ULTRA-LOW LOSS AND LARGE AEFF RING MARKED FIBER FOR HIGH COUNT SUBMARINE CABLE

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Abstract: In order to dramatically increase transmission capacity over a single submarine cable, increasing the number of fibers in a cable is a straightforward way and has been actively studied. One of the challenges for realizing high count submarine cable is fiber identification; ring marking on a submarine fiber having an enlarged core area has caused loss increase due to micro-bending. In this paper, we report on realization of a ring marked fiber having enlarged Aeff of 160 μm^2 and ultra-low transmission loss of 0.149 dB/km at 1550 nm keeping its low loss characteristics over entire the C- and L- bands. By applying a coating system with very low Young's modulus at the primary layer and long spacing of 200 mm between adjacent ring marks, we clarify the micro-bending loss can be efficiently suppressed as low as that of a fiber having the same value of Aeff without ring marks. Furthermore, mass-productivity has been verified with 2,000 km long fabrication, with averaged loss of 0.151 dB/km at 1550 nm and averaged Aeff of 150 μm^2. In addition, high environmental reliability and mechanical durability of ring-marked fibers has been confirmed.

1. INTRODUCTION

To keep up with the exponential growth of global data traffic, transmission capacity through submarine cable systems has been increasing. There are two ways to increase the submarine cable capacity; one is to increase transmission capacity per a single fiber, and the other is to increase the number of fibers in a single cable. For the former, high bit-rate signals shall be transmitted through a high quality submarine transmission fiber having low loss of 0.15 dB/km and enlarged effective area (Aeff) of 110 – 150 μm^2 [1-5]. Thanks to recent progress of transmission technologies based on digital coherent optics, fiber-capacity is approaching its physical limit, the so-called Shannon limit, and therefore, it would not be easy to increase the fiber-capacity dramatically. Consequently, the latter way, increasing the number of fibers, is becoming very important. Here, one of the challenges is the identification of each fiber in a submarine cable. In a terrestrial high count cable with standard single mode fibers (SSMFs) having an Aeff around 80 μm^2, ring marking on a fiber is generally utilized for identification of each fiber. In a submarine cable, however, ring marking is not an easy solution, because to put ring marks on a fiber having large Aeff around 110 μm^2 to 150 μm^2 often makes the transmission loss high due to induced micro-bending.

In this paper, we present a ring marked fiber having enlarged Aeff of 160 μm^2, standard outer diameter of 250 µm, and ultra-low loss of 0.149 dB/km at 1550 nm keeping its low loss performance over entire the C- and L-bands. In addition, we fabricate ring marked 150 μm^2 fibers with accumulated length of 2,000 km based on mass-production processes. We confirm their ultra-low loss of 0.151 dB/km on average and verify high mechanical reliability and environmental durability as well.

2. DESIGN OF A RING MARK ON LARGE AEFF FIBER

Ring marked fiber has narrow strips of marking on each colored optical fiber for identification of each fiber in a high count cable as shown in Fig. 1 (a). The ring mark is generally utilized to SSMF with Aeff of 80 μm^2 in a terrestrial application. To realize ring marked fiber with enlarged Aeff of 110 μm^2 or more up to 160 μm^2, loss increase induced by micro-bending has to be solved. It is known that Aeff-enlarged fibers are sensitive to micro-bending because light propagation confined in the core becomes weaker if a fiber has a larger Aeff. Since slight surface irregularities from ring marks induce the micro-bending, it is essential for ring marked fiber with large Aeff to supress the micro-bending loss.

Applying improved coatings with a soft primary layer is one of ways to overcome micro-bending loss. A two-layer fiber coating system with a soft primary coating and a hard secondary one is shown in Fig. 1 (b). The primary coating layer with the lower modulus of elasticity effectively protects the glass fiber from outer disturbances, and therefore, reduces micro-bending losses.

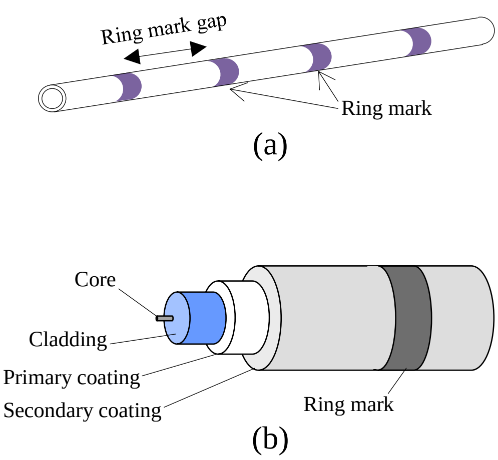

Figure 1. Schematic drawing of ring marked fiber.

Figure 2 shows the loss difference at 1550 nm between with and without ring marks as a function of Aeff on fibers applied with "previous coatings (see square plots)" and "improved coatings (see circle plots)" having the softer primary layer. In this measurement, a fiber-under-test having 50 mm ring mark gap is wound on a standard shipment reel with 170-mm diameter barrel. The "ring mark gap" is the spacing between adjacent ring marks, as illustrated in Fig. 1 (a). The loss increase by ring marks on a fiber with the previous coatings was 0.006 dB/km at Aeff of 130 μm^2 and rose to 0.012 dB/km at the larger Aeff of 150 μm^2. This results show that the micro-bending loss induced by ring marks increases as the Aeff enlarges and therefore the the transmission loss of fiber wound on the reel was increased. On the other hand, the loss increase of a fiber with the improved coatings was negligibly small at Aeff of 130 μm^2, reducing micro-bending loss by applying a soft primary layer. However, at Aeff of 150 μm^2, loss increase around 0.004 dB/km was observed, even though the improved coatings were applied. Therefore further improvement for the micro-bending loss was necessary.

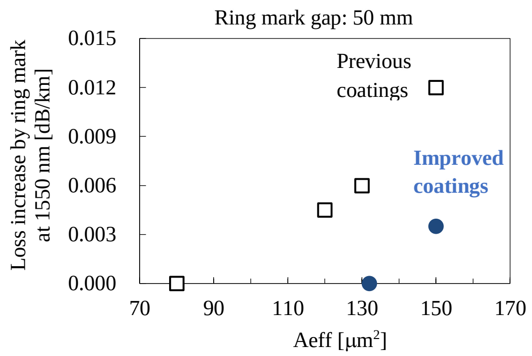

Figure 2. Loss increase after placement of ring marks with a 50 mm gap.

In order to mitigate micro-bending induced by slight surface irregularities from ring marks, we considered micro-bending loss would be able to be suppressed with an elongated ring mark gap to make frequency of surface irregularities lower. Figure 3 shows the relationship between a ring mark gap and transmission loss increased by ring marks at 1550 nm on a fiber with Aeff of 150 μm². As we anticipated, the loss increase was reduced as the ring mark gap was elongated. The measurement results of the loss increase by ring mark at 1550 nm were summarized in Table 1. The loss increase was negligibly small even at Aeff as large as 160 μm², in the case of a fiber with 200 mm ring mark gap and with the improved coatings.

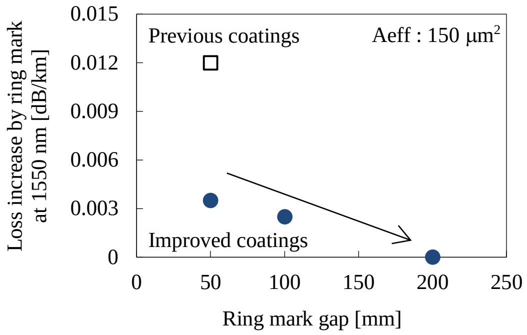

Figure 3. Loss increase of a fiber with Aeff of 150 μm² as a function of ring mark gap.

Table 1. Measurement result of loss increase by ring mark at 1550 nm.

Coating	Ring mark Gap	Loss increase [dB/km]		
		Aeff		
		130 μm²	150 μm²	160 μm²
Previous	50 mm	0.006	0.012	No data
Improved	50 mm	0.000	0.004	No data
Improved	100 mm	0.000	0.002	0.003
Improved	200 mm	0.000	0.000	0.000

Figure 4 shows the relationship between Aeff and micro-bending loss measured, by using a wire mesh drum method [6, 7]. In this measurement, a 500-m-long fiber-under-test was wound with a tension of 0.8 N on a 405 mm-diameter drum covered with metal wire mesh with 50 μm thickness and 100 μm interval. The increase in loss caused by winding on this drum was measured as micro-bending loss. As is shown in Fig. 4, the micro-bending loss monotonically increases as the Aeff enlarges, and the fiber with improved coatings has the lower micro-bending loss compared to the previous one having the same Aeff [5], in accordance with the above mentioned explanation. In addition, the ring marked fiber with 50 mm gap on the previous coatings has the higher micro-bending loss compared to the fiber without ring marks. In the case for fiber with improved coatings, on the other hand, the micro-bending loss of ring marked fiber with 200 mm gap is equivalent to one without ring marks, which will result from mitigation of outer stress induced by ring marks because of applying the soft primary coating and long ring mark gap.

Figure 5 shows measured transmission loss spectra of fibers having Aeff of 160 μm² applied the improved coatings with ring marks (200-mm-gap) and without ones, respectively. We realized ring marked fiber having ultra-low loss of 0.149 dB/km at 1550 nm without degradation of loss over the entire C- and L-bands compared to no ring marked fiber.

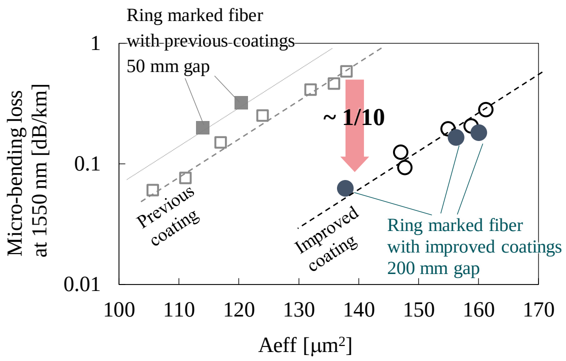

Figure 4. Micro-bending loss as a function of Aeff.

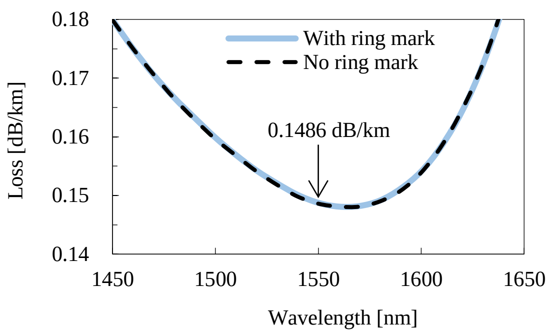

Figure 5. Loss spectra of the fiber having Aeff of 160 μm² with and without ring mark.

3. FABRICATION OF ULTRA- LOW LOSS RING MARKED FIBER WITH LARGE AEFF

Then we verified stable mass production of ring marked fiber with enlarged Aeff and feasibility of stable supply. Figure 6 shows the fiber loss distribution with accumulated quantity around 2,000 km of ring marked fiber with Aeff of 150 μm^2 based on mass production processes. The average transmission loss of 0.151 dB/km at 1550 nm was successfully realized and the loss distribution seems to be Gaussian in shape having a small standard deviation of 0.003 dB/km. The average loss and the standard deviation of the fabricated ring marked fibers were equivalent to one without ring marks. As a result, we confirmed the stable loss performance of ring marked fiber having enlarged Aeff fabricated on mass production basis.

Table 2 summarizes typical optical characteristics of fibers enlarged Aeff of 150 μm^2 with and without ring mark. By applying the improved coating and the ring mark gap of 200 mm, the ring marked fiber has equivalent optical characteristics to ones of fiber without ring mark including fiber loss, chromatic dispersion, chromatic dispersion slope, macro-bending loss, PMD, and Aeff. We also confirmed that the ring marked fiber was fully compliant to the Recommendation ITU-T G.654.D on cut-off shifted single-mode optical fiber [8], so that this ultra-low loss ring marked fiber will be able to be applicable to submarine ultra long haul transmission.

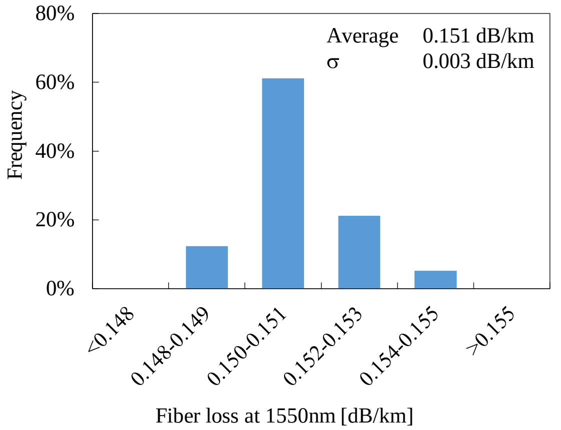

Figure 6. Manufactured fiber loss distribution of ring marked fiber having Aeff of 150 μm^2.

Table 2. Typical optical characteristics at 1550 nm of ring marked fiber.

	Ring mark	No ring mark	ITU-T G.654.D	Pass / Fail
Fiber loss at 1550 nm [dB/km]	0.151	0.151	≤ 0.20	Pass
Chromatic dispersion at 1550 nm [ps/nm/km]	20.8	20.8	≤ 23	Pass
Dispersion slope at 1550 nm [ps/nm^2/km]	0.06	0.06	≤ 0.070	Pass
Macro-bending loss, at 1625nm, 100 turns, ϕ60 mm [dB]	0.03	0.03	≤ 2.0	Pass
PMD on drum [ps/km$^{1/2}$]	0.03	0.03	N/A	-
Aeff [μm^2]	150	150	N/A	-

We also tested environmental stability and mechanical durability required in submarine communication cables for the fabricated ring marked fiber with Aeff of 160 μm^2, according to the international standard IEC 60793-2-50 [9] including the damp heat, dry heat, change of temperature, water immersion, proof stress, coating strip force, fiber curl and tensile strength tests. All test results fell well within criteria required on IEC60793-2-50 as summarised in Table 3 and 4, which indicates excellent reliability and durability of the ring marked fiber, practicable for submarine cabling. As an example, Figure 7 shows the fiber loss change during damp heat test at a temperature of 85 °C and relative humidity of 85 % for 30 days, in which measurable degradation was not found.

Table 3. Loss change at 1550 nm for environmental reliability tests.

Test item	Conditions	Requirement of IEC	Result	Pass/ Fail
Damp heat [dB/km]	85 °C / 85%, 30days	≤ 0.05	0.00	Pass
Dry heat [dB/km]	85 °C, 30 days	≤ 0.05	0.00	Pass
Change of temperature [dB/km]	-40 °C ~ 70 °C, 2 cycles	≤ 0.05	0.00	Pass
Water immersion [dB/km]	23 °C, 30 days	≤ 0.05	0.00	Pass

Table 4. Mechanical stability test results.

Test item	Requirement of IEC	Result	Pass/Fail
Proof stress level [GPa]	≥ 0.69	≥ 1.4	Pass
Coating strip force [N]	$1.0 \leq F_{ave} \leq 5.0$ $1.0 \leq F_{peak} \leq 8.9$	F_{ave} 2.0 F_{peak} 2.5	Pass Pass
Fiber curl radius [m]	≥ 2	≥ 10	Pass
Tensile strength (median) for 0.5 m specimen length [GPa]	≥ 3.8	4.4	Pass

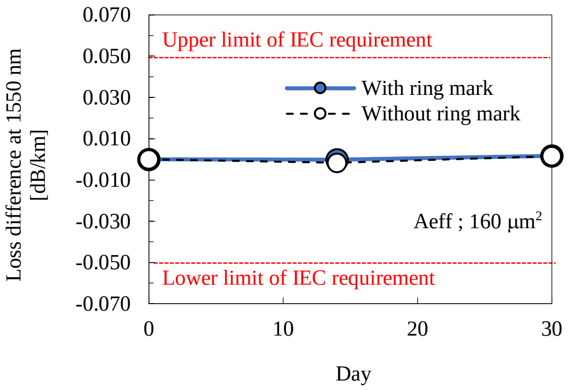

Figure 7. Damp heat test result.

4. CONCLUSIONS

We reported realization of a ring marked fiber having enlarged Aeff of 160 μm^2 and standard outer diameter of 250 μm without degradation of its ultra-low loss performance over entire the C- and L- bands, 0.149 dB/km at 1550 nm. With applying a primary coating having very low Young's modulus and a longer ring mark gap of 200 mm, we clarified the micro-bending loss could be efficiently suppressed as low as that of a fiber without ring marks. Furthermore, mass-productivity was verified with 2,000 km long fabrication, realizing ultra-low averaged loss of 0.151 dB/km at 1550 nm with Aeff of 150 μm^2. In addition, high environmental reliability and mechanical durability were also confirmed.

This ring marked fiber technology would contribute to constructions of ultra-high capacity global optical networks.

5. REFERENCES

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