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# Ultra-high photon flux high-harmonic generation

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**Abstract:** We present a highly stable, easy-to-use HHG source delivering a record photon flux of >$10^{11}$ photons/s at 69eV-75eV, being tunable to approx. 100eV which will be used for future photon-hungry applications. 

High-harmonic generation (HHG) driven by ultrashort laser pulses is an established process for the generation of coherent extreme ultraviolet (XUV) to soft X-ray radiation, which has found widespread use in various applications [1]. In recent years photon-hungry applications such as coherent diffractive imaging [2,3] and applications based on statistical analysis [3] have required more powerful HHG sources employing higher repetition rates. This need can be addressed by using high-average-power fiber lasers as the HHG drivers [4]. Here, we present a HHG-based XUV source providing a large photon flux across a wide range between 66 eV and 150 eV. It is driven by a commercial XUV beamline from Active Fiber Systems GmbH consisting of an 100-W average power fiber-laser system delivering up to 300 µJ at <300-fs pulse duration. For HHG, this system is operated at 100 W and 600 kHz. A post-compression unit is part of the device to shorten the pulses to ~35 fs, the average power remains at 63W. The turnkey source provides unprecedented photon flux of >$10^{11}$ photons/s in each harmonic between 69 eV and 75 eV (HH57-HH63). All flux values are given at the generation point, i.e. directly after the source.

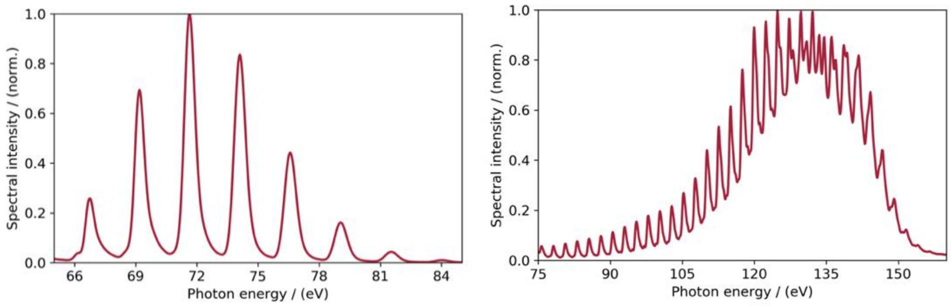


Fig. 1 Left: HHG spectrum generated in argon and optimized for ~70eV operation. Right: HHG spectrum generated in neon and optimized for operation at >92eV.

Figure 1 (left) shows a typically measured HHG spectrum using argon. The photon flux is analyzed by accounting for the transmission of the measurement apparatus (flat-field grazing incidence spectrometer) showing that the strongest harmonic (HH59) at 71 eV features $3 \cdot 10^{11}$ photons/s. This constitutes a record-high photon flux at this photon energy for any reported laser-driven source to date [5,6,7]. Therefore, it can be expected that this source will enhance and speed up applications that currently suffer from long measurement times.

A second focus of optimization is put on the spectral range around 93 eV (Fig.1 (right)), because of its significance for semiconductor industries [8]. Without changing the optical setup, the source can be tuned to this wavelength by using neon. At 93 eV, the source delivers $5 \cdot 10^{9}$ photons/s/(1% bandwidth), which enables numerous experiments in that important wavelength range. Generally, the source can deliver photon energies of up to 150 eV with a photon flux >$10^{10}$ photons/s/(1% bandwidth) for harmonics between 115eV and 140eV, which also constitutes a record flux in that spectral range. Generally, an important aspect of each HHG source regardless of its particular application is their user-friendliness and output stability. Over the time span of one hour, the photon flux is as stable as ~1% RMS in the spectral range around 70 eV and 90 eV, respectively.

## References

[1] T. Popmintchev *et al*. Nat Phot. 4, 822–832 (2010).
[2] J. Rothhardt *et al.* J. Opt. (United Kingdom) (2018).
[3] G. S. M. Jansen *et al*.l. Optica 3, 1122–1125 (2016).
[4] S. Hädrich, *et al.* J. Phys. B At. Mol. Opt. Phys. 49, 172002 (2016).
[5] J. Rothhardt *et al.* Opt. Express 24, 18133–18147 (2016).
[6] C. M. Heyl *et al.* J. Phys. B At. Mol. Opt. Phys. 50, 013001 (2017).
[7] R. Klas *et al.* Opt. Express 28, 6188–6196 (2020).

[8] C. Wagner and N. Harned, "Lithography gets extreme," Nat. Photonics 4(1), 24–26 (2010).