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Wavelength-tunable high harmonic generation by blue-shifting solitons

F. Tani[1], M. H. Frosz[1], J. C. Travers[1], and P. St.J. Russell[1, 2]

1. Max Planck Institute for the Science of Light, Günther-Scharowsky-Str. 1 / Bau 24, 91058 Erlangen, Germany
2. Department of Physics, University of Erlangen-Nuremberg, Erlangen, Germany

Soliton dynamics offers a range of powerful tools for nonlinear manipulation of ultrashort light pulses. In gas-filled hollow-core photonic crystal fibres (PCFs) they have been successfully exploited for efficient generation of UV-VUV radiation through dispersive wave emission [1] and pulse compression down to single-cycle durations [2,3]—an ideal source for high harmonic generation (HHG) [4]. Here we explore the effect of plasma-driven soliton self-frequency blue-shifting on HHG.

In the experiment we launched 25 fs, 800 nm pulses, with energies in the range 10-50 µJ, into a 26 cm long kagomé-PCF. One end of the fibre was enclosed in a gas cell filled with a few bar of He, while the other fed into a vacuum chamber. At the output the fibre tip was precisely positioned facing the side of a gas-jet flowing out of a 200 µm diameter nozzle. On the other side of the jet, aligned so as to face the fibre endface, were two 200 nm thick aluminium filters, followed by an XUV flat-field spectrometer. The pulsed gas-jet was backed by Ar at 5 bar and its piezo-valve was synchronised with the laser and the CCD camera of the XUV spectrometer. We repeated the experiment with two different samples of kagomé-PCF, with core diameters and He pressures 33 µm & 1.8 bar, and 46 µm & 4 bar.

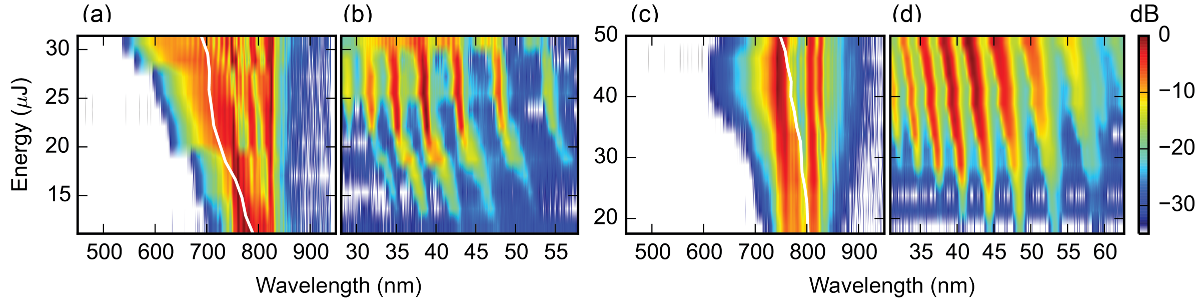

Fig. 1 (a,c) The recorded spectra of the driving pulse at the fibre output for increasing pump energy, with core diameters of (a) 33 µm and (c) 46 µm; (b,d) show the corresponding high harmonic spectra. The white lines in (a) and (c) shows the average wavelength of the 17th harmonic multiplied by the harmonic order.

The pulse dynamics in the fibre depends strongly on the He filling pressure, which was selected so that the pulses propagated in the anomalous dispersion regime with relatively low soliton order (between 2 and 4.6, depending on the input energy). Under these conditions the pump pulse experiences clean adiabatic soliton self-compression as it propagates along the fibre, and as the pulse gets shorter and its peak intensity rises, the influence of ionisation becomes more important, eventually causing the soliton to blue-shift [5]. The resulting few-cycle output pulses have sufficient intensity for HHG in the gas-jet at the output of the fibre. We expect the harmonics generated by the blue-shifted solitons also to be shifted to shorter wavelengths as the input energy is increased.In Fig. 1 we show the pulse spectra at the output of each fibres, together with the resulting high harmonic spectra, as the launched pump pulse energy increases. For the smaller core fibre, a strong blue-shift is already visible at low energies, while for the larger core fibre this becomes clear only at energies of around 30 µJ. In both cases there is a clear correlation with the high harmonic spectra. The harmonics do not follow the average pump pulse wavelength, but the central wavelength of the blue-shifting soliton. This is indicated by the white line drawn on top of the pump pulse spectra (Fig. 1(a&c)), representing the average wavelength of the 17th harmonic multiplied by the harmonic order ($17\lambda_{17}$). This shift to shorter wavelengths is particularly marked for the small core fibre, permitting the harmonic spectra to be tuned continuously from at least 25 nm to 60 nm.

References

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