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A Resistance-Heated High Temperature Furnace for Drawing Silica-Based Fibers for Optical Communications

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A description is given of a resistance-heated furnace suitable for drawing silica-based optical fibers with a high degree of precision. The furnace is compact, heats from cold to its operating temperature of 2000°C in 3 min and has a power consumption of only 1.4 kW. During a fiber pull, the temperature fluctuation is < 0.1°C.

CURRENTLY THERE is considerable interest in the production of ultra low-loss fibers for optical communications. A suitable material might comprise a compound glass, but it has proved difficult to produce material of the required purity. However, nearly pure silica can be made, and is available commercially, so that various techniques have been developed for making silica-based fibers.[1-3] Unfortunately, silica has a disadvantage in that it must be heated to $\approx$2000°C before the viscosity becomes low enough for it to be drawn into fiber, and therefore a furnace is required which will operate up to $\approx$2200°C.

The method generally used in the past has been to heat the silica by burning appropriate gases in a flame furnace but this technique, while being inexpensive, has many disadvantages. 1) It is difficult to control the temperature accurately and to produce a high degree of repeatability.[4] 2) Temperature distribution fluctuates somewhat with the variation in gas flow through the furnace. 3) It is difficult to produce a given, stable, temperature profile along the furnace. 4) It is difficult to produce radially symmetric heating. 5) There is always a possibility of contamination of the fiber from the gases in the flame.

Another method[5] uses a CO_2 laser as a "clean" source of heat, but the process is complex and rather expensive. Induction and rf heating can be applied[6] to glass melting, but they involve the use of expensive, high power rf generating equipment.

Experience with compound glass fibers has indicated the value of precision pulling conditions and especially of an accurate temperature control and profile, since uncontrolled diameter variation can produce higher attenuation, particularly in fibers of low numerical aperture. However, it has been shown[7] it is possible to make fibers of very low cross-sectional variation (<1 μm in 150 μm over a length of 1 km) which produce very low mode conversion. To make silica-based fibers of comparable quality, a precision fiber-drawing furnace, capable of operating at high and accurately controlled temperatures, is required.

Design Criteria

Resistance heating is the simplest and most readily controlled form of heating. Accurate temperature control can be achieved by thermocouple or pyrometric monitoring; power can be regulated by a standard SCR power controller. A further advantage is the hot zone can be closely contained and temperature profiled as desired by adjusting the local resistance of the heating element. In view of these factors and because it is possible to obtain high accuracy at relatively low cost, resistance heating was chosen as the optimum method.

The selection of materials capable of operation at temperatures $>$2000°C is somewhat limited. Most of those available require an inert atmosphere to prevent rapid deterioration by oxidation, and in addition several are brittle and have poor thermal shock resistance. Further difficulties are that different materials in contact at these elevated temperatures tend to react, and problems are caused by their dissimilar thermal expansion coefficients. Another requirement for a fiber-drawing furnace is that the furnace components should be compatible with silica vapor, since silica is relatively volatile at its drawing temperature, and it is not uncommon to have to blow condensed silica dust out of the furnace periodically.

Of the various possibilities, graphite is the most acceptable because of its remarkable combination of thermal and mechanical properties. Also, it is available in pure form, is relatively cheap and can be machined into intricate shapes. A wide variety of graphite products are available, including insulating felt, string, cloth and paper, so that the entire furnace can be constructed from one material thus avoiding the problems caused by having dissimilar materials in contact at high temperature. In addition, graphite has a very high thermal shock resistance, good strength at high temperatures and a high emissivity. The main disadvantage is its high rate of oxidation which makes an inert atmosphere essential. However, since other candidate materials also require an inert atmosphere, it is not a serious drawback.

The design of a fiber-drawing furnace presents some unique problems in that a highly compact hot zone is required with good radial symmetry and a closely controlled temperature, even though the furnace must be open to atmosphere at both top and bottom. The length of the furnace should also be small to avoid unnecessary loss of preform at start and finish of the fiber pull. Further requirements are: 1) the time taken to reach working temperature should be short, preferably a few minutes; 2) power consumption should be low to allow easy control; 3) recovery from transient temperature disturbances should be rapid. These latter requirements dictate a design of very low thermal mass.

Design Details

The main body of the furnace is of water-cooled stainless steel and comprises a cylinder to which the base plate assembly is permanently welded. The top plate assembly is removable, complete with the heating element, but is sealed to the main chamber in operation by an O-ring. Inside the body of the furnace there is graphite-felt insulation, a monitoring thermocouple assembly and a graphite tube into which the heating element is inserted. The latter is of graphite suitably machined to give the desired resistance. To prevent deterioration due to atmosphere, air is excluded by a continuous flow of argon which must be smooth, reproducible and accurately defined to ensure high quality of the resulting fiber. Gas enters at both top and bottom of the furnace and exhausts from a single opening at the bottom. The gas flow is so controlled by openings that leakage around the preform and the fiber has a negligible effect.

Details of the construction (Fig. 1) are as follows: The graphite heating element consists of a split cylinder (1) with a flange at one end, to which electrical connections are made, and the hot zone at the other. The two parts of the split cylinder conduct the electric current into and out of the hot zone. The electrical resistance of the latter is increased by machining it into two component meander elements which are in parallel and so arranged as to give radial symmetry. One of the pair of meander elements forming the hot zone can be seen clearly in the center of Fig. 1 and is so cut as to cause the current to flow in a winding path with the individual elements close and parallel to each other in the longitudinal direction. The thickness of the walls of the split cylinder must be carefully chosen to keep the heat conducted away from the hot zone to a minimum while not producing any appreciable heating due to the current flow. The cross section of the meander element in the hot

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zone is designed to produce the required temperature when the appropriate value of electric current is passed through it. At the high temperature of operation, arcing between surfaces at different voltages must be avoided; therefore there is a limit on the operating voltages which can be used and adequate clearances must be provided. Allowance must also be made for thermal expansion.

The flange of the heating element is bolted to a ceramic ring (2) which provides support and stability, as well as thermal and electrical insulation. The ceramic supporting ring is, in turn, fastened to the terminal and upper gas flow assembly (3) by electrical terminals which are spring loaded to allow for expansion. Connection to a small stepdown transformer is made by flexible copper cables. The terminal and upper gas flow assembly forms part of the detachable top plate (4) which is water-cooled and is bolted to the body (5) of the furnace through an O-ring vacuum-tight seal. All the metal components are of stainless steel. Incoming gas flows into the rectangular section annular chamber (6) and then, via an annular slot, down the center of the heating element. The gas flow is arranged to pass over the lead-in connectors to provide cooling. Air is excluded from the top of the furnace by a spring loaded iris diaphragm (7) which also locates the incoming silica preform.

The heating element is surrounded by an outer furnace liner (8) consisting of a graphite tube which serves to contain the insulating felt, thus preventing an electrical short circuit. It is fixed to the furnace base plate and has the additional function of providing an exhaust path for the flowing argon. Gas also enters the annular chamber (9) of the lower gas flow assembly and flows through the annular slot up to the heating element. The gas exhausts through the annular channel (10) between the inner and outer furnace liners and the smaller annular chamber (11). At the bottom of the lower gas flow assembly is another iris diaphragm (12) which is normally closed to a diameter of 2–3 mm around the fiber. The insulation (13) is provided by spiral wrapped graphite felt in two sections, between the outer liner and the body of the furnace.

A tungsten/rhenium thermocouple (14) is inserted through a hole in the outer furnace wall and a small hole in the furnace lining, with the thermocouple bead placed as close as possible to the hot zone. Electrical connections are made to the thermocouple by O-ring seals in the furnace wall.

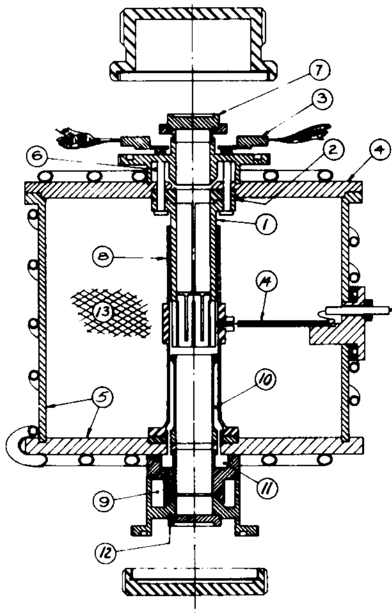


Fig. 1. Schematic cross section of furnace. Components are (1) graphite heating element, (2) ceramic ring, (3) terminal and upper gas flow assembly, (4) top plate, (5) stainless steel body, (6) upper gas inlet chamber, (7) iris diaphragm, (8) outer furnace liner, (9) lower gas inlet chamber, (10) annular gas outlet passage, (11) gas outlet chamber, (12) iris diaphragm, (13) graphite insulation and (14) W-Re thermocouple. End caps are shown in detached position.

The furnace is sealed so that when end caps are in position and the gas inlet and outlet are closed, the whole structure can be evacuated to remove all traces of oxygen before filling with inert gas. Using a conventional rotary pump, the required evacuation is achieved within ≈30 min. However, if the furnace has been exposed to the atmosphere for any length of time, then pumping for 24 h is required to completely remove the water vapor absorbed by the graphite felt. Since the furnace is sealed after use to exclude the atmosphere, extensive pumping is not normally necessary.

Performance

The hot zone is 32 mm long with a 22 mm ID, so that preforms up to 16 mm OD can be accepted and the furnace operates successfully up to 2200°C.

Externally the furnace is ≈280 mm high by 200 mm in diameter, and despite its compactness, the outside walls remain at a temperature only a few degrees above ambient. The small difference in temperature is a measure of the efficiency of the design in confining the hot zone to a small central region. The overall power consumption is a modest 1.4 kW during a typical fiber pull at 2035°C. The extremely low thermal mass of the furnace, coupled with the high thermal shock resistance of graphite, has enabled the working temperature to be reached ≈3 min after switching on from cold, so

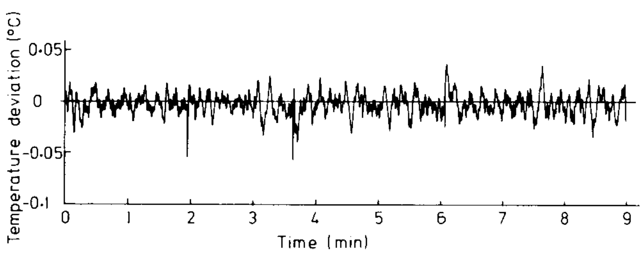
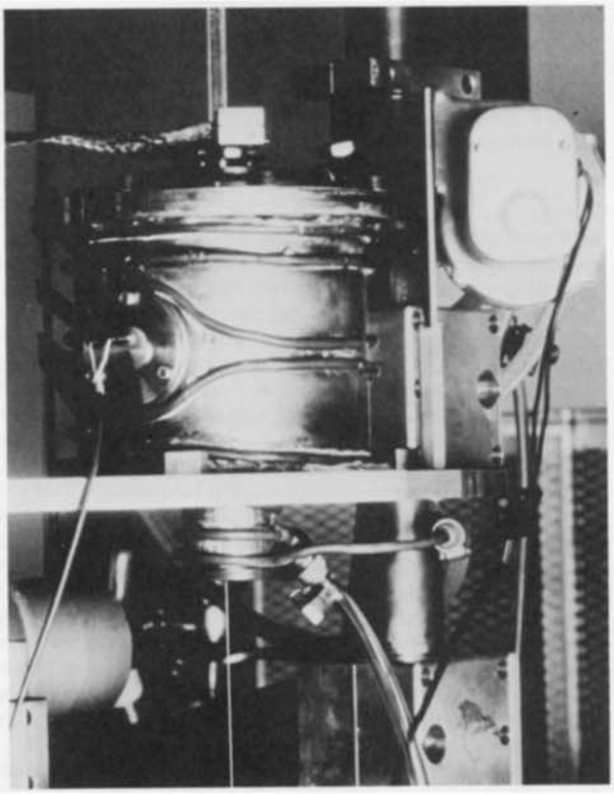


Fig. 2. Variation of temperature deviation from set point of 2070°C during fiber pull.



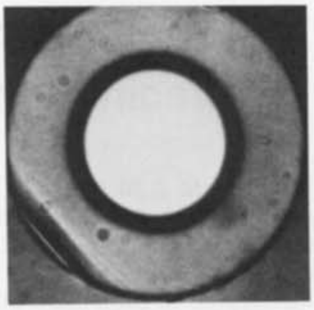
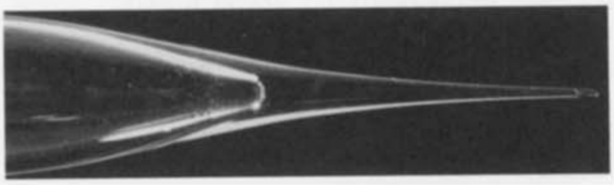


Fig. 5. Cross section of borosilicate-cladded phosphosilicate-core optical fiber with external support layer of pure silica; the circularity is excellent.



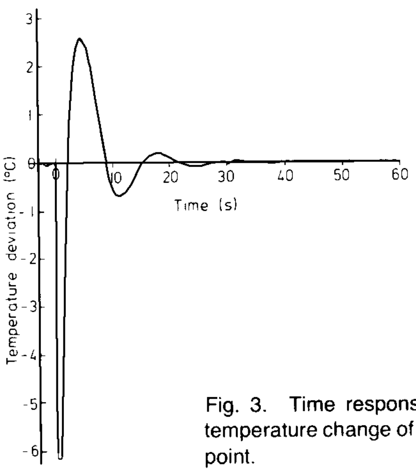


Fig. 3. Time response of furnace to step temperature change of 7.5°C in controller set point.

Fig. 5. Cross section of borosilicate-cladded phosphosilicate-core optical fiber with external support layer of pure silica; the circularity is excellent.

Fig. 6. Boule remaining after tubular preform shown in Fig. 4 has been simultaneously collapsed and drawn into fiber.

there is considerable economy in both time and amount of argon used. Furthermore, the preform can be positioned in the furnace cold, and the operator may then start the fiber pull at his convenience by turning on the furnace power.

Although an argon flow of 10 *l*/min is required during operation, there is no sacrifice in the accuracy of temperature control. Figure 2 shows the change of temperature deviation from set point during a fiber pull. A temperature of 2070°C was set on the three term temperature controller and the power turned on. Drawing from a 5 mm diameter silica preform commenced 3 min later. The trace represents the typical temperature stability during a pull and covers some 9 min or 400 m of fiber. The temperature is stable to within 0.06°C of the setpoint, and although this reading represents the furnace stability at the control thermocouple position only, it is unlikely that the deviation will be significantly greater elsewhere.

Figure 3 shows the time response to a step temperature disturbance which was initiated by an abrupt change of 7.5°C in the controller set point. The trace represents the deviation from the new set point during the period of recovery which is complete within 20 s, again demonstrating the advantages of a low thermal mass.

The furnace has now been in use for 18 months and has given eminently satisfactory service. The life of the heating element appears to be dictated largely by the care of the operator in excluding air from the furnace during the preform loading and fiber starting operations, and it is typically several months before the element becomes reduced in section by oxidation and requires replacement. The life of the remaining components is considerably longer.

The furnace, shown in operation in Fig. 4, has been used in the fabrication of solid silica fibers, hollow silica for liquid-filled fibers, single material silica fibers, silica cladded fibers with a phosphosilicate glass core and borosilicate-cladded, phosphosilicate core[3] fibers. The latter two have had attenuations of 2 dB/km and 3 dB/km, respectively. The excellent radial uniformity of temperature is reflected in the good circularity of the fibers as shown by the typical cross section in Fig. 5. The boule remaining after a tubular preform has been simultaneously collapsed and drawn into fiber is shown in Fig. 6. The preform consisted of a silica tube with layers of phosphosilicate glass deposited on the inside.

Fig. 4. Operation of furnace showing tube preform entering at top and fiber emerging below. The preform is a silica tube with layers of phosphosilicate glass deposited on the inside.

Conclusions

A graphite resistance furnace having accurate temperature control and capable of the precision drawing of silica-based fibers at temperatures up to at least 2200°C has been constructed. It is strong and reliable in operation and is suitable for routine production purposes.

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References

[1] D. B. Keck, R. D. Maurer and P. C. Schultz, "On the Ultimate Lower Limit of Attenuation in Glass Optical Waveguides," *Appl. Phys. Lett.*, **22** [7] 307–309 (1973).

[2] W. G. French, J. B. MacChesney, P. B. O'Conner and G. W. Tasker, "Optical Waveguides with Very Low Losses," *Bell Syst. Tech. J.*, **53**, 951–54 (1974).

[3] D. N. Payne and W. A. Gambling, "A Borosilicate-Cladded Phosphosilicate-Core Optical Fibre," *Opt. Commun.*, **13** [4] 422–25 (1975).

[4] P. H. Krawarik, "Power Spectral Measurements for Optical Fiber Outer Diameter Variation," postdeadline paper presented at topical meeting on Optical Fiber Transmission, Williamsburg, January 1975; PDI–1.

[5] L. L. Blyler, A. C. Hart, R. E. Jaeger, P. Kaiser and T. J. Miller, "Polymer-Clad Silica Fibers Produced by Laser Drawing," paper presented at topical meeting on Optical Fiber Transmission, Williamsburg, 1975, TuA5.

[6] B. Scott and H. Rawson, "Preparation of Low Loss Glasses for Optical Fibre Communication Systems," *Opto-Electron.*, **5** [4] 285–88 (1973).

[7] W. A. Gambling, D. N. Payne and H. Matsumura, "Mode Excitation in a Multimode Optical-Fibre Waveguide," *Electron. Lett.*, **9**, 412–14 (1973). □