Optics Communications 384 (2017) 107–110

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

In-fiber rectangular air fabry-perot strain sensor based on high-precision fiber cutting platform

Yong Zhao*, Mao-qing Chen, Ri-qing Lv, Feng Xia

College of Information Science and Engineering, Northeastern University, Shenyang 110819, China

ARTICLE INFO

Keywords:
Fiber-optic sensors
Fabry-Perot interferometer
Fiber cutting platform
Hollow-core fiber

ABSTRACT

An in-fiber rectangular air Fabry-Perot (FP) strain sensor based on a high-precision fiber cutting platform (HFCP) is proposed. The HFCP consisting of a CCD notation system, a micro-displacement platform, and an optical fiber cleaver can be used to precisely control the length of FP cavity. The microcavity of FP (even only tens of microns) with smooth reflective surface can be realized easily by using this system. The FP structures with different cavity lengths have been fabricated in this paper. Simulation and experimental results prove that the shorter length the cavity has, the higher strain sensitivity and the larger free spectral range (FSR) the sensor obtains. The strain sensitivity and FSR of in-fiber rectangular air FP sensor with a cavity length of 35 μm can be up to 2.23 pm/με and 28.5 nm respectively. Moreover, the proposed FP strain sensor has a negligible temperature sensitivity in the range of 25–75 °C. It is anticipated that such easy making, compact and low-cost fiber-optic strain sensors could find important applications in practice.

1. Introduction

Various types of fiber optic strain sensors have been studied for the health monitoring of the building, bridge, dam, including photonic crystal fiber (PCF) devices [1], fiber Bragg gratings (FBGs) [2] and Mach-Zehnder interferometers [3,4] and so on. The strain sensitivity is typically less than 1.2 pm/με for an FBG [5,6], about 5.0 pm/με for a fiber Mach-Zehnder interferometer [7,8], however, the cross-sensitivity between strain and temperature is hard to be overcome in these sensor schemes. As an alternative to these existing fiber optic strain sensors, in-fiber Fabry-Perot strain sensors are particularly attractive due to a range of unique advantages, such as low cost, high sensitivity, compact size, and low temperature cross-sensitivity [9–14]. S. Liu et al. demonstrated a highly-sensitive strain sensor based on an in-fiber Fabry-Perot interferometer (FPI) with an air cavity, which was created by splicing together two sections of standard single-mode fibers. Moreover, such a strain sensor has a very low temperature sensitivity of 1.1 pm/°C, which reducing the cross sensitivity between tensile strain and temperature [9]. Zhang et al. presented a novel fiber Fabry-Perot sensor based on polyimide diaphragm, and when salinity increases from 0 mol/L to 5.47 mol/L, the maximum sensitivity can be 0.45 nm/(mol/L) [10]. Several complex methods have been proposed to fabricate in-fiber air Fabry-Perot interferometers by use of a Micro Electro Mechanical System (MEMS) diaphragm as the reflecting surface [11,12], direct micromachining using femtosecond laser or CO_2 laser [13], and assisted chemical etching [14]. The above-mentioned fabricating methods usually require specially treated coating materials (TiO_2 or photonic-crystal membrane), high-cost micromachining instrument, or/and hazardous acid corrosion treatment. In addition, these methods are very difficult or complex to control the length of the FP cavity, and the microcavity of FP is a common pursuit.

In this paper, a novel and low-cost method of fabricating Fabry-Perot cavity is presented. The microcavity of FP (even only tens of microns) with smooth reflective surface can be realized easily and the length of FP cavity can also be controlled with the minimum step length of 1 μm. In-fiber rectangular air FP structures with different cavity lengths have been fabricated in this paper, and the strain sensitivities and FSRs of these FP cavities are compared and analyzed. In addition, the experimental results show that the in-fiber rectangular air FP strain sensor has a negligible temperature sensitivity in the range of 25–75 °C.

2. Preparation and principle

2.1. Preparation of FP microcavity

In-fiber FP cavity is an axisymmetric cylinder-structure with the fiber core. The two reflective surfaces are parallel to the axial-vertical plane, and the internal material of microcavity is air. In-fiber FP cavity with shorter cavity length, which has higher strain sensitivity and

* Corresponding author.
E-mail address: zhaoyong@ise.neu.edu.cn (Y. Zhao).

http://dx.doi.org/10.1016/j.optcom.2016.10.005
Received 10 July 2016; Received in revised form 3 October 2016; Accepted 3 October 2016
Available online 17 October 2016
0030-4018/

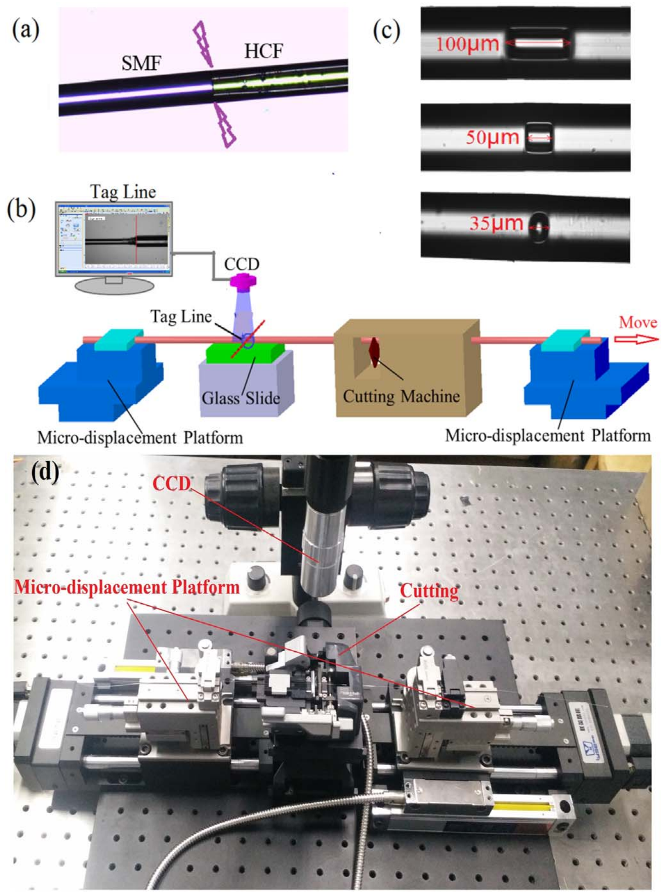

Fig. 1. Preparation process of in-fiber air FP cavity. (a) Welding process of SMF-HCF (b) Cutting process base on HFCP (c) Physical map of FP (d) High-precision fiber cutting platform.

Table 1
Parameter table of in-fiber rectangular air FP structure model.

Parameter	Core diameter	Cladding diameter	Core refractive index	Cladding refractive index	Air refractive index
Value	8.3 μm	125 μm	1.4679	1.4613	1

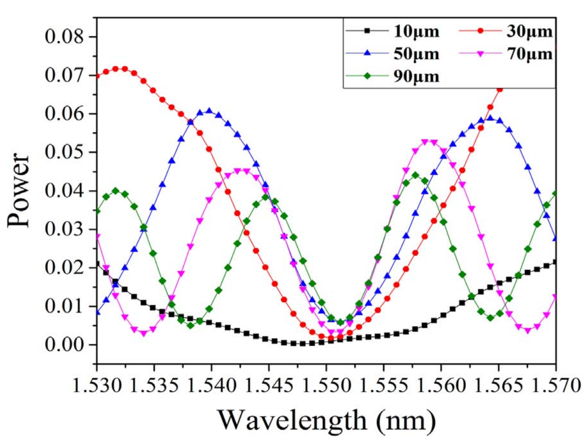

Fig. 2. Interference spectrum curve contrast. (Wavelength range is 1530–1570 nm; the model parameter is: the height (H) of the FP cavity is 50 μm, the cavity length L is 10–90 μm.).

bigger FSR, has become a long-term goal for fiber FP sensing. In this paper, the preparation technology of in-fiber rectangular air FP strain sensor based on high-precision fiber cutting platform is proposed, and the microcavity of FP (even only tens micron) with smooth reflective surface can be realized easily. Compared with femtosecond laser [13] and CO_2 laser machining [15], the fabrication method shows the merits of low cost and high fabrication efficiency. Fig. 1 shows the preparation process of in-fiber air FP cavity.

To fabricate the proposed in-fiber rectangular air FP cavity, a conventional fusion splicer (Fitel, S178) and a mechanical fiber cleaver (Fitel, S325) are required The fiber structure under consideration consists of an input SMF (Corning SMF28), a hollow-core fiber (HCF) section with a diameter of 50/125 μm (hole/outerclad), and an output SMF. Fig. 1(a) and (c) are the photographs of fusion between SMF and HCF, and it is easy to find that there is no collapse area in the fusion point, which is achieved by adjusting splicing parameters. Parameter settings are as follows: discharge time of 400 ms; discharge intensity of 100 unit; first push distance of 8 μm, then stretch distance of 3 μm; the end face spacing between SMF and HCF of 5 μm.

Fig. 1(b) shows the fiber cutting process based on HFCP: Firstly, optical fiber cleaver, micro displacement platform and CCD object stage are fixed on the electric rail, then a segment of commercially available SMF is placed in the cleaving system and cleaved. Secondly, the SMF is removed from the cleaving system for the no-collapse fusion splicing with a segment of HCF by the fusion splicer (Fitel, S178). After splicing, the SMF-HCF structure is placed back in the same position of the cleaving system. Both ends of the structure are fixed on micro displacement platform. CCD is used for real-time monitoring of optical fiber movement, where the initial reference line is the node of fiber coating layer. Then, the SMF-HCF structure is precisely moved by the micro displacement platform in order to get the desired length of HCF segment. Finally, the SMF-HCF structure is cleaved and spliced with another segment of SMF to form the in-fiber FP strain sensing structure. Fig. 1(c) shows the photographs of the fabricated device, in which the lengths of the middle HCF segments are 35 μm, 50 μm, 100 μm. Fig. 1(d) is practicality picture of high-precision optical fiber cutting platform, and the minimum step of micro displacement platform is 1 μm.

2.2. Principle of sensing

The traditional Fabry-Perot interference principle is based on the theory of parallel plate multi-beam interference. The derived condition of theory is: (1) Consider the two reflective surfaces of the Fabry-Perot cavity as strictly parallel; (2) Ignore the light transmission loss and the absorption loss of reflective surface. But actual production of FP has inevitable interference factors, such as face tilt, weld micro collapse, etc. Under this condition, the multi-beam interference analysis on this structure is so complex. Research shows that the interface reflectivity between optical fiber and air is less than 0.04, so we can use double beam interference principle to simply analyze the sensor. The refractive index of air is 1. The interference light intensity of the sensor reflectance spectra is $I_r(\lambda)$:

$$I_r(\lambda) = (R_1' + R_2' - 2\sqrt{R_1' R_2'}\cos\frac{4\pi L}{\lambda})\cdot I_0(\lambda) \tag{1}$$

The maximum value of $I_r(\lambda)$ is $I_{\max}$:

$$I_{\max} = (R_1' + R_2' + 2\sqrt{R_1' R_2'})\cdot I_0(\lambda) \tag{2}$$

The interference fringe contrast of the sensor reflection spectrum is V:

$$V = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}} = \frac{2\cdot\sqrt{R_1' R_2'}}{R_1' + R_2'} \tag{3}$$

In the formula, R_1' is an effective reflectivity of the reflective surface