Spectral and Temporal Control of Resonant Dispersive Wave Emission in Hollow Capillary Fibres Using Pressure Gradients

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Abstract: We demonstrate that resonant dispersive wave emission in hollow capillary fibres filled with a gas pressure gradient results in fast spectral tuneability and the generation of near transform-limited UV pulses.

Resonant dispersive wave (RDW) emission accompanies soliton self-compression of ultrafast laser pulses and results from the nonlinear phase evolution of the soliton in combination with its extreme bandwidth and higher-order linear dispersion. In gas-filled hollow waveguides, it enables the efficient generation of tuneable coherent radiation from the vacuum ultraviolet to the visible [1] and near infrared [2]. We recently demonstrated that this process can be dramatically scaled up in energy by using pre-compressed driving pulses and long lengths of simple hollow capillary fibre (HCF) [3]. Here we show that the use of pressure gradients in the HCF can greatly improve the capabilities offered by RDW emission, particularly in terms of spectral tuneability and achievable pulse duration on target.

We compress 30 fs pulses delivered by a Ti:Sapphire amplifier to 7.5 fs duration using a gas-filled HCF followed by chirped mirrors. To observe RDW emission, these pulses pump a second, argon-filled HCF with a core diameter of 250 μm and a length of 3 m. By evacuating one end of the second HCF, we can create an increasing or decreasing pressure gradient. The pressure is adjusted such that the integrated pressure-length product is the same—this is achieved by simply increasing the fill pressure by a factor of 3/2 as compared to the constant pressure case.

Fig. 1 shows measured output spectra as a function of pump energy for three cases: a constant pressure of

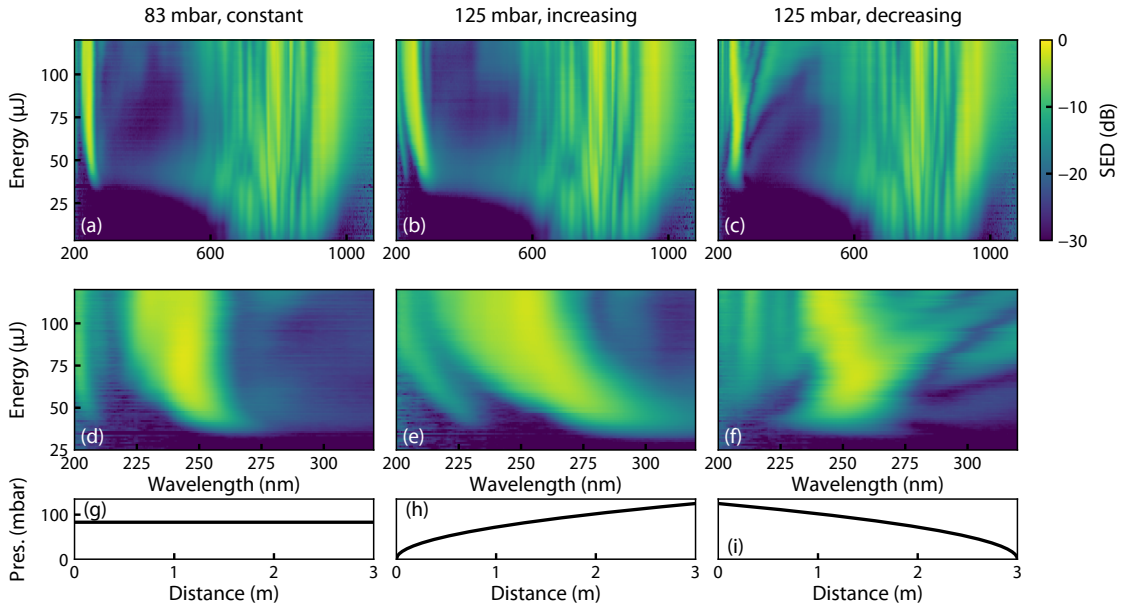

Fig. 1. (a-c) Measured energy-dependent output spectra from the HCF filled with argon with (a) constant pressure, (b) an increasing pressure gradient and (c) a decreasing pressure gradient. The pressure between constant pressure and gradient is adjusted to maintain the same integrated pressure-length product. The colour scale is logarithmic. (d-f) same as (a-c) but showing the UV spectrum. (g-i) Plot of the pressure profile along the HCF for each case. SED: spectral energy density.

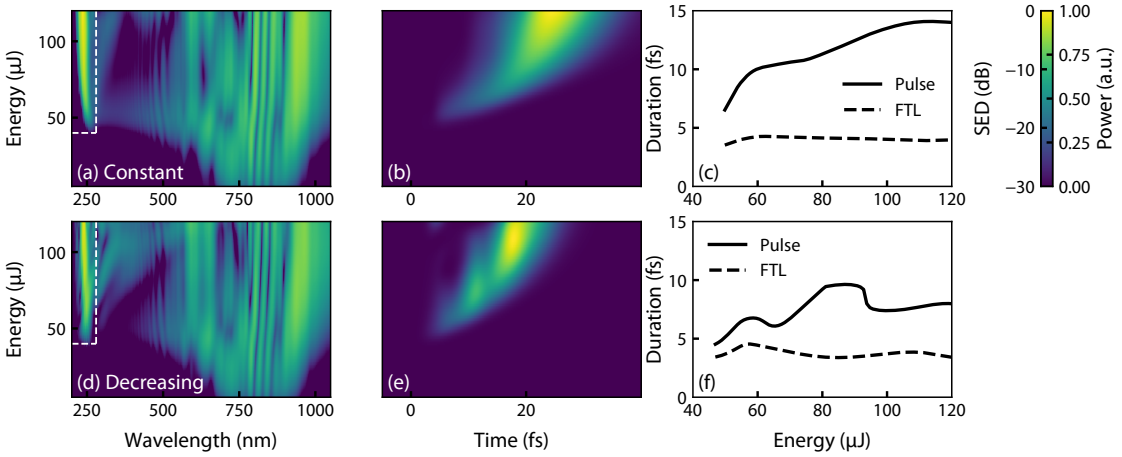

Fig. 2. (a) Simulated output spectra for same conditions as those in Fig. 1(a). The colour scale is logarithmic. (b) RDW pulse profile at the end of the HCF as a function of energy for the simulations shown in (a). The spectral window applied ranges from 200 nm to 280 nm as indicated by the vertical dashed line in (a). The colour scale is linear. (c) Actual pulse duration (solid) and Fourier-transform limit (dashed) of the pulses shown in (b). The minimum energy shown is indicated by the horizontal dashed line in (a). (d-f) same as (a-c) but for the case of decreasing pressure gradient.

83 mbar, an increasing gradient from vacuum to 125 mbar, and a decreasing gradient from 125 mbar to vacuum. Despite the complex interplay between nonlinearity and dispersion which underlies soliton dynamics, the simple pressure scaling produces similar behaviour. RDW emission first appears at an energy of around 45 μJ and at approximately the same wavelength in all cases. However, as previously observed in gas-filled microstructured fibre [1], the RDW spectrum evolves differently.

For constant pressure, the nonlinear contribution to the RDW phase-matching leads to a blue-shift as the energy is increased. This is strongly enhanced in an increasing gradient by the fact that the pulse self-compresses more quickly for higher energy, so that RDW emission occurs at a point of lower gas pressure, which also leads to shorter wavelengths. As a consequence, a UV source based on this approach can be wavelength-tuned on very fast timescales by simply changing the input energy, albeit over a smaller range than achievable with pressure-tuning.

In contrast, for a decreasing gradient, the two effects compete, and the wavelength of the RDW remains close to constant for all energies. Besides enabling direct delivery to vacuum [4], this configuration leads to shorter pulse durations even in the generation itself. Fig. 2 shows simulated RDW emission using our experimental parameters. The excellent agreement with the experiment allows us to infer the temporal dynamics [Fig. 2(b) and (e)] and the RDW pulse duration [Fig. 2(c) and (f)]. For constant pressure, the RDW pulse at the HCF exit is always significantly longer than its Fourier-transform limit and stretches further for higher energy, because it propagates through a dispersive medium after being generated. This effect is strongly reduced in a decreasing gradient, allowing the efficient generation of near-transform-limited pulses at the HCF exit.

Some of the most promising applications of ultrafast light sources based on RDW emission rely on its spectral tuneability and the ability to generate very short pulses. Our work clearly demonstrates that both of these capabilities are improved by the use of pressure gradients, allowing for shorter pulse durations or faster, albeit limited, tuneability. These considerations will be of critical importance for the next generation of time-resolved spectroscopy, for which RDW emission is an ideal source.

References

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