# A Dual-Parameter Sensor Based on a No-Core Fiber and Fiber Bragg Grating

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***Abstract***

*A dual-parameter optical sensor is demonstrated by connecting together a fiber Bragg grating and a no-core fiber. The hybrid configuration permits the detection of the temperature and the external refractive index.*

**Introduction**

Optical fiber sensors have become potentially useful for a wide range of applications for measurements of various physical parameter, such as strain, temperature, and refractive index [1-3]. By means of the different optical properties of the FBG and LPG, strain, temperature, and refractive index can be measured simultaneously. For instance, using a combination of LPG and FBG elements for simultaneously measuring strain and temperature is presented [4]. In the publication [5], a hybrid LPG–FBG sensor was frabricated by UV writing in a D fiber that increased the sensitivities to external refractive index, and decreased the sensitivity to temperature after etching of the cladding with HF.

The multimode interference concept has been applied to a single-mode–multimode–single-mode structure (SMS), and the characteristics have been studied extensively [6-7]. The MMI-based displacement sensor was demonstrated giving a linear relationship between displacement of the end facet of the MMF and mirror with wavelength [8]. The SMS bandpass filter parameters such as center wavelength, bandwidth, and isolation are disscussed with their relationships to the MMF segment length, the geometries of SMF and MMF [9].

In this study we propose a novel dual-prameter fiber sensor based on connecting a fiber Bragg grating and hetero-core structured fiber which is composed of a short piece of no-core (coreless) fiber (NCF) sandwiched between two single-mode fibers (SMF). The refractive index and temperature of the environment surrounding the sensor can be detected by means of measuring the change in the transmission spectrum of NCF and FBG. The experimental results demostrate that this innovative sensor can test two different parameters including temperature and refractive index simultaneously.

**Principle**

The sensing head includes a FBG spliced to a hetero-core-structure fiber. The FBG in the sensing head is fabricated in hydrogen-loaded SMF by using the phase mask writing technique. The hetero-core-structure fiber consists of a NCF spliced between two SMFs without offset at the two interfaces as shown in Fig. 1.

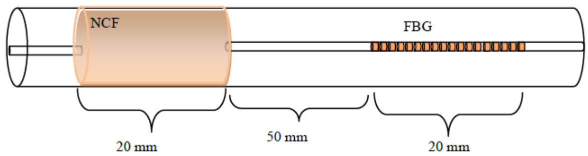


Fig. 1. Schematic diagram of a FBG connected in series with a NCF for the mode coupling.

The NCF is a high-precision pure silica fiber with an un-doped core, which was fabricated by the Prime Optical Fiber Corporation. When the incident light wave propagates along the axial direction of the NCF, the outer medium of the fiber with lower refractive index cladding layer facilitates total internal reflection due to Fresnel reflection. Thus, the section of NCF can be viewed as a MMF with an inner core of 125 μm which is surrounded by a lower-refractive-index outer environment.

In this hetero-core-structure device, the single mode light beam traveling in the SMF excites a few guided modes of the NCF, which can support several modes. The interference between the modes propagating in the NCF as in a multi-mode interference device (MMI) gives rise to the formation of self-images of the input field as a function of length in the NCF. The interference pattern is seen in the transmission spectrum of the sensor. The effective refractive index of the modes in the NCF is strongly influenced by the surrounding refractive index, and the loss-peak wavelength of the NCF changes proportionally. Due to the waveguide mode being confined to the core, the FBG's Bragg wavelengthy, $\lambda_B$ is insensitive to the ambient refractive index variation. The temperature sensitivity of the FBG is dependent on the coefficient of thermal expansion, $\alpha$ and thermo-optic coefficient, $\zeta$ and the effective index of the mode [10]. Therefore, the temperature, and index can be simultaneously obtained by means of the measurement of the wavelength shift ($\Delta\lambda$) of the Bragg wavelength and the NCF, that can be expressed as the following matrix:

$$\begin{bmatrix} \Delta\lambda_{NCF} \\ \Delta\lambda_{FBG} \end{bmatrix} = \begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix} \begin{bmatrix} \Delta n \\ \Delta T \end{bmatrix} \quad (1)$$

where $\Delta n$ is the variation of refractive index and $\Delta T$ is the variation of temperature. The coefficients of $M_{11}$ to $M_{22}$ can be determined by the wavelength shift of Bragg grating and NCF in the experiments by applying various temperature and indices to the sensor head.

**Experimental results**

Two broadband light sources are coupled to the fiber via the two input ports of a 3-dB fiber Y-coupler and the output end is spliced to the sensing head, and an optical spectrum analyzer (OSA) is utilized for monitoring the transmission spectrum from the sensing head. For refractive index measurements, the sensing head is placed on a wafer of silica where droplets of different-index oil are brought into contact with the sensing area to monitor the related shifts in the wavelength of the loss dips.

Fig. 2 shows the original transmission spectrum with two loss-dips seen with the new fiber sensor. For this experiment, the loss-dip wavelength of the NCF at 1468.36 nm and the FBG with the Bragg wavelength of 1550.14 nm are selected for demonstrating the sensing scheme.

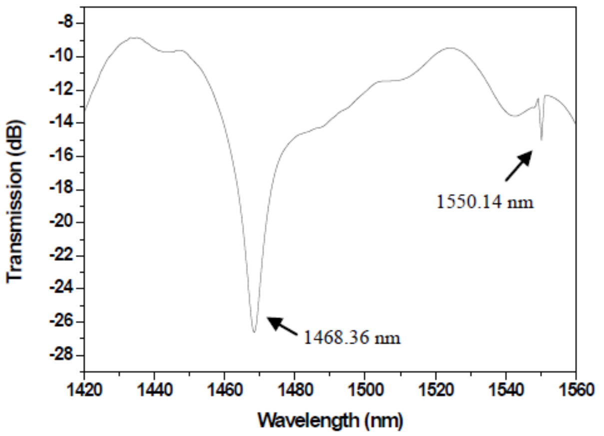


Fig. 2. The original transmission spectrum of MMI and FBG (n=1).

When the temperature is increased the loss-dip of the NCF and the transmission spectrum of the FBG are red shifted. Fig. 3 shows the relationship between the temperature and the wavelengths of the NCF and FBG; the sensitivity of NCF and FBG are 11.95 pm/$^o$C and 12.18 pm/$^o$C, respectively.

For the refractive index measurement, the loss-dip wavelength shifts toward longer wavelengths as the refractive index is increased. This phenomenon of loss-dips shift is attributed to the interference between the co-propagation core and the cladding modes in the NCF. Fig. 4 indicates the relationship between the the loss-dip wavelengths and the refractive indices varying from 1.3 to 1.44 RIU. The sensitivity of NCF is 82.598 nm/RIU and the RI sensitivity of FBG is 0 nm/RIU, which is due to the fundamental mode of FBG propagating in the core without being affected by the ambient refractive index changes on the outside of the fiber.

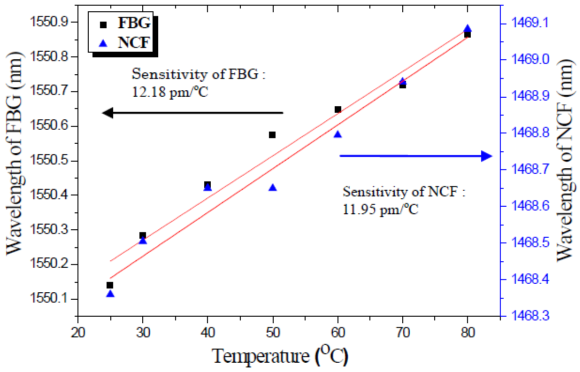


Fig. 3. The relationship between the temperature and the loss-dip wavelength shift of the NCF and the FBG with air as the surrounding medium and the FBG.

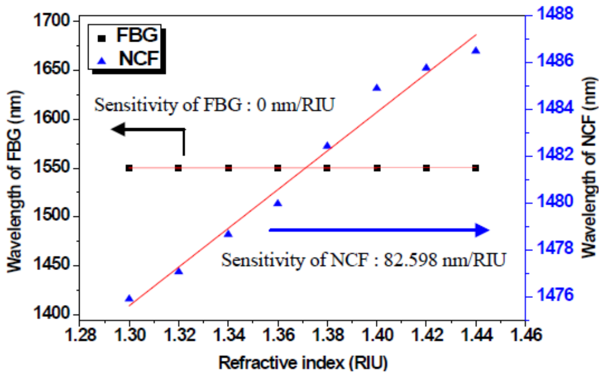


Fig. 4. The relationship between the refractive index and the loss-dip wavelength shift of NCF and FBG.

According to the above experimental results, it is clear the device has reasonablly good linearity for the wavelength shift induced by temperature and the SRI. The two unknown physical parameters ($\Delta n$ and $\Delta T$) in the transfer matrix of Eq. (1) can be obtained from the given wavelength shift of the FBG and the NCF as shown in Eq. (2).

$$\begin{bmatrix} \Delta\lambda_{NCF} \\ \Delta\lambda_{FBG} \end{bmatrix} = \begin{bmatrix} 82.598 & 0.01195 \\ 0 & 0.01218 \end{bmatrix} \begin{bmatrix} \Delta n \\ \Delta T \end{bmatrix} \quad (2)$$

These data allow the multi-parameter fiber sensors device to be used for sensing applications.

**Conclusions**

This paper demonstrates a sensing scheme with a fiber Bragg grating used in series with an NCF sandwiched between two SMFs. The measured wavelength shifts of the transmission function, both of the NCF and FBG, can be used to obtain the variation in the SRI as well as temperature. A transfer matrix allows the determination of the important parameters of the sensor for device design. Different refractive index materials coated on the surface of a no-core fiber would allow sensing in different ranges of refractive index of the surrounding environment, as well. The proposed scheme is a highly promising one and simple to design for a wide range of sensing applications.

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