An electric field tunable switch with liquid crystal infiltrated photonic crystal fiber grating*

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The nematic liquid crystal (NLC) infiltrated photonic crystal fiber (PCF) used as a switch modulated by electric field is demonstrated. The switch consists of the infiltrated solid core PCF into which Bragg gratings are written. It is confirmed that the switch can achieve an accurate operation through measuring the reflected light with the change of electric field intensity from 1.4 kVrms/mm to 2.1 kVrms/mm. When the electric field intensity exceeds the threshold, the change of only 0.01 kVrms/mm can cause the wavelength shift of 1 nm. It is approved that the switch with such a structure provides a high sensitivity. The reflection peak is stabilized at about 15 dB which is high enough to separate from the factors such as system noise and error, and it can improve the control precision.

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Photonic crystal fibers (PCFs) are micro-structured optical fibers, which are characterized by an arrangement of micron-sized air holes along the length of the fiber. Infiltrating the air holes with liquid crystal (LC) can convert an initial index guiding PCF to a band gap guiding PCF[1]. Fiber Bragg grating (FBG) is a new type of passive optical component, which is based on the periodical distribution of refraction index in fiber core. Commonly, the periodical refraction index is fabricated by the fiber photosensitivity, and the periodical light intensity oscillation is formed by interference of UV light. The reflection and transmission peak wavelengths are related to the period and the core index of the FBG. The changes for nematic liquid crystal (NLC) molecular orientation are produced by environmental temperature, external electric field, magnetic field and stress[2,3]. Optical properties of liquid crystal infiltrated PCFs can be tuned thermally, electrically and optically[4,5]. Because of the large size and the great power loss, the traditional optical switch cannot achieve accurate switching effect. But optical switch realizes switching through its own structure, so it can get higher sensitivity and accuracy. Compared with the transmission devices, the research of the reflection devices with the Bragg gratings is rare[6]. In this paper, a reflection-type switch with liquid crystal infiltrated photonic crystal fiber grating is presented. In experiment, we connect the source and the optical power meter with an optical fiber circulator, and provide electric field through the parallel electrodes. By measuring the shift of the reflected light wavelength, the effects of electric field on the switch are achieved.

The structure of the infiltrated solid core PCF with Bragg gratings is shown in Fig.1. The fiber used in the experiment is LMA-10, which is a large mode field solid core PCF structure, and the parameters are set as follows: air hole diameter is 1.8 μm, pitch of holes is 6.67 μm, and SiO_2 refractive index is 1.444. Using the external interference method, a Bragg grating with period of 517 nm is written in the fiber[7]. Infiltrated NCL type is P0616A. Owing to the mode field mismatch between PCF and single-mode fiber, fusing them together forcibly would cause great splice loss[8]. So we take the fiber alignment stages instead of fusing to reduce the coupling loss. As shown in Fig.2, operating at sealed negative pressure, NCL is infiltrated in FBG for about 19 mm at room temperature. Without any extra electric field, the molecular arrangement of NLC is parallel to the axis of optical fiber as shown in Fig.3.

The experimental setup is shown in Fig.4. Two parallel plates connected to a voltage source provide an electric

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field for the switch. The output voltage source frequency is set as 1 kHz, and the direction is vertical to the fiber axis. Use HP8163A as the broadband light source, and the output wavelength ranges from 1520 nm to 1580 nm. Due to the infiltrated high refractive index NCL, an electric field causes the molecules of NCL to distribute in a way which alters the optical properties.

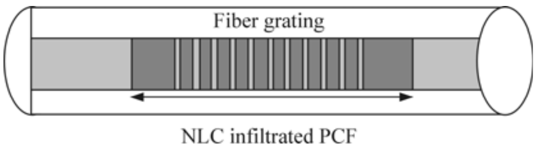


Fig.1 Schematic diagram of the switch with NLC infiltrated PCF

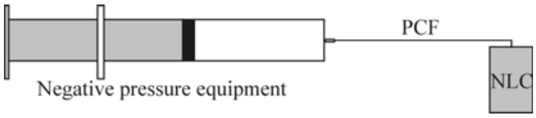


Fig.2 Equipment with negative pressure for infiltrating LC into PCF

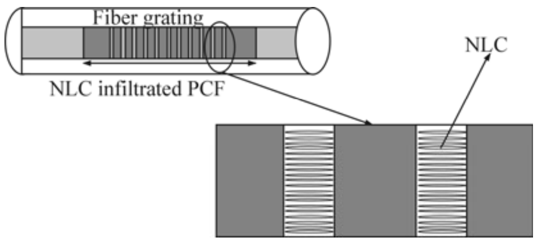


Fig.3 Enlarged diagram of NCL in grating

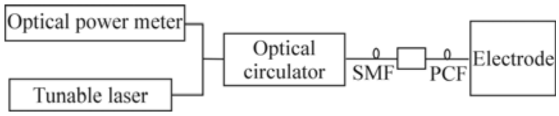
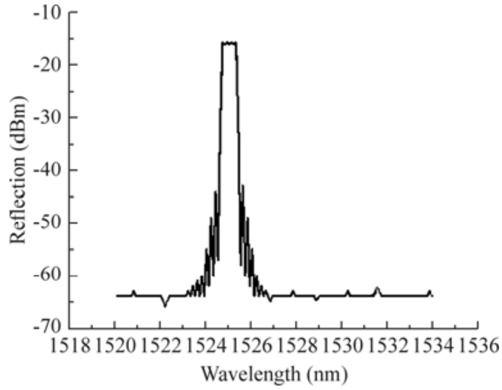


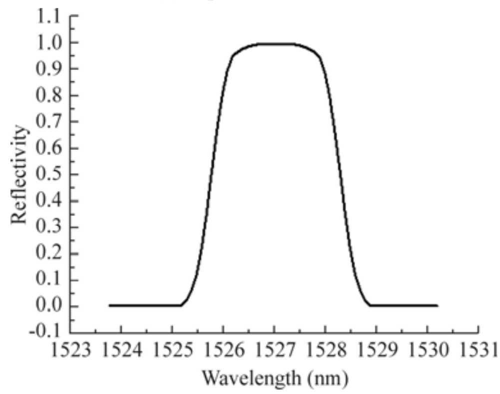
Fig.4 Schematic diagram of the experimental setup

Fig.5(a) and (b) show the relation of reflection and wavelength without electric field in experiment and simulation, respectively. Compared with the theoretically calculated value shown in Fig.5(b), the measured resonant wavelength shown in Fig.5(a) moves to the shorter wavelength gradually. It approximately shifts 2 nm from 1527 nm to 1525 nm. It is a blue shift caused by the smaller effective refractive index of PCF cladding[9]. In addition, there are some phugoid oscillations on both sides of the resonant peak in experimental result. On one hand, it is caused by Fabry-Perot reflection effect formed by refractive index abruption of grating. On the other hand, with the special structure of PCF cladding, it is much easier to inspire the counter-directional coupling of high order modes in cladding, and finally leads to lots of reflection peak side lobes[10-14].

Fig.6 shows the relation of reflection and wavelength with extra electric field of 2 kVrms/mm. Comparing Fig.5(a) with Fig.6, it is suggested that the change of electric field can cause the drift of reflection peak. It provides a possible way to realize dynamic switching.



(a) Experimental result



(b) Simulation result

Fig.5 The relation of reflection and wavelength without electric field

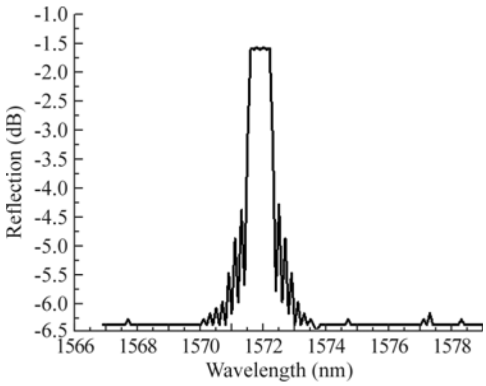


Fig.6 The relation of reflection and wavelength with electric field of 2 kVrms/mm

The relation of reflection wavelength and electric field intensity from 0 kVrms/mm to 3 kVrms/mm is shown in Fig.7. It is shown that the reflection peak has no significant deviation in electric field with intensity of 0–1.4 kVrms/mm. It means that the threshold electric field intensity of P0616A is near 1.4 kVrms/mm. The electric field intensities below the threshold can not cause the change of molecular orientation, so it does not cause the light intensity change. When the electric field intensity is from 1.4 kVrms/mm to 2.1 kVrms/mm, the reflection peak shifts with the increase of electric field intensity. It can be explained by that when the electric field values exceed the threshold, the long axis of NLC molecules deflects to the direction of electric field. It results in that the reflection peak shifts to the longer wavelength. When the electric field intensity exceeds 2.1 kVrms/mm, the reflection signal reduces to 0 drastically. It is due to that the reflection peak wavelength is beyond the light source measurement range.

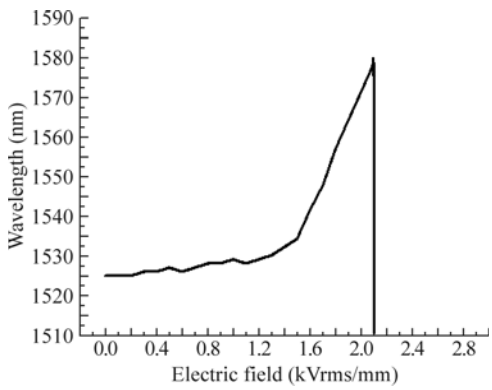


Fig.7 The relation of reflection wavelength and electric field intensity

Fig.8 shows the relation of reflection and wavelength with intensities of 1.71 kVrms/mm, 1.72 kVrms/mm and 1.73 kVrms/mm. It can be seen from Fig.8 that when the electric field intensity exceeds the threshold, the change of only 0.01 kVrms/mm can cause the wavelength change of 1 nm. It approves that the switch with such a structure can provide high sensitivity. The reflection peak is stabilized at about 15 dB which is high enough to separate from the factors such as system noise and error, and it can improve the control precision[13-15].

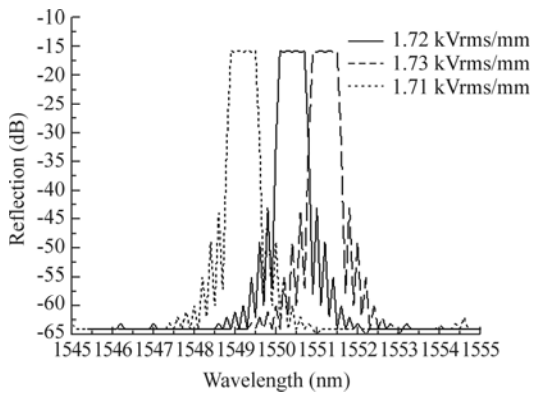


Fig.8 The relation of reflection and wavelength with electric field intensities of 1.71 kVrms/mm, 1.72 kVrms/mm and 1.73 kVrms/mm

An electric field tunable switch with NLC infiltrated photonic crystal fiber grating is designed. The switch is based on an infiltrated PCF with Bragg gratings. At room temperature, the relationship between reflection peak and electric field intensity is obtained. We can get from the results that when the electric field intensity is from 1.4 kVrms/mm to 2.1 kVrms/mm, the reflection peak shifts with the increase of field intensity. It is confirmed that LMA-10 solid core PCF with P0161A LC infiltrated can be used as an electric control optical switch. When the electric field intensity exceeds the threshold, the change of only 0.01 kVrms/mm can cause the wavelength change of 1 nm. So the switch with such a structure provides high sensitivity. The all-fiber and small-size design makes the switch easier to integrate into other devices and reduces the coupling loss. It also provides a powerful basis to manufacture a dynamic switch with high transmission efficiency and low loss.

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