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저 반사율을 가진 광섬유 거울의 제작

박재희*

Fabrication of Low Reflectance Optical Fiber Mirrors

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요 약

연속적인 단일모드 광섬유에 설치 가능한 저반사율을 가진 광섬유 거울들이 기계식 접합기와 깨끗이 절단된 끝단면에 TiO_2 유전체 물질로 코팅된 광섬유 단편들을 사용하여 만들어 졌다. 0.1%의 반사율을 가진 광섬유 거울들이 만들어 졌을 때 광섬유 거울의 삽입손실의 범위는 0.055dB 부터 0.3dB 였으며 평균 삽입손실은 0.15dB 였다. 저반사율을 가진 광섬유 거울들은 필드에서 쉽게 만들어 질수 있었다.

Abstract

Low reflectance optical fiber mirrors in the continuous length of the single mode fiber were fabricated using mechanical splices and pieces of fiber coated with TiO_2 dielectric film at the cleaved end. When fiber mirrors of refelctance of about 1% were produced, the insertion loss ranged from 0.055dB to 0.3dB and the average insertion loss was 0.15 dB. These mirrors could be produced easy in the field.

I. Introduction

An optical fiber mirror serving as a reflector in the continuous length of the fiber is attractive in optical fiber communication and sensor systems[1-2]. Some types of optical fiber mirrors have previously been demonstrated[3-6]. An optical fiber mirror was produced by butt jointing a metal coated fiber to an uncoated fiber[3]. Other optical fiber mirrors configured as cleaved fiber ends separated by a small air gap[4] and as a fiber ring produced with a directional coupler[5] were reported. These mirrors had the reflectances greater than 2% and had high excess losses. The fusion splicing technique[6] for making a fiber mirror was reported. The mirror was fabricated by joining two fibers, one of which was coated on the end with about 1400Å of TiO_2 by electric arc splicing. The reflectances of the mirrors fabricated by the fusion splicing technique were adjustable and the excess losses were in the range of 0.5dB to 1dB[7]. And also the fabrication was not easy in the field. Therefore, the mirrors produced by the fusion splicing technique as well

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as other mirrors would not generally be suitable for deployment in a multiplexed sensor having many reflectors because of high excess lossess, high reflectance, or fabrication difficulty in the field.

In this paper, a fabrication technique is described for producing low loss and low reflectance fiber mirrors in the continuous length of single mode fiber which can be fabricated easy in the field. The configuration of the mirror fabricated by this technique is shown in Fig. 1. The mirror is produced using a mechanical splice and a piece of fiber coated with a TiO_2 dielectric film.

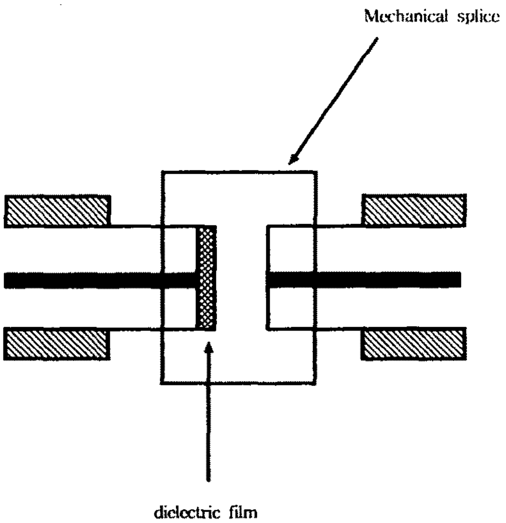

Fig. 1. Configuration of low reflectance optical fiber mirror.

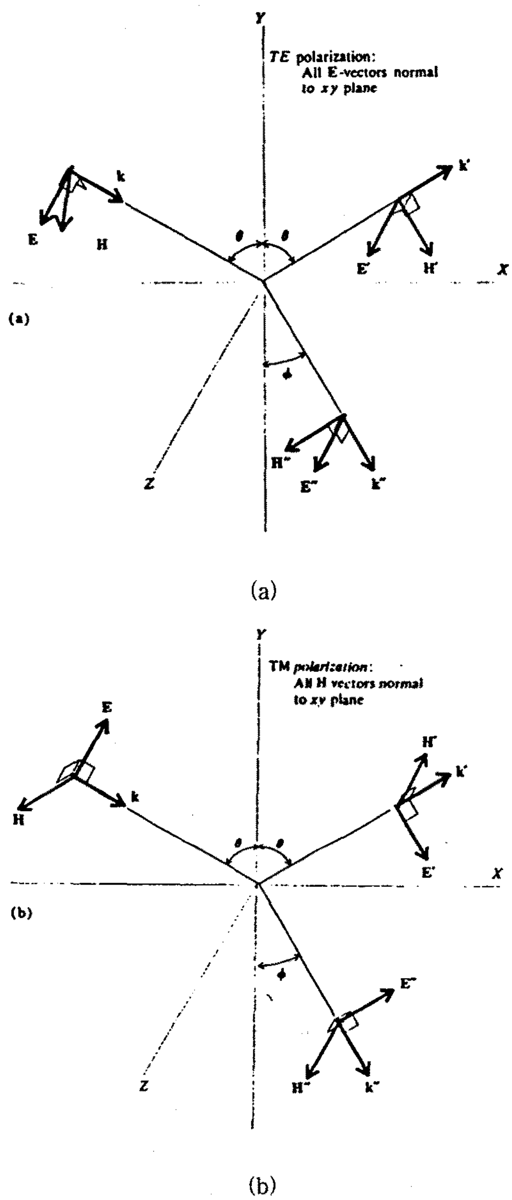

Fig. 2. Wave vectors and associated fields for (up) TE(all E-vectors normal to xy plane) (down) TM(all H-vectors normal to xy plane)[8].

II. Background

1. Reflection at a plane dielectric interface

When light is incident on an interface between two different optical media, a reflected light and a transmitted light propagated away from the interface due to the difference of refractive indices between two different optical media as in Fig. 2. This phenomena can be described mathematically by Fresnel's equations (for dielectric media) as follow[8]:

$$(r)_{te} = [E'/E]_{te} = \frac{n_1 \cos\varphi - n_2 \cos\theta}{n_1 \cos\varphi + n_2 \cos\theta} \qquad (1)$$

$$(r)_{tm} = [E'/E]_{tm} = \frac{-n_2 \cos\varphi + n_1 \cos\theta}{n_2 \cos\varphi + n_1 \cos\theta} \quad (2)$$

where E is the incident electric field amplitude, E′ is the reflected electric field amplitude, n_1 is the refractive index of media 1, n_2 is the refractive index of media 2, φ is the reflection angle, and θ is the refraction angle.
The ratio of reflected to incident power[9] for the TE and TM waves in the case of normal incidence both θ and φ are zero are

$$R = R_{te} = R_{tm} = (r)_{te}\,(r)^*_{te} = (r)_{tm}\,(r)^*_{tm} = \left(\frac{n_1 - n_2}{n_1 + n_2}\right)^2 \quad (3)$$

The power ratios for the TE and TM waves are the same in the case of the normal incidence. For reflection between light in a fused silica fiber with n_1=1.46 and air with n_2=1.00, R=0.035=3.5%. This value is a basis for the calculation of the reflectance of a fiber mirror during fabrication.

2. Mechanical splice

Electrical arc fusion splicing is commonly employed for making a permanent low loss connection between optical fibers but it is difficult to use in the field. Hence, mechanical splices have been developed and commercialized[10]-[11]. The features of commercial mechanical splice are shown in Table 1. Among them the 3M Fibrlok mechanical splice[10] was developed for subscriber loop application. This splice has a molded plastic case which contains two entry ports and a cap. An index maching gel filled, V-shaped metallic fiber alignment and clamping element is located inside the housing. The 3M Fibrlok mechanical splice possesses the lowest insertion loss. The average insertion loss under laboratory conditions was reported to be about 0.07dB. Additionally this mechanical splice provides the following benefits: low cost, excellent temperature and environmental stability, high tensile load capability, construction in one minute or less, and preparation with many commercially available fiber stripping and cleaving tools. Because of these benefits, 3M Fibrlok mechanical splice will be used for the fabrication of a low reflectance fiber optic mirror.

Table 1. The features of mechanical splices.

Mechanical splice	Features
IBM ULTRA SPLICE	One splice accepts any combination of buffer sizes from 250um- 900um. Average loss is less than 0.2dB with a fiber retention of over 2 lb. Installation is simple.
3M FIBRLOK II	Insertion loss < 0.2dB with a fiber retention of >.75lb. Low Reflection. Splice completed in 30 seconds. Thermal stability of -40C ~ 80C
AMP FINGER SPLICE	Norminal insertion loss of 0.2dB with a 1.12lb. Loss variation at -30C ~ 60C of 0.05dB
GTE FASTOMERIC	Low insertion loss of .2dB typical.
NORLAND SPLICE	The splice accepts 125um to 140um and all types of buffer to 1 nm. Insertion loss of 0.2dB. May be used with splice holder.

Ⅲ. Fabrication of the optical fiber mirror

The fabrication of optical fiber mirrors using the mechanical splices consists of the following procedures(Fig. 3): fiber end preparation, end surface coating, adjustment, and splicing[7].

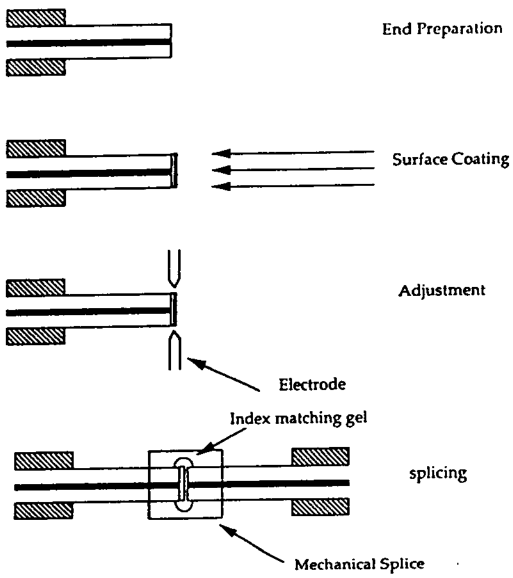

Fig. 3. Fabrication procedures of fiber mirrors.

Fiber end preparation begins with the removal of the fiber jacket using a mechanical(stripping tool) and chemical stripping(acetone or methylene chlroride) technique. After removing the jacket, the end of a piece of fiber is prepared by either cleaving or a polishing technique. One end surface of a piece of fiber prepared by cleaving is coated with a TiO_2 film which is produced by sputtering in an atmospher of 70% of argon and 30% oxygen in a DC planar magnetron system. The film is also deposited on a silicon proof substrate. The refractive index and thickness of the film are determined from the proof substrate after coating using an ellipsometer and a surface profiler. Adjustment of the reflectance of the fiber mirror can be performed using a electric arc fusion splice. The experimental arrangement for monitoring fiber mirror reflectance is shown in Fig. 4. The uncoated end of a piece of fiber is cleaved and connected to the coupler. The coated end is placed between the electrodes in a fusion splicing unit. For adjusting reflectance, the fusion splicing unit is operated at much lower arc current and arc duration than the recommended value for splicing ordinary fibers. After a splicing pulses applied, the coated end is removed from the splicing unit and is put into the index matching liquid for monitoring the reflectance. If the desired reflectance is not achieved, the coated end is cleaned with a chemical solution(methanol) and again placed between the electrodes. These procedures is carried out repeatedly until the desired reflectance is achieved. After obtaining the desired reflectance, the coated end is mechanically spliced.

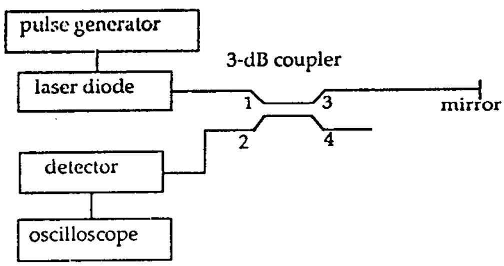

Fig. 4. Experimental arrangement for monitoring the power reflected at a fiber mirror.

Ⅳ. Experimental setup and Results

The experimental setup is shown in Fig. 4. Light emitted from a laser diode(Rockel DFB laser) was modulated by a pulse generator (Tektronix PG502). The pulse modulated light was propagated inside the fiber through the 3-dB coupler and was reflected at interfaces beyond port 3. The reflected light pulses were monitored with a photodetector(PCO RTZ-090-065) and an oscilloscope.

First, the fiber end connected to port 3 of the coupler was cleaved and the amplitude of the reflected light pulse was monitored. This was the light power reflected at the boundary between fiber and air and was 3.5% of incident light power(R=3.5%). This amplitude was used for monitoring the reflectance of optical fiber mirrors.

The relation between the number of splicing pulses and the reflectance of the fiber mirror was checked for adjusting the reflectance of a fiber mirror. To check the reflectance of the fiber mirror the electric arc fusion splicing unit(Siecor Model M-67) and a piece of Corning Payout single mode fiber coated with TiO_2 film were used. The initial value of the TiO_2 film thickness was 500Å and arc current and arc duration of the splicing unit were 3mA and 0.3sec, respectively. The reflectance of a fiber mirror is plotted in Fig. 5 against number of splicing pulses. The reflectance was calcualted using the equation:

$$R_i = \frac{P_i}{P_a} \times 3.5\% \qquad (4)$$

where R_i was mirror reflectance when the number of splicing pulse was i, P_i was the power reflected at a mirror when the number of splicing pulse was i, and P_a was the power reflected at the fiber-to-air interface. The reflectance decreases as the number of splicing pulse increases. When the initial coating thickness was 400 and 300Å and the fusion splicing unit was operated at the same arc current and duration, coating material deposited on the fiber end was evaporated at one splicing pulse.

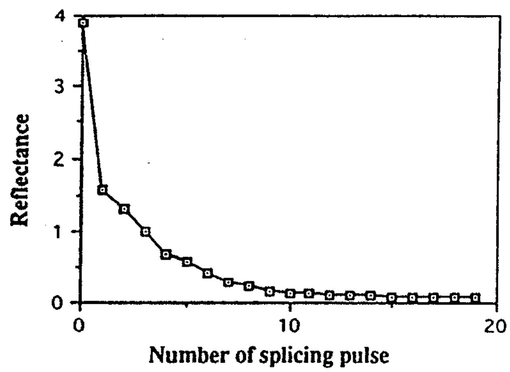

Fig. 5. Reflectance as a function of the number of splicing pulses.

Fiber mirrors with the reflectance of about 0.1% were produced with mechanical splices(3M Fibrlok 2525) using pieces of Corning Payout single mode fiber with one end coated with a TiO_2 dielectric film according to the fabrication procedures. The insertion losses of fiber mirrors with the reflectance of about 0.1% are shown in Table 2. In the experiments, five mechanical splices were used three times. Mirror insertion losses were in the range from 0.055dB to 0.3dB and the average insertion loss was 0.15dB.

Table 2. The insertion losses of fiber mirrors with the reflectance of 0.1%.

	loss(dB)		
	first	second	third
Splice #1	0.055	0.079	0.11
Splice #2	0.099	0.21	0.3
Splice #3	0.11	0.25	0.22
Splice #4	0.07	0.17	0.13
Splice #5	0.09	0.14	0.21

V. Conclusion

The low reflectance optical fiber mirror in the continuous length of single mode fiber was produced using a mechanical splice and a piece of fiber coated with TiO_2 dielectric film. When the mirrors with reflectance of about 0.1% was fabricated, the insertion loss ranged from 0.055dB to 0.3dB and the average insertion loss was about 0.15dB. If the multimode fibers or the single mode fibers with the core size larger than the Corning Payout single mode fiber are used, we anticipate lower insertion loss. These mirrors could be fabricated easy in the field because of using mechanical splices which were easy to use in the field. Because of easy fabrication in the field and low insertion loss, they may be suitable for deployment in a fiber optic Fabry-Perot multiplexed sensor for wide coverage whose sensing arm will be buried underground.

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