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Mid-infrared supercontinuum generation in tapered ZBLAN fiber with a standard Erbium mode-locked fiber laser

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Mid-InfraRed (MIR) broadband SuperContinuum (SC) sources are desirable for applications such as polution monitoring, spectroscopy, and IR countermeasures due to their high spatial coherence and high power density over a broad bandwidth [1]. Conventional silica fibers cannot facilitate this need due to their intrinsic IR transmission edge at 2.4 µm, so instead soft glasses are used for MIR SC sources. The soft glass ZBLAN is in particular interesting as it has low loss out to 4.5 µm [Fig. 1(a)]. Additionally, it has a material Zero Disperison Wavelength (ZDW) around 1.6 µm that with proper fiber design allows to generate a broadband SC using direct pumping with commercially available Erbium (Er) mode-locked fiber lasers at 1550 nm. Formation of SC is manipulated both in the UV and IR by changing the fiber dispersion and nonlinearity using tapers. This has been much studied in various silica fiber designs and is now also becoming used in ZBLAN [2], and other soft glasses such as chalcogenide [3] and tellurite [4]. The aim of this nummerical work is to show how pumping tapered commercially available ZBLAN fibers with an Er mode-locked fiber laser can generate a broadband SC approaching the ZBLAN long wavelength transmision edge. The taper employed here is a 20 cm long symmetric taper with a down- and up-taper length of 2 cm and a 16 cm long waist [see inset in Fig. 1(c)] and can be easily fabricated on a conventional Vytran taper stage.

Ten meters of uniform ZBLAN Step Index Fiber with NA=0.3 (max. commercially available), core diameter D_c=7 µm, and ZDW=1.5 µm, is pumped with T_{FWHM}=10 ps and P_0=10 kW pulses from an Er mode-locked laser with a 40 MHz repetition rate and 4W average power. The resulting MIR SC seen in Fig. 1(b) is based on Modulation Instability breakup of the pump pulse, which generates solitons that undergo Soliton Self Frequency Shift (SSFS). The -30 dB SC IR edge is at 3.06 µm. The increasing dispersion (D) for D_c=7 µm [see Fig. 1(b)] decreases the rate of SSFS, which is why the IR edge is still far away from the ZBLAN transmission edge. This is overcome by tapering the fiber with taper start at 8 m down to D_c=5.5 µm. At the taper waist a region of normal dispersion now appears in between the solitons, which generates MIR Dispersive Waves (DWs) between the second and third ZDW and also accelerates a large number of solitons towards the IR, as we will detail in the presentation. This moves the IR edge to 4.36 µm, close to the ZBLAN transmission edge.

In Fig. 1(c) we show the integrated power above 3.06 µm and the -30 dB IR edge versus the taper waist between 5 and 7 µm for a fixed taper start at 8 m (optimum found through extensive modelling to be presented). Both indicate that a taper waist of 5.5 µm provides the maximum power of 45 mW above 3.06 µm.

The ZBLAN taper in [2] resembling this work is based on *very high* NA fiber and is 6m long, which can only be made on the draw tower. The resulting SC in [2] covers 1.5-3 µm, where our spectrum covers 0.8-4.4 µm and uses only realistic fiber and laser parameters and a short taper, which can be fabricated on a taper station.

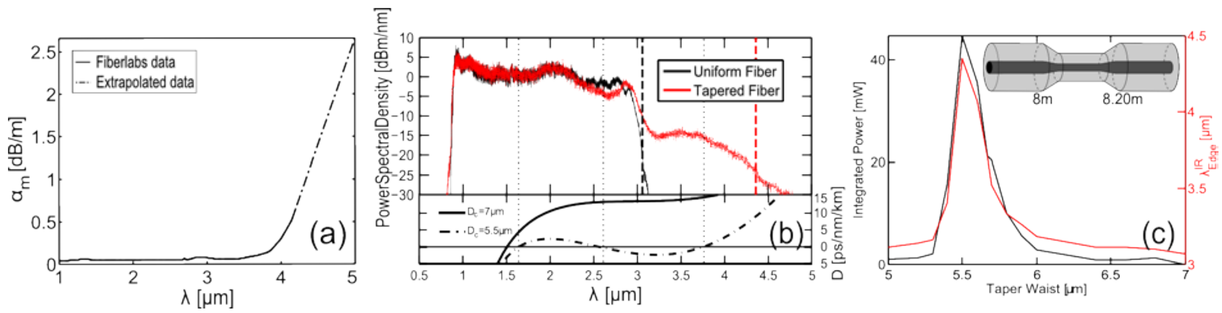

Fig. 1 (a) ZBLAN material loss (solid) provided by Fiberlabs Inc., Japan. (b) Top: SC spectrum in a10 m uniform (black) and tapered (red) fiber with the -30 dB IR edge indicated by a dashed line. Below: Dispersion (D) of the uniform fiber (D_c=7 µm) and the taper waist (D_c=5.5 µm). Dotted lines are ZDWs at taper waist. (c) Integrated power above 3.06 µm versus taper waist core diameter for a 20 cm long symmetric taper with start at 8 m (see inset).

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