Key issues for the development of a modular laser-plasma source for EUV lithography

A. Bonnefois, G. Cheymol, Ph. Cormont, D. Farcage, M. Gilbert, P.-Y. Thro, J.-W. Weulersse
CEA/ Saclay, DEN/DPC/SCP, 91191 Gif-sur-Yvette Cedex, France, e-mail : pthro@cea.fr
T. Ceccotti, O. Sublemontier, J.-F. Hergott, M. Schmidt, CEA/Saclay, DSM/DRECAM/SPAM, 91191 Gif-sur-Yvette Cedex, France
J. Skrzypczak, S. Muller, E. Marquis Thales Laser, Domaine de Corbeville, Route Départementale 128, BP 46, 91401 Orsay Cedex, France
*B. Barthod, I. Gaurand, M. Davenet,B. Fay**, Alcatel Vacuum Technology France, 98, avenue de Brogny 74 009 Annecy Cedex France
** Consultant*

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Abstract :

Laser produced plasma is one of the two options left (with the gas discharge plasma) for the next generation of EUV Lithography tools.

Within the frame of the European MEDEA+ initiative, the French EXULITE consortium is developing a laser-produced plasma power source for lithography at 13.5 nm following the requirements for future production tools. The ELSAC prototype is currently assembled and uses an original design that allows for both multi-beam laser heating of the target and optimized EUV collection. The different sub-elements of the so-called ELSAC prototype will be presented. In particular, we use a water-cooled source chamber that is efficiently pumped using an approach based on differential pumping towards the EUV collector. A filament target injector is used which presents satisfactory spatial stability at a working distance of several cm. The injected xenon is recycled and purified. In 2005, the optical interface of ELSAC will couple 6 laser beams on the target but the number of lasers may reach up to 20 units in the future. Finally, the use of many identical laser modules, according to our original approach already proposed in 2000, opens the way to very precise EUV dose control.

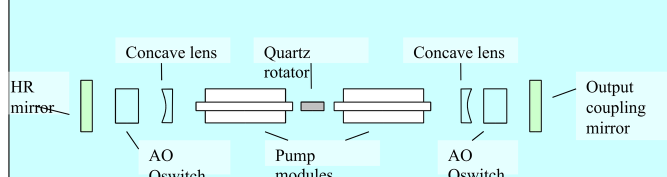
The potential advantages of LPP are already known – low debris emission and erosion, high collection efficiency, relaxed thermal management – but also the drawbacks such as the cost of ownership (CoO). We present a system taking into account all the requirements for an LPP source.

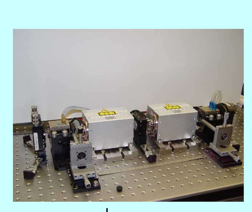
3 kW laser system development :

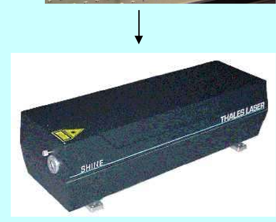
The laser system is by far the most expensive part of an LPP source. Thus the designers have to take into account not only the technical performances but also essential characteristics such as cost, efficiency, reliability and industrial availability.

Using Xenon as target with an average conversion efficiency (effectively collectable) of 1 %, the laser system will have to provide at least 35 kW optical output.

This can hardly be obtained with a few laser chains so we developped a modular LPP source based on identical, moderate power laser chains simultaneously focused on the same spot [1].





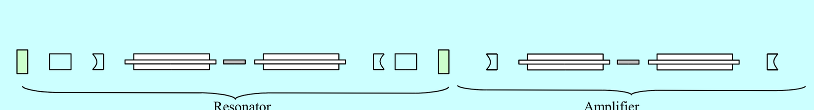


Output Power (W)	500
Beam Quality	13
Jitter [RMS]	1,2
Plug Efficiency [%]	7
Duration [ns]	35
optical/optical efficiency	21%

Insdustrial laser by Thales

Six such lasers will be included in the ELSAC prototype leading to 3 kW optical power.

The final goal is to obtain 1 kW or 1.5 kW per laser unit. The output power is increased by adding one or more amplifier stage :



Due to the high input energy, first calculations show that as much as 70 % of the stored energy can be extracted from first pump module and 80 % from second. First experiments show encouraging results and we should have a 1kW laser by the end of this year.

With this level of output power, an HVM LPP source still needs approximately 20 laser systems (which is compatible with our multiplexing system).

We are developping simple, cost-effective, **industrial** lasers which should meet the requirements for an LPP source by adding one or more amplifying stages.

[1] European patent EP1320913

Spatial multiplexing of laser beams:

The multi-beam focusing developped by Exulite is a spider-like side attack. In order to optimize the collection efficiency, we use a grazing incidence EUV collector [2]:

As much as 10 laser beams can be focused on the 50 µm Xenon jet. The full angle needed for the laser is approximatively 8°.

For the laser focusing optics, we considered the critical issue related to the heat load induced by EUV and thermal power emitted by the source spot. To avoid defocusing, mirrors with efficient rear-side cooling have been privileged.

Focusing configuration

Picture of the focusing mirror

Increasing the spot size to 100 µm allows the coupling of 20 laser beams with intrinsic good stability and low sensitivity to thermal effects.

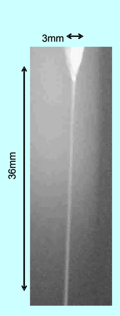
[2] : P.-Y Thro&al., *« Detailed analysis of the optical scheme for the EXULITE LPP source »,* 2nd EUV Symposium, 2003, Anvers

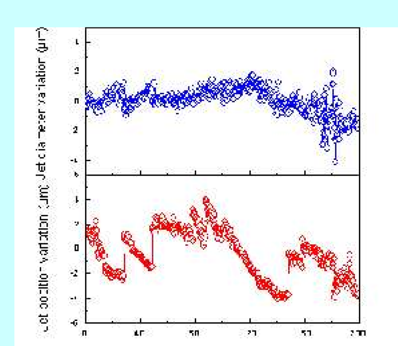
The Xenon micro-jet target :

A filament target is thought to be a suitable source for LPP. Its directivity allows a large working distance (many centimeters) and large collecting angles.

Our hardware were provided by Microliquids GmbH and has been improved in our lab.

The size of filament is 40 µm (+/- 4 µm peak to peak at 15 mm from the nozzle) and very stable without laser. With the laser power, degradation occurs within 10^7 shots.





With unoptimized laser intensity , we obtained 0.12 % CE max. (I = 6.7 10^{10} W/cm²)

Picture of the filament jet and temporal stability

Plasma induced nozzle degradation:

Under laser radiation, we see a relativily rapid degradation of the nozzle (as seen on the picture below).

Nozzle orifice

We observe localized fused matter around the nozzle hole which is obviously not due the isotropic emission of the plasma. It is believed that this degradation comes from radiation coupled into the micro-jet which acts like an optical fiber.

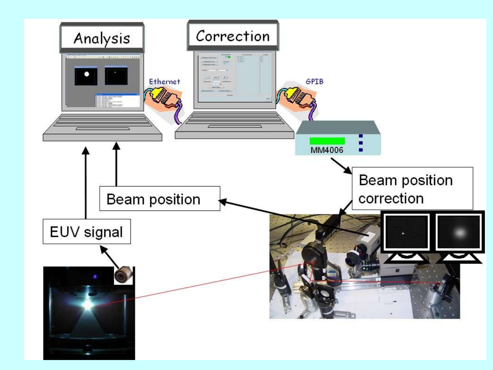
At the hole the coupled light is absorbed by the fused silica which melts. We are studying other materials with better heat conductivity to reduce this problem.

But, this could limit the use of liquid micro-jets to relatively low power/low energy laser system or to relatively short experiments.

Dose control and energy stability :

Each part of a wafer has to receive a well controlled EUV dose in order to be correctly processed. The requirements are ±0.3% in 3σ over a long period of time. Thus, two different systems are needed. One to avoid long term drift of the laser beams and another to control the EUV power received by the wafer shot by shot.

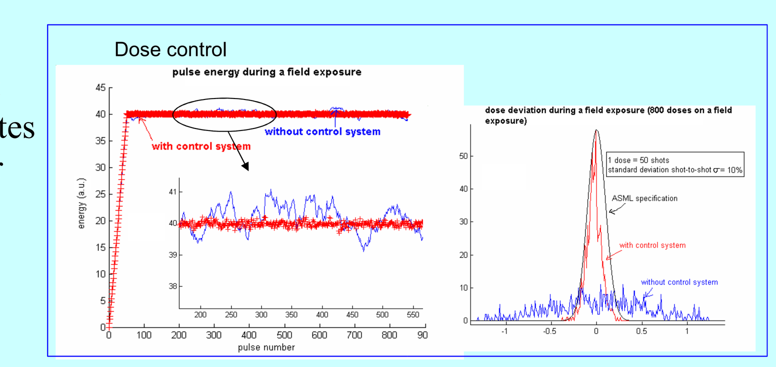
The first system is a closed-loop system checking the near-field and the far-field of each individual laser beam and moving it to its original position, if needed.



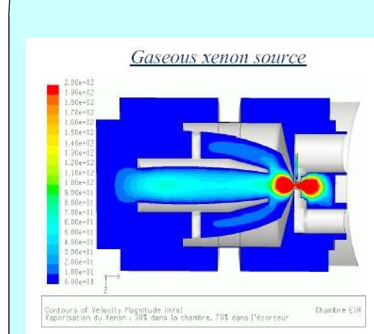
A schematic insight of the closed loop system is depicted on the figure beside. The optimization happens during wafer changes.
The time response is below 5 seconds and the precision is better than 1% of the beam diameter at the focus.

Our dose control system is based on the fact one single laser produces no or very little EUV radiation (due to low power density). So to modulate the EUV power we temporarily shift one or more laser pulses. Doing that we don't modify the thermal equilibrium around the µjet.

The system measures the energy of the first 49 pulses and calculates the energy needed for the last shot to reach the required EUV dose.



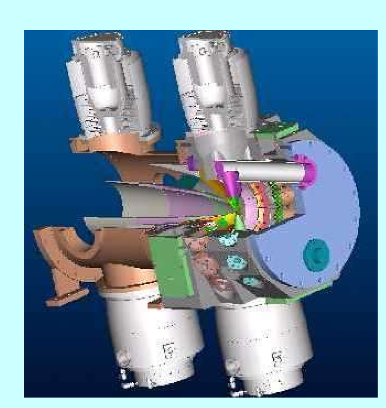
System optimization :



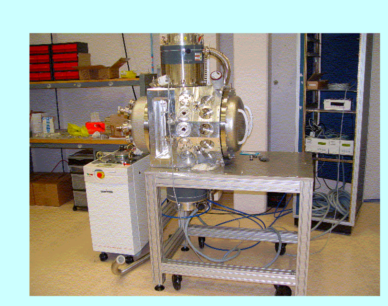
The vacuum technology is key issue to avoid the reabsorption of the EUV emission. A particular care was taken in the conception of the vacuum chamber.

The design of Elsac is now completed, including :

- thermal management,
- the optimization of the pumping scheme,
- a new recycling system,
- vibration control,
- vessel cooling optimization,
- EUV condenser design,
- diagnostics set.



The all system with six 500-W lasers is now being assembled and will be ready for tests at the beginning of next year.



Conclusion :

The Exulite consortium is developing a EUV source prototype which will be ready for tests at the beginning of next year. It will consist of a 3 kW modular laser system with different optimized sub-systems such as recycling and purifying system for xenon, an original focusing scheme, a closed-loop control system, ... On one hand, it will allow to qualify the different parts of the tool and, on the other hand, to conduct fundamental research on the laser-jet interaction. The advantage of this system is that it could be evolutive (up to 20 lasers beams). The modular architecture offers a good redundancy, a good overall efficiency and a potential lower cost of ownership.