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Permanent Multiple Splices of Fused-Silica Fibers

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A method for obtaining low-loss splices of multimode optical fibers has been devised that uses no adhesives, mechanical clamps, or adjustable alignment tools. Simultaneous splices were made of three-fiber as well as single-fiber pairs. The coupling efficiency was over 95 percent for single-fiber pairs and 93 percent for three-fiber pairs. The strength of the joint was two-thirds the breaking strength of the fibers.

I. INTRODUCTION

Recently, several techniques for connecting both multimode and single-mode fibers have been developed.[1–5] The problems associated with obtaining good optical ends of the fibers to be spliced have also been the subject of a recent work.[6] These efforts have been motivated by the fact that, for optical communications to become a reality, permanent low-loss splices of fibers must be achieved.

In this paper, a method of permanently joining single and multiple pairs of fibers is described. The method used is summarized here, and a complete description of the technique and results is given in the following sections. It should be noted that the results reported for single bonds were obtained with eight splices and for the multiple bonds with 30-fiber pairs. In brief, coupling efficiency is over 95 percent, and the strength of a joint does not fail until a force of over 300 grams is applied to the end of the fiber. The fiber breaks at a force of approximately 450 grams. Alignment of the fibers is achieved by feeding the fiber into flared tunnels over a fused-silica substrate and is easily done by hand.[4] After the fibers are aligned, an aluminum washer $\frac{1}{16}$-inch in diameter is placed against the aligned fibers. The washer is centered so that the splice is in the open center of the washer. The washer is then compressed against the aligned fibers so that the aluminum yields around a portion of each fiber. The pressure required is below the breaking strength range of the fiber, and the aluminum is permanently bonded to the fibers without bonding to the silica substrate. The yielding of the aluminum protects the fiber from the ram pressure and acts as a control, making the process independent of the heated ($\approx 300°C$) ram pressure. The process is schematically illustrated for a single fiber in Fig. 1, and photographs of the spliced single and multiple fibers and washer are shown in Fig. 2. The bonding process occurs in less than five seconds. After splicing, the washer weight is easily supported by a single fiber. This splicing technique differs from results reported previously in that the splice is a consequence of a metal oxide-glass bond and is not a result of end fusing,[1,2] mechanical clamping,[3] glass-to-glass bonds,[4] or crimping.[5]

The coupling efficiency is measured at a light wavelength of 6328 Å. The index-matching fluid used between the fibers is glycerol having a refraction index of approximately 1.48, and the fiber cores have an index of 1.45. The core diameters are approximately 100 μm and the fiber diameter 142 μm. The ends of the fibers are cut using the diamond cutter.[6]

The washer provides a convenient container for the index-matching fluid.

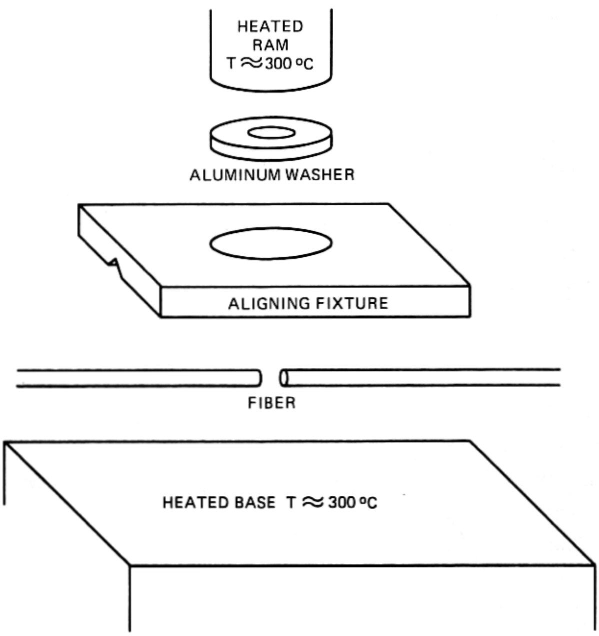
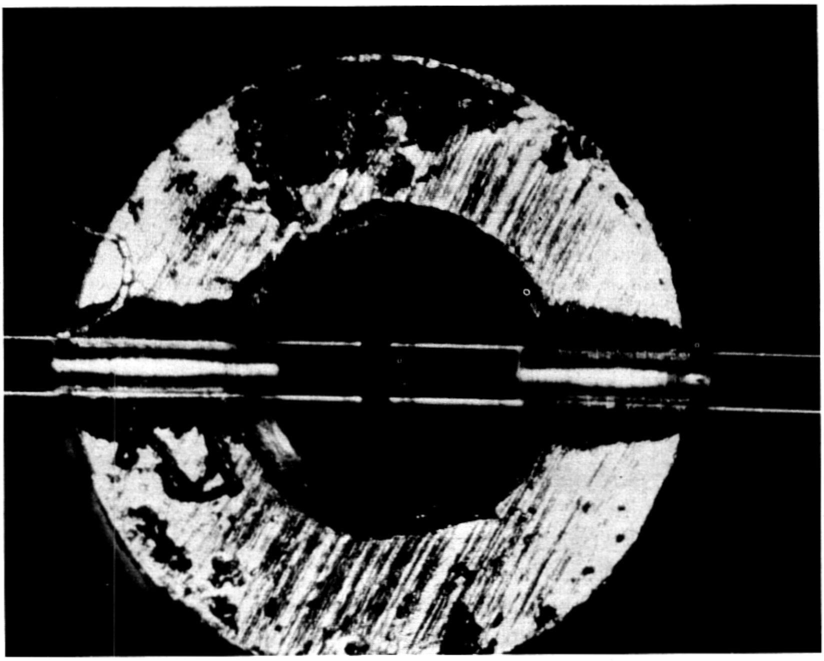
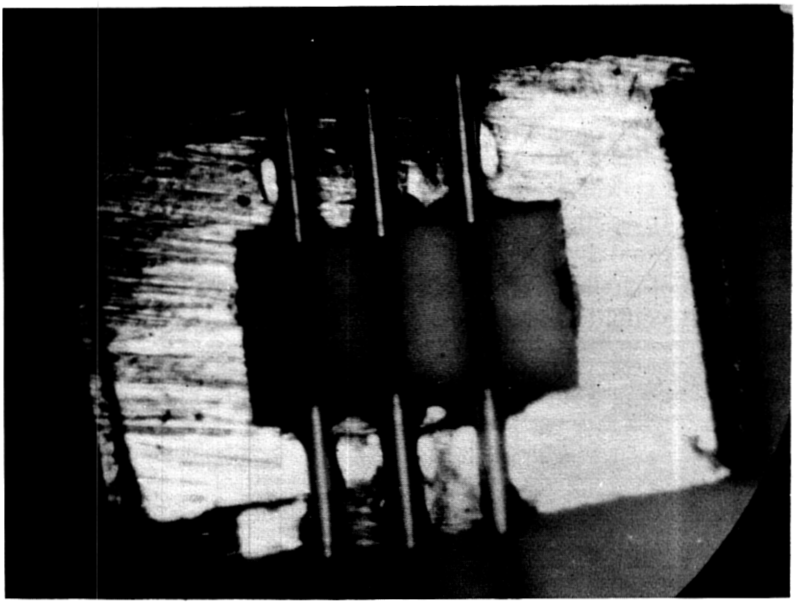


Fig. 1—Schematic of fiber splicing apparatus.



(a)



(b)

Fig. 2—Spliced optical fibers embedded in an aluminum washer. The fiber diameter in both photographs is 142 μm. (a) Single-fiber pairs. (b) Multiple fiber-pairs.

II. JOINING TECHNIQUE

To obtain a joint as shown in Fig. 2, the alignment tool shown schematically in Fig. 1 is used. Variations of this tool, using no adjustable alignment tools, have been used to splice fibers having outer diameters as low as 18 μm, and even at this small diameter the fibers were hand-fed.[4] A hole in the center of the alignment tool allows access for the bonding ram. The fibers are fed by hand from both tunnels and meet in the access hole of the ram. The ends of the fibers are cut flat by means of a diamond-cutting technique,[6] giving a measurable improvement in the coupling efficiency over fibers whose ends are not cut flat.

An aluminum washer is placed over the aligned fibers. The entire apparatus is then placed over a heated ($\approx$300°C) base, and a heated ($\approx$300°C) ram applies pressure to the washer, which yields around the fibers. The pressure applied by the ram is generated by hand, and the total force is quite low. The spliced fibers are then removed from the alignment tool by unclamping the fused-silica substrate. The final spliced fibers are shown in Fig. 2.

III. OPTICAL MEASUREMENTS

The optical measurements used apparatus and techniques that are similar to those described previously[3] and are made at a wavelength of 6328 Å. The results of the various measurements are given in Table I, which gives the average and worst results. The single-fiber-pair transmissions data exclude only one instance in which a clearly identified "mistake" occurred that was a burr of aluminum remaining in the washer and blocking the passage between the splices. The results of the multiple splices are also given in Table I, and are based on ten consecutive three-fiber splices.

The index-matching fluid used between the fibers is glycerol. It should be noted that if the ends are properly cut and the alignment maintained, coupling efficiency depends on when the glycerol is added.

Table I — Experimental results

No. of Fiber Pairs	Transmission			Breaking Strength		
	Worst (%)	Ave. (%)	No. of Meas.	Worst (grams)	Ave. (grams)	No. of Meas.
1	90.5	94.5	8	235	284	7
3	89.5*	92.7	30†	290	331	11†

* Lowest average of three-fiber pair.
† Number of fiber pair measured.

If the splices remain outside the index-matching fluid for a day, splicing efficiencies in the low-90-percent range were recorded. If the glycerol is added approximately 4 hours after splicing, the efficiency is approximately in the mid-90-percent range. Measurements made immediately after splicing showed no measurable loss (less than 2 percent).

IV. BONDS

The strength of the bonds is measured by vertically suspending a fiber splice pair and pulling the fibers apart. The results are given in Table I and exclude a single instance where a fiber failed at a point considerably removed from the bond area. The fiber failed when a force of approximately 450 grams was applied to the end of a single fiber.

The bonds are probably oxide bonds and arise when the fibers break through the alumina (Al_2O_3) coating on the washer leaving the fused-silica fiber embedded in the aluminum. The bonds could not be made at room temperature, but no research has been conducted to determine the optimum bonding temperature.

It is interesting to note that bonds of up to three-fiber pairs using a single washer have been completed. No degradation of the strength of the splice has been observed in these multiple-fiber bonds.

V. CONCLUSION

Single and multiple permanent optical connections between fibers using aluminum as a joining medium have been made. The results are strong bonds with high efficiency.

VI. ACKNOWLEDGMENT

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