160-to-40Gibt/s Time Demultiplexing in a low dispersion Lead-Silicate W-Index Profile Fiber

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Abstract: A 2.2m long sample of lead-silicate W-index profile fiber with nonlinear coefficient of 820W^{-1}km^{-1} and exhibiting low and flat dispersion across the C-band is used in an all-optical 160-to-40Gbit/s demultiplexing scheme based on four-wave-mixing.

OCIS codes: (190.0190) Nonlinear optics; (190.4380) Nonlinear optics, four-wave mixing.

1. Introduction

Optical parametric effects can play an important role in several processing applications of optical communication signals, such as regeneration, wavelength conversion and demultiplexing [1-2]. Their manifestation requires phase matching between the signals involved and a number of technologies have been explored in order to gainfully exploit these effects for the processing of ultrafast signals. For example, a four-wave mixing (FWM)-based demultiplexing scheme from 640Gbit/s down to 10Gbit/s was demonstrated in a 5-cm long chalcogenide glass waveguide chip with a nonlinear coefficient γ of ~4100 W$^{-1}\cdot$km^{-1} [3], whereas in Ref.[4] a 6-mm long integrated organic-silicon-on-insulator compound waveguide with a γ of ~104000 W$^{-1}\cdot$km^{-1} was employed to demultiplex a signal from 130Gbit/s to 10Gbit/s. Both of these technologies offer significant benefits in terms of compactness; however questions relating to coupling, power handling and the onset of deleterious side effects, such as two-photon absorption are still to be resolved. Highly nonlinear silica-based optical fibres, on the other hand, represent a more technologically mature alternative, and are usually preferred for their superior control over the dispersion characteristics, automatic compatibility with fiber systems and low splicing losses (typically 0.1dB/splice). However, their relatively low nonlinear coefficients (of ~20 W^{-1}km^{-1}) require the use of fiber lengths of the order a few hundreds of meters. Long fiber samples are not desirable, not only since they result in the realization of relatively bulky devices with high latency, but also because maintaining the polarization of the interacting signals in a long fiber length is not a trivial task. Attractive solutions are represented by soft-glass fibers that exhibit a high nonlinear coefficient and allow for the realization of ultrafast optical devices in ~metre long samples. However, soft glasses, which include lead silicates, bismuth oxide, tellurite and chalcogenide exhibit high losses (in comparison to silica) and a high material dispersion at telecommunication wavelengths. Despite the high fiber dispersion, demultiplexing of a 160Gbit/s signal down to 10Gbit/s was demonstrated in a 1m long sample of Bi-NLF [5], confirming the potential of non-silica fibers for these kind of applications. However, the large dispersion of the Bi-NLF limited the wavelength range in which efficient FWM could be observed. To this end, we have employed all-solid W-index profile fiber designs in soft-glasses in an attempt to compensate for the material dispersion with a controllable degree of waveguide dispersion. Using this approach we have recently fabricated a near-zero dispersion, highly nonlinear lead-silicate fiber and experimentally demonstrated its use for telecom applications at 1.55μm [6-8].

In this paper we experimentally demonstrate the use of a 2.2-m sample of this fiber in a 160Gbit/s-to-40Gbit/s FWM-based demultiplexing experiment and assess the quality of the scheme in terms of eye diagrams and bit-error-ratio (BER) measurements.

2. Experimental setup and results

The experimental setup used for the implementation of the FWM-based demultiplexer is shown in Fig.1. The pump signal was generated by a mode-locked Erbium Glass Oscillator (ERGO) pulsed laser generating ~2ps Gaussian pulses at a repetition rate of 10GHz and operating at λ_p=1550nm. The optical pump signal was then passively multiplexed to 40GHz. The corresponding eye-diagram, measured using an optical sampling oscilloscope (OSO), with a temporal resolution of 800fs, is shown as an inset to Fig.1. A second mode locked erbium fiber ring laser (EFRL) (λ_s=1560.5nm), generating ~2.5ps sech^2-pulses and operating at 40GHz, was first intensity-modulated by a 2^{31}-1 pseudorandom bit sequence (PRBS) and then passively multiplexed to 160Gbit/s, see corresponding eye diagrams in the inset of Fig.1. The two lasers were properly synchronized by using the same radio frequency (RF) clock, appropriately scaled down to 10GHz or up to 40GHz, as shown in Fig.1. An optical delay line in the pump arm was used to temporally align the pump pulses with the desired tributary channel of the 160Gbit/s signal to be demultiplexed. The states of polarization of the pump and the signal were aligned to one polarization axis of the fiber through polarization controllers (PCs) in order to maximize the generated FWM components. The signal and the pump were amplified using two independent EDFAs, properly filtered to remove any undesired amplified spontaneous emission (ASE) noise, combined together in a 3dB coupler and launched into the 2.2-m sample of the W-index-profile lead silicate fiber. The average power levels at the input of the fiber were 21.1dBm and 14.5dBm for the pump and the signal, respectively. The generated idler (λ_i=1539.5nm) at the output of the fiber was selected using a 2-nm bandpass optical filter.

The structure of the W-index profile fiber consisted of three different commercial lead silicate glasses. The fiber core (1.6µm in diameter) was made of a high index glass, Schott SF57 (n=1.82 @ 1550 nm) which was surrounded by a first cladding (6.7µm in diameter) made of a low index glass, Schott LLF1 (n=1.53 @ 1550 nm). The outer cladding was made of a different glass with a higher refractive index, Schott SF6 (n=1.76 @ 1550nm). A Scanning Electron Microscopy (SEM) image of the cross-section of the fiber is shown as an inset to Fig.1. The nonlinear coefficient, dispersion and loss at 1550nm were 820$W^{-1}km^{-1}$, -3ps/nm/km and 2.1±0.2 dB/m respectively. More details on the fiber design, fabrication and characterization can be found in [6]. However, to highlight the flattened dispersion profile at telecommunication wavelengths we also report the measured fiber dispersion profile from 1200 to 1680 nm in Fig.1(inset). Initial indications have shown that this material is spliceable to silica and work is in progress on this front. However, in this particular experiment, free-space launching was used with a coupling efficiency of 25%.

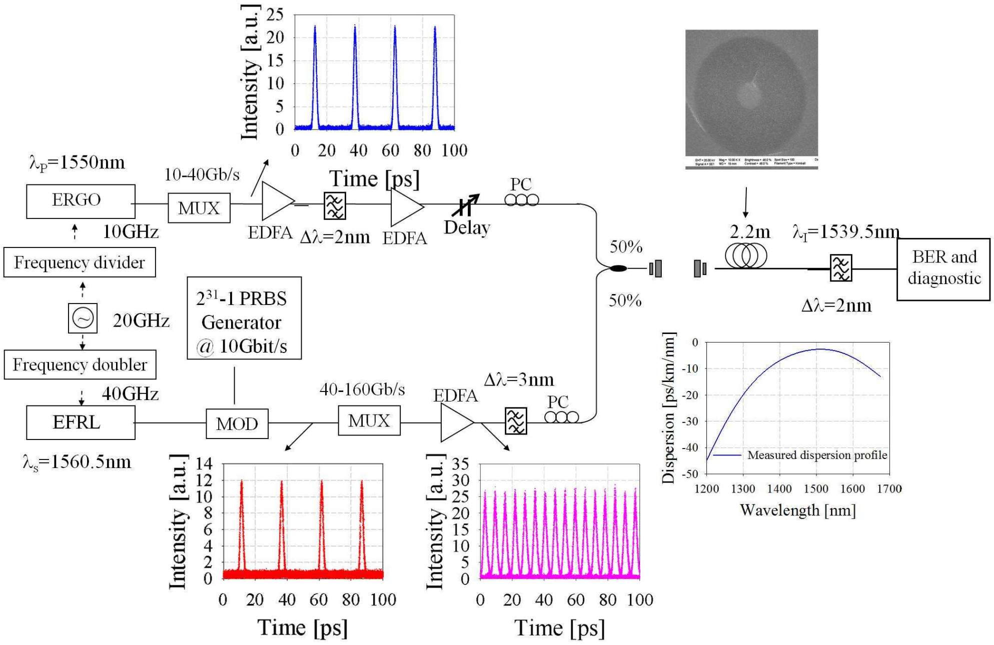

Figure 1: Experimental setup for the demonstration of demultiplexing of 160-to-40Gbit/s pulses. Insets: Eye diagrams measured using an OSO at different points of the system, an SEM image of the fiber and measured fiber dispersion profile from 1300 to 1680 nm.

The measured optical spectrum at the output of the fibre is shown in Fig.2. As discussed above, the 40Gbit/s demultiplexed idler generated by FWM was maximised by optimising both the relative delay and the polarisation of the pump and data signals. The 40Gbit/s demultiplexed idler was about 15dB weaker than the 160Gbit/s data. Note however, that considering the difference in the duty cycle between the data signal and the idler, this yields a conversion efficiency of more than 10% for a pump power of just 21dBm.

Eye diagrams of the filtered 40Gbit/s idler for each of the four tributaries of the 160Gbit/s signal are reported in Fig. 3, showing clean and open eyes for all four cases. The corresponding pulsewidth was ~3ps resulting in a time-bandwidth product of 0.44. The good quality of the eye diagrams is reflected in the corresponding BER measurements, also shown in Fig.3. Error-free operation is achieved for all of the four demultiplexed channels, showing a variation smaller than 0.3dB, while the maximum power penalty between the back-to-back (B2B) signal at 40Gbit/s and the four demultiplexed channels is <4dB. This degradation in the signal performance relative to the back-to-back is attributed mainly to the limited in-band OSNR of the original signal after the multiplexer. Indeed all signals show an out-of-band OSNR better that 30dB (Fig.2). However, the quality of the data signal is somewhat compromised after multiplexing, as can be appreciated from a comparison with the eye diagrams shown in Fig.1.

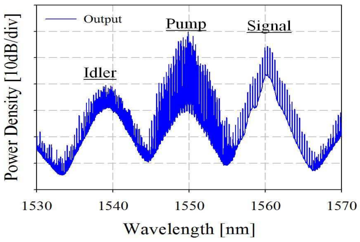

Figure 2: Optical spectrum at the output of the fiber with a span of 40nm (Res. bandwidth = 0.01nm).

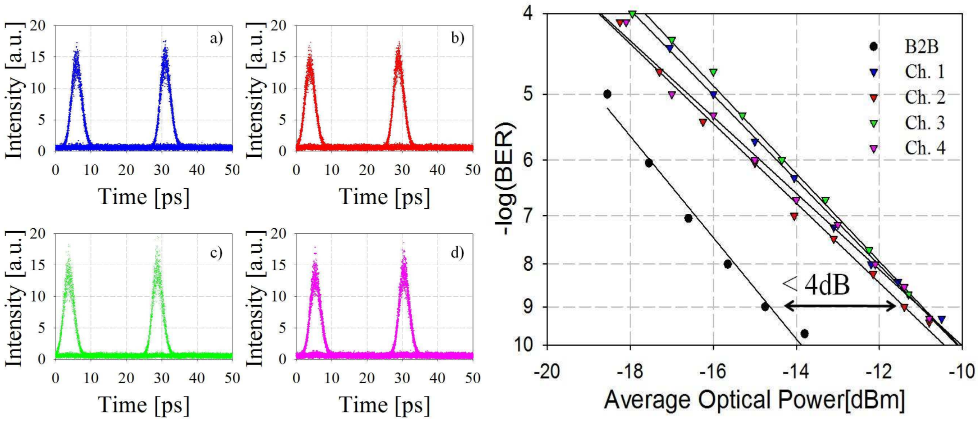

Figure 3: Eye diagrams of the four demultiplexed tributaries at 40Gbit/s and BER measurement of the 40Gbit/s (B2B) and of the 4 demultiplexed signals.

3. Conclusions

A FWM-based demultiplexer of 160Gbit/s signals down to 40Gbit/s has been demonstrated in just 2.2 m of a lead silicate fiber. The all-solid geometry and W-index profile design of the fiber allow low values of dispersion to be achieved using highly controllable fabrication procedures. The good performance of the demultiplexing system confirms the potential of this fiber for the processing of ultrafast optical signals.

Acknowledgments

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4. References

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