A nanofiber coupler refractrometer with ultrahigh sensitivity

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Refractometry is an important method for many applications in metrology, environmental monitoring, chemical and bio-medical sensing. Several types of optical fiber refractometers have been developed including those based on fiber Bragg gratings (FBGs), long period gratings (LPGs), photonics crystal fibers (PCFs), and in-line interferometers [1, 2]. Yet, all these approaches require complex fabrication procedures for fabricating a sensing structure.

The optical microfiber coupler (MFC) with a waist diameter of a few microns found applications in various types of sensing because of its high evanescent field [3]. By reducing the coupler waist diameter to few hundred nanometers, the evanescent field can be strongly enhanced leading to a higher sensitivity to any environmental change. The diameter also affects the number of supermodes supported by the coupler. When the diameter (d) of the optical fiber coupler is smaller than 1 μm, only the first and second supermodes exist and at d~200 nm only one supermode is supported at λ=1.5μm. In the multimode region at λ<1.1μm, the beating between two supermodes gives oscillations with high extinction ratios. In the cut-off region (1.1μm<λ<1.12μm), the two supermodes stop beating as one of the supermodes is weakly guided because of the small diameter of the coupler. This results in a spectral region with flat transmission over nearly 10 nm as shown in Fig. 1(a). Here, the nanofiber coupler (NFC), with a diameter (d) of ~200 nm is used as a high sensitivity refractive index (RI) sensor.

The NFC was fabricated by tapering and fusing two telecom fibers (Corning SMF-28) using the microheater brushing technique [4]. The length of the uniform waist region was 4 mm with a waist diameter of ~0.2 μm. In the refractive index measurement, the NFC coupling region was immersed in 100 ml of distilled water. Light from an incoherent white light source (Bentham, WLS100) was launched into port 1 of the NFC and the output of port 3 was connected to an optical spectrum analyzer (Yokogawa, AQ6370) to monitor in real time the transmission spectrum. The solution RI was increased by adding ethanol into the distilled water at a rate of 2 μl per step. The flat region in the transmission spectrum was monitored for changing ambient RI showing that the transmission wavelength of the NFC shifted to lower wavelengths for increasing ambient RI. To measure the RI sensitivity of the sensing device, the RI of an ethanol solution was calculated from the calibration curve of ethanol and water mixture as presented in Fig. 1(b) [5]. By fitting the relationship between the dip wavelength shift and the ambient RI with a linear fit, the calculated slope is -4.82×10^{-6} nm/RIU, providing an overall refractive index sensitivity of 4.82×10^{6} nm/RIU (Fig. 1(c)). This is the highest refractive index sensitivity reported for a glass fiber refractometric sensor.

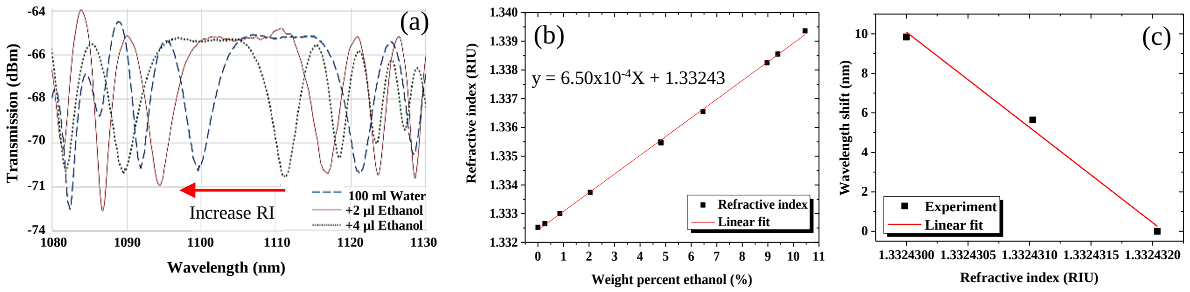

Fig. 1 (a) Change in transmission spectrum at cut-off region of NFC at different ambient refractive index, (b) calibration curve of the refractive index of the ethanol solution with weight percent of ethanol [5], (c) Relationship between wavelength shift and the RI value of the surrounding medium.

References

[1] Lee, K.J., et al., *Refractive index sensor based on a polymer fiber directional coupler for low index sensing.* Optics Express, 2014. **22**(14): p. 17497-17507.
[2] Wang, P., et al., *Enhanced Refractometer Based on Periodically Tapered Small Core Singlemode Fiber.* IEEE Sensors Journal, 2013. **13**(1): p. 180-185.
[3] Jung, Y., G. Brambilla, and D.J. Richardson, *Optical microfiber coupler for broadband single-mode operation.* Optics Express, 2009. **17**(7): p. 5273-5278.
[4] Brambilla, G., *Optical fibre nanowires and microwires: a review.* Journal of Optics, 2010. **12**(4): p. 043001.
[5] Troy, A., Scott Jr, *Refractive index of ethanol-water mixtures and density and refractive index of ethanol-water-ethyl ether mixtures.* Journal of Phys. Chem., 1946. **50**(5): p. 406-412.