Low loss optical coupling structure between two ends of silica glass optical fibers by inserting TeO_2 melt

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Abstract

Less than 1.5dB of insertion loss was realized in an optical coupling structure in which two TEC (Thermal-diffusion Expanded Core) fibers are spliced via quenched TeO_2 melt whose length was 0.5mm. The quenched melt seems to be free of precipitates because they would bring about larger loss if existed. The loss due to imperfect optical coupling between the fibers is estimated to be about 1 dB, which can be reduced by introducing some refractive index modulation into the present structure.

Key words: optical fiber, tellurite glass

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1 Introduction

Making a low-loss optical connection among photonic components is an essential art for integrating photonic circuit but also a challenging work when the modules

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are made of different kind of materials, such as silica fiber and non-silica glass having low softening temperature. Recently, the authors succeeded to make an optical coupling structure between two ends of silica glass optical fibers by inserting several nano litters of tellurite glass melt (80TeO_2-20ZnO in mol%[1] and TeO_2[2]). In spite of the large gap in thermal expansion coefficient among these glasses, no fracture and bubbles were observed in the tellurite glass segment. Its insertion loss was, however, quite high as about 10dB for 0.5mm-long tellurite glass segment because there is no waveguide structure in the segment.

In order to decrease the insertion loss, we tried to make this structure by using TEC (Thermal-diffusion Expanded Core) fibers in which the diameter of the core at the fiber-end is expanded so as to make the outgoing beam collimated.

2 Experimental procedures

Commercial single-mode fiber cables with TEC treatment are used in this study. Their expanded core diameters are about 30μm. Two fibers were placed on fiber holders so that their ends face each other. A gold plate with a small heater was set between the two ends of the fibers. A small amount of TeO_2 powder (5N, Shinko Chemical Co., Ltd.) was melted on the heater, which was kept at a constant temperature of about 460 $^\circ$C. The end of the fibers were inserted into the glass melt from its side(see Fig. 1(1)). Then, the plate is lowered to leave a small amount of the melt between the two ends(Fig. 1(2)). The fibers were immediately moved to an appropriate position before the melt was solidified(Fig. 1(3)). It takes few seconds to perform all the movements of the fibers and the heater described above, which are controlled by a personal computer. We made two set of this coupling structures and also made another group of sets by using normal single-mode(SM) fiber cables, whose core diameter is about 10μm, for reference.

The location of scattering points along the light path of the optical coupling structure was determined by a high-resolution reflectometer (AQ7410A, Ando Electric Co.,Ltd.) which consists of a Michelson interferometer and a laser of 1.31 μm. This information gives us not only the distance between the two fiber ends but also whether or not some crystals and/or bubbles precipitated in the glass segment. Transmittance of the laser light through the optical coupling structure was measured by an optical multimeter (AQ-2140, Ando Electric Co.,Ltd.). These measurements also performed on an empty fiber pair varying the distance of two fiber ends.

3 Results

Fig. 2 shows a typical side view of the coupling structure in which any visible precipitation is not observed. The reflection measurement also shows that there's no reflection along the light path except at the two interfaces between the fiber and the glass.

Fig. 3 shows the insertion loss values of the optical coupling structures (closed marks) and empty fiber pairs (open marks) as a function of the distance between the two fiber ends, d. 0 dB of the insertion loss corresponds a configuration where two fiber ends are physically contacted to give a minimum transmission loss.

The loss values of empty fiber pairs increase with d since the transmitted light between the fibers is not completely collimated even for TEC fibers. The loss values of the coupling structures with SM fibers are smaller than that of the fiber pair because the outgoing beam from the fiber end refract to inner angle in the glass segment compared with that in the air. This situation is not clearly observed for

TEC fibers because the outgoing beam is already collimated.

There are variations in loss value because of a dis-alignment of facing fiber centers, which is due to an accumulated displacement of the fiber holders during their motions in fabrication. The lowest values for SM fibers in the present trial is 7.63 dB while the values for TEC fibers are 1.33 and 1.48 dB, which are less than one-fifth of the former value.

4 Discussion

These insertion loss values includes Fresnel reflection loss at the interface of silica and TeO_2 glasses or air, which is estimated as 0.18 dB or 0.16 dB per an interface, respectively, on the assumption that their refractive indices are 1.46, 2.19 (extrapolated value in [3]) and 1.00, respectively. Scattering loss due to precipitates at the TeO_2 glass segment is not probable because insertion loss values of the coupling structure with SM fibers for TeO_2 glass and $80TeO_2$-20ZnO glass, which is more thermally stable, are nearly the same[2]. Thus, loss factors intrinsic to TeO_2 glass, i.e. absorption and scattering during 0.5mm segment, are expected to be very small. Consequently, the residual loss for the TEC fiber pair is about 1 dB, which is mainly due to the optical coupling efficiency between the TEC fibers.

These reflection loss and coupling loss can be reduced by refractive index modulation at the interface and the glass segment. The reflection is suppressed if the refractive index gap at the interface become decreased by introducing refractive index gradient at the end of the fibers[4]. The coupling efficiency is expected to increase when waveguide structure is induced inside the glass segment by an irradiation of high-energy laser pulse ($\sim$fs)[5].

The quenching rate of the inserted melt is expected to be more than 10^3K/sec on the assumption that the quenched TeO_2 melt completely vitrified[2]. This implies that even the melts with poor stability, i.e. which can vitrify only by twin roller quenching method, can be spliced to silica fibers without precipitation. Thus, this fabrication technique has a possibility of introducing new active function of non-silica glasses into passive silica waveguides.

TeO_2 has the following advantages as bonding agent in the present fabrication method. 1) It forms glassy state only in single component, 2) TeO_2 is non-hygroscopic, and 3) melting time is only less than ten seconds so as to avoid volatilization problems.

5 Conclusion

Low loss optical coupling between two TEC fibers is demonstrated via quenched TeO_2 melt. The lowest insertion loss is 1.33 dB, whose main loss factors are Fresnel loss (about 0.35 dB) and imperfect coupling between two fibers. Further loss reduction can be possible by modulating refractive index at the coupling structure. Moreover, this fabrication method is useful to make a connection between silica waveguides and non-silica glasses with poor thermal stability.

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Figure Captions

Fig. 1 Illustration showing an experimental setup and a procedure to make an optical coupling structure(see text).

Fig. 2 Sideview of an optical coupling structure. The diameter of the fiber is 125 μm and the distance between the two fiber end is about 0.5mm.

Fig. 3 Insertion loss vs. distance between the two fiber ends for the optical coupling structure (closed marks) and an empty fiber pair (open circles).

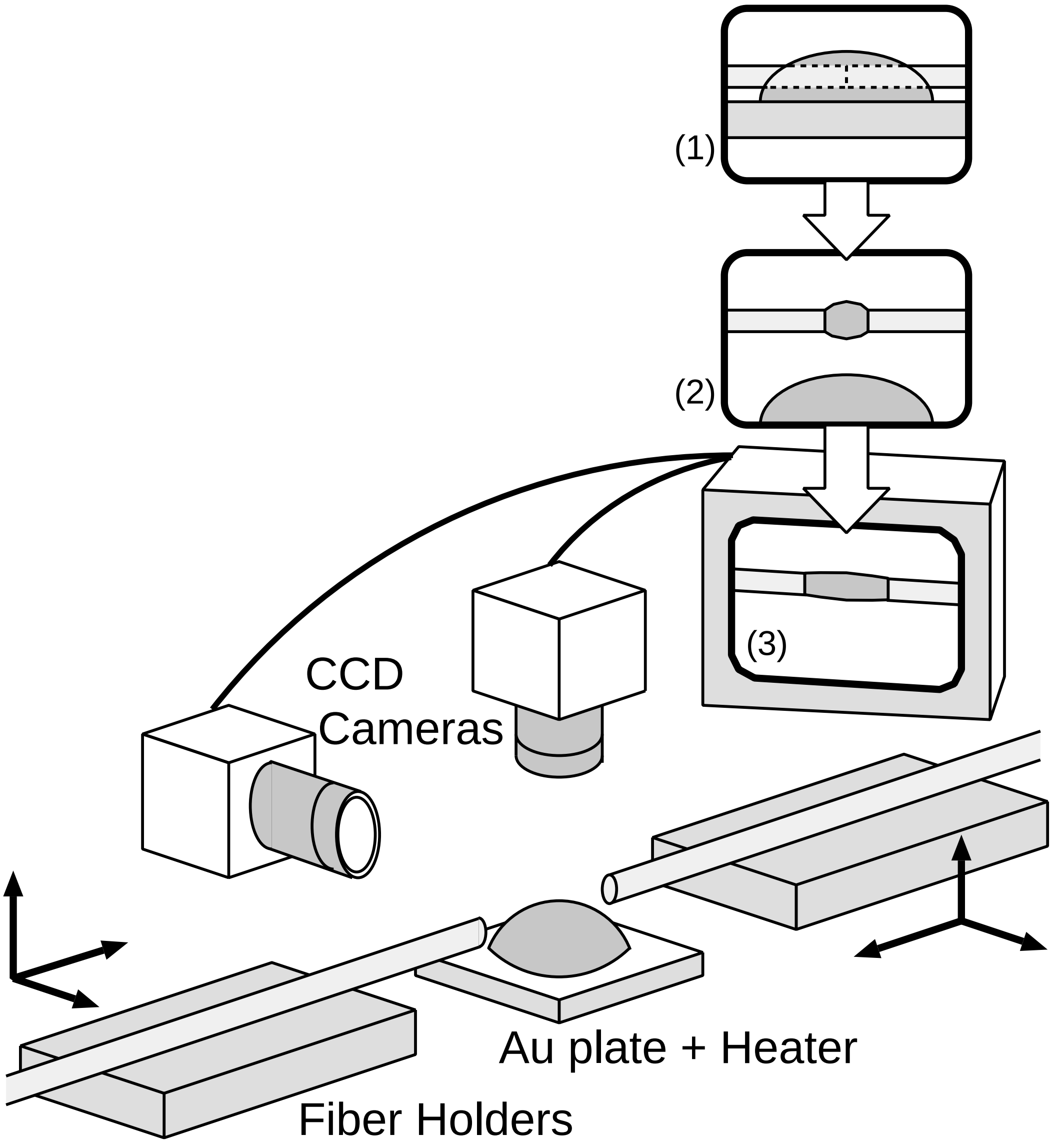

Fig. 1. Illustration showing an experimental setup and a procedure to make an optical coupling structure(see text).

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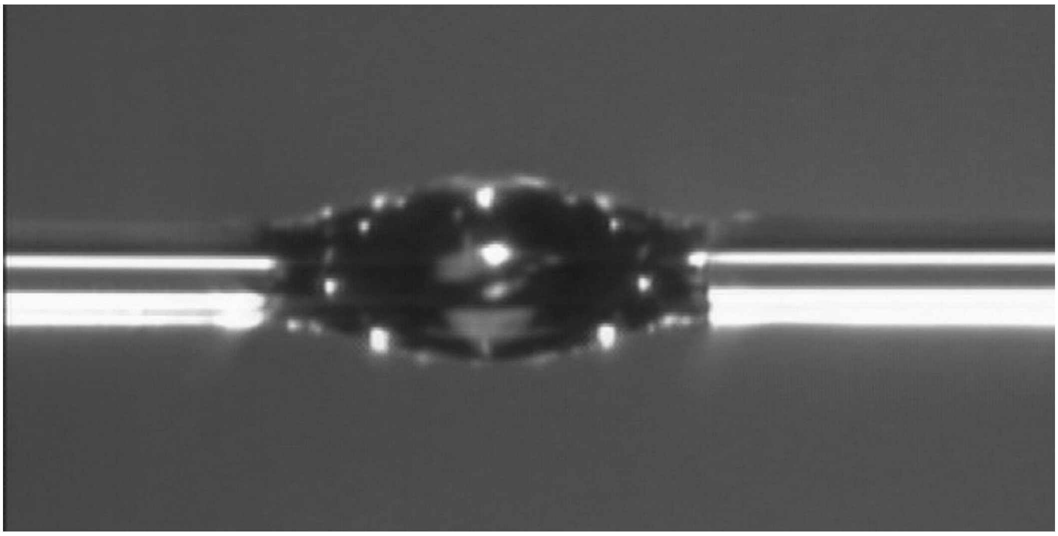

Fig. 2. Sideview of an optical coupling structure. The diameter of the fiber is 125 μm and the distance between the two fiber end is about 0.5mm.

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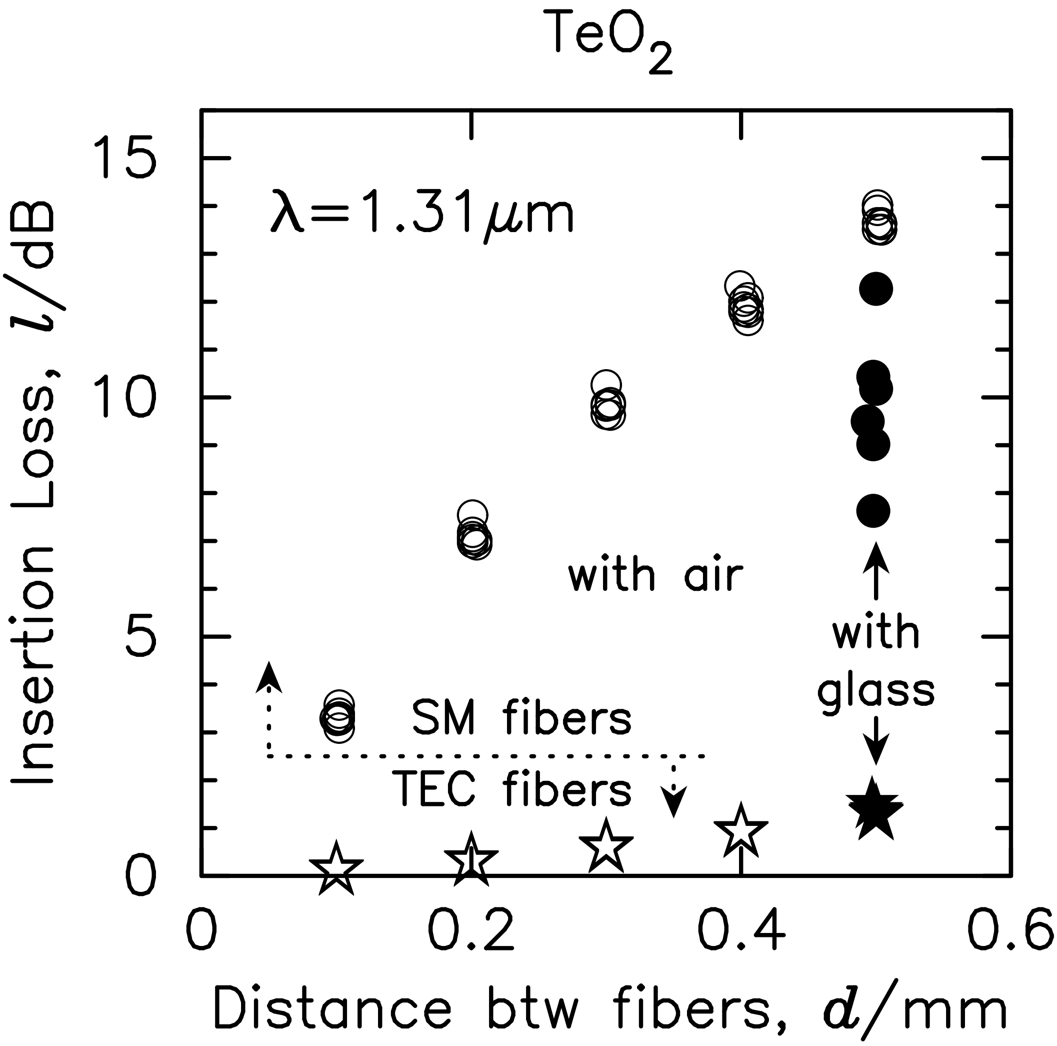

Fig. 3. Insertion loss vs. distance between the two fiber ends for the optical coupling structure (closed marks) and an empty fiber pair (open circles).

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