Source.

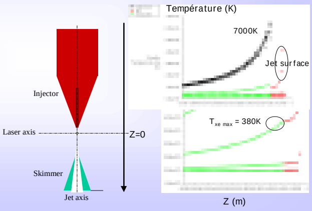
Local thermal study



Temperature field around the plasma

We have achieved a 2D axi-symmetrical finite element modeling to evaluate the influence of some design parameters on the temperature distribution in the injector system.

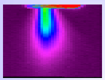
We have determined the influence of the following parameters:
- material of the injector
- distance between plasma and injector
- shape of the injector
- heat load of the plasma
- speed of the xenon flow



Injector temperature distribution along the jet axis

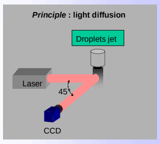
Jet study

Conversion efficiency is a key parameter to optimize to obtain a high power EUV source. It is why we are continuously working on the optimization of the target: material, structure, geometry, with modeling as well as with experimental tests.

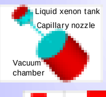

View of the micro-droplets jet with light diffusion system

Fluid dynamic modeling have been achieved for different nozzle types: conical, cylindrical, trumpet, capillary ... Best configuration allows to obtain a very dense and directive xenon jet, as shown on left figure.

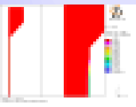
Complementary to the modeling, tests have been achieved with experimental setup based on light diffusion as shown on the right figure. We have measured and studied density, divergence and conversion efficiency of many different nozzles, with first prototype of LPP source, when varying different physical parameters such as xenon pressure and temperature.

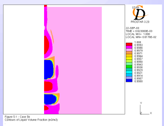


Light diffusion system principle



It is important to understand physical process in the Xenon targets, such as cavitation and bubbles formation. Modeling are under process for better understanding of these phenomena.


Contour of liquid volume fraction using a Rayleigh model



Contours of liquid volume fraction in the vacuum chamber showing chock waves

2nd International EUVL Symposium Antwerp, Sept 2003