

Recirculating loop transmission experiment over 57.6-km photonic crystal fiber

Beáta Zsigri

Christophe Peucheret

Technical University of Denmark
Research Center COM
Building 345V
DK-2800 Kgs. Lyngby
Denmark
E-mail: bz@com.dtu.dk

Martin Dybendal Nielsen

Crystal Fibre A/S
Blokken 84
DK-3460 Birkerød
Denmark

Palle Jeppesen

Technical University of Denmark
Research Center COM
Building 345V
DK-2800 Kgs. Lyngby
Denmark

Abstract. We demonstrate a 57.6-km-long linear photonic crystal fiber (PCF) transmission experiment using a recirculating loop with a 19.2-km PCF spool. A 10-Gbit/s non-return-to-zero signal was transmitted over PCF transmission fiber without dispersion compensation. © 2005 Society of Photo-Optical Instrumentation Engineers.
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Photonic crystal fibers (PCFs) are very attractive for optical communication as they possess radically new features that cannot be achieved by their solid core-cladding fiber alternatives.¹ A large variety of PCF types can be produced with pure silica core, potentially offering low loss, large effective area, and therefore reduced fiber nonlinearity. Single-mode PCFs have been fabricated with effective areas as large as $600 \mu\text{m}^2$ (Ref. 2) and the endlessly single mode property has been shown to open up the possibility of building communication systems with over 160-THz bandwidth.³ PCFs have also been proved to be applicable to distributed Raman amplified systems⁴ and short return-to-zero pulse propagation over a dispersion managed link.⁵ Recent improvement in production technologies has resulted in significantly reduced fiber loss and longer fibers.^{5,6} This has inspired intense research on using PCFs as transmission fibers.^{3-5,7-10} However, the transmission distances for linear, nondispersion managed systems reported until now have been limited to 12.7 km.⁴ In this

article, we demonstrate for the first time, to our knowledge, a recirculating loop experiment including 19.2 km of transmission PCF, thus extending the total length of transmission over PCF to 57.6 km.

Two spools of endlessly single-mode PCF with lengths of 8.8 and 10.4 km have been used in the transmission experiment. The fibers are made from pure silica. The cladding has a closed packed structure with hole-to-hole spacing (Λ) of 7.5 and 6.3 μm for the 8.8- and 10.4-km spools, respectively, and the diameter of the air holes relative to Λ is 0.49 in both cases. Both fibers have a cladding diameter of 125 μm and a coated diameter of 240 μm . The two spools were spliced together from five pieces of fiber with an average length of 4 km, the longest piece being 6.4 km long. All fiber pieces have less than 1 dB/km loss at 1550 nm. The 10.4-km fiber has a mode field diameter of 7.5 μm and a dispersion of 34.5 ps/nm/km at 1550 nm, while the mode field diameter and the dispersion of the 8.8-km fiber are 9 μm and 31.5 ps/nm/km at 1550 nm, respectively. These mode field diameter values translate into effective areas of 44 and 64 μm^2 for the 10.4- and 8.8-km spools, respectively.

The setup used for the transmission experiment is shown in Fig. 1. The transmitter consisted of a CW laser source emitting at 1550 nm followed by a polarization controller and a chirp-free LiNbO₃ Mach-Zehnder modulator (MZM). A pseudo random bit sequence (PRBS) with a length of $2^{31}-1$ was applied to the MZM to generate a 10 Gbit/s non-return-to-zero (NRZ) modulated signal. An erbium-doped fiber amplifier (EDFA) boosted the signal before it was coupled into the loop switch via a variable attenuator and a polarization controller. The loop switch consisted of two cascaded acousto-optic switches (AOS) to control the filling time of the loop and an additional AOS to control the number of round trips the signal travels before detection. In the loop, the signal was first boosted by an EDFA before being launched in the transmission line. The transmission line consisted of the two spools of PCF with lengths of 10.4 and 8.8 km. The average input power into the PCF was 15.8 dBm. At the output of the second PCF, an EDFA was used to compensate for the span loss before the signal was

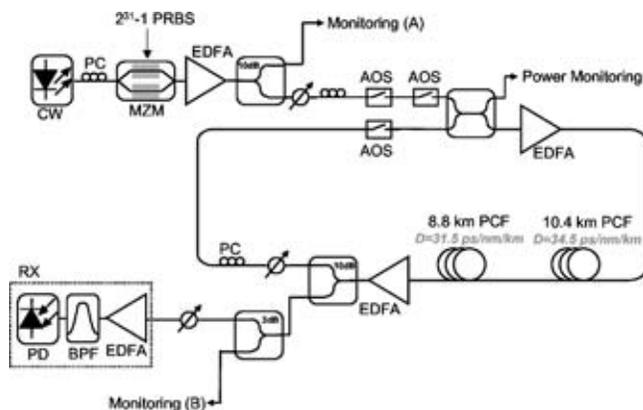


Fig. 1 Experimental setup. CW: continuous-wave laser; PC: polarization controller; MZM: Mach-Zehnder modulator; EDFA: erbium-doped fiber amplifier; AOS: acousto-optic switch; PCF: photonic crystal fiber; BPF: optical bandpass filter; PD: photodiode.

reinjected into the loop switch. A 10-dB power splitter enabled the signal to be coupled into an optically preamplified receiver.

The back-to-back eye diagram (recorded at point A in Fig. 1) corresponding to an extinction ratio of 14.8 dB is shown in Fig. 2(a). The eye diagrams after 19.2-, 38.4-, and 57.6-km transmission over PCF (recorded at point B in Fig. 1) are shown in Figs. 2(b), 2(c), and 2(d), respectively. All eye diagrams were monitored in a 26-GHz bandwidth. The eye-diagram distortion is mainly attributed to dispersion. Due to the high fiber input power, some pulse reshaping due to self-phase modulation (SPM) in the anomalous dispersion regime can also be observed in the eyes.

The bit error rate curves measured in the back-to-back case and after transmission are plotted in Fig. 3. A back-to-back sensitivity of -33.9 dBm has been obtained. The power penalty measured after 19.2, 38.4, and 57.6 km (corresponding to 636, 1272, and 1908 ps/nm accumulated dispersion, respectively) was 0.1, 0.7, and 3.4 dB, respectively. As a comparison, in the case of linear propagation, 1-dB power penalty is expected in a standard single-mode fiber-based transmission line for around 1000-ps/nm accumulated dispersion.¹¹ The measured lower power penalty values confirm the interaction of SPM with anomalous dispersion.

We have demonstrated what we believe is the longest nondispersion managed transmission experiment using PCF as a transmission fiber to date. A 10-Gbit/s NRZ signal was transmitted in a recirculating loop consisting of a 19.2-km transmission PCF. The signal was successfully transmitted over 57.6 km of PCF with only 3.4-dB power penalty. The transmission distance was mostly limited by dispersion.

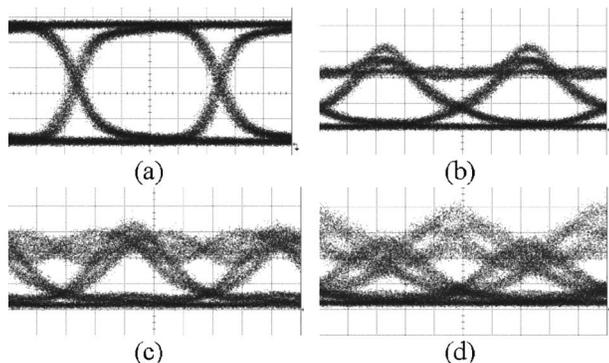


Fig. 2 Eye diagrams measured (a) in the back-to-back case and after (b) 19.2-km, (c) 38.4-km, and (d) 57.6-km transmission over PCF.

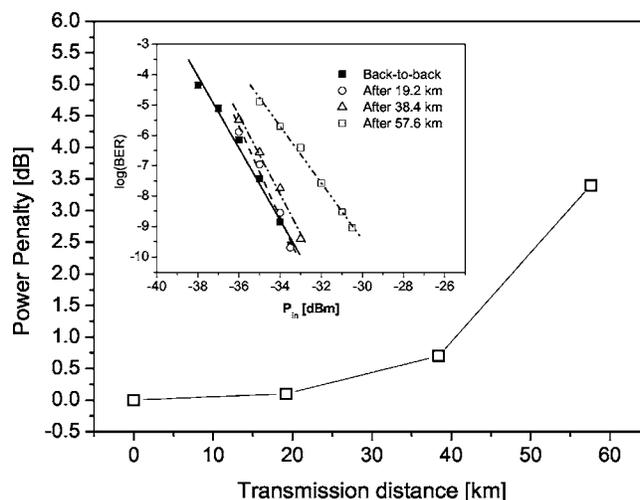


Fig. 3 Power penalty as a function of transmission distance. The inset shows the bit error ratio curves measured in the back-to-back case and after 19.2-, 38.4-, and 57.6-km transmission over PCF.

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