

Temperature dependence of the PER in PM-PCF coil

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A piece of domestic polarization-maintaining photonic crystal fiber (PM-PCF, 964 m in length) is made into a fiber coil, and its polarization extinction ratio (PER) is measured in a temperature range of -45 – 80 °C before and after PM-PCF is wound and solidified. A fiber coil made of commercial panda PM fiber (PMF) is also fabricated and measured for comparison. Our experiments show that the PER variation of the PM-PCF coil (2.25 dB) is far smaller than that of the panda PMF coil (10 dB) in the whole temperature range because PM-PCF is intrinsically insensitive to the temperature variation and stress in the fiber coil induced by the winding and solidification process. This characteristic is important for the real application of PM-PCFs in temperature-insensitive fiber interferometers, fiber sensors, and optical fiber gyroscopes.

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Polarization-maintaining fiber (PMF) is a kind of optical fibers with high birefringence (i.e., a large difference between the propagation constants of its two fundamental modes with orthogonal polarizations is present). Most commercial PMFs have two stress units in addition to the fiber core, which induce stress on the core area and lead to high birefringence in the fiber due to the elastic-optic effect. Because the PMF can maintain the polarization state of light, which is polarized along one of its polarization axes, it is widely used in fiber interferometers, fiber sensors, and fiber gyroscopes. However, the performance of PMF based on the internal stress is sensitive to variations in environmental temperature and external stress, which limits its application under conditions requiring a large operational temperature range.

In recent years, the development of photonic crystal fiber (PCF) has provided a promising way to realize PMFs with high performance. Such PCFs have microstructure claddings with periodically arrayed holes, which are usually made of pure silica and fabricated by the stack-drawing method. In 2000, the first polarization-maintaining PCF (PM-PCF) was reported by Ortigosa-Blanch *et al.*^[1]. By changing the air holes near the core area, the symmetry of the PM-PCF structure was broken, enabling the fiber to have high birefringence. After one year, a PM-PCF with two large air holes close to the fiber core was reported by Suzuki *et al.* with low transmission loss and ultrahigh birefringence, showing potential in real applications^[2]. Because this PM-PCF is fabricated using pure silica, thereby realizing high birefringence by the geometrical distortion of the fiber core, the performance of this kind of PM-PCF is intrinsically insensitive to temperature variation, as demonstrated by the birefringence or beat length measurements of short PM-PCF samples under different temperatures^[3]. Its potential application for temperature-insensitive fiber interferometers and fiber gyroscopes has also attracted much attention^[4–9]. However, under the condition of real applications, PM-PCF should be used in the form of solidified fiber coil wound by a long fiber sample, and its birefringence performance should be evaluated using the polarization extinction ratio (PER). For example, the fiber coils used as sensing

elements in fiber optical gyroscopes typically require fiber lengths of several hundreds or thousands meters. Hence, the birefringence measurement of a short fiber sample is not sufficient for guiding the real application of the PM-PCF. In Ref. [6], experiments showed that the PM-PCF could be coiled into a small circle without significant impact on its birefringence, indicating its potential to realize fiber coils with high stability; however, comprehensive investigation on the solidified PM-PCF coils was yet to be conducted.

In this letter, a solidified PM-PCF coil was fabricated using a long piece of domestic PM-PCF sample (964 m). The PER measurements were taken in a temperature range of -45 – 80 °C before and after the PM-PCF was wound and solidified. For comparison, a fiber coil made of a piece of commercial panda PMF with the same fiber length was also fabricated and measured in the same way. The experimental results show that the PER variation of the PM-PCF coil in the whole temperature range is far smaller than that of the fiber coil made of panda PMF, demonstrating that the PM-PCF has great potential for realizing temperature-insensitive fiber coil applied under conditions requiring large operating temperature range.

The domestic PM-PCF sample is shown in Fig. 1. Figures 1(a) shows the sketch of the fiber structure, which has a solid core and a cladding with air holes arranged in a triangular pattern. Two air holes near the fiber core are enlarged to generate high birefringence. The diameters of the small holes and the two large holes are denoted by d and D , respectively. The pitch of the air holes is denoted by P . Figure 1(b) shows the cross-section photograph of the domestic PM-PCF sample, from which the structure parameters of the sample are measured as $D = 5.5$ μm , $d = 2.8$ μm , and $P = 5.2$ μm .

First, the birefringence beat length of the domestic PM-PCF was measured under different temperatures by a method based on the hybrid Sagnac interferometer^[10]. The PM-PCF sample under test was ~ 20 cm in length, and a thermostat was utilized to control its temperature. The temperature variation range of the measurement was -40 – 120 °C, with a variation speed of 1 °C/min. The measurement was taken at certain temperatures after temperature stabilization of 30 min. For comparison,

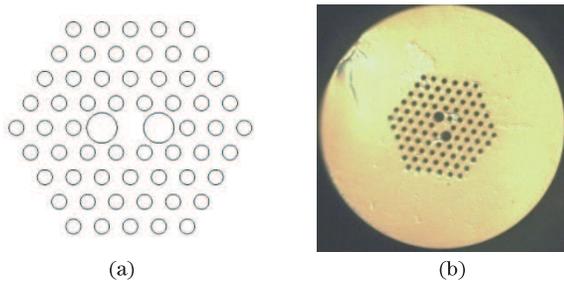


Fig. 1. (a) Sketch and (b) cross-section photograph of the domestic PM-PCF sample.

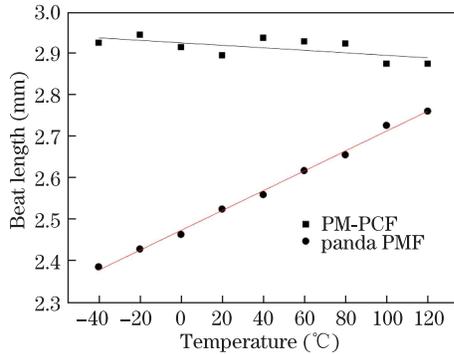


Fig. 2. Birefringence beat lengths of the PM-PCF and panda PMF sample in a temperature range of -40 – 120 °C.

the beat length of the panda PMF in this temperature range was also measured in the same way. The experimental results in Fig. 2 show that the temperature variation has different impacts on the beat lengths of the PM-PCF and panda PMF. The beat length of the panda PMF increases with increasing temperature, with a temperature coefficient of 2.38×10^{-3} mm/°C. In contrast, the beat length of the PM-PCF decreases with increasing temperature, with a temperature coefficient of -3.00×10^{-4} mm/°C which is one magnitude smaller than that of the panda PMF in absolute value. These results show that the birefringence of the domestic PM-PCF is far more stable than that of the panda PMF under temperature variation, which agrees with previous works^[3,4] on this kind of non-domestically fabricated PM-PCFs.

Because the beat length measurement of short fiber sample cannot demonstrate the performance of the PM-PCF under the condition of real applications comprehensively, PERs of the fiber coils made of the long PM-PCF and panda PMF samples are measured under different temperatures. In the measurement, an erbium-doped fiber broadband light source with a central wavelength of 1550 nm was used, with linear polarized output by a panda PMF pigtail. The PER measurement was taken by a PER meter (ERM101, General Photonics). The PER of the light source, as measured by the ERM101, was 30 dB. The fiber coil was placed into a thermostat to control its temperature. One end of the fiber coil was aligned to the output pigtail of the light source by a polarization-maintaining fusion splicer (SFU995PM, Ericsson), whereas the other end was connected to the ERM101. Before the measurement, the pigtail of the light source was rotated by the fiber splicer, and the variation of the PER value shown by the ERM101 was

observed. When the PER reached its maximum value, the pigtail of the light source and the end of the fiber coil were spliced, thereby ensuring that the polarization axes of the PMF pigtail were aligned perfectly to that of the fiber coil. Then, measurements under different temperatures were taken by changing the temperature of the thermostat. The speed of the temperature variation was 1 °C/min. Measurement was taken at specific temperatures after temperature stabilization of 30 min.

A long piece of domestic PM-PCF sample (964 m in length) was used in this experiment. Before it was wound and solidified into a fiber coil, its PER in the loose state was measured in a temperature range of -45 – 80 °C. The PER of a piece of the panda PMF of the same length was also measured for comparison. The experimental results are shown in Fig. 3, where the circle and square dots represent the results of the PM-PCF sample and panda PMF sample, respectively. As Fig. 3 shows, the PER variation of the panda PMF was small and in the temperature range of -45 – 30 °C. However, it rose rapidly with increasing temperature when the temperature was higher than 30 °C. The PER variation was higher than 8 dB in the whole temperature range for the panda PMF sample. In contrast, the PM-PCF sample showed wider temperature range with small PER variation. Its PER rose markedly when the temperature was higher than 60 °C. The PER variation of the PM-PCF sample in the whole temperature range was approximately 4 dB, far smaller than that of the panda PMF sample. Notably, the loose state of both fibers did not change during the PER measurement; hence, the measured PERs were stable and repeatable. The PER measurement results may differ under different fiber loose states due to the variation of the external stress; however, we can expect the temperature dependence of PER of both fiber samples to show the same tendency as the experimental results.

Next, according to the requirement of fiber coils for fiber optic gyroscopes, two non-skeleton fiber coils were fabricated using the two long fiber samples through the same winding and solidification processes, in which fibers were wound symmetrically by the quadrupole winding method and solidified by ultraviolet radiation.

The two fiber coils had the same structure. Both had 48 fiber layers, and their internal diameters and thicknesses were 92 and 15 mm, respectively. Their PERs were measured also in the temperature range of -45 – 80 °C, as shown in Fig. 4. The circles and square dots in Fig. 4 represent the experimental results of the PM-PCF

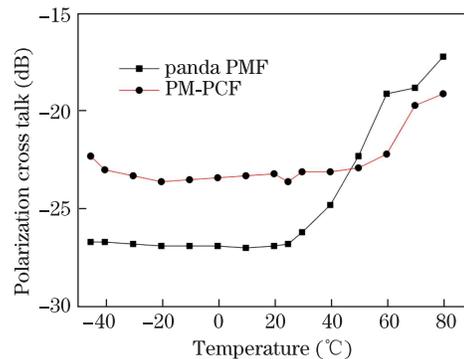


Fig. 3. PERs of the loose PM-PCF and panda PMF sample in a temperature range of -45 – 80 °C.

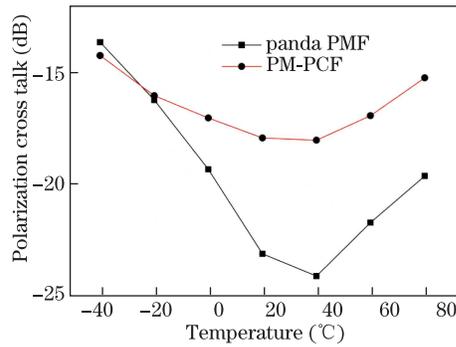


Fig. 4. PERs of the PM-PCF and panda PMF coils in a temperature range of -45 – 80 °C.

coil and the panda PMF coil, respectively. The PERs of both fiber coils were clearly reduced when compared with the results of the fiber samples in the loose state. The impacts of the temperature variation were similar for the two fiber coils. The PERs of both fiber coils reached their maximum at a temperature of ~ 30 °C. The PER variation of the panda PMF coil in the whole temperature range was 10 dB, whereas the PER variation of the PM-PCF coil in the whole temperature range was 2.25 dB, far smaller than that of the panda PMF coil.

The experimental results in Fig. 4 show that both PERs of the PM-PCF coil and panda PMF coil exhibit similar variation tendency under the temperature variation; however, the PER variation of the PM-PCF coil is far smaller than that of the panda PMF coil in the whole temperature range. Considering that the stress in the fiber coils induced by the winding and solidification process is the dominant factor for the PER reduction when the fiber samples are made into the fiber coils, the stress is also the factor dominating the PER temperature dependence of the fiber coils. The two fiber coils are fabricated by the same winding and solidifying process; hence, their PERs will naturally have similar temperature dependence. In contrast, because PM-PCF is fabricated by pure silica and realizes high birefringence by geometrical distortion of the fiber core, it is intrinsically insensitive to environment variation, including temperature variation and external stress. Hence, the PM-PCF can maintain its advantage to the panda PMF of high temperature stability, even when made into fiber coils.

In conclusion, according to the requirement of real ap-

plications, a piece of domestic PM-PCF (964 m in length) is made into a fiber coil, and its PER is measured in a temperature range of -45 – 80 °C before and after it is wound and solidified. A fiber coil made of commercial panda PMF is also fabricated and measured for comparison. Experimental results show that the PERs of the PM-PCF coil and panda PMF coil have similar variation tendency under temperature variation; however, the PER variation of the PM-PCF coil (2.25 dB) is far smaller than that of the panda PMF coil (10 dB) in the whole temperature range. The reason for this difference is that the stress in the fiber coil induced by the winding and solidifying process dominates the PER temperature dependence of the fiber coils. PM-PCF is intrinsically insensitive to temperature variation and external stress; hence, its advantage of high temperature stability over the panda PMF is maintained, even after it is made into fiber coils. This characteristic is important for the real application of PM-PCFs in temperature-insensitive fiber interferometers, fiber sensors, and optical fiber gyroscopes.

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