Optical Fiber

Whitepaper

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An Experimental Study of the Deposition Rate in the ACVD Process

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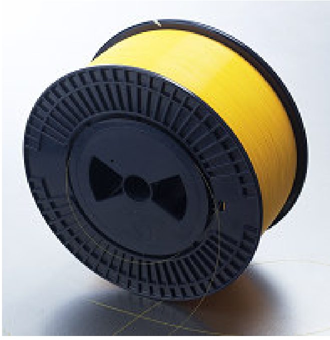
Abstract

Atmospheric Chemical Vapor Deposition (ACVD) process is widely used for silica soot deposition in the manufacture of optical fiber. In the present work a series of experiments were done on the ACVD lathe to study the deposition rate. Target core rod diameter, number of deposition burners, distance between the burners, distance between the target core rod and the burners were found the key parameters affecting the deposition rate. Average deposition rate of 30.2 gm/min with a material efficiency of 34% were achieved in three-burner experiment.



Keywords

Deposition rate, ACVD process

1.0 Introduction

In recent years optical fiber is being extensively used in telecommunication and sensor applications. Reduction in prices and increase in demand of optical fiber has induced the need to develop new techniques to increase the productivity of the machine. For manufacturing of optical fiber using the ACVD process, sub micrometer porous soot particles are deposited on the rotating and traversing target rod by passing the vapor stream of chloride and fuel gases through a burner. Soot deposition rate decides the capacity of the deposition machine. Target core rod diameter, chloride vapors and fuel gases were found to be the key process parameters affecting the deposition rate. Similarly no. of burners, distance between the burners and the distance between target core rod and the burners were the key hardware parameters affecting the deposition rate. The equipments used in this study consist of a lathe that is used for deposition of soot particles onto the surface of target core rod.

2.0 Experiment and Findings

The first step in the ACVD process is soot deposition on the target rod. In this step, a hot stream of soot particles of desired composition is generated by passing the vapor stream through a fuel gas i.e. oxy hydrogen flame directed towards a rotating and traversing target rod. The raw materials used were $SiCl_4$, $GeCl_4$ and O_2 and the burner gases were H_2 and O_2. The dominant mechanism of soot deposition in the ACVD process is thermophoresis, which is the tendency of particles to migrate down with the local gas temperature gradient. During deposition, the burner traverses back and forth parallel to the target rod axis so that one layer of the soot is deposited per pass. Soot particles are built up on this rod layer by layer. The soot for the core material is made of mixture of SiO_2 and GeO_2 with an appropriate proportion and deposited on the target rod depending on the refractive index profile of the desired optical fiber. The soot for the cladding material is silicon dioxide (SiO_2). When enough soot particles are deposited for both the core and the cladding of the optical fiber, deposition is stopped and the porous preform is slipped off the target rod. A weight measurement system was built to calculate the instantaneous deposition rate during the deposition process.

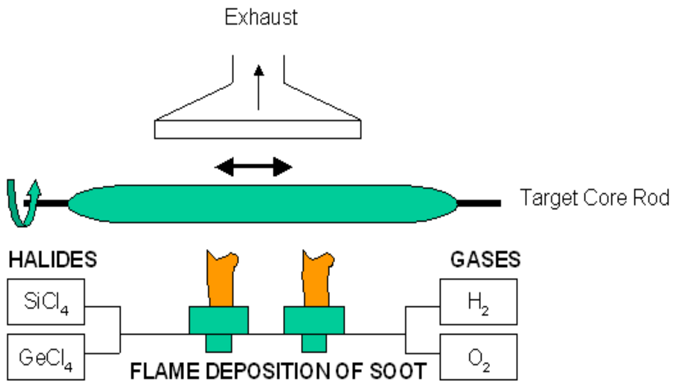


Fig. 2.1 Schematic diagram of over cladding process

The chemical reactions involved in the formation of the soot are given in equation (1) and (2). The chlorides react with Oxygen (O_2) in the flame to produce soot (SiO_2) and chlorine (Cl_2).

$$SiCl_4 + O_2 \rightarrow SiO_2 + 2Cl_2 \qquad (1)$$

$$GeCl_4 + O_2 \leftrightarrow GeO_2 + 2Cl_2 \qquad (2)$$

Equation (2) is shown as equilibrium because GeO_2 is not significantly more stable than $GeCl_4$ at this temperature. The water from the combustion of the fuel gas reacts with chlorine to produce hydrogen chloride.

$$2H_2O + 2Cl_2 \leftrightarrow 4HCl + O_2 \qquad (3)$$

The effect of this reaction is to consume a large portion of the chlorine gas produced by the formation of SiO_2 and GeO_2. In the next step, called sintering, a hollow porous preform is dehydrated and collapsed in a furnace at a temperature of 1550 ^{0}C in the presence of helium to form the desired mother preform. Core rods were drawn from mother preform for further over cladding. Normally 8 to 12 core rods were drawn from 10 kg of mother preform.

In the soot over cladding process, the desired amount of porous soot was deposited on the core rod (Fig 2.1). Soot preforms up to 1200 layers have been fabricated. Soot preforms were about 1300 mm in length, 180 mm in diameter and had a weight of around 15 kg. The average deposition rates were around 24 gm/min.

The porous preform is then taken to sintering stage. In this process again, the porous soot preform is sintered or consolidated to a dense glass rod by passing it vertically through the hot zone of a special annular furnace. During this step, the temperature is raised to 1550 ^{0}C. By using an atmosphere of helium with a few percent of chlorine within this furnace, OH-ions was removed very effectively resulting in very low OH-content fiber preforms. The preforms are then as usual drawn to fibers in the next process step.

The soot particle begins within about 10 mm from the burner face and is nearly complete within 100 mm. The first particles formed are of the order of 0.1µm. These grow by collision and coalescence to produce particles of up to 0.25 µm. Soot particles vary in composition, depending on the part of the flame in which they are formed and are collected on the target rod due to thermophoresis. Average deposition rate is defined as total deposited weight on the target rod divided by total deposition time, whereas the instantaneous deposition rate is the ratio of increase in weight deposited on the target core rod and time required for depositing the same.

Following experiments were conducted to study the effect of various parameters on deposition rate in over cladding process of target core rod.

2.1 Target Core Rod Diameter versus Deposition Rate

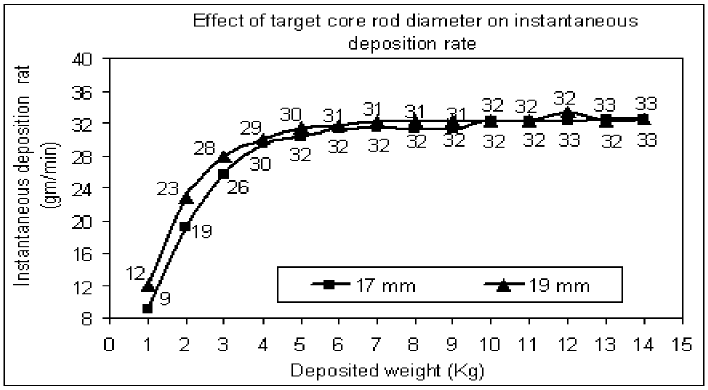


Fig. 2.1.1 Instantaneous deposition rate as a function of the target rod diameter.

Core rod diameter is found to be the key process parameter affecting the deposition rate (Fig 2.1.1). At the beginning of soot deposition, larger target diameters result in high deposition rate. For the first one kg of deposition, deposition rate was 14 and 10 gm/min for 19 and 17 mm target core rod diameter respectively.

High circumference and surface area of the preform allows more time and area during which the particles are close enough to the surface to be collected. Also, the average preform temperature is reduced, thereby increasing the thermophoretic force. Deposition rate and material efficiency both were found high with the higher target core rod diameter. Average deposition rate was found 26 gm/min in case of 19 mm target rod diameter and 24 gm/min in case of 17 mm target core rod diameter. The material efficiency of the process was 44 % and 40% in case the core rod diameter as 19 and 17 mm respectively.

2.2 Number of Burners versus Deposition Rate

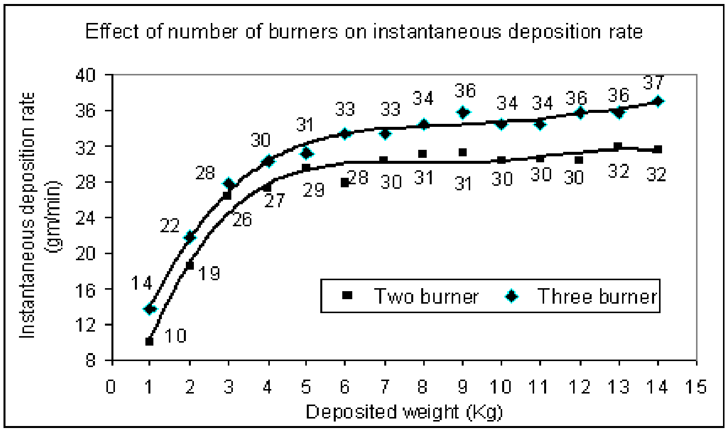


Fig. 2.2.1 Instantaneous deposition rate as a function of no. of burners

Fig.2.2.1 presents the instantaneous deposition rate for the two burner and three burner experiments. The instantaneous deposition rate went to 37 gm/min at the end of process in three-burner experiment and 32 gm/min in two-burner experiment. The deposition rate saturates during the soot deposition process when a critical soot diameter is achieved. Due to separation between the burners there was a formation of conical shape at the ends of the target core rod. A good quality optical fiber cannot be drawn from these conical parts due to undesired proportion of core and cladding. Lengths of cones were longer in case of three-burner than two-burner. Three-burner can be cost effective in increasing the capacity in case of longer target rod length. Again if the burners are too far apart, the length of the end regions increases too much. Average deposition rate in three-burner was 30.2 gm/min whereas in two-burner it was 25 gm/min. The material efficiency in three-burner was 34 % where as in two-burner it was 44 %.

2.3 Distance from Target Core Rod versus Deposition Rate

Increasing the distance of the target core rod from the burners increases the density of the soot layer. This is due to coagulation of the particles in the flame before they touch the target core rod. It is also possible that when the burner is moved farther from the target core rod, a hotter part of the flame touches the target core rod and partially sinters the formed soot layers. The increasing density again restricts the growing diameter of the target core rod. This explains why increasing the burner distance from the substrate decreases the deposition rate.

Initial deposition rate was 13 and 11 gm/min in case of distance between burner and target rod as 36 and 30 cm respectively. However in case of 36 cm deposition rate was high towards end of the process (Fig 2.3.1).

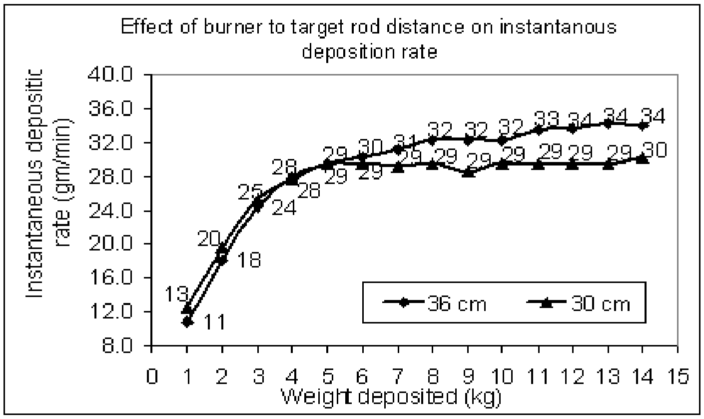


Fig. 2.3.1 Instantaneous deposition rate as a function of distance between burner and target core rod

Average deposition rate was 27 gm/min and 25 gm/min and material efficiency was 41 % and 44 % in case of burner to core rod distance as 36 cm and 30 cm respectively.

2.4 Distance between Two Burners versus Average Deposition Rate

Effect of distance between the two burners on average deposition rate has been given in fig. 2.4.1.

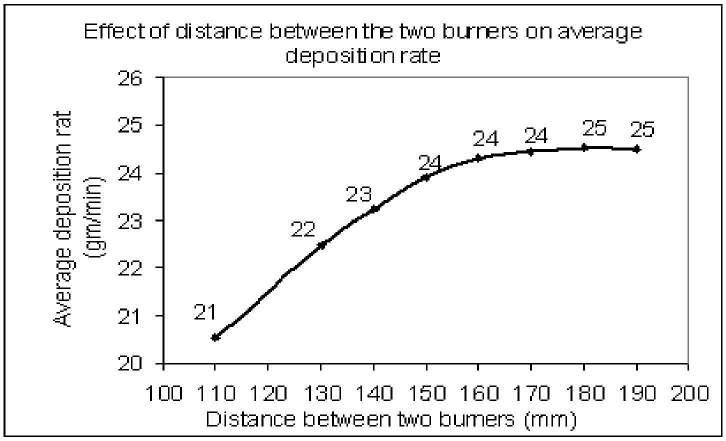


Fig. 2.4.1 Average deposition rate as a function of distance between two burners

This experiment was performed to find the optimum distance between the two burners. The trials were done for the distances between 100 to 200 mm. There was interaction between the burner flames when the distance between the burners was small. This interaction guides the soot particles past the target and in turn decreases the deposition rate and material efficiency. If the burners are too far apart then length of conical part at the ends region of target core rod increases too much and a good quality optical fiber cannot be drawn from these parts. The optimum distance was found to be around 150 mm.

Fiber drawn from the above experiments had an attenuation of less than 0.320 dB/km at 1310 nm and less than 0.210 dB/km at 1550 nm wavelengths. All the drawn fiber had very good geometrical parameters particularly core cladding concentricity, which was 0.22 µm, and cladding non-circularity, which was 0.3 % as measured using the PK 2400 geometry analyzer. Typical tensile strength was 4.4 Gpa and corrosion susceptibility factor n was found 20 as measured by dynamic tensile mode. All the optical, geometrical and reliability parameters were comparable with currently commercially available optical fibers.

Conclusion

The thermophoretic force has been found the main force pulling the particles towards the target core rod. By optimizing the process and hardware parameters one can increase the thermophoretic forces and in turn deposition rate. The average deposition rate was found 30.2 gm/min in three-burner experiment with material efficiency of 34%. There is trade-off between deposition rate and material efficiency as in case of two-burner material efficiency is 44% but deposition rate is 25 gm/min. The future potential lies in the larger preform size for which higher deposition rates and material yield can be achieved.

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