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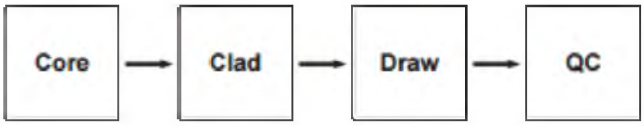
OPTICAL FIBER EXHAUST MANAGEMENT SYSTEMS AND INNOVATIVE TECHNOLOGIES FOR ITS PRODUCTION

Abstract. The article gives an overview of manufacturing technologies for optical telecommunication fibers and related innovative solutions. The production stages are described using the following methods: Vapor Phase Axial Deposition - VAD, Outside Vapor Deposition - OVD, Plasma Chemical Vapor Deposition - PCVD and Modified Outside Vapor Deposition - MCVD. Control systems for the drawing of optical fibers by disturbance and deviation are considered.

Keywords: optical fiber cable pulling control systems, optical fiber cable manufacturing, fiber core fabrication, axial vapor deposition method, external vapor deposition method, modified chemical vapor deposition method, chemical vapor deposition method using a furnace, plasma chemical vapor deposition method.

Introduction. Over the past few years, the production of optical fibers has undergone serious changes in terms of the technologies used. The fluctuations in demand and the decline in prices for optical telecommunications fibers have led to the need to develop new cost-effective manufacturing technologies and new fiber designs. This article describes the industry-accepted technologies for the production of optical telecommunications and specialty fibers, as well as several recent innovative solutions for the production of half finished products and fibers. The incentive for the development of innovative technologies is the desire to reduce production costs, increase productivity, achieve economies of scale, and improve the performance of optical fiber. Fibers of a special purpose, produced in small batches, with numerous types of structures (subcategories), are sold in meters, while the incentive for new technological solutions is the requirements of production flexibility in connection with the ever-changing designs of optical fibers.

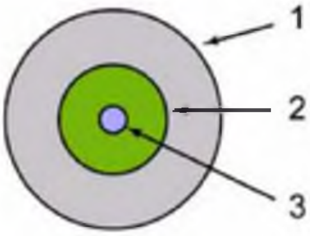
Overview of manufacturing technologies for optical telecommunications fibers and related innovative solutions. The standard sequence of the manufacturing process for single-mode optical fibers consists of the following steps: fabrication of the core of the optical fiber (Core), Build-up of the shell (Clad), drawing of the template into the fiber (Draw) and, finally, Testing for compliance with fiber quality (strength test, geometric test and optical testing) (QC).



Picture 1 – Process Steps

Manufacturing of core preform for a single mode optical fiber. Fiber parts with high resolution can only be obtained by using light guides with the same geometry. Deviations of individual elements of geometry (cross-sectional shapes, sizes, etc.) lead to a decrease in the frequency-contrast characteristics of the part, the appearance of micro structural noise and various defects in the working area of details.

The core blank determines the quality and performance of the fiber and is therefore its most important part. Known core manufacturing processes include the following: Vapour Phase Axial Deposition – VAD, Outside Vapour Deposition – OVD, Plasma Chemical Vapour Deposition – PCVD and Modified Outside Vapour Deposition – MCVD. The most widely used methods are VAD and OVD.



Picture 2 – Core and sheath of optical fiber:
1 – protective coating, 2 – reflection shell, 3 – core of optical fiber

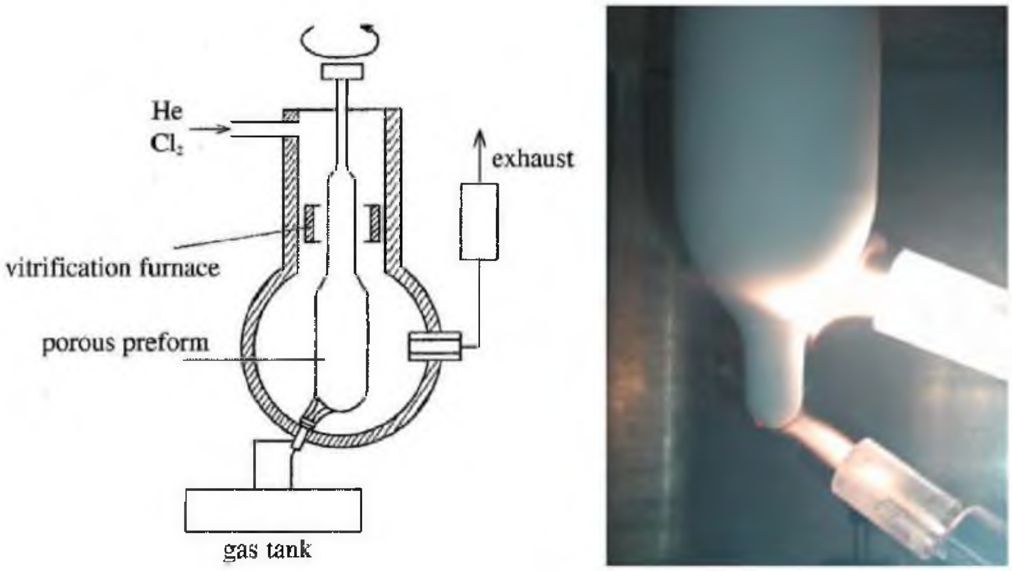
The process of manufacturing the fiber core by the VAD method. The method of axial vapor deposition (VAD), invented in 1970 in Japan, is a chemical process of flame hydrolysis, in which a vapor phase reaction forms nanoparticles of glass forming oxides. The particles (SiO_2, GeO_2) are deposited axially on a rotating quartz rod by thermophoresis deposition [4]. The porous preform is then sintered (dehydrated and vitrified), and then pulled into a rod, ready to build up the shell. The VAD method is best suited for the manufacture of optical fibers with a low content of hydroxyl groups, but it is also a very difficult process for industrial production. In conventional VAD deposition technology, concentric quartz burners made in glass workshops are used and small sedimentation chambers with a natural air flow. The metal burner is made of a metal gas distributor with a corrosion-resistant tube treated on a precision machine and forms a thermal and chemical barrier by supplying clean air. The formation of a flame and a chemical reaction occur in a laminar flow of clean air. This makes it possible to obtain very accurate and repeatable deposition, to control the volume and velocity of gases by means of the design, to use standard formulations, since they behave uniformly in any deposition plant. A large forced air chamber has separate outlets for the core and casings with minimal deposition on the walls of the chamber, provides a good opportunity to control unwanted secondary deposition, and also improve the stability of the flame due to the laminar deposition zone. This chamber design is successfully used to produce optical fibers with a low water peak at a deposition rate of 6 g/min. Currently, further development is being carried out to increase the productivity of these plants.

The management of the VAD process is very thorough. Refraction depends on the distribution of temperature over the surface of the preform, the position and angle of the flame. The consumption of raw materials, materials, fuel and exhaust gases, the speed of rotation of the porous billet and its position must be constant. The increase in deposition rate entails problems. The deposition efficiency of SiO2 is from 60 to 80%. In the production of single mode fiber, one burner is used for basic deposition and one or more burners for coating applications.

The VAD method is analogous to the OVD method to the extent that the deposition is not an internal process but an external process, in which a porous preform is formed, which is then dewatered and sintered. However, when using the VAD method, quartz powder (white carbon) precipitates in the axial direction and not in the radial (as is the case in the OVD process). This circumstance complicates the modification of the refractive index profile, but facilitates the production of longer blanks.

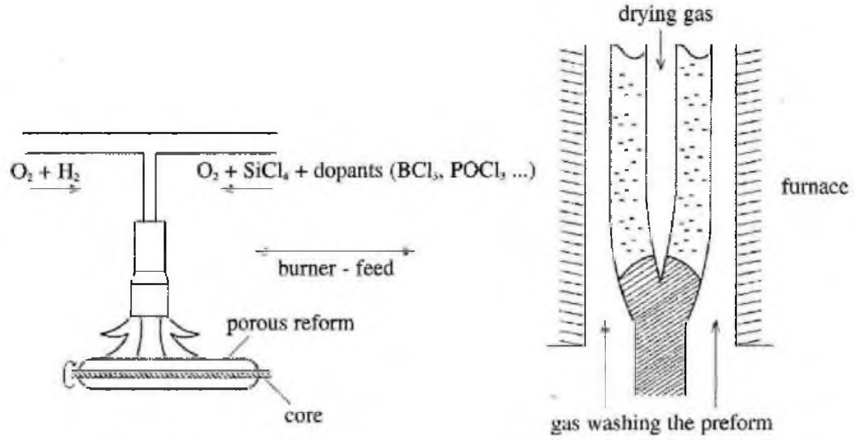
The process of manufacturing the fiber core by the OVD method. The method of external vapor deposition (OVD), like the VAD method, is a process of flame hydrolysis. Unlike the VAD method, which traditionally uses concentric quartz burners, manufacturers always used metal torches for the OVD process. The use of metal burners did not adversely affect the quality of the optical fiber.

This method uses lateral deposition on the core, which rotates at a constant speed. As a rule, the core is 0.5 cm in diameter and made of Al2O3 or graphite. Fuel, SiCl4, and the corresponding impurities are fed into the burner. The principle of this method is shown in Figure 4, a. Hydrolysis of halogenides in a flame results in the appearance of a solid carbon oxide or a mixture of oxides, some of which settle on the core, forming a porous substance whose density is about 1/3 of the density of the silicon glass. The layers



a) b)

Figure 3 – a – Production by VAD technology; b – VAD deposition method



a) b)

Figure 4 – The principle of production by the OVD method

are doped to a rod, after which they are formed into an elongated fiber. After doping, the rod, due to various thermal expansions, is carefully removed and the porous structure is sintered in the furnace at a temperature of about 1500 ° C (Figure 4, b). This method provides high requirements for protecting the environment from pollution.

Management of OVD technology also requires: the need to maintain a constant flow rate of raw materials and fuel, rotation of the perform and a constant temperature of the burner. During glass transition, the gas velocity, rotation and temperature of the burner must be constant. When vitrified, chemical reactions occur between the impurities and the gas which lead to a change in the profile of the refractive index.

Processes for manufacturing fiber core using MCVD and FCVD methods. The modified method of chemical vapor deposition (MCVD) consists in the process of formation of submicron quartz particles as a result of oxidation of $SiCl_4$ and subsequent deposition of ultradisperse powder SiO_2 and GeO_2 inside a high-quality rotating support tube. This technology has been used since the 1980s and is a simple layer-by-layer deposition process. In the MCVD process, the source of heat is the oxygen-hydrogen burners located outside, while in the FCVD (chemical vapor deposition method using a furnace); the heat source is the furnace. After the deposition occurs, the tube "collapses" into the rod, usually on the same machine for manufacturing the prefroms. The MCVD method is widely used for manufacturing special-purpose optical fibers, since it makes it easy to control the refractive index of each layer.

The main advantage of the MCVD process is that both the structure and properties of the light guide can be provided even in the preform, and then stored in the finished fiber. The relative dimensions and the profile of the refractive index of the preform are transferred to the finished fiber during the drawing process.

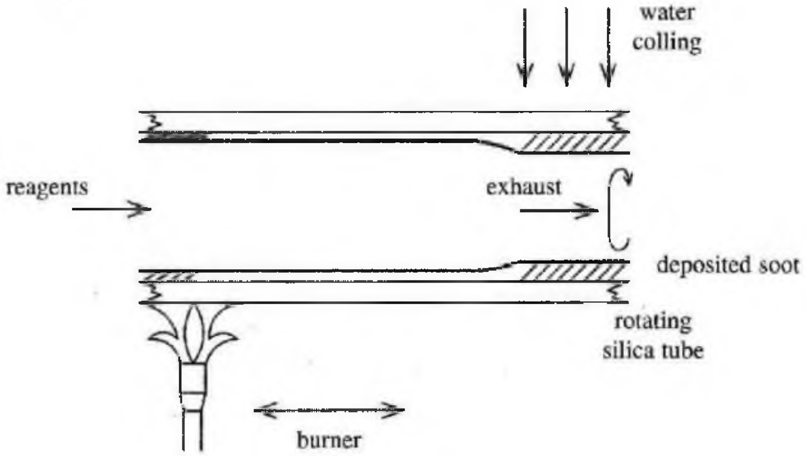


Figure 5 – The principle of production by MCVD

However, this method is no longer so widely used in the production of telecommunication optical fibers, since it does not make it possible to produce very large billets; the length of the deposition zone is often limited to 1 meter. An improved version of this method using a heating furnace instead of burners (FCVD) allows to reduce the content of hydroxyl groups in the billet and to produce fibers with a low peak of water. It also allows you to increase the "useful" size of the support tube.

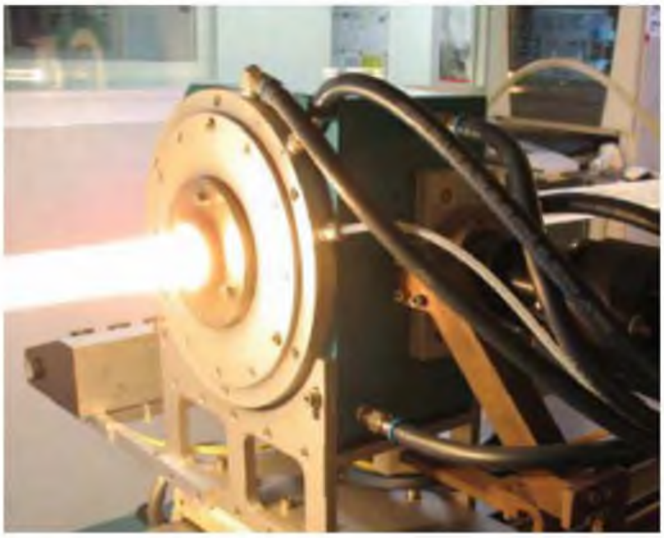


Figure 6 – Heating furnace for FCVD process

PCVD process. The plasma chemical vapor deposition (PCVD) method invented by Philips in the 1980s, patented and owned by Draka company, as well as the MCVD / FCVD methods, is an internal deposition process. The only significant difference is that the heat source used for sintering the precipitated ultradisperse powder inside the support tube is the low-pressure plasma inside, created by the radio-frequency field. This makes it possible to very accurately control the sintering process of the layers, which provides a more accurate control of the profile of the refractive index, especially in the case of optical fibers with a gradient refractive index, but at the same time a significant inclusion of doping impurities. The development of this technology for manufacturing of telecommunication optical fibers goes in the same direction as the development of MCVD technology, that is, the goal of further development is the manufacture of fiber core blanks with a smaller B/A ratio and rods for making a core with large diameters, which will lead to increased productivity.

It is easier to control PCVD than other methods. Raw materials should meet high requirements. Other parameters, such as pipe pressure, furnace temperature, plasma energy, resonator speed, etc. substantially do not affect the resulting parameters.

In the development of the process for manufacturing cores for single-mode optical fibers, steps are noted to increase the size of the blanks, increase productivity, and solve problems associated with the presence of hydroxyl groups, attenuation, and new fiber designs requiring new refractive index profiles.

Important distinctive features of the process are as follows:

- permanent build-up of preform;
- precise regulation of raw material consumption;
- maintaining a constant flame temperature;
- maintaining a constant temperature in the heating zone of the preform;
- maintaining a constant rotation speed of the preform;
- preservation of the preform extension area.

The finished core preform (regardless of the way it is made) is stretched into the fiber.

For each type of fiber parts, a specific fiber drawing technology is required. The technology is determined by the methods of its conduction, the regimes and the conditions for the production of its individual semi-finished products. But in all technological processes the operation of manufacturing single-core rods (light guides) is invariably present. It can be hollow tubes, thin bars with a cross-sectional diameter of 0.5 ... .2 mm. When they are manufactured, a drawing method is used from the die or a method of tugging from a preform, the end of which is softened by the action of temperature.

The glass so softened can be stretched under the action of its own gravity, external tensile forces, or squeezed out of a closed volume.

Control systems for the extraction of optical fibers. The drawing process requires constant monitoring and control. Therefore, it is necessary to know its characteristics and be able to evaluate the influence of all significant factors on the quality of the drawn fiber. First of all, it concerns the main technological parameters: the heating temperature of the glass mass, the speed of the glass supply to the heating zone, the speed and force of the fiber extraction.

The choice of management criteria is a crucial step, because this determines the structure of the management system as a whole.

For the process of drawing optical fibers, you can use control systems for disturbance and deviation.

In the studied process, perturbations of any kind lead to a change in the configuration of the formation zone and the pulling force. Therefore, the control structure can be constructed according to the scheme shown in the figure 7.

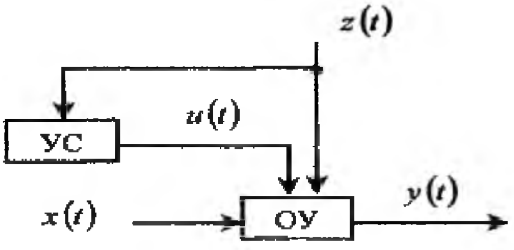


Figure 7 – The disturbance control system

In the figure, the following is indicated: OU - control object; US - control device; X (t) - control command (input, for example, drawing speed); Y (t) is the adjustable value (output, diameter of the fiber); and z (t) is the control action. This control parameter is controlled by z (t) (e.g., pulling force), which reacts immediately to the changes within the control object. This is the main advantage of such a management structure. However, since the output parameter of the drawn fiber is not controlled, this requires the detection of a connection between the changes in the pulling force and the diameter of the fiber.

The deviation management structure is shown in Figure 8.

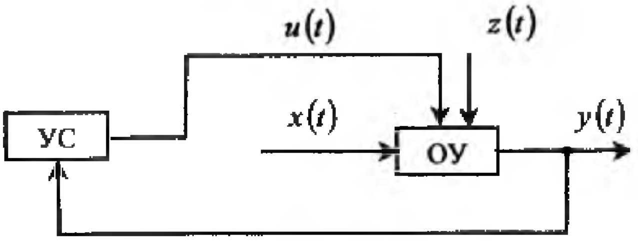


Figure 8 – Deviation Management System

For such a control structure, the output parameter y (t) is continuously monitored. Management is formed based on the results of control. In this case, the problem of transport delay arises. That is, information on the state of the control object cannot be obtained in real time. Therefore, it is necessary to establish dependencies that allow to determine the state of the control object at certain subsequent instants of time, if control and disturbing influences are known in the previous moments.

These dependences force us to search for the values of the controlled parameter that are optimal for the concrete conditions. In this case, the control signal is generated continuously and it must correspond to the optimal values.

Conclusion. Thus, the development of automated production facilities revealed problematic issues that do not find their solution empirically. These include: forecasting and optimization of process parameters; Stabilization of its characteristics; Finding dependencies between input and output parameters of the process; Optimal organization of control systems; Estimation of the level of interference that does not affect the quality of control.

This is explained by the complexity of the processes that occur when the fiber is formed. In addition, the characteristics of the control object are determined both by the processes occurring in the formation zone and by the parameters of the devices that draw the fibers.

The decision of arising problems and accordingly decision making at designing of technological complexes, that is a choice of control schemes, measuring devices, executive devices, calculation of adjustments of regulators, an estimation of quality of control systems in conditions of uncertainty is possible on the basis of creation of mathematical models adequately describing technological process.

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СИСТЕМЫ УПРАВЛЕНИЯ ПРОЦЕССА ВЫТЯЖКИ ОПТИЧЕСКОГО ВОЛОКНА И ИННОВАЦИОННЫЕ ТЕХНОЛОГИИ ЕГО ПРОИЗВОДСТВА

Аннотация. В статье приведен обзор технологий изготовления оптических телекоммуникационных волокон и связанные с ними инновационные решения. Раскрыты этапы производства с использованием следующих методов: Vapour Phase Axial Deposition - VAD, Outside Vapour Deposition - OVD, Plasma Chemical Vapour Deposition - PCVD и Modified Outside Vapour Deposition - MCVD. Рассмотрены системы управления процесса вытяжки световодов по возмущению и отклонению.

Ключевые слова: системы управления процесса вытяжки световодов, производство оптоволоконного кабеля, изготовление сердцевины волокна, метод осевого парофазного осаждения, метод наружного парофазного осаждения, модифицированный метод химического парофазного осаждения, метод химического парофазного осаждения с помощью печи, плазменный метод химического парофазного осаждения.

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ОПТИКАЛЫҚ ТАЛШЫҚТЫ СОЗУ ПРОЦЕСІН БАСҚАРУ ЖҮЙЕЛЕРІ ЖӘНЕ ОНЫ ӨНДІРУДІҢ ИННОВАЦИЯЛЫҚ ТЕХНОЛОГИЯЛАРЫ

Аннотация. Мақалада оптикалық телекоммуникациялық талшықтарды даярлау технологияларына және олармен байланысты инновациялық шешімдерге шолу келтірілген. Келесі әдістерді пайдаланып өндіру кезеңдері ашылған: Vapour Phase Axial Deposition - VAD, Outside Vapour Deposition - OVD, Plasma Chemical Vapour Deposition – PCVD және Modified Outside Vapour Deposition - MCVD. Жарықжолдарын ауытқу және жаңылу бойынша созу процесін басқару жүйелері қарастырылған.

Түйін сөздер: жарықжолдарын созу процесін басқару жүйелері, оптоталшықты сымды өндіру, талшық өзекшесін даярлау, остік парофазалық тұндыру, сыртқы парофазалық тұндыру әдісі, химиялық парофазалық тұндырудың түрлендірілген әдісі, пеш көмегімен химиялық парофазалық тұндыру әдісі, химиялық парофазалық тұндырудың плазмалық әдісі.