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High stability Michelson refractometer based on an in-fiber interferometer followed with a Faraday rotator mirror

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ABSTRACT

We demonstrated an optical fiber refractive index (RI) sensor based on an in-fiber Michelson interferometer (MI), which is fabricated by splicing a Faraday rotator mirror (FRM) to a singlemode-thin core-singlemode (STS) optical fiber interferometer. From our experiments, it can be found that thus a FRM as reflector can eliminate the polarization random fluctuation of interference spectrum, which makes the sensor exhibit a high stability. Core to core splicing of thin core to standard single mode optical fibers and high reflectivity mirror of FRM can reduce the optical power loss and improve the fringe contrast of sensor spectrum. Both high stability and low power loss are very important in such kinds of reflection interference spectrum modulation and high resolution sensors. This sensor wavelength and intensity RI sensitivity is −48.858 nm/RIU and −6.548 dB/RIU at the liquid RI from 1.38 to 1.435, respectively. The temperature sensing performance of this sensor is also studied, the sensor wavelength versus temperature sensitivity is 66.18pm/ °C and intensity hardly change with temperature, which means that the temperature cross sensitivity can be eliminated when intensity modulated, and this sensor also has compact size, simple structure, easy fabrication and good repeatability.

1. Introduction

Optical fiber liquid refractive index (RI) sensors play a crucial role in chemical and biochemical sensing applications. In recent years, all fiber in line (in-fiber) Michelson refractometers attract more interests due to its high sensitivity, well established and immune to electromagnetic. Numerous in fiber Michelson refractometers are proposed. In 2008, Tian et al. proposed a RI sensor based on Michelson interferometer (MI) consisting of an abrupt taper in a single-mode fiber and a gold coating on the end of the fiber as a reflection mirror [1]. In the same year, they also presented an in fiber Michelson RI sensor by utilizing a core-offset single-mode fiber with gold coating on the end of the fiber [2]. After that, Liang et al. also proposed a structure by using an abrupt taper based on MI with a mirror in 2014 [3]. In 2011, Zhou et al. presented a MI liquid RI sensor which including an asymmetrical twin-core fiber and etched section with the end surface of the fiber as a mirror [4]. In 2013 and 2014, Rong et al. showed a RI sensor which was fabricated by singlemode-thin core-singlemode (STS) structure and singlemode-mutilmode-siglemode (SMS) structure with a thick silver film on the end of the fiber, respectively [5,6]. In 2014, Li et al. also described a RI sensor by using STS structure and fiber end-face refraction as a mirror [7]. In 2015, Zhou et al. raised a RI sensor was fabricated by STS structure with a core offset and the fiber ends are used to be the mirror [8]. However, there are two main problems of these existing in-fiber Michelson refractometers need to be solved. Power loss is the first one. In these sensors, mismatch in-fiber structure such as abrupt taper, SMS and core offset STS, etc., low reflectivity and broadband reflection mirrors such as fiber end surface and metal coated end are often used. These will inevitably lead to the reduction of the signal to noise ratio (SNR) of sensing spectra. The second problem is the stability of the interference spectrum. Spectral instability of these in-fiber MI is mainly derived from the random polarization of light in the sensor. This can lead to sensor output spectral intensity and phase random fluctua-

Abbreviations: RI, refractive index; MI, Michelson interferometer; FRM, Faraday rotator mirror; STS, singlemode-thin core-singlemode; SMS, singlemode-mutilmode-siglemode; SNR, signal to noise ratio; RIU, refractive index unit; TCF, thin core fiber; SMF, single mode fiber; BBS, broad band source; OSA, optical spectrum analyzer; ASE, amplified spontaneous emission.

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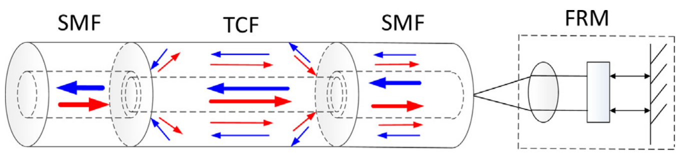

Fig. 1. Schematic diagram of STS followed with a FRM.

tions. In-fiber Michelson refractometer is a kind of high resolution optical fiber sensor, so high single to noise ration and high spectral stability are needed.

In this paper, we proposed and demonstrated a high stability Michelson refractometer based on an in-fiber interferometer followed with a Faraday rotator mirror (FRM). In order to reduce the power loss, an in-fiber STS (a thin core fiber spliced between two single mode fibers) structure is fabricated. In this structure, small core diameter difference of these two kinds of optical fibers and core to core splice method is used. A high reflectivity FRM with fiber tail is cascaded with the end of STS to eliminate the polarization random fluctuation and increase the single-noise ratio. The FRM is used to eliminate the polarization-induced fading of the all fiber Michelson interferometer beginning in 1991[9], because of it is also a key problem of that kinds of two beam sensors [10]. In this paper, the FRM is used in-fiber MI, for the first time to our knowledge. As a result, this sensor has a high stability and SNR with −48.858 nm/RIU and −6.548 dB/RIU RI sensitivity, respectively. Temperature sensitivity of this sensor is 66.18pm/ °C. In temperature sensing experiment, it is also found that sensor spectrum intensity hardly change with temperature, which can be used to eliminate the temperature cross sensitivity when the intensity is sensitive to a measuring physical parameter.

2. Principle

The schematic diagram of the STS followed with a FRM is set up in Fig. 1. This in-fiber structure is fabricated by splicing a 30 mm long TCF with 4.5/125 μm core/cladding diameter between two standard SMFs. In order to reduce the power loss, core to core splice method is used. Through the lead-in SMF, the light launched. Due to the core mismatch, at first SMF and TCF splice point, the light power is divided into two parts, one part still transmit in the fiber core, and another part of the light power couple to the cladding and several cladding modes is excited. The two part of light will be reflected at the high reflection mirror of the FRM and then re-couple into the core of the lead-in SMF at the mismatch spliced joint, resulting in Michelson interference in the core of the SMF.

The FRM working process is shown in Fig. 2. The light transmit through the Faraday revolver with polarization direction rotating angle 45° and reflected by the high reflection material, then the light transmit through the Faraday revolver again and its polarization direction also rotate 45° again. Consequently, the FRM make the input and output light have a mutually perpendicular polarization direction in order to eliminate the polarization disturbance of the interference spectrum. Since low birefringence of SMF, the

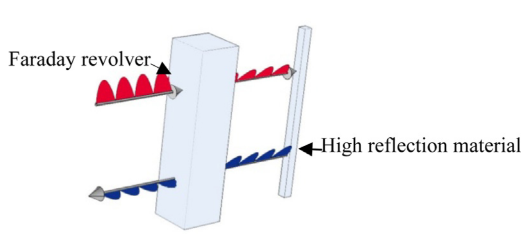

Fig. 2. Schematic diagram of FRM.

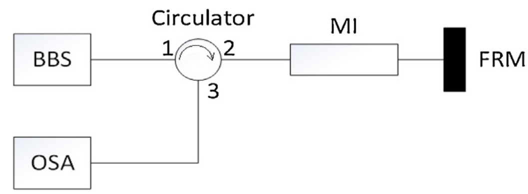

Fig. 3. Schematic diagram of experimental setup.

transmission light can be considered as vector angles of x axis and y axis polarization direction in the Cartesian coordinate system and its Jones matrix can be expressed as

$$J_0 = \begin{bmatrix} A_x \exp\left(i\delta_x\right) \\ A_y \exp\left(i\delta_y\right) \end{bmatrix} \quad (1)$$

where A_x and A_y is the light amplitude and δ_x and δ_y are phase angle of wave vector of x and y polarization direction, respectively. The Jones matrix of FRM is

$$T = \alpha\frac{1}{2}\begin{pmatrix} -\cos 2\theta & -\sin 2\theta \\ -\sin 2\theta & \cos 2\theta \end{pmatrix} = \alpha\frac{1}{2}\begin{pmatrix} 0 & -1 \\ -1 & 0 \end{pmatrix} \quad (2)$$

where α is the polarized light attenuation coefficient of FRM. θ is rotation angle of FRM equal to 45°in our experiments.

The light is reflected by the FRM, the Jones matrix of core and cladding light after reflection can be expressed as

$$E_{core} = \begin{bmatrix} E_{xcore} \\ E_{ycore} \end{bmatrix} = -\alpha\frac{1}{2}\begin{bmatrix} A_{ycore}\exp\left(i\delta_{ycore}\right) \\ A_{xcore}\exp\left(i\delta_{xcore}\right) \end{bmatrix} \exp\left(i\omega\tau\right) \quad (3)$$

$$E^m_{clad} = [\begin{matrix} E^m{}_{xclad} \\ E^m{}_{yclad} \end{matrix}] = -\alpha\frac{1}{2}[\begin{matrix} A^m{}_{yclad}\exp(i\delta^m{}_{yclad}) \\ A^m{}_{xclad}\exp(i\delta^m{}_{xclad}) \end{matrix}]\exp(i\omega\tau + \phi^m) \quad (4)$$

where,

E_{core},

E_{clad} is light field in fiber core and cladding, respectively. m is cladding mode order. $\phi^m$is the phase delay between the core mode and the mth cladding mode. ω is angular frequency and τ is transmission time of light.

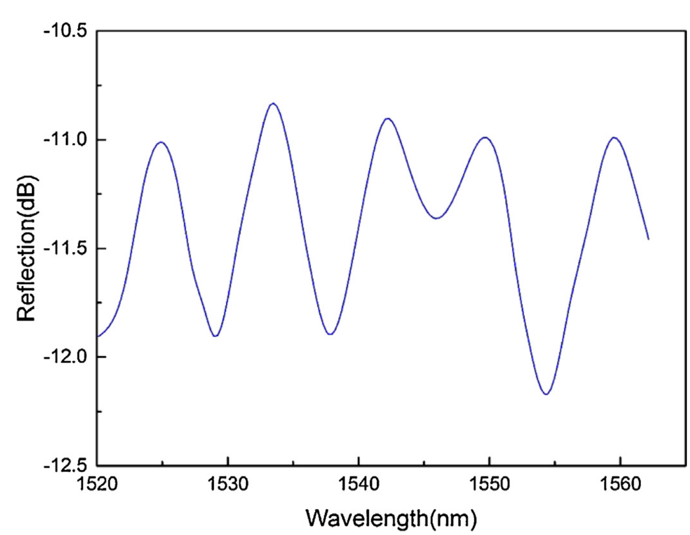

Fig. 4. Spectrum of MI sensor in the air.