In-Line Fiber-Optic Fabry-Perot Ultrasound Sensor Formed by Hollow-core Photonic-Crystal Fiber

Yun-Jiang Rao¹,², Wei Wang¹, Tao Zhu¹,², Dewen Duan¹

¹Key Laboratory of Optoelectronic Technology and Systems (Education Ministry of China), Chongqing University, Chongqing 400044
²Key Lab of Broadband Optical Fiber Transmission & Communication Networks (Education Ministry of China), University of Electronic Science & Technology of China, Chengdu, Sichuan 610054, China
E-mail: yjracc@cqu.edu.cn or zhutao@cqu.edu.cn

Abstract- An in-line fiber-optic Fabry-Perot sensor formed by hollow-core photonic crystal fiber is used for ultrasound detection. The experimental results show that the wavelength-pressure sensitivity is \(-7.29 \times 10^3\) nm/MPa, which is about twice more than that of FBG.

I. Introduction

Fiber-optic sensors have been widely studied and used because they have many inherent advantages over conventional electrical sensors, such as immunity to electromagnetic interference, capability of responding to a wide variety of measurands, high resolution, small size, etc[1]. Among various types of optical fiber sensors, the fiber-optic Fabry-Perot (F-P) interferometric sensor is an important branch[2,3], which have been widely utilized for health monitoring of composite materials, large civil engineering structures (e.g. bridges and dams), space spacecrafts, and airplanes, etc. In this paper, we report an in-line fiber-optic F-P (ILFP) sensor formed by hollow-core photonic crystal fiber (HCPCF) used for detection of ultrasound. Such a sensor has low temperature sensitivity and high resolution when compared with fiber Bragg gratings (FBG)[4]. Also, this in-line sensor is much smaller and more stable than those based on fiber-optic intrinsic interferometers such as Michelson interferometers and Mach-Zehnder interferometers[5,6].

II. Sensor Fabrication and Principle

The HCPCF-ILFP[7] is formed by splicing single mode fibers (Corning: SMF-28) to a HCPCF (Blaze Photonics: HC-1550) with a core diameter of 10.9µm. The configuration of the sensor is shown in Fig. 1.

A cleaved segment of HCPCF is respectively fused to two cleaved single mode fibers using commercial electric-arc fusion splicing machine. The ratio of the reflected power \(P_r\) to the incident power \(P_i\) for a F-P interferometer with reflectivity, \(R\), is given by[8]

\[
\frac{P_r}{P_i} = \frac{2R(1 - \cos \phi)}{1 + R^2 - 2R \cos \phi}
\]

where \(\phi\) is the round trip phase shift of the laser light inside the cavity, and is given by

\[
\phi = \frac{4\pi nL}{\lambda}
\]

where \(L\) is the length of the cavity, \(n\) is the refractive index and \(\lambda\) is the free space wavelength of the light. If \(R \ll 1\), Eq.(1) can be approximated given by

\[
\frac{P_r}{P_i} = 2R(1 - \cos \phi)
\]

When the ultrasound is applied, \(\phi\) in Eq.(3) is modulated by the change of refractive index \(n\) via the elasto-optic effect.
and the cavity length L due to the mechanical effect, inducing the wavelength shift of the interferometric spectrum.

III. Experimental Results and Discussion

The experimental ultrasound detection system in a water tank is shown in Fig. 3. The ultrasound is generated by a transducer driven by an ultrasonic generator, and the ultrasound head can be vertically or horizontally shifted. The optical system is composed of a tunable laser (TL, Ando AQ4321D), a fiber coupler, the ILFP ultrasound sensor, and the photodetector (PD, New Focus: 2053). The sensor was mounted on the set-up with a screw which can make the sensor move up and down. The optical phase change of the interferometric signal induced by the ultrasound was transformed to an intensity change via tuning the wavelength of the TL to the position of the linear part of the interferometric fringe. The obtained electrical signal from the PD was displayed on a digital oscilloscope.

![Diagram of experimental setup](image)

**Fig. 3. Schematic diagram of the experimental set-up**

It is obvious from Fig. 6 that the sensitivity of HCPCF-ILFP sensor is twice higher than that of FBG. The wavelength-pressure sensitivity of the bare FBG is $3.48 \times 10^{-3}$ nm/MPa, while the wavelength-pressure sensitivity of the HCPCF-ILFP is $7.29 \times 10^{-3}$ nm/MPa. Compared with FBG and Fabry-Perot cavity with a solid core, the HCPCF-ILFP has a hollow interferometric cavity in which air is fully filled. The reasons for the significant enhancement in the ultrasound-detection sensitivity by using the HCPCF-ILFP may be: (1) as the acoustic impedance of silica is much larger than that of air, the interferometric cavity-length would vary much more due to stronger sound-pressure induced; (2) the ultrasound has an interaction with the air in the interferometric cavity when a part of ultrasound transmits into the air cavity. In our preliminary analysis, the first one is the main reason. More detailed study is under way.
IV Conclusions

An HCPCF-ILFP sensor is first used to detect ultrasound. The experimental result shows the HCPCF-ILFP sensor is approximately twice more sensitive than that of FBG.

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References