

# DEVELOPMENT OF A NEW PALM-SIZE AND CLEAN SPHERICAL MIRROR-FINISH SURFACE PROCESSING MACHINE FOR THE FABRICATION OF OPTICAL FIBER CONNECTORS

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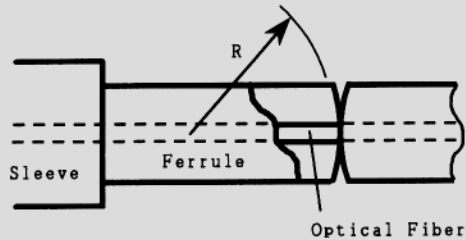
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## 1. Introduction

With the increasing use of optical fiber networks has come an increasing demand for on-the-spot mirror-finish processing of optical fiber connector surfaces in order to respond to network design changes or new construction needs. For such purposes, a small, light-weight, portable processor is needed. Table 1 shows an example of optical fiber connector specifications. In general, PC(Physical Contact) connectors, used with single mode optical fibers are used in optical fiber networks. Figure 1 illustrates a typical PC connector and shows fiber-to-fiber contact. In this type of connector, convex spherical mirror-finish endfaces of 10~25mm radius curvature are needed to avoid optical loss and reflection. This paper describes a new palm-sized processing machine(processor) that employs lapping tape to fabricate spherical mirror-finish surfaces on PC connectors for optical fiber communications networks.

**Table 1** Optical fiber connector specifications

Item	Specification
Sphered radius	10-25mm
Sphered symmetry degree	$\leq 50\mu\text{m}$
Sphered shape	Undistorted, smooth sphere
Insertion loss	$\leq 0.3\text{dB}$
Return loss	$\geq 40\text{dB}$



**Fig.1** PC connectors in contact

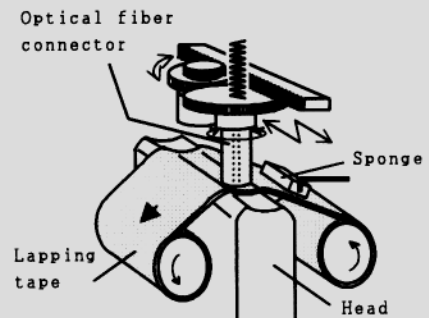
## 2. Development of a New Processing Machine for the Fabrication of Optical Fiber Connectors

Figure 2 shows the principle of operation and an external view of the newly developed processor. The processor is, 89mm in width, 90mm in depth, 102mm in height, and about 0.5kg in weight.

The head of the processor has on its surface a spherical depression, into which the connector end is pressed, with lapping tape between the head and the connector end. The lapping tape is moved at a slow speed, and the connector is rotated at the same time, which produces a spherically convex surface on the connector end.

Space savings with this processor are significant: the tape is rolled, so that a long length of tape can be contained within a compact cartridge, and the need for a large polishing pad is eliminated. Further, the tape cartridge is secured with only a single screw, making cartridge replacement fast and simple.

A sponge is used to supply moisture to the lapping tape.



**Fig.2** A new palm-size spherical mirror-finish surface processor

### 3. Experimental Method and Results

#### 3-1 Experimental method

Table 2 shows the main experimental conditions. There are two stages to actual processing: spherical shaping and mirror-finishing. Since the sphered radius of the connector end depends on that of the head, we set the latter at 17.5mm, which is the middle value of the sphered radius specification for optical fiber connectors.

Table 2 Experimental Conditions

	Spherical shaping process	Mirror-finishing process
Sphered radius of stage	17.5mm	
Connector feed mean speed	2000mm/min	
Lapping tape mean speed	75mm/min	
Load	220-900gf	
Processing time	30sec-50min	
Lapping tapes (Grain size)	Alumina(8 $\mu$ m) SiC(8 $\mu$ m) Diamond(8 $\mu$ m) Diamond(5 $\mu$ m)	Diamond(1 $\mu$ m) Diamond(0.3 $\mu$ m) CeO <sub>2</sub> (0.3 $\mu$ m) Alumina(0.1 $\mu$ m) SiO <sub>2</sub>

The workpieces are a glass ferrule optical fiber connector and a zirconia ferrule optical fiber connector of 2.5mm in diameter.

#### 3-2 Results and discussion

##### 3-2-1 Spherical shaping of glass ferrule optical fiber connectors

First of all, optical fiber connectors (with a flat connector end) were shaped into a spherical configuration, using three kinds of lapping tapes (alumina, diamond, and Silicon Carbide (SiC)), all of which are 8  $\mu$ m in grain size, and the surface conditions on the processing side of the optical fiber connectors were compared and evaluated after the shaping was finished. Figure 3 compares the profiles of the processing sides processed with alumina tape, diamond tape, and SiC tape. When using alumina tape and diamond tape, surface roughness was 0.2  $\mu$ m Rmax and 0.15  $\mu$ m Rmax respectively, and scratches remained on the fiber core part of the connectors. On the other hand, when using SiC tape, the surface roughness was only 0.07  $\mu$ m Rmax, and no scratches on the fiber core part were observed.

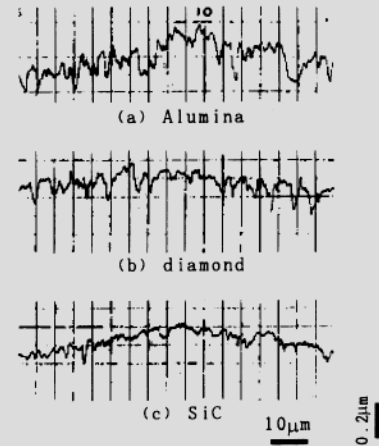


Fig. 3 Profile of endface after spherical shaping process

In observing the surface conditions of the lapping tape by SEM, it was found that the angles of the alumina grains had been rounded, and that the diamond grains were completely covered by the binder. In contrast, the angles of the SiC grains were sharp and the grain blades were not covered by the binder. This appears to be the reason for the excellent performance obtained in using SiC tape for the spherical shaping.

Diamond tape removes 2~2.5 times as much material as SiC tape; however, as previously described, scratches remained on the fiber core part. It appears that SiC tape is most suitable for use as the lapping tape for the spherical shaping process, because it is desirable for the surface roughness to be as low as possible at the end of the spherical shaping process.

##### 3-2-2 Mirror-finishing of glass ferrule optical fiber connectors

The glass ferrule optical fiber connectors were mirror-finishing processed with three kinds of lapping tapes, and the mirror-finishing processing sides were evaluated. The three kinds of tape were cerium oxide (CeO<sub>2</sub>, 0.3  $\mu$ m grain size), alumina (0.1  $\mu$ m grain size) and diamond (0.3  $\mu$ m grain size). Generally, CeO<sub>2</sub> is used for the surface-finishing of glass systems. It is expected that using alumina or diamond can improve

processing efficiency because of their high hardness. For the workpieces, we used glass ferrule optical fiber connectors, and SiC tape, with which the excellent results described in the previous section were obtained was used for the spherical processing. The three kinds of lapping tapes all achieved a surface roughness of less than  $0.01 \mu\text{mRmax}$ , and no scratches on the fiber core part were observed.

We evaluated whether these lapping tapes could be applied to the mirror-finishing process of an optical fiber connector by measuring the insertion loss and return loss. Figure 4 and Figure 5 show distributions of insertion loss and return loss against a master connector. For insertion loss, 0.3dB or less was obtained with all optical fiber connectors, and the specifications were satisfied. An average return loss of 34.1dB was obtained in the optical fiber connectors mirror-finishing processed by alumina tape, and 36.3dB on the average was obtained for those processed by diamond tape. In comparison, the average obtained for those processed by  $\text{CeO}_2$  tape was 50.2dB.

It appears that alumina tape and diamond tape damage the fiber endface considerably more than  $\text{CeO}_2$  tape, and that this is the cause of the thin damaged layer produced by the mirror-finishing process on the fiber endface processed by alumina tape or diamond tape.

From these examinations, it became clear that, in the mirror-finishing process,  $\text{CeO}_2$  tape, because it only lightly damages the processing side, even though processing efficiency is higher with the other two tapes.

### 3-2-3 Spherical shaping of zirconia ferrule optical fiber connectors

This section describes the results obtained in examining spherical shaping of zirconia ferrule optical fiber connectors. When zirconia ferrule optical fiber connectors are processed, the fiber withdraws because zirconia ferrule is harder than the fiber (consisting of the fused silica). Therefore, zirconia ferrule and the fiber are removed at the same time and it is necessary to control the withdrawing of the fiber when the endface is processed. Optical fiber connectors were processed by using diamond tape with high removing power and cheap SiC tape, and the processing sides were observed. The examined processes were the following:

- a) diamond tape(8  $\mu\text{m}$  grain size) - diamond tape(5  $\mu\text{m}$  grain size) - diamond tape(1  $\mu\text{m}$  grain size)
- b) SiC tape(8  $\mu\text{m}$  grain size) - diamond tape(5  $\mu\text{m}$  grain size) - diamond tape(1  $\mu\text{m}$  grain size)

Figure 6(a) and (b) show respectively, the profiles on the processing side to which the a) and b) spherical shaping processes were applied. No fiber withdrawing occurs and excellent spherical shaping is obtained for both processes. In terms of processing cost, process b) appears to be more suitable because it uses SiC tape instead of diamond tape in the 1st step of the process.

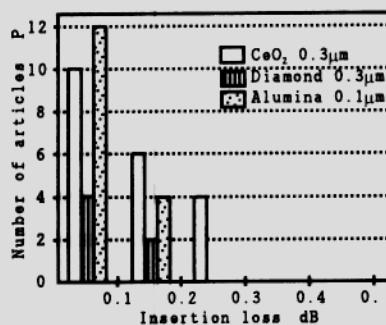


Fig.4 Histogram of insertion loss According to abrasive type

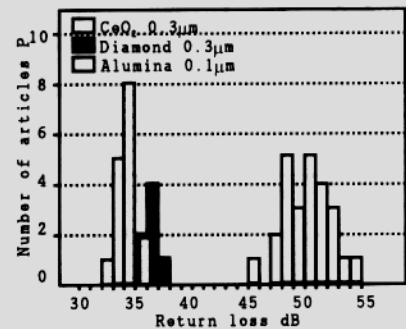


Fig.5 Histogram of return loss According to abrasive type

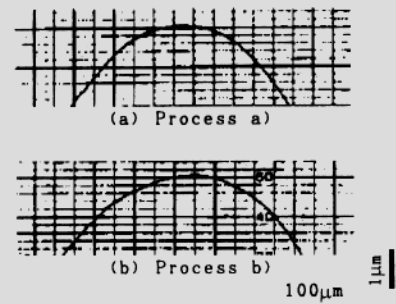


Fig.6 Profile of endface after spherical shaping process

### 3-2-4 Mirror-finishing of zirconia ferrule optical fiber connectors

We next continued our study of mirror-finishing of zirconia ferrule optical fiber connectors. To control the fiber withdrawing in the mirror-finishing process, we used lapping tape made of silicon dioxide( $\text{SiO}_2$ ) which is the same material as that used in fused silica fibers, because the processing rate of the fused silica to zirconia is decreased.

Figure 7 shows the result of changing processing pressure in four stages(220gf, 500gf, 700gf, 900gf) mirror-finishing, and measuring return loss. It can be seen that the return loss performance is excellent, and that the processing is steadiest under processing load of 700gf( $14\text{kgf/cm}^2$ ).

Mirror-finishing of 10P was processed under these conditions. Figure 8 shows the result of measuring the return loss; an average of 51.7dB was obtained and thus it was concluded that the connectors had sufficient reliability for practical use.

### 4. Conclusion

A new palm-sized processing machine that employs lapping tape to fabricate spherical mirror-finish surfaces on PC(Physical Contact) connectors has been developed. The experimental results obtained with this machine are as follows:

- (1) In tests on glass ferrule optical fiber connectors, silicon carbide tape( $8\mu\text{m}$  grain size) was used for the spherical processing and achieved a surface roughness of only  $0.07\mu\text{mRmax}$ . Cerium oxide tape( $0.3\mu\text{m}$  grain size) was used for the mirror-finishing, and achieved a surface roughness of only  $0.01\mu\text{mRmax}$ , and an average optical return loss of 50.2dB.
- (2) In tests on zirconia ferrules, the finest spherical shaping was attained with a SiC tape( $8\mu\text{m}$ ) $\rightarrow$ diamond tape( $5\mu\text{m}$ ) $\rightarrow$ diamond tape( $1\mu\text{m}$ ) process. This use of SiC tape for initial shaping reduces the need for diamond tape, thus helping to hold down costs. Silicon dioxide tape was used for the mirror-finishing. With a processing load of 700gf( $14\text{kgf/cm}^2$ ), average return loss was 51.7dB.

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### References

- [1] T. Kanda, et al., "A New Spherical Mirror-Finish Surface Machining Technology for Optical Fiber Connector," *NEC Res. & Develop.*, **36**, 2, pp. 271-279,1995.
- [2] Y. Ando, et al., "Advanced Optical Connector for Single-Mode Fibers," *NTT Rev.*, **3**, 3, pp. 110-121,1991.

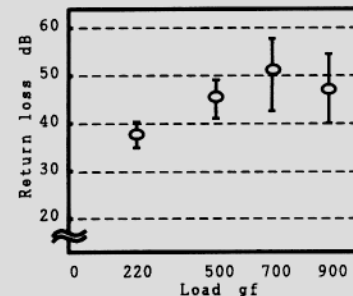


Fig. 7 Return loss vs. load

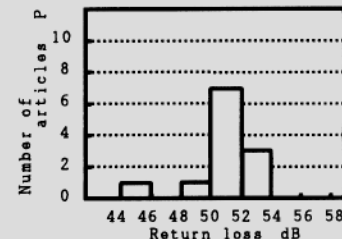


Fig. 8 Return loss in connectors