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All-Glass Optical-Fiber Tapes

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We propose and demonstrate a new approach to the problem of splicing optical fibers in a fiber cable. The optical fiber cable subgroups (tapes) are made in such a way that the relative positions of the optical fibers are accurately maintained. By using glass as a rigid matrix material in which the optical fibers are held, we demonstrate that a simple scoring and stressing technique can be used to simultaneously prepare all the fiber ends for splicing.

The potential of optical fibers as transmission media for optical communications systems has stimulated much work on the various problems that need to be overcome before a practical system can be built. One of these problems involves the development of techniques for connecting and splicing these fibers and fiber cables. Although several laboratory techniques for splicing fibers and groups of fibers with low splice losses have now been developed, they are all relatively complex techniques that require operations of high precision and are thus difficult to carry out in the field.

In this paper, we propose a different approach to the splicing problem. Linear arrays ("tapes") of optical fibers have been suggested as building blocks for optical fiber cables,[1] and a number of techniques for producing plastic-bonded tapes have been investigated.[2] We propose here a technique for fabricating a precision all-glass optical fiber tape that would have considerable advantages with regard to splicing operations. The precision operations would be performed during the manufacturing of the tapes, and splicing operations in the field would become relatively simple. The basic idea is to make a fiber tape in which the optical fibers are held in a rigid matrix with their relative positions accurately maintained. Further, by using a glass for the rigid matrix material, we can greatly simplify the problem of preparing the optical fiber ends for splicing: All the fibers comprising the tape can be prepared for splicing in a single operation by utilizing the scoring and stressing technique described earlier in Ref. 3.

We made all-glass tapes by fusing conventional clad soda-lime-silicate glass optical fibers together with lower melting point glass fibers in a precision jig. To get a stable bond, the glasses must have very nearly the same thermal expansion coefficient even though their softening temperatures are different. Glasses with these characteristics can be obtained.

As an example, let us consider glass composed of SiO_2, Na_2O, and CaO ("soda-lime-silicate" glass). Morey[4] defines the softening point of glass as that point at which the viscosity becomes $10^{7.6}$ poises. From Ref. 4, we see that by changing the composition of our soda-lime-silicate glass, it is possible to make one composition that has a viscosity of $10^{7.6}$ poises at 650°C and another with a viscosity two orders of magnitude greater than this at the same temperature. The thermal expansion coefficient of the first will be 9.7×10^{-6} per °C, while that of the second will be 11.3×10^{-6} per °C. Thus, we can obtain glasses that have viscosities different by two orders of magnitude at the softening point, while their thermal expansion coefficients differ by only 15 percent. By using such glasses, we could ensure that the deformation during the fusing operation would take place only in the low-melting-point glass, and the optical fibers would be essentially undistorted.

The optical fibers used for these experiments were conventional clad multimode fibers made from soda-lime-silicate glass. The low-melting-point fibers were made from ferrite sealing glass obtained from the Corning Glass Works (No. 8463). The optical fibers had a softening temperature of $\approx$650°C and a thermal expansion coefficient of 9.7×10^{-6} per °C, while the softening temperature of the low-melting-point fibers was $\approx$375°C, and the thermal expansion coefficient was 10.4×10^{-6} per °C.

Figure 1 is a schematic view of the precision guide used to fabricate the all-glass fiber tape. The optical fibers are held accurately in place by the precision guide, while the low-melting-point triangular fibers are introduced in such a way that they press against two adjacent optical fibers. By means of a heating element, the glass is fused at the contact points and then allowed to cool as the completed tape is pulled out of the guide.

The heating element is a 500-μm outer diameter nichrome wire mounted on a manipulator. When the heating wire is brought to within 100 μm of the cold fibers and heated by passing current through it, the triangular fibers melt and form beads of molten glass that touch the heater. This glass is then smoothly spread along the round fibers as the fibers are fed into the guide, giving a uniform bond.

The precision guide is made of boron nitride—a material that resembles soapstone. It is used because it is easily machinable to

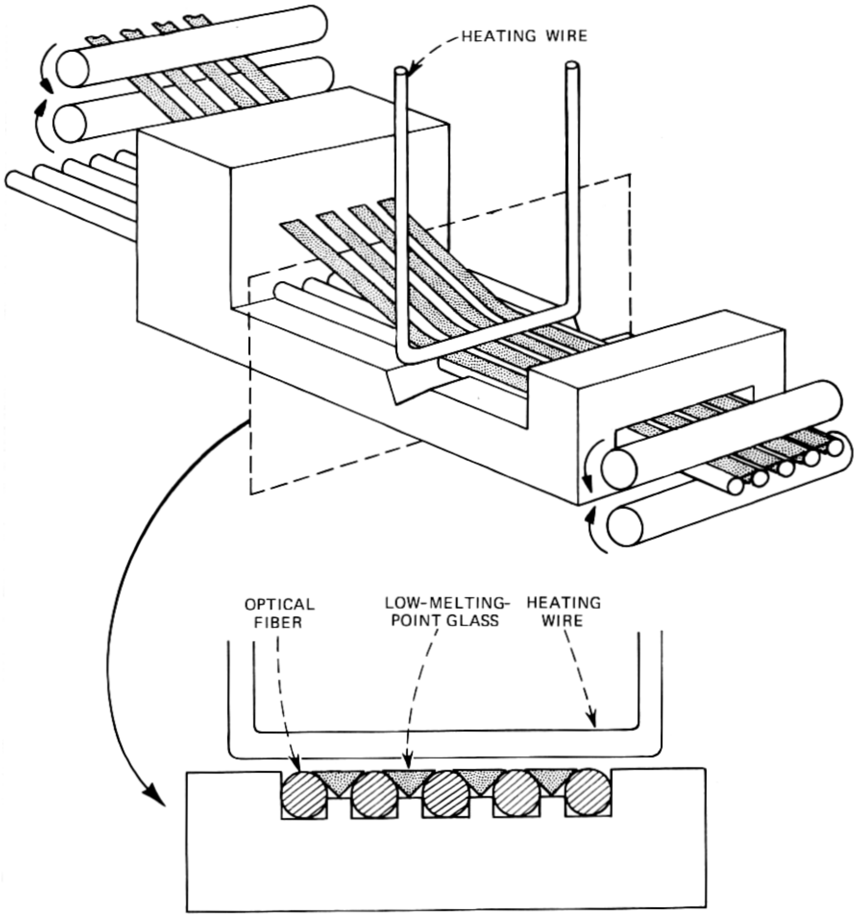

Fig. 1—Schematic diagram of the device used to fuse the all-glass fiber tapes.

close tolerances, has a slick surface, and is not affected by the heat applied.

To feed the fibers through the precision guide, rollers are used as shown in Fig. 1. One pair of rollers is used to push the triangular fibers into contact with the round fibers, and one pair is used to pull the fused tape out of the guide. The lower roller in each pair is a 6.25-mm shaft with a tight-fitting sleeve of vinyl 0.5-mm thick giving an outer diameter of 7.25 mm. The upper roller of each pair is a 6.25-mm shaft with a flexible plastic sleeve giving an outer diameter of 9.38 mm. One of the smaller rollers is driven by a variable speed motor and is connected to the other small roller through an idler gear. Before entering the guide, the fibers were cleaned by passing through a solvent-soaked wick.

To make the tape, the heater current is turned on while the heating wire is still far from the fibers (more than 250 μm), the driving motor is turned on, and then, while the fibers are passing through the guide, the heating wire is lowered by a manipulator (while the operator watches through a microscope) until the triangular fibers melt and bond smoothly to the round fibers. The tape was formed at about 3 cm per minute. Figure 2 is a photograph of the resultant fiber tape.

It has previously been shown that, by scoring an optical fiber and subjecting it to a properly tailored stress distribution, a smooth fracture perpendicular to the fiber axis can be obtained.[3] It has also been observed that such fracture behavior can be obtained with more complex fiber cross sections. We used a diamond stylus to score the fiber tape and fractured it by subjecting it to bending and tension stress. The fracturing operation was performed with the aid of a device similar to that described in Ref. 5. Internal strains would sometimes cause the tape to fracture in such a way that the break was not perpendicular to the tape axis. Nevertheless, good fiber ends were usually produced. Figure 3 shows a fiber tape end produced in this way.

The solder-glass fibers that were used tended to break very easily

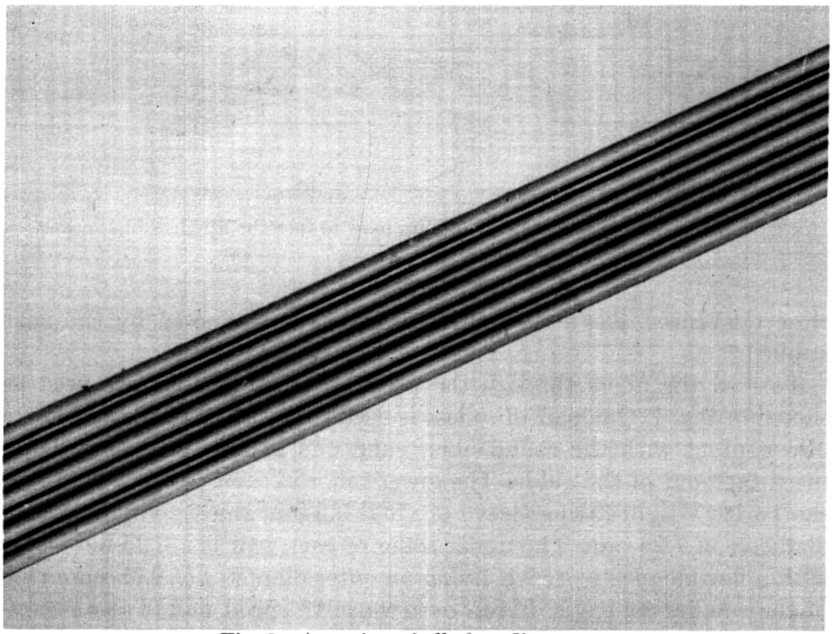

Fig. 2—A section of all-glass fiber tape.

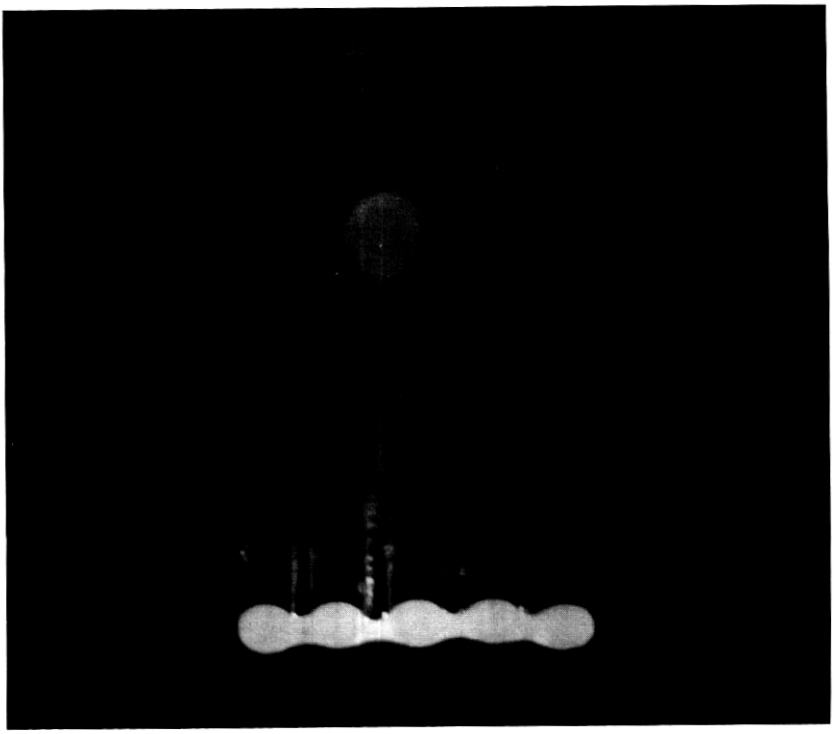

Fig. 3—A fiber tape end prepared for splicing by the scoring and stressing technique.

and had to be handled with great care; thus, the tapes we made were fragile. When fused together, the round and triangular fibers are so intimately bonded together that a crack originating in the glass of a triangular fiber would propagate across the whole tape. If low-melting-point glass with better mechanical properties were used, we would expect the finished tape to be appreciably stronger. As can be seen in Fig. 3, the tape is no thicker than its round fibers, so it is flexible in the direction of its thinner dimension.

Because the optical fibers are accurately positioned during the manufacture of the tape, the most difficult part of the splicing problem has already been solved, and the splicing of these tapes merely involves preparing the tape ends by scoring and bending and placing the prepared ends in a suitable holder with matching fluid and a cover to hold the tape ends in place, as shown in Fig. 4. To make a permanent splice, a transparent index-matching epoxy may be used. Note that at no stage during the entire splicing process does one have to deal with single optical fibers, and that the tapes can be placed by hand in the splicing holder without the need for any precise visual alignment.

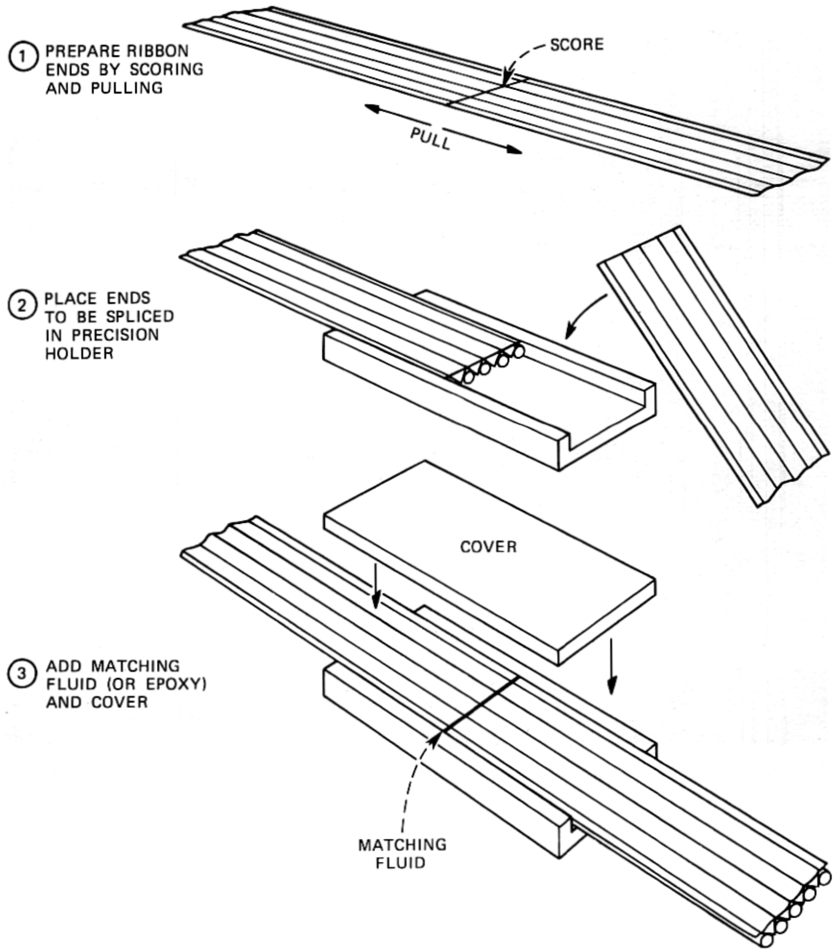

Fig. 4—Schematic representation of tape splicing operations.

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