Development of the Novelty G.654 Optical Fibers for Long-haul Terrestrial Optical fiber Communication

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Abstract:
In this letter, we analyzed and designed a kind of novelty G.654 optical fibers' refractive index waveguide for the long-haul terrestrial application. The fiber's core index is 1.46117, and its diameter is 14.0 μm. The depressed refractive index of the inner-cladding is 1.45565, and its width is 6.96μm. The mode-field-diameter of 1550nm wavelength is 13.85 μm, and the effective area of 1550nm wavelength is 150 μm^2. Their typical attenuation coefficients are 0.163dB/km, 0.176dB/km at 1550nm and 1625nm wavelength respectively. Moreover, the novelty optical fibers have outstanding anti-bending performance, on the condition of 30 mm bending radius and 100 turns, its bending additional loss is 0.035 dB and 0.097dB at 1550nm and 1625nm wavelength respectively. The 22m sample's cut-off wavelength is 1490.6 nm, below 1510nm wavelength, which ensures the communication of the 1510nm Optical Supervising Channel (OSC) in the Dense Wavelength Division Multiplexing (DWDM) communication system.

Key words: long haul terrestrial, high-data-rate communication, ultra-low-loss optical fiber, large-effective area

1 Introduction

In order to meet the rapid growth of China's demand for data traffic, a new generation communication network needs a great improvement on the communication rate, transmission capacity, transmission distance. But the traditional G.652 fiber could not meet the demand of the development of a new generation of long distance communication network due to the effective area of only 80μm^2. Therefore, the researchers in the communication fields hope that the cut-off wavelength shift single mode optical fiber, which is the G.654 in ITU-T standard, could be used to the long haul terrestrial fiber communication network [1-5].

But due to the great differences between the terrestrial and marine environments, submarine cable was made of stainless steel pipe welding and armored, and at the bottom of the ocean the environmental temperature is constant about - 1℃ to 2℃. But on the land, temperature changes larger from -45℃ to 40℃,in some special occasion, maybe the temperature varies much larger. What's more, the cable on the land application will be faced complex environments, such as the environment pressure, bending stress, mechanical impact and so on. This need the novelty kinds of fiber could resist all kinds of stress and have great anti-bending performance.

Traditional the cut-off wavelength shift single mode optical fibers, including G.654.A, G.654.B, G.654.C, G.654.D fiber, could not meet the higher requirements for optical signal loss and nonlinear in the next generation high data-rate communication network [6-9]. Therefore, it is urgent and important to study the novelty kind optical fibers, which have the advantages of large-effective-area and ultra-low-loss, the ability of anti-bending, for the long haul terrestrial fiber communication in the 400G communication system.

Through the basic theory of electromagnetic field, using the scalar wave equation the weakly guiding approximation, a new type of optical fiber waveguide structure for the next generation of optical fiber communication network was designed. Then the large-effective-area and ultra-low-loss, characteristics of a new type of optical fiber was fabricated the continuous chemical vapor deposition (CCVD) process.

2 The design and fabrication of the novelty G.654 optical fiber

The effective area of the optical fiber is determined by the refractive index profile of the optical fiber and the diameter of the core layer of the fiber. It is a physical quantity that represents the distribution of the electromagnetic field in the optical fiber waveguide. The key factors affecting the power loss coefficient of the optical fiber include the waveguide structure, the high and low refractive index, the species and distribution of the doped ions, the viscosity of the interface, the stress in the fiber. As a result, the waveguide structure of the optical fiber is firstly designed before the preparation of the optical fiber.

Optical fiber is a circular symmetrical waveguide. On the conditions of the weakly guiding approximation, $\Psi(R)$ could meet the scalar electromagnetic wave equation [10].

$$\left[\frac{d^2}{dR^2}+\frac{1}{R}\frac{d}{dR}+a^2(k_0^2n^2(R)-\beta^2)\right]\Psi(R)=0 \quad (1)$$

$$\left[\frac{d\Psi_{core}(R)}{dR}\right]_{R=1}=\left[\frac{d\Psi_{cl}(R)}{dR}\right]_{R=1} \quad (2)$$

$$[\Psi_{core}(R)]_{R=1}=[\Psi_{cl}(R)]_{R=1} \quad (3)$$

Where, k_0 is the vacuum wave number, R is the radial coordinate, a is the core radius of the fiber, R=r/a, R denotes normalized radius of the optical fiber, N (R) represents the radial refractive index profile, $\Psi(R)$ is the fundamental mode of the electromagnetic field spatial distribution function. $\Psi_{core}(R)$ is the electromagnetic field distribution function of fundamental mode fiber core area, β represents the axial propagation constant of the optical fiber, $\Psi_{cl}(R)$ represents the fundamental mode propagation constant in the cladding.

After calculating the electromagnetic field distribution of the fundamental mode function $\Psi(R)$, then substitute $\Psi(R)$ into formula (4) to calculate the effective area of the optical fiber A_{eff} [10].

$$A_{eff}=\frac{2\pi(\int_{-\infty}^{+\infty}|\Psi(R)|^2RdR)^2}{\int_{-\infty}^{+\infty}|\Psi(R)|^4RdR} \quad (4)$$

The refractive index profile of the new G.654 optical fiber is shown in Figure 1. The fiber core refractive index of the optical fiber is 1.46117, and the core diameter is 14 microns. The relative refractive index difference between the core and the cladding is adjusted to 0.278%. Compared with the 0.35% relative refractive index difference of the conventional single-mode fiber core, the doping concentration in the optical fiber is reduced by 20%. Therefore, the Rayleigh scattering of light in the fiber waveguide structure is greatly reduced.

In order to adjust the distribution of the electromagnetic field in the optical fiber waveguide, and to improve the bending resistance of the long wavelength of the fiber, a low refractive index region is deposited in the optical fiber. Its refractive index is 1.45565, and the width is 6.96 microns. By simulation analysis, the effective area of the Ultra-low-loss and Ultra-large-effective Area (UUA) of the new optical fiber at 1550nm wavelength is 150μm^2 (Fig.2) .

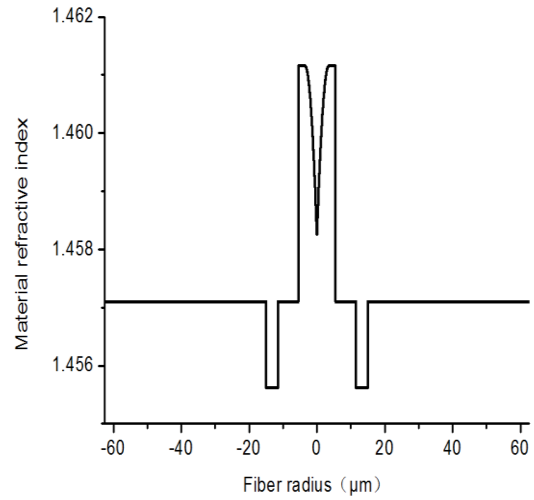

Fig.1 The refractive index structure diagram

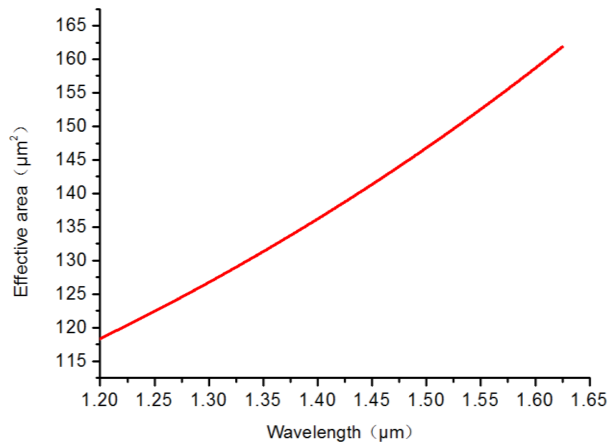

Fig.2 The fiber's effective area at different wavelength

3 The optical performance index test and environmental experiments analysis

Optical fiber preform was fabricated by Continuous Chemical Vapor Deposition (CCVD) process, and then the optical fiber preform is placed on the tower of the self-made optical fiber wire drawing. Starting the heating system, the high temperature of the furnace is controlled at 2100℃±50℃, quartz glass preform is melted and soften. By high-speed closed-loop self-feedback controlling technologies, the silica preform is drawn into optical fiber with 124.6±0.3 micron glass cladding diameter.

Test results show that the mode field diameter of the new optical fiber at 1550nm wavelength is 13.85μm, the effective area is 150μm^2, the attenuation of the 1550nm wavelength is

0.163dB/km, the attenuation of the 1625nm wavelength is 0.176dB/km (Table 1).

To take 22 meters of optical fiber, the cut-off wavelength of the sample fiber is tested by multi-mode storage reference method. The cut-off wavelength of the new optical fiber sample is 1490.6nm. This ensures that the 1510nm optical monitoring channel (OSC) could communicate normally in the present Dense wavelength division communication system. This is an important feature of the novelty G.654 fiber, which is different from the common G.654 ITU-T provisions with the cut-off wavelength less than 1530nm，including the common G.654.A , G.654.B, G.654.C and G.654.D. The bending loss test shows that the fiber has good bending resistance. On the condition of 30 mm bending radius and 100 turns, its bending additional loss is 0.035 dB and 0.097dB at 1550nm and 1625nm wavelength respectively. As can be seen from the below table-2, the new type of G.654 fiber attenuation performance is better than the G.654.D ITU-T standard.

Table.1 The G.654 sample and its comparison to the common G.654.D

No.	Specification		Unit	Value of the G.654sample	Common G.654.D value
1	1550nm MFD		μm	13.85	11.5-15.0
2	λ cc		nm	1490.6	≤1530
3	Attenuation	1550nm	dB/km	0.163	≤0.20
3		1625nm	dB/km	0.176	TBD
4	Dispersion	1550nm	ps/nm/km	21.3	≤23.0
5		1625nm	ps/nm/km	23.0	TBD
6	Dispersion slope（1550nm）		$ps/nm^2/km$	0.063	≤0.07
7	A_{eff}（1550nm）		μm^2	150	TBD
8	Macro-bending loss(ф 60mm，100turns）	1550nm	dB	0.035	TBD
9		1625nm	dB	0.097	≤2.0

In order to further verify that the optical fiber can withstand high and low temperature environment changes, Temperature cycling test was made according to national standard GB/T 15972.52-2008. The sample length of the test fiber was 2 km, high and low temperature cycling test was carried out in the range of -60℃ to 85℃. The heating rate is 0.8℃/min, the cooling rate is 0.5℃/min, and the heat preservation time is 120 minutes. Because the optical fiber is a kind of large effective area fiber, in order to investigate the sensitivity of the long wavelength to temperature, the attenuation coefficient of 1625nm wavelength was monitored during the test process. After two cycles of temperature cycling test, the additional loss of the optical fiber at 1550nm and 1625nm wavelengths were less than 0.01dB/km (Fig.3).

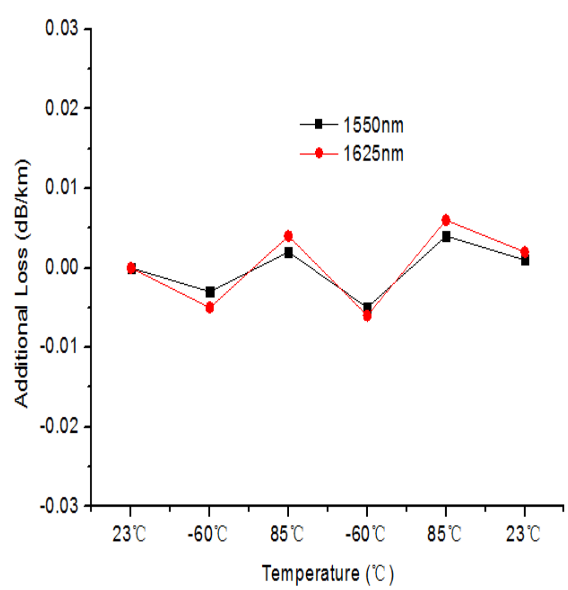

Fig.3 The additional loss curves for temperature cycling

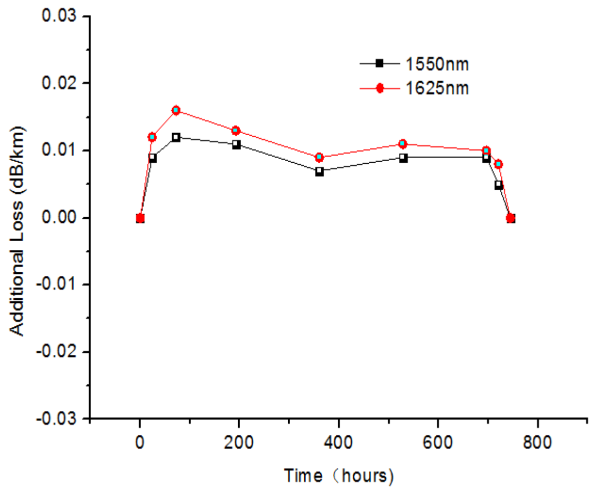

Fig.4 The additional loss curves for damp heat test

The damp-heat test was carried out in the relative humidity of 85%, 85 ℃ temperature environment according to national standard GB/T 15972.50-2008. The maximum additional loss of the 1550nm wavelength of the fiber was 0.012 dB / km, the maximum additional loss of the 1550nm wavelength of the fiber was 0.016dB/km(Fig.4), and when return to the room temperature after 24 hours of test, the additional loss at both wavelengths recovered back to zero. High and low temperature cycling test and damp-heat aging test showed that the fiber could withstand the harsh environment of high temperature and high humidity, and has good reliability.

National communication trunk engineering applications in China show that their key technological specifications are much more superior than the international technological level at present，they can meet on the demands of the long haul terrestrial 400Gbit/s high-data-rate fiber communication.

4 Conclusions

In this letter, a new type of G.654 fiber for long distance high speed communication is designed and fabricated. The novelty optical fiber has better low attenuation characteristics, its attenuation at 1625nm wavelength is 0.176dB/km, the attenuation of 1550nm wavelength is 0.163dB/km. The novelty optical fiber has excellent resistance to bending properties, the additional macro-bending-loss of the fiber at 1625nm wavelength is 0.097dB, the additional macro-bending-loss at 1550nm wavelength is 0.035dB. The 22m sample's cut-off wavelength is 1490.6 nm, below 1510nm wavelength, which ensures that the Optical Supervising Channel (OSC) could be used in the Dense Wavelength Division Multiplexing (DWDM) communication system. High and low temperature cycling test and damp-heat aging test showed that the fiber could withstand the harsh environment of high temperature and high humidity, and has good reliability. They can meet on the demands of the long haul terrestrial 400Gbit/s high-data-rate fiber communication.

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