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Atlanta Fiber System Experiment:

Preform Fabrication and Fiber Drawing by Western Electric Product Engineering Control Center

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Optical fibers for the Atlanta Fiber System Experiment were produced in the Western Electric Product Engineering Control Center development laboratory. The processing methods and facilities used in preform fabrication and fiber drawing are described. The results obtained in terms of yield and process control factors are also presented.

I. INTRODUCTION

In 1974, the acquisition of a fiber-optics development laboratory was started by the Western Electric Product Engineering Control Center in Atlanta. This facility was intended to provide the experience needed by Western Electric to establish manufacturing methods and machinery in the new field of fabricating low-loss optical fibers. The first preform fabrication facility and its companion tube-cleaning installation became operational in April 1975. Operation of the fiber-drawing machine started in August 1975, and fiber delivery to Bell Laboratories commenced in September. All fibers were characterized by Bell Laboratories in Atlanta and subsequently used in their ribbons and cables. The delivery of fibers for the Atlanta Fiber System Experiment was completed in November 1975.

II. TUBE PREPARATION

The facility for acid-etching, fused-quartz starting tubes (Fig. 1) consisted of a bench-mounted cleaning chamber containing a rack for seven tubes. Adjacent to the chamber was a work position for mixing and

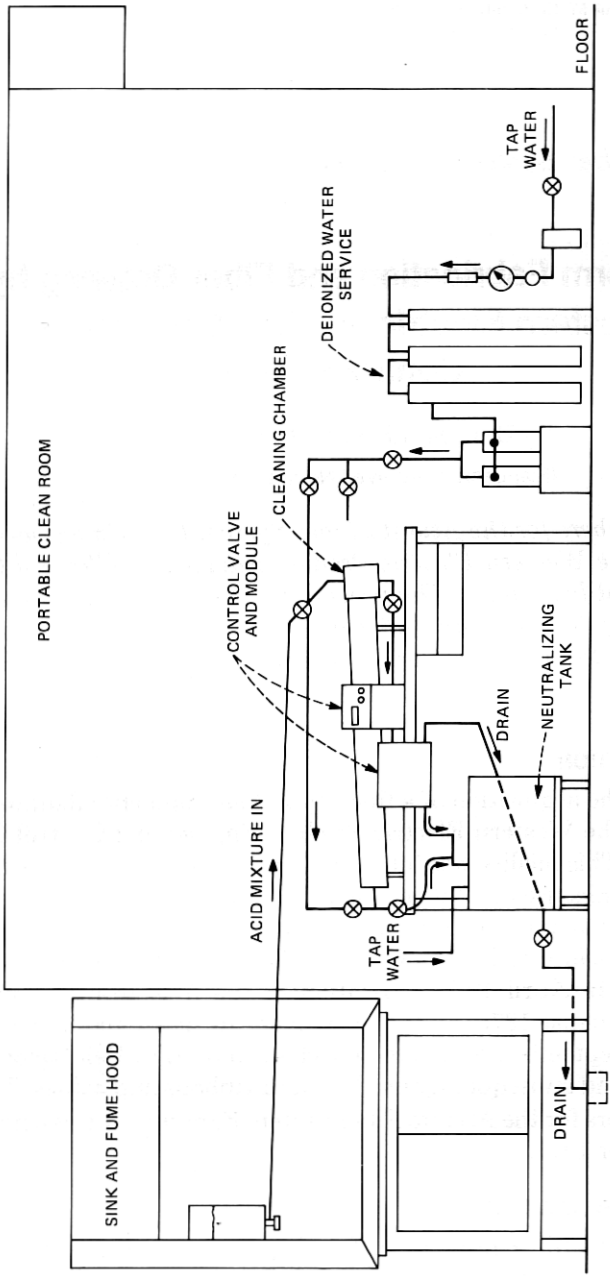

Fig. 1—Tube cleaning facility.

supplying the acid mixture to the cleaning chamber. A commercial deionized water system provided clean rinsing water, and a marble chip vat permitted neutralization and dilution of the acid mixture after each etching cycle.

The 12 × 14-mm diameter, 0.91-m long tubes (Amersil* T08 grade) were etched in a 50-percent solution of nitric acid, hydrofluoric acid, and deionized water. After etching and a thorough deionized water rinsing, the tubes were dried with nitrogen and then capped to maintain a clean inside tube surface.

III. PREFORM FABRICATION

Although two preform fabrication installations were provided in anticipation of future development and fiber needs, only one was initially used. Both installations were identical (Fig. 2) and were modeled after facilities used at Bell Laboratories in Murray Hill, N.J. for modified chemical-vapor deposition.[1,2]

The glass working lathe was equipped with an oxygen-hydrogen torch mounted on a motorized burner carriage. Tube temperature was monitored with an infrared pyrometer, while oxygen and hydrogen flow rates were controlled by flowmeters.

The chemical system consisted of stainless steel bubblers containing liquid silica tetrachloride ($SiCl_4$) and germanium tetrachloride ($GeCl_4$). The third chemical, boron trichloride (BCl_3), was supplied in a commercial cylinder. Oxygen to the bubblers and the extra oxygen added in the chemical vapor stream were supplied from the liquid oxygen tank also used to supply the burner. The chemical system O_2 supply line was equipped with a purifier and filter. All chemical vapors and the extra

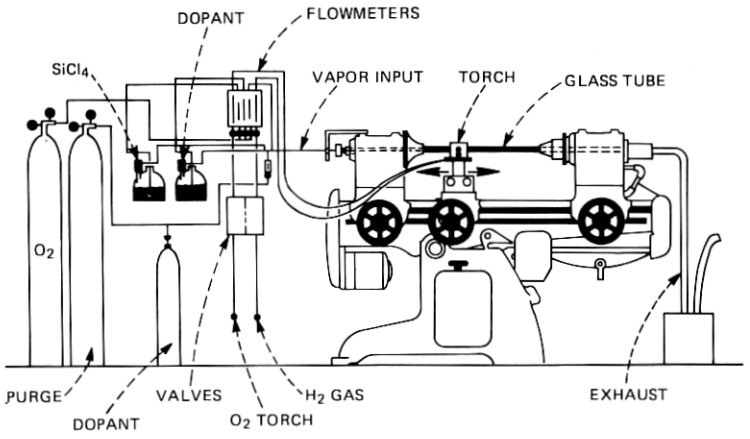

Fig. 2—Modified chemical-vapor deposition process.

* Amersil, Inc., Sayerville, New Jersey.

O_2 flow rates were controlled by means of flowmeters, which were calibrated for O_2 flow rates.

A typical run was very similar to that reported by DiMarcello and Williams.[3] Table I gives the details of such a run. Note that in Steps 4 and 5, BCl_3 and O_2 are passed into the tube without $SiCl_4$. Instead of building a barrier layer as previously done, BCl_3 was used to try to eliminate surface water. The graded-index profiling is accomplished in Steps 6 through 50 by increasing the $GeCl_4$ flow rate for each step.

IV. FIBER DRAWING

The fiber-drawing machine design was also based on exploratory equipment used at Bell Laboratories. The main frame consisted of two vertical I beams on a base frame which was shock-mounted and stabilized. The subassemblies for drawing and tandem coating were attached to the main frame (Fig. 3). At the top was the feed mechanism utilizing a traverse unit for lowering the preform into the drawing furnace.

The drawing furnace was a graphite resistance furnace modified to operate without a muffle tube. Operating such a graphite furnace in the 2000°C region requires careful control of an inert gas atmosphere such as argon. A high argon flow rate reduces element deterioration but creates a turbulence detrimental to drawing stability. Thus, a restriction of the furnace entrance and exit was provided to reduce the argon flow.[4]

The furnace entrance restriction was a disk slightly larger than the preform. The furnace exit restriction was a pair of interlocking, adjustable sliding plates, separated at start-up to provide a large opening for grasping the tip of the preform. After start-up, the plates were moved together so that the fiber passed through a small hole. An electronic micrometer was positioned near the furnace exit to monitor fiber diameter.

Table I — Deposition sequence

Operation	Step No.	$SiCl_4$ gms/min	O_2 to $SiCl_4$ cc/min	$GeCl_4$ gms/min	O_2 to $GeCl_4$	BCl_3 cc/min—cmj.k-min—°C	Torch Vel. cc/min	Temp	Extra O_2
Polish	1	—	—	—	—	—	—	1500	750
Polish	2	—	—	—	—	—	25.4	↓	750
Polish	3	—	—	—	—	—	↓	↓	750
BCl_3 to tube	4	—	—	—	—	10	↓	↓	515
BCl_3 to tube	5	—	—	—	—	↓	↓	↓	↓
$SiCl_4$ and	6	0.6	260	0.02	75	↓	↓	1580	↓
$GeCl_4$ to tube for deposit	↓	↓	↓	↓	↓	↓	↓	↓	↓
End deposit	50	0.6	260	0.43	515	10	25.4	1590	515
Collapse	51	—	—	—	—	—	15.8	1740	
Collapse	52	—	—	—	—	—	8.8	1750	515
Collapse	53	—	—	—	—	—	3.2	1770	—

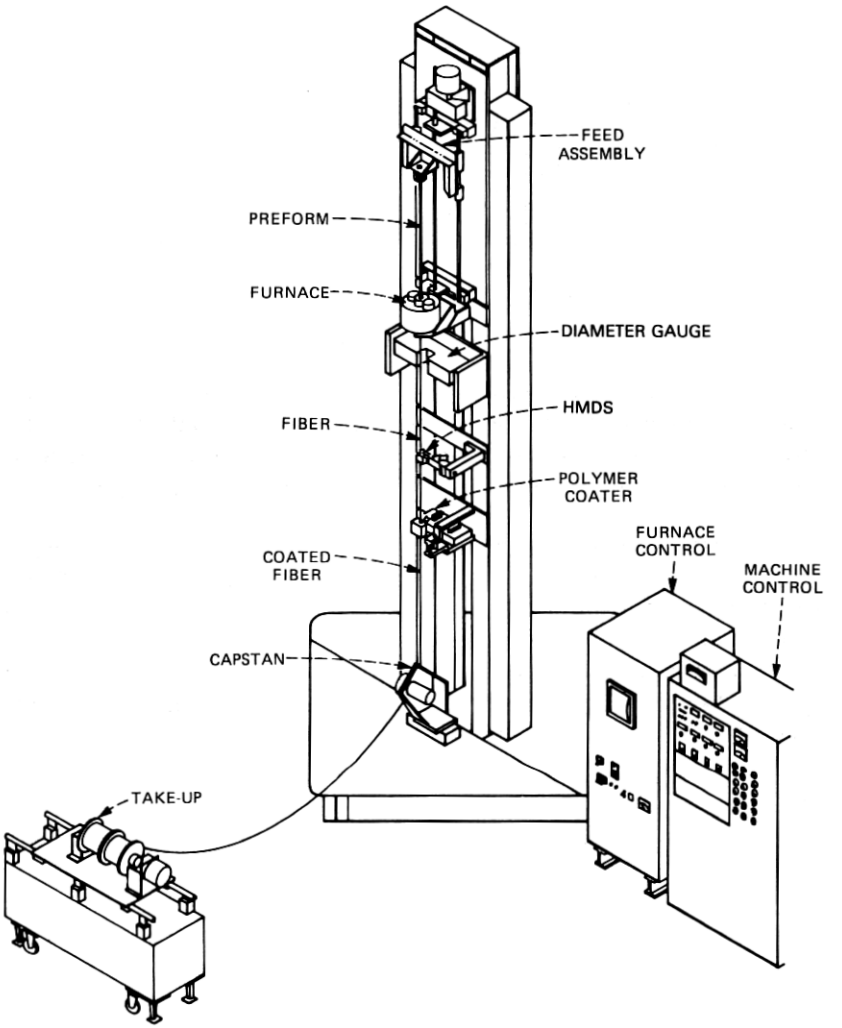

Fig. 3—Fiber-drawing machine.

Two coating applicators were provided. The first was a compressed polyurethane foam wiper to apply hexamethyldisilizane (HMDS). The HMDS was dripped onto the pads to maintain a wet condition and minimize frictional contact with the fiber. Directly below this applicator was a radiant-heat-tube furnace, which vaporized the excess silane.

The second coating mechanism was a polymer applicator which applied a solution of ethylene-vinyl acetate (EVA).[5] This applicator consisted of a heated reservoir attached to a coating die cavity such that a nearly constant solution level was maintained above the die. The die and die cavity were a split design to permit alignment of the fiber in the die

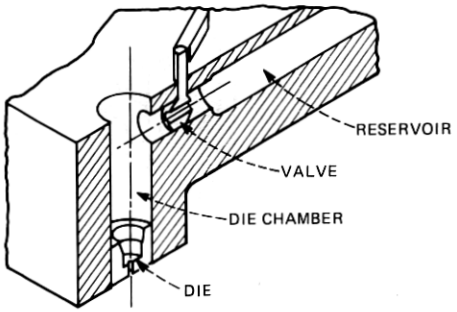

Fig. 4—Fiber coater.

hole (Fig. 4). The entire coating assembly was mounted in an X-Y positioning arrangement. The EVA used was mostly Dupont Alathon* 3172 although a small quantity of fiber was coated with Alathon 3170 (Elvax* 460). The solution mixture was 28.3 gms EVA to 100 ml 1,1,1 trichloroethane.

The distance between the coating applicator and drawing capstan permitted a 2-s gelation time at 0.8 m/s draw speed. This was sufficient to prevent distortion of the coating in the belt-type drawing capstan where a minimum belt pressure was used.

The reel take-up was positioned a few feet from the capstan so that a fiber catenary could be maintained for minimum winding tension. The take-up was capable of supporting two 15-cm-diameter expanded

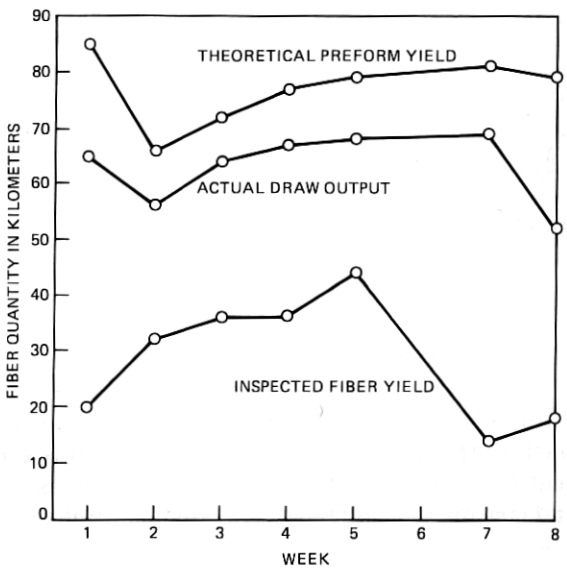

Fig. 5—Fiber drawing results.

* Trademarks of E. I. DuPont de Nemours and Company.

Table II — Fiber rejection, Atlanta Experiment

	Percent Rejection
1. Cladding diameter ($110\ \mu \pm 2.5\%$)	10
2. $\frac{\text{Cladding diameter}}{\text{Core diameter}}$ ratio ($2.0 \pm 6\%$)	9
3. Core ellipticity $\left(\frac{\text{max} - \text{min}}{\text{min}} \text{ dia.} \leq 6\%\right)$	2
4. Bandwidth (200 MHz – km)	0
5. Loss @ 0.82 μm ($\leq$7.0 dB/km)	18
6. Proof testing (30K psi)	16
Total	55

polystyrene reels, one for start-up and one for accumulating the fiber length in a loosely wrapped package.

The drive motors were dc permanent magnet servo type with integral optical tachometers. These were used in a frequency and phase-locked loop digital circuit for superior speed control.[6] In the operational mode used, the draw speed control capstan was set at a speed of 0.8 m/s. The take-up tracked the capstan while partially compensating for the diameter change as the reel filled. Preform feed speed was manually selected as a ratio based on preform-to-fiber diameter.

V. RESULTS

Figure 5 shows fiber drawing output results for the eight-week period during which most of the fibers were drawn. The theoretical output is the number of preforms drawn multiplied by the expected 2.2-km length for each preform. The length of fiber drawn is that quantity delivered to Bell Laboratories for quality measurement. The difference between the two curves represents machine failures, general processing difficulties, and preforms that would not yield the full 2.2 km.

The yield curve is simply the fiber passing the quality measurement criteria. The early low yield was due to problems associated with the diameter monitor. After procedures were established for calibrating and adjusting the gauge, a gradual improvement was realized. The dip near the end occurred when loss problems were experienced. Conditions contributing to the high loss, primarily oxygen impurity, were subsequently cleared and higher yields returned. Table II shows the six criteria limits for fiber quality and the percent rejection for each parameter.

As previously described, fiber diameter was controlled manually by adjusting preform feed velocity. With this technique, the time required for the diameter to respond to a step change in feed speed was too long,

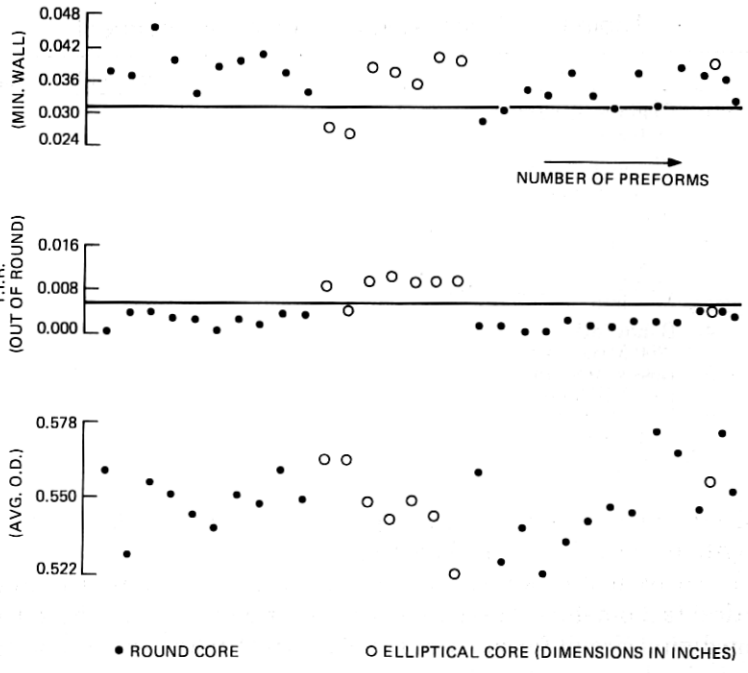

Fig. 6—Glass-tube dimension vs preform core.

and most diameter charts showed a sinusoidal variation. Preform nonuniformity also affected the fiber diameter. Starting tube diameter and wall thickness variations coupled with short-term variations in deposition rates result in diameter changes along a preform. A random sample of 37 preforms showed this variation to be as much as 5 percent. These factors, along with the diameter monitor inaccuracies, furnace turbulence, and preform particle contamination caused by the furnace seal, were major concerns in fiber diameter control.

Core-to-cladding ratio variations are a function of starting tube diameter, wall thickness differences, and long-term deposition rate drift. These variations are strongly related to tube dimensions and are larger than the short-term variations previously mentioned. Therefore, the ratio limits are larger than the fiber diameter limits.

Core ellipticity was originally a difficult problem. Nineteen of the first 67 preforms (28 percent) failed to meet limits. A study of 31 starting tubes was made, and the results of fiber drawn from these are shown in Fig. 6. The study illustrated that tube out-of-roundness and wall thickness variation at a cross-section were the important factors determining core ellipticity. Therefore, 0.006-inch (0.152-mm) limits were placed on each, which lowered the rejections to 2 percent.

Losses greater than 7.0 db/km at 0.82 μm were generally the result of impure materials and material-handling procedures. It was found that

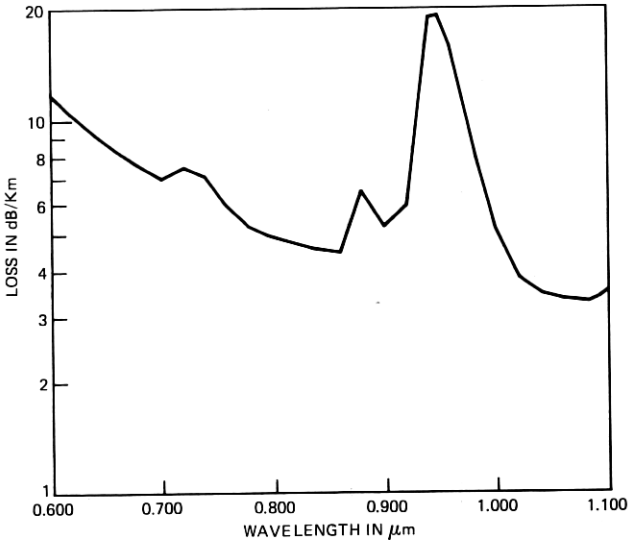

Fig. 7—Typical fiber loss.

purging all lines prior to installing a refilled bubbler was very important. If not done properly, it was common to have a high-loss preform on the first run. Leaks in the system also resulted in high loss fibers. They were difficult to eliminate when Teflon* fittings were used. Leaks also developed in the oxygen supply line from the liquid oxygen tank. This problem was eliminated by using high-purity oxygen obtained in bottles. High loss could also be induced by inadequately fusing the doped silica layers during deposition. Since the tube temperature was manually controlled, the H_2-O_2 flow increases for each deposit pass depended on the accuracy of the flow meter settings. If the tube wall thickness varied significantly, a large temperature change was noted. Figure 7 shows a typical fiber loss curve, and Fig. 8 shows the loss distribution for the fibers.

Proof test failures stemmed from a number of processing conditions. Obviously, methods of handling tubes and preforms could cause damage. Preforms were in contact with the top furnace seal, and the drawn fiber would at times contact the die in the coating apparatus.

The bandwidth requirement was low and could be met without difficulties. The average bandwidth was approximately 450 MHz—km. A high value of nearly 1200 MHz—km was measured.

In all, the above specifications led to a 45-percent yield. This yield was considered a reasonable accomplishment, but certainly pointed to the need for improvement in all aspects of fiber preparation.

* Registered trademark of E. I. DuPont de Nemours and Company.

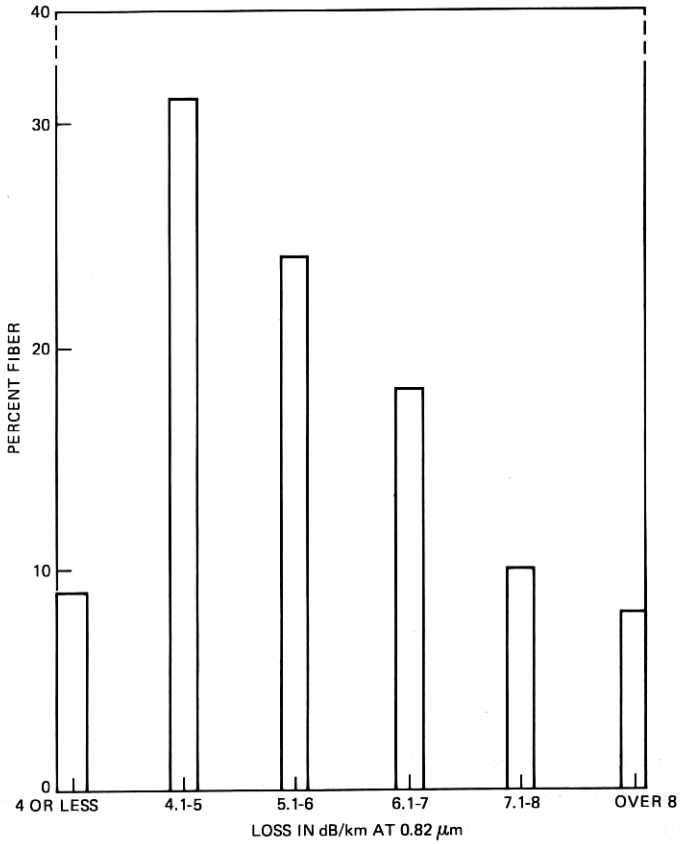

Fig. 8—Fiber loss distribution.

VI. ACKNOWLEDGMENTS

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