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Coherent multi-octave spanning supercontinuum in tapered sulphide fibres.

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Frequency combs are the new frontier in ultra-precise optical measurements utilised in applications such as optical clocks, ultra precise spectroscopy, etc. [1]. Especially, in the rapidly growing field of mid-IR photonics, mid-IR frequency combs have a great potential for delivering precise spectroscopic data in applications such as early stage cancer detection and food analysis [2,3]. Frequency combs consist typically of ultra-fast lasers such as mode-locked generating femto-second long pulses in conjunction with an appropriate nonlinear device that generates an octave spanning supercontinuum. The mode-locked laser in itself is almost a frequency comb as a single ultra-short pulse consists of many laser lines that are phase-locked with each other. However, for such short femto-second long pulses the pulse-to-pulse change in the so-called carrier envelope offset (CEO) needs to be stabilised. This has up to now been done through so-called self-referencing using the octave spanning supercontinua [1]. In this work we present a novel frequency comb laser design utilising a newly developed 3μm ultra-fast fibre laser in conjunction with a chalcogenide micro-taper such as seen in the Fig.1(a).

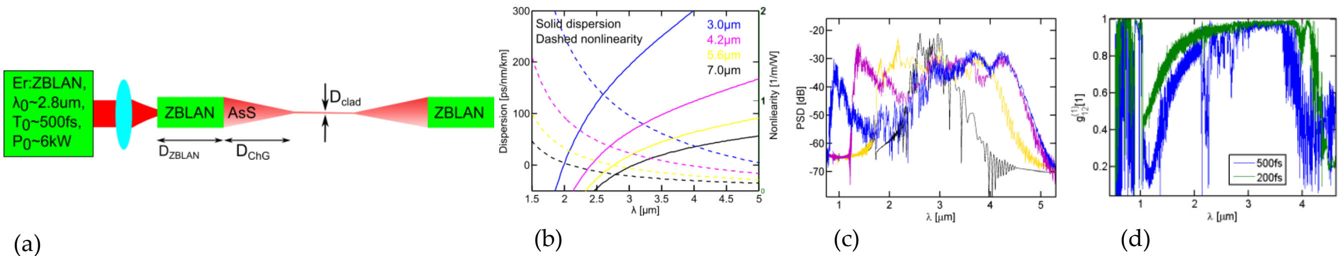

Fig. 1. (a) Mid-infrared supercontinuum setup with a 2.8μm mode-locked laser, collimating lens and fluoride-chalc fibre taper. (b) Dispersion and nonlinearity at the taper waist for different cladding diameter. (c) Simulated supercontinuum. (d) Coherence for 200 and 500fs pulses durations supercontinuum in the 3μm taper.

The ZBLAN fibre laser pumped a chalcogenide fibre taper with ZBLAN fiber attached on either side. The fluoride fibre provided added handling and compensated the strong chalcogenide normal dispersion. This ensured that the pump pulse was transform limited at the taper waist. At the taper waist light was guided in the cladding allowing the pulse to undergo strong nonlinearity. This was due to the high chalc-air index allowing the fibre to be pulled down to very small dimensions as seen Fig. 1(b). The bandwidth of the supercontinuum was highly influenced by the dispersion and the nonlinearity at the taper waist. The widest continuum was achieved with a taper waist of 3μm. At smaller dimensions the dispersion increased further, which limited solitonic effects, and the mode cut-off moved to shorter wavelengths that also limited the achievable bandwidth of the continuum.

The 500fs pulses were short enough to provide a coherent continuum such as seen in Fig. 1(d). The temporal and spectral stability of the frequency combs are an important initial step in obtaining a stable comb structure. Reducing the temporal duration of the pump pulses from 500 to 200fs by compressing the pulses temporarily further reduced the pulse-to-pulse noise fluctuations and thereby improved the coherence of the supercontinuum [4].

[1] Jones *et al.*, Science **288**, 635-639, (2000)
[2] Kubat *et al.*, Opt. Exp. 22, 19169-19182, (2014)
[3] Petersen *et al.*, Nat. Phot. Lett. 8, 830–834, (2014)
[4] Dudley *et al.*, Opt. Lett. 27, 1180-1182, (2002)