3.2 Sensitivity

Here we calculate and compare the sensitivities obtained for 1, 2, and 3 hole separation between the cores of the dual-core mPOF, based on the simple principle of tracking the resonant wavelength shift of transmittance as a function of the biolayer thickness, using the methodology described in the previous section. Because the coupling length increases significantly when going to a 3 hole separation, we will consider both a 7 cm coupler and a 15 cm coupler. We will consider only a wavelength window of 500-900 nm, so if a capture of biomolecules blue-shifts a given resonance outside the window, then this point is not included in the sensitivity curve.

The sensitivity can be expressed as $S = \Delta\lambda/\Delta t$ (nm/nm), where Δt is the change of the biolayer thickness when the antibody biomolecules are captured, which in our case is 5 nm. We have so far used an antigen sensor layer of thickness 40 nm in order to compare directly the sensitivity of our biosensor with the previous record of 10.4 nm/nm [17]. However, the proposed dual-core mPOF biosensor exhibits similar sensitivity also for a sensor layer of thickness 10 nm, as confirmed in Fig. 6(a) for the case with one hole in between the two cores (blue triangles). In both cases Fig. 6(a) shows that the sensitivity is between 1.5 and 1.4 nm/nm at around 550 nm, while decreasing monotonically as the wavelength increases. We have considered a device length of both 7 cm (black squares) and 15 cm (red dots). The sensitivity for the two device lengths will lie on the same curve $S(\lambda)$, but by going to a longer length one can move further down in wavelength on the $L_C(\lambda)$ curve in Fig. 4 and thereby obtain a higher sensitivity. However, with only one hole separation the sensitivity curve is rather flat and so nothing is gained by using a longer fiber length, when taking into account that the loss is then also larger. Clearly one hole separation is not enough to achieve a good sensitivity.

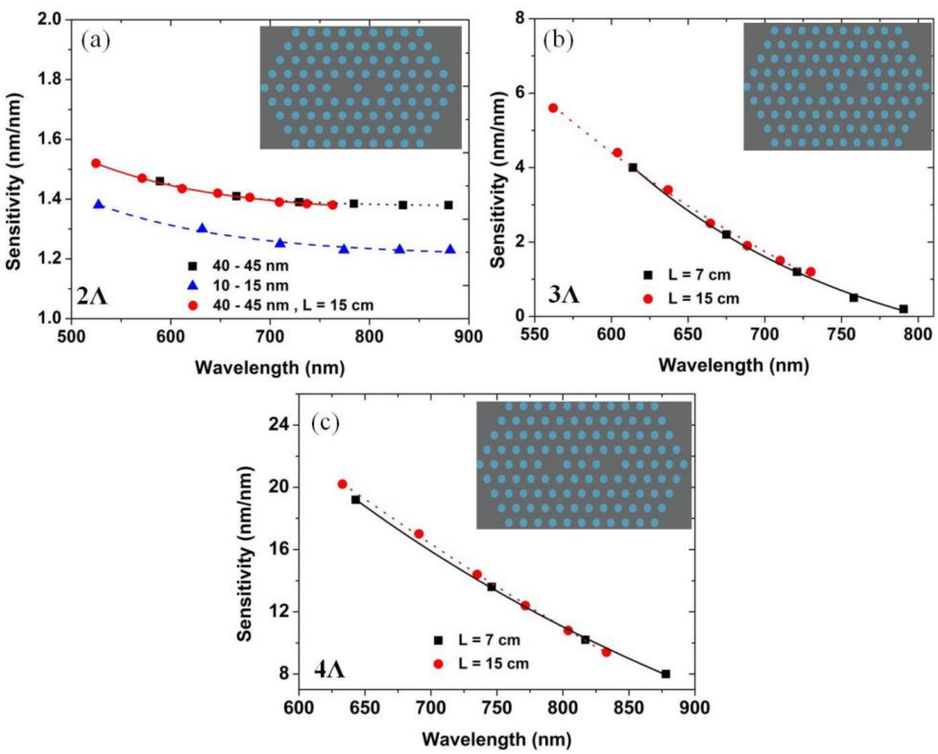

Fig. 6. Sensitivity versus wavelength of the dual-core mPOF biosensor for a separation of (a) 2Λ (comparison of 40-45 and 10-15 nm layer thickness for L = 7cm), (b) 3Λ and (c) 4Λ between the cores. Square dots correspond to a fiber length of L = 7 cm and red dots to L = 15 cm. The solid, dashed and dotted lines are the exponential fitting for each case.

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In Fig. 6(b) we show the sensitivity of the dual-core mPOF with two holes (3Λ) between the cores. As expected the sensitivities for the two device lengths of 7 cm and 15 cm lie on the same curve, but the sensitivity is now higher. The maximum sensitivity is now 5.6 nm/nm at 560 nm and again the sensitivity decreases monotonically. However, the slope of the S(λ) curve is much steeper, as shown in Fig. 4(b), and thus there is much to be gained by operating at shorter wavelengths. Thus the maximum sensitivity for a 7 cm device is 4.0 nm/nm at 610 nm, while increasing the length to 15 cm allows to operate at a shorter wavelength of 560 nm and thereby increase the sensitivity to 5.6 nm/nm

By increasing the core separation to 3 holes (4Λ), Fig. 6(c) shows that the sensitivity reaches a level as high as 20 nm/nm at around 630 nm for the 15 cm long device. Importantly, this sensitivity is twice the hitherto record of 10.4 nm/nm using FWM [17].

4. Conclusion

We have proposed a dual-core mPOF suitable for label-free and selective biosensing. The evanescent wave sensing is carried out inside the holes of the mPOF, which makes the sensor robust, while the dual-core functionality means that no post processing of the fiber is required as e.g., when using grating-based sensors. The basic operation principle relies on tracking the shift of an extremum in the transmittance when the sensor captures a layer of antibody biomolecules.

In our design, we considered a PMMA mPOF with a hexagonal hole structure with a hole diameter of 1 μm and a pitch of Λ = 2 μm. We calculated the coupling lengths for three different dual-core mPOFs with 2Λ, 3Λ and 4Λ core separation and a fixed fiber length of 7 cm and 15 cm. All the design parameters of the dual-core mPOF design are feasible for fabrication and operation and no selective filling is required. In order to verify the appropriate length of the device, we experimentally measured the loss of a single-core mPOF with the same characteristics as the proposed dual-core coupler.

Our results demonstrate that the sensitivity increases with increasing the distance between the solid cores, as also observed by Town *et al.* for planar structures in a study of refractive index sensing [31]. The distance of course cannot be increased indefinitely, given that the structure has to fit into a preform of a realistic size below 80 mm, where we use 60 mm, and given that hole sizes less than 1.5 mm are impossible to drill sufficiently deep to obtain a long enough preform. A further limitation is in terms of loss, given that the necessary length of the fiber increases with increased core separation.

The sensitivities of the most sensitive dual-core mPOF with 4Λ distance between the cores is for example 20.3 nm/nm at the He-Ne wavelength 633 nm and 8.9 nm/nm at 850 nm, where cheap CMOS technology is available. At these two important wavelengths the loss of our fiber is around 0.15 dB/cm and 0.07 dB/cm, respectively. This is acceptable when considering device lengths less than 15 cm. We note that, the loss can be reduced further, as described in Section 2, to levels less than 1dB/m, as reported by Large *et al* [29].

Our record sensitivity of 20.3 nm/nm, i.e., a shift of the resonant peak of transmittance of 20.3 nm per nm thickness of biolayer, is therefore obtained for experimentally very feasible design parameters. The sensitivity is twice the hitherto predicted record of 10.4 nm/nm for a MOF-based biosensor, which required longer fiber lengths and a high-power laser [17].

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