Optical and Acoustical Methods in Science and Technology

Coupling in Core-Ring Photonic Crystal Fibers

N. Palka[a], W. Ciurapiński[a], J. Wojcik[b] and M. Szustakowski[a,*]

[a]Institute of Optoelectronics, Military University of Technology
S. Kaliskiego 2, 00-908 Warsaw, Poland
[b]Laboratory of Optical Fibre Technology, Maria Curie-Skłodowska University
20-031 Lublin, Poland

Experimental investigations of light coupling from a core into a ring caused by microbendings in photonic crystal fibres are shown. We present a setup arrangement, mode fields with and without coupling and a plot of power transfer versus localisation of the modulator along the fibre. We also show the most probable explanation of the obtained data.

PACS numbers: 42.81.Bm, 42.81.Cn, 42.81.Dp

1. Introduction

Over the past few years, a substantial effort has been made in fabricating photonic crystal fibres (PCFs) — new dielectric structures with a refractive index that varies periodically in the transverse plane, with a period of the order of an optical wavelength [1]. PCFs constitute a new kind of lightguides that possess huge possibility of parameters tailoring [2–5]. It seems that a new generation of optical fibres can outperform conventional germanium-doped fibres especially for sensing applications.

We propose PCF which can transmit light in the two independent regions — a core in the middle of the fibre and ring — around the core. The SiO_2-based fibre comprises: defect in the centre (SiO_2 core), 3 rings of air holes, 3 rings of defects — rods (SiO_2) and 3 rings of air holes. Both defect regions (the core and the ring) guide light by modified total internal reflection [1]. We can change the effective refractive index of the photonic regions by means of a hole diameter (d) to a pitch (Λ) ratio.

In this fibre modes with similar phase constants can couple from core into ring in the presence of microbendings. Selective pulse excitation of the mode in

*corresponding author; e-mail: mszustakowski@wat.edu.pl

the core and the introduction of microbendings along the fibre produces an optical pulse train at the output with different amplitudes and time delays compared to the first (the fastest) pulse train which is carried by the mode in the core. From the delay between the fastest core pulse and the ring pulse, the position of the disturbance along the fibre can be calculated [6, 7].

This paper shows experimental investigation of light coupling from the core into the ring caused by a microbending modulator. We present a setup arrangement, mode fields with and without coupling and a plot of power transfer versus localisation of the modulator along the fibre. Next, we show the most probable, in our opinion, explanation of the obtained data.

2. The manufactured PCFs

We manufactured two PCFs (P1 and P2) which can transmit light in two independent regions. Atomic force microscope images of manufactured PCFs (P1 and P2) are presented in Fig. 1. Next, image processing was conducted to determine geometrical parameters of the PCFs. Images were sharpened and holes were approximated by circles. Geometrical and transmission parameters of the manufactured PCFs are presented in Table.

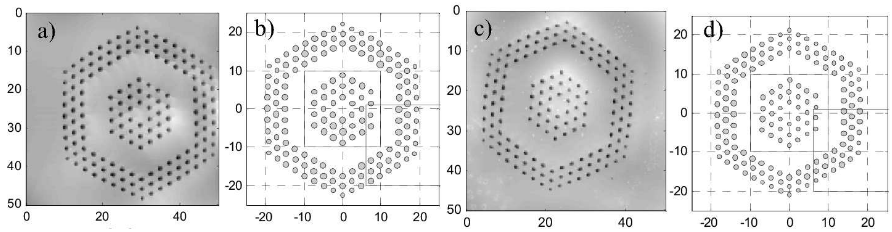

Fig. 1. Atomic force microscope images of manufactured PCFs: P1 (a) and P2 (c). Processed images: P1 (b) and P2 (d) (axes in μm).

We measured attenuation for wavelength 670 nm and 1300 nm (Table). Light from lasers through single mode fibres (MFD = 4.3 μm and 9 μm, respectively) was coupled into the PCFs using a fusion splicer as a positioner. Therefore, we could stimulate different regions of the fibres — cores or rings. It is seen that for $\lambda = 1300$ nm attenuation is about twice smaller, which agrees well with theoretical expectations.

Figure 2 presents intensity distributions of the near field at the end of the fibres. For both fibres we can see single mode operation (if central region of the fibres is stimulated) or bright hexagonal images (if the ring is stimulated).

We measured the time differences between signals that propagated inside the cores and the rings by means of a transmitter-receiver unit with 3 ns impulses. We obtained: P1(485 m) — 15.0 ns, P2 (185 m) — 5.2 ns. We recalculated these values with reference to 1 km — 31 ns and 27 ns were obtained, respectively. It

TABLE

Geometrical and transmission parameters of the manufactured PCFs.

Fibre	P1		P2	
length [m]	485		185	
region	core	ring	core	ring
mean diameter d [μm]	1.48±0.13	1.47±0.14	1.12±0.14	1.28±0.15
mean pitch Λ [μm]	2.90±0.07	2.73±0.12	2.69±0.08	2.56±0.21
mean ratio d/L	0.51±0.06	0.54±0.07	0.41±0.07	0.50±0.10
attenuation [dB/km] at 670 nm	–80	–42	–52	–67
attenuation [dB/km] at 1300 nm	–31	–34	–13	–47

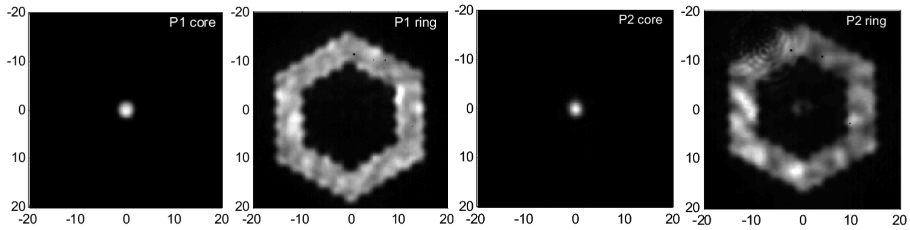

Fig. 2. Near field intensity distribution: P1 core, P1 ring, P2 core, P2 ring. $\lambda = 670$ nm (axes in μm).

is observed that there was no impulse broadening even for the 485 m long fibre for both regions of propagation. Moreover, the flying time through the cores and the rings did not depend on the position of the stimulation (inside these regions). Therefore, we assumed that the stimulated modes travel with the same velocity.

3. Core-ring coupling

In order to determine transfer of light from the core modes into the ring modes we build a setup (Fig. 3). Light from 670 nm laser is coupled through a single mode fibre (MFD = 4.3 μm) into the PCFs using a fusion splicer as a positioner. Microbendings were generated by a modulator that consists of two rows of small fibres (diameter ≈ 1 mm) placed perpendicularly to the PCF. Images were observed by a microscope with a CCD-camera.

Figure 4 presents intensity distributions of the near field at the end of the fibre P1 for three cases: without the modulator (a), the modulator at the beginning (b) and at the end of the fibre (c). It is seen that for case (b) some transfer of light from the core to the ring is observed.

To present the transfer of light quantitatively we determined power inside the core and inside the ring (the region between big circles in Fig. 4). Figure 5 presents power inside the ring as a function of localisation of the microbendings modulator along the fibre. The straight line represents the power without microbendings.

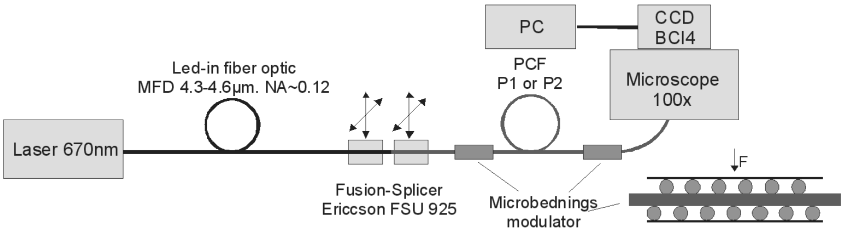

Fig. 3. Experimental setup for core-ring coupling.

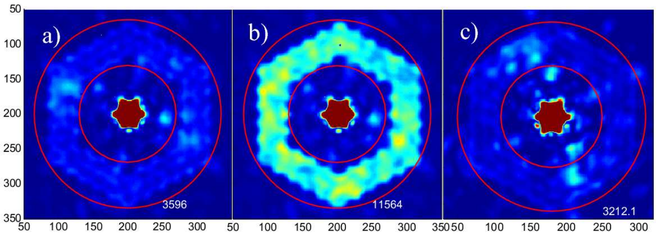

Fig. 4. P1 near field intensity distributions: without modulator (a), the modulator at the beginning of the fibre (b) and at the end of the fibre (c). $\lambda = 670$ nm. Images were overexposed to emphasise the ring. Axes in pixels.

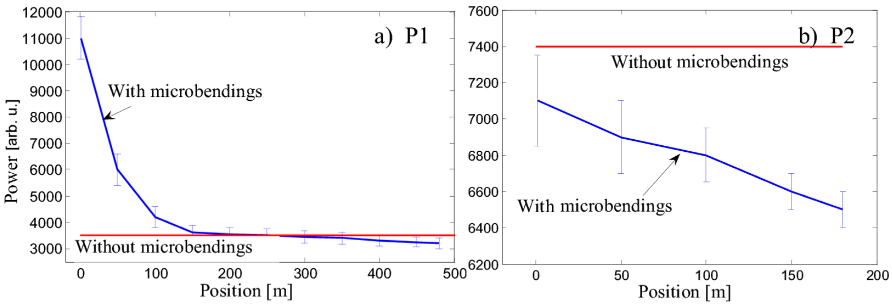

Fig. 5. Power inside the ring versus localisation of the microbendings modulation for P1(a) and P2 (b).

4. Discussion and conclusions

In the considered fibres light is coupled into the core while part of it is transferred spontaneously into the ring along the whole length (Fig. 5) because the core is surrounded only by 3 layers (rings) of holes which is depicted in Fig. 4a. For the same reason, part of the light from the ring region is also transferred spontaneously into the cladding (Fig. 6). Moreover, we should also remember about attenuation and absorption. When microbendings are activated, the core-ring and ring-cladding couplings are intensified.

As far as the P1 fibre is concerned, for an initial part of the fibre (about 200 m) core-ring coupling prevails over ring-cladding coupling because power of

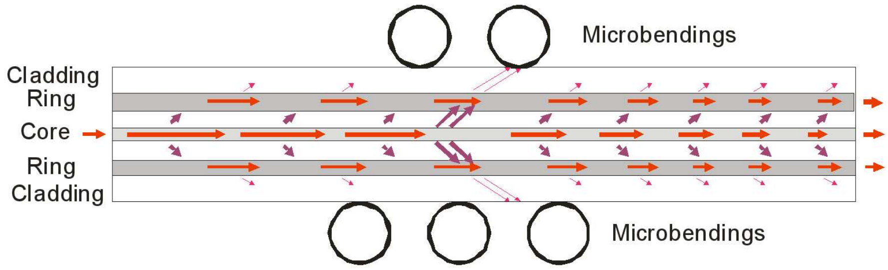

Fig. 6. Analysis of the core-ring transfer in the PCFs.

light inside the core is relatively high. For the length of about 250 m balance is observed and microbendings do not change power inside the ring region. For longer distances power inside the core is small and cannot compensate the ring-cladding coupling. As a result, drop of power inside the ring region is observed.

Situation is quite different for P2 fibre. In this case, the ring-cladding coupling prevails at once and drop of power is observed along the whole fibre. It could result from the fact that d/Λ ratios are smaller in this case which means better spontaneous ring-cladding coupling.

To sum up, in this paper we present two PCFs with core and ring regions manufactured to determine the coupling caused by microbendings. The setup arrangement and mode fields with and without couplings are presented. The plot of power transfer versus localisation of the disturbance modulator along the fibre enables us to present the most probable explanation of the observed phenomenon. We think that there is a need for strong simulation and experimental effort to better understand the couplings inside PCFs.

References

[1] T.A. Birks, P.J. Roberts, P.St.J. Russell, D.M. Atkin, T.J. Shepherd, *Electron. Lett.* **31**, 1941 (1995).

[2] J.C. Knight, T.A. Birks, P.St.J. Russel, D.M. Atkin, *Opt. Lett.* **21**, 1547 (1996).

[3] P. Russel, *Science* **299**, 358 (2003).

[4] E. Nazarova, A. Tcheryatian, *Mol. Quant. Acoust.* **28**, 259 (2007).

[5] V. Balakshy, A. Vostrikova, *Mol. Quant. Acoust.* **28**, 265 (2007).

[6] K. Jasek, B. Mazurek, M. Pasternak, *Mol. Quant. Acoust.* **27**, 141 (2006).

[7] N. Palka, W. Ciurapiński, J. Wojcik, M. Szustakowski, *Europ. Phys. J. Special Topics* **154**, 143 (2008).