Long-Length Polarization Maintaining Optical Fiber Fabricated in China

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Abstract

A novel polarization maintaining fiber is introduced. Many application tests from users’ side have proved that this kind of PMF can be used in fiber gyroscope, fiber hydrophone and some other fiber-optic sensors. Besides several advantages in small SAP area, uniform geometry, good temperature/bending adaptabilities, compatibility to MIOC and axial homogeneity, the obvious character is the length of this kind of PMF fabricated by MCVD technique is relative long. The uniform portion length of the PMF drawn from a single preform can reach 8 km at diameter 125 micron or 20 km at diameter 80 micron.

1 Introduction

Polarization Maintaining Fiber (PMF) is used to keep the state of polarization unchanged when the polarized light travels along the fiber. To reach such performance, the PMFs usually should induce high birefringence within the fiber core. Birefringence refers to a difference in the propagation constant of light traveling the fiber for two perpendicular polarizations.

According to the mechanism of forming birefringence, there are many kinds of PMFs. They can be classified as stress induced types, core shape induced types and waveguide induced types, etc. No matter what kind of PMF it is, the main aim is to enable the fiber to have high birefringence. And only those validated by the application can be regarded as usable.

The four regular types\(^1\) are: Panda, Bowtie, Elliptical Jacket and Elliptical Core. The schematic diagrams are shown in Figure 1. The former three types belong to stress induced PMFs, and the latter one belongs to core shape induced PMF.

\(^{1}\)Reference [1]

![Figure 1](image1.png)

**Figure 1.** Four general PMF cross-sections: Panda, Bowtie, Elliptical Jacket and Elliptical Core.

![Figure 2](image2.png)

**Figure 2.** Microscopic view of 1-type PMF cross-section.
The fabrication process of different types of PMF has large differences. Even for a certain type of PMF, the actual cross-section of the PMF fabricated by different manufacturer is also different, because the fabrication process of every manufacturer is still of a bit difference. For example, the Panda PMF can be fabricated either by digging two holes alongside the core of the preform, then filling them by stress applying rods, or by piecing up the core and stress applying parts (SAPs) into a tube, patching up the gaps with quartz filaments to form a preform. So, the microscopic view of the cross-section of an actual PMF is more or less different from the above ideal schematic diagrams.

None of the structure of the above mentioned PMFs are circular symmetric. Except that for the Panda PMF adopting the hole-digging process, VAD (Vapor Axial Deposition) or OVD (Outside Vapor Deposition) technique has the advantage in making large preforms, for such complicated structures, Modified Chemical Vapor Deposition (MCVD) technique is better to be applied to fabricate the preform, together with some special treatment.

But according to previous experiences of those who have ever studied fiber fabrication, MCVD technique is not favorable if requiring to draw long-length optical fiber from a single preform, particularly in the case of special optical fiber. One reason is that the deposition rate of MCVD is very low and too large or thick tubes can not be applied because of indirect heating; another reason is that MCVD process has an intrinsic disadvantage ---- “inlet taper” which leads to shorter uniform portion length of the preform. So, the uniform portion length of PMF fabricated by MCVD technique normally is less than 3km in the case that the fiber diameter is 125 micron.

2 A novel structure of PMF

Jiangsu Fasten Photonics Company, P. R. China has developed a new type of PMF based on the MCVD method with the aid of a special fabrication process plus a “ramping” technique. A microscopic view of the cross-section is as shown in Fig. 2.

Its SAP shape is different from that of conventional PMFs. Because the stress jacket is like Arabic numeral “1”, we call it 1-type PMF. The existence of the inner cladding helps the reduction of fiber attenuation. The minor axis of the 1-type stress jacket still has a bit SAP, which is helpful to keep the core in a good shape. The outer cladding acts as a barrier to prevent the impurities and inclusions in the substrate tube from migrating into the inner cladding and the core.

The latest generation of MCVD system has imported ramping software, which can be used to adjust the set value of many parameters\(^2\) during every phase, like gas or carrier flow, temperature, speed, pressure, etc.

To get long homogeneous PMF, the substrate tube whose diameter is over 30mm should be used. Though large diameter and thick wall tube is difficult to operate, it is still able to be handled through proper adjustment to process conditions.

Each layer of the preform is deposited in the inner surface of the substrate tube. After depositing the outer cladding and the stress jacket, some special treatment is necessary to be applied to have the stress jacket in special shape. Then the inner cladding and the core are deposited. Finally, the tube is collapsed to a solid preform. The diameter of such preform is around 16mm, and the uniform portion length is over 600mm. If such a single preform would be drawn into fiber, the length of homogeneous portion could be over 8 km at diameter 125 micron or over 20 km at diameter 80 micron.

3 The performance of the 1-type PMF

The main specifications and some typical values of the 1-type PMF at diameter 125 micron are listed in Table 1, while the specifications of the 1-type PMF at diameter 80 micron are listed in Table 2.
The Advantages of the 1-type PMF

1) Excellent polarization crosstalk
   The crosstalk of 1km of this kind of PMF is normally better than ~25dB. One reason is that the orientation of the SAP is very clear; another reason is that the core shape’s major axial paralleling to the SAP’ major axial is also benefit to the strengthening of polarization maintaining.

2) Small SAP area
   To achieve required high birefringence, most kinds of the regular PMFs should apply large SAP area. For the actual PANDA and Bow-tie PMF, the percentage of SAP area over the fiber’s cross-section area is more than 10%, some fibers’ SAP percentage even exceeds 15%. But for the novel 1-type PMF, to reach the same birefringence, the SAP percentage is less than 5%.

   The SAP percentage of the conventional Elliptical Jacket PMF is less compared with that of PANDA or Bow-tie PMF, but the beat length of the conventional Elliptical Jacket PMF can hardly be less than 3mm at 1310nm wavelength.

   The small SAP area is also benefit to the fiber strength, because the high stress area of this kind fiber is far from the fiber’s outer surface compared with that of other types of PMF. According to the fiber-break mechanism, the outer surface’s defects are the main causes of fiber break. The closer the distance between the SAP and the outer surface is, the higher the break probability occurs.

3) Good temperature adaptability
   The birefringence of the stress induced PMF is mainly caused by the difference of the expansion coefficient between the B-doped stress jacket and the core. But if the SAP area is too large, it will impact PMF’s extinction ratio while temperature varying, which causes the zero-drift of gyroscope in the whole working temperature range.

   Table 3 shows the extinction ratio (ER) variations with temperature of the 1-type PMF at diameter 125 micron.

<table>
<thead>
<tr>
<th>Temp. (°C)</th>
<th>27.5</th>
<th>+40</th>
<th>+50</th>
<th>+60</th>
<th>+70</th>
<th>+85</th>
<th>-10</th>
<th>-20</th>
<th>-30</th>
<th>-40</th>
<th>-45</th>
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<tr>
<td>Note:</td>
<td>Sampling length of PMF is 550m.</td>
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   If we strictly set a ±3dB variation of ER (compared with that at room temperature) as the acceptable criteria at different temperature, we find from –45°C to +85°C, the extinction ratio well fits the requirement. This temperature range fully covers the general fiber gyroscopes’ working temperature. Many tests from users’ side draw the same conclusion.
4) **Excellent bending adaptability**

Because the SAP area of 1-type PMF is small, the additional stress induced from the bending is so limited that it can hardly impact the birefringence of the fiber. Winding the 1-type PMF round the diameter 20 mm mandrel 20 turns, practically does not cause a degradation of the extinction ratio. This means that the 1-type PMF is insensitive to bending. The typical diameter of fiber gyroscope coil frameworks is around 40mm. So, the 1-type PMF can completely endure the bending in winding gyroscope coils.

Good application performance with 1-type PMFs has been achieved from several users. The fibers were wound into gyroscope coils and immersed into the glue, then temperature adaptability tests were performed. After the gyroscope’s gauge had been attached to, the vibration tests and some other application tests were also carried through. All the results support the feasibility of this fiber in these application areas.

5) **Nice matching to LiNbO$_3$ Y-shape waveguide**

The 1-type PMF has excellent performance in extinction ratio or polarization cross-talk even at short length. So, after connecting it to the LiNbO$_3$ Y-shape waveguide to compose a multi-function integrated optic chip (MIOC) of fiber gyroscopes, the extinction ratio can still be very nice.

Because the SAP area is small and the fiber strength is quite good, the fiber’s end is not easy breaking during polishing, which is quite important in fabricating MIOC. As the orientation of the 1-type PMF’s major and minor axis is quite clear, this kind of PMF is quite fit to be used as the pigtailed fiber of the LiNbO$_3$ Y-shape waveguide. Some users even said the performance of the 1-type PMF was better than some imported PMFs from some famous manufacturers.

6) **Fine geometric performance**

With fine modified drawing process, the 1-type PMF fabricated by Jiangsu Fasten Photonics Company has fine geometric performance. The specification listed above shows that the geometric performance of the 1-type PMF has been in accordance with the advanced requirements to communication fibers, which is very benefit to the winding of fiber coils.

7) **Good axial homogeneity**

The other predominance of 1-type PMF is its axial homogeneity. The good homogeneity is achieved by well-controlled MCVD deposition process. Ramping is used to fine-tune every layer’s uniformity.$^{[2]}$. Because the 1-type PMF drawn from a single preform is longer compared with most other kinds of PMFs fabricated through MCVD process by other manufacturers, the length of the uniform portion can also be longer. The users believe the consistency can be assured if a batch of fiber gyroscopes use the PMF drawn from a single preform.

5 **Conclusion**

The 1-type PMF developed by Jiangsu Fasten Photonics Company has shown quite good performance. With its advantages in polarization crosstalk, temperature and bending adaptabilities, compatibility to MIOC, geometry, homogeneity and long length, the fiber has great potential in applications like fiber gyroscope, fiber hydrophone and other fiber-optic sensors.

Many customers have accepted the fact that the 1-type PMF can be used as the pigtailed fiber of the LiNbO$_3$ Y-shape waveguide as a substitute of some imported sensor applied PMFs.

6 **Acknowledgement**

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REFERENCES