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A Molded-Plastic Technique for Connecting and Splicing Optical-Fiber Tapes and Cables

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We describe a new technique for optical-fiber cable connecting and splicing. Preliminary tests with multimode fibers produced splices with an average loss of less than 0.1 dB and a peak loss of 0.18 dB.

I. INTRODUCTION

Despite the efforts of many investigators,[1–12] the problem of connecting and splicing optical-fiber cables and subgroups of fibers[13] (tapes) has remained a serious one. The continued improvement of optical fibers to the point where losses approaching 1 dB/km have now been achieved[14] has made it increasingly apparent that practical connectors and splices should have losses much lower than those initially considered.

Someda[4] demonstrated a splicing technique in which individual fibers are aligned by pressing them into a grooved substrate. Much subsequent work has involved extensions and improvements of this idea. Miller[9] used precision-grooved aluminum spacers and prepared the fiber ends by grinding and polishing. Cherin[10] used embossed grooves and devised a jig for inserting tapes with previously prepared fiber ends into these grooves. The lowest losses in splices based on this technique were obtained by Chinnock et al.,[12] who prepared the ends of the fibers using a fiber-fracture technique.[7] All these methods, however, have drawbacks resulting either from difficulties associated with the preparation of the fiber ends or with the mechanical alignment of the previously prepared ends. These problems may make such techniques difficult to apply in the field.

In this paper we describe a new fiber-splicing technique that eliminates some of the difficulties associated with the grooved substrate type of splices, can function as a removable connector, and should be readily adaptable for field use.

II. THE MOLDED-PLASTIC SPLICING TECHNIQUE

The basic technique is illustrated in Fig. 1. The end of the tape to be spliced is prepared for molding by dissolving the plastic coating over a short region (≈ 1 cm) to expose the individual fibers. The tape with the exposed fibers is then placed in the mold as shown in Fig. 1a. The fibers are held accurately in position by means of a thin spacer plate (see insert). After a suitable plastic material is molded around the fibers, the entire assembly is removed from the mold (Fig. 1b). The fibers are exposed over a narrow region where the spacer plate held them in position in the mold. The exposed fibers are now scored, and the entire assembly is fractured by bending and applying tension in the manner previously described for single fibers.[7] The plastic material fractures in the same plane as the optical fibers, and the tape termination is now ready for splicing (Fig. 1c). To make a splice, two tapes with terminations prepared as described above are placed in an alignment channel, and a suitable index-matching epoxy is used to index-match and to hold the assembly together (Fig. 1d).

The splicing technique described above has a number of important features. Each operation is relatively simple and involves no handling of individual fibers. The fiber-breaking technique quickly produces clean ends of good optical quality. Minimal handling of the prepared ends is required. The technique can easily be adapted to make a removable connection.

To demonstrate these ideas, a mold was constructed as shown in Fig. 2. The mold was machined from brass and was made in two parts so that it could be taken apart to facilitate the removal of the molded tape ends. The spacer plate was made from 175-μm steel feeler gauge stock which was tapered to about 100 μm at the top. Figure 2b shows a close-up of the spacer plate.

Because polyester resin* is readily available, has a low initial viscosity, and shrinks little on hardening, it was used as the molding

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* The polyester resin used for these experiments was No. 50111, Berton Plastics, Inc., South Hackensack, N. J.

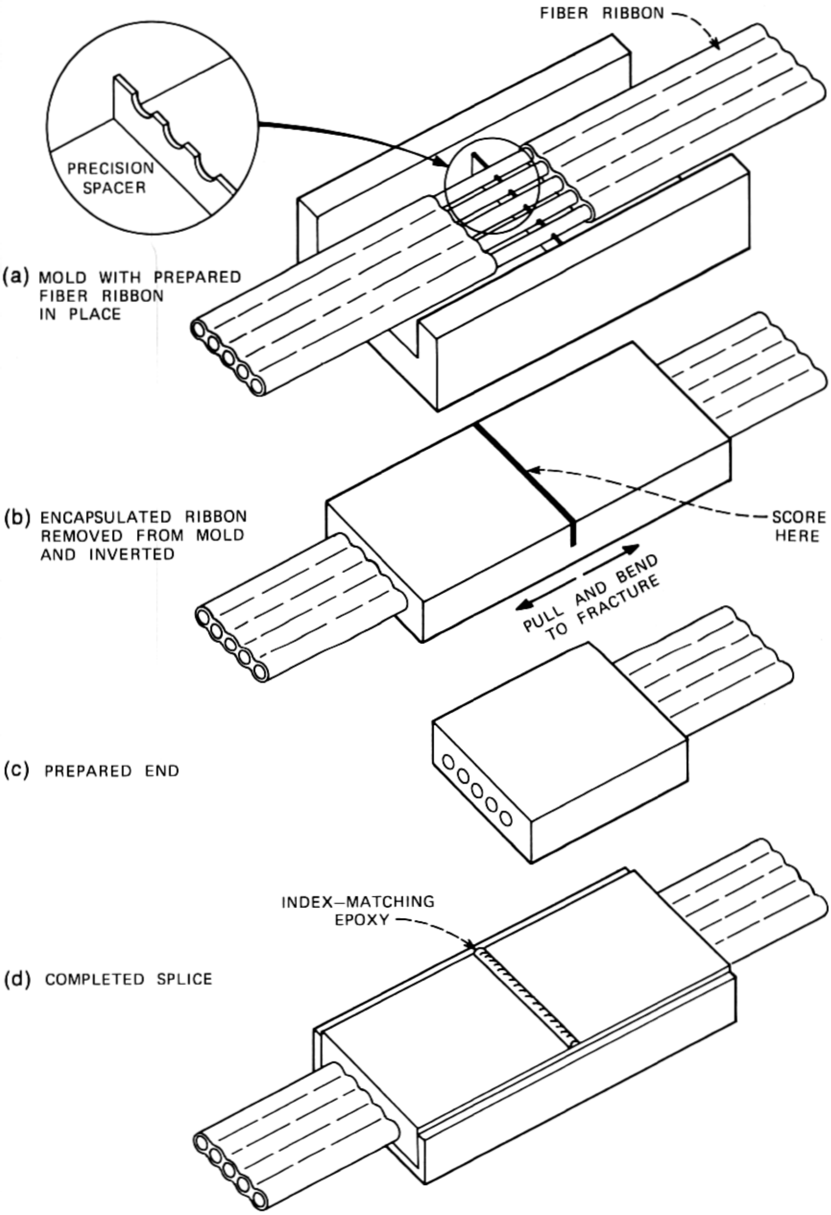

Fig. 1—The molded-plastic fiber-tape splicing technique.

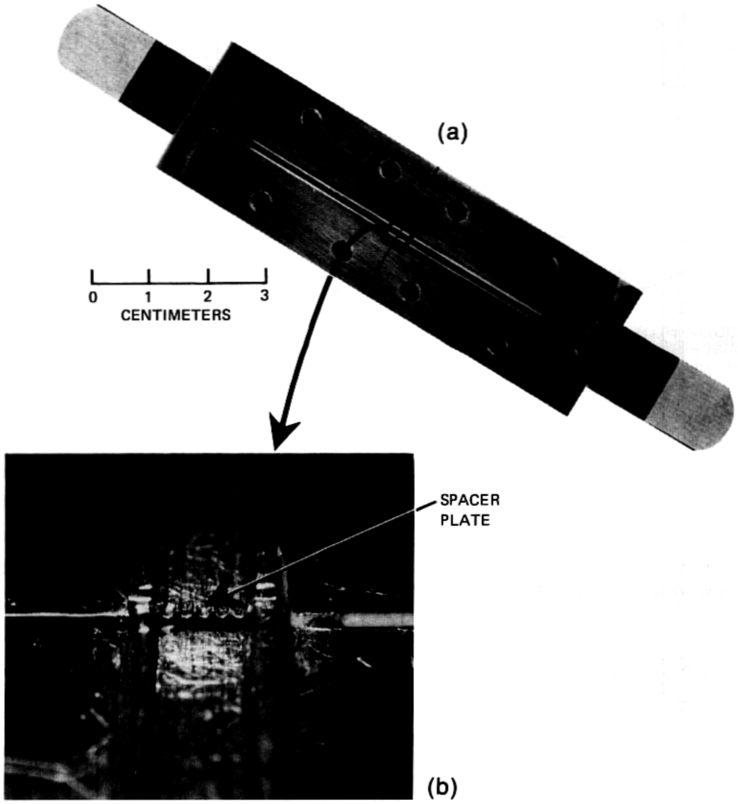

Fig. 2—Photograph of the mold used for these experiments. (a) Overall view. (b) Close-up view of precision spacer.

material, even though it required curing for several hours at approximately 50°C. Low-shrinkage plastics are available, however, that cure in a short time at room temperature.[*]

The optical-fiber tapes used for these splicing experiments were made from multimode silicate glass fibers of 120-μm outer diameter and 80-μm core diameter. The numerical aperture of these fibers was measured to be 0.15. The fibers were made into tapes by dipping 2-m lengths of fiber into a solution of plastic material[15†] and then slowly

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[*] For example, Facsimile, made by Flexbar Machine Corp., Farmingdale, New York.

[†] The coating material used was 3M Kel-F-800, a co-polymer of vinylidene fluoride and chlortrifluoroethylene.

withdrawing the fibers. In this way, a 25-μm plastic coating was applied to the fiber. To eliminate crosstalk between fibers, a black dye was mixed with the coating material. The plastic-coated fibers were then fused into a linear array using the technique previously developed by Eichenbaum.[15]

Figure 3 shows a section of five-fiber tape with the plastic material removed in preparation for splicing. The material was easily removed by applying acetone with a cotton swab. The next step in the splicing operation involves placing the prepared tape in the mold shown in Fig. 2. To hold the fibers positively in the grooves of the spacer plate, a slight tension was applied to the tape by clamping it to the spring steel extensions on either side of the mold (see Fig. 2). Because the mold we were using was somewhat wider than the tape, we also placed pads on either side of the tape to hold the fibers straight as they passed over the spacer plate. Such pads would not be required if a narrower mold were used. Small pads of balsa wood were also used on top of the tape about 1 cm on either side of the spacer to ensure that the fibers remained pressed into the spacer grooves during the molding process. Polyester resin was then poured around the fibers, the lid of the mold

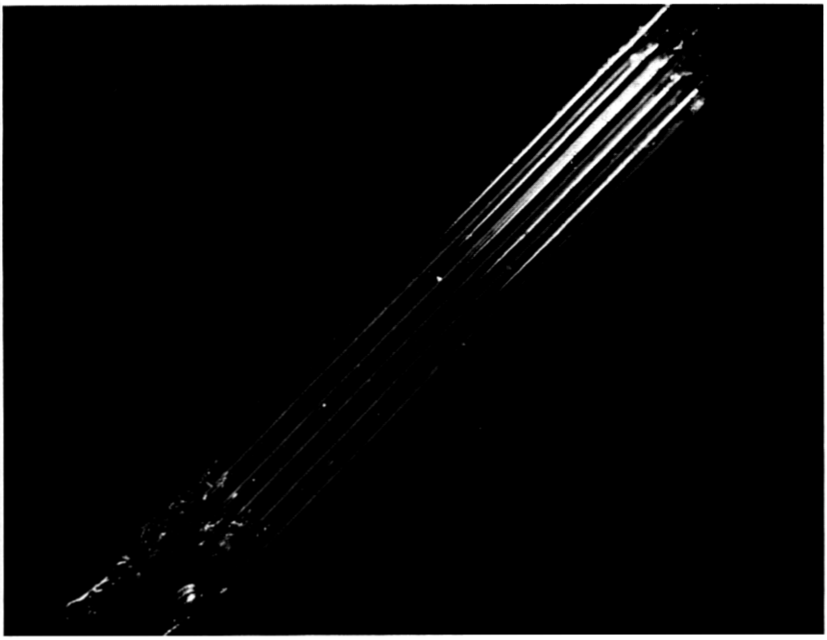

Fig. 3—Fiber tape with plastic material removed in preparation for placing in mold.

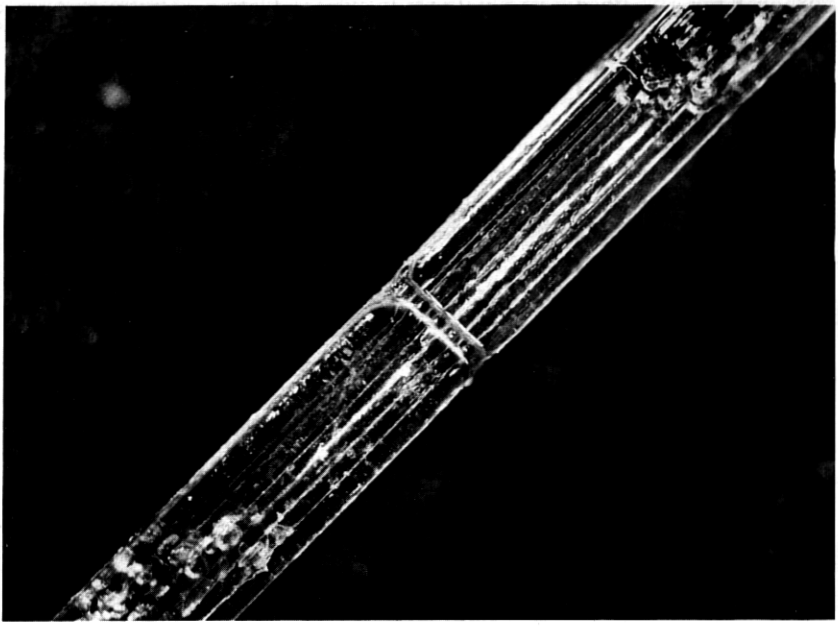

Fig. 4—Fiber tape end after molding polyester resin and before scoring fibers. Note exposed fibers.

closed, and the entire assembly allowed to cure. Figure 4 shows the molded section after removal from the mold. To facilitate removal, the brass mold was coated with mold-release compound.*

Two methods for scoring the fibers have been studied. An abrasive spray of compressed air and dental abrasive powder was found to be effective in scoring the fibers where they are exposed. Alternatively, a narrow carbide blade can be drawn across the fibers. After the fibers have been scored, the entire assembly is fractured by bending the tape and applying axial tension. This can conveniently be done by using the device described in Ref. 12. The theory of glass fracture under these conditions is derived in Ref. 7. We found that the fracture of the molded plastic always took place in the same plane as that of the fibers, and the prepared tape ends looked as shown in Fig. 5.

To complete a splice, the two ends prepared as described above are placed in a suitable alignment channel, described at the end of Section III, and an index-matching fluid is added.

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* Satisfactory results were obtained with Dow Corning "Pan Shield" silicone spray. This can be removed easily with acetone.

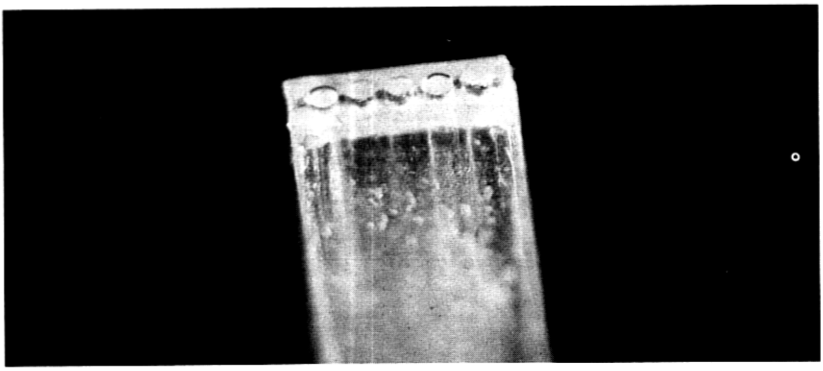

Fig. 5—Tape end after scoring and fracturing. Note the polyester resin breaks in the same plane as the optical fibers.

III. SPLICE LOSS MEASUREMENTS

The accurate measurement of small losses in good fiber-tape splices requires each fiber of the tape to be excited in the same way and with the same amount of light. Repeatable and stable focusing of the input beam on a given spot within the fiber core is a prerequisite. To accomplish this, we built the launching assembly shown in Fig. 6, which is rigidly attached to a commercially available HeNe laser. The assembly not only holds the fiber tape and shields it and the laser beam from dust and air movement, but also permits a precise visual alignment by way of a built-in microscope. The tape is epoxied to a tape holder which slides into a micropositioner from the right of Fig. 6. A three-way alignment of each fiber-front face with the focus of the launching lens is possible (only one positioning screw is shown).

The launching lens, the beam splitter, and the eyepiece form a microscope arrangement that provides a magnified view of the front end of the tape. When the beam is launched into one of the fiber cores, the entire core area lights up as a result of back-scattered light from the inside of the fiber. A cross hair built into the eyepiece facilitates the alignment of beam focus and fiber core. The beam splitter also serves as an attenuator and deflects a portion of the laser beam onto a silicon detector that provides a reference signal proportional to the input light power. As the circuit diagram of Fig. 7 indicates, both the transmitted signal and the reference signal are compared in a ratio meter where the result is displayed in digital form. This measuring technique, together with the precise visual alignment, was found to reproduce the excitation of each fiber to within ±0.01 dB over a period of at least one hour.

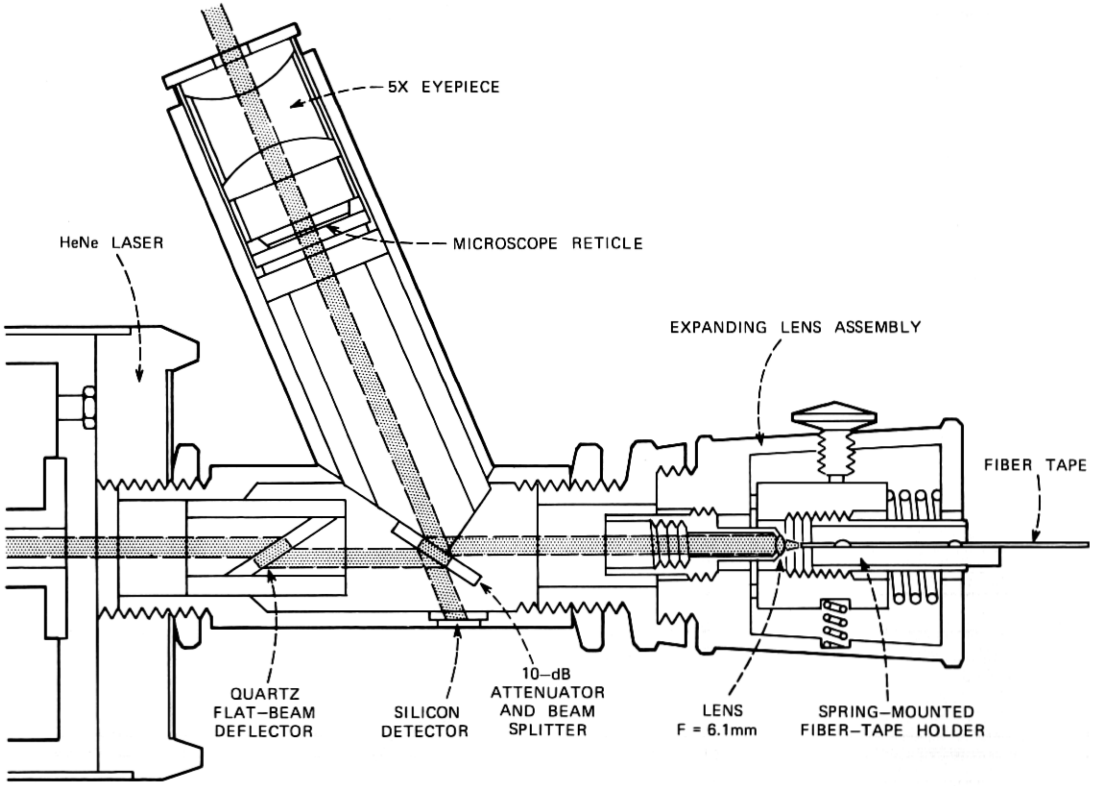

Fig. 6—Apparatus used for loss measurements.

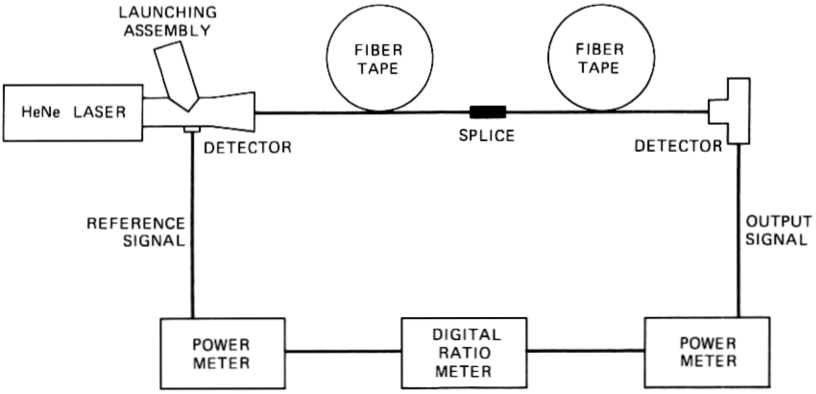

Fig. 7—Cross section of beam-launching assembly.

Radiation losses of the above order of magnitude (0.01 dB/m) can be incurred in the high-order modes as a result of minute bends along the fiber. The bends, and hence the loss, depend on the particular placement of the fiber and its holding fixtures, and can change during the breaking and splicing operation. To minimize the influence of this effect, the focal length of the launching lens is chosen to excite a numerical aperture of 0.10 out of the total numerical aperture of 0.15, so that some of the high-order modes are not excited. On the other hand, these modes may participate to some extent in the transmission (and in the splice loss), if long fiber lengths are involved. The resulting change in splice loss is expected to be small, but needs to be explored.

Our splicing tests were conducted by making two molded sections approximately 10 cm apart near the center of a 2-m length of tape. The same mold in the same orientation was used for each molded section. Prior to the splicing test, the transmission of each fiber in the unbroken tape was measured using the apparatus previously described. The two molded sections were then fractured, the center 10-cm section removed, and the two ends replaced in the mold. A drop of glycerine was added for index-matching, and the ends of both molded sections were held down with a single Teflon* blade about 1 mm in width. The transmission of each fiber was again measured.

Figure 8 is a histogram of the measured losses for tests on 20 fibers, and Fig. 9 shows the cumulative loss distribution. In two cases, either because of inadequate scoring or because of a weak region in the fiber, a fiber fractured at a point other than the desired fracture point. These cases have not been included in our data. Also omitted are three

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* Registered trademark of Dupont Corporation.

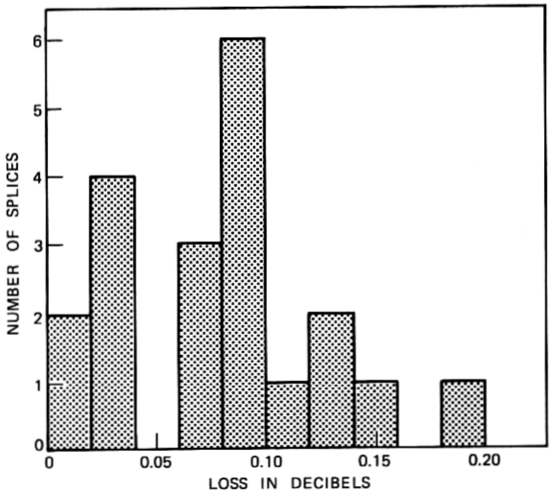

Fig. 8—Histogram of loss measurement data.

cases where fibers in one of the tapes were broken during handling. The average measuring error for these experiments was found to be 0.01 dB. No correction for this scatter was applied to the data.

Permanent splices were made using epoxy instead of glycerine as an index-matching material. This did not increase the splice loss when the

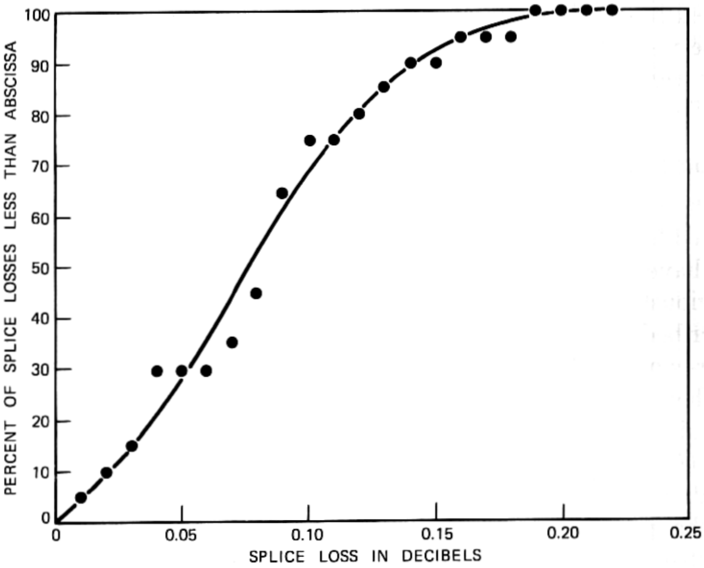

Fig. 9—Cumulative distribution of measured splice losses.

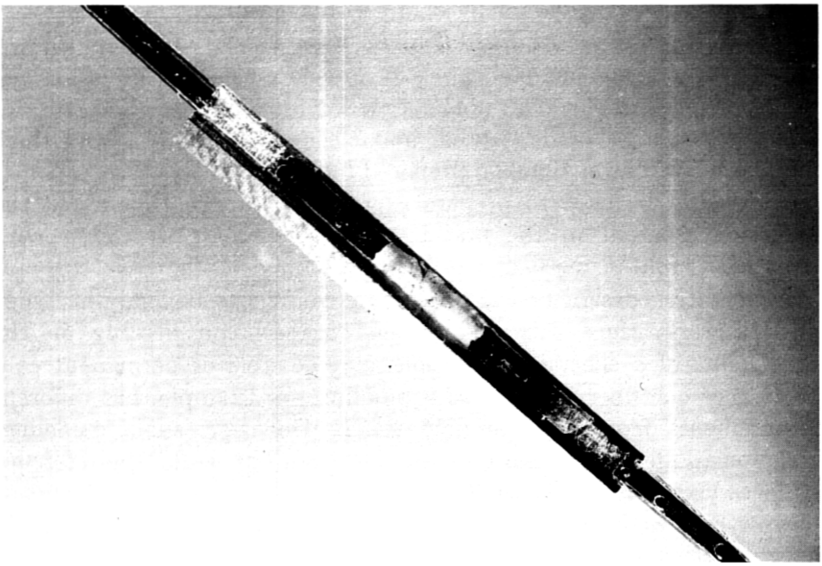

Fig. 10—Completed splice using brass alignment channel and epoxy cement both for index matching and for holding the assembly together.

mold was used as an alignment channel. To make more compact and permanent splices, we epoxied molded tape ends into either a channel made from 125-μm-thick phosphor bronze sheet or a 1-mm-by-0.3-mm milled brass channel, as shown in Fig. 10. The resulting loss increase of between 0.1 and 0.3 dB was attributed to imperfections of the mold that were reproduced in the molded ends. The use of alignment sleeves to alleviate this problem is discussed in the next section.

IV. DISCUSSION AND CONCLUSIONS

The splice losses reported in Section III are lower than those reported for other splice techniques[9,10] and are comparable with the losses we have observed using a grooved substrate to align fibers with previously prepared ends.[12] We believe, however, that the technique described in this paper has a potential for adaptation to a variety of fiber-connector problems and to field splicing of fiber cables.

There are two "precision" operations involved in our splicing technique, (*i*) the intial placing of the prepared fiber tape in the mold and (*ii*) the placing of the molded ends in the holder. Suitably designed molding tools and alignment sleeves should facilitate these operations to the point where they require no special skills. One important problem is that of maintaining a high degree of cleanliness. If the same mold is used to prepare both ends to be spliced and this mold is also used as the alignment channel, a high-precision mold is not required. If, on the other hand, the prepared ends are to be joined in a different alignment channel, precision molds must then be used. The use of precision molds does not present a major problem, however, for the molds can be made, tested, and cleaned in advance, and these molds can, at a later time, be prepared for reuse. In this case, separate molds would be used to prepare each tape end; we thus avoid the problems inherent in the first-described technique associated with cleaning a mold in the field.

A definitive design of the alignment channel is beyond the scope of this work, since this design must depend considerably on the constraints of a specific connection: a removable or permanent connection of one fiber tape inside a building, for example, has different requirements from a cable field splice. However, some guidelines common to all designs can be extracted from our work: the reference surfaces used for the alignment of two molded terminations should be narrow and well defined to avoid misalignment as a result of mold irregularities and contamination. Thus, rather than using the channel of Fig. 10, which encloses the terminations on three sides, a sleeve that makes contact with the terminations only along their narrow sides may be more practical. More specifically, the sleeve might comprise two V-grooves designed to accept the V-shaped narrow sides of terminations molded in the shape shown in Fig. 11. The width of the V-grooves should be somewhat wider than the thickness of the terminations so that contact is only made along the grooves and not at the top and bottom surface of the molded piece. Besides minimizing and defining the alignment surfaces, this approach permits a space-saving and simple arrangement of stacks of terminations in the case of a fiber cable, as illustrated in Fig. 11. This figure shows two grooved chips spring-mounted opposite each other inside a cartridge that aligns the terminations and serves as the inside housing and protection for the cable splice.

This approach, together with the molding technique, seems particularly well suited to produce removable connections. In this case, the index-matching epoxy or liquid would be advantageously replaced by a gel that can easily be removed when the connection is dismantled. When such terminations are prefabricated in the factory, the technique proposed here offers the additional advantage that the terminations can be delivered unfractured, so that the end faces remain protected until they are fractured on site shortly before the connection is made.

In conclusion, we have described and demonstrated a new splicing technique for optical fiber tapes that yields an average splice loss of

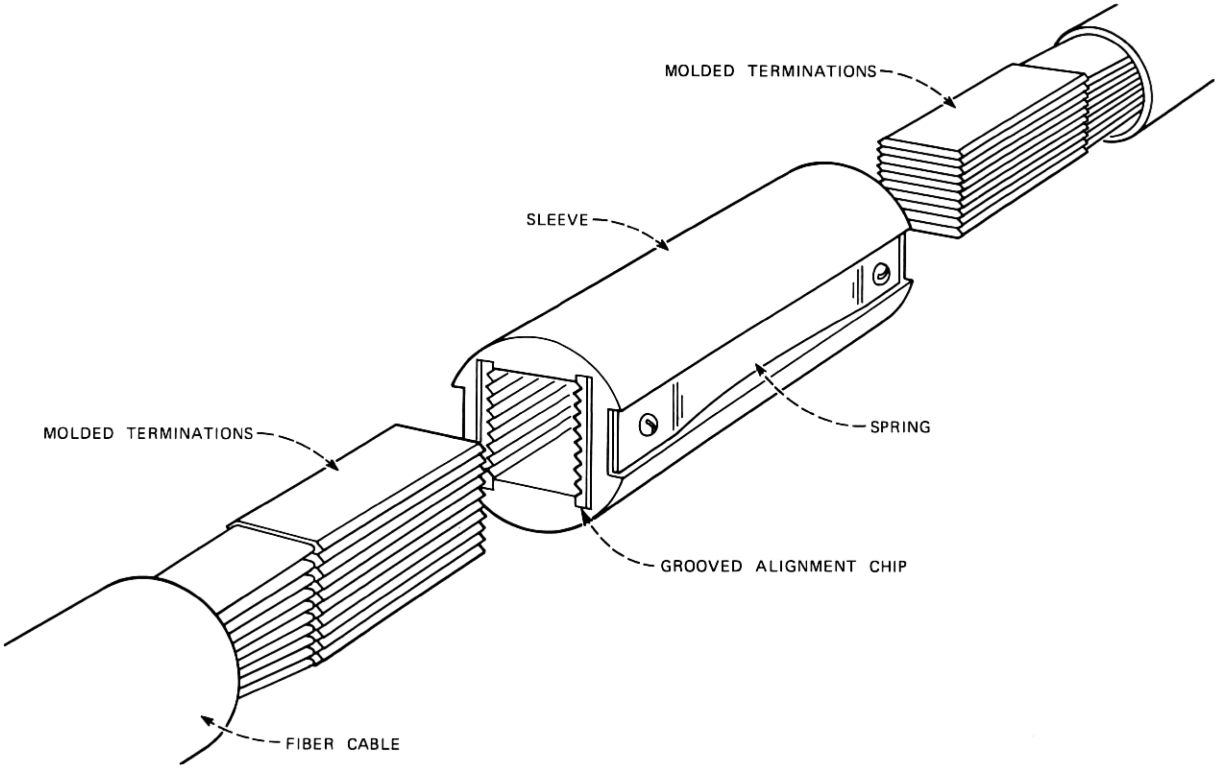

Fig. 11—Grooved alignment sleeve for cable splicing and connectors.

less than 0.1 dB. This technique involves no handling of individual fibers and alleviates some of the difficulties of fiber-end preparation and mechanical alignment of previously prepared ends that are encountered with other techniques.

An adaptation of our technique for field use would involve developing a molding technique applicable at room temperature with a quick-setting plastic encapsulating material and the design of molding tools and alignment sleeves to facilitate the joining operation.

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