New Progress for Fused PM Fiber Components

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Abstract
According to qualitative theoretical analyses and repeated experiments, these authors came to the conclusion that fused biconical stress-applied polarization-maintaining fiber component working on the fast axis than on the conventional slow axis, has many advantages such as low excess, low temperature dependence.

1 Introduction

It is known to all that PM fiber optic component is one of the most important components for high quality optical communication systems and optical fiber sensor systems. Therefore, the study and development of PM fiber optic component has significant value. The late 1970s and early 1980s saw the PM fiber optic components booming in the aspects of theory and experiment. Traditionally, PM fibers work on the slow axis mainly for two reasons: propagation loss on the slow axis is relatively, though not significantly, lower than that on the fast axis; also, the bending loss on the slow axis is lower than that on the fast axis, especially when the bending diameter smaller than 6cm, the difference being significant. As a result, fused biconical PM fiber optic components also work on the slow axis. For example, fiber optic gyro systems work on the slow axis, because their optic fiber rings are tightly spaced due to the system requirement. However, for fused biconical PM fiber optic component made by stress-applied PM fiber, the choice between slow axis and fast axis should be based on the characteristics of this particular fiber optic component itself. Based on our qualitative analysis and repeated experiment results, we found that biconical PM fiber optic components have several advantages on the fast axis, mainly, improved optical performance and temperature stability.

2 Analyses of Coupling Characteristics for Fused Biconical PM Fiber Components

According to the coupled mode equations, when unit optical power at input port 1 is the input polarized light aligned on the slow axis, the coupling characteristics of the optical power between the PM fiber 1 and PM fiber 2 can be expressed as:

$$\begin{aligned} &P_{1S}(z) = \cos^2\left(\int_0^{2L} C_S(d(z), n_S(y,z,\lambda))dz\right) \\ &P_{2S}(z) = 1 - P_{1S} \end{aligned} \qquad (1)$$

Supposing PM fiber 1 is completely identical to PM fiber 2. 2L is the effective length of the coupling region. C_S is the coupling coefficient of the PM fibers on the slow axis, which is decided by the distance between the fiber cores, as well as the refractive index $n_S(y,z,\lambda)$ on the slow axis.

When the input polarized light is aligned on the fast axis, the coupling characteristics of the optical power between the PM fiber 1 and PM fiber 2 can be expressed as:

$$P_{1F}(z) = \cos^2\left(\int_0^{2L} C_F(d(z), n_F(x,z,\lambda))dz\right)$$
$$P_{2F}(z) = 1 - P_{1F} \qquad (2)$$

where 2L is the effective length of the coupling region, and C_F the coupling coefficient of the PM fibers on the fast axis, decided by the distance between the fiber cores and the refractive index $n_F(x,z,\lambda)$ on the fast axis. Due to the existence of stress-applied region (low refractive index) on the slow axis, for components whose effective length of the coupling region are 2L, the coupling coefficient $C_F \geq C_S$, meaning the effective coupling will take place first on the polarized light aligned on the fast axis. In another word, for same splitting ratio, the required effective length of the coupling area is smaller for light aligned on the fast axis. Therefore, fused biconical PM fiber components working on fast axis have low excess loss. In contrast, for the same splitting ratio, fused biconical PM fiber components working on the slow axis have relatively higher excess loss.

In addition, the coupling coefficient is closely related to the refractive index. For stress-applied PM fiber, e.g. PANDA fiber, due to the existence of stress-applied rod on the slow axis, the change in temperature will directly affect the stress or refractive index on the slow axis, as well as the beat-length of the PM fiber. On the cross-section of the coupling area of a fused biconical PM fiber component, stress-applied rods exist on the slow axis, therefore the coupling characteristic of the fused biconical PM fiber component is temperature sensitive as the temperature change is significant on the refractive index. The stress variation on the slow axis will affect the refractive index of the fast axis at certain degree; however, the magnitude of the refractive index change on the fast axis is much smaller than that on the slow axis. Thus, we have shown that for the same wavelength and same splitting ratio, fused biconical PM fiber components made of PM fibers aligned on the fast axis is less temperature sensitive than those components made of PM fibers aligned on the slow axis.

3 The Characteristic and Application of Fused Biconical PM Fiber Components Aligned on Fast Axis or Slow Axis

During our experiments, we used Fujikura standard 1310nm PM fiber to make components with different splitting ratios. We performed thorough experiments testing coupling characteristic, excess loss, and temperature sensitivity on these components.

Table 1 lists the coupling ratio on the slow axis vs. fast axis for all of four components. With the increase of coupling ratio, we observed the consistent increase of coupling ratio difference between the fast axis and slow axis; furthermore, the coupling ratio on the fast axis is always bigger than that on the slow axis, proving that the effective coupling takes place first on the fast axis. There has been earlier literature regarding this topic.

Table 1: Coupling Ratio Difference (%) between Fast Axis and Slow Axis

		Sample1	Sample 2	Sample 3	Sample 4
Coupling Ratio	Slow Axis	95.1/4.9	70.5/29.5	59.2/40.8	50.3/49.7
	Fast Axis	93.8/6.2	52.2/47.8	41.3/58.7	29.8/70.2

Table 2 lists the excess loss from 10 50:50 PM splitters with 5 aligned on the slow axis, and the other 5 on the fast axis. All 10 PM splitters have identical PM fibers and are made with same fused biconical process. Table 2 shows that on average, the excess loss for components aligned on the fast axis is half that for components aligned on the slow axis. This is a very significant advantage for fast axis alignment. It proves that components using fast axis alignment have lower excess loss.

Table 2: Excess Loss Characteristics

	Sample1	Sample2	Sample3	Sample4	Sample5
Slow Axis	0.35dB	0.40dB	0.37dB	0.31dB	0.34dB
	Sample6	Sample7	Sample8	Sample9	Sample10
Fast Axis	0.18dB	0.19dB	0.15dB	0.21dB	0.14dB

With respect to the temperature characteristics of the component, we have performed qualitative analysis as previously discussed. Using the same 10 50:50 PM splitters, we tested the temperature characteristics, with temperature ranging from -40°C to +85°C. Through a real time monitor, we discovered that the change in splitting ratio for fast axis aligned components is less than half of those aligned on slow axis. Table 3 lists the test results. The results showed that fast axis aligned components are more stable.

Table 3: Change in Splitting Ratio (%) Caused by Temperature Change from -40°C to +85°C

	Sample1	Sample2	Sample3	Sample4	Sample5
Slow Axis	4.9	5.2	4.3	6.0	5.6
	Sample6	Sample7	Sample8	Sample9	Sample10
Fast Axis	2.2	2.4	2.1	2.5	2.2

Above is only a small portion from test results of our large quantitative production. Test results in large scale have shown the same conclusions. Thus, we highly suggest the use of fast axis aligned fused boconical PM fiber components (splitters, mixers, WDMs, etc). Because current laser sources and connectors are aligned on slow axis, when fusing fast axis aligned fused PM fiber components to the fiber pigtails of such sources and connectors, one should rotate the fiber pigtail of one side by 90 degree then fuse right after the automatic alignment. The 90 degree rotation can be done by pressing the functioning button on the PM fiber splicing machine. Such new splicing function can be programmed without any change on the hardware of splicing machine. For a short distance system, laser source, component and connector can all be designed to align on the fast axis. Such request can be made to the provider with no additional cost. By doing this, system stability is greatly improved with no increase in the cost.

4. Conclusions:

Based on the qualitative analysis and repeated experiment, we have found that under same performance criteria, fast-axis is more advantageous than slow-axis for components made with stress-applied PM fibers (such as PANDA) and by using fused biconical process. Such components, when aligned on the fast-axis, have low excess loss, high anti-vibration ability, and temperature insensitivity. Therefore, the implementation of components working on fast axis is very important to the stability of systems requiring fused biconical PM fiber optic components.