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A High Circularly Birefringent Helical-Core Fiber

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Abstract　A kind of high-performance helical-core fiber used in sensing systems of large current or strong magnetical field is fabricated. Its specifications of pitch, core offset, beatlength and loss are 1.5 mm, 255 μm, 3.5 mm and less than 0.5 dB/m, respectively.

Key words　helical-core fiber,　circular birefringence,　sensing system.

1　Introduction

As well known, there are two kinds of circularly birefringent fibers. One is helical-core fiber which uses geometrical birefringence[1, 2]. The other is twisted fiber which uses stress birefringence after fiber drawing[3]. The former possesses Faraday effect of optical rotation and circularly polarizing stability, and, therefore, can be widely used in monitoring bus of large current or strongly magnetical field. The latter is restricted in its application because its beatlength cannot reach 10 cm due to fragileness of the twisted fiber. In other words, the difference of circular birefringence between the two fibers is more than 10^1 or 10^2 times. Nevertheless, the loss of helical-core fiber increases sharply as soon as its beatlength is less than 5 mm. It is interested that under larger normalized frequency V_c (for example $V_c = 20\sim 50$), the fiber can operate in monomode state still.

Based on the rotation angle of polarizing surface in the helical-core fiber being proportional to the contour integral of the magnetic field, the position and size of the fiber-coil rolled around the operating bus have proper flexibility, which is very convenient for designing or manufacturing optical fiber sensors.

In this paper, the helical-core fiber is manufactured. The specifications of the fiber, as shown in the Abstract, seem to reach its technical limitation.

2　Analysis

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1) As mentioned above, helical-core fibers can operate in monomode state under larger normalized frequencies because bending losses of high-order modes in the fiber are much larger than that of fundamental mode and they are attenuated. The relation among normalized frequency V_c, core offset Q and pitch P can be described by

$$V_c \leqslant \frac{u \sin \theta}{\sin (\theta_c - \theta_p)} \tag{1}$$

where $\theta_c = 90° - \arcsin \frac{n_2}{n_1}$, $\theta_p = 90° - \arctan (\frac{P}{2\pi Q})$, n_1 and n_2 are refractive index of core and cladding, θ_c and θ_p are critical angle between core and cladding and pitch angle, respectively. V_c and lateral wavenumber u should satisfy the eigen equation of the first-high-order mode.

2) According to the calculating method of bending loss in a conventional step fiber, the loss formula of the helical-core fiber can be expressed as follows[4]:

$$IL = 10 \lg \exp (- \gamma L), \qquad \gamma = (\frac{2}{a})^{1/2} \frac{\pi^2 Q V_c^{5/2}}{\Delta^{1/4} P^{3/2} u^2 (1 + \delta)^{1/4}} \exp \left[- \frac{2}{3} \frac{\Delta^{1/2}}{\pi} \frac{S}{a} \frac{w^2}{V_c} \frac{1}{(1 + \delta)^{1/2}} \right], \tag{2}$$

here $L = 1$ km, a-core radius, w-lateral wavenumber, $\delta = 2\left[\frac{\theta_p}{\theta_c}\right]^2 \left[\frac{V_c}{w}\right]^2$, Δ-difference of relative refractive index, $S = \sqrt{P^2 + D^2}$ and $D = 2\pi Q$. The calculated curves of the formula are shown in Fig. 1.

3) For a conventional helical-core fiber, pitch angle $\theta_p < 45°$, beatlength formula of the fiber can be written as[5]:

$$BL = \frac{S^2}{2(S - P)}, \qquad S = \sqrt{P^2 + D^2}, \tag{3}$$

The relative curves between beatlength BL and pitch P are shown in Fig. 2.

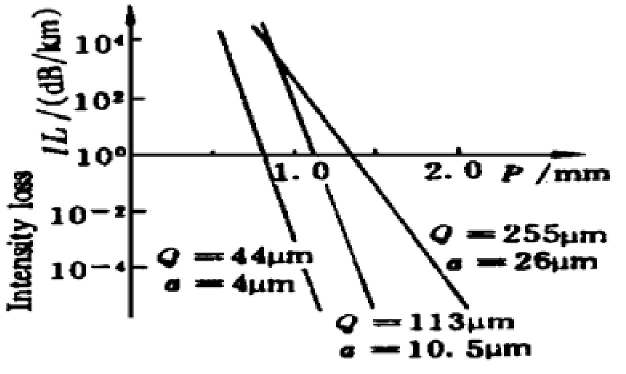

Fig. 1 Curves of insertion loss IL vs pitch P

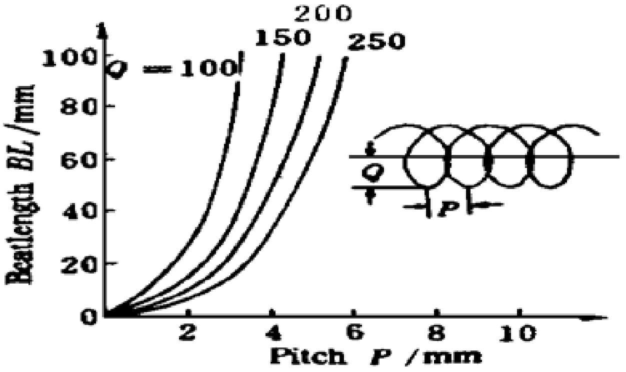

Fig. 2 Curves of beatlength BL vs pitch P

3 Technology

A series of technical troubles in manufacturing process have been settled and can be briefly listed below:

3.1 Manufacturing technology for high Ge-doping preforms

The difference of relative refractive index Δ of the preform fabricated has reached 3% by our special technology. The refractive index profile of the fiber from the fabricated preform is shown in Fig. 3.

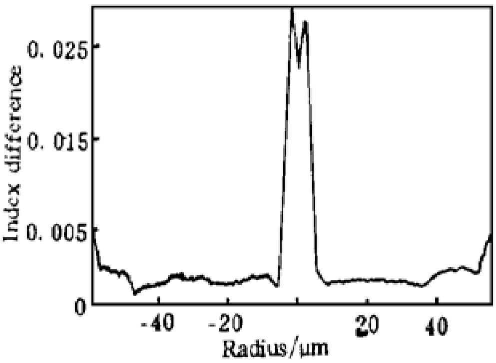

Fig. 3 Profile of the fiber refractive index after the fiber drawing from the preform

3. 2 **Manufacturing technology for large core-offset preforms**

The core offset Q of the fiber from the fabricated preform can reach 255 μm by Huang's method* .

3. 3 **Stable technology as spin drawing of the helical-core preform**

The spin-shiver phenomenon in drawing process can be eliminated by so called "soft connection" designed by ourse.

3. 4 **Technology of slowly pulling fiber in drawing process**

Using a slowly rotating fiber-pulling capstan designed by ourselves, fiber-pulling speed can reach 0.48 m/min, from which very short pitch P can be obtained, even reached its technical limitation.

3. 5 **Optimum furnace-temperature control**

Data of optimum furnace-temperature under a variety of conditions have been obtained and recorded, with which the problem of low loss and continually drawing can be settled.

4 Conclusion

The cross sections of the typical helical-core fibers measured by York Fibercheck are shown in Fig. 4. In Fig. 4 (a) the core of the helical fiber has reached the cladding edge of the fiber. Some specifications of typical fiber samples are listed in Table 1:

Table 1. Some measured specifications of the typical fiber samples

$\Delta = 3\%$ $\lambda = 1.29\ \mu m$

sample no.	core diameter $2a$ /μm	core offset Q /μm	fiber diameter $2R$ /μm	pitch P /mm	beatlength BL /mm
HF 01#	40	250	550	2	6.0
HF 05#	52	255	599	1.5	3.5
HF 08#	27.8	126	300	1.5	7.3

Fig. 4 The cross sections of the typical helical-core fibers: (a) The core is quite near to the edge of the helical-core fiber, (b) The helical shape is emerged below the cross section

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[*] The technological method here is proposed and promised by Professor Huang Hung-chia, Academician of the Chinese Academy of Sciences

It seems that the specifications of the fiber above are better than data which have been reported.

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高圆双折射率螺旋芯光纤

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摘　要　已研制出一种高性能螺旋芯光纤, 这种光纤广泛使用于大电流或强磁场光纤传感系统。其性能指标分别为: 螺距 1.5 mm、芯偏 255 μm、拍长 3.5 mm 及损耗小于 0.5 dB/m。

关键词　螺旋芯光纤,　圆双折射率,　传感系统。