High power HHG source driven by a Black Dwarf laser system

B. Manschwetus[1], E. Escoto[2], A. Alangattuthodi[1], A. Zablah[2], S. Rajhans[2], S. Jana[1], T. Braatz[1], S. Starosielec[1], H. Goudarzi[1], M. Wieland[3], M. J. Prandolini[1,3], M. Schulz[1], T. Gorkhover[3], M. Drescher[3], C. M. Heyl[2,4,5], R. Riedel[1]

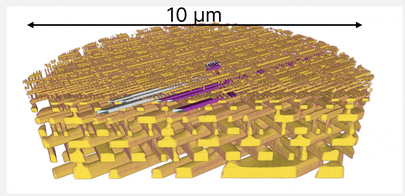
[1] Class 5 Photonics, Notkestraße 85, 22607 Hamburg, Germany
[2] Deutsches Elektronen Synchrotron (DESY), Notkestraße 85, 22607 Hamburg, Germany
[3] Universität Hamburg, Institut für Experimentalphysik, Luruper Chaussee 149, 22761 Hamburg, Germany
[4] Helmholtz-Institut Jena, Fröbelstieg 3, 07743 Jena, Germany
[5] GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany

XUV light enables insight

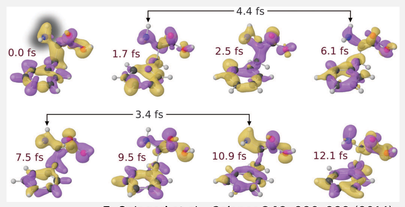
High harmonic generation (HHG) sources [1] provide fully coherent laser-like radiation in the Extreme-Ultraviolet (EUV/XUV) and soft X-ray spectral range ideal for metrology in scientific or industrial applications:

- The short wavelength enables very high spatial resolution in scattering or imaging of nanostructures
- Their spectral bandwidth and ultrashort pulse durations are employed in ultrafast spectroscopy to observe the chemical reactions occurring in catalysis or the carrier dynamics in semiconductors on their natural timescale.

For all these applications, HHG sources with high repetition rates and high average power and at the same time high robustness and stability of the source are required.



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

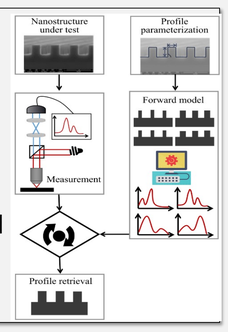


F. Calegari et al., *Science* **346**, 336–339 (2014)
Few femtosecond hole dynamics in phenylalanine

MEGA EUV project

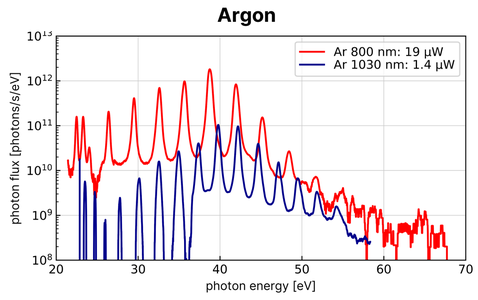
- **EUV scatterometry demonstrator based on high harmonic generation**
- Kilowatt-class Yb pump laser
- High-throughput pulse post compression
- HHG source with highest efficiency at 13.5 nm wavelength
- High speed scatterometry instrument

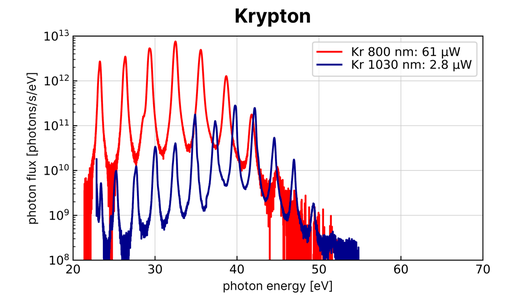
Scatterometry:
Identify structure of a test sample of known general structure, i.e. a grating:
Model scattering pattern and compare to measurement



XUV sources: Output photon flux

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

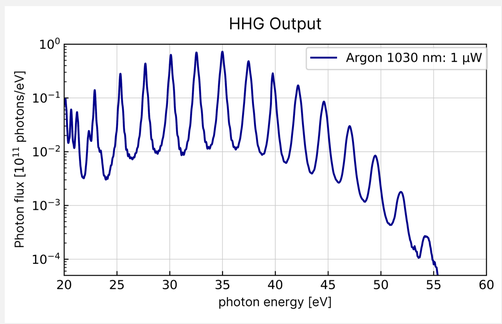




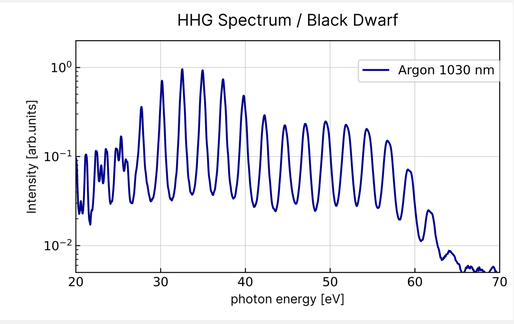
Measured photon flux after metal filter		
Target gas	MPC 1030 nm	OPA 800 nm
Argon	1.4 µW	19 µW
Krypton	2.8 µW	61 µW

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

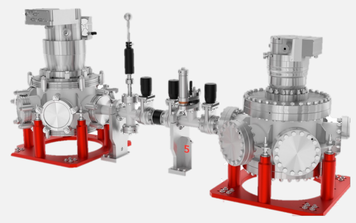
50 W, **750 kHz**, 1030nm, 300 fs



40 W, 1MHz, 1030 nm, 80 fs

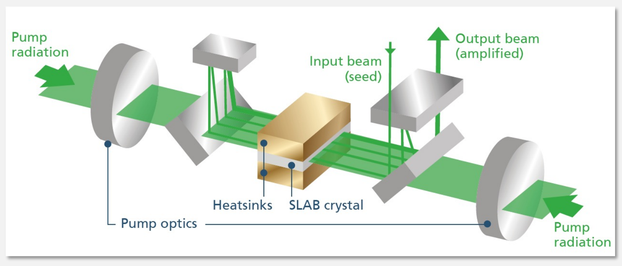


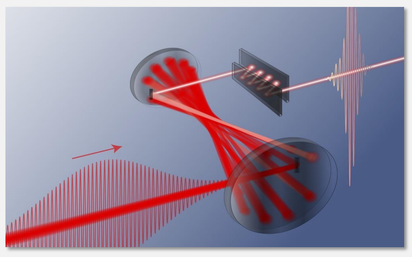
Employed XUV source with different laser drivers:
Class 5 Photonics Moonlander-HHG



Towards kW-level femtosecond lasers: Multipass cell compression of Yb:YAG innoslab lasers

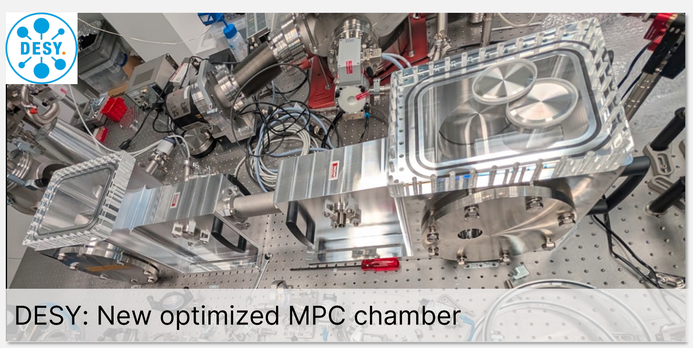
Scaling the robust Innoslab ytterbium laser architecture and combine it with the efficient multipass cell compression technology





Amphos: High power amplifier

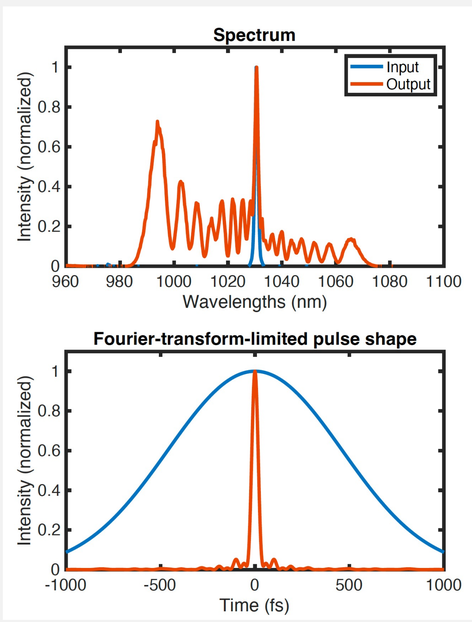
Target: 5 mJ, < 1000 fs , 150 kHz
Average power > 750 W



DESY: New optimized MPC chamber

Target: > 600 W, 150 kHz, > 4 mJ
Pulse duration: < 30 fs

Spectral broadening using test laser from AMPHOS in Class5 Photonics

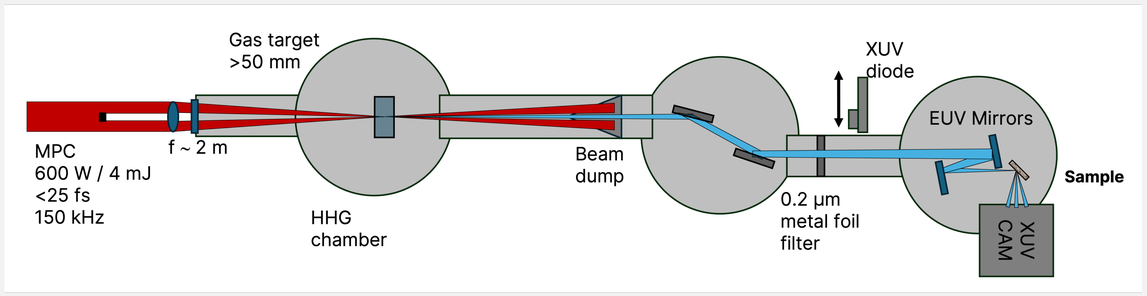


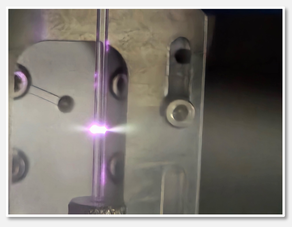
Input:
- 150 W (3.75 mJ)
- 1 ps transform-limited duration

Output:
- 137 W (3.425 mJ)
- 38 fs transform-limited duration
- 91% throughput

MPC parameters:
- 1-m long
- Argon pressure 2 bar
- 26 roundtrips

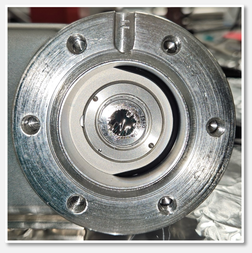
High harmonic generation: Challenges





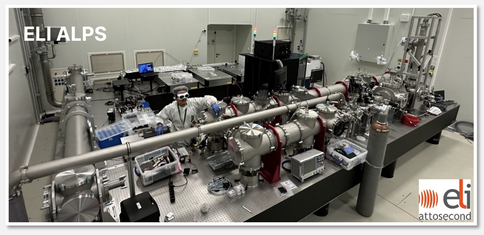
Gas exchange rate

- Refresh target gas within 6 µs 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 with efficient multipass-cell-based pulse compression technology enables a breakthrough in high-harmonic-generation-based XUV sources, delivering milliwatt-level average power.
- Femtosecond lasers well beyond 100 W average power are readily available and systems with average power close to 1 kW 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 successfully 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.
- Within the MEGA EUV project we aim to advance our sources to operate with up to 600 W average power for an efficient XUV 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.

Contact: sales@class5photonics.com
www.class5photonics.com