

# Development of optical fiber technology in Poland

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**Abstract**—Optical fiber technology is an important branch of science and technology, but also economy. Together with related disciplines it creates wider areas like optoelectronics and photonics. Optical fiber technology is developed in this country rather dynamically, proportionally to the available funds designed locally for research and applications. Recently this development was enhanced with considerable funds from European Operational Funds Innovative Economy POIG and Human Capital POKL. The paper summarizes the development of optical fiber technology in Poland from academic perspective during the period of last 2-3 years. Probably the digest is not very not full. An emphasis is put on development of optical fiber manufacturing methods. This development was illustrated by a few examples of optical fiber applications.

**Keywords**—Optical fiber technology, manufacturing/fabrication of optical fibers, photonics, optoelectronics, photonic optical fibers, micro-structured optical fibers, polymer optical fibers, optical polymers, silica glass, optical fiber glass

## I. OPTICAL FIBER TECHNOLOGY

OPTICAL fiber technology is an important discipline of science and technology as well as economy. Together with related areas of technical sciences it co-creates such widening disciplines as optoelectronics and photonics. Combined with laser technology, electronics and mechatronics, these branches are a solid foundation for many economic areas of activity of contemporary society basing on knowledge. These areas are among others, but not limited to: industrial automation, robotics, biomedical engineering, natural environment monitoring and protection, distributed telemetric networks, telecommunications, tele-informatics, global Internet, large databases, homeland and global security. Only complementary and, as it has turned out, strongly synergetic combination of optical fiber communications, semiconductor optoelectronics, information technology, and wireless technologies is a real cause of telecom and information revolution. We are not only witnessing this revolution ourselves every day but also actively participate in it.

The Nobel Prize in physics for 2009 was awarded to, one of the major creators of contemporary optical fiber technology, dr Charles K.Kao (together with inventors of CCD matrices). Ch.K.Kao, as the first researcher, predicted in 1966, and confirmed these predictions with calculations [1], that optical fibers can possess very low losses. A theory of light propagation was already well known during this time. It was described fairly precisely by N.S.Kapany and by E.Snitzer [2].

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Ch.K.Kao published 20dB/km as a value which may be easily obtained in optical fibers. At this time, he considered this value as a threshold one for potential development of optical fiber communications. Indeed, this value has triggered an intense research on the causes of optical losses in the glass fibers. The loss sources were, for the first time ever, very precisely classified. The conclusions were simple, yet stunning. The losses were fully attributed to the trace pollutants in SiO<sub>2</sub> (with relative levels ranging from ppm to ppb) and not to light dissipation or manufacturing defects. It was completely in reverse to the prevailing opinions at that time. Literally from this moment, the research world observed a global, intense race to lower the fiber losses. The race had a very clear economic background. Already in 1970, at the cost of numerable investments in optical fiber manufacturing infrastructures, located in tens of institutions, a magic threshold of 1dB/km was broken. A nearly ultimate value of 0,2 dB/km was obtained in 1976, only a decade after Kao's visionary paper.

Optical fiber technology started practically in this country in 1976, from a summary of own research work carried during earlier period of time. This summary had a form of the first national conference on "Optical Fibers and their Applications" which took place in the Jabłonna Palace near Warsaw. The first European conference on "Optical Fiber Communications" was organized only a year earlier in London. There were organized two key conferences, concerning the relevant areas, in this country, during this year (2009). There were: the XII<sup>th</sup> national conference on "Optical Fibers and their Applications" and the IX<sup>th</sup> national conference on "Laser Technology". The events were supplemented by an annual WILGA meeting of young researchers in photonics. The paper summarizes the development of optical fiber technology, from the academic perspective, during the last years. The digest is surely not full. The emphasis is put on manufacturing of various kinds of optical fibers in Poland. The research on manufacturing was illustrated by a few examples of novel fiber applications. A number of the described local research trends is very topical for the global status of this science and technology.

## II. OPTICAL FIBER COMMUNICATION – REFRACTIVE AND PHOTONIC

Optical fiber technology consists of two fundamental areas – telecommunications and instrumentation (non-telecom oriented research). These areas are very different, as far as fiber technology is concerned. Optical fibers for communications do not distort the signal and are resistant to external reactions. Optical fibers for instrumentation are optimized individually for signal processing in a complex and usually preset way.

Optical fiber communications, in a particular area of

broadband transport and backbone networks is strictly dominated by large industry. The industrial products are tightly normalized. Introduction of a new component requires industrial attestation, possible only in specialized industrial laboratories. A progress in this area is made in large laboratories of immense telecommunications industry, also with some participation of academic labs. The development of broadband transport networks, which are based on singlemode silica optical fibers working in 1550nm band, is very close to optimal. The optimization criteria are transmission losses and dispersion compensation of digital optical signal as well as distributed signal amplification. Further development undergoes monotonically by modifications and fine tuning of the existing solutions inside the main stream of the prevailing DWDM technology – transmission of densely distributed colors.

A slightly different situation is in the area of local and access networks, where the attenuation and dispersion are not so critical. Thus, there are allowed various specialist solutions fit to a particular application. The dominating criteria for wide area transport networks are minimal losses, dispersion and nonlinear effects. The dominant criteria for local area networks are: large branching ability, large optical power available, passive optical architecture, easy access, a variety of accepted signal formats, self-configuration and network recognition, etc. These criteria influence the choices for used optical fibers, essentially different in both cases.

A theoretical possibility and, thus, a hope for a step change in the technology of the transport networks for optical communications, has recently emerged with the invention of a new class of photonic optical fibers (POF). There are two essential species of POFs: porous-hole and capillary-hole. In the latter one, the optical field is carried essentially in the air or vacuum, by a photonic – non-refractive mechanism, while the evanescent wave (less than 1% of optical power in the fundamental mode) is supported by a thin layer of the fiber glass encircling the capillary hole. Carrying most of the light in the vacuum means very low loss in such a photonic fiber. Till now such an ultimately low-loss capillary photonic fiber has not yet been manufactured. A capillary fiber is researched and looked for with transmission parameters (including optical, mechanical, thermal) comparable or better than the standard telecom one. No one knows now if this hope will be fulfilled one day. It is necessary to solve a number of theoretical and technological problems. Now, the best photonic capillary optical fibers, oriented potentially for telecom applications, have losses 1dB/km, or 5-7 times more than the best classical telecom fibers working in 1,6 $\mu$ m band.

In a non-macro-capillary photonic optical fiber (of a porous, nano-capillary microstructure) the wave is guided by two essentially different and usually separated mechanisms: photonic (diffractive and interference) or effective refractive index based. The capillary photonic optical fiber, where most of the light is in the air, only the photonic, non-refractive guidance is possible, because glass has always essentially higher refraction than the air. Part of the wave transmission in the latter fiber can be, however, coupled to the refractive guidance in the capillary cladding what leads directly to losses. A fundamental, photonic capillary mode is propagated along

the structures which build the core-cladding boundary, which in turn is here a boundary for a two-dimensional photonic band gap – analogous to the electronic band gap in a semiconductor. Each non ideality of this boundary, which stems from a thermodynamic character of its creation from liquid glass, translates to the non ideality of the band gap. It is estimated now, that it is possible to obtain the transmission parameters of photonic optical fibers similar to the classical ones, but further essential breaking of this boundary seems vague.

### III. INSTRUMENTATION OPTICAL FIBER TECHNOLOGY

The instrumentation area of optical fiber technology embraces essentially two kinds of filaments, components and devices: functional components for laser technology, image optoelectronics, and optical fiber communications, as well as optical and optoelectronic sensors. Active and passive, optical fiber functional components used for communications embrace: amplifiers, modulators, fixed and tunable polarizers, couplers, attenuators, filters, and even wavelength converters, optical supercontinuum generators, nonlinear pulse compressors, etc. These components are usually, or at least expected to be, fully or partly signal compatible with the optoelectronic devices which they cooperate with.

Optical fiber sensors are a growing group of fibers and associated optoelectronic devices sensitive to external reactions, including physical-chemical and biomedical. The sensors are build of classical optical fibers and micro structured ones, including photonic. Among such sensors, the following ones can be listed: networked, distributed, multi-point, single-point. A discrimination sensors of stress and temperature are embedded as networks in composite materials. Optical fiber hydrophones serve for security purposes and for natural water environment monitoring. High power optical fiber links serve for remote powering of optoelectronic devices, avoiding direct electrical power supply or transmission. Optical fiber and laser gyroscopes have recently found numerable application niches for inertial process measurement. Optical fiber luminescence and Cherenkov sensors serve for monitoring of high energy processes. Optical fiber nonlinear components are manufactured from glasses of very high  $n_2$  index, bigger of several orders of magnitude than in silica glass. They are a class of sensors of exceptional sensitivity for some optical processes. Optical fiber sensors with evanescent wave, due to long interaction length, have extremely big sensitivities, only very rarely met in different constructions. Optical sensors and functional components made of capillary fiber transmitting refractively a black empty, singlemode beam of light use the big field gradient to guide the deBroglie wave.

### IV. OPTICAL FIBER MANUFACTURING

High silica glass doped with rare earths is synthesized by OVD method using a complex burner. The aim is to obtain high quality glass at high rate of the deposition. Low deposition rate is caused by low partial pressure of the rare earth substrates and ions clustering. A method was designed of

direct nanoparticle glass synthesis and deposition by a modified OVD burner with incorporated additional solution sprayer. It is possible to use gas and liquid substrates in the burner. Silica chloride is provided in gaseous form. Alcohol solutions of lanthanide chlorides are provided in liquid form. The solution is atomized to an aerosol in the burner. It is mixed and burned together with glass substrates, hydrogen and oxygen. The method gives glass of high quality, but the efficiency is low. The increase in efficiency requires additional atomizer: electrostatic, pneumatic, high pressure or ultrasound. The work is carried out at UMCS.

#### V. OPTICAL FIBER GLASSES AND GLASS OPTICAL FIBERS

The influence of lanthanide dopants on various kinds of heavy oxide and non-oxide, multi-component, optical fiber glasses is researched. The glasses include: telluride, germanium-telluride, oxide and mixed fluoride-oxide. The glasses are extensively tested for applications in lasing fibers. Excitation of these glasses in IR resulted in anti-stokes luminescence band in the UV. This shows that an effective energy exchange is taking place between  $\text{Yb}^{3+}$  donor ions and  $\text{Tm}^{3+}$  acceptor ions.

A similar research is conducted in respect to mixed, oxide – fluoride glasses, silica glasses containing lanthanide ions. These materials have a wide range of metamaterial phase (glass-ceramics) – with crystallized nanostructures of lanthanide fluorides. This is a phase susceptible to excitation resonances in a particular glass matrix. There were detected, in the metamaterial matrix, void spaces of the volumes comparable to doubled diameter of the hydrogen atom. Numerable atomic vacancies were also measured. This glass-ceramics is prone to laser assisted densification, thus is appropriate for writing 3D waveguide structures. The work is carried out in AGH and Białystok UT.

The best ever material now for optical telecom and instrumentation fibers is pure or weakly doped silica glass as well as high silica glass. The parameters of concern are optical and thermo-mechanical. Multicomponent glasses compete successfully only in the area of instrumentation optical fibers. Nearly ideal structurally and of ultimate low-loss, high silica material is synthesized by CVD method. These fibers have high economic meaning not only in telecommunications. Since the early nineties the UMCS laboratory fabricates numerable kinds of classical and photonic high-silica fibers. Very high elastic modules in these glasses and abrupt mechanism of fragile cracking, and low compatibility with certain biomedical equipment eliminates these high silica fibers from a number of novel instrumentation applications. An alternative are: low temperature silica and non-silica fibers, non-oxide and polymer fibers.

#### VI. KINDS OF PHOTONIC OPTICAL FIBERS

A bigger freedom of fiber design and a greater number of design parameters in photonic optical fibers is a direct cause of a great number of them. They differ by transmission characteristics and optical signal processing ability. These additional parameters are combined with the fiber structure.

The structure decides of propagation and transformation of the EM wave inside the fiber.

Aside of many kinds of photonic – micro structured optical fibers, there are developed single-structured fibers or mixed mono-multi-structured ones. The example are multi-clad optical fibers or of a spiral core. These fibers are destined mainly for research on novel construction of filamentary lasers. The spiral core enhances the acceptance power from the optical pump. Optimization of material and geometrical parameters leads to a singlemode guidance, simultaneously for a greater volume of the active area in the core. The work on spiral core fibers doped with lanthanides is carried out in Białystok UT.

A supermode can be excited in a singlemode, multicore optical fiber. The supermode is a rigorous phase superposition of the individual core modes. The conditions of supermode propagation can be effectively determined theoretically as well as practically. In certain conditions the supermode behaves like a fundamental mode of this complex multicore fiber.

#### VII. MICROSTRUCTURED POLYMER OPTICAL FIBERS

Highly transparent, low-loss polymers and co-polymers are now one of the fundamentals of the development of organic optoelectronics and photonics. These materials are cured with UV radiation or by an electron beam. The applications include: optical fiber jackets, photonic circuits packages, substrates, and optical fibers – active and passive. The advantage of these materials is immediate polymerization in the whole volume without any gas products. The polymerization process may be optimized for a concrete photonic application. The material may be printed to other structures and then cured. The conversion dynamics for double bond present in the liquid phase is researched. The work is carried out in UMCS on Ebecril and N-winylopirolidine.

Classical polymer optical fibers are widely applied in a local networks of data transmission, and so called deck systems (automobiles, airborne, ships) of relatively short distance and low speed transmission links. It can be assumed, that from the economical point of view, they occupy the second position on the list after the trunk communications. Similarly to glass optical fibers, the polymer optical fibers are also designed and manufactured in the photonic versions. These fibers are also considered for applications in sensors and photonic functional devices. A laboratory production of such fibers is always associated with the ability to synthesize own ultra-pure polymer or organic glass like PMMA. The commercially available polymers are completely unsuitable for low-loss fiber production. The technological work is carried out at UMCS.

The complexes of europium and terbium are incorporated in a polymer matrix. The doped polymer is used for building an optical fiber sensor. The sensor is a converter of UV radiation to the visible – red and green. The complexing agents are organic acids. The most important factor of the sensor is the resistance of the complexes to excessive doses of the UV radiation and maintaining of the luminescence ability after system polymerization.

### VIII. PHOTONIC CAPILLARY OPTICAL FIBERS

Essential part of optical power of the fundamental mode in a capillary photonic optical fiber propagates in air. The wave is kept in the hole by a photonic band gap on the boundary with glass. The fiber is designed for a proper internal structure taking into account the dispersion. A multi-capillary structure is made either of high-silica glass or soft-glasses, like SK. The internal cob-web has frequently a hexagonal geometry and contains a few or even more than ten circles of nano-holes, situated around the central, optical core micro-capillary. The capillary core is obtained by omitting a number of axial nano-capillaries. The fiber filling factor may change within the range 0,6 – 0,9. Diameter of the core is within the range of 2 - 20 $\mu\text{m}$ . A period of the cladding cob-web is from 0,1 to 1 $\mu\text{m}$ . Wall thickness between nano-capillaries is from 20 to 100nm. Optical fibers made of soft glasses have usually not so good internal structure as the ones made of high silica glass. The result are bigger losses. Non-telecom photonic optical fiber capillaries possess comparatively wide band gap, due to high refraction contrast. This feature is favorable for testing of photonic propagation and its susceptibility to external reactions. The fiber is excited by an optical supercontinuum source 0,5-1,2 $\mu\text{m}$ . The work is carried out in ITME.

### IX. MICROSTRUCTURED POLARIZING OPTICAL FIBERS

Photonic optical fibers from high silica glass of high birefringence are constructed by embedding structural anisotropy of the nano-capillary filling factor around the core. The fiber is a phase sensor of many physical quantities. The distribution of anisotropy has V shape. The work is carried out at UMCS. V shape is built by a step change in the capillary diameters. Both sides of the core are occupied by capillaries of bigger diameter. The basic application of these fibers are measurements of the pressure. Their construction is optimized to make them insensitive to temperature changes. Temperature insensitivity enhances considerably the pressure and stress measurements.

### X. POROUS PHOTONIC OPTICAL FIBERS

The internal surface in nano-capillaries of a porous photonic optical fiber can be covered by a nanometer layer of various substances. One of the sensing choices are layers of noble metals, like gold. Transmission properties of such a fiber are essentially modified. Thin layer of gold may evoke a surface plasmon resonance for a chosen optical frequency which depends on the layer thickness. This resonant effect, which is a quantum confinement phenomenon, is used for wave polarization by removing the orthogonally polarized component of the transmitted wave.

The internal surface in nano-capillaries is covered by electrostatically self-aligning nanoparticle layer. The layer has an active function against the propagated optical wave. The layer can also be a catalyst for a reaction taking place inside nano-capillaries. A rich collection of different interaction effects between optical wave, fiber glass, chemical reaction products and external reactions leads to the construction of

numerable sensors which use porous photonic optical fibers.

### XI. LIQUID CRYSTAL PHOTONIC OPTICAL FIBERS

Liquid crystal photonic optical fibers are a combination of a passive structure of a porous photonic optical fiber impregnated with an active agent, which is liquid crystal [3]. Such a combination introduces to the fiber a wide possibility to tune the device optically in terms of phase, amplitude, polarization, nonlinearity. The work is carried out at WUT, MUT and UMCS. The applications of liquid crystal optical fibers embrace a wide range of functional photonic components including nonlinear devices. The fibers are made of high silica glass of the refraction equal to 1,48, i.e. smaller than the ordinary and extraordinary refractions of the majority of liquid crystals. The propagation is possible only with the use of the photonic bandgap.

A dual mode of liquid crystal fibers, of refractive propagation, has to be constructed of high-refraction multicomponent glasses. Such fibers are made of PBG glass of refraction 1,95. The guided optical wave penetrates nano-capillaries, which are filled with liquid crystal, with its evanescent tail. The losses are relatively small and the sensing characteristics completely different. A continuous tuning of the birefringence is obtained in these liquid crystal fibers of refractive mechanism of wave propagation. Their applications are preferred in polarimetry, like polarization setting in optical links and complex photonic instrumentation systems and sensors.

Classical, non-photonic optical fiber capillaries with high index ring like optical glass core, carrying singlemode dark empty beam, are also filled with liquid crystal. The crystal influences strongly the evanescent field of the dark beam. Propagation and sensitivity parameters of these optical capillaries depend on the orientation of the liquid crystal. The initial orientation in a liquid crystal fiber is determined by self alignment of the molecules. The molecules are introduced to the fiber using natural capillary forces. The dominating orientation is planar. The orientation conditions may be changed in a large core capillary by covering its internal surface with a conditioning polymer. The polymer itself may be photo- aligned in an assumed direction. Introducing liquid crystal to such capillary with polymer covered wall forces the molecules, for example, to planar or other orientation. These forced orientations may be compared with the natural self orientation. The following reorientation of the liquid crystal is done by external electrical field. The fibers possess self induced own anisotropic structure.

### XII. OPTICAL FIBER BRAGG GRATINGS

The sensors based on optical fiber Bragg gratings are now the most popular, important and most frequently used optical fiber devices. They are widely used in civil engineering to monitor the state of such constructions like bridges, dams, railway tracks, mines, speedways. Bragg gratings are written in a standardized way into classical telecom singlemode optical fibers which are either doped with germanium or are intentionally hydrogenised. New possibilities are associated

with micro structured – photonic fibers in this area. Writing a grating in these fibers is more difficult because the internal structure obstructs the image. It is, however, possible to write such a grating by a phase mask method, interference one and by the most flexible method – writing point-by-point by a laser. The latter method gives a wide range the spectral characteristic tailoring of the device. The devices are usually configured in networks.

Given a particular Bragg grating, the analysis of uncertainty of its parameters is a reverse problem. Spectral characteristics of the grating are measured. Stability of the grating period is investigated along the optical fiber. A relative elongation of the grating is determined. The uncertainty of measurements is a difference between the measured shape of the grating spectrum and the real value. The real spectrum is situated in a certain range, somewhere between assumed threshold values of the probability. The analysis is necessary for application of the gratings in the precision mechanical sensors

Long period optical fiber Bragg gratings have completely different properties from the classical, short period ones. The gratings of higher order couple, in a resonant way, polarization modes propagated in a photonic optical fiber of high birefringence. Long period gratings are manufactured also with the usage of a fiber welding machine (apart from a classical interference or multipoint method). The fiber is shifted by an assumed step, twisted and heated locally which results in a localized small distortion. The gratings are fabricated, with this method, also on fibers doped with boron or fluoride rather than germanium. The gratings are multi-resonant because the phase birefringence is strongly dispersive. Location of the resonances depends on the grating period. Long period gratings are used as core mode to cladding modes couplers in two-cladding fibers which are simultaneously single and multimode. These fibers are used for pumping of fiber lasers.

### XIII. INTEGRATED OPTOELECTRONICS

The circuits of integrated optics (IO), including MOEMS, are build in certain analogy to classical VLSI chips. This analogy has to take into account a difference between the nature of electrical and optical signals. Optical signal requires deflection or guidance. In telecommunications, the IO circuits work as modulators, multi- and demultiplexers, couplers. In instrumentation systems, they are used as sensors, similarly to optical fibers. They work in amplitude and phase modulation configurations like: interferometers, with evanescent wave, in direct contact with the measured medium, etc. The work on IO sensors in all aspects – measurements, technology, applications, are carried out at Silesian UT, WAT and PW.

To build IO circuits, glasses, wide gap semiconductors (like lithium niobate) and polymers are used. These circuits are based essentially on 2D waveguide layers. The layers are manufactured by a few basic methods like: ion exchange in glasses, chemical deposition from gas state CVD and its modifications – PECVD, LPCVD, and sol-gel. The ion exchange method is cheap, easy and gives refraction gradients in waveguides of small numerical aperture. CVD and sol-gel methods give refraction combinations of wide extent of values, step-index of big contrast. The CVD method requires

advanced laboratory set-up. The sol-gel method is efficient and cheap, thus, is widely used in many laboratories. The sol-gel method is used for SiO<sub>2</sub>-TiO<sub>2</sub> glass system. There are obtained thin films (100-300nm in thickness), which possess high refraction (1,8), and very low losses (0,15dB/cm). Low loss means also high layer homogeneity and very good smoothness of the surface with roughness smaller than 1Angstrom. The sol-gel method uses glass precursors, which are TEOS for silica and TET for titanium dioxide. The losses of these layers are determined by a dissipated beam method with the usage of a CCD camera. The measurement is done for two polarizations TE and TM.

Two dimensional waveguide layers of high quality are an output substrate for rib waveguides. The optical ribs (strip waveguides) are manufactured by selective masking, photolithography and chemical etching. The basic parameters of such waveguides are: transverse dimensions and refraction. For the following parameters - dimensions 3x1μm and refraction 1,8, the waveguides are singlemode for near IR and visible spectra.

SU8 is an effective, low-loss polymer used widely in the IO technology. SU8 stands for a glycol ether of bisphenol A. SU8 is a cheap material, which plays a role of a very sensitive resist. The resist undergoes a cation photo- polymerization. It possesses high thermal and mechanical stability and big adhesion to glasses. The polymer layers cover the glass substrate. The thickness of these layers can be changed in a wide range. The IO circuits are build by selective, plasma assisted etching and photo-lithography. SU8 layers and waveguides on a glass substrate build planar micro-interferometers for sensing purposes.

MOEMS circuits are made almost always in silica technology. Work of the systems in adverse environments (temperature, pH, ionizing radiation) requires the usage of diamond or diamond-like layers. The layers are made by CVD method. The basic requirement is that the layers are homogeneous, sufficiently thick and cover large surfaces. The layer has to be fully integrated with the background substrate, which is made in CMOS technology. The work is carried out in ITME and Lublin UT.

### XIV. APPLICATIONS OF OPTICAL FIBERS

Photonic optical fibers, polarization maintaining, and doped with lanthanides are used for building of filamentary lasers. The aim of the work is to obtain high power of emitted radiation and the best possible spectral characteristic. The laser uses either linear or circular resonators. The mirrors are optical fiber Bragg reflectors. The laser works in a single- or multi-wavelength work regime. The latter is used for the DWDM transmission standard. The laser is tunable within a range of a few nm, by a change in the polarization state of the propagated wave, The work is carried out at Wrocław UT.

Photonic optical fibers are used for generation of optical supercontinuum and for building of broadband sources of high energy conversion efficiency and low threshold power. The fibers have strongly isolated core (from the refractive and photonic points of view) of small effective modal area. They exhibit anomalous dispersion in a wide spectrum of wavelengths. Application of optical glasses with high value of

nonlinear refraction  $n_2$  and of low energy of phonon wave (in reference to silica glass) additionally lowers the value of the threshold power. Femtosecond Ti:sapphire laser is used to excite such fibers. The following spectrum of the output wave is obtained, for a fiber of a few tens of m in length and for two different glasses: glass F2 –  $\lambda=0,5-1,5 \mu\text{m}$ , glass PBG –  $\lambda=0,7-3 \mu\text{m}$ .

One of a very promising applications of polymer, planar and fiber waveguides are so called photonic skins. The skin covers irregular objects and consists of electrical, photonic and optoelectronic components distributed in a matrix form inside a thin, elastic and rugged layer. The skin enables quasi distributed measurements of touch, pressure and grip strength over a complex surface [4]. In the future, the skin may be a standard equipment for advanced robotic arms, armed with the sense of touch. The skin is a sort of a distributed, large format MOEMS.

One of the most dynamically developing areas are photonics applications for the construction of biomedical microsystems. Per analogies to the systems called a lab on a chip, they are referred to as a lab on a fiber or MOEMS. The photonic system serves for identification of a chemical or biological agent, detection, monitoring and finally integration of many measurement channels. In this approach, all sensory functions, transmission, and decoding are based on an optical fiber. Surfaces of the fiber – external and internal are covered with nano-layers optimized and sensitized for the kind of a searched reagent. The reagent may be vapor of explosive in air or cyanobacteria toxins in water. The work is carried at UQO University in Canada. Technical solutions are based on long period optical fiber gratings, co-linear optical fiber interferometers of core-cladding type, and fibers with evanescent wave and high ability for light collection.

Optical fibers were applied in the construction of a vortex shedding flow meter. The von Karman device is designed for measurements in high temperatures. Such measurement conditions are met in the atomic industry, high power utilities, where the cooling agent for high temperature reactors are liquid metals. Several optical fibers in transmission configuration is attached to the sensing membrane reading the flow perturbation introduced by a bluff body. The state membrane is monitored for distortions in the range 1nm - 10 $\mu\text{m}$ , extent of pressures 10Pa – 100kPa, range of frequencies 0,5 – 5kHz, and ranges of work temperatures -200°C - +800°C. The work is carried by industrial laboratories.

Composite materials are used widely for building of construction components. The status of construction is monitored by a measurement fiber optic network integrated with the material. There are measured on-line distortions, their 3D distribution, vibrations, resonances. The sites of crack initiation are localized. The applied kinds of embedded optical fibers for these purposes are: with Bragg gratings, nonlinear Brillouin effect, polarimetric birefringent. The work is carried out at WUT. The applications embrace such elements and components like used for aircraft wings.

Applications of optical fiber technology are systematically widening. One can mention the following novel and more classical areas, including practical solutions like sensors of magnetic field with the usage of glasses of high value of the

Verdet constant, liquid level meters using polymer fibers, optical gradient lenses, chemical laboratory on a capillary optical fiber, optical fiber probes for photodynamic tumor therapy, optical fiber probes for observations of industrial processes and areas –like a flame in large industrial burners, work of combustion engines.

## XV. FINANCING OF OPTICAL FIBER TECHNOLOGY

Optical fiber technology is developing in this country fairly intensely, proportionally to the financial investments for research and applications. Recently this development was strengthened with considerable funds from European Operational Programs like Human Capital and Innovative Economy. Also, a number of governmental projects were realized in photonics in recent years, including blue optoelectronics and photonic functional components and modules for industry, environment engineering, biomedicine and safety. A few projects are realized in the FP7 program.

## XVI. MEETINGS OF OPTICAL FIBER RESEARCH COMMUNITIES

Regular meeting of the national photonics community take place since a few decades. The fiber optics community meets every year and a half in Krasnobród and Białowieża. The meetings were started in Jabłonna in 1976. Białowieża conferences are devoted to optical fiber applications and are organized by Białystok UT. The meetings in Krasnobród are devoted to optical fiber technology and are organized by Lublin UT and UMCS. The XII technological meeting took place in Krasnobród in October 2009. There were presented 80 papers including a few invited. The XIIIth meeting will take place in Białowieża in February 2011.

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