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Efficient XUV out-coupling mechanisms for intra-oscillator HHG

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High harmonic generation (HHG) using GW-level peak power ultrafast lasers enables coherent XUV light generation in laboratory-scale setups. Historically, most of these systems were based on Ti:sapphire laser amplifiers operating at kilohertz repetition rate. Nowadays, Yb-based laser systems deliver comparable peak powers, but at megahertz repetition rate, thus allowing to further increase the XUV flux. Towards even higher repetition rates, passive femtosecond enhancement cavities (fsEC) are used. The field enhancement within the cavity enables generating the required peak power even at up to several-hundred-megahertz repetition rate [1]. A simplified approach of fsEC is to drive the HHG directly within a high-power femtosecond laser oscillator [2]. Both these concepts typically use a collinear generation geometry, which requires optical elements to separate the generated XUV from the driving laser. In contrast to fsEC, the intra-oscillator approach allows for higher intra-cavity losses, thus, offering a wider choice of XUV out-coupling methods and different trade-offs between the fundamental and XUV wavelengths. In this study, we report on two of the XUV out-coupling methods, namely a coated grazing-incidence plate (GIP) and a pierced mirror, as schematically shown in Fig. 1a,b). Both these methods are highly suitable for intra-oscillator HHG since they strongly benefit from the higher tolerance to IR losses.

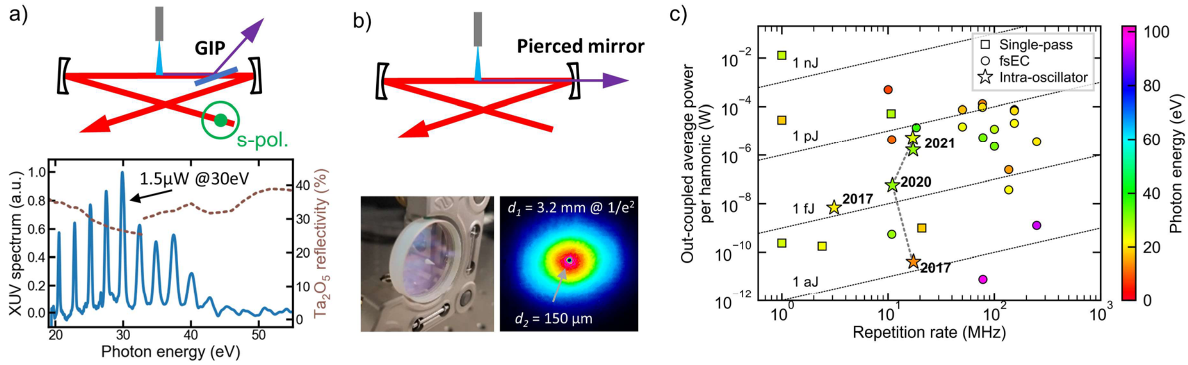

Fig. 1 a) Out-coupling scheme with a coated GIP, the measured XUV spectrum generated in Argon, and the XUV reflectivity. b) Out-coupling scheme with a pierced mirror, a photo of the pierced mirror, and the beam profile of the mode-locked laser on the mirror. d_1 – beam diameter, d_2 – hole diameter c) Overview of out-coupled XUV flux of state-of-the-art HHG systems. Stars connected with a dotted line depicts the progress of our intra-oscillator source. Our most recent results approach fsEC sources operating at similar photon energy.

We experimentally demonstrate for the first time XUV out-coupling from a cavity using a coated GIP. The concept was theoretically proposed in 2011 [3] offering high and broadband XUV reflectivity. Nevertheless, due to the high losses for the fundamental laser wavelength of up to several percent it has never been used inside an fsEC. Here we show that this concept is well-suited for intra-oscillator HHG and photon energies beyond 50 eV. The out-coupled XUV flux generated in argon amounts to 1.3 µW at 37 eV, which is approaching the results obtained with fsEC operating at similar photon energies as shown in Fig. 1c).

For even higher photon energies, a so-called pierced mirror with a small on-axis hole can be used. Likewise, this concept benefits from the higher tolerance to IR losses within a laser oscillator, allowing to increase the through-hole diameter boosting the XUV out-coupling efficiency. As a first step in this direction, we show that our thin-disk laser oscillator operates with the pierced mirror inside the cavity without a significant change in performance. Since we only have the pierced mirror on a flat substrate, we cannot yet demonstrate the XUV out-coupling due to spatial constraints of the gas target focus. The achieved intracavity performance of 1 GW at 90 fs pulse duration, however, is certainly sufficient to drive the HHG. The expected peak intensity in the gas target should allow for HHG in neon extending to photon energies even beyond 100 eV.

In conclusion, we have shown that intra-oscillator HHG systems offer new avenues for efficient XUV out-coupling thanks to their higher loss tolerance compared to fsECs. We have shown for the first time XUV cavity out-coupling using a coated GIP. In the near future, we plan to use a pierced mirror on a curved substrate which should allow us to demonstrate 100 eV photon energies by driving HHG in neon.

References

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