# Multimode quasi-phase-matching of high-order harmonic generation in gas-filled photonic crystal fibers

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Driving bright high-order harmonic generation (HHG) with few-μJ pulses is a crucial step towards compact, high average power sources of coherent extreme ultraviolet (XUV) radiation for time-integrated applications including imaging. Unfortunately, reaching a sufficiently strong E-field to perform HHG with these pulses requires tight focusing, greatly reducing the interaction volume. An elegant solution to this problem is to restrict HHG to a hollow waveguide [1] and in particular a photonic crystal fiber [2]. Strong reabsorption in the XUV prohibits the use of multi-atmosphere pressures to achieve phase-matching [3], and instead quasi-phase-matching (QPM) is preferred. Here we demonstrate QPM of HHG for the first time within a gas-filled PCF.

We have developed several variants of the multimode-QPM (MM-QPM) scheme [4, 5] applicable to PCFs. All of these utilize a "control" pulse coupled into a high-order mode that modulates either the amplitude or polarization of a "drive" pulse propagating in the fundamental. The dispersion characteristics of the fiber then dictate the modulation period and maximum interaction length. This was investigated experimentally by launching 800 nm, 30 fs, 5 μJ "drive" and "control" pulses derived in a Mach-Zehnder interferometer into a 22.5 mm long section of hollow core negative curvature PCF [6]. The PCF spans two vacuum chambers: the first chamber is filled with 800 mbar of argon and the second chamber contains an XUV spectrometer maintained at high vacuum. Fig. 1(a) shows the spatially integrated intensity of H19 (30 eV) as a function of drive pulse delay. The large periodic enhancement in signal away from t = 0 is consistent with our MM-QPM scheme, and the positioning of the peaks compares favorably with simulations. The enhancement in flux attributed to MM-QPM can be quantified (blue circle, Fig. 1(b-c)) by a factor of 60 at 30 eV.

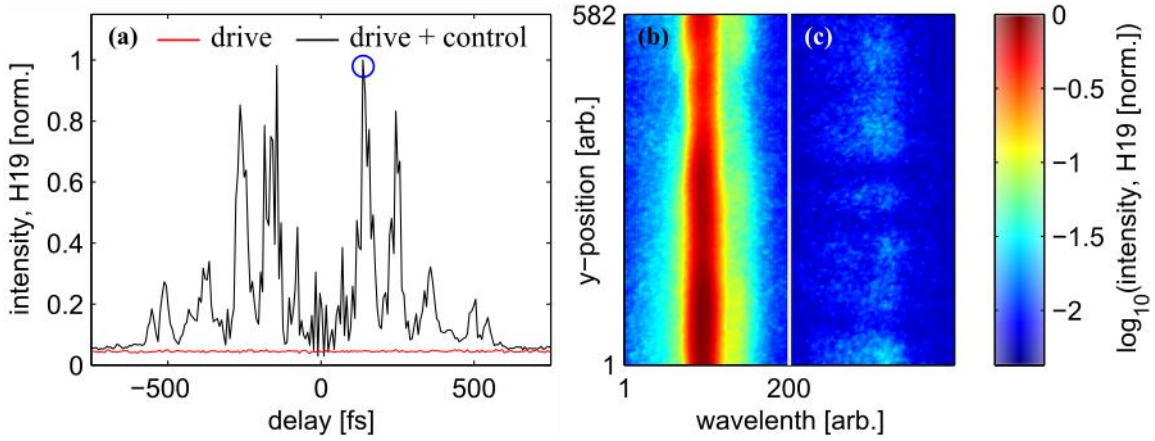


**Fig. 1.** (a) The intensity of the 19th harmonic (30 eV) recorded as a function of drive pulse delay. When the control pulse is introduced (black) significant enhancements in flux are observed along with a periodic structure consistent with MM-QPM. The spatio-spectral distribution at the highlighted delay (blue circle) is plotted with (b) and without (c) the control pulse. From this the enhancement in flux attributed to MM-QPM is estimated to be a factor of 60 at 30 eV.

## References

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