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b）報文種類 論文

c）C1-a C2 C3

d）シリカガラス光ファイバ先端間をテルライトガラスで満たした光結合構造の形成

Formation of optical coupling structure between two ends of silica glass optical fibers by inserting tellurite glass melt

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f) Several nano liters of tellurite glass melt was inserted and quenched between two ends of silica glass optical fibers to form a optical coupling structure, whose length was several hundred μm. Dispite the large gap of thermal expansion coefficient between these glass materials, neither fracture nor bubbles were observed, which usually lead to a large optical propagation loss. The insertion loss was less than 10 dB, which was mainly due to the lack of an optical waveguide structure in the tellurite glass segment. Further loss decrease is expected to be possible by introducing a refractive index modulation.

g) 数 nl のテルライトガラス融液を２本のシリカガラス製光ファイバの間の数百μｍの空間に挿入後急冷した光結合構造を作製した。両ガラスの熱膨張係数が大きく異なるにもかかわらず、光散乱の原因になるようなヒビや気泡は発生しなかった。挿入損失は 10dB 以下であり、この原因はテルライトガラス部分に導波構造を持たないことによる。屈折率変調を導入すれば、この損失値を低下させることが可能と考えられる。

h) optical fiber, tellurite glass, thermal expansion

注意) 写真の原本は JPEG ファイルである。(Fig.2: 1600x600, Fig.6: 1600x800)

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Formation of optical coupling structure between two ends of silica glass optical fibers by inserting tellurite glass melt.

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(Received)

Several nano liters of tellurite glass melt was inserted and quenched between two ends of silica glass optical fibers to form a optical coupling structure, whose length was several hundred μm. Dispite the large gap of thermal expansion coefficient between these glass materials, neither fracture nor bubbles were observed, which usually lead to a large optical propagation loss. The insertion loss was less than 10 dB, which was mainly due to the lack of an optical waveguide structure in the tellurite glass segment. Further loss decrease is expected to be possible by introducing a refractive index modulation.

KEYWORDS: optical fiber, tellurite glass, thermal expansion

1. Introduction

Constructing integrated photonic circuit needs the technologies to connect various optical modules each other, such as light sources, modulators and detectors, via optical waveguides. The most typical material for optical waveguide is silica glass because its transmission loss is so low that it is used for optical fibers and planar lightwave circuit (PLC), which is made of deposited a-SiO_2 thick film on Si substrate.1) The connection between PLC and semiconductor-based optical modules is easily accomplished, because their fabrication technique is common, i.e. deposition, lithography and etching.

As for the modules made of inorganic glasses, except silica glass, it is not so easy because these glasses are mainly fabricated via liquidus state at higher temperature. Optical fiber is the typical example; hot glass melt is poured into a mold to make a fiber preform, which is then re-heated to draw fibers.2) In order to introduce non-silica glass materials into existing fabrication process for semiconductors, some deposition techniques are being investigated.3)

In this study, we propose another approach to connect non-silica glass device and silica-glass-based waveguide, that is, shaping the glass melt directly on the waveguide by introducing spot-heating and manipulating technique of small amount of hot melt. This is possible in theory if the hot melt does not react with the waveguide and the quenched glass acts as an optical device itself. The first limitation is satisfied by using glasses with low softening temperature. Tellurite glasses are appropriate for this purpose because their softening temperature is about 350 °C, much lower than that of silica glass, and is known to show active properties such as non-linear optical effect,4) acousto-optics effect5) and broad band amplification for 1.55 μm band when Er^{3+} ions are doped.6) In this study, tellurite glass melt is inserted between two ends of silica glass optical fibers to form an optical coupling structure. Furthermore, transmittance and reflectance of this device is evaluated.

2. Experiment

Commercial optical fiber cables (single mode, 3m, with FC connectors) are used in this study. Bare fibers were cut by a diamond blade with ultrasonic vibration which was placed on the surface of the fiber stretched along its length. Two fibers were placed on fiber holders so that their ends face each other, as shown in Fig. 1. A Pt plate with a small heater was set between the two ends of the fibers. Their relative positions were controlled by a personal computer. The heater was kept at a constant temperature of about 400 °C which was monitored through a thermo couple placed on the back. A small piece of 80TeO_2-20ZnO (mol%) glass was melted on the Pt plate. The glass transition temperature for this glass is 307 °C, which was determined by DTA measurement (heating rate: 10 K/min). The droplet was observed through video cameras placed from its top and side. Two fibers were inserted into the droplet from its side. Then, the plate is lowered to leave a small amount of the melt between the two ends. The fibers were immediately moved to an appropriate position before the melt was solidified. The movement of the fibers described above ends within 1 seconds.

Reflection from the optical coupling structure was measured by a High-Resolution Reflectometer (AQ7410A, Ando Electric Co.,Ltd.) which consists of a Michelson interferometer and a laser of 1.31 μm. Transmittance was measured by a halogen lamp and spectral analyzer (AQ-6315B, Ando Electric Co.,Ltd.).

3. Result

Fig. 2 shows a side view of the optical coupling structure. The diameter of the fiber is 125 μm and the distance between the two fiber end is about 0.6mm. Fig. 3 is the distribution of reflected light along the light path of the optical coupling structure and an empty fiber pair. There is only two sharp peaks which correspond to the reflection from the fiber ends. The fine structure below -65dB is due to the noise of light source. Since this measurement assumes the refractive index of the whole path to be 1.5, the length between the two peaks is not correspond to its true length, that is, the length seems to be shorter for glass ($n \sim 2$) and longer for air ($n \sim 1$).

Transmittance spectrum of the same structure and an optical fiber only are shown as the dashed lines in Fig. 4. The subtraction of these spectrum corresponds to the insertion loss of this optical coupling structure, which is less than about 10 dB. The hole located near 1100nm appears because there is a difference in the cut-off wavelength of single mode propagation among these two fiber cables. Since these cables are commercial products, their cut-off wavelengths are not guaranteed to be the same value as their propagation losses are. Thus, the subtraction spectrum is reliable except at around the hole.

4. Discussion

On splicing two materials each other, we have to be careful for the gap between their properties such as refractive index and thermal expansion coefficient. The former gap bring about Fresnel's reflection and the latter an internal stress. After discussing these effects, the merits of this process are discussed.

4.1 Origin of the insertion loss

According to Fresnel's laws of reflection, reflectance and transmittance in energy at normal incidence are given as

$$R = \left(\frac{n_1 - n_2}{n_1 + n_2} \right)^2 \tag{1}$$

and

$$T = \frac{4n_1n_2}{(n_1 + n_2)^2}, \tag{2}$$

where n_1 and n_2 are refractive indices of incidence and transmittance sides respectively. In this section, we assume the refractive indices of the glasses used in this study, i.e. silica glass and tellurite glass, as 1.46 and 2.00. Thus, $R = 0.024$ and $T = 0.976$ are obtained. Then, under an ideal condition that this optical coupling structure has no loss except Fresnel's reflection loss, its insertion loss is calculated as $T^2 = 0.95 = -0.2$ dB (see Fig. 5 top).

On the other hand, the actual transmittance for 1.31μm light is -8.6 dB ~ 0.14 (see Fig. 5 bottom) as shown in Fig. 4. The gap appears because there is no waveguide structure in the tellurite glass segment, which bring about low optical coupling. Assuming the coupling ratio x, the actual transmittance is written as xT^2. Thus, $x = -8.4$ dB ~ 0.14 is obtained.

In order to observe light propagation in the glass segment, we made a coupling structure by using Er^{3+}-doped tellurite glass melt, which is known to show upconversion fluorescence when excited by 800nm light.7) The Er^{3+} ions were excited by an irradiation of CW Ti:Sapphire laser light (800 nm, 10 mw) which is propagated in multi-mode through one of the fibers. As shown in Fig. 6, the propagation is recognized as a expanding beam of green upconversion fluorescence.

To increase the optical coupling efficiency in this structure, the beam expansion in the glass segment should be restricted. This can be performed by TEC (Thermal-diffusion Expanded Core) fiber, where refractive index distribution near the end of the fiber is modified so that its beam propagation is controlled. It may be also effective if a refractive index modification is induced inside the glass segment by an irradiation of high-energy laser pulse ($\sim$fs).[8)]

4.2 Effect of thermal expansion coefficient

When we splice two materials by melting, it is desirable if their thermal expansion coefficient are same value. Because, if the amount of shrinkage on cooling is different each other, an internal stress is generated along the interface of these two materials, which may bring about some cracks and/or precipitation of dissolved gases.

Between the two glasses used in the present coupling structure, there is a large gap in thermal expansion coefficient as listed in Table I. The gap is one order larger than that for a-SiO_2/Si pair. This pair is used in commercially available PLC. In spite of this two-order-gap, no fracture and bubble are observed in the glass segment. This is supported by the reflection data shown in Fig. 3 that no reflection is found between the two interfaces. The reason is considered that the area of the interface is so small that the induced internal stress is under the critical point of appearing cracks and bubbles. The absence of reflection also shows that there's no precipitation of crystals which causes light scattering.

4.3 Merits of the process proposed

Generally, optical fibers made of non-silica glasses are fabricated by preform method or double crucible method. By the former method, the glass melts are once quenched to room temperature, reformed to make a fiber preform, and re-heated to draw fibers. During this process, crystallization may occur because the glass stays at just above the glass transition temperature, at which nucleation rate is its maximum. By the latter method, the glass melts stay long time at its softening temperature in the crucible, which may also bring about precipitation of crystals.

As for the proposed process, the glass segment is connected with optical waveguides by a mechanical operation in a few seconds. Since the volume of the glass segment is several nano liters, the melt can be quenched so quickly to prevent precipitation of crystals. Therefore, this method can be applied for even the glass materials not suitable for fiber drawing due to its poor thermal stability.

5. Conclusion

We fabricated an optical coupling structure in which two silica glass optical fibers are spliced by tellurite glass. This was made by manipulating small amount of the glass melt through the optical fibers. In spite of a large gap in thermal expansion coefficient among these glasses, no fracture and bubbles are observed in the tellurite glass segment. Although the insertion loss is about 10dB, this can be reduced by modification of refractive index profile of the structure.

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Figure captions

Fig. 1. Experimental setup.

Fig. 2. Sideview of an optical coupling structure. The spacing between the two silica fibers is about 0.6 mm.

Fig. 3. Distribution of reflection along the light path of the coupling structure and an fiber pair which is separated by air.

Fig. 4. Transparent spectra of the coupling structure and an silica glass fiber without air-spacing.

Fig. 5. Illustration of analysis in loss factors(see text).

Fig. 6. Sideview of an optical coupling structure with Er^{3+}-doped tellurite glass. Upconversion fluorescence is observed by exciting 800nm laser light.

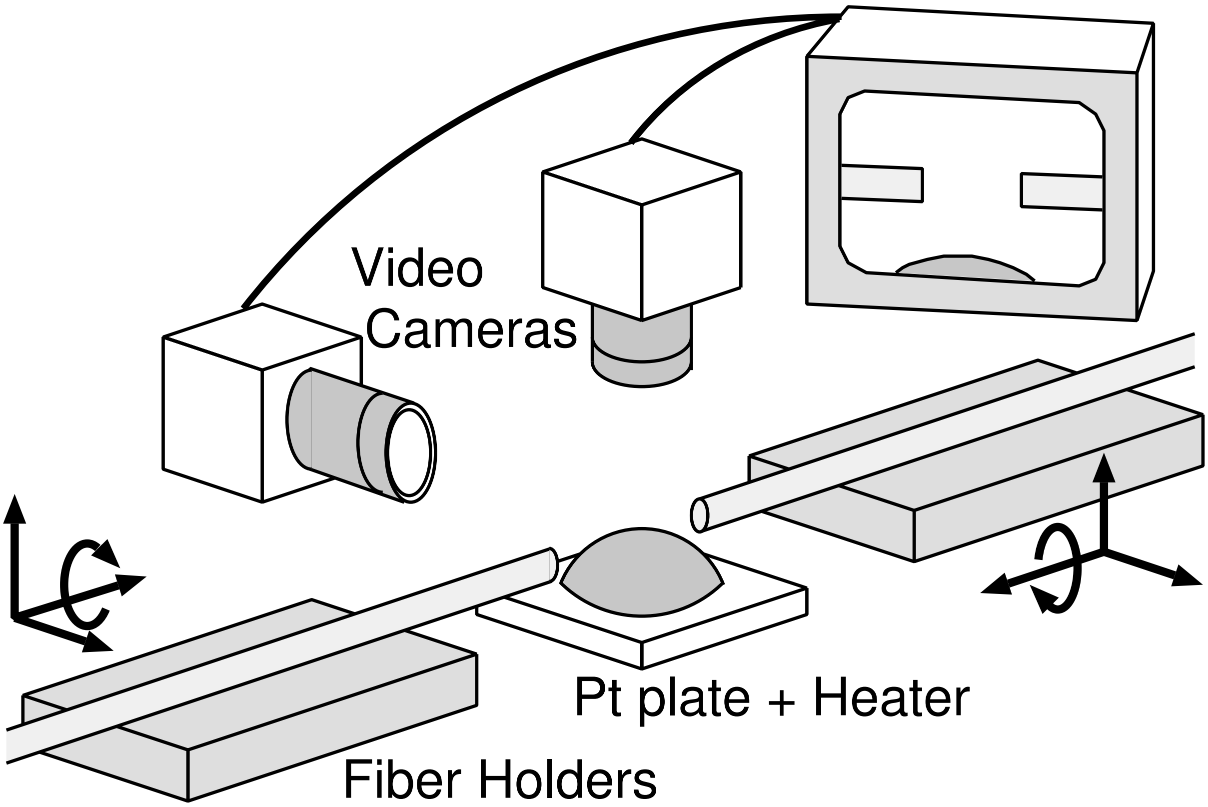

Fig. 1 (TODOROKI)

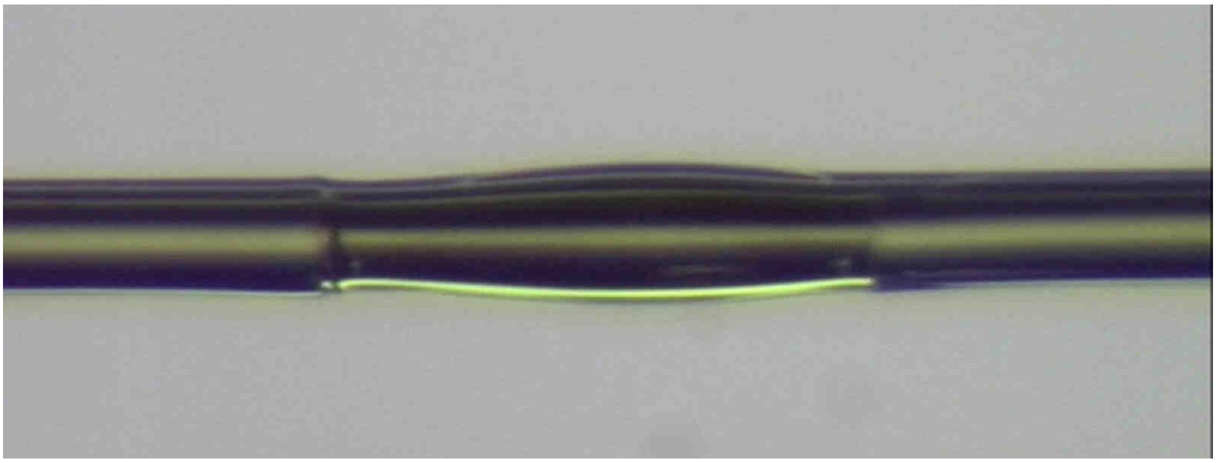

Fig. 2 (TODOROKI)

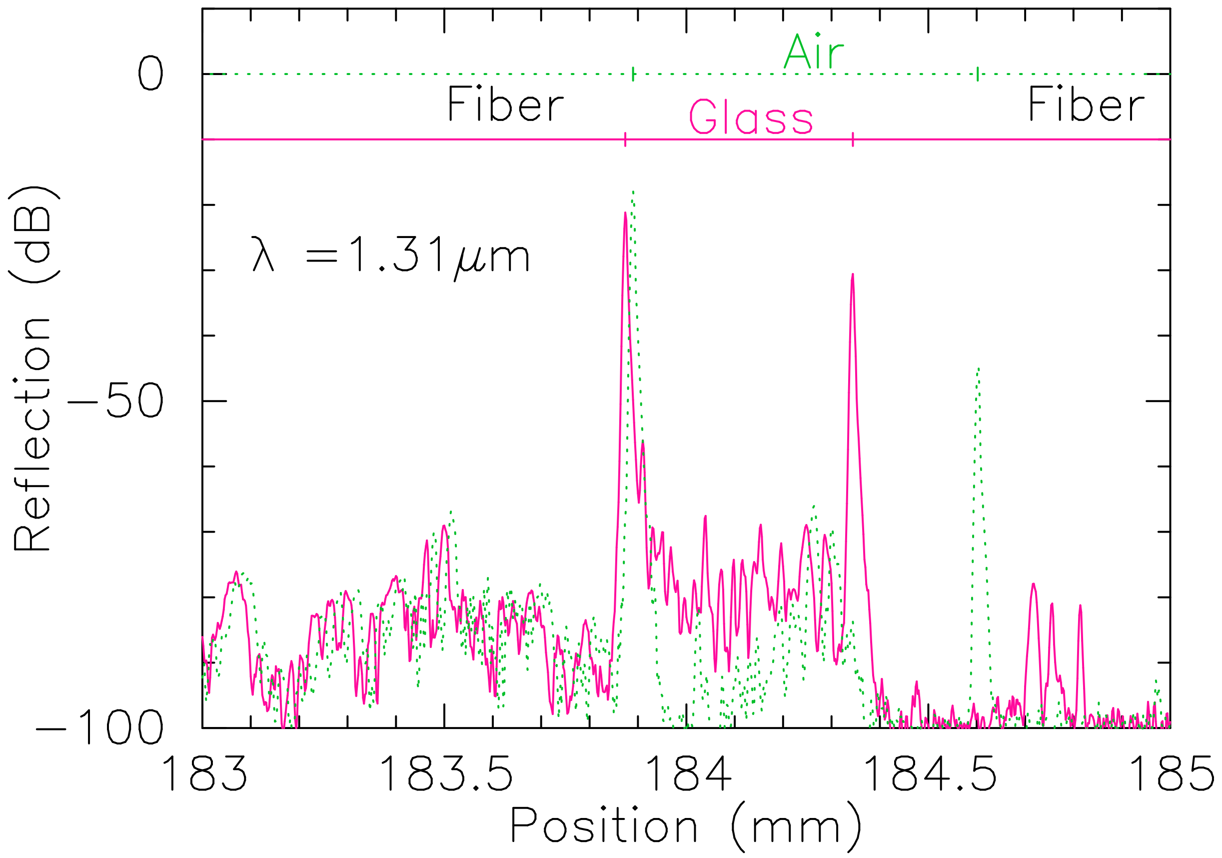

Fig. 3 (TODOROKI)

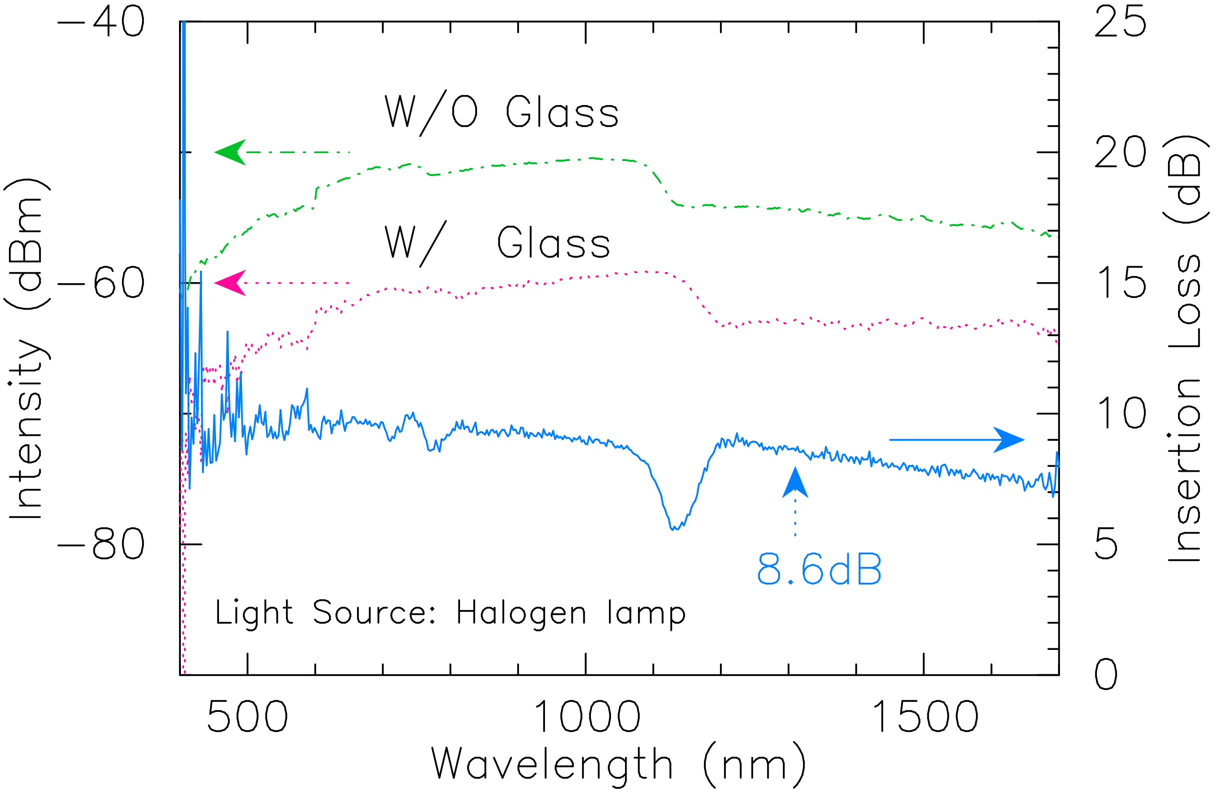

Fig. 4 (TODOROKI)

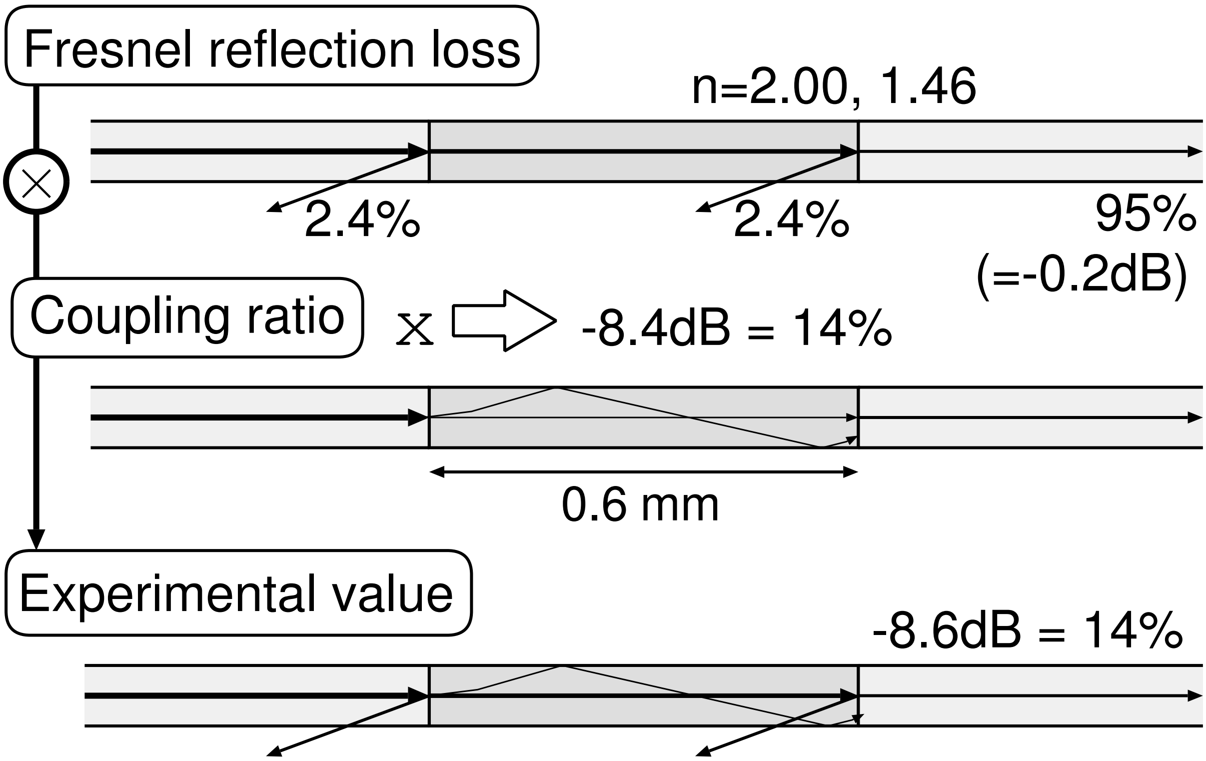

Fig. 5 (TODOROKI)

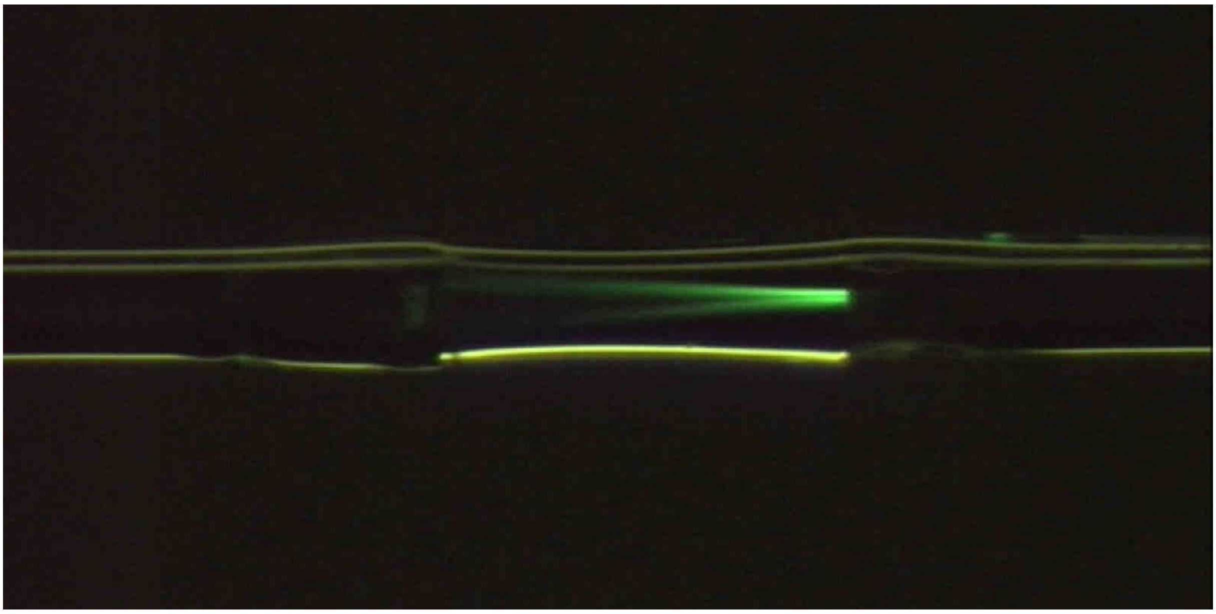

Fig. 6 (TODOROKI)

Table I. Thermal expansion coefficient for several materials taken from some databooks($\times 10^{-7}/^\circ$C).

silica glass	$\sim$6
Silicon	26.3
80TeO$_2$-20ZnO glass (mol%)	170