High repetition rate, high average power XUV sources based on High Harmonic Generation

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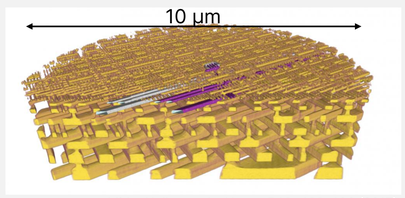
XUV light enables insight

High harmonic generation (HHG) sources [1] provide fully coherent laser-like radiation in the Extreme-Ultraviolet (EUV/XUV) and soft X-ray spectral range with femto- or attosecond pulse duration. These sources are ideal metrology tools in scientific or industrial applications:

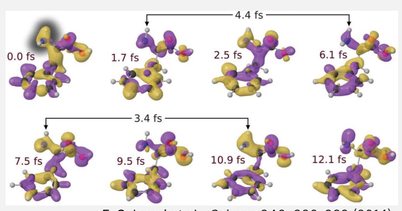
- The short wavelength allows very high spatial resolution in scattering or imaging of nanostructures created by state-of-the-art microchip EUV lithography.
- Their spectral bandwidth and ultrashort pulse durations are very useful in ultrafast spectroscopy to investigate the fast reactions occurring in solar cells, catalysis or to observe directly the carrier dynamics in superconductors or next generation semiconductors.

For all these applications, HHG sources with high repetition rates and high average powers are required to minimize the acquisition times, leading to a fast turnaround in sample characterization. At the same time, a high robustness and stability of the source is needed for low-maintenance operation with minimal down times.

[1] X. F. Li et al., Phys. Rev. A 39, 5751–5761 (1989)
[2] A.Viotti et al., Optica 9, 197-216 (2022)



Mirko Holler et al., *Nature* 543, 402–406 (2017)
X-ray tomograpy image of the integrated circuit of a Intel Pentium G3260 prozessor

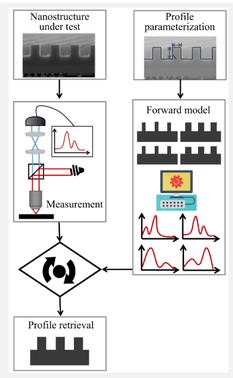


F. Calegari et al., *Science* 346, 336–339 (2014)
Few femtosecond hole dynamics in phenylalanine

MEGA EUV project

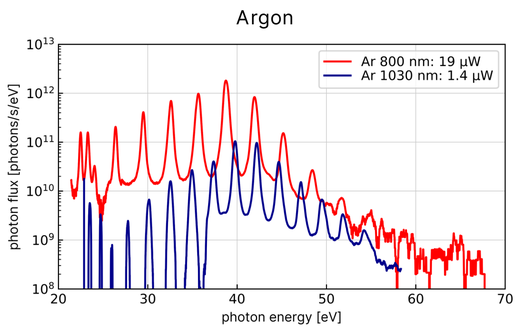
- EUV Scatterometry demonstrator based on High harmonic generation
- Kilowatt-class Yb pump laser
- High-throughput pulse post compression
- HHG source with highest efficiency at 13.5 nm
- High speed scatterometry instrument

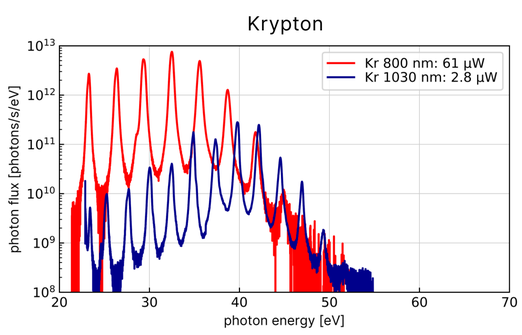
Scatterometry:
Identify structur of a test sample with known general structure, i.e. a periodic grating:
Model scattering pattern and compare to measured data



Output flux

20 W, 800 nm / 1030 nm, 100 kHz, <30 fs



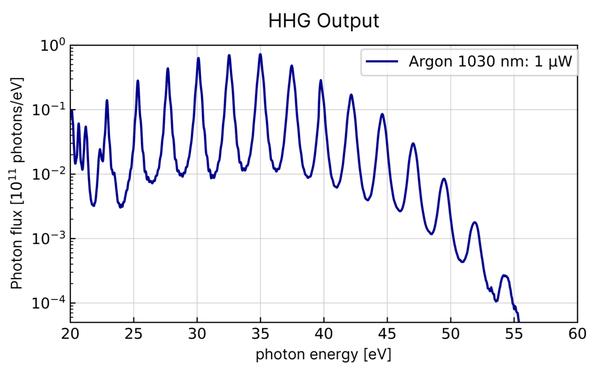


Measured photon flux after metal filter		
Target gas	MPC 1030 nm	OPA 800 nm
Argon	1.4 µW	19 µW
Krypton	2.8 µW	61 µW

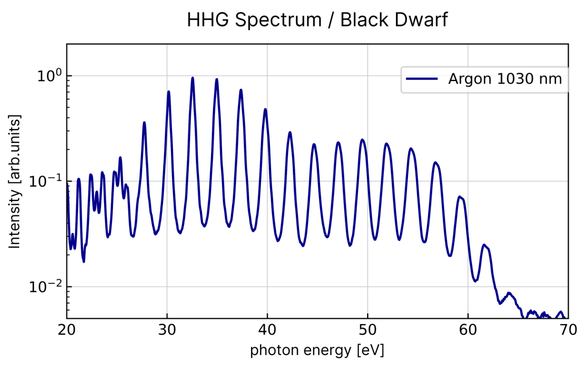
Conversion efficiency		
Target gas	OPA 800 nm	MPC 1030 nm
Argon	1.1E-6	0.8E-7
Krypton	3.6E-6	1.6E-7

Average power and repetition rate scaling

50 W, 750 kHz, 1030nm, 300 fs



40 W, 1MHz, 1030 nm, 80 fs

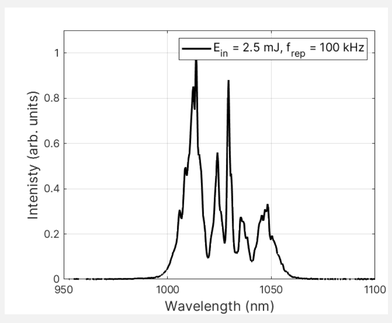


Towards 1000 W femtosecond lasers: Multipass cell compression of Yb:YAG innoslab lasers

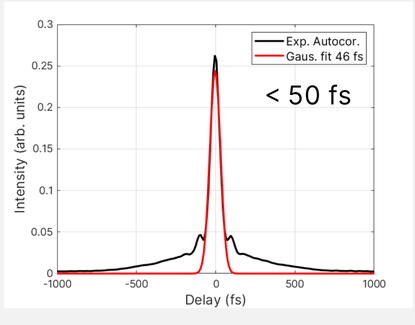
Class 5 Black Dwarf: Femtosecond laser with high average power

- Average power > 227 W
- Pulse energy: 2.27 mJ
- Pulse duration: < 50 fs
- Repetition rate: 100 kHz

Pump laser: Amplitude Tangor 300

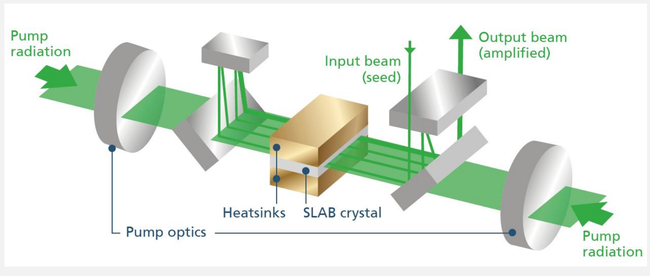


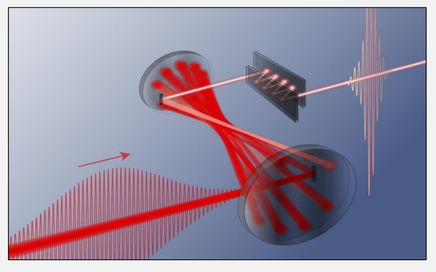
Non-linear spectral broadening



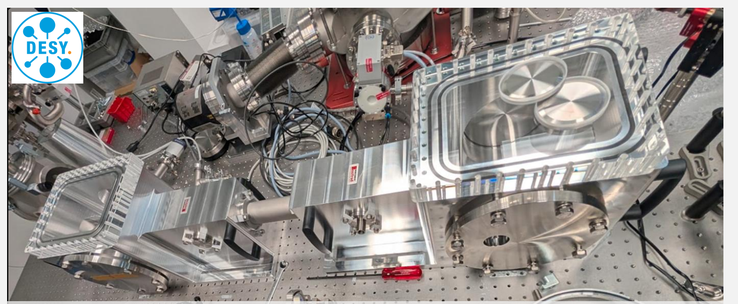
Non-linear pulse compression

Scaling the robust Innoslab ytterbium laser architecture and combine it with the efficient multipass cell compression technology



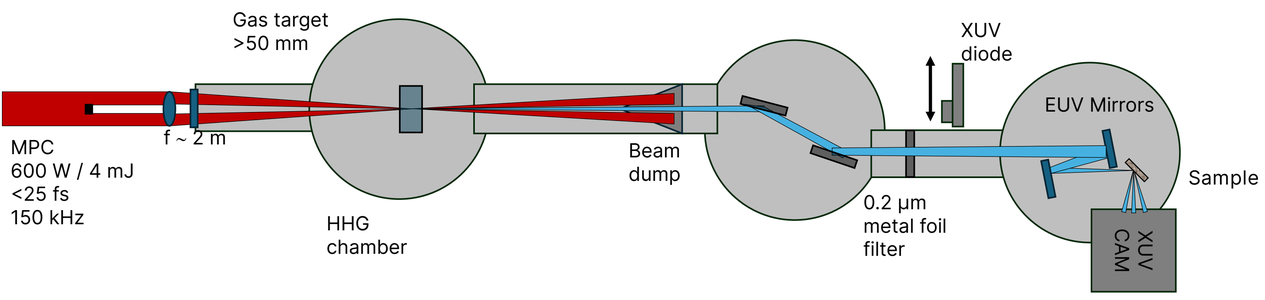


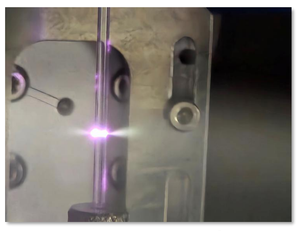
Amphos: High power amplifer
Target: 5 mJ, < 1000 fs , 150 kHz
Average power > 750 W



FS-PRI DESY: New optimized MPC chamber
Target: > 600 W, 150 kHz, > 4 mJ
Pulse duration: < 30 fs

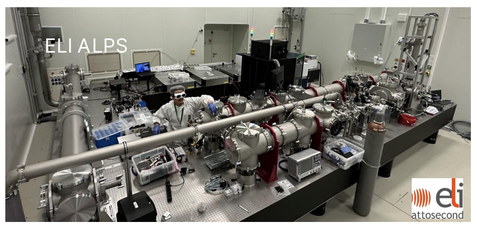
High harmonic generation: Challenges





Gas exchange rate
- Refresh target gas with 6 us in a large interaction volume

Filter power handling
- 15x power level
- Annular beam
- IR rejection mirrors



Size
- Loose focusing geometry, long focal length
- Beamline length > 6 m

Summary

The combination of high average power Yb:YAG Innoslab lasers and the efficient multipass cell compression technology enables a breakthrough for high harmonic generation based XUV sources. Femtosecond lasers well beyond 100 W average power are readily available and systems with average power close to 1000 W are in development with first operational prototypes. The multipass cell technology allows to compress these high-power levels to pulse durations below 50 fs giving rise to laser providing simultaneously high average power and high peak power.
To make use of these system for driving a high harmonic generation based XUV source requires careful optimization of the gas target and XUV/IR beam filtering section.
Class 5 Photonics has succesfully demonstrated XUV systems working with 20-50 W average power drivers, providing XUV output power in the µW range with state-of-the-art conversion efficiencies.
With in the MEGA EUV project we aim to advance our sources to operate with up to 600 W average power for an efficient generation up to 13.5 nm / 92 eV and employ the source for metrology in the context of EUV lithography for a demonstration of high-speed scatterometry analysis of nanometric structures.

Interested in demo experiments?
Contact: sales@class5photonics.com