TECHNOLOGY DESCRIPTION

MCVD Optical Fiber Preform Fabrication Technology

1 Introduction

Modified Chemical Vapor Deposition (MCVD) preform fabrication technology is the most common method for production of special optical fibers, used in applications in the industrial, sensing, geothermal, oil, biomedical, defense and aerospace applications.
Typical optical fibers produced from MCVD-made preforms include:

- Special multimode gradient- and step index fibers,
- Modified refractive index profile, cut-off wavelength and dispersion single mode fibers
- Polarization maintaining fibers (panda, bowtie, or elliptical core types
- Low birefringence fibers
- Core rod fibers for microstructured fibers
- Active fibers, doped by rare earth- and metal-ions for laser and amplifier applications,
- Photosensitive fibers for Bragg grating applications
- Down-the-hole sensor fibers
- Special fiber designs used in sensing applications (micro- o macro bend fibers, …),
- Harsh environment and hermetic coating fiber, radiation resistant fibers
- Special bend insensitive fibers of different designs

MCVD process versatility, availability of fabrication equipment on the open market, public domain IP access, relatively low equipment complexity and lower investment cost compared to other preform fabrication methods, make the MCVD equipment and technology the widest fabrication platform for experienced or newcomer special optical fiber makers globally.

2 MCVD equipment description

2.1 Experience and knowledge

MCVD equipment and technology evolved and advanced over many years since its introduction in the late 1970s. Bimes pro, in cooperation with Plasil and other partners, is able to provide state-of-the art equipment and process solutions for MCVD fabrication labs, providing a whole line of fabrication equipment, from gas and dopant precursor delivery systems to the effluent control equipment.
Bimes MCVD system is the result of continuous development for over 15 years, with hands-on experience in preform fabrication process. Bimes and Plasil specialists and engineers have been involved in preform processes since 1986 and have therefore accumulated significant process and product knowledge.

2.2 Basic MCVD system configurations

Main components of an MCVD preform fabrication system are:

- Gas cabinet with vapor sources
- Preform lathe
- MCVD control system,
- Special doping equipment (used for active optical fiber preforms).

2.2.1 Gas cabinet

Gas cabinet role in MCVD equipment is preparation of gases and vapors, injected into preform substrate tube for reaction resulting in doped or undoped, deposited silica glass layers, the core of the future optical fibers.

Gas cabinet design features are very important for stable and repeatable gas and vapor delivery to the MCVD process. All the cabinet piping is made of pure piping components, ensuring leak-free operation with no gas purity deterioration. Gas flows are controlled by high quality mass flow controllers. Stable valve and flow controller operation is achieved by controlling gas panel operating temperature and pressure of all used gases.

Reaction vapors are generated by bubbling carrier gas through the liquid reagent in specially constructed bubblers. Bubblers are kept at precise constant temperature for stable and repeatable reagent vapor generation, in thermal oil baths, with oil temperature variation better or equal to ±0.1°C.

As gas panels, the lines bringing vapors and gases to preform lathe are heated as well, to prevent recondensation and gas temperature variations.

Only highest grade piping and piping components are used throughout the gas cabinet.

Special attention is paid to safety, both for the equipment and the operating personnel. All cabinets and panels containing aggressive or dangerous gases are vented to effluent treatment lines. Doors are leak tight and as option, leakage sensor can be mounted inside the cabinets.

2.2.2 Gas cabinet design: polymer vs. stainless steel piping

Critical piping components for MCVD process are bubblers and all the wetted line (lines carrying liquid chlorides or their vapors). A lot of confusing information is published on internet regarding this issue and discussions whether a combination of glass and polymer piping is better than metal, or vice-versa, is started quite often. The fact is that both solutions are able to give excellent fiber results, if used properly, in a production environment with trained personnel and good raw material selection with correctly designed infrastructure.

2.2.2.1 Glass and polymer material combination

If glass/polymer combination is used for wetted lines, the whole piping section has to be contained in a dry chamber. The reason for this is the fact that polymer piping (PFA and PTFE materials) is porous to some extent, meaning that some vapor or gas can permeate out of the gas line, and consequently gas or vapor (most damaging is hydroxyl or water) can also permeate into the gas line and contaminate the inner surface. Dry chambers are filled with a ultra pure gas (hydroxyl content 1 ppmv or better), typically nitrogen at pressure slightly higher than atmospheric. In this way, humidity cannot adhere to polymer piping surfaces and permeates into the vapor.

Any polymer line carrying MCVD vapor and gas mixture outside the dry chamber should be protected against permeation of oxygen and hydroxyl (or any other hydrogen containing gas) into the line. This can be prevented by using dual containment piping with vapors in the center and inert or less reactive gas around the vapor line.

2.2.2.2 Metal (stainless steel or Ni-alloy) combination

Metal bubblers and metal wetted line piping combination requires more effort for customer in providing infrastructure and proper gas quality to preform production premises. Metal components and piping ensure several orders of magnitude better sealing (leak-tightness) over polymer materials, therefore there is no need to put bubblers or piping components into dry chambers with controlled hydroxyl content. But, on the other hand, purge and carrier gas purity defines life time and quality of the fabricated fibers.

If all the process gases, especially carrier gas (usually oxygen) and purge gas (usually nitrogen) are hydroxyl-free according to our specifications, then no problem from liquid reagent or their vapor’s reaction with metal piping or components is expected.

For those reagents that have some compatibility issues with stainless steel SS316EL (i.e. $POCl_3$), we suggest using bubblers made from C-22 Nickel-alloy.

There are some other advantages to use of metal bubblers and piping components:

- Metal components can withstand high pressure conditions (if such pressure is applied by error) that can break glass bubblers or pull polymer piping out of fittings. Even if bubblers break inside dry chamber, it is not a pleasant safety situation to resolve,
- Metal bubblers can be used with a variety of level sensors (float, ultrasound, …), permitting fully automatic bubbler refill operations with added safety, while glass bubblers are usually filled by visual level determination,
- Pressure inside the bubbler, over the liquid, is an important process parameter for repeatable and stable chloride evaporation, when using metal bubblers, such sensors can be installed directly on bubbler top flange without the need to purge line or protect them against gas permeation.

2.2.2.3 Bimes / Plasil solution

We at Bimes and Plasil recognize our customers may have a preference, therefore we are ready to offer them the choice – either use glass bubblers and polymer piping, or metal bubblers and piping.

The cost of both solutions is very similar, as polymer piping components are often more expensive than metal ones, while glass bubblers tend to be cheaper (and offer less functionality) than metal ones.

We offer the following services, to provide customers with proper information and knowledge, to use MCVD systems regardless of piping design:

- Advice and support about the gas delivery systems, prior to delivery or even in the laboratory design stage, with purity specifications and suggested gas state and suppliers,
- Operator and engineer training for proper use and understanding of MCVD equipment concept,
- Delivery of GPS centralized gas purifiers, or individual gas purifiers or getters, as hardware solutions to ensure low hydroxyl and impurity content in carrier, reaction, and purge gases.

2.2.3 Preform lathe

Preform lathe is where the chemical reaction and silica glass deposition takes place. This happens inside a substrate tube, made of fused silica, and heated externally to very high temperature by a suitable heat source, most often by a hydrogen/oxygen burner and sometimes by a special furnace. Preform lathe has many functions: holding substrate tube, connecting substrate tube to rotary seal and to the soot box, rotate the chucks, and traverse heat source along the tube. Several subsystems are installed on the preform lathe: support with IR temperature measurement, camera and flame detectors, soot box with tube inner pressure control, tube end burners, motor to traverse tailstock, hot air exhaust hood and safety devices. Electrical control cabinet is installed under the lathe and gas cabinet for burners, soot box and cooling water stands behind the lathe. Preform lathe can be enclosed in a semi-open or fully enclosed cabin with hot air extraction hood.

2.2.4 OptiFACT MCVD control system

Over the whole platform, Bimes equipment solutions use **OptiFACT (Optical Fiber Automation Control)** systems (previously named WinMCVD or WinCONTROL), with common GUI interface and machine control concept, developed since 2009 by **Blubit** company. OptiFACT control system is described in detail here in **Bimes home page**.

OptiFACT control system development was started by Blubit and Optacore companies in 2009. It is the result of common development of automation specialist, equipment designers and optical fiber process specialist. Over the years OptiFACT software package has been constantly upgraded, optimized and new functionalities were added, based on requirements by the perform process engineers and operators.

OptiFACT software and hardware has been developed from the start to provide control systems the whole range of different preform or fiber making machines and devices, including scrubbers, gas cylinder cabinets, bubbler refilling systems, glass working lathes, vertical jacketing lathes, fibers draw towers, plasma deposition systems, and others from the Bimes and Plasil equipment portfolio. Over the years, OptiFACT (as earlier version WinMCVD) has been often used to upgrade control systems in MCVD equipment from other suppliers. Wide customer base and advanced functions make OptiFACT one of the leading control system and software packages, available for optical fiber industry.

2.2.4.1 OptiFACT Hardware Description

OptiFACT control system is based on program and database operating on industrial PC computer (IPC) with latest Windows operating system (or even older version, where required). Software is designed to keep compatibility with the future Microsoft operating system versions.

Hardware part of the control system is based on components supplied by **Beckhoff**, a global supplier of open automation systems based on PC-based control technologies, with EtherCAT Fieldbus I/O devices and PLCs (Programmable Logic Controllers) using TwinCAT runtimeThe automation package is made up from IPC), Beckhoff TwinCAT PLCs, and connection tofieldbus I/O devices through EtherCAT (dedicated GigE LAN cards). Actuators and sensors in Bimes equipment are selected so that they operate through EtherCAT or using other digital interfaces. This simplifies the wiring complexity and makes troubleshooting easier.

Safety of operation is an important issue, to prevent any harm to the personnel or the equipment, PLC has a heartbeat detection - in case of connection fault between the PLC and the IPC with OptiFACT, a safe close-down is performed to ensure safety of both the personnel, and the equipment.

All control system components (except lathe control panel) are installed inside a standard size electrical cabinet. All cabinet materials are carefully selected to provide the best protection against corrosive environment and provision of longest lifetime. Cabinet provides compartments for all necessary parts and subsystems; a small UPS unit is installed inside the electrical cabinet to provide uninterrupted power to PC and I/O devices in case of power failure.

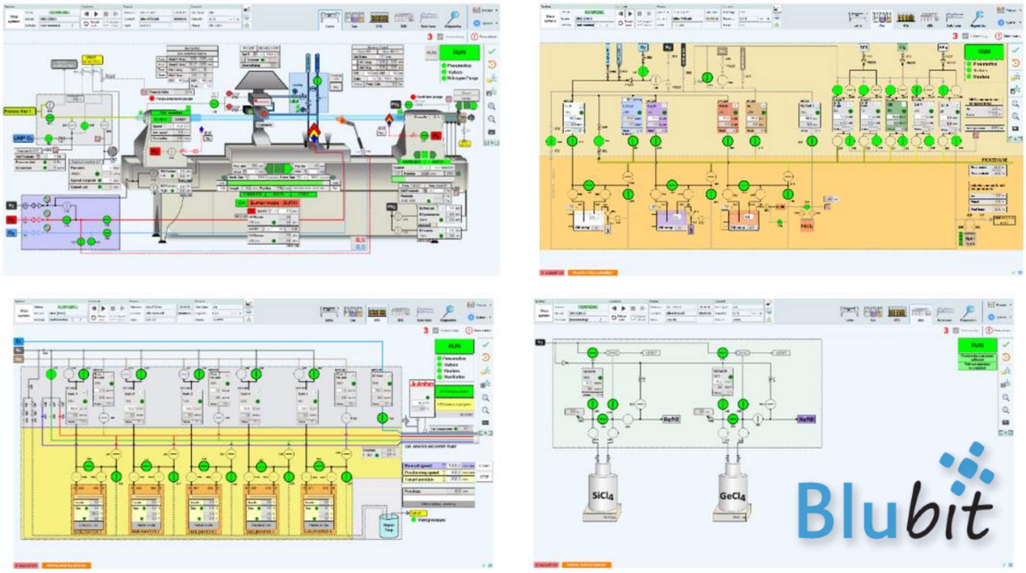
IPC configuration includes:

- Software components for complete implementation of OptiFACT
- dedicated communication card for connection the the Beckhoff PLC and further I/O devices
- dedicated communication card for CCD camera
- dedicated communication card for Infrared Line Scanner.

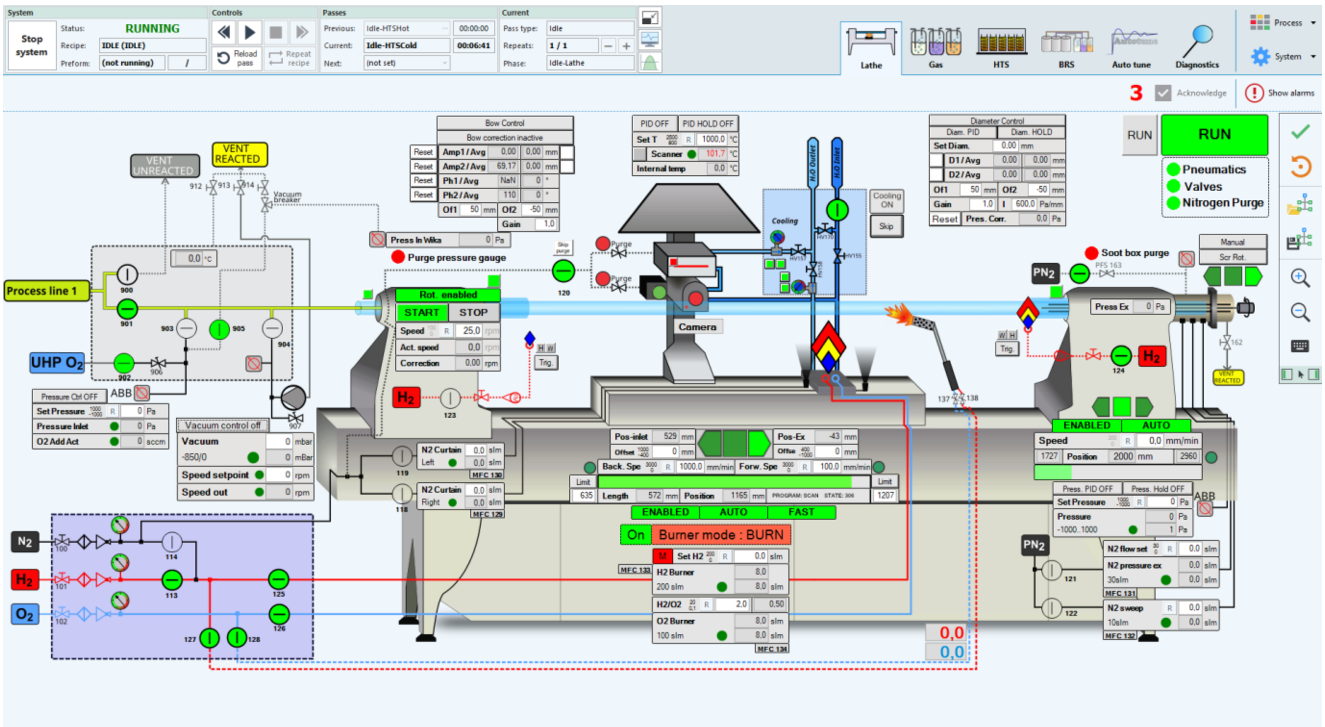
A lathe manual control panel is provided for operation of preform lathe during glass working operations, or during preform fabrication. This panel is installed close to or directly on the lathe carriage, functions include burner ON/OFF and burner flow setting in manual mode, carriage traverse, spindle rotation, setting of limit switches for carriage traverse, motor clutch control, etc.).

2.2.4.2 OptiFACT software package

OptiFACT software is written in the C# language using .Net Frameworkand combines all the necessary control functions for MCVD or other optical fiber or preform fabrication processis.
One of the key features of the OptiFACT program is the capability to control one or several devices or accessories through several control screens, where each screen is called a “machine setup” with all related control functions. Standard MCVD system control has twomachine setups”, the preform lathe and the gas cabinet. But control system can control devices which are not part of the MCVD system, like BRS Bubbler Refilling System), SGS gas cylinder cabinets, GTS gas scrubber, GPS centralized gas purifier, and others (see image below).



OptiFACT software shows a screen for each device and accessory, each screen is called a "machine". Preform lathe, gas cabinet and HTS doping systems screens are shown here.



OptiFACT software preform lathe screen (no MIF furnace) is shown in detail.

OptiFACT control software is the central controller when running in manual mode or executing recipes / running the system in automatic mode. This program has the following functions:

1) Database structure for complete machine set-up, including fabrication recipe, ramp file, data logging, and alarm management systems.
2) Display of process data and controls on computer screen,
3) Communication with all control devices, sensors, and actuators in the MCVD system, also with devices outside MCVD system (i.e., bubbler refill devices, CDS-03 system, …) or with infrastructure and auxiliary systems trough data exchange with PLC using real-time communication with all the fieldbus devices.

4) Automatic operation of MCVD system by running a recipe (either in idle or preform fabrication).
5) On-line process analysis tools (real time diagrams showing evolution of process parameters)
6) Logging of process data for post process analysis and evaluation.
7) Recipe editor (on-line during process run, or off-line) allowing recipe changes even during preform fabrication.
8) Tool for generation and management of ramping files in an intuitive graphic display format
9) Display of historical process data on screen from logged data in database.
10) Extensive alarm reporting system.
11) Remote access and monitoring of system operation (including remote upgrade, maintenance, etc.) through network connection or remote desktop application.
12) PID control algorithms for most functions (tube temperature by burner or furnace, tube inner pressure control, all gas cabinet and other heating zones, optionally tube diameter and preform bow control) in closed or open loop, based on signals or data provided by sensors or controllers in the system.
13) Training tools and off-line recipe preparation through program's so called virtual module allowing process simulation.
14) Possibility to change language version of software through set-up functions.

Recipe preparation and management can be done in MS Excel™ spreadsheet program or directly in the OptiFACT's recipe editor. System allows recipe correction and management functions even while process is running. All process parameters provide ramping functions through unique graphical ramp generation subroutine. OptiFACT provides functions to import or export recipe from/to Excel spreadsheet. Export to PDF file is also supported.

Process data logging is freely configurable and can record any logical input or output device. For convenience of smaller file type and cross-platform management, logging files are generated from database using built-in function to delimited ASCII format, they can then be opened and edited by any spreadsheet program or database.

3 Key MCVD features for optimal process control

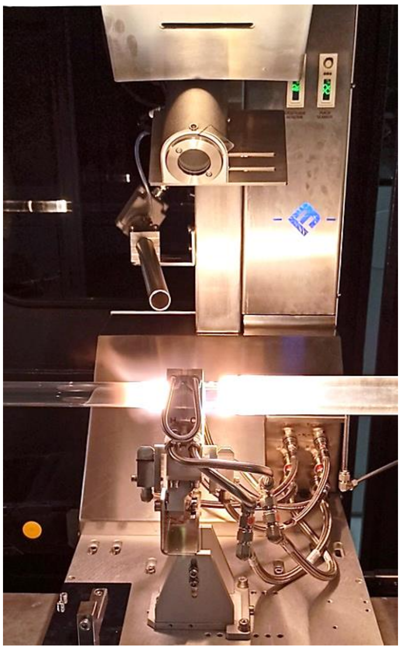
While selection of high grade components, purity of all wetted materials and leak tightness of MCVD preform making systems is very important and constitutes the basis for properly equipped fabrication devices, there are a number of process related functions that are key factors for successful, high yield, bubble-free glass fabrication with high productivity. Bimes MDS preform fabrication systems are designed and constructed by process specialists with more than 35 years of hands-on experience. The following functions and subsystems or devices are the basis for versatile and XXXX MCVD process:

- Precise temperature measurement in different process conditions
- Substrate tube inner pressure control with competent soot removal
- CCD camera vision system and controllers for tube diameter and preform bow control
- Recipe and ramping function configurator
- Process logging system
- Doping systems for different types of fiber preforms (active, PM, photosensitive, …)

In the section below, each of these Bimes MCVD key solutions is described more in detail.

3.1 Advanced temperature control

Substrate tube surface temperature is one of the most important parameters in MCVD preform process. Hot zone temperature and shape define:



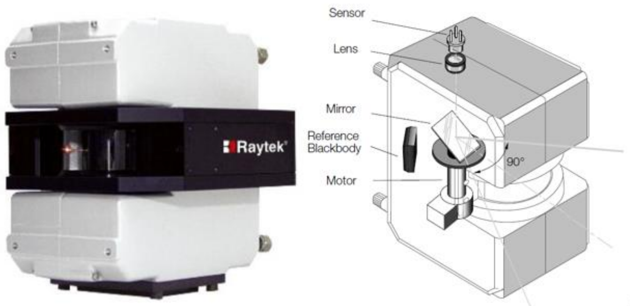
- chemical reaction dynamics
- silica glass particle nucleation conditions
- porous layer vitrification conditions
- radial homogeneity of deposited layer

Surface temperature is measured in the 5 µm wavelength window (when H_2/O_2 burner is used as heat source) by infrared pyrometers. In Bimes MCVD equipment, IR scanner replaces the traditional single point IR pyrometer, to be able to measure temperature on the tube over a length larger than hot zone.

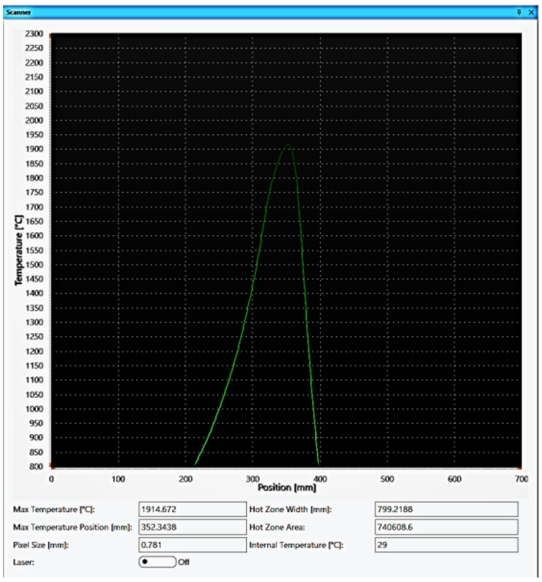
The Raytek MP150 LineScanner Series is a family of advanced infrared linescanners providing accurate, real-time, thermal imaging for a wide variety of industrial applications, including optical fiber preform fabrication using H_2/O_2 burner as main heat source.

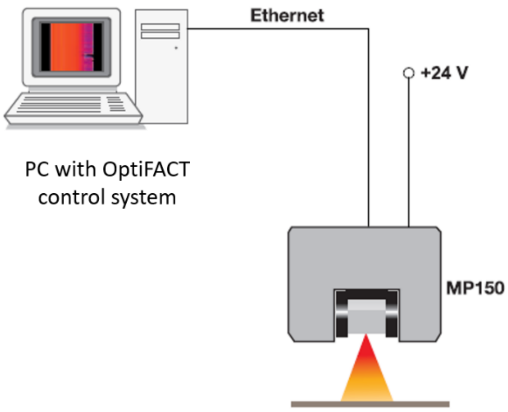
Main the Raytek MP150 LineScanner parameters are:

- up to 1024 measurement points per line, 150 lines per second,
- 5µm wavelength pyrometer with adjustable emissivity from 0.2 to 1
- temperature measurement range between 800°C and 2300°C
- high optical resolution up to 150:1
- fast and reliable Ethernet communication
- 40.000 hours MTBF brushless scanning motor
- field-replaceable window, with built-in air purge and water cooling



OptiFACT control software directly acquires line scanner's raw data through Ethernet network then calculates maximum temperature, its relative position on tube, and hot zone shape parameters.





OptiFACT display of hot zone shape and Raytek LineScanner installation diagram.

The above parameters are used for further process control by adjusting H_2 and O_2 flows as well as H_2/O_2 ratio using OptiFACT' s PID hot zone shape algorithm. This function permits very exact optimization of process parameters in different process steps. Key advantages of the OptiFACT burner controller are:

- regardless of carriage speed, tube temperature is always measured correctly, without the need to adjust sensor position,
- accurate maximum tube temperature is measured regardless of the carriage direction (forward of backward deposition) which is the key solution in deposition of porous silica layers and solution doping process,
- hot zone shape adjustment (very important) for high precision collapse process along the whole length of preform due to variations in outer diameter or thickness of deposited layers,
- scanner position has very little influence on measurement results (within range) improving process repeatability with less maintenance and calibration procedures,
- easier longitudinal temperature ramping due to accurate readout of maximum temperature at various burner speed,

With these functions, OptiFACT in combination with Bimes hardware is the best solution for any fiber maker using MCVD technology, for the widest portfolio of products.

3.2 Tube inner pressure control and soot removal

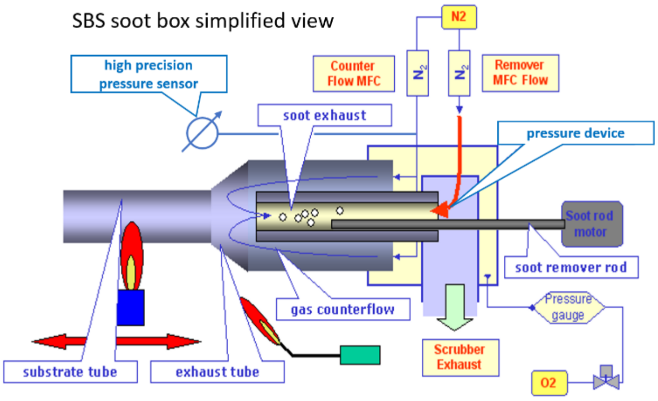
3.2.1 SBS soot box design

SBS soot box is the key components of the tube inner pressure controls and also the key to successful control of the substrate tube outer diameter (see below). SBS is made of material, resistant to exhaust gases and installed inside tailstock bore. At one end (tube side) it provides sealing element to exhaust (soot collection) tube, and on the other (soot box side) non-rotating support for soot remover and for connections to scrubber, pressurizing gas, and pressure sensor.
The soot box body protects the inside of the tailstock bore against corrosive gases and soot accumulation. Seal to quartz exhaust tube is made from soft elastomeric seal (chlorine and heat resistant) mounted on an insert, which is fixed to soot box in such a way that removal and insertion is made quickly and without requiring special tools. Elastomeric seals can be made by customer with tools delivered with SBS. By cutting the seals to the right dimension a wide range of exhaust tube diameters can be accommodated, from 20 to 55 mm.

Soot box construction permits quick disassembly for fast and simple maintenance. Soot remover rod is made of stainless steel and is inserted so that it lies inside the central exhaust glass tube. The soot remover is connected to an actuator, for automatic soot removal, stroke can be made manually, actuated on the control screen, or from recipe for fully automatic operation.

3.2.2 Tube inner pressure control

Tube inner pressure control is one of the most important functions of a state-of-the-art MCVD system. Fabrication of preforms with large diameter or large deposition rate, or with deposition of layers that require high vitrification temperature, is not possible without controlling the inner pressure, to prevent or limit precollapse of the substrate tube during the deposition stage, or increased ellipticity of very soft highly phosphorous or boron-doped silica layers in collapse.



Tube inner pressure control on MCVD systems equipped by a SBS soot box, uses two pressure sensors.

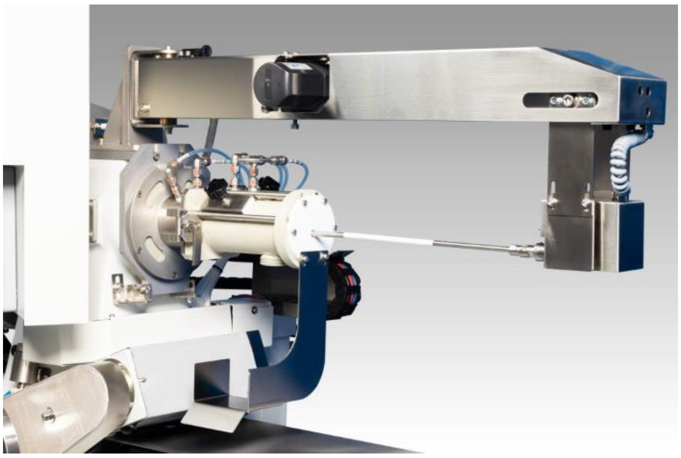
The first one is connected to vapor delivery at the entrance to rotary seal, in such a way that it can measure pressure inside the tube/preform at the start of the substrate tube. This measurement is important during backward collapse operation. A special PID controller is provided for control of this pressure and is usually used in the final preform collapse stage. Pressure in the inside section of the preform is actually controlled by adjusting additional reaction oxygen flow into preform line. Pressure reading is also a valuable help in evaluating at which moment the preform is "closed" at one end (either inside or exhaust side) as the pressure rises significantly as compared to conditions during deposition or initial stages of collapse (shrinking the tube).

The second pressure sensor is connected to the soot box in such a way, that it senses the inner pressure at the joint of substrate tube to exhaust tube. The pressure at this end of the substrate tube is controlled by additional pure (UHP) nitrogen gas flowing into exhaust tube. Nitrogen flow is controlled by two mass flow controllers. One of the nitrogen lines is connected in such a way that is provides a constant preset (controlled manually or by recipe) flow into exhaust tube in counterflow direction to reaction gases, while the second line provides flow to a pressure creating nozzle at exit of reaction gases from exhaust tube. This flow is actively controlled by a PID controller during preform fabrication process.

PID controllers are implemented in OptiFACT control software and can control pressure in either location in a closed loop, reading pressure sensor signals and controlling N2/pressurizing gas flows via mass flow controllers. Proper operation conditions must be set up during process start up (i.e., scrubber duct should be connected, and proper suction provided). Pressure controller functions can be switched on and off by a recipe or manually from the control screen.

Required precision of tube inner pressure control should be equal or better than better than ± 2.5 Pa, Bimes system can achieve better than ± 1 Pa if scrubber suction and other operating conditions are stable.

3.2.3 Soot removal



Soot removal does not seem to be an important parameter for quality of produced preforms, but experience shows that competent soot removal has a large impact on preform yield.

Substrate tube is usually welded to a larger diameter exhaust tube, which evacuates reaction product gases and silica soot (only approx. 50% or less soot or particles are deposited in substrate tube in a typical MCVD process due to thermophoretical conditions). To remove accumulated soot from the cool exhaust tube, a soot remover is used. If soot remover is not designed properly or due to operator errors (bad welding between tubes, improper end burner position, awkward handling of soot remover), soot can accumulate on the welding point or in the exhaust tube, and cause clogging, which in turn, causes the substrate tube to inflate uncontrollably. Such preform runs end in scrap material and lost production time.

Another known problem is penetration of soot backwards (counterflow) into the substrate tube deposition area, causing generation of bubbles and inclusions, which cannot be vitrified properly. Significant preform useful length loss results from such phenomena. Operation of the soot remover should not interfere with tube inner pressure control.

With Bimes-designed soot box SBS and automated soot remover problems with clogging of exhaust tube and soot penetration into substrate tube are solved for different types of deposition conditions, even when extremely sticky soot is produced (i.e. high boron, phosphorous or germanium doping). SBS design and operating conditions prevent soot build-up at the welding point, clogging and semi-vitrified soot deposition on initial length of the exhaust tube. With SBS soot remover rod can be used by hand, or its stroke in and out can be made by electromechanical arm (actuator). Stroke length and speed of forward/backward movement are set up through **OptiFACT** control system setup and setting of safety limit switches on support arm. The soot remover rod has a rotation motor, providing approx. 15 RPM, improving soot removal from the central soot box tube. As soot remover rod never penetrates exhaust tube all the way to substrate tube, danger for overheating the rod or for pushing loose soot into substrate tube is practically nonexistent. In case when long deposition with high rate is done and soot is sticky (high boron or phosphorous content), automatic soot removal needs to be visually checked and exhaust tube cleaned manually.

3.3 PID Tube diameter & preform bow controller using CCD camera

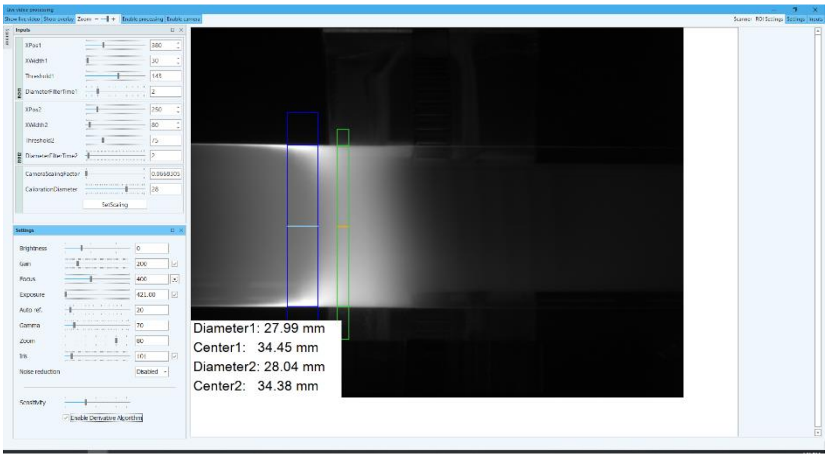
3.3.1 Tune diameter control and vision system

Controlling substrate tube outer diameter during preform fabrication or in tube preparation is one of the most important functions of an advanced MCVD system. Proper diameter control during different process steps improves preform longitudinal and radial homogeneity, recipe repeatability and therefore also the overall MCVD fabrication yield.

Tube diameter control is a complex task, as changes to tube diameter due to process conditions depend on several parameters, which are closely linked to each other. These parameters are:

- Tube geometry (outer and inner diameters i.e. wall thickness),
- Tube silica material viscosity, as well as deposited layer thickness and viscosity,
- Tube temperature and hot zone characteristics,
- Burner translation speed and flame pressure.

Tube diameter control is done by changing the tube inner pressure, as burner speed and tube temperature parameters are usually predetermined by preform fabrication process conditions. No diameter control is possible without a precise and competent tube inner pressure control, of the type as described above.

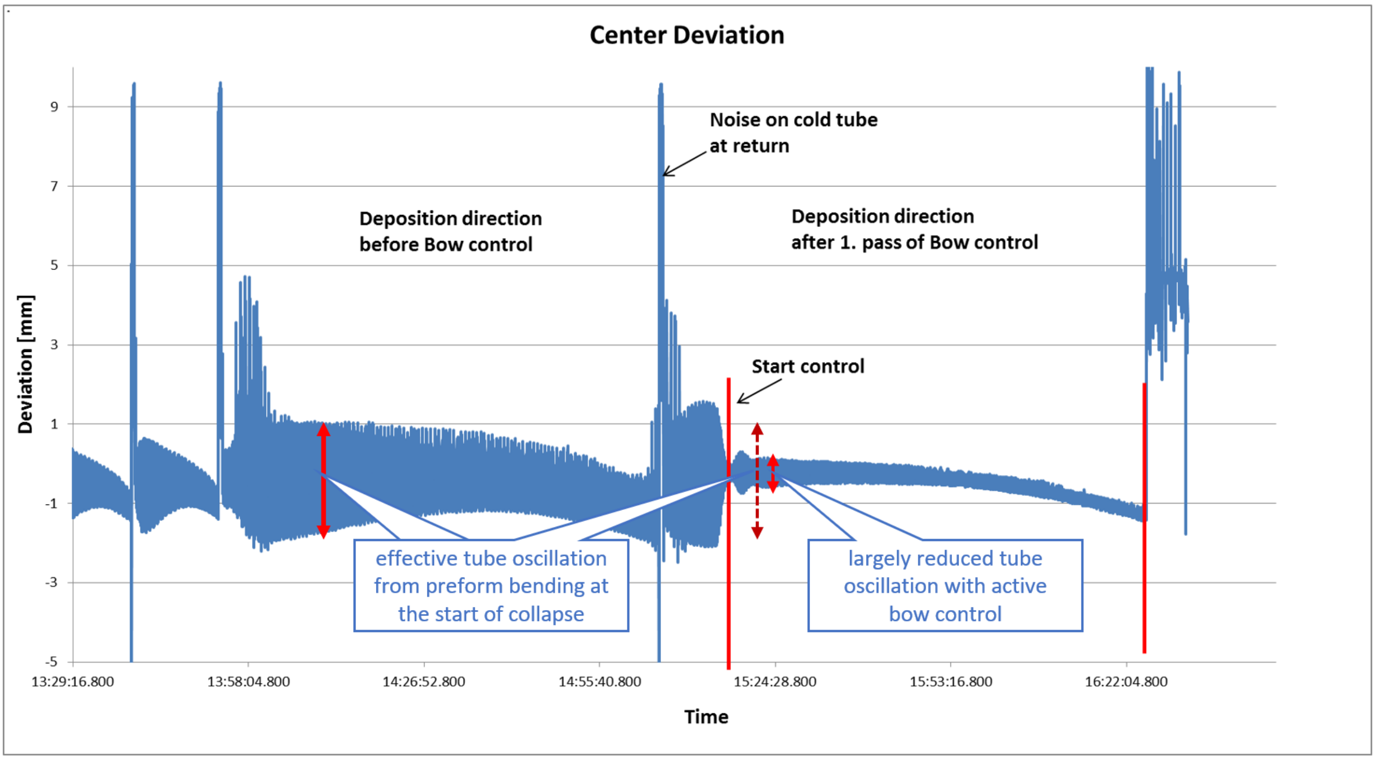


Tube outer diameter has to be measured in real time and with precision even though IR and UV radiation from heated silica tube blinds the visual measurement. A fast CCD camera with suitable focal distance, auto focus and aperture control are used for this purpose. Camera is installed inside water cooled housing on a swivel mount, installed on IR scanner support arm and it is aimed so that it observes the tube in the hot zone. Images from camera are sent to OptiFACT software, where tube diameter and tube center position are evaluated in real time.

Tube diameter PID controller is also implemented in the OptiFACT software and control parameters are defined so that a wide range of process conditions can be covered. For specific products (tube sizes and deposition thickness), PID parameters have to be adjusted.

3.3.2 Preform bow control

High temperature processing of the substrate tube during deposition and collapse process introduces a certain of tube deflection from a straight line (bow or bending). Proper preform lathe maintenance (alignment) and good quality tube preparation by operators can minimize bending in later stages of the fabrication process, but it is impossible to completely eliminate this problem, on all preforms. Preform bow is an important parameter as bent preforms can influence final optical fiber quality and yield.



Results of preform bow control operation during 1st and 2nd collapse pass.

For this reason, OptiFACT software and preform lathe hardware together with CCD camera vision provide a tool for reduction or elimination of the preform bow (bending). This straightening operation is done when tube/preform hot zone temperature is high enough for silica glass to be softened, usually in the first steps of preform collapse.

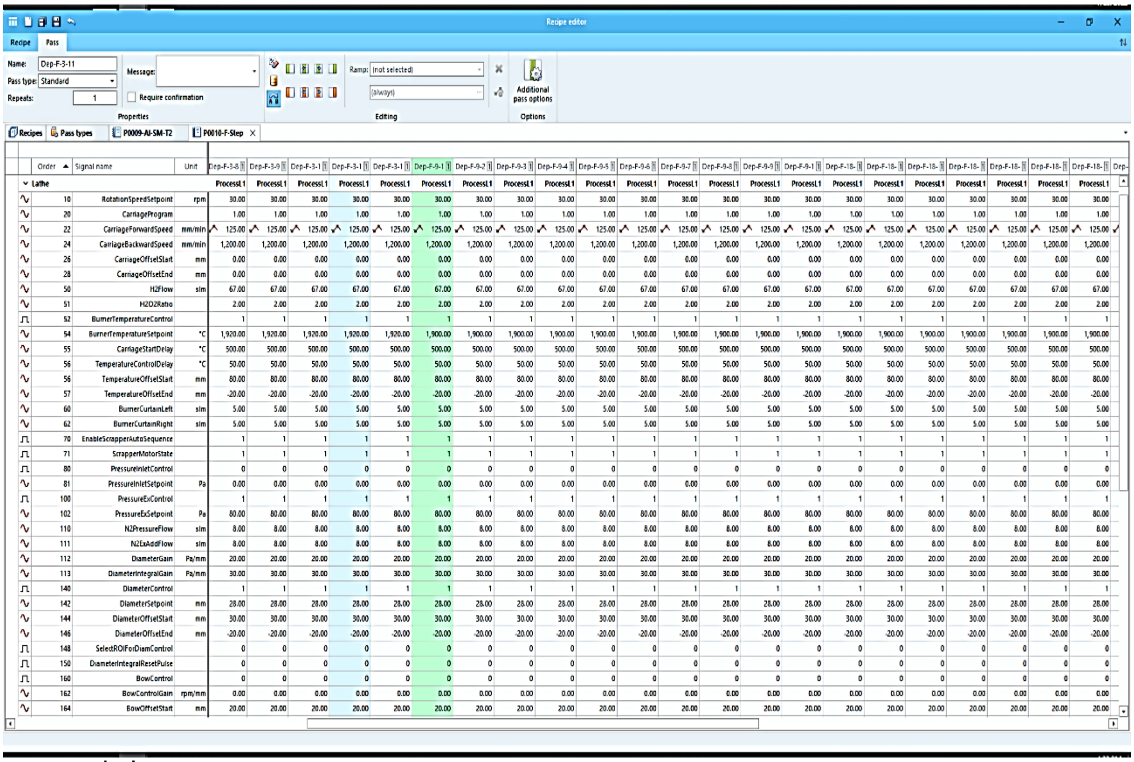
The diagram above shows the result of bow control action on a preform in two burner traverses. In the first one, no correction is used, and camera detects significant oscillation of the tube center in the view field. In the second traverse, bow control is switched on and the trace of the preform center position is significantly improved (note: bent curve indicates preform sag due to weight and it is not a permanent deformation).

In fabrication of polarization maintaining, low birefringence, laser optical fibers or any fibers requiring perfect core alignment with outer glass surface, preform bending has to be eliminated before core preforms are jacketed or further processed. Bow control is therefore a tool that must be included with the MCVD system for most special fiber makers.

3.4 Recipe and ramping

3.4.1 Recipe editor, execution

Automatic operation of an MCVD system is done by using a recipe, a table with a set of instructions for each process pass (step) to be executed. Recipes contain information about process parameters and their settings, like gas flows, valve positions, set temperature, pressure, ramping information, and in OptiFACT also messages and prompts for operators to carry out certain manual operations. OptiFACT has a built in recipe editor, but preparation and management can be done in MS Excel™ spreadsheet program, and then imported into process computer.

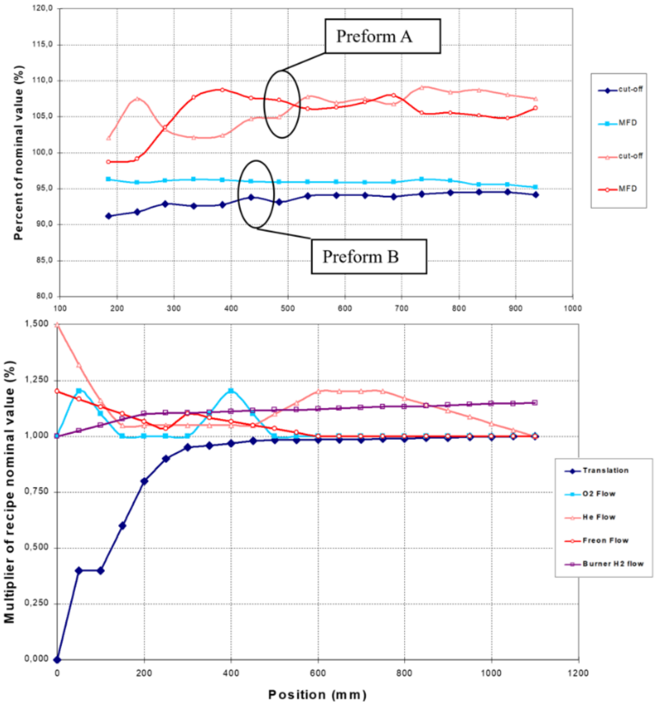


Internal OptiFACT recipe editor.

Built-in recipe editor allows on screen recipe creation, correction and offers file management functions while edited or another recipe is running. Currently executing recipes can also be edited which allows for quick process adjustment. All process parameters allow ramping functions to be added to the recipe. Recipes can be exported to spreadsheet files or printed to PDF.

Recipe structure (list of included parameters) can be generated using OptiFACT configurator. The system is fully configurable through software functions and provides the easiest upgrade path for the future expansion of the system. Recipes can handle large number of passes or very complex structure, with the option to start new recipe from currently running recipe (nested recipes).

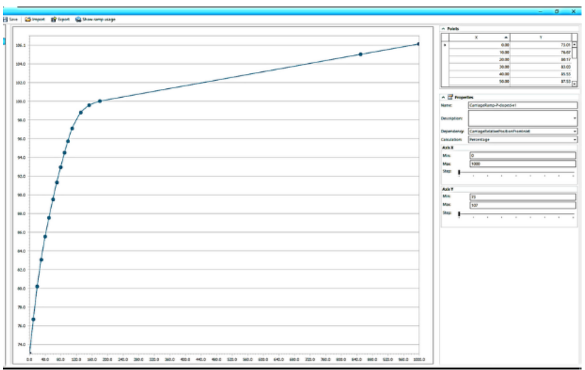
3.4.2 Ramping tools



In OptiFACT, variation of process parameters is preprogrammed through a set of “ramps”, functions that define how the parameter value changes as a function of other process variable. Ramps are programmed as tables or curves in ramp editor tool. Ramping parameters become more important with fabrication of longer preforms, with higher reagent flows, thicker deposited layers, or complex glass compositions. Parameter ramping is also important in preform collapse phase or in preform jacketing processes.

Diagrams here (right) show the importance of ramping for preform longitudinal homogeneity, even simple ramping functions can mean a difference of 15% or more in useful preform length.

OptiFACT ramping tools also permit switching any analog or digital signal based on any type of parameter (for example switching collapse valves based on preset tube inner pressure value) or trigger process pass changes by many control system variables. This functionality permits generation of complex recipes for fully automated preform fabrication, contributing to improved yield and better repeatability of the fabrication process.



3.5 Logging system, Real Time Analysis and Process Analyzer

3.5.1 Logging

OptiFACT software offers a comprehensive logging system that saves process data to logging report files. Any process parameter can be logged, and for each logging time interval can be set individually, through the logging configurator. Properly setup logging is very important for analysis of accumulated data to check process procedures and detecting any deviations or errors in recipe execution for recipe editing or preventive/corrective maintenance. To accompany this two tools are additionally available to provide displaying of data during fabrication (Real Time Analysis) and post fabrication (Process Analyzer).

3.5.2 Real Time Analysis

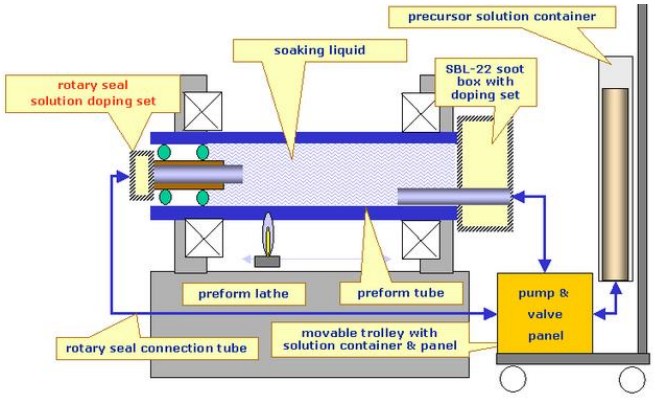
Real Time Analysis tool is used to display process data at the time of fabrication. It allows for multiple charts to monitor as many process parameters as possible as well as both time and signal dependent charts. The charts have a history window configurable by the user. All the system parameters are available to be displayed on the given chart.

3.5.3 Process Analyzer

Process analyzer tool is used to read log files to:

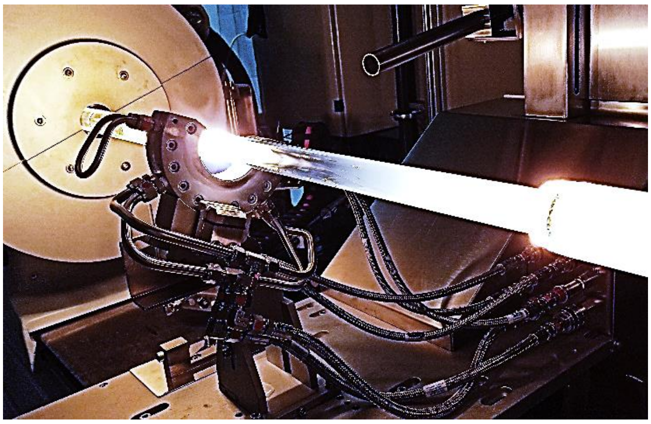
- display historical process data at the time of fabrication on synoptic charts, showing actual values of all the process parameters
- display alarms during entire recipe run
- display any manual changes done by the process engineer throughout the recipe run.

Logging system and process analyzer are essential tools for MCVD process analysis and control.



3.6 Special doping systems

Fabrication of optical fiber preforms, doped with metal- and rare earth-ions for different applications (sensor-, amplifier-, ASE-, laser-, high attenuation-, thermooptic-fibers) require special MCVD doping methods or equipment.
In recent years, vapor phase doping techniques (link) have proven their suitability for fabrication of silica glasses with high active ion concentration, reduced photodarkening effect, and low background loss. Another advantage of vapor phase method is the ability to increase deposited core size significantly, over other doping methods. Large core does not only increase productivity, but also improves laser fiber homogeneity and therefore better laser operating characteristics.

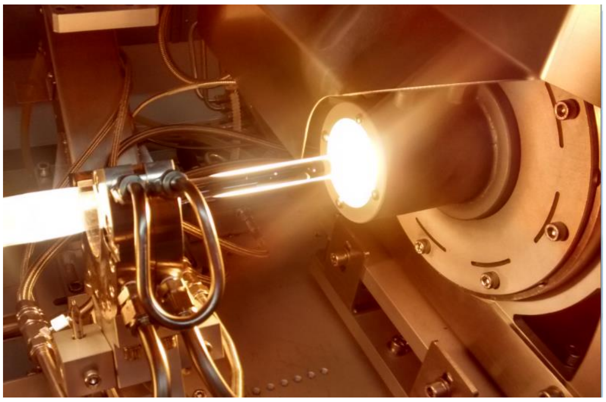


Chelate vapor phase doping technology (supported by Bimes' HTS high temperature doping system) is today a widely accepted fabrication method, which can demonstrate excellent results with different active ion dopants.
Many laboratories and facilities are using solution doping technique. Its advantages are lower investment cost and process simplicity, but the need to deposit homogenous porous core and to remove the substrate tube from the lathe to carry out the soaking process adds to its complexity. Core size is limited in solution doping process due to MCVD limitations in depositing porous core layers, as well as by diffusion depth and most importantly, to the capability of drying vitrifying porous layers. Solvents contribute to background losses of such fibers.
Nevertheless, Bimes MCVD systems with the advantages described in above chapter, are best suitable for fabrication of homogenous porous core layers, with optimal substrate temperature measurement and control, combined with the tube diameter control and reduced preform bending.

For customers who can soak preform in-situ (not removing the substrate tube from the preform lathe), IDS doping systems (link) for in-situ porous layer soaking, is available

Whichever is the preferred method, Bimes MDS preform fabrication system offers most extensive functionality and process options for high quality, highly doped, homogenous preforms.

3.7 Furnace MCVD process



MIF furnace is used in fabrication of optical fiber preforms by MCVD process using substrate tubes with outer diameter (OD) from 10 to 45 mm. MIF furnace eliminates typical disadvantages of the H_2/O_2 burners and allows easier, more accurate and repeatable preform collapsing process. It improves final preform geometry, reduces hydroxyl penetration to preform surface, reduces hydroxyl diffusion into core, and shortens collapsing time by at least a factor of 2. MIF furnace is a valuable tool in core laser fiber preform fabrication and in core preform jacketing.
MIF furnace is a graphite inductive furnace. Furnace width is optimized to provide maximum carriage traverse length. Furnace disassembly and maintenance is extremely straightforward, and all graphite and insulation parts are of simple geometric shape to reduce their fabrication cost. Usually, MIF furnace is installed on preform lathe carriage in parallel with a burner (longer lathes are available as option). Furnace is positioned on a slide that permits removal from the preform line, so that lathe can be used with burner only.. Graphite heating element temperature is measured by IR pyrometer and temperature is PID controlled. MIF furnace and power supply are fully integrated with OptiFACT MCVD control system which is used over the whole platform of Bimes equipment.

4 MCVD services

MCVD and other optical fiber fabrication equipment performance depends strongly on design characteristics, operator, and engineer skills (see Training services) and proper maintenance. Regular preventive maintenance is crucial for MCVD system up-time and productivity, as well as production yield. Skilled maintenance engineers are needed to take care of different MCVD and similar equipment parts and subsystems. As MCVD equipment is more and more complex, it is often quite difficult to have skilled personnel available for most demanding maintenance activities.

At Bimes we are aware of the importance of keeping all equipment in perfect working condition, so we offer different maintenance services to our customers:

- Regular service on-line support through dedicated e-mail channel
- Spare parts and consumable delivery, including support for pre-2020 Optacore delivered equipment.
- Periodic equipment services
  - Yearly or periodic MCVD equipment inspection and calibration
  - Custom service contracts for BIMES range of equipment
- Process know-how support and process analysis
- Software and control system maintenance
- Software development or modification services

Bimes with partners Plasil (process and technology) and Blubit (software and control systems) can provide services either on-line or dispatch engineers to customer's site. Most of the maintenance issues regarding control system operation and software are performed on-line, from headquarters in Slovenia.

On-line support offers the following options:

- Help desk, operating during office hours daily,
- E-mail support at support@bimespro.com with a ticketing system,
- Internet chat support by calling to WhatsApp, Skype, or WeChat (others available on request),
- Remote upgrades to OptiFACT software,
- Remote OptiFACT maintenance, checking and troubleshooting,
- Teleconferences with equipment, software, and technology specialists (by appointment only)
- Parallel on-line process monitoring and consulting by process specialist (Plasil by appointment only)

There is a number of tasks which cannot be made remotely, and services have to be performed by customer or by Bimes personnel on-site:

- Repair or exchange of piping panels and piping components,
- Exchange of electrical or electronic parts or instruments,
- Pyrometer or IR scanner calibration (performed by original supplier),
- Mass Flow Controller repair and calibration (performed by original supplier),
- Any other maintenance or service task where the cause of trouble is not clear after remote consultation.

In cases where problems cannot be solved by the customer, original equipment supplier or by remote consultations, Bimes can dispatch service engineer or process specialist, upon receiving an order, based on Bimes service quote.

Bimes also offers spare part and consumable supply for Bimes-made equipment. Bimes supports customers who own equipment delivered before 2020 by Optacore company. For spare parts please send a request to above mentioned mail addresses, or to sales@bimespro.com and Bimes representative shall write back with the shortest possible delay. Many parts and devices are kept in stock in Bimes facility. Bimes can also offer service and spare part supply agreements, where key components are kept on Bimes stock against a moderate fee.

4.1 Installation & Commissioning

With sales of new or refurbished equipment, Bimes offers full installation and commissioning support, by service team, at customer's site. Prior to commissioning, the customer has to provide proof that all infrastructure (electrical power, cooling water, scrubber ducts, hot air exhaust, process gases and chemicals) to be used for process start-up is available and in operation.

Commissioning of the system does not include startup, test run materials and consumable.

4.2 CE and UL mark

All Bimes supplied equipment is CE certified and certificates are available on request, for customers in America, support is offered to be able to obtain UL mark.

5 Training (provided by Plasil)

MCVD preform fabrication process is the most common method for production of special optical fibers. This method is well-known and documented, nevertheless the fabrication of advanced optical fiber preform designs requires specific knowledge and experience. Users not familiar with MCVD and vapor-phase doping methods are facing many challenges during preform design and fabrication process start-up or new developments. Proper engineer and operator training enables customers to shorten the learning curve and reach higher productivity and yield within a shorter timeframe, making investment into MCVD or related equipment more efficient and profitable.
Bimes partner Plasil provides theoretical and practical training for technical managers, development & process engineers and operators with customized scope and duration for new or existing customers, either at customer's site, or in own premises in Slovenia.

Theoretical course includes a selection of the following themes:

- Introduction and basic waveguide theory relevant to fabrication process
- MCVD process with overview of other fabrication processes and methods
- MCVD and evaporation equipment design, characteristics, and use
- Facility requirements for preform and fiber fabrication.
- Raw materials – quality and handling
- Glass reshaping processes and calculations (stretching, jacketing, grinding)
- Introduction to fiber drawing and coating application processes
- Preform and fiber measurement and test procedures & devices.
- Maintenance and calibration procedures
- Basics of active fiber design and fabrication, applied to MCVD process.

Practical training may include:

- MCVD system set-up and recipe preparation, glass working procedures.
- Proficiency in using OptiFACT control system and software
- Preform fabrication on customer's or BIMES lab MCVD system.
- Jacketing preparation and process
- Preform handling and measurement.

Optionally, fiber drawing practical training may be included:

- Draw tower set-up and preform preparation.
- Fiber drawing process
- Fiber handling and measurement

Training duration is adapted to specific customer needs and the scope, but 3 week course is recommended for newcomers to fiber fabrication technology.

6 Technology and process know-how (provided by Plasil)

For customers who need more support in starting up MCVD based preform fabrication process but lack experience or knowledge of how to produce specific optical fiber preform types, Bimes and Plasil offer support in the form of technology transfer or know-how support.
Based on specific process support agreement, Plasil dispatches process and product specialist(s) to customers site, where they work together with customer's specialists, engineers, and operators, to achieve agreed goals.
Process support as technology package or know-how transfer shall be provided in the form of:

- process start-up after successful equipment installation and commissioning,
- additional theoretical and practical (hands-on) training,
- set of instructions, procedures, and literature,

- set of recipes and control system setup specifications for OptiFACT control system,
- fabrication of preforms and other preform processing procedures together with customer’s specialists (jacketing, measurement, reshaping, fiber drawing),
- modeling, calculations and preform/fiber result analysis and correction of fabrication recipes,
- support for specific measurement and test techniques, not available at customer’s site
- fabrication test runs to confirm knowledge has been transferred successfully
- post-project support in the form of on-line consultations and discussions, based on customer-provided data

Plasil process support is available for a number of preform/fiber types or process procedures. Some of the covered fields are:

- proficient use of OptiFACT control system and software, as well as all components of an MCVD system with connected devices (refilling operations, gas purification, effluent treatment, etc.),
- proficient use of vapor phase doping process and equipment (supplied by Bimes)
- fabrication of standard step index and gradient index preforms for different passive optical fiber preforms
- procedures and process conditions for fabrication of active (rare earth-doped) preforms with aluminosilicate or phosphoaluminosilicate matrix
- fabrication of stress rods for PM fibers
- special coating application in fiber drawing process (carbon, metal, polyimide, …)
- doping with less common dopants (metal ions, $TiCl_4$, etc.)

Customers are cordially invited to write to our sales team with requirements and specifications.

For more information and quotes please write to sales@bimespro.com or info@bimespro.com