Broadband Characterization of ZBLAN Fiber for Short-Wave Infrared Applications Using All-Fiber Interferometer

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Abstract: Group-velocity dispersion, third-order dispersion and propagation losses of 14m normal dispersion ZBLAN fiber are directly and continuously measured over 1500-2100nm range using all-fiber Mach-Zehnder interferometer. The fiber is then used for dispersion compensation at 2μm.

OCIS codes: (060.2270) Fiber characterization; (260.2030) Dispersion; (060.2390) Fiber optics, infrared

1. Introduction

Fluoride-based glasses, and, particularly, ZrF_4–BaF_2–LaF_3–AlF_3–NaF combinations (ZBLAN), are considered as a prospective material for optical fibers transparent beyond 2 μm. Various rare-earth (RE) metal cations-doped ZBLAN fiber lasers were demonstrated [1]. Moreover, supercontinuum (SC) generation in ZBLAN fibers, spanning from deep-ultraviolet to mid-infrared (MIR), has been recently reported [2]. In both applications, the precise information about the dispersion is crucial for the design of ultrashort pulsed fibers sources, or for optimization of the pump wavelength to drive nonlinear processes, respectively.

There are multiple linear and nonlinear methods, developed for dispersion measurement in optical fibers [3,4]. The linear interferometric technique represents the most suitable tool for broadband characterization of short and medium length fibers (up to few tens of meters) [5]. Group velocity dispersion measurement (GVD) of short pieces (up to 2.1m) of various ZBLAN fibers using free-space interferometers was reported [2,6,7]. Supercontinua in 0.8-1.3 μm [2], and 0.9-1.6 μm bands [6], and combined superluminescent source in 1.7-2.0 μm with mode-locked laser in 2.2-2.4 μm bands [7], were exploited as broadband input. Although the latter tests covered wavelengths around 2 μm [7], the power spectral density in this range was low, thus resulting in a degraded signal-to-noise ratio and a reduced accuracy of measurements. Moreover, free-space optics setups require a careful alignment, and are therefore much less robust comparing to fiber-based ones.

In this paper, we present results on the short-wave infrared (SWIR) characterization of a relatively long 14 m ZBLAN fiber designed to have normal dispersion. The characterization is performed over a continuous 1.5-2.1 μm band using virtually all-fiber Mach-Zehnder interferometer (MZI) setup, resulting in a robust and simplified measurement. A custom SC source, assembled from commercial off-the-shelf fiber optical components, which provides high power and 10 dB spectrum flatness over about 600 nm, is used as an input signal. Measured values, in good agreement with simulated data, are confirmed through all-fiber dispersion compensation at 2 μm.

2. Experimental setup and results

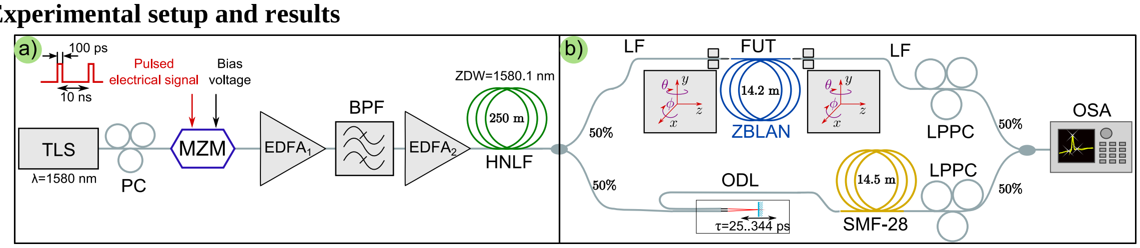

Fig. 1: Experimental setup: a) SC source, b) MZI layout. TLS – tunable laser source; PC – polarization controller; MZM – Mach-Zehnder modulator; BPF – bandpass filter; LF – lensed fiber; FUT – fiber under test; LPPC – large paddle PC; OSA – optical spectrum analyzer

To experimentally measure dispersion, we used an interferometric measurement technique tracing the position of a broad central fringe [5, 8]. The experimental setup consists of two main parts: a custom broadband SC source (Fig. 1a), and an all-fiber MZI (Fig. 1b). A pulsed pump signal (sub-100 W peak power) is coupled to 250 m long highly-nonlinear fiber (HNLF, manufactured by Sumitomo Electric Industries Ltd, Japan) with zero dispersion wavelength (ZDW) at 1580.1 nm. The pump wavelength is set at 1580 nm in order to generate a stable SC signal with good uniformity and high power over the entire 1.5-2.1 μm wavelength range as seen in Fig. 2a. The SC has a limited bandwidth due to increasing losses in fused silica beyond 2.4 μm. It could be possible to extend the measurement range toward MIR band by using SC generated in ZBLAN or chalcogenide fibers. The SC signal is sent to the MZI which includes the 14.2 m long section of ZBLAN step-index fiber (Fiberlabs Inc, Japan). The fiber parameters, i.e. numerical aperture $NA = 0.2 \pm 0.02$ and core diameter 6 ± 0.5 μm, were carefully chosen through simulations to achieve normal dispersion in 2 μm band (theoretical ZDW at 2.5 μm). Junctions between lensed fibers (LF, 5 μm spot size in focus) and FUT are the only free-space optics interfaces in the setup. Coupling losses estimated at 1580 nm are less than 1 dB per facet, and propagation losses in the FUT are measured at 0.22 dB/m over the entire measurement range (Fig. 2a). The reference arm (REF) contains a pigtailed motorized tunable optical delay line (ODL), and an additional section of SMF-28 for average balancing of optical paths in MZI. The ODL time delay τ was swept to shift the central fringe wavelength over the entire bandwidth of the SC (Fig. 2b).

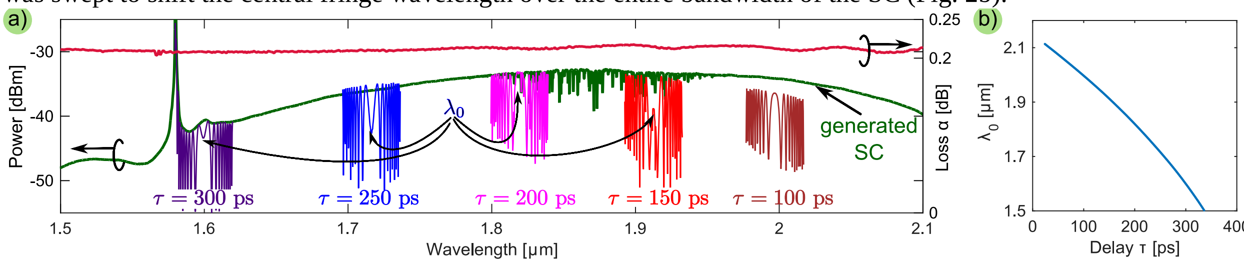

Fig. 2: a) SC spectrum, superimposed with interferograms for chosen values of τ, and fiber propagation losses α ; b) central fringe position $\lambda_0(\tau)$

The measurement results are shown in Fig. 3a-b. The GVD coefficient β_2 was evaluated first by numerical differentiation $d\lambda_0/d\tau$. Additionally, β_2 and third-order dispersion (TOD) coefficient β_3 were directly retrieved from the interferogram $I \sim \cos\varphi(\lambda)$, where $\varphi(\lambda)$ is a phase difference spectrum between FUT and REF arms. As it is shown in Fig. 3a, both above-described dispersion evaluation techniques provide similar results that are in a good agreement with theoretical predictions, and stay within the design margins defined by possible variations of fiber core diameter and NA (shadowed areas). As the normal dispersion behavior of the fiber was confirmed, the 20 m section of the same ZBLAN fiber was used to partially compensate for the linear chirp of a broadband pulsed signal (70 nm FWHM centered at 1970 nm). The relative delay of filtered spectral components of the signal was measured before and after ZBLAN compensation (Fig. 3c). Indeed, the slope of the delay curve was reduced, and β_2=12.3 ps^2/km and positive TOD β_3=0.0044 ps^3/km at 1970 nm were estimated from the difference of delay functions. These results are coherent with normal dispersion β_2=8.1 ps^2/km and β_3=0.008 ps^3/km, retrieved from $\varphi(\lambda)$. It should be noted that full compensation was not achieved due to limited length of available ZBLAN fiber.

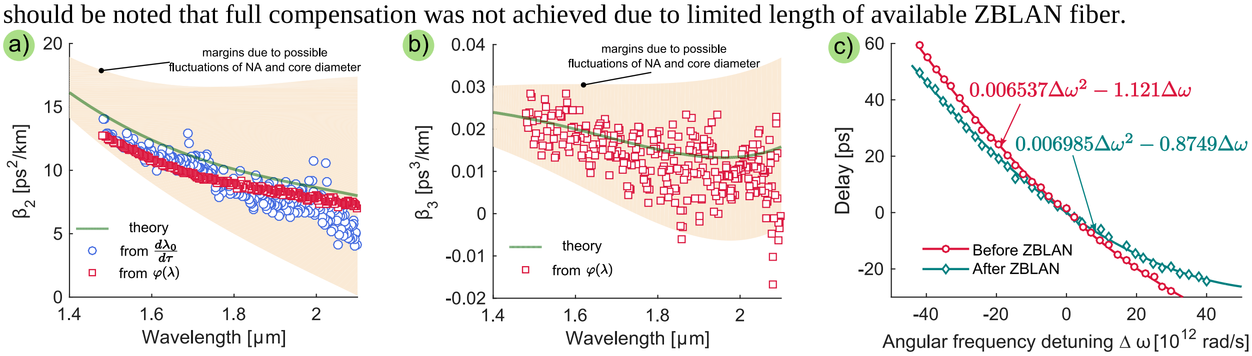

Fig. 3: Dispersion characterization and compensation results: a) β_2; b) β_3. The possible deviations of $\beta_{2,3}$ due to core diameter and NA variations are indicated by shadowed regions. c) Delay of the spectrally sliced components of a chirped broadband signal vs. detuning from the central wavelength of 1970 nm before and after propagation in ZBLAN fiber: dots – experimental data, lines – quadratic fits.

In conclusion, we presented the dispersion characterization of a 14.2 m long ZBLAN fiber section in the continuous 1500-2100-nm wavelength range using virtually all-fiber interferometer. The measured β_2 and β_3 values are in good agreement with the theoretical predictions of normal dispersion over the entire range. Moreover, it is the first, to the best of our knowledge, direct evaluation of TOD in fluoride fibers. The fiber can be used for dispersion compensation (as demonstrated), or as a host fiber for RE-doped fiber lasers with a normal dispersion in SWIR.

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3. References

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