Sensors and Actuators A 213 (2014) 89–93

Contents lists available at ScienceDirect

Sensors and Actuators A: Physical

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

Compact and wide range polarimetric strain sensor based on polarization-maintaining photonic crystal fiber

Tae Kyu Noh [a,b], Uh-Chan Ryu [c], Yong Wook Lee [a,b,*]

[a] School of Electrical Engineering, Pukyong National University, Yongso-ro 45, Nam-gu, Busan 608-737, Korea
[b] Interdisciplinary Program of Marine-Bio, Electrical & Mechanical Engineering, Pukyong National University, Yongso-ro 45, Nam-gu, Busan 608-737, Korea
[c] Specialized Graduate School of Science and Technology Convergence, Pukyong National University, Sinseon-ro 365, Nam-gu, Busan 608-739, Korea

ARTICLE INFO

Article history:
Received 7 November 2013
Received in revised form 23 March 2014
Accepted 24 March 2014
Available online 6 April 2014

Keywords:
Optical fiber sensor
Strain sensor
Polarization-maintaining photonic crystal fiber
Sagnac birefringence loop

ABSTRACT

We demonstrated a polarimetric fiber strain sensor based on Sagnac birefringence interferometer, which had a compact sensing element and wide measurement range. A short polarization-maintaining photonic crystal fiber (PM-PCF), the length of which was ~2.0 cm, was employed as a sensor head. The length of the PM-PCF was reduced approximately by half, compared with the shortest one in the previous works. In particular, the measurement range was extended to 16 mε with a strain sensitivity of ~1.01 pm/με comparable to those of fiber Bragg gratings. Furthermore, the dependence of strain sensitivity on the wavelength shift of fringe dips was investigated to facilitate the practical use of the proposed sensor.

1. Introduction

Photonic crystal fibers (PCFs) presenting a new concept of the optical waveguide have brought many changes in the area of optical fiber sensors, and various optical fiber sensors with new schemes and functions have been proposed using unique waveguide properties of PCFs [1,2]. Due to its core and cladding composed of a single material like pure silica, PCF-based sensors have extremely low thermal dependence, which reduces the demand of additional temperature compensation. Using this superior thermal property of PCFs, many temperature-insensitive strain sensors have been proposed through the implementation of a fiber Mach-Zehnder or a Fabry-Perot interferometer [3–6]. In particular, reports on polarimetric fiber strain sensors (PFSSs) incorporating the polarization-maintaining PCF (PM-PCF), which can construct a Sagnac birefringence interferometer (SBI) [7] frequently used as a sensing element or a demodulation filter for some advantages such as simple design, high sensitivity, and polarization independence, are substantially growing in recent years [8–11].

By employing an 8.6-cm-long PM-PCF as a sensor head, the first PFSS was proposed in 2007, showing a strain sensitivity of ~0.23 pm/με and a measurement range of 0–32 mε [8]. In the same year, a 38-cm-long PM-PCF was used for a PFSS, revealing a strain sensitivity of ~1.21 pm/με and a measurement range of 0–1.4 mε [9]. In 2009, another PFSS with a strain sensitivity of ~1.30 pm/με and a measurement range of 0–1.6 mε was embodied using the polarization interference structure based on a 13.6-cm-long PM-PCF sandwiched by two linear polarizers [10]. Recently, we demonstrated a PFSS with a 3.9-cm-long PM-PCF, achieving a strain sensitivity of ~2.34 pm/με and a measurement range of 0–10 mε [11]. In addition, an intensity-based PFSS utilized a 13.6-cm-long PM-PCF for creating polarization interference [12], and a wavelength-encoded strain sensor employed a 9.2-cm-long PCF for realizing a Mach-Zehnder interferometer [6].

In comparison with fiber gratings (whose lengths are generally less than 3 cm), the interesting merit of the PFSSs based on PM-PCFs is a wide measurement range, but its demerit is a long sensor head that can limit the scope of sensing applications. The long sensor head may hinder localized sensing, let alone sensor compactness, and is apt to be exposed to external disturbances such as temperature or pressure changes. In this paper, we report a temperature-insensitive PFSS based on an SBI composed of PM-PCF, which has a compact sensing element and a wide measurement range. A PM-PCF as a sensor head was reduced to as short as ~2.0 cm, that is, the length of the PM-PCF was reduced

* Corresponding author at: School of Electrical Engineering, Pukyong National University, Yongso-ro 45, Nam-gu, Busan 608-737, Korea. Tel.: +82 51 629 6323; fax: +82 51 629 6305.
E-mail address: yongwook@pknu.ac.kr (Y.W. Lee).

http://dx.doi.org/10.1016/j.sna.2014.03.034
0924-4247/

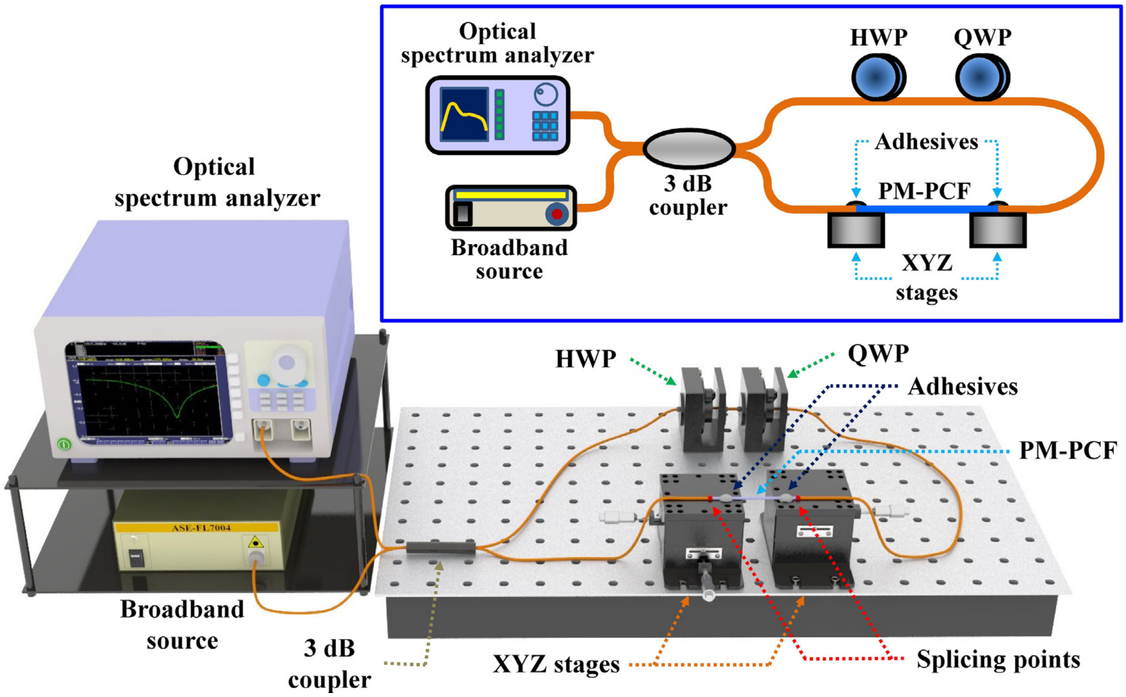

Fig. 1. Experimental setup of proposed polarimetric fiber strain sensor. An inset shows the schematic diagram of the proposed sensor.

approximately by half, compared with the shortest one used in the previous works. To the best of our belief, the proposed sensor has the shortest sensing element among the PFSSs based on the PM-PCF. In particular, the measurement range was extended to 16 mε with a strain sensitivity of ∼1.01 pm/με comparable to those of fiber Bragg gratings. Furthermore, the dependence of the strain sensitivity on the absolute wavelength shift of fringe dips of the SBI was investigated to facilitate the practical use of the proposed sensor.

2. Experimental preparation

Fig. 1 shows the experimental setup of the proposed PFSS, and its schematic diagram is shown in the inset. The proposed sensor system is composed of a broadband light source (Fiberlabs FL7004), an optical spectrum analyzer (Yokogawa AQ6370 C), a 3 dB fiber coupler, a fiber-pigtailed half-wave plate (HWP), a fiber-pigtailed quarter-wave plate (QWP), an XYZ translation stage, and a 2-cm-long PM-PCF (Crystal Fibre). The diameters of the small and the large holes of the PM-PCF used in the experiment are typically 2.2 and 4.5 μm, respectively, with the pitch (spacing between holes) of 4.4 μm, and the diameter of the entire holey region is 40 μm, as shown in the inset of Fig. 2(a). The beat length of the PM-PCF is less than 4 mm, and its temperature coefficient of birefringence is up to 30 times less than that of other conventional polarization-maintaining fibers. Both ends of the PM-PCF were connected to single-mode fibers (SMFs) by using an arc fusion splicer (Fujikura FSM-60S), and the splicing loss was measured as ∼5.50 dB including losses at two splicing points. The splicing loss is relatively large compared with the conventional fiber because of the mismatch of the mode field diameter and the numerical aperture between the SMF and the PM-PCF [13] and the loss of the PM-PCF itself caused by the air hole collapse phenomenon during the splicing process. Except for theoretically induced loss such as one resulting from the mismatch of the mode field diameter, the splicing loss can be diminished through the minimization of the air hole collapse phenomenon. As can be seen from Fig. 1, the two splicing points at both ends of the PM-PCF were fixed at each XYZ translation stage with

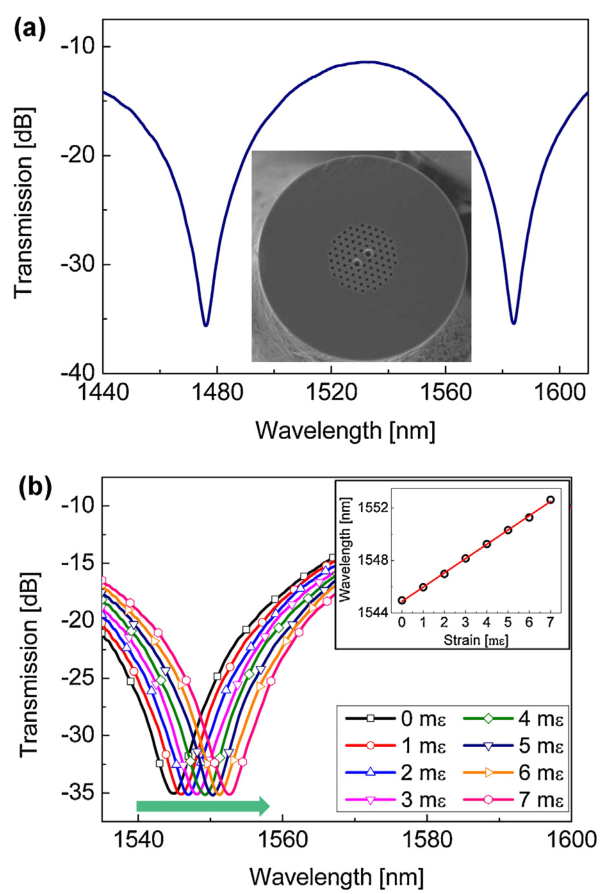

Fig. 2. (a) Transmission spectrum of fabricated SBI shown in Fig. 1 and (b) strain response of proposed sensor measured for a variety of applied strain ranging from 0 to 7 mε. The inset of (a) shows the cross-section image of the PM-PCF. The inset of (b) shows the wavelength shift of the transmission dip with respect to the applied strain, indicating the linearity of the strain response.