High brightness LPP EUV source for metrology applications

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Motivation

An inspection tool is needed to provide feedback on any defects at each semiconductor manufacturing process step. Indeed, inspection at the actinic wavelength is required in order to detect defects on EUVL photomasks that would otherwise print onto wafers. Metrology tools include Actinic Blank Inspection (ABI), Actinic Pattern Inspection (API) and Aerial Image Measurement System (AIMS), which all require high brightness. There are some essential parameters needed from the EUV source to fulfil mask inspection requirements. Examples of these requirements are; firstly, source brightness, this is necessary due to the limited sensitivity of imaging sensors. Hence, the need for high throughput is critical for inspection. Secondly, metrology tools have a specific requirement regarding energy stability, which is mainly driven by the need to resolve the required critical dimension (CD).

Source requirements

The key requirements for the Actinic inspection tool:

- **High brightness (>100 W/mm²/sr)**
- **Stability of plasma position < 3% of FWHM***
- **Energy stability < 3.5% (3σ) pulse-to-pulse**
- **Cleanliness 100% (debris containment must be included in the source)**
- **Availability / Reliability**

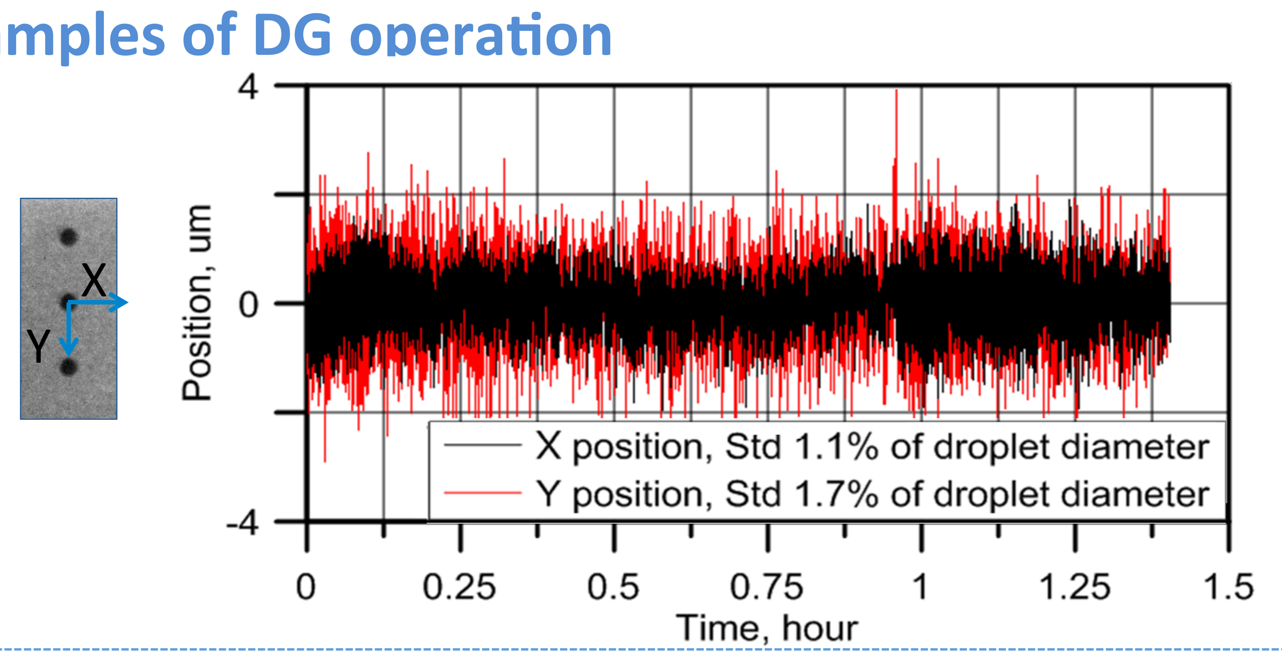
* The positional stability requirement varies depending on source characteristics and the illumination concept.

Classical tin DG approach

Examples of DG operation

Nozzle:	**30 um**
Modulation frequency:	**40 kHz**
Pressure:	**5 bar**
Droplet diameter:	**46 um**
Droplet velocity:	**7 m/s**
Droplet diameter range:	**45-65um**
Droplet diameter STD:	**1%**

Center of mass displacement:
σ_x = 0.5 um; σ_y = 0.8 um
High target position stability



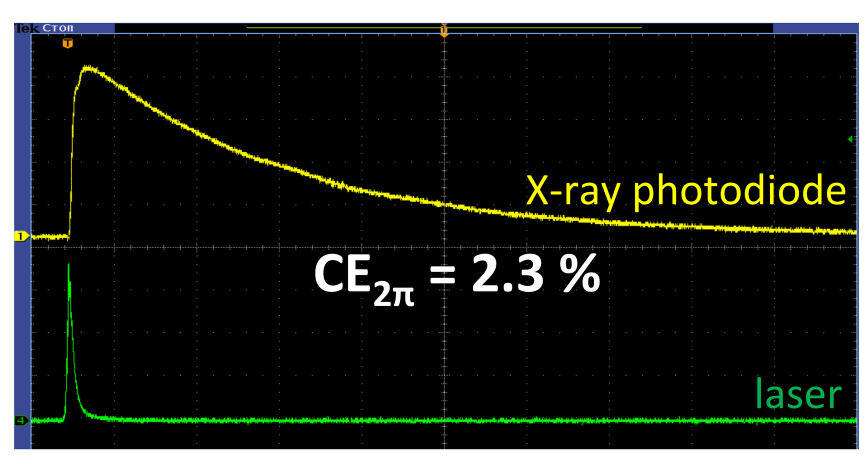
Proof of concept with 10 Hz Nd:YAG laser

Laser parameters:

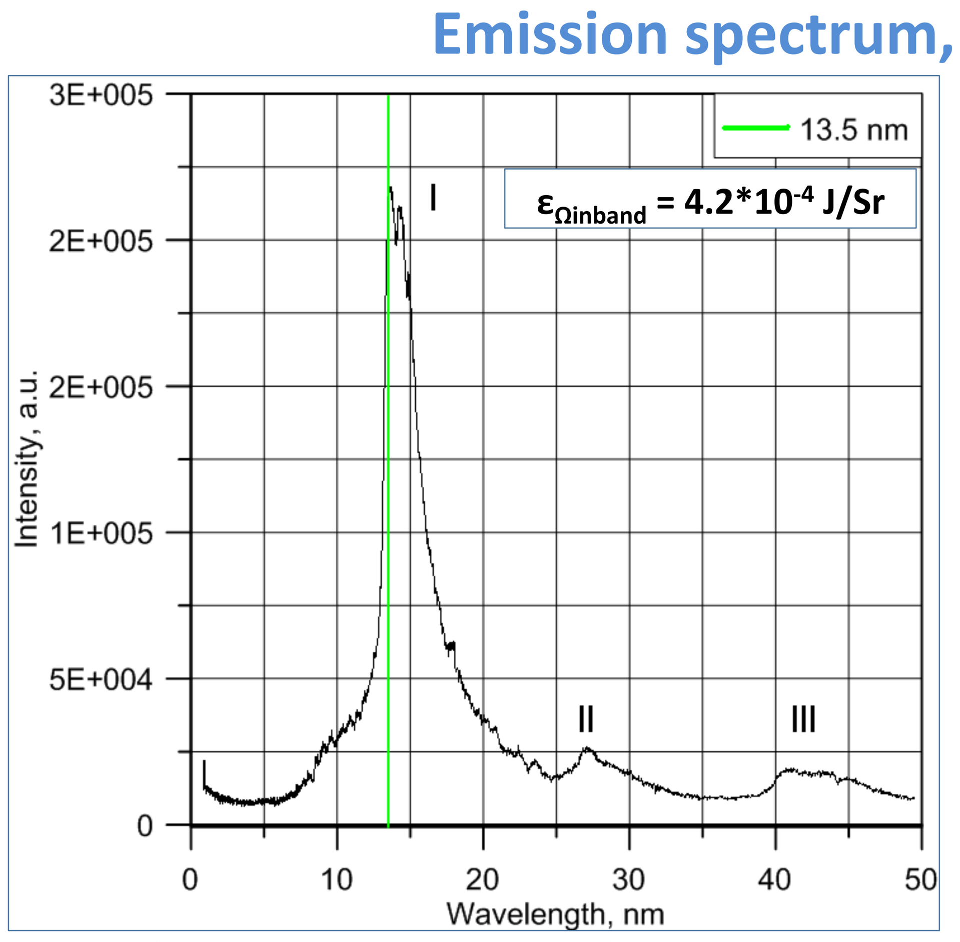
Parameter	Value (Std %)
Pulse energy, mJ	100 (9.9 %)
Pulse width, ns	28 (8.1 %)
Peak intensity, MW	2 (10.9 %)
Focal spot size (FWHM)	50 um
Average power density at focal spot, W/cm²	1.8*10¹¹ (13 %)

Droplet target parameters:

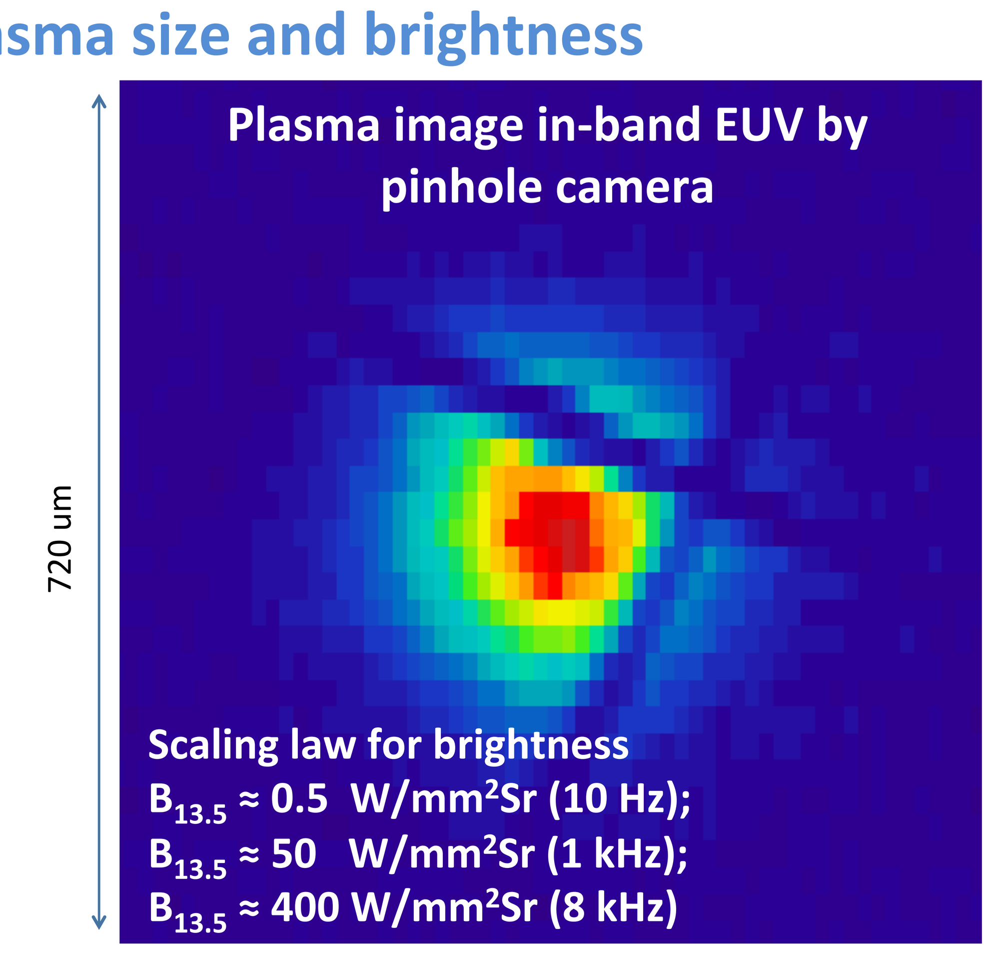
Diameter, um	70
Temperature, K	413
Material	Sn/In
X-Y position Std, um	$\sigma_x \approx \sigma_y \approx$ 0.5 um



Emission spectrum, plasma size and brightness



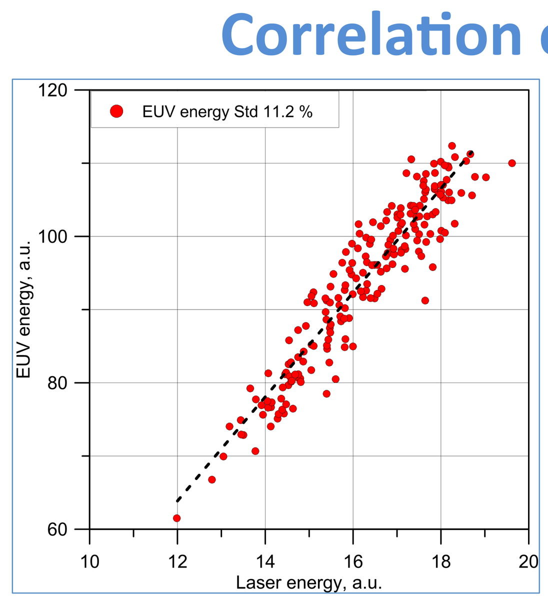
4˚ GIS spectrometer; I, II, III – diffraction orders

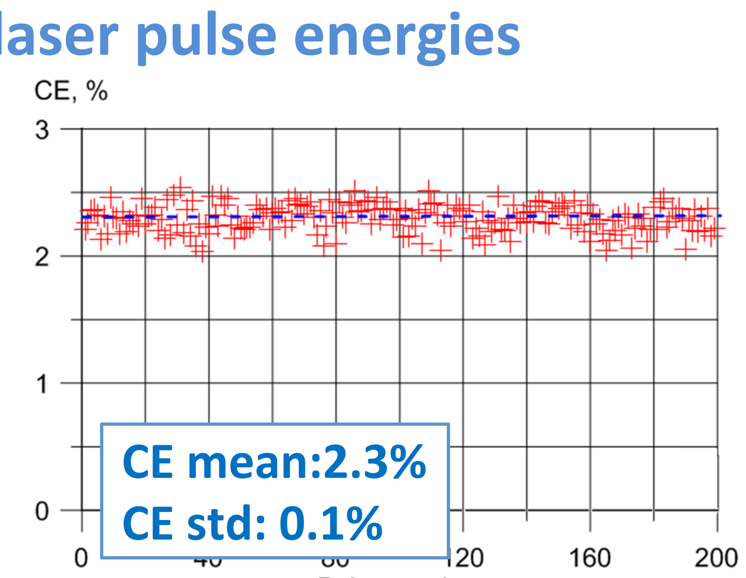


Source size ~ 100 um (FWHM)

High brightness can be achieved

Correlation of EUV and laser pulse energies





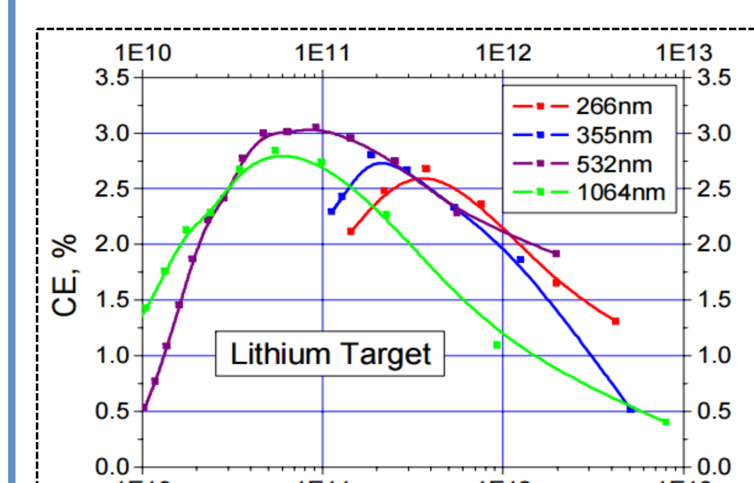
EUV pulse-to-pulse stability can be improved via improving laser parameters: energy pulse, pointing and pulse duration stability

Lithium jet approach

Advantages of lithium target

Lithium has relatively high conversion efficiency and number of advantages, which makes it highly attractive for the 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



	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)

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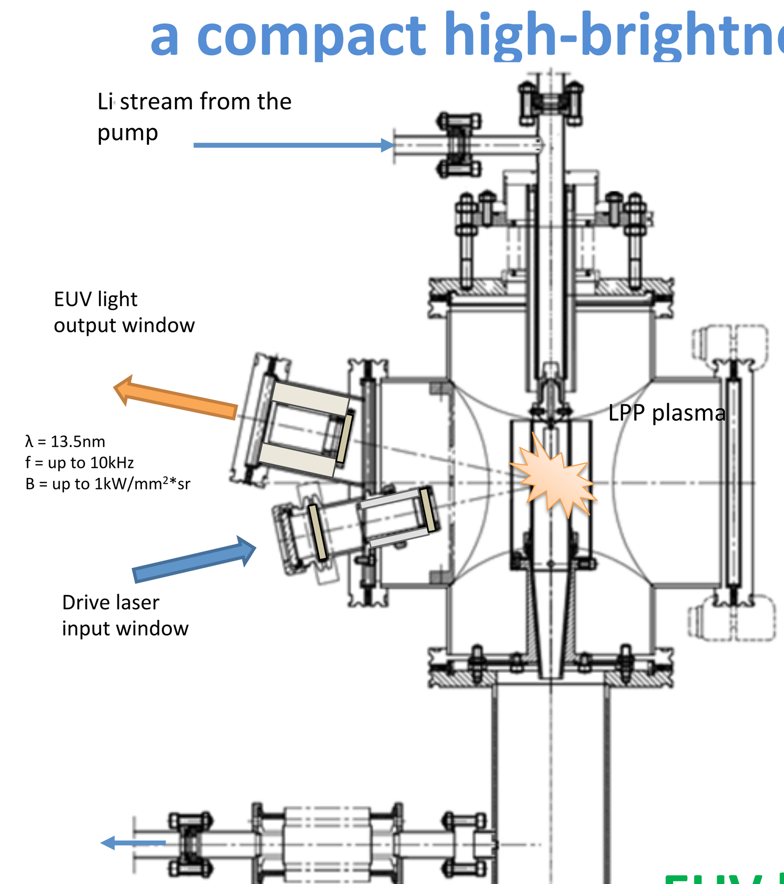
ISTEQ and RnD-ISAN have developed a new concept of a compact high-brightness lithium EUV source:



Source components :

- Target: continuous Li liquid jet
- Drive laser: Nd:YAG, 1.06um, up to 10 kHz, 1 kW [to be selected]
- Self-cleaning Input and Output windows
- Recycling target system

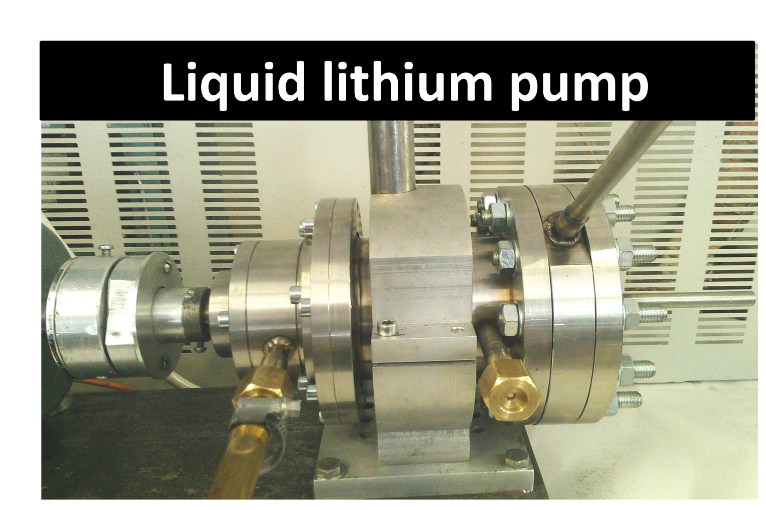
Main source parameters:

- Wavelength: 13.5nm
- Brightness: up to 1kW/mm²·sr
- Frequency: up to 10kHz
- Collectable in-band power: >60mW
- Etendue: 2-4·10⁻⁵mm²·sr

EUV brightness: up to 1 kW/mm²·sr

Preliminary experiments have been successfully performed and the feasibility of the approach has been proved.
Unique hardware has been developed and tested, making the technology ready for implementation:

Jet approach provides **extreme stability, renewable and infinite** in space target



Centrifugal pump for generation of liquid lithium jet was tested under varying conditions, up to **200 hours** in non-stop regime at temperature of **350℃**

CONCLUSIONS

1. The droplet generator based on induced Rayleigh jet breakup was developed.
2. The high droplet position stability and mass uniformity was demonstrated both in short & long term operation.
3. The flexibility of operation regimes (droplet diameter, velocity and frequency) was demonstrated.
4. Two types of jet modulation was developed: piezo in hot zone, which limits an operation temperature (250˚C), and waveguide with piezo at room temperature, which allows to operate at higher temperatures.
5. Was shown that such DG can be used for high brightness and high stability LPP EUV source.

1. 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.
2. Long source lifetime: EUV optics placed outside the LPP chamber.
3. High spectral purity: usage of Li plasma with narrow “in-band” line spectra, concentrated at 13.5nm.
4. High EUV dose stability: provided by stable position of the target and its infinite size.
5. Long (infinite) duty cycle: provided by continuous operation of liquid lithium pump.

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