A Bend-insensitive Ultra Low Loss and Large A_{eff} fibre for Long Haul transmission

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Abstract: A large effective area fiber (110μm^2)with excellent bend-insensitive characteristics and attenuation lower than 0.160dB/km is presented. It's excellent bend-insensitive performance is benefit for cable temperature cycling test and attenuation change during cabling process.
OCIS codes: (060.2280) Fiber design and fabrication; (060.2270) Fiber characterization

1. Introduction

What is the trend of single-mode fiber supporting the next generation high speed 400G/400G+ communication? As the accelerating bandwidth and capacity demand, we are searching for a super single mode fiber supporting large capacity transmission. It is well known that ultra low loss and large effective area are the most key factors in long-haul coherent communication. The balance between spectrum effectiveness, capacity and transmission reach is the essential issue. Larger effective area (Aeff. for short) can support higher optimum launch power into the fiber which is good for improving OSNR. Lower loss can increase the output optical signal-to-noise (OSNR) and Q-factor of transmission system for the same distance, or extend the transmission reach. To achieve better system performance, we combine the ultra low loss and large Aeff. into one more perfect fiber for the next generation fiber.

At present, G.654.B and G.654.D fiber are used in transoceanic cable system, while the terrestrial cable installation, application and service environments are quite different from submarine cable. So it requires more performance optimization and design for terrestrial ultra low loss & large Aeff fiber. A new category G.654.E has been strongly proposed in 2013, which is used in terrestrial large capacity transmission system. The new ITU-T proposal of G.654.E for terrestrial cable will be released before the end of 2016.

In this paper, we introduce the design and characteristics of ultra low loss & large Aeff fiber for long-haul terrestrial cable. And the key fiber and cable performance for terrestrial application are also discussed.

2. FOM of ultra low loss G.654 fibre

As discussed above, lower attenuation and larger Aeff can improve system performance. Fiber-Of-Merit (FOM) is used to quantitative evaluate the contribution of loss and Aeff.[2-4]. FOM is usually easily predicted as a function of fiber parameters. Here, n_2, L, L_{eff} mean nonlinear refractive index, span length, and effective length, respectively.

$$FiberFOM(dB) = 10\log\left[\frac{A_{eff}\cdot n_{2,ref}}{A_{eff,ref}\cdot n_2}\right] - \left[\alpha(dB/km) - \alpha(dB/km)\right]\cdot L - 10\log\left[\frac{L_{eff}}{L_{eff,ref}}\right]$$

$$L_{eff} = \frac{1-e^{-\alpha L}}{\alpha} \qquad \alpha = \frac{In10}{10}\alpha_{dB/km} \qquad (1)$$

According to the FOM calculation, we obtain the FOM value of different fiber in Fig.1 and the figure also shows the great advantages of fiber which combine ultra low loss and large effective area together than only ultra low loss fiber with 80μm^2 Aeff. or larger Aeff. with common attenuation.

3. Fiber design and manufacture

The core-cladding refractive index design was optimized for macrobend and cuoff wavelength and is compliance with the ITU-T G.654.B standard. As shown in Fig.2, compared with conventional F doped outer cladding structure's ultra low loss & large Aeff fiber, pure SiO2 is used as our fiber's outer cladding, which is possible to make our fiber products more cost competitive and easier to control the drawing process.

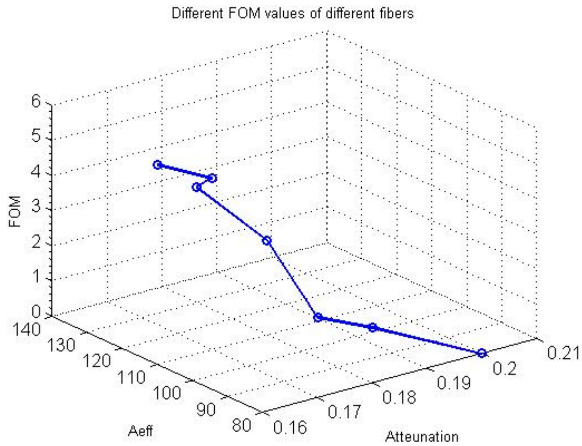

Fig. 1. different FOM values of different fibers

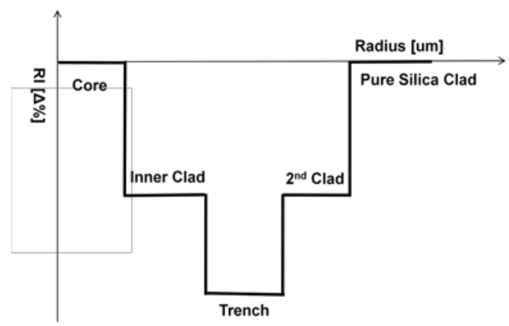

Fig. 2. Schematic of fiber RI profile structure

4. Fiber and cable performance

4.1 Attenuation

Rayleigh scattering is the main composition of fiber loss(almost 90%), and it has relation with concentration factor ρ_C and density factor ρ_D . In theory, we can low ρ_C by reducing fiber dopant and low ρ_D by reduce fiber fictive temperature. Fewer dopant can reduce ρ_C and lower fictive temperature can decrease ρ_D . Fictive temperature is proportional relation with cooling rate(Fig. 3), We have done so many studies and simulation on decreasing the fictive temperature to obtain a attenuation lower than 0.160dB/km.

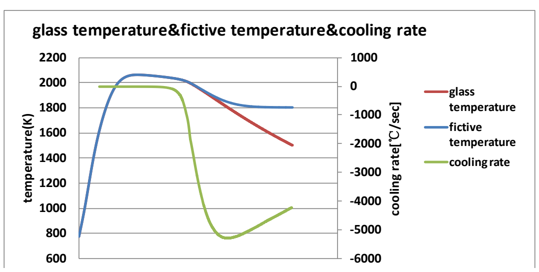

Fig. 3. Fictive temperature & cooling rate

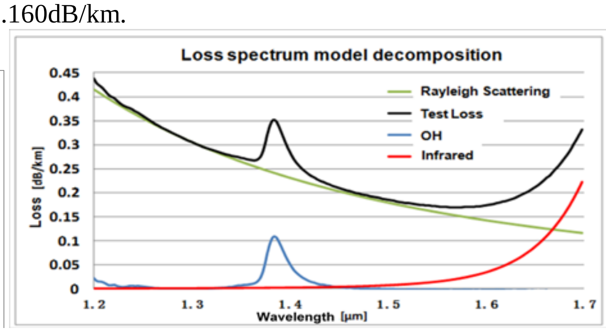

Fig.4 Loss spectrum model decomposition of ultra low loss & large Aeff. fiber

4.2 Splicing performance

Mode field diameter(MFD) mismatch is the most impact factor of splicing loss . The bigger the MFD mismatch, the larger the splicing loss, as shown in formula(2). Obviously, splicing loss of A_{eff} 110μm^2 is lower than A_{eff} 130μm^2 with standard fiber. It's worth noting that self splicing performance of ultra low loss fiber with A_{eff}-110μm^2 is 0.02~0.03dB, while 0.03-0.04dB for G652.D fiber self splicing.

$$\mathrm{Loss_{splicing}} = 20 * \log \frac{2 * \mathrm{MFD}_1 * \mathrm{MFD}_2}{\mathrm{MFD}_1^2 + \mathrm{MFD}_2^2} \qquad (2)$$

4.3 Bend insensitive performance

In conventional knowledge, a bigger Mode field diameter(MFD) means easier eaky mode wave. By the trench assisted structure,which is a mature bending insensitive design method in G.657 fiber [5], we optimize a reasonable trench volume to achieve a better bending resistance performance, even exceed the G.657.A1 specification(Fig.5). At the same time, the excellent macro-bending performance can remain much attenuation/power margin which will ensure stable overtime while materials are aging and guarantee the fiber performance stability under 25-year lifetime in complicated deplot condition,no matter in submarine cable or terrestrial cable.

Micro-bending performance is of importance for cabling design and cabling processing. Excellent micro-bending performance can reduce the difficulty of cable design and cabling process and also can improve the cable performance’s stability in different application conditions under extreme environment. Fig.6 depicts the micro-bending comparison of our ultra low loss & A_{eff} -110μm^2 fiber with G.652.D fibre, while the typical micro-bending induced loss under all wavelength is far below 0.8 dB/km at longer wavelength.

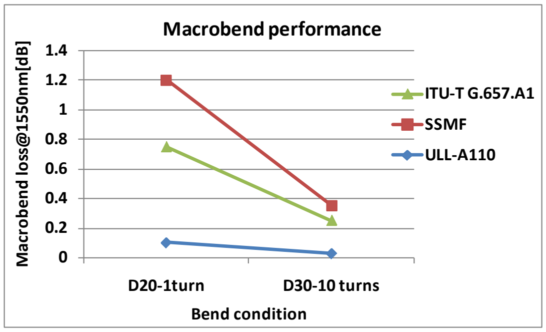

Fig.5 Macro-bending comparison

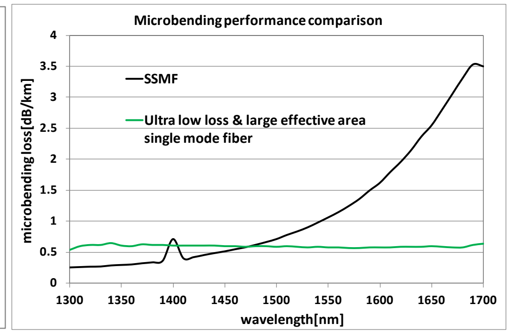

Fig.6 Micro-bending loss comparison

4.4 cable performance

As mentioned above, Micro-bending performance is of importance for cabling design and cabling processing. The attenuation after cabling at 1550nm keeps the same level or even lower than the original fiber attenuation before cabling due to the excellent micro-bending performance as shown in Table 1. So no special cabling process control is needed.

Table 1 Fiber loss and cabled loss

NO.	core 1	core 2	core 3	core 4	core 5	core 6	core 7	core 8	core 9	core 10	core 11	core 12
Fiber spool attenuation [dB/km]	0.158	0.157	0.161	0.162	0.159	0.165	0.163	0.160	0.165	0.165	0.165	0.167
cable attenuation [dB/km]	0.161	0.160	0.160	0.160	0.161	0.164	0.164	0.162	0.165	0.167	0.168	0.167

The land temperature is not as stable as ocean, so the terrestrial cable have to experience more severe temperature change and still keep the link loss stable. 12-core cable temperature cycling Test (TCT) is tested for checking the attenuation change with temperature.

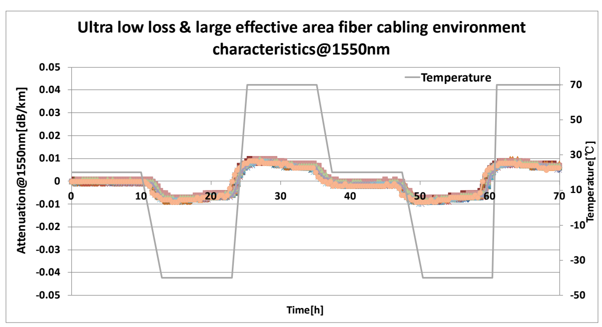

Fig.7. The fiber attenuation change with temperature

5. Conclusions

In this paper, we presented A large effective area fiber (110μm2)with excellent bend-insensitive characteristics and attenuation lower than 0.160dB/km. Considering the complicated cable installation and application environment on the land, the fiber compatibility, micro & macro-bending, TCT and attenuation change during the cabling process are tested to ensure the reliability in system link. The fiber is the visible choice for the next 400G/400G+ communication.

6. References

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