Benefits of Ultra low Loss Fiber in Submarine Transmission (Review Article)

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Abstract - *As per latest research, researchers demonstrated the lowest transmission loss 0.1419dB/km at 1560nm wavelength and 0.1424dB/km at 1550 nm wavelength in a Ge-free silica-core optical fiber. As per previous records, it was improved by 4mdB/km from previous lower loss. Fluorine co-doped, Ge-free silica core, which reduces the disorder in the microscopic glass network structure, that causes Rayleigh scattering losses without a major increase waveguide imperfection loss. With the help of two layered polymer coating with an inner layer having lower elastic modulus then before, also contributed to very low loss without major change in micro bending loss increase even with an large effective area of 147 μm². As per new demonstrated fiber, we can reduce 7% of no. of repeaters compared to previous record loss fibers, and this will reduce the capex of long haul transmission and improve link budget. Such research will be very useful in the area of transoceanic submarine cable communication system.*

***Key Words*: Submarine cable, Long haul transmission, low loss fiber, Ge-Free silica-core fibers, Repeaters Reduction.**

1. INTRODUCTION

Since 1966 when low loss silica glass fiber cable introduced in communication[1], much remarkable work done in the field of low loss optical fiber cable. Among of them, in 1986 [2], Ge-free silica core fiber demonstrated 0.154dB/km loss at 1550 nm wavelength and this cable was commercialized in 1988 at a loss of 0.170 dB/km, and this was also a very remarkable achievement because previous Ge-dopped silica fiber loss was 0.20 dB/km and demonstrated fiber showing 0.170 dB/km at that time. After Ge-free silica core demonstration more improvements came with time and fibers demonstrated at a loss of 0.162dB/km in 2010[3], 0.154dB/km in 2013[4] and 0.151dB/km in 2016/17[5]. This improvement after 2010 has been surly driven by introduction of digital coherent techniques in long distance transmission systems, in which the lower loss becomes essential since it enhances optical signal-to-noise ratio (OSNR). Such type of high importance of lower loss also influenced the R&D fibers with a slight delay from the commercial fibers. As also seen in Fig. 1, improvement in the R&D fibers was slow until 2013, such as 0.150 dB/km in 2002 [6], and 0.149 dB/km in 2013 [4], the improvement after 2013 has been spiked, such as 0.1467 dB/km in 2015

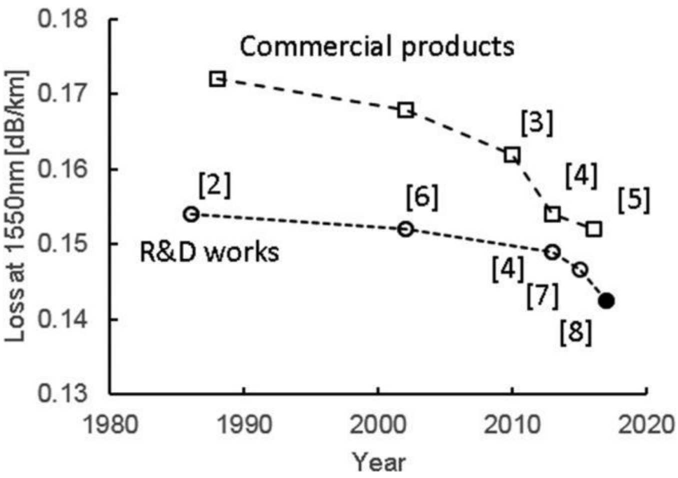

Fig-1. History of improvement in losses of Ge-free silica core optical fibers measured at 1550 nm wavelength.[7], and most recently 0.1424 dB/km in 2017 [8]. The rate of improvement after 2013 is −1.7 mdB/km/year, being almost 7 times as fast as −0.25 mdB/km/year before 2013.When experiments done in terms of lower losses, OSNR also increased in large effective area A_{eff} by allowing signal with high power launched into the fiber without nonlinear effect. As per previous history of submarine cables, we categories it in three generations. In first generation 1980s, A_{eff} of 80 μm², in second generation A_{eff} of 110 μm² in the year 2000 and in recent third generation A_{eff} of 130-153 μm²[4,7,9], third generation fiber specially designed for digital coherent transmission.

Such type of low loss and Aeff area fibers are very useful in transoceanic transmission. Because the costing of repeaters and maintenance is very high and such types of low loss fibers can reduce no. of repeaters from transmission links.

2. CHARACTERISTIC

Demonstrated fiber was fluorine doped, Ge-free silica core surrounded by matched cladding. The core was slightly doped in fluorine (not restricted) as low as it does have any effect on the refractive index of the core but because of it viscosity reduced and the activation energy for relaxation of the microscopic glass network [12], and same character was using for reduction in loss.

A standard shipment fiber real was approx 12.85km, and its transmission loss was calculated by standard cutback method. As per Fig-2 (b), we can see the lowest loss was at 1560 nm and it was 0.1419 dB/km (± 0.0001dB/km as a standard error). As per reports at 1550 nm wavelength lowest loss recorded as 0.1424 dB/km(± 0.0001dB/km as a standard error). In the loss reduction process we have to understand some causes of the significant loss reduction, instead of conventional loss spectrum we have to evaluate the fictive temperature and that is shown to higher order modes in the wavelength shorter than the cut-off wavelength. Temperature of equilibrium SiO_2 liquid having same degree of disorders, which causes Rayleigh scattering, as the non –equilibrium SiO_2 glass under test is called fictive temperature[13]. This disorder comes in melted state of fiber drawing process and minimized by glass relaxation process, when drawing fiber cooled down [14].

Because of viscosity increases in cooled glass, this relaxation is limited. So the fictive temperature calculated by relation between viscosity and temperature and history of temperature of glass relaxation process, means glass composition and drawing temperature can affect the fictive temperature. By introducing fluorine [12], chlorine [15], and alkali metals [16, 17] in glass we can reduce the fictive temperature. For drawing process fictive temperature controlled reduction, we have to reduce the drawing speed

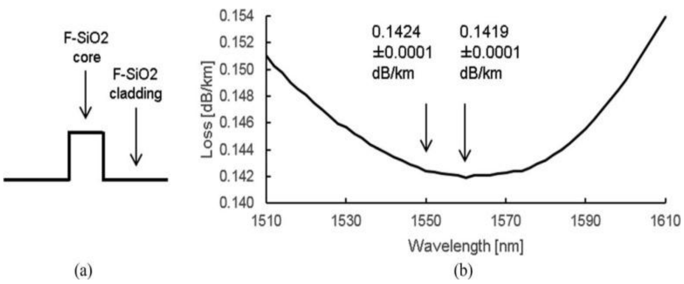

Fig-2 (a) Fiber view (b) Transmission loss spectrum by cutback method

and passing the annealing furnaces after exiting the drawing furnace [18, 19]. Due to reduced disorder in SiO_2 microscopic glass network, Rayleigh scattering reduced and it is directly related to loss reduction from fiber.

As we know, we have used fluorine doping in the core and it will reduces the viscosity [13], and it will contribute lower waveguide imperfection loss, it may be possible because of viscosity mismatch of core and cladding [20]. As per Ogai [21], slightly fluorine doped Ge-free silica core fiber had a lower wavelength independent loss, which was because of waveguide imperfection, than pure silica-core fiber, and as per result we had minimum loss of 0.156 dB/km loss at 1550 nm wavelength. Whereas Ogai did not mention fictive temperature, reducing fictive temperature in the slightly fluorine-doped core structure should be an effective way to realize the present ultra-low loss.

Table-1 Characteristic of fabricated fiber at 1550nm wavelength

Characteristics	Value	Unit
Loss at 1550 nm	0.1424	dB/km
Minimum Loss	0.1419	dB/km
Wavelength at minimum loss	1560	nm
Aeff	147.4	μm^2
MFD	13.5	μm
Cable cut of wavelength	1507	nm
Chromatic dispersion	20.5	ps/nm/km
Dispersion slope	0.06	$ps/nm^2/km$
30mm-redus macrobending loss at 1625 nm	0.04	dB/100turn
PMD on drum	0.05	$ps/km^{1/2}$
Cladding diameter	125	μm
Coating diameter	245	μm

3. IMPECT ON NETWORK

For transmission as long as transoceanic long haul submarine transmission, these types of ultra low loss fibers are very useful. Because of in this type of transmission, losses should be compensated for more than hundred amplifiers and amplifiers can create noise in transmission, high costing, and more power consumption of the system. In the discussion on advantages of low/reduced loss by the theory of fiber figure-of-merit (FOM) [22, 23]. Figure-of-merit formulates as a relative OSNR in reference to know fibers in repeated DWDM equipment composed of positive dispersion fiber. Where the nonlinear loss can be noted as an additive white Gaussian noise [24].

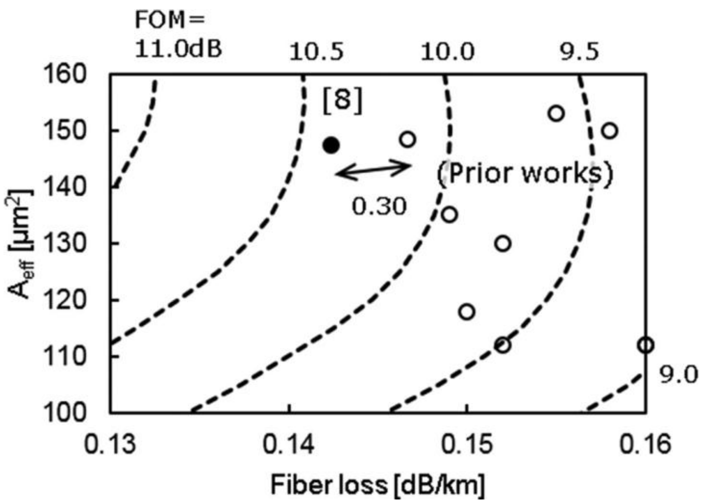

Fig-3 FOM contour map for an 80 km span. The solid and open plots show the present and previously reported works, respectively. The dashed lines show contours of FOM value represented as Q-factor assuming QPSK-100G transmission

We calculated the FOM against fiber loss and Aeff showed the result as shown lines in Fig.3. The FOM were expressed as an expected Q-factor in a 10,000km span 50GHz grid, QPSK-100G transmission based on reference experiment. As we are assuming span length is approx 80 km , the EDFA output limit to be -2dBm/ch and splice losses at repeaters to be given by the MFD mismatch loss b/n SMFs 10.5 μm. As fig-3 shows, the present ultra-low loss fiber with 0.1424 dB/km at 1550 nm had 0.30dB or higher FOM than the previously demonstrated low loss and large Aeff fibers.

Low loss fibers are very beneficial in terms of the decreased number of repeaters which ware necessary for transmission. These benefits can be calculated by FOM theory with varied span length and constant FOM. Calculated necessary number of repeaters for transmission to carry a 50GHz grid 8QAM-150G signal over 10,000km span with 7dB Q-factor minimum as it can. Now the demonstrated ultra low loss fiber can reduce the no. of repeaters by 7% as compared to previous low loss fibers use. This 7% reduction in repeaters number can improve the efficiency of the system in terms of repeaters capex/costing and power consumption. The electric power supply from the source to submarine repeaters is showing the constraint for system capacity [11, 12]. The reduction of the number of repeaters can gives an effective option to enlarge the capacity of the power-limited system.

All experiments are based on single coil of low loss fiber which was 12.85km long. For transoceanic transmission, production of this should be in large volume and it is not sure that all high volume product will work as a demonstrated 12.85km.

4. CONCLUSION

The future in Ge-free silica core and micro bending resistant polymer coating shows the result in the form of low loss fiber of 0.14dB/km. If this ultra low loss fiber are deployed for transoceanic transmission, then it will deliver a good output in the terms of efficiency, reduced no. of repeaters, power consumption and capacity point of view the limit imposed by electrical power supply to repeaters, so the importance of ultra low loss fiber increases.

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