Temperature-Insensitive Fiber-Optic Curvature Sensor Based on Sagnac Loop Interferometer Incorporated with Novel-Structured Polarization Maintaining Photonic Crystal Fiber

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Polarization maintaining photonic crystal fiber (PM-PCF) has been widely researched for sensing applications because of the high birefringence (1) and insensitivity to temperature (2). The birefringence can be formed in PCF by applying two large air holes along the principal axis, making this kind of PM-PCF an ideal candidate for temperature-insensitive fiber-optic sensors.

In this paper, we implemented and evaluated a temperature-insensitive curvature sensor using a novel-structured PM-PCF, which has two big air holes outside the air cladding region in order for the maintenance of high birefringence. Due to such geometry, the sensitivity to curvature was varied depending on the position of two big air holes. When two big air holes are placed horizontally on the axis of applied curvature, the maximum sensitivity of 0.16 nm/m^{-1} was accomplished. In addition, its temperature sensitivity was measured to be 0.93 pm/ºC.

A novel-structured PM-PCF was fabricated with pure silica using stack-and-draw technique. We made the preform by stacking a number of capillaries based on the hexagonal structure. In this step, we inserted two very large air holes (stress-applying parts, SAPs) opposite to each other outside the inner three layers of air cladding region in order for the maintenance of high birefringence. After that, the preform was drawn down to an intermediate cane. This intermediate cane was jacketed and drawn down again to yield the fiber. The fiber has 125 μm diameter and 3 μm core. The small and large air hole diameter is 1.89 μm and 14.7 μm. The ratio of the air hole diameter to the pitch (Λ) is 0.72.

Fig. 1 illustrates the experimental setup of Sagnac loop interferometer, which is composed of a 3 dB fiber coupler, a 0.3m-long PM-PCF, a conventional single mode fiber, and a polarization controller (PC) for interferometer optimization. The loss of Sagnac loop interferometer is approximately 17 dB and includes both the loss of the PM-PCF and the two splicing points between the PM-PCF and SMFs, which is relatively high due to the mismatch of mode field and numerical apertures (NA). In Fig.1, the curvature is given by $1/r = 2h / (h^2 + L^2)$, where h is the bending displacement at the center of the PM-PCF, r is the curvature radius and L is the half-distance of the PM-PCF (3).

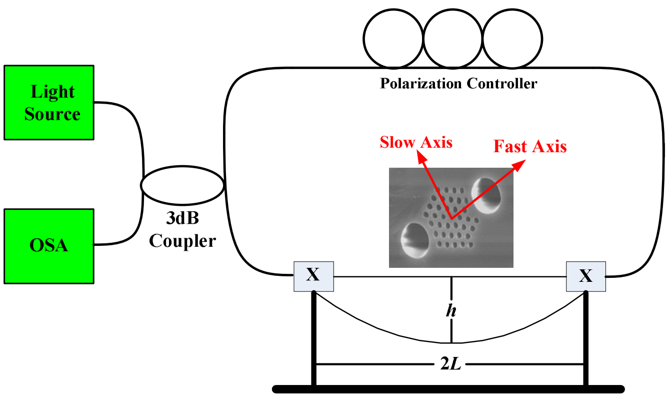

Fig. 1 Experimental setup of curvature sensor with a novel-structured PM-PCF based Sagnac loop interferometer. The inset is the cross section of fiber.

Before beginning the curvature sensing, the direction of the PM-PCF was chosen since the sensitivity to applied curvature was different depending on the position of two big air holes. Fig. 2 shows the spectral responses of Sagnac loop interferometer for two different bending directions of the fiber when the curvature was varied from 0.3 m^{-1} to 11.5 m^{-1}. When the fiber is bent along the slow axis, it has the largest sensitivity to curvature. In this case, the increase of effective refractive index of slow axis (n_{slow}^{eff}) is much larger than that of fast axis (n_{fast}^{eff}) since the curvature directly influences on n_{slow}^{eff} and the fast axis of fiber is never affected by the curvature at all due to the existence of two big air holes. So, in this case, the effective refractive index difference between fast and slow axis ($\Delta n = n_{slow}^{eff} - n_{fast}^{eff}$) is the largest of all the possible positions of two big air holes. Therefore, the group birefringence is expected to increase substantially, causing the wavelength to shift toward longer wavelengths. On the contrary, when the fiber is bent in the fast axis, it has the lowest sensitivity to curvature as shown in Fig. 2(b).

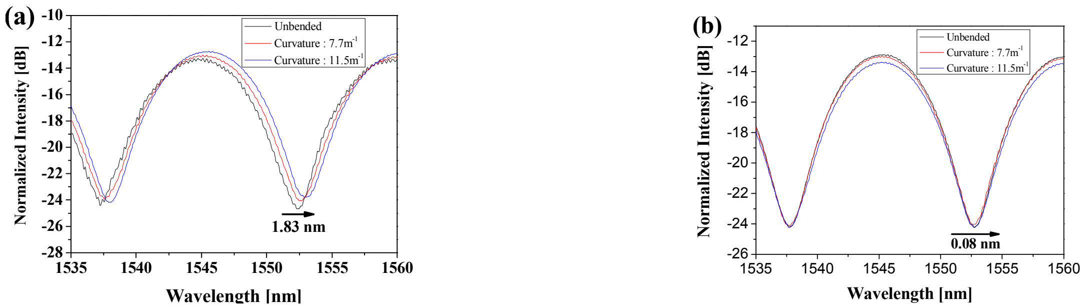

Fig. 2 Spectral responses of Sagnac loop interferometer for two different bending directions. Two big air holes are placed (a) vertically and (b) horizontally to the axis of applied curvature.

Fig. 3(a) shows the transmission peak variation of Sagnac loop interferometer depending on the curvature for two different bending axes. When the curvature increases, the fringe peak shifts to the longer wavelengths. When the fiber is bent along the slow axis, the maximum curvature sensitivity of 0.16 nm/m^{-1} is obtained. Fig. 3(b) shows the temperature sensitivity of the Sagnac loop interferometer for the fixed curvature of 11.5 m^{-1} around 1550 nm. When the ambient temperature is increased from 25 ºC to 70 ºC, the wavelength peak slightly shifts to the shorter wavelength and the temperature sensitivity is only 0.93 pm/ºC. The reason of this low temperature sensitivity is that the core and the cladding parts of the fiber are made from the same material (pure silica). The variation of group birefringence against temperature for the curvature of 11.5 m^{-1} is shown in Fig. 3(b) and it is about 3.1×10^{-6}/ºC.

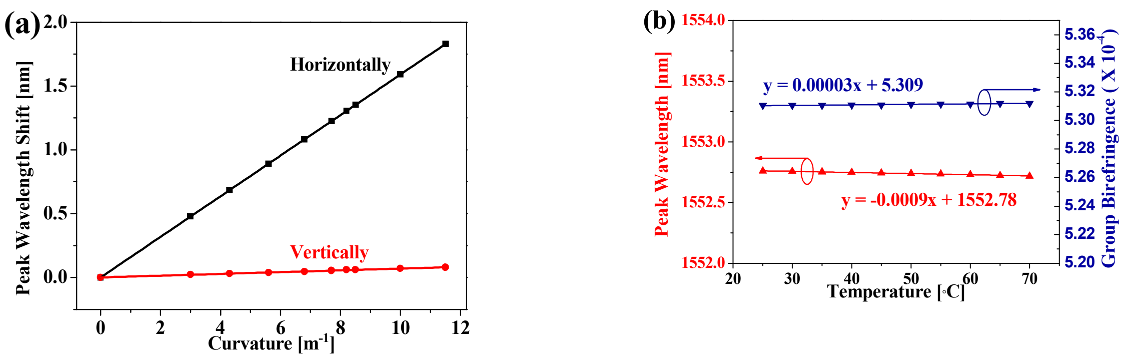

Fig. 3 (a) Peak wavelength variation of Sagnac loop interferometer depending on the curvature for two different bending axes and (b) peak wavelength variation of Sagnac loop interferometer and group birefringence as a function of temperature.

A temperature-insensitive curvature sensor based on Sagnac loop interferometer using a novel-structured PM-PCF was implemented and evaluated. In this experiment, we got the maximum curvature sensitivity of 0.16 nm/m^{-1} when the fiber is bent along the slow axis. Also, we got the temperature sensitivity of 0.93 pm/ºC, which is about 1000 times lower than that of conventional optical fiber based interferometer, resulting in no need for temperature compensation in normal temperature condition.

References

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