POWER SCALING OF THE XTREME LDP EUV SOURCE

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SUMMARY

- Optimization of the basic electrical discharge parameters and the introduction of ***Tailored Laser Pulses*** improves the LDP efficiency by a factor up to ***1.8***
- For HVM IF power levels (> 200 W) the LDP technology allows flexible parameter choice (20 kHz ≤ f ≤ 100kHz , E_{in} ≤ 12 J, *CCE* ≥ **1.6%**)

LDP PRINCIPLE AND BASICS

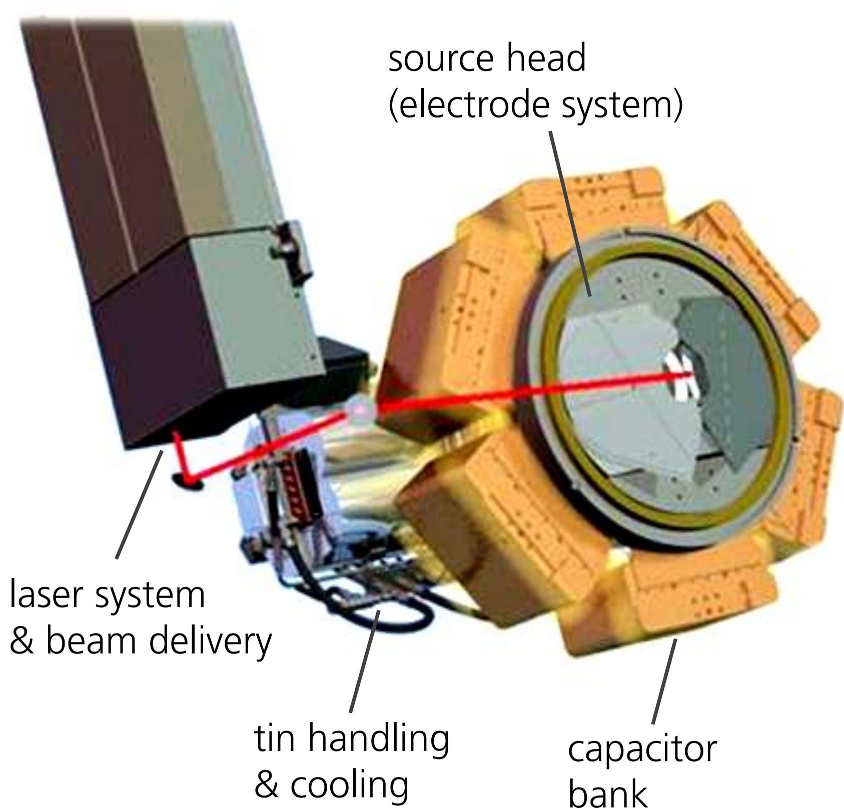


Fig. 1: Sketch of the Xtreme LDP source for ASML's 3100 scanner generation

- Electrical energy is stored in the capacitor bank ($E_{in}=½\ C·U^2$)
- Tin is evaporated from the electrode surface by laser pulse(s)
- The electrically stored energy is transferred into the tin vapour
- The hot and dense tin discharge plasma emits EUV

HVM POWER SCALING PARAMETERS

- The LDP technology allows a flexible choice of parameters in order to scale the IF power level

$$P_{IF} = \underbrace{\overbrace{f \cdot E_{in}}^{P_{in}} \cdot \underbrace{CE \cdot \eta_{col}}_{CCE}}_{\text{collectable EUV energy}} \cdot T_{opt}$$

P_{IF}	clean EUV power at IF
P_{in}	electrical input power
f	discharge repetition rate
E_{in}	energy stored in capacitor bank
CE	conversion efficiency
η_{col}	collection efficiency
T_{opt}	optical system transmission
CCE	collectable conversion efficiency

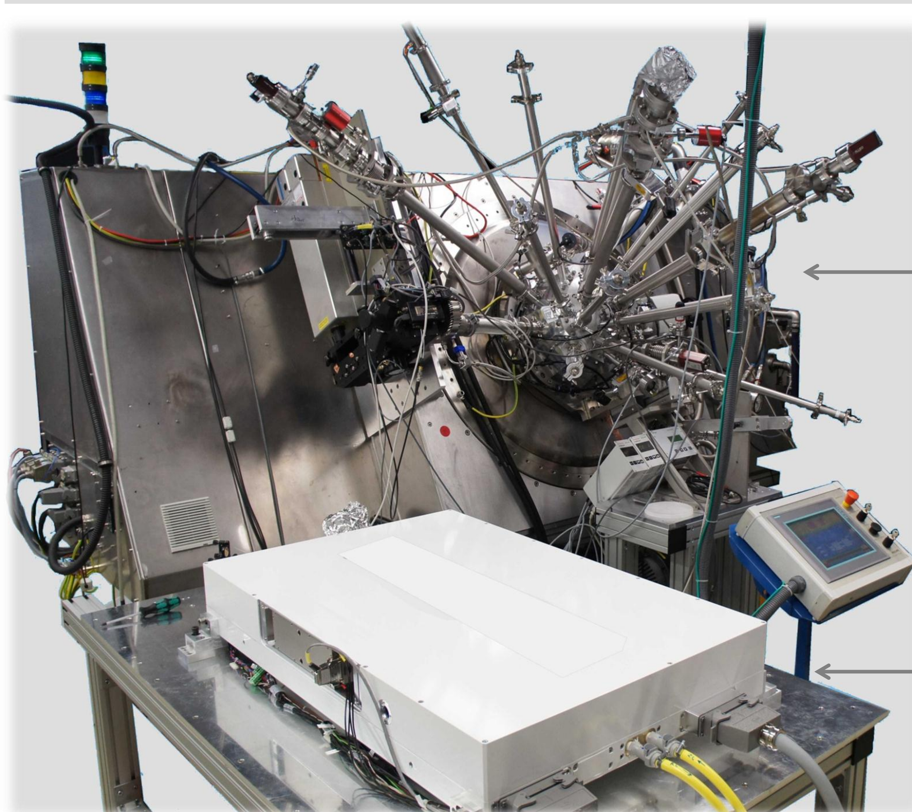
- Frequency scaling proven:
  - ✓ 100 kHz operation shown in proof-of-principle experiment [1]
  - ✓ 40 kHz operation demonstrated in a 5000 pulses burst [2]
- T_{opt} dependent on IF aperture size and optical track length

➔ IF Power scaling by increasing the collectable EUV energy

[1] Wagenaars E et al.: *Power scaling of an extreme ultraviolet light source for future lithography*, Applied Physics Letters, Volume 92 Issue 18 (2008)

[2] Marc Corthout et al.: *Sn DPP Source Collector Modules for Beta and HVM*, International Symposium on EUVL (Sematech), 28 Sept. – 1 Oct. 2008

MODIFIED ß-SOURCE FOR R&D



- Hardware flexibility
- Plasma diagnostics for in-band and OoB
- Flexible electrical circuit (capacitance, voltage, inductance)
- Novel prototype laser for pulse tailoring

Fig. 2: OBELIX2 source as experimental platform for process optimization

SCALING OF THE COLLECTABLE EUV ENERGY

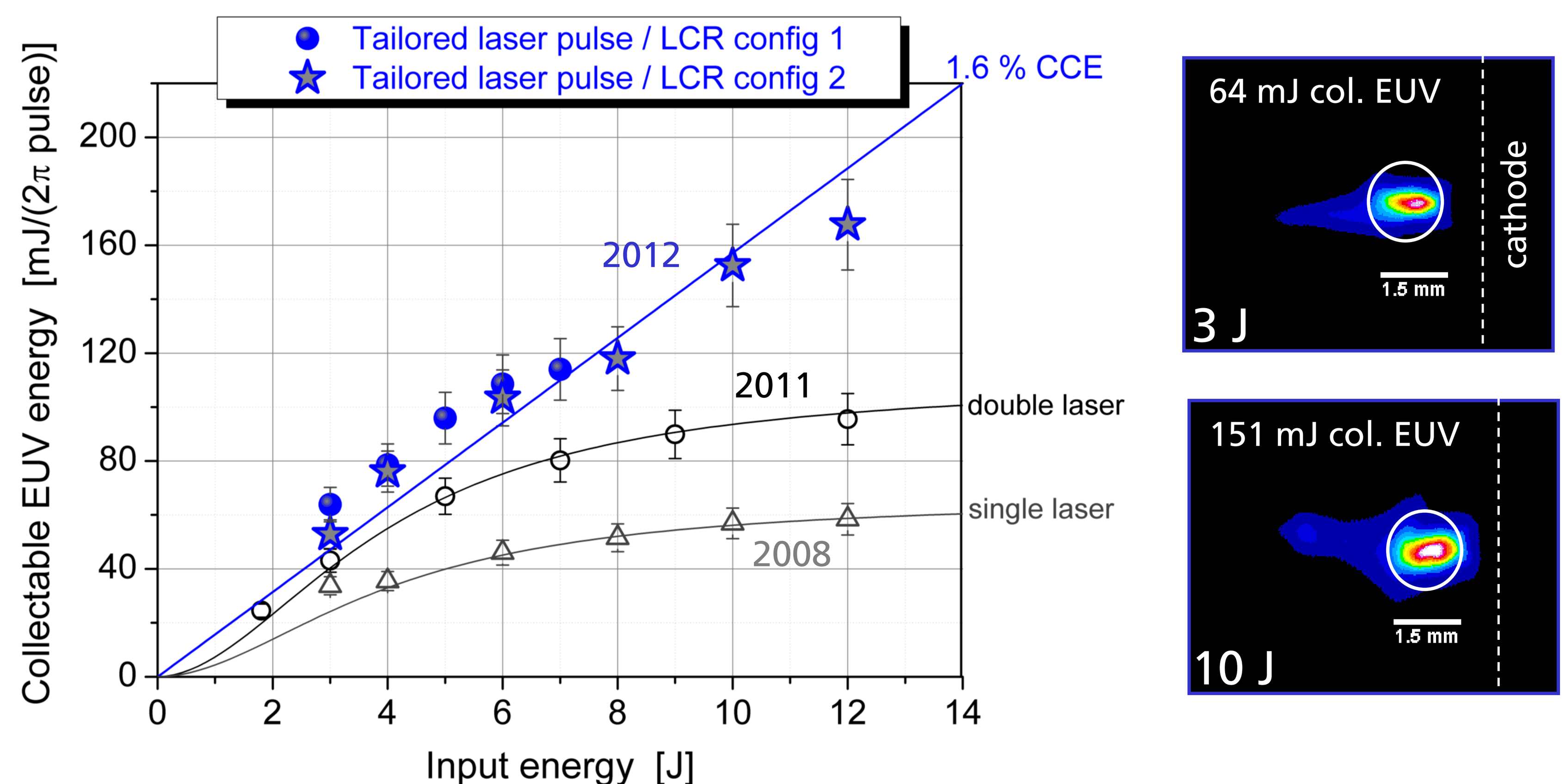


Fig. 3: Collectable EUV energy as function of the input energy (left) and corresponding in-band plasma images for 3 and 10 Joule (right)

- Collectable EUV energy scales linearly with input energy
- Emission volume does not exceed 1.5 mm étendue match
- Champion CCE of 2.1% for 3 J and 1.6% for 10 J achieved
- Further efficiency scaling potential by continuous optimization of the Tailored Laser Pulses identified

PLASMA DYNAMICS OPTIMIZATION

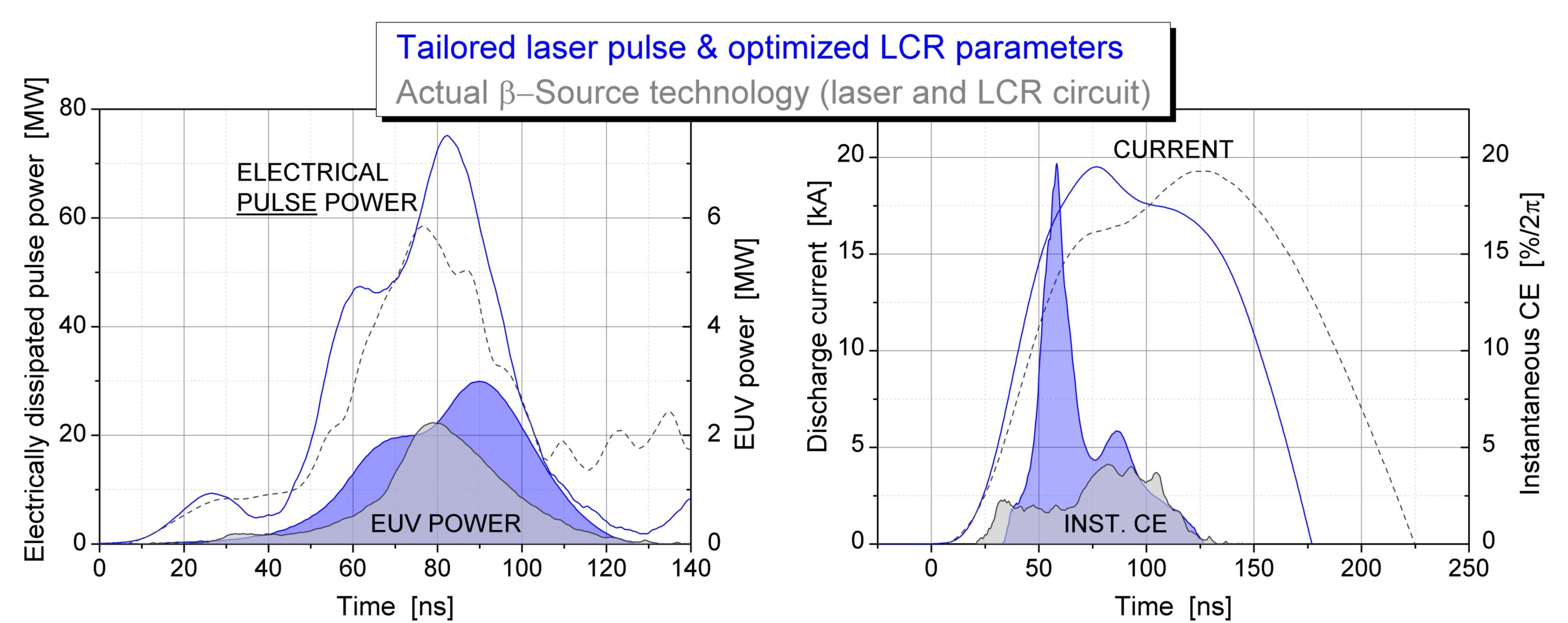


Fig. 4: EUV in-band power evolution in context of the electrically dissipated power (left), instantaneous conversion of electrical power into in-band EUV in context of the discharge current pulse (all measurements: E_{in} = 5J)

- The trigger laser defines Sn particle density and dynamics during the electrical discharge ➔ *Tailored Laser Pulses*
- Optimized match between LCR circuit and plasma dynamics

SPECTRAL EFFICIENCY

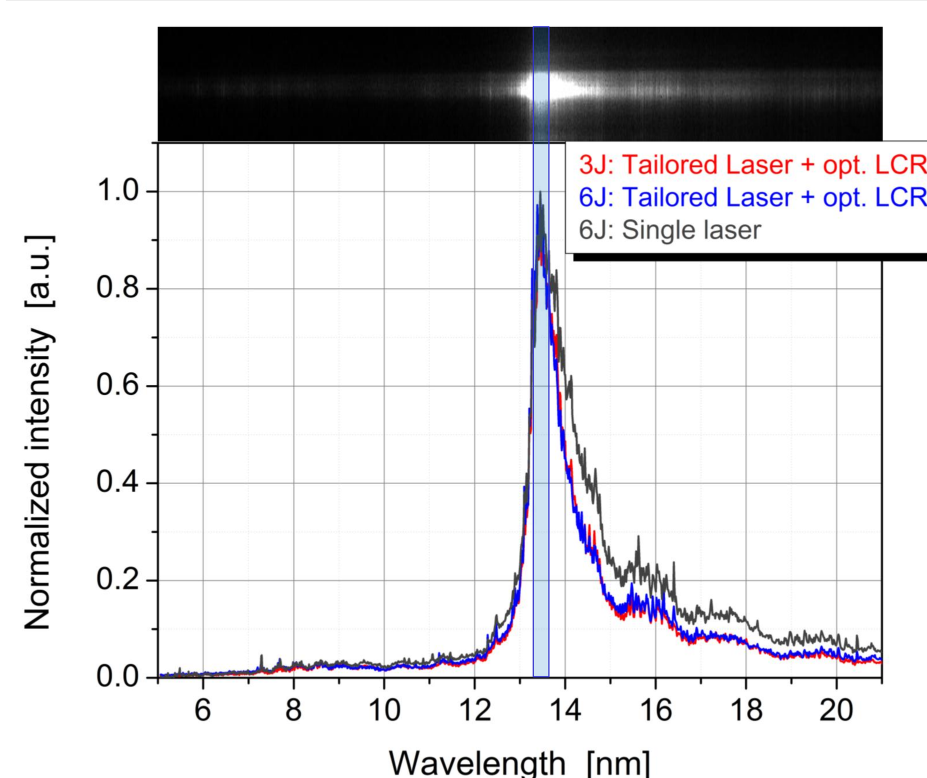


Fig. 5: PTB calibrated EUV Spectra recorded for source parameter variations

- Spectral purity:

13.5nm (2% b.w.) /	10 - 20 nm	5 - 21nm
3J Tailored Laser	17.6%	16.3%
6J Tailored Laser	17.5%	16.0%
6J Single Laser	13.5%	12.7%

- Up to 1.3x higher spectral efficiency
- Less heat load on scanner optics
- Spectral purity does not change with increasing electrical pulse energy

ACKNOWLEDGEMENTS

This presentation is the result of the collaboration between Xtreme Technologies GmbH (as subsidiary of Ushio) and Fraunhofer ILT on Laser assisted Discharge Plasma (LDP) sources for EUV lithography.

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