New concept for a high brightness LPP EUV source

15th June 2016

Presentation outline

- ✧ Company introduction
- ✧ ISTEQ's mission
- ✧ ISTEQ's expertise
- ✧ An EUV source based on the tin droplet approach
- ✧ An EUV source based on a lithium jet approach
- ✧ Principal advantages of Li target over Sn target
- ✧ Summary

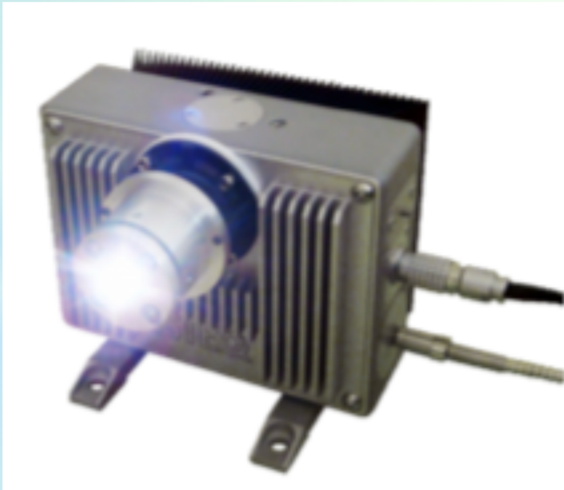
Company introduction

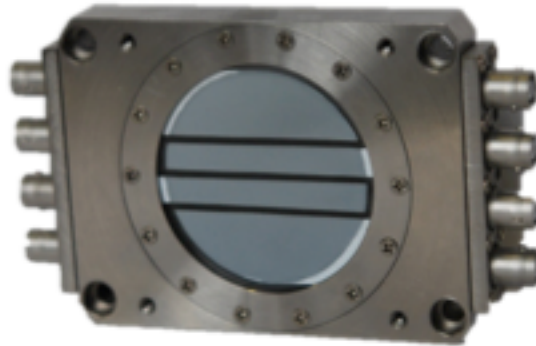
- Spinoff from EUVLabs / ISAN:
  - ISAN is a well-known research institute (located in Moscow), which focuses on EUV light research activities.
  - ASML has been an important client of ISAN for many years.
- Outstanding dedicated team of scientists and engineers:
  - Highly experienced in theoretical work and modeling in different aspects of plasma physics
  - Extremely innovative in many aspects of plasma physics experimentation.
- Patent portfolio covers all components.
- ISTEQ is located in the High Tech Campus in Eindhoven/ The Netherlands. Currently the main business is manufacturing broadband light sources.

ISTEQ's mission

- To manufacture reliable and cost effective products to be used for various industrial applications.

Examples of ISTEQ's products:





Broadband light source 180-2600nm

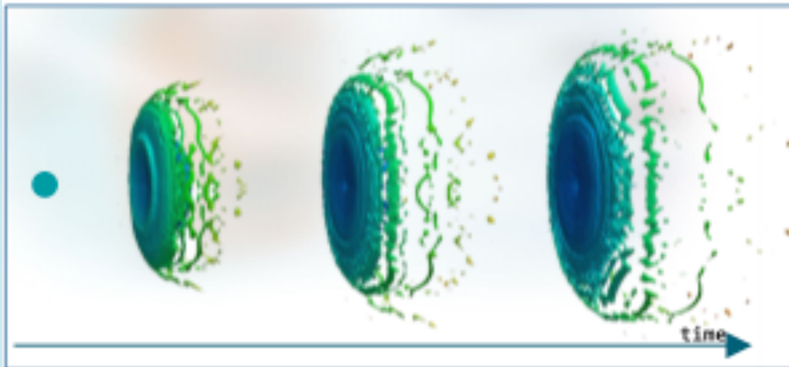
MCP detector

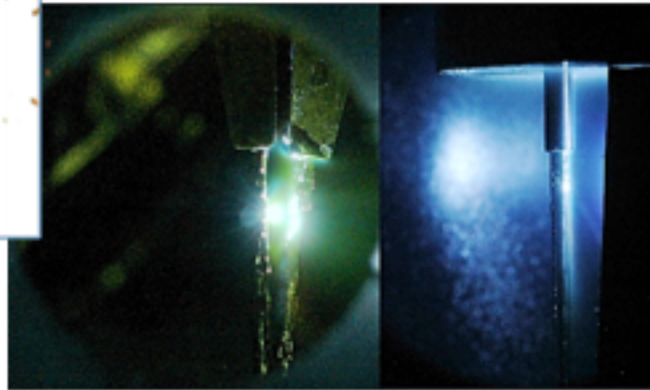
Various types of X-ray/EUV/VUV metrology equipment

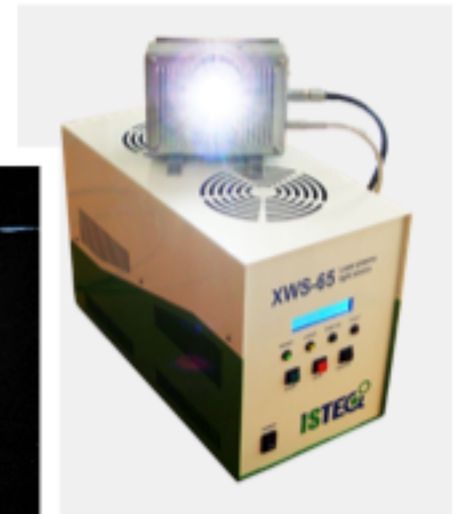
For more details about ISTEQ's products; brochures and description are available at the poster session- P36. Please feel free to talk to me directly.

ISTEQ's expertise

- Laser pumped plasma light sources for various applications
- UV broadband and EUV DPP/LPP light sources for semiconductor applications and metrology
- Numerical modeling of physical processes in plasma sources
- Metrology equipment for UV, EUV and X-ray







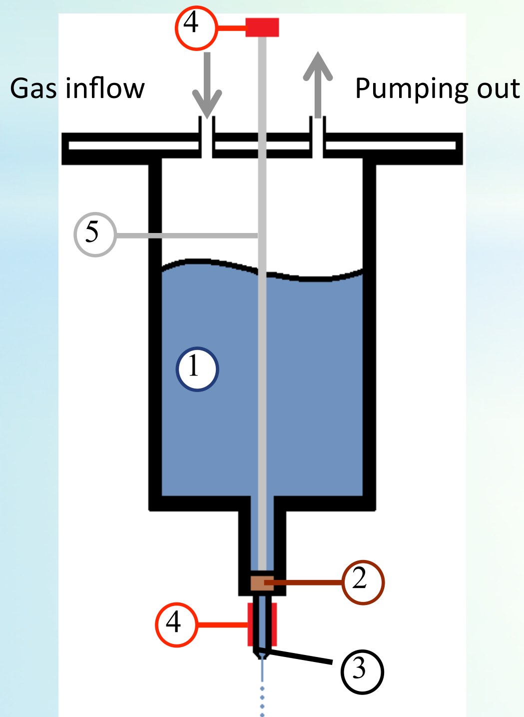
An EUV source based on the tin droplet approach

DG principle and design

Droplet generation based on excited Rayleigh breakup of falling jet.
Two ways possible for jet excitation:

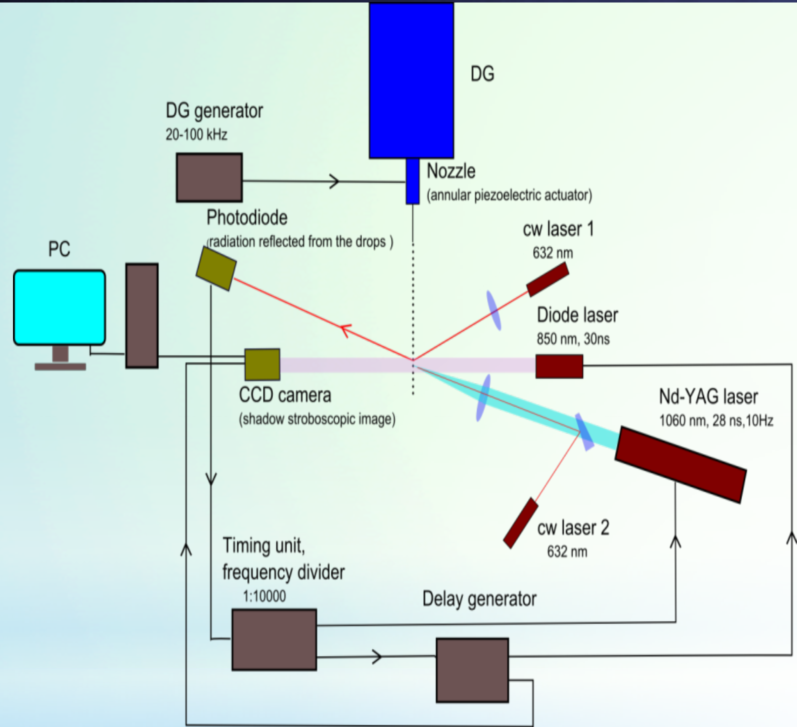
- Actuator on the nozzle (hot zone)
- Actuator on waveguide (cool zone).

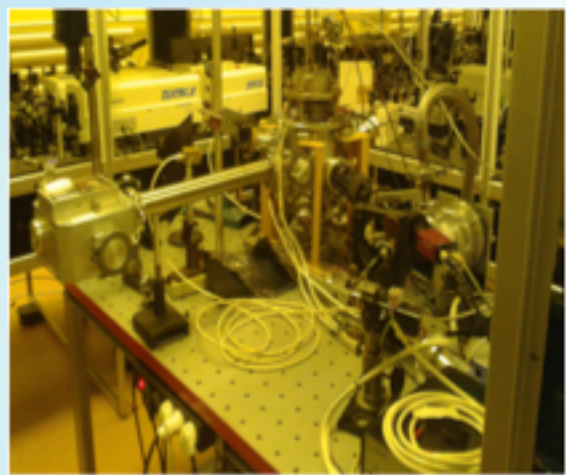
Modulation with waveguide used for metals with high melting temperature (>250 ˚C).



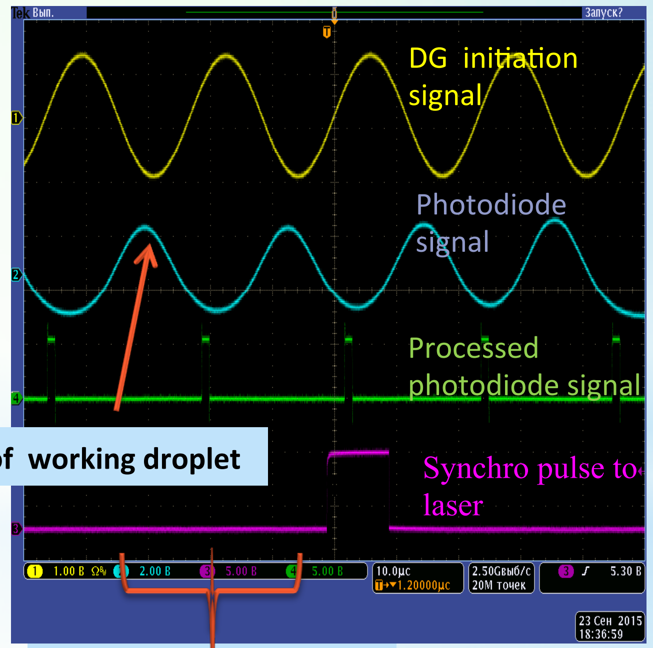
1. Tank with liquid metal
2. Filter element
3. Nozzle
4. Piezo actuators
5. Waveguide.

Experimental setup & synchronization





Oscillograms of main synchronization signals



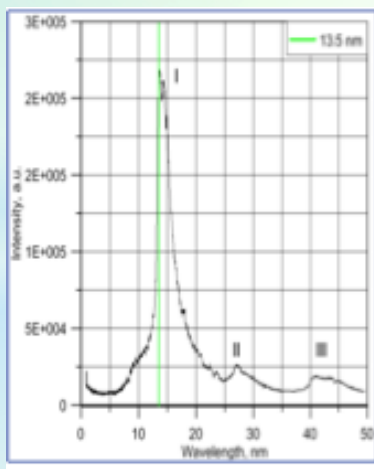
Proof of concept: scaling for brightness

Drive laser parameters:

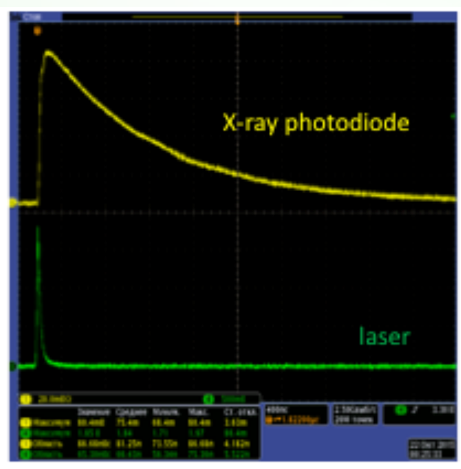
- Energy per pulse: 100mJ
- Pulse length: 28ns
- Laser beam focal spot: 50um
- Average power density: $1.8*10^{11}W/cm^2$

Nd:YAG laser is used for EUV generation:

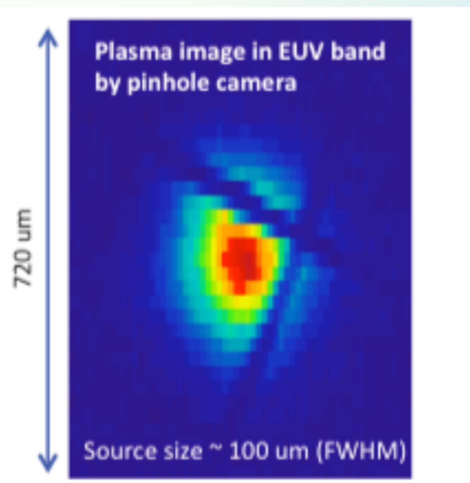
Emission spectrum



Conversion efficiency



Source size



System with 10Hz repetition rate provides EUV plasma with brightness up **to 0.5W/mm²sr**.

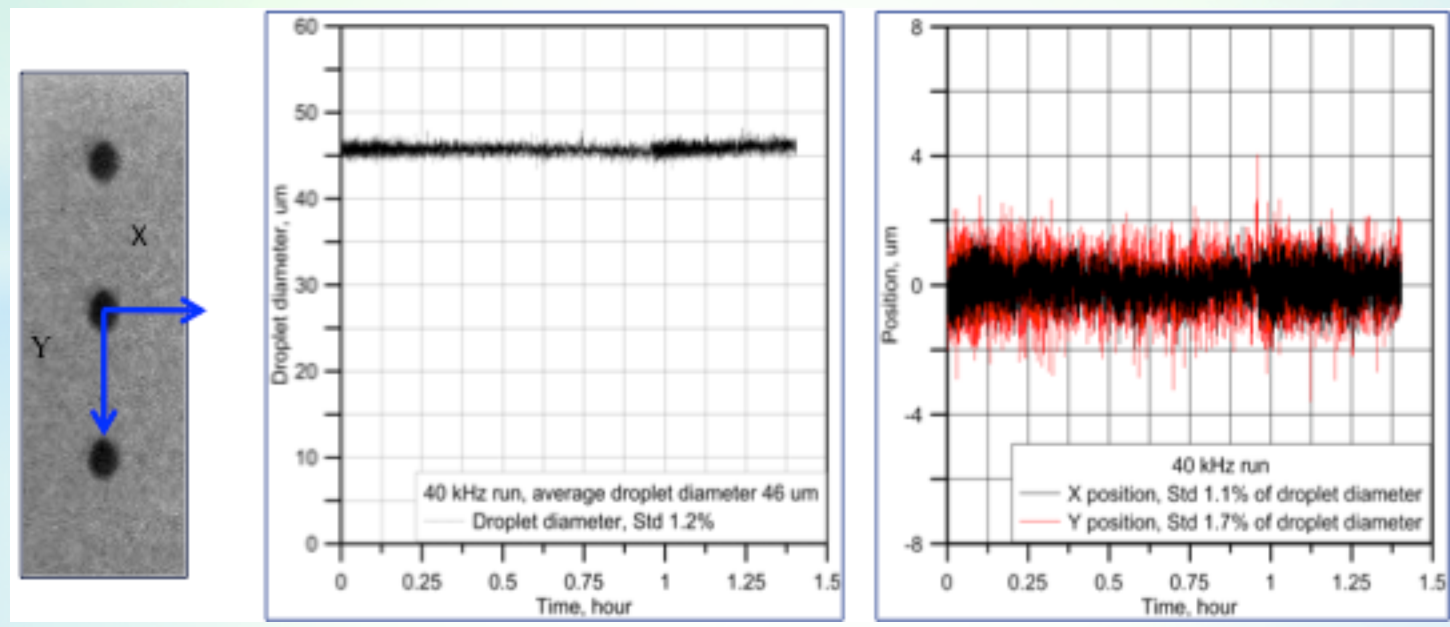
Experimentally was shown, that the brightness can scaled up linearly with repetition rate, demonstrating

400W/mm²sr @8kHz drive laser repetition rate

Positional stability

Examples of operation with Sn-In eutectic alloy:

Nozzle	30 um
Modulation frequency	40 kHz
Droplet Ø	46 um
Spacing	175 um

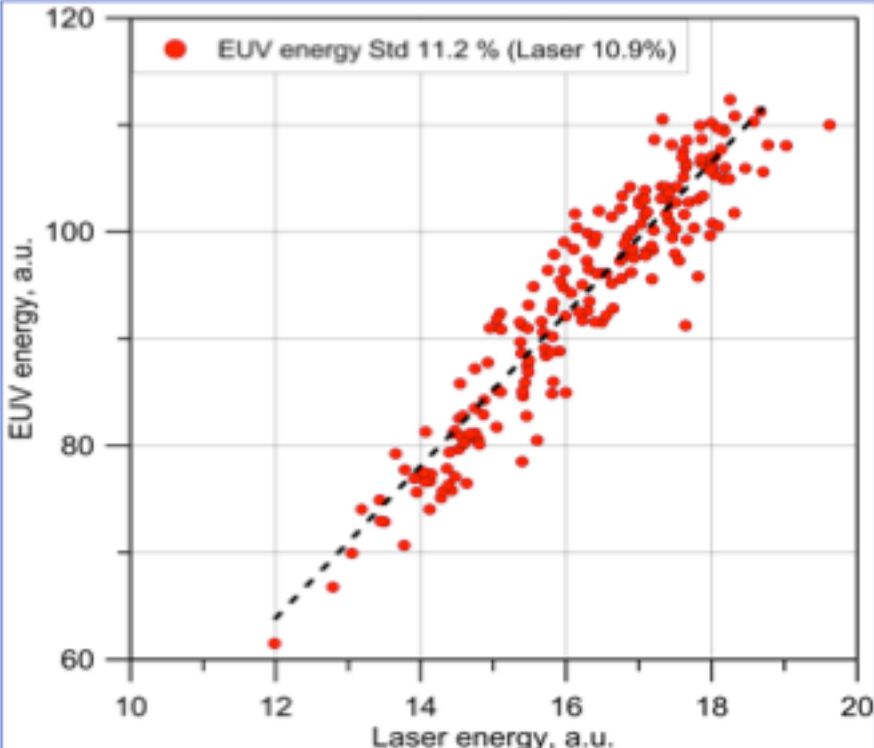


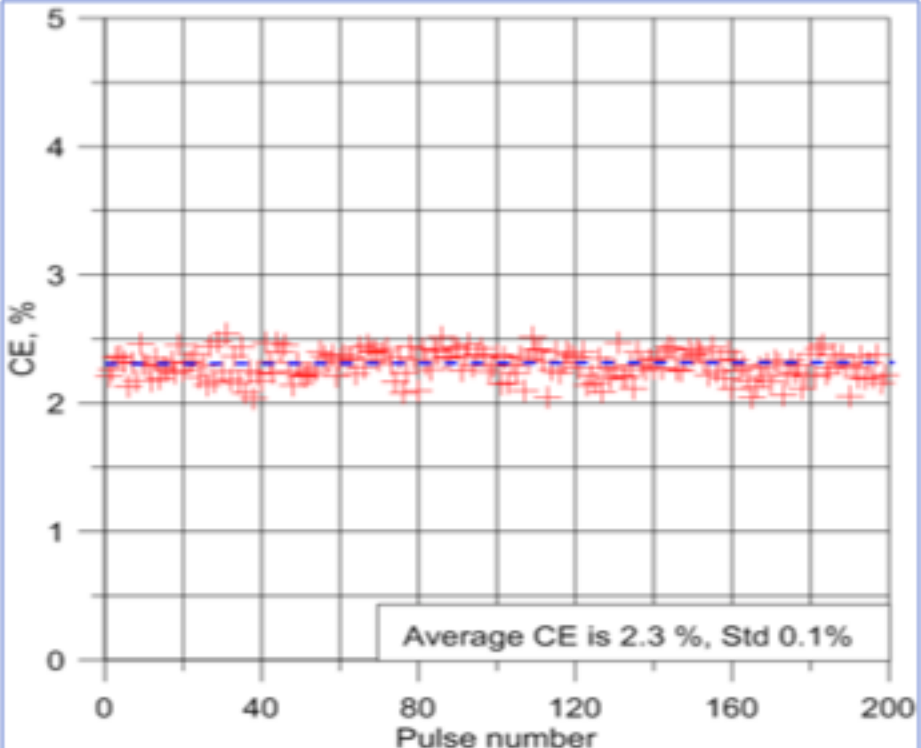
Center of mass displacement

σ_x = 0.5 um; σ_y = 0.8 um.

High position stability & mass uniformity

EUV energy stability



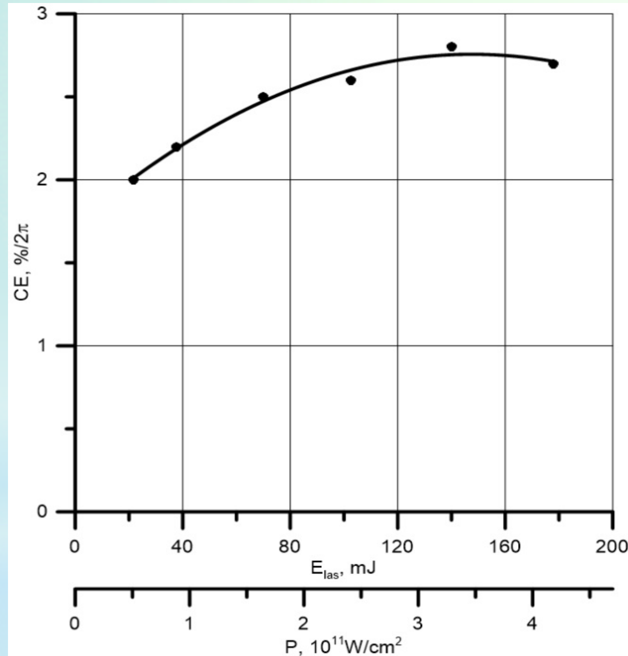


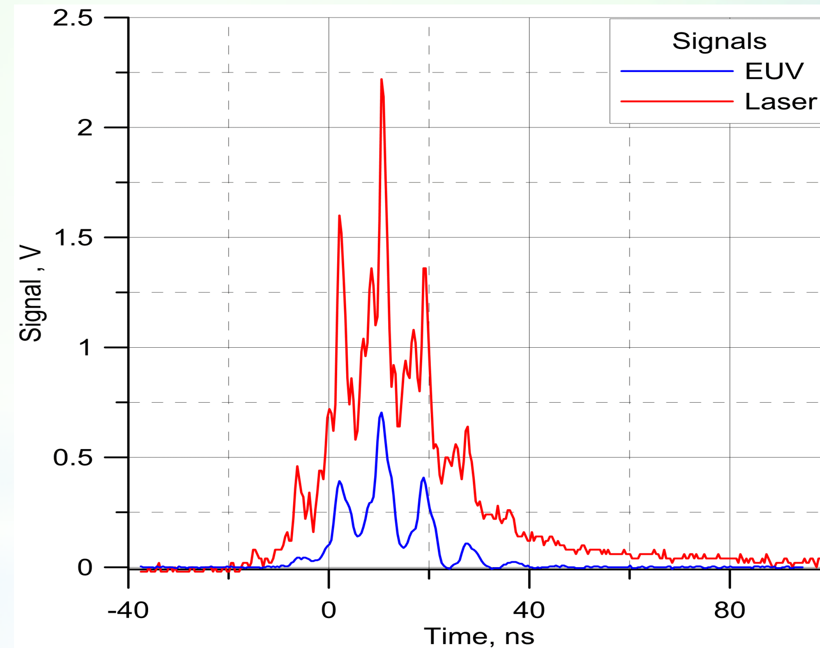
Average CE: 2.3%
CE std: 0.1%

EUV pulse-to-pulse stability can be improved via improving the laser parameters

Latest update

Optimization of the drive laser allows to increase EUV CE up to 2.8%:





Increasing of the drive laser power density allows to significantly increase brightness of the plasma, providing up to **2 kW/mm²·sr** (8kHz laser rep rate and irradiance of $4x10^{11}$ W/cm^2).

The latest results was achieved by ISAN in Moscow in May/June, the results are in preparation for publishing.

EUV source based on an innovative lithium jet approach

Compact Li target design

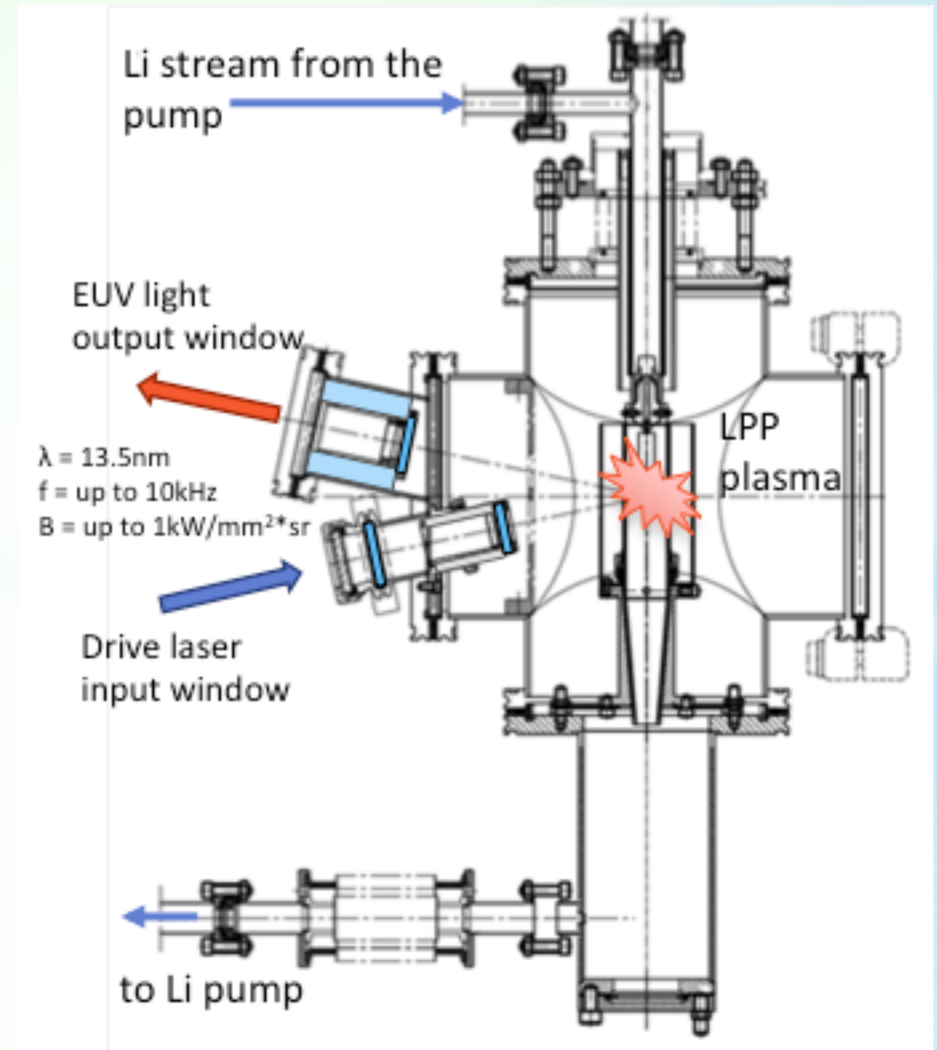
Source components :

- Target: continuous Li liquid jet
- Drive laser: Nd:YAG, 1.06um, up to 10 kHz, 1 kW
- Li high temperature
- Collection optics
- Recycling target system

Main source parameters:

- Wavelength: 13.5nm
- Brightness: up to 1kW/mm²·sr
- Frequency: up to 10kHz
- Collectable in-band power: >60mW
- Etendue: $2\text{-}4 \cdot 10^{-5}$ mm²·sr

Patent pending

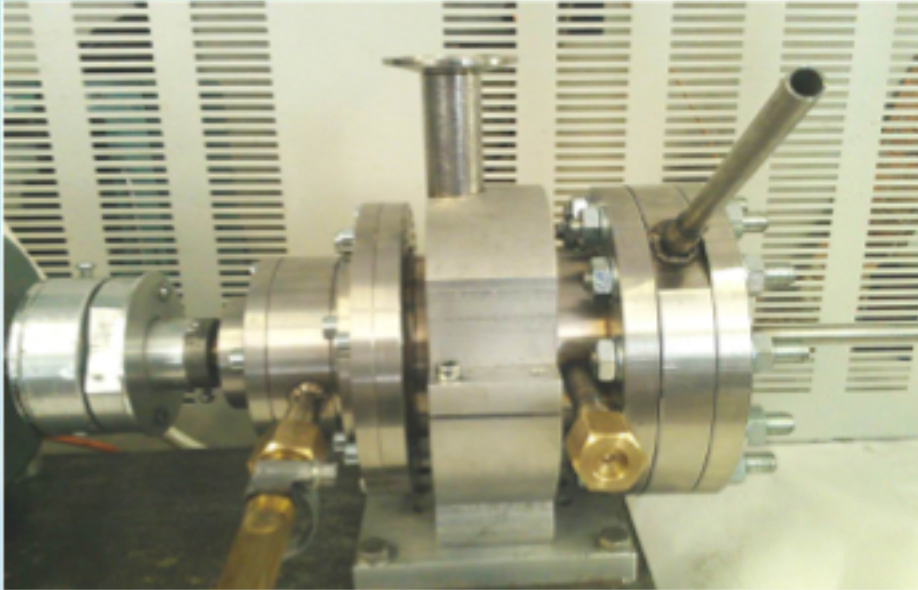


Schematic picture of Li EUV LPP source

Trial experiments using high temperature pump

Experiments have been performed to prove the feasibility of the technology

- Centrifugal pump for generation of liquid lithium jet was tested under varying conditions, up to 200 hours in non-stop regime - Phase 1



Lithium pump

Target management system:

- Liquid Li pump
- Nozzle for jet generation
- Lithium filtering system
- Lithium collector
- Phase 2 of MD pump is under development for more efficiency and to increase non- stop regime >200hours

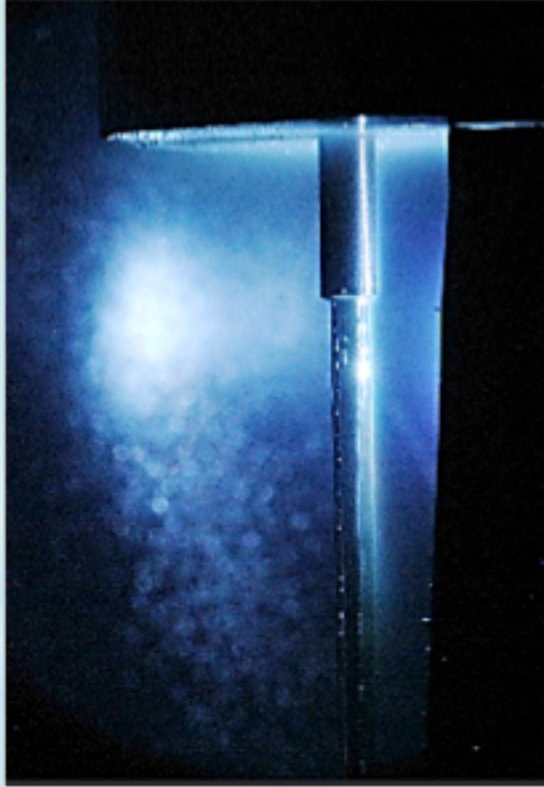
Pump operational conditions:

- Temperature up to 350℃
- Pressure up to 1 atm

Pump advantages:

- Liquid lithium is pumped in a closed loop, which makes refilling and cleaning of the lithium unnecessary
- The system is designed to keep the Li jet an extremely stable and constantly refreshable target for EUV plasma generation

Li jet and source parameters



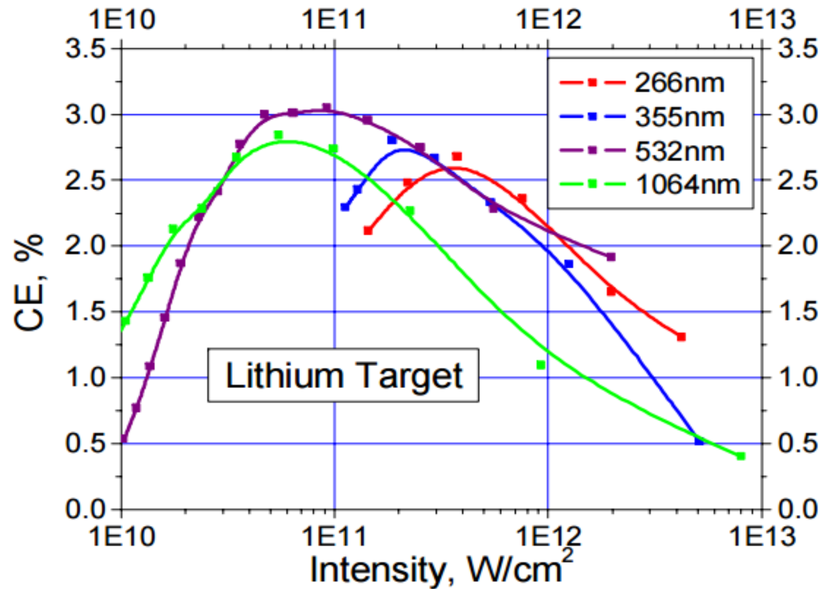
Source parameters:

- Expected CE: up to 3%
- EUV in 2pi: 30W
- Output window size: $3cm^2$
- Plasma-window distance: 16cm
- Output solid angle: 0.012sr
- EUV output window transmission: 50%
- EUV output power: 60mW
- EUV output energy: 6uJ
- Photon energy: 92.5eV
- Photons # per pulse: $4 \cdot 10^{11}$
- **EUV brightness: up to 1 kW/mm²·sr**

Jet parameters:

- Lithium jet velocity: up to 20m/s
- Diameter: 1mm
- Distance nozzle-plasma: 50mm
- Jet approach provides extreme stability, renewable and infinite in space target

Li jet conversion efficiency



	Sn	Li
Excimer (351nm)	0.5-1.0%	2.0-2.5%
Solid State (1064nm)	1.5-2.0%	2.0-2.5%
CO_2 (10.6μm)	3.5-4.0%	1.0-1.5%*

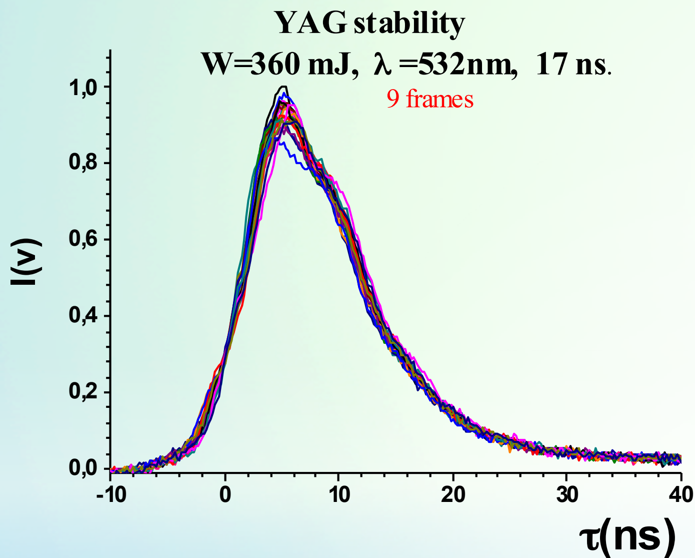
Conversion efficiency (Peak values)

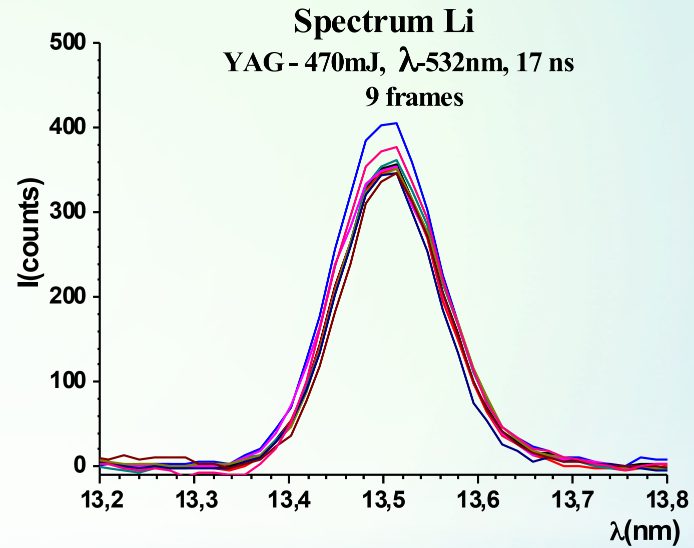
Sematech 4th International EUVL symposium, San Diego CA, 2005

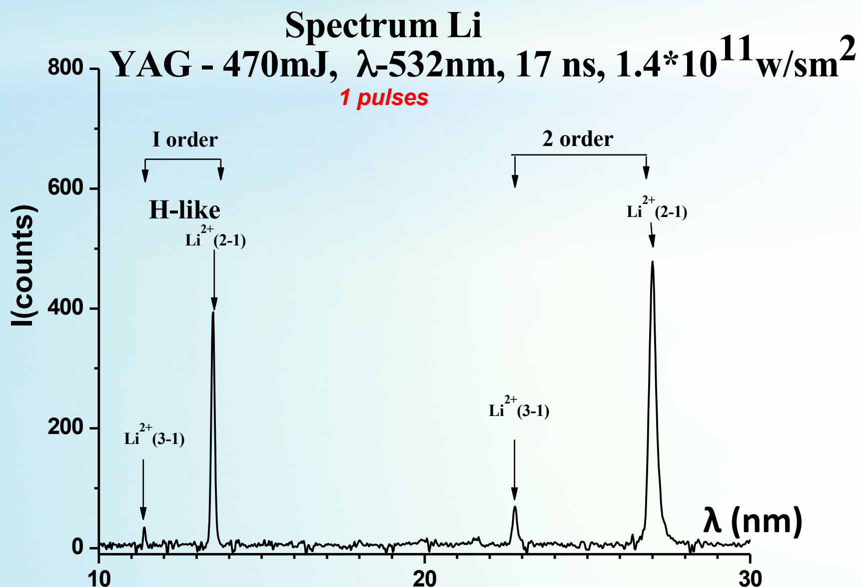
Lithium has relatively <u>high conversion efficiency</u> and a number of advantages, which makes it highly attractive for actinic source development:

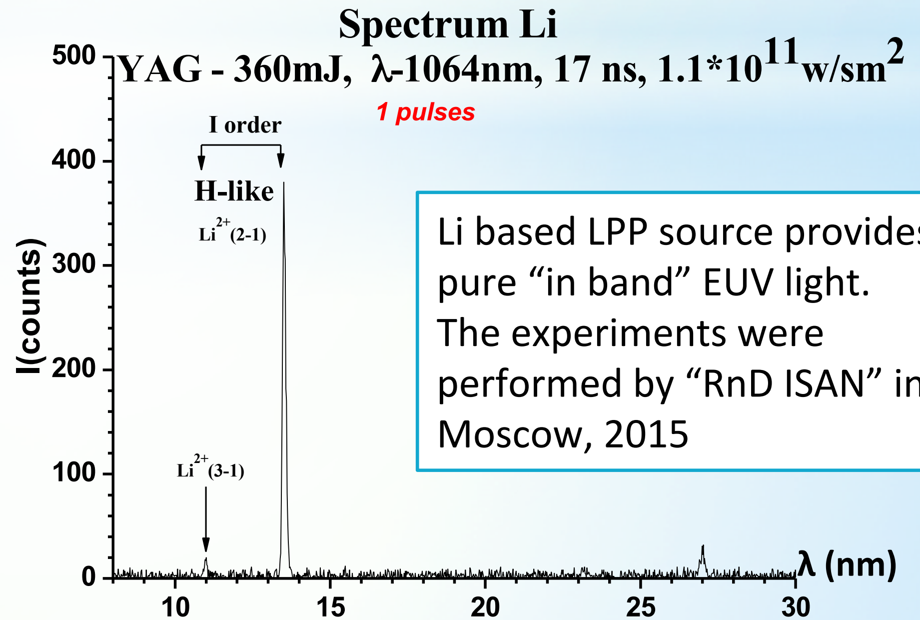
- Li produces narrow in-band spectral emission and low ultraviolet-visible out-of-band radiation
- No spectral purity filter needed
- Lithium has low ion energy intensity
- Debris mitigation is considerably less in comparison to Tin, which in turn gives longer component lifetime
- No opening of the vacuum chamber is needed

Stability and measurement of Li spectrum









Li based LPP source provides pure "in band" EUV light. The experiments were performed by "RnD ISAN" in Moscow, 2015

Principal advantages of the Li target over Sn target

- **Li target has no debris in comparison to the Sn target:** due to “closed LPP chamber” design using self-cleaning radiation input and output windows
- **Long source lifetime:** special optical design allows the placement of the collection EUV optics outside the LPP chamber
- **High spectral purity:** usage of Li plasma with narrow “in-band” line spectra, concentrated at 13.5nm
- **EUV dose stability:** provided by stable position of the target and its infinite size (in comparison to the “Tin droplet generator” concept)
- **Long (infinite) duty cycle:** provided by continuous operation of liquid lithium pump.
- **Relative system simplicity**: easier to handle and to recycle, no vacuum chamber opening or optic cleaning is needed
- **Compact design**

Summary

- Two approaches of EUV targets; tin droplet and lithium have been addressed by ISTEQ and its partners.
- Both approaches have shown very good performance.
- Li approach has shown high potential suitability for mask inspection due to its simplicity and repeatable performance.
- ISTEQ is looking for a potential partner/ system integrator to take this technology to the next level.

Acknowledgments

THAK YOU FOR YOUR ATTENTION

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