Fabrication and characteristics of character-1 shaped reduced diameter polarization-maintaining optical fiber

Jianxiang Wen (文建湘), Letian Liang (梁乐天), Tianpeng Xiao (萧天鹏),
Xiaojun Xu (徐晓军), Hua Yu (俞 华), and Wu Su (苏 武)

Jiangsu Fasten Photonics Company, Jiangyin 214400

Received May 11, 2006

A novel structure reducing diameter polarization maintaining optical fiber with high birefringence and strength is introduced. The fiber is fabricated through using modified chemical vapor deposition (MCVD) method, which is able to produce the optimum predicted character-1 shaped fiber structure. As a result, a low-loss fiber with beat length close to 2.0 mm at 1310 nm wavelength and extinction ratio approximately −25 dB has been produced. The process is both simple and reproducible.

OCIS codes: 060.0060, 060.2280, 060.2420, 060.2800.

Polarization-maintaining fibers (PMFs) are expected to play an important role in high bit-rate fiber transmission systems. For example, PMFs can eliminate the influence of polarization mode dispersion (PMD) or stabilize the operation of optical devices. Currently, PMFs[1−3], such as panda shape, bow-tie shape, and elliptical jacket shape, are used in polarization-maintaining applications and transmission lines. The resultant birefringence results from stress acting on the core region. It is known that the stress-birefringence relation satisfies stress-photoelastic effect, its corresponding principal stress is coincident in the same direction, and the different stress regions have different structure parameters[4]. There are three important parameters in characterizing the PMFs: birefringence constant (B), beat length (L_{b}), and extinction ration (ER). In a conventional single mode fiber, the propagation speed is different from orthogonal linear-polarization modes because of intrinsic imperfections and change of environmental conditions. So the two propagation constants β_x and β_y are different. The birefringence constant B is in proportion to the difference of β_x and β_y, $B = n_x - n_y$, where n_x, n_y are mode indexes of HE_{11}^{x} mode and HE_{11}^{y} mode respectively. Another parameter is L_{b}, defined that the beat length L_{b} is the length among which HE_{11}^{x} mode and HE_{11}^{y} mode will generate 2π phase delay. If the length of L_{b} is far smaller than the space frequency of the interference phase, the fiber can maintain the polarization state well. So B and L_{b} characterize the polarization-maintaining ability of PMF. The third parameter is extinction ratio ER, $\mathrm{ER} = 10\lg(P_y/P_x)$, where P_x and P_y are the powers of the excited mode and coupled mode in an ensemble of fiber length.

The geometrical structure design to PMFs is very important. High birefringence PMFs can be classified into two categories: geometrical effect fibers such as elliptical core and dumbbell core; and stress-induced fibers such as bow tie, panda, and elliptical jacket. Then the character-1 shaped reduced diameter PMF belongs to the stress-induced PMF. Character-1 shaped fiber produces the highest birefringence with the least stress-applied part (SAP) whose area is approximately 5% or less. And the SAP looks like numeral "1", then we name it the character-1 shaped reduced diameter PMF.

Further fabrication is analyzed as follow, stress part structure is shown in Fig. 1. 1) The broad radius a of the character-1 shaped SAP area should be as small as possible. However, this is normally limited by the requirement of low attenuation. 2) The long radius b of the character-1 shaped SAP area should be about 1/3 of the fiber radius (R). Large value of b actually causes birefringence to increase, but it is easy to cause the cracking and to increase the production cost. 3) The circularity of core is very important, which has effect on light transmission, mode field diameter, and dispersion. The core radius is r.

When optical fiber materials are defined, the modal birefringence B turns into a function of geometrical parameters: a, b, c, r. According to the experiments, we design $b = (2 \sim 3)a$. If the stress-applying part is too close to the core, namely the smaller the c is, the higher the attenuation may be produced. It is thus necessary to find a suitable compromise between the conflicting requirements of high birefringence and low attenuation, so we design $c = (1.5 \sim 2.0)r$. Then the structure design typical value is that the core diameter ($2r$) is 5 μm and the fiber diameter ($2R$) is 80 μm.

Preform of character-1 shaped reduced diameter PMF is fabricated having an analogy to that of single mode fiber by normal modified chemical vapor deposition (MCVD) process. Main fabrication phase consists of aggradations, embellishment, and collapse. The process is 1) selection and preparation of subtract tube (SiO_2), 2) deposition of cladding ($SiO_2/P_2O_5/F_2$) and

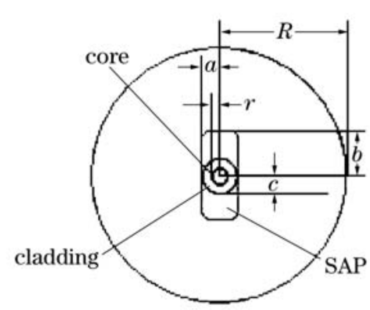

Fig. 1. Structure sketch of character-1 shaped reduced diameter PMF.

stress applied part area (SiO_2/B_2O_3), 3) embellishment of stress applied area, 4) deposition of inner cladding (SiO_2/P_2O_5) and core (SiO_2/GeO_2), 5) collapse and figuration of reduced diameter PMF preform.

Firstly, several layers of fluorine and phosphorous-doped silica are deposited, which form a buffer layer and a resistance layer to impurities such as moisture, hydroxide, which may penetrate into core layers and result in attenuation rising sharply. Dopant concentration is selected so as to produce the refractive index-matched to silica. Secondly, the stress-applied layers, which highly doped borosilicate glass, are deposited. Then the substrate tube rotation is stopped and two burners are ignited to touch up SAP areas. At the same time, freon gas got through the tube at high temperature. Through this method, the borosilicate lays are etched away from tow strips on opposite sides of the tube, but not completely. And then rotate again and further inner cladding layers are conventionally deposited, subsequently germanium doped core layers are deposited. After that the tube is collapsed with overpressure and slow velocity in order to ensure fine structure core. And noticed, processes 3) and 4) have very important effect on formation of geometrical structure, birefringence, and strength of character-1 shaped reduced diameter PMF. At last drawing fiber, the cross section of reduced diameter PMF observed through optical microscope is shown in Fig. 2.

The process can maintain the optimum character-1 shaped geometrical structure with remarkable consistency, homogeneity, and efficiency of preform fabrication by a single MCVD lathe without using other extra machines to operate. So the process avoids inducing high attenuation and low strength. Ramping was used to fine-tune the uniformity of every layer, especial stress-apart area layers. By using ramping, such as carrier gas flow, burner temperature, and inner tube pressure, the homogeneity of almost every fiber attribute can be effectively improved and also can compensate the inherent “inlet taper” of MCVD process, what is more, only one preform, it can be drawn about 25 kilometers and the fluctuating of fiber parameters, such as cut-off wavelength, mode field diameter, and core/cladding concentricity, is a little. So the high homogeneity can be achieved by well-controlled MCVD process.

The SAP area is very small. The percentage of SAP area over the whole cross section area of character-1 shaped reduced diameter PMFs is less than 5%. To achieve required high birefringence, most kinds of general PMFs have been applied larger SAP area[5]. Such as

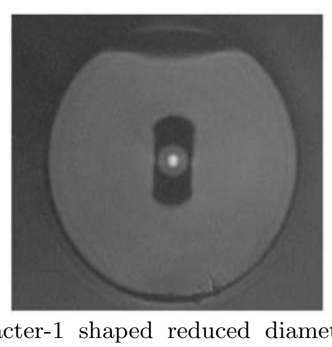

Fig. 2. Character-1 shaped reduced diameter PMF cross section-structure.

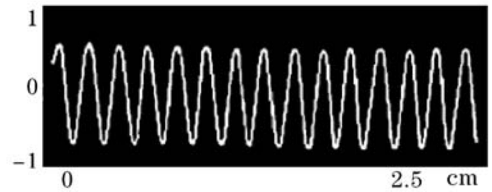

Fig. 3. Beat length test curve of character-1 shaped reduced diameter PMF at 1310 nm.

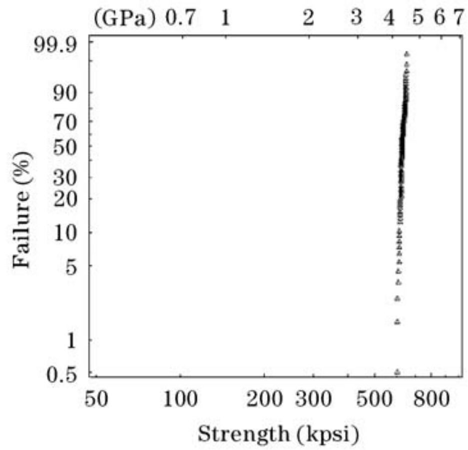

Fig. 4. Dynamic strength test of character-1 shaped reduced diameter PMF. Gauge length is 10 m. Strain rate is 2.5%/min.

panda and bow-tie PMF, the percentage of SAP area over the fiber’s cross-section area is more than 10%, the SAP percentage of some suppliers’ products even exceeds 15%. But the beat length of the conventional character-1 shaped PMF can be less than 2.5 mm at 1310-nm wavelength, the test curve is shown in Fig. 3. $L_{\mathrm{b}} = S/(N-1)$, where S is the peak separation between the beginning and the end, N is the wave peak counts. The extinction ratio typical value is better than −25 dB, one reason is that the orientation of the SAP is very symmetry, another is that the SAP is very closer to the core, and then the action of SAP on core is enhanced. The small SAP area is benefit to the fiber strength. Dynamic fatigue parameter test is shown in Fig. 4. Because the high stress area of this kind of fiber is far from the fiber’s outer surface compared with that of other types of PMFs. According to the fiber-break mechanism[6], 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.

The character-1 shaped geometry section structure, which obtained in reduced diameter PMF, is shown in Fig. 2. Despite the unconventional shape, the geometry structure has been found to be remarkably reproducible. According to the optimum geometry structure guidelines given in Fig. 1, the preform is fabricated in MCVD lathe by accurately control of the relative dimensions of core, cladding, character-1 shaped regions and fiber outer diameter.

Characteristics of character-1 shaped reduced diameter PMF are shown in Table 1. A character-1 shaped reduced diameter PMF has been fabricated with close to optimal geometry structure and extremely short beat length. The fabrication process is relatively simple and can be easily

Table 1. Characteristics of Character-1 Shaped Reduced Diameter PMF

Index of Characteristic	Specification	Typical Value
Working Wavelength (nm)	1300—1310	1310
Cut-off Wavelength (nm)	1100—1300	1100—1250
MFD at 1310 nm (μm)	6.0 ± 1	6.0 ± 0.5
Attenuation at 1310 nm (dB/km)	≤ 2.0	≤ 1.0
Bare Fiber Diameter (μm)	80 ± 1	80 ± 0.5
Coating Diameter (μm)	160 ± 10	165 ± 5
Proof-Test Strength (kpsi)	100	100/200
Beat Length at 1310 nm (mm)	≤ 3	≤ 2.5
Extinction Ratio (dB)	≤ -23	≤ -25

controlled. The novel structure PMF has significant advantage to other reduced diameter PMFs in homogeneity, strength and birefringence. It has great potential in the fields of gyroscope, fiber hydrophone, interferometer, and other sensors.

This work was supported in part by the National "863" Project of China under Grant No. 2003AA312120. J. Wen's e-mail address is wenjx@chinaphotonics.com.

References

1. T. Hosaka, K. Okamoto, Y. Sasaki, and T. Edahiro, Electron. Lett. **17,** 191 (1981).
2. R. D. Birch, D. N. Payne, and M. P. Varnham, Electron. Lett. **18,** 1036 (1982).
3. T. Katsuyama, H. Matsumura, and T. Suganuma, Appl. Opt. **22,** 1748 (1983).
4. R. Guan, F. Zhu, Z. Gan, D. Huang, and S. Liu, Opt. Fiber Technol. **11,** 240 (2005).
5. R. Guan, X. Wang, X. Wang, D. Huang, and S. Liu, Chin. Opt. Lett. **3,** 42 (2005).
6. M. Poulain,N. Evanno, and A. Gouronnel, Proc. SPIE **4639,** 64 (2002).