

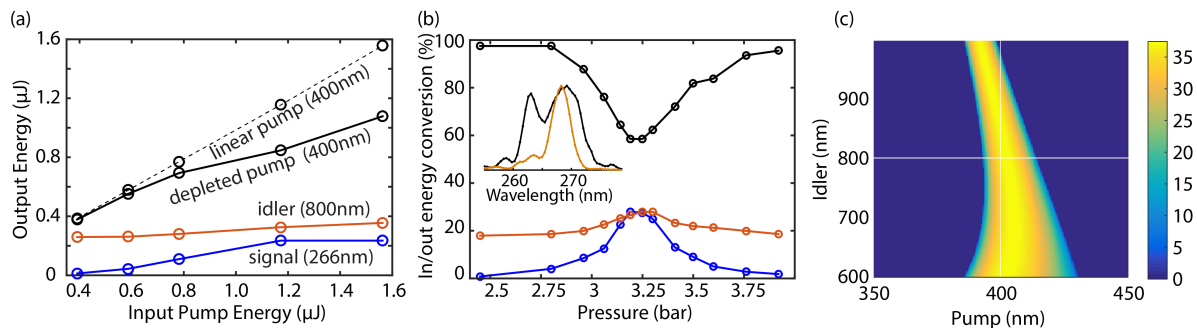
## Ultrafast Four-Wave-Mixing to the Deep-UV in Gas-Filled Kagomé-PCF

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Many different nonlinear effects have been predicted and observed in gas-filled kagomé photonic crystal fibre (kagomé-PCF), including soliton self-compression [1,2], dispersive-wave (DW) emission [3] and vacuum ultraviolet (VUV) supercontinuum generation [4,5]. In particular, DW emission has enabled tunable coverage of 110 nm to 550 nm, with conversion efficiencies up to 8%. One disadvantage of DW emission is that the emitted spectra are very tightly coupled to the propagation dynamics, which limits independent control over both the bandwidth and central frequency. In addition, control of the DW chirp is so far not demonstrated. Ultrafast four-wave mixing (FWM) does not suffer from these restraints, and potentially offers even broader bandwidth pulse emission, larger conversion efficiencies and reduced energy fluctuations (through gain saturation).

In hollow-core photonic band-gap fibre, FWM has been demonstrated by carefully tuning the locations of three transmission windows to coincide with the required pump, signal and idler wavelengths [6]. However, the narrow guidance windows limit the bandwidth of the signals, and hence the duration and achievable spectral coverage. In hollow capillary fibres, ultrafast FWM has been used at 100  $\mu\text{J}$  energy-scales to produce a tunable VUV pulse source [7] with broad bandwidths at low repetition rates (1 kHz), but average power scaling is difficult due to the high single-pulse energy requirements.



**Fig. 1** (a) Measured output energy for the signal, idler and pump as a function of input pump energy for 3.16 bar Ar and a fixed idler input energy of 0.26  $\mu\text{J}$ . (b) Experimental conversion efficiencies as a function of pressure at a fixed input pump energy of 1.55  $\mu\text{J}$  and idler energy of 0.48  $\mu\text{J}$  (the inset shows the spectra achieved at two different pump/idler delays); (c) calculated gain for 3.25 bar Ar.

In this paper we report the generation of highly efficient deep-ultraviolet light pulses using FWM in a 26  $\mu\text{m}$  diameter Ar-filled kagomé-PCF. We demonstrate up to 30% conversion efficiency from a pump wavelength of 400 nm to a signal at 266 nm, when also seeding at the idler wavelength of 800 nm. Fig. 1(a) shows the output energy as a function of pump energy at 3.16 bar and an idler energy of 0.26  $\mu\text{J}$ . The signal energy is more than 200 nJ. Fig. 1(b) shows the results of pressure tuning at 1.55  $\mu\text{J}$  pump energy. At the optimum phase-matching pressure and optimal setting of the delay between the pump and idler, we achieve around 30% conversion efficiency, with 490 nJ at the signal wavelength. The spectrum (Fig. 1(b) – inset) is 10.4 nm broad and would support  $\sim 10$  fs pulses. Fig. 1(c) shows the theoretically calculated gain for 3.25 bar Ar, showing good agreement (in terms of phase-matched wavelength) with the experimental results. Numerical simulations (not shown here, but will be presented) provide excellent agreement with these results and illuminate the additional role of cross-phase modulation in the conversion dynamics. We predict the possibility of an efficient, tunable, chirp controlled, ultrafast pulse source extending into the VUV when suitable pump and idler seeding conditions are selected. The energies required are easily within reach of high repetition-rate pump sources, offering a route to average power scalability.

### References

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