Refractive index sensor based on a curved biconical tapered fiber

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Abstract

Biconical tapered fibers have been widely used to modify the propagation characteristics of standard fiber in optical communication systems. They are obtained by a heating and stretching process along the propagation axis that results in a uniform waist between two transition regions [1]. Depending on the geometry of these tapered regions adiabatic and non-adiabatic tapered fibers with gradual and abrupt transitions, respectively, can be distinguished. In the non-adiabatic case the fundamental mode couples into two modes, one propagating in the core of the waist and another traveling through the air-cladding interface. Each mode experiences different propagation conditions because of their distinct effective indexes. The interference between these two modes creates a spectral fringe pattern whose visibility and periodicity depends on the waist length and the effective indexes of the modes.

Different devices based on optical technology have been developed to perform sensing. Those based on optical fiber are especially convenient because they provide high mode confinement with little losses. Fiber-based sensors have been developed to detect, among others, changes in temperature, strain or refractive index. For the latter, the air-cladding mode interacts with the outer medium shifting the sensor response thus providing an indirect measurement of the medium refractive index. Depending on the technology employed different sensitivity values have been achieved [2], including those based on tapered fibers [3].

In this work we propose a simple way to carry out refractive index measurements through bending of a tapered fiber. Low-loss sharp curves can be made in the tapered fiber when the refractive index of the sensed medium is considerably lower from that of the cladding. In this case the mode simply suffers from propagation losses. However, when the outer refractive index becomes similar to the index of the cladding a sharp curve will result in high radiation losses because the mode is poorly confined. It is therefore possible to estimate the refractive index of the outer medium through measurement of the radiated power.

Figure 1(a) shows the profile of the straight (i.e. without any introduced curvature) tapered fiber used in the experiment, where T_t = 1 mm, L_w = 13 mm and ρ = 18 µm. Figure 1(b) shows an schematic of the same tapered fiber after being curved. The refractive index sensor is characterized by means of a broadband optical source and an optical spectrum analyzer. Three different surrounding mediums were considered to characterize the sensor: air, deionized water (DIW) and 10% ethanol concentration in DIW being their refractive indexes n_{air} = 1, n_{DIW} = 1.3173 [4] and $n_{Ethanol10\%}\approx 1.338$ [5], respectively. All these values are inferior to the cladding effective index which exceeds 1.4. The transfer function of the tapered fiber for the different external indexes is plotted in Fig. 2. It can be seen how losses for the straight taper do not change considerably despite the different absorption coefficient of the ethanol. In this case the refractive index must be deduced from variations in the period of the spectral fringes. However, when the same tapered fiber is curved an increasingly high amount of radiation losses are introduced for outer refractive indexes getting closer to the fiber cladding index. In this case an average power of 0.2 mW becomes 0.05 mW for an estimated increase in the refractive index of 0.0207. Careful interpretation of these results must be made since the relationship between radiated losses and refractive index is not necessarily linear.

In conclusion, a simple technique to fabricate refractive index sensors using curved tapered fibers is presented. It is based on converting changes in the confinement of the air-cladding mode into optical losses through bending of the tapered fiber. A prototype of the device show good sensitivity in terms of losses per refractive index variation. The whole subsystem can be built using cheap broadband optical sources as LEDs instead of expensive CW lasers required by current approaches.

References

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Figures

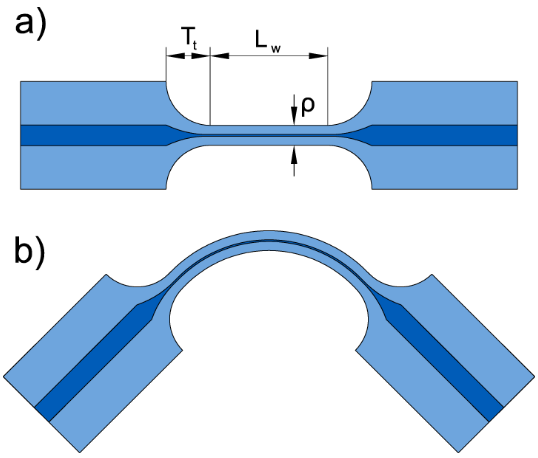

Figure 1: (a) Straight and (b) curved biconical tapered fiber

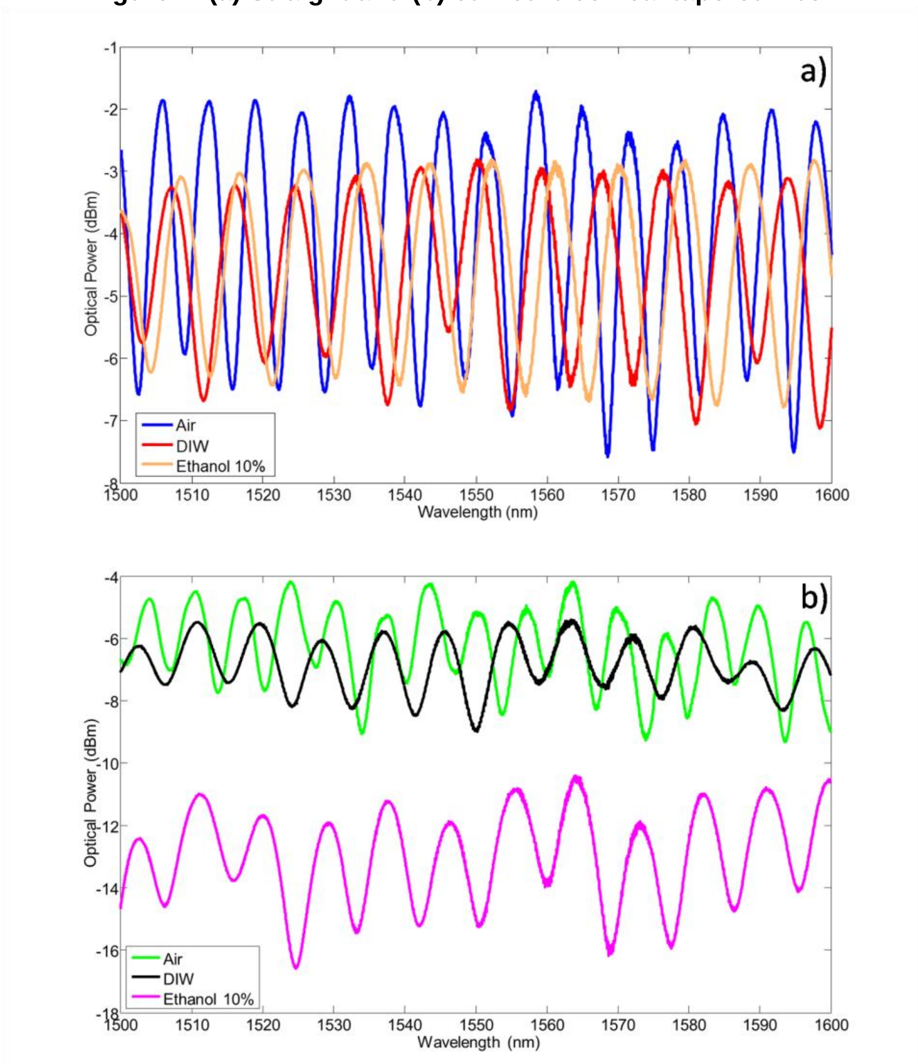

Figure 2: Experimental transfer function of the (a) straight and (b) curved tapered fiber.