WC2.4 (Invited)
11:30 – 12:00

A First Glance at Coherent Optical Transmission using Photonic Bandgap Fiber as a Transmission Medium

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Abstract

Photonic bandgap fibers (PBGF) potentially offer a very substantial increase of capacity per fiber over solid core fibers. We review transmission experiments using PBGF and their viability for next-generation transmissions systems.

I. INTRODUCTION

Spatial division multiplexing (SDM) is seen as a potential means to increase the capacity per fiber in order to fulfill future data traffic needs. Recent research mainly focusses on solid core approaches, exploiting either multiple cores and/or multiple modes as separate transmission lanes to increase the fiber capacity. Impressive values of spectral efficiency have been demonstrated using either method [1-4], outrunning the highest capacity shown for single-mode fibers [5].

Another potential technology to increase the capacity per fiber is that of hollow core photonic bandgap fibers (PBGFs). These fibers have several beneficial properties compared to solid core fibers, the most appealing being ultralow nonlinearity, potential for low loss and low latency [6]. Although the loss is still high with manufactured span lengths of only several hundreds of meters, steady improvement in the manufacturing of these fibers has been achieved over the last two years resulting in improved transmission bandwidth and modal properties which led to the first coherent optical transmission experiments using PBGFs as transmission medium [7,8].

In this paper we review the transmission experiments using PBGF as a fiber type and look at the challenges yet to be addressed.

II. SINGLE-MODE TRANSMISSION EXPERIMENTS

Table I summarizes the transmission experiments conducted over PBGF up to now. In [9] a 150m, 7 cell PBGF was used to transmit 10-Gb/s non-return-to-zero (NRZ) on-off-keying (OOK) on a single mode. Using a 3.5 dB/km, 250m long 19 cell PBGF supporting ~6 mode groups [15], successful transmission was obtained by using only the fundamental mode and sending 37 wavelengths carrying 40-Gb/s NRZ-OOK in the C-Band (1.48 Tb/s) [12]. A slightly shorter sample of the same fiber was used to perform the first single mode, coherently detected optical transmission experiment. 96 wavelength channels spanning from 191.35 THz to 196.1 THz were 256-Gb/s dual-polarization 16-level quadrature amplitude (DP-16QAM) or 320-Gb/s DP-32QAM modulated, transmitted and received using coherent detection (Fig. 1) [7]. By doing so, a total transmitted net capacity of 24 Tb/s was achieved over this PBGF (gross 30.7 Tb/s). These experiments show the potential of PBGF for the use in single-mode transmission. It should

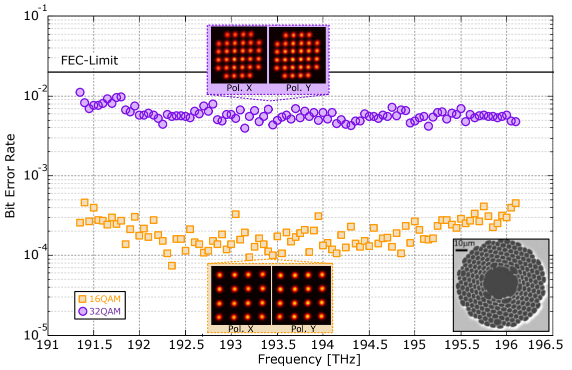

Fig. 1. Single-mode transmission results for all 96 channels carrying either 256-Gb/s DP-16QAM or 320-Gb/s DP-32QAM over 230m of 19 cell PBGF [7,15].

TABLE I
TRANSMISSION EXPERIMENTS CONDUCTED USING HOLLOW CORE PHOTONIC BAND GAP FIBER

Paper	PBGF	Length	Single- / Multi-mode	Wavelength	Modes	No. Ch.	Datarate (total)
[9]	7 cell	150 m	Single-mode	1545 nm	1	1	10.0 Gb/s (10.0 Gb/s)
[10]	7 cell	30 m	Multi-mode	1550 nm	2	1	10.7 Gb/s (21.4 Gb/s)
[11]	19 cell	0.75 m	Multi-mode	1550 nm	2	1	20.0 Gb/s (40.0 Gb/s)
[12]	19 cell	250 m	Single-mode	C-Band	1	37	40.0 Gb/s (1.48 Tb/s)
[13]	19 cell	290 m	Single-mode	2008 nm	1	1	8.0 Gb/s (8 Gb/s)
[14]	19 cell	290 m	Single-mode	2000±4 nm	1	4	8.5+3x2.5 Gb/s (16Gb/s)
[7]	19 cell	230 m	Single-mode	Ext. C-Band	1	96	320 Gb/s (30.7 Tb/s)
[8]	37 cell	310 m	Multi-mode	Ext. C-Band	3	96	256 Gb/s (73.7 Tb/s)

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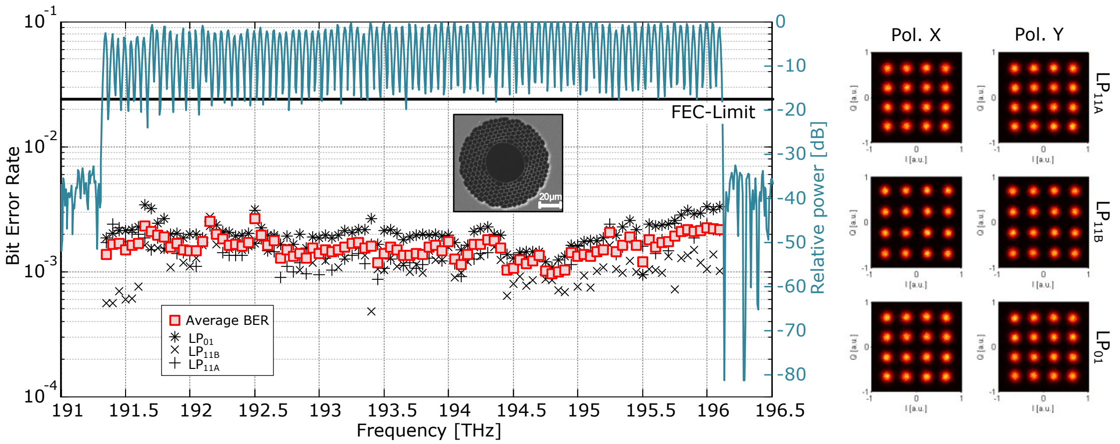

Fig. 2. Left: Bit-error rate of the demodulated signal after MDM transmission over the 37-cell PBGF and the received spectrum at the LP$_{01}$ port. Right: Received 16QAM constellations for the channel at 193.4 THz. [8]

be noted that in such a setup a PBGF can provide extended capacity compared to current single-mode fibers, due to the much lower nonlinearity and the potentially lower loss. This will lead to a higher received OSNR and the possibility to increase the spectral efficiency achievable.

PBGFs are predicted to have the lowest loss at about 2000nm [13]. The first experiments in this new transmission window at relatively low data rates have been shown in [13, 14].

III. MULTI-MODE TRANSMISSION EXPERIMENTS

Increasing the core size of PBGFs will reduce the loss of the fiber because the overlap between the light and the material will get lower. Inherently low-loss PBGFs will therefore be heavily multi-mode. This fact however could be exploited to increase the capacity per fiber even more using SDM.

The first conducted multi-mode transmission experiments used short fiber lengths and exploited the LP$_{11A}$ and LP$_{11B}$ modes of a 7 cell PBGF [10], or the LP$_{01}$ and LP$_{21}$ of a 19 cell PBGF [11] transmitting 10.7 Gb/s and 20 Gb/s NRZ-OOK per mode, respectively, although they are already outperformed by the single-mode transmission experiments presented.

The first ever transmission experiment over a 37 cell PBGF of 310m length was performed using three modes, i.e. LP$_{01}$, LP$_{11A}$ and LP$_{11B}$, with a 3.3 dB/km loss for the fundamental mode. Mode-division multiplexed (MDM) transmission using 96 channels carrying 256-Gb/s DP-16QAM modulation was successfully achieved (net capacity 57.6 Tb/s, gross capacity 73.7 Tb/s) [8]. The result of this experiment, depicted in Fig. 2, provided compelling evidence of the suitability of PBGFs for MDM, demonstrating a third dimension to increase the capacity per fiber compared to single-mode fibers.

IV. CHALLENGES AHEAD

The main challenge right now is to increase the manufacturability of PBGFs to multi-km ranges and as well reduce the loss down to < 1 dB/km for the fundamental mode. It should also be noted that any loss improvements are expected to lead to lower intermodal crosstalk as well. As such single-mode transmission over PBGFs will become very interesting as in principle it can be used for gradual upgrades of current transmission systems as well as for low-latency transmission purposes.

To be able to use PBGFs for MDM transmission more challenges lie ahead. For instance, current PBGFs show measurable mode dependent loss (MDL) [8] and DGD values which are larger than the best solid-core few-mode fibers. At the moment it still looks possible that these issues can be at least in part addressed through fiber design improvements. Apart from DGD and MDL other non-assessed fiber characteristics might also impair MDM transmission over PBGF.

V. CONCLUSIONS

We have presented a review of the first coherently detected optical transmission experiments over hollow-core PBGFs showing transmission up to 3 modes x 96 channels x 256-Gb/s yielding a net data rate of 57.6 Tb/s. Whilst a number of challenges clearly still lie ahead, especially for MDM transmission, these experiments provide a strong endorsement of the suitability of these radically novel fibers for high capacity transmission.

ACKNOWLEDGMENT

This work was supported by the EU FP7-ICT MODE GAP project under grant agreement 258033.

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