INTL JOURNAL OF ELECTRONICS AND TELECOMMUNICATIONS, 2011, VOL. 57, NO. 2, PP. 191–197
Manuscript received February 25, 2011; revised March 2011. DOI: 10.2478/v10177-011-0027-6

Development of Optical Fiber Technology in Poland

Jan Dorosz and Ryszard S. Romaniuk

Abstract—**In this paper, the authors, chairmen of the 13th Conference on Optical Fibers and Their Applications OFA2011, and editors of the conference proceedings summarize the development of optical fiber technology in Poland (during the period of 2009-2011) on the basis of papers presented there and consecutively published in this volume. The digest is thus not full but covers the periodically presented material every 18 months during the meetings on optical fibers in Białystok-Białowieża and Lublin-Krasnobród.**

Keywords—**optical fibers, optical communication systems, photonic sources and detectors, photonic sensors, integrated optics, photonics applications, photonic materials.**

I. Optical Fibers and Their Applications

OPTICAL fiber technology, as a part/mixture of material engineering, optics, optoelectronics, photonics and telecommunications is intensely developed in his country in academic communities, governmental laboratories and in the industry. The national research community of optical fiber technology is organized in a few professional associations including: Section of Optoelectronics – Committee of Electronics and Telecommunications [1]–[3] – Polish Academy of Sciences , Polish Committee of Optoelectronics – Association of Polish Electrical Engineers (sister organization to the IEEE), Section of Optics – Polish Physical Society and Photonics Society of Poland (closely cooperating with SPIE) – and publishing its journal Photonics Letters of Poland [4].

The community is also active in the following international organizations: SPIE, IEEE Photonics Society, OSA, ICO and EOS. The fiber optics part of this community meets every year and a half during the national conferences on 'Optical Fibers and Their Applications'. The aim of these meetings is to summarize the current developments in optical fiber photonics and indicate the directions of the next research and technical undertakings. Similar customs prevail in the national community of laser technology, embracing also partly optical fiber technology, which meets cyclically, every three years, in Szczecin and Świnoujście, during the National Symposium on Optical Fiber Technology STL. The STL is organized by the West-Pomeranian University of Technology (previously Szczecin University of Technology) [5], [6]. Optical fiber technology is also present during the professional conferences organized by the Polish Ceramic Society , Polish Society of Sensor Technology – organizer of a conference cycle on Optoelectronic and Electronic Sensors COE, and PERG/ELHEP Laboratory at ISE WUT Warsaw University of Technology – organizer of the annual WILGA symposium cycle for young researchers on Photonics Applications and Web Engineering [7]–[13].

Białowieża and Krasnobród Conferences on Optical Fibres and Their Applications gather every year and a half the majority of the academic research community from this country and a number of invited guests from neighboring countries. The paper presents considerations concerning the development directions of optical fiber technology in Poland during the last period (2009-2011) basing on the research and technical material submitted to the XIIIth National Symposium on Optical Fibers and Their Applications, which was held in Białystok and Białowieża on 26-29 January 2011. The symposium has gathered more than 80 persons from academia and industry. There were presented 60 papers and 6 plenary presentations.

The subjects of symposium were: materials for optoelectronics, technologies of optical fibers, optoelectronic components and circuits, metrology of optical fibers and optoelectronic components, applications of optical fibers and DELs. The previous XIIth symposium was held in Krasnobród in October 2009 and the next one XIVth will be also in Krasnobród in October 2012. The XVth meeting on Optical Fibers and Their Applications, to be held in Białystok and Białowieża is scheduled for January 2014.

The XIIIth Conference on Optical Fibers and Their Applications was organized by the Department of Optoelectronics and Lighting Technology (previously the Department of Optical Radiation) at the Faculty of Electrical Engineering – Białystok University of Technology in cooperation with Białystok Section of PTETiS. The conference organizer – the Department of Optoelectronics and Lighting Technology was established in 1983 by prof. M.Banach (as a Department of Radiation Technologies). The department was chaired for many years by prof. W. Dybczyński and now is chaired by prof. J. Dorosz. Optical fiber technology has been present in the department since the mid seventies of the XX century. The subjects covered by the conference were: materials for optoelectronics, technology of optical fibers, optoelectronic components and circuits, metrology of optical fibers and optoelectronic circuits, applications of optical fibers, applications of modern LED light sources.

The conference cycle on 'Optical Fibers and Their Applications' started in 1976 in the Jabłonna Palace by Polish Academy of Sciences, under the patronage of KEiT PAN and next PKOpto SEP, and Photonics Society of Poland. The initiators of these first conferences were professors Adam Smoliński from Warsaw University of Technology (WUT) and Andrzej Waksmundzki from Maria Curie-Skłodowska University in Lublin (UMCS). Now this cycle is continued every 18 months and organized, in an alternate way, by optical fiber technology and research centers by Białystok University

J. Dorosz is with Białystok University of Technology, Poland (e-mail: doroszjan@pb.bialystok.pl).
R. S. Romaniuk is with Warsaw University of Technology, Poland (e-mail: rrom@ise.pw.edu.pl).

of Technology (BUT) [14]–[16] in Białowieża and by Lublin University of Technology (LUT) [17] in cooperation with the UMCS [18] in Krasnobród.

The 2011 Białowieża conference on Optical Fibers has gathered more than 80 persons from his country, mainly from the universities and from the governmental laboratories (Białystok, Gliwice, Katowice, Kraków, Lublin, Łódź, Poznań, Warszawa, Wrocław). There were presented 6 plenary papers, around 20 contributed papers and 50 posters reporting own results from the current projects run by research teams. The inauguration session was held at the Faculty of Electrical Engineering of LUT. The conference was opened by prof. W.Woliński, member of PAS, honorary chair of the Scientific Committee.

Prof. W. Woliński reminded the outstanding representatives of this branch of technology in this country who passed away during the last year: prof. Jan Rayss and dr Jan Wójcik from UMCS . These persons, remarkable graduates and co-workers of prof.A.Waksmundzki, were the builders of the optical fiber technology center in Lublin at the UMCS. Prof.J.Rayss and dr J.Wojcik were the organizers of the previous XIIth conference on Optical Fibers and Their Applications, which was held in Krasnobród in October 2009 [18]. During the conference plenary session, the rector of BUT prof T.Citko presented the current development problems of the university – which is the biggest academic institution in the North-West part of Poland. The development perspectives are huge and accompanying difficulties are similar as at other Polish technical universities.

The plenary papers of the conference, presented during the inauguration session on fibers, sources and detectors and next sessions on photonic material engineering and optical fiber communications were:

- R. Romaniuk (Warsaw University of Technology), Optical fiber technology in the future Internet [19], [20],
- A. Rogalski (Military University of Technology), IR photon detectors [21],
- W. Nakwaski (Łódź University of Technology), Electroluminescent diodes,
- E. Bereś-Pawlik (Wrocław University of Technology), Multimode, passive optical fiber LAN networks,
- W. Urbańczyk (Wrocław University of Technology), Birefringence in photonic optical fibers – origins, measurement and applications,
- M. Żelechower (Silesian University of Technology in Katowice), Oxide-fluoride, glass-ceramic optical fibers.

Three conference sessions covered the subjects of active optical fibers, planar optical waveguides, mainly technological aspects, and modeling and simulations of technology solutions of optical fibers and functional components. The following particular subjects were debated:

- optical fibers with hanging core, design, characteristics, differences with classical fibers, applications,
- generation of supercontinuum in optical fibers, power of levels, width of generated spectrum, damage thresholds,
- multi-core active optical fibers with a super-mode, phase conditions for generation of a supermode,
- integrated optics components and porous optical glass obtained by sol-gel method,
- optical fiber communication systems with super-dense WDM, ultimately dense spacing of channels,
- thermally tuned liquid crystal photonic optical fiber components, optical nonlinearities, range of tenability,
- liquid crystal optical fibers of low, medium and high refraction, homogeneous and hybrid propagation of beam,
- highly nonlinear photonic optical fibers with micro-structured core, role of nano-pores in the fiber core,
- micro-structured, polymer optical fibers, materials, losses, spectral behavior, thermal resistance, structural solutions,
- active optical fibers, amplifiers and lasers, novel solutions to mixed and multicomponent low-loss glasses,
- capillary optical fibers with noble metal nano-layers, methods of deposition, layer homogeneity, plasmonics.

Two poster sessions of the conference concerned mainly the metrology and optical fiber applications. The exemplary applications embraced: remote observations and optical analysis of the combustion processes of coal dust and biomass; thermal, mechanical and dilatometric measurements with optical fiber sensors; distributed multi-point optical fiber vibration sensors; optical fiber broadband on-off switch, and optical fiber based light sources.

Direct research on optical fibers concerned: modeling of chromatic dispersion in micro-structured optical fibers, optimization of bending losses in photonic optical fibers, optimization of solitonu optical fibers, optimization of optical fiber wavelength converter as a light source for WDM channel, wavelength conversion processes in optical fibers, doped telluride glasses for optical fibers, mechanical properties of polymer optical fibers, optical fiber phase demodulator with space integration in the Fourier plane, polarization measurements of optical fibers.

II. Glasses and Optical Fibers

Topical Track on Optical and Photonic Materials and Optical Fiber Technology gathered over 30 papers. The major subjects were: liquid crystal photonic optical fibers, meta-glass (glass-ceramic) optical fibers, polymer photonic optical fibers, photonic fiber sensors, and new solutions of nonlinear and active optical fibers. The strength of this topical track stems from over 35 years of research on specialty optical fibers carried out in the optoelectronic laboratories in this country. Three labs were then active: UMCS in Lublin , ITME in Warsaw and Białystok Glass Works (next Biaglass GW) with Białystok University of Technology [14], [16], [22]–[37], cooperating with WUT and WAT. Now the work on specialty optical fibers is spread also to Warsaw University of Technology – Faculty of Physics, Faculty of Electronics and Information Technologies; Wrocław University of Technology, Military University of Technology and other university labs.

Photonic optical fibers have been one of the major research subjects since around 15 years, which is caused by the refractive and non-refractive propagation ability of the single mode beam of light. Non-refractive guidance is effective in low-loss low-refraction regions of any kind confined by prohibited area, via the photonic band gap mechanism, of the high-refraction. The beam is compulsory confined by two dimensional Bragg structure or any other kind of periodic structure, per analogism to the band-gap in a semiconductor. The only allowed direction of propagation is intentionally delimited along the low-loss fiber axis, irrespective of the refraction (glass, liquid-crystal, gas or vacuum in a capillary) of this region. Isotropic photonic fibers are built of a subtle air-glass net or cobweb (depending on density) of the biggest possible symmetry and the lowest possible perturbations of the structure. A refractive fiber is built of this structure with filled defects on the axis, while holey, non-refractive fiber is built of this structure with empty defects on the axis. The defects (by removing rods from the fiber preform) may be single or multiple, adjacent, overlapping or isolated. A beam of light in the fundamental mode propagates in air in the holey fiber, while its evanescent fields propagate in glass. Majority of the propagation parameters of holey fiber as dispersion, losses, and mode conversion depends on the glass-air boundary.

Birefringent photonic optical fibers (refractive and non-refractive) are built by embedding asymmetry in the fiber structure like: presence of micro-holes of different dimensions, introduction of stress agents near the core, etc. The fibers which are ideally axially symmetric (circular, hexagonal, etc.) can not be birefringent. Birefringence is defined as a difference of effective refractions of two polarization sub-modes of the fundamental mode. In practice, like fiber measurements or polarization fiber sensors, as a measure of birefringence, a beat length is used. The beat length is defined as a ratio of the propagated wavelength and the birefringence at this wavelength. Large birefringence (approaching 10^{-2}) can be induced in singlemode photonic optical fibers. This value is bigger than the birefringence of classical birefringent optical fibers 10^{-3}, Bow-tie and Panda. Polarization maintaining optical fibers are used in the transmission systems for elimination of the harmful polarization dispersion PMD effect.

Optical fibers made of glass-ceramic are investigated for photonic components of new propagation and beam processing/transformation properties. They are researched for building of optical fiber lasers of new construction, nonlinear fiber components, resonant refraction/losses components, plasmonic devices, etc. Crystalline originators initiated in optical fiber glass, of nanometric dimensions are generally difficult for very precise control. To investigate the very beginning of the crystallization processes there are used microscope methods as well as roentgen and spectroscopic ones. There were investigated mixed oxide-fluoride glasses for optical fibers, doped with mixed, energetically coupled rare earth ions like erbium and iterbium. The aim of the optimized technology of such glasses and fibers is to release nano-crystallization process and let the crystallization radicals grow only to designed dimensions. The nano-crystallites should be essentially enriched with the active doping ions. Optical parameters of the active ions, such as quantum efficiency, life time of the metastable level, half-width of the absorption line for the optical pump, in the monocrystals are better than in the glass. Modified, highly efficient EYDFA amplifiers may base on the glass ceramic metamaterial, where the optical activators are gathered in nano-crystallites.

Active specialty optical fibers [37] are increasingly important field of research in photonics. Non-telecom oriented, active optical fibers for all infrared bands, from NIR to FIR, are researched for instrumentation, functional, sensory, optical signal processing, signal amplification, improvement of the system noise performance, optical band conversion, and have various theoretical solutions, constructions, technologies and applications. There were investigated the following active optical glasses for specialty optical fibers: alumina-silica, phosphate, oxide-fluoride, and antimonite. The glasses were doped with with multiple activators like Nd3+, Yb3+. There were determined stability areas of these glasses for high doping levels and cross acceptance levels for doping. The reaction kinetics of the crystallization processes in these glasses were analyzed with the Friedman and OFW methods. The fiber should have an intentionally introduced asymmetry for building of fiber amplifiers and lasers - to enable efficient optical power coupling into the active core from the oversized or double cladding excited by external optical pump. There are used fibers with special optical cladding or with a helical core.

Polarization state of light propagating in liquid crystal photonic fibers [38]is used for optical sensing purposes or for on-line processing of the propagated optical beam. A micro-structured optical fiber is impregnated with liquid crystal, which enables dynamic tuning of its propagation characteristics. Three basic cases can be distinguished for three basic refraction values of the fiber core in reference to the refraction of the liquid crystal. Low refraction optical fibers allow for selective light propagation, where the localization of the transmission bands depends on light polarization. For medium refraction optical fibers, where the core refraction lays in-between the ordinary and extraordinary refractions of the liquid crystal, a hybrid propagation may be obtained. One of the polarizations is propagated refractively while the other, orthogonal non-refractively (photonic). Low-loss optical fibers of high refraction allow for wide tuning of the birefringence from 0 to above 10-4. Reorientation of the liquid crystal molecules may be done by the external electric field. Permanent orientation of the molecules inside the fiber may be enforced by orienting polymer layers.

III. Detectors

Near infrared detectors are generally divided to two main groups: thermal and photon. Thermal detector is built of an absorber which is isolated from the base and coupled to a thermometer. The radiation signal to be detected, increases the temperature of the absorber. The photon detector is a semiconductor component. The radiation signal enforces intra band electron transits. The sensitivity of thermal detectors does not depend on the wavelength, while is quite selective in case of proton detectors. The following semiconductors are used for photon detectors in the visible: AlGaN, CdS, CdSe, GaAs, and first of all Si. The materials used for IR photon detectors are: HgCdTe, $LiTaO_3$, PbS, PbSe, InSb, PtSi, InGaAs, InGaAsP, Ge, Si:Ga, Si:As, Si:Sb, Ge:Au, Ge:Cu, Ge:Zn. On the other hand, thermal detectors are thermocouples and bolometers.

Out of the listed materials, a straight band gap possess the following ones: InSb, InAs, GaAs, GaN, ZnS, CdS, CdSe, and the skew one Si, Ge, GaP, AlAs. Si has ~1,1eV bandgap what is equivalent to the absorption edge at 1,1μm. Carrier mobility in Si is 1500cm^2/Vs. GaAs has the bandgap of 1,5eV, absorption edge at 0,8μm and carrier mobility 8500cm^2/Vs. GaAs devices can be in principle faster than Si ones.

The simplest photodetector is a photoresistor. The basic technical parameter of a photodiode considered by a user is detectability. It is measured in [cmHz1/2/W]. The detectability is confined by background radiation noise and thermal noise. Photodiodes are made with the following types of junctions: p-n, m-s, m-n (Schottky), pin, avalanche n^+-p-π-p^+, m-s-m. The m-s junction has several advantages over the classical p-n junction: simpler technology, larger saturation current because thermoelectric emission is more effective than diffusion, and faster response. The response time is a sum of the following factors: diffusion time of carriers from the place they were generated to the area of space charge, flight time through the space charge region, time constant of charging the junction capacity. The RF photodiodes have the capacitance below a few pF. InGaAs photodiodes are used for the long-wavelength bands of optical fiber communication systems. They have maximum of spectral characteristic in the area of 1,1 – 1,7 μm.

IV. Sources

Electroluminescent diodes are expected to replace, in not so distant future, other light sources for lighting purposes. This is due to their large quantum efficiency measured by the ratio of emitted photons to the electrons passing by the p-n junction during a second. The user is interested, however, in the energy efficiency which is a ratio of the emitted optical power to the electrical energy provided to the LED. Now the LEDs are generating from the IR (GaInNAs, GaInNAsSb, InGaAsP, InAs/GaAs, AlGaAs) to UV (AlN, AlGaN, AlGaInN, GaN, ZnO), including the visible range: red 610-760nm (AlGaAs, GaAsP, AlGaInP, Gap:ZnO), orange 590-610nm (GaAsP, AlGaInP, Gap:ZnO), yellow 570-590nm (GaAsP, AlGaInP, GaP:N), green 600-570nm (GaP:N,AlGaInP, AlGaP, InGaN), blue 450-500nm (InGa, ZnSe), violet 400-450 (InGaN) and white. The radiation is generated efficiently in semiconductors with the straight bandgap, and in some with skew bandgap doped with iso-electron substances (GaP:N, GaP:ZnO, GaP:CdO).

Modern LEDs have active regions doped intermediately or even lightly, in order not to introduce defects to the crystalline structure. The defects usually increase the level of non-radiant processes. Proper concentration of carriers in nearly non-doped regions is obtained by dynamic injection of n and p carriers. The junctions in LEDs have the following constructions: homo-junction, bi- and multi-hetero-junction, super-lattice and quantum wells. The most important problems in LEDs leading to the increase of the energy efficiency are avoidance of factors which increase the losses and decrease particular factors of the overall efficiency: decrease nonradiant recombination, absorption, mask the outgoing radiation, reflections, increase extraction efficiency – output taper, reflecting mirrors in the substrate, periodic micro-scribing of the substrate, output micro-lenses, output of the beam via the thinned substrate, matted emitting substrate, optimization of current flow in the component between the electrodes.

The LEDs are constructed as classical components, with a luminophore (radiation converter), superluminescent (using ASE – amplified spontaneous emission), resonant (with Fabry-Perot cavity), white (cichromatic, trichromatic, ttrachromatic, pentachromatic, multi-chromatic). The bichromatic sources have to mix two waves, longer and shorter, in a proper balance, to excite, in the human eye a feeling of the white light. The balance in multi-chromatic sources between the color components is approximately 1:1:1. A mixture of the waves 470nm and 570nm in proportions 1:1 give a feeling of the white light. Dichromatic LEDs are made of GaN-AlGaN-GaInN, have multi-quantum well structure, are manufactured as monolithic components on a sapphire substrate. Multi-color LEDs are also build with a luminophore. A basic parameter of a white LED is the CRI – color rendering index. It is equal to 60-95% for LEDs. CRI for sunlight and incandescent bulbs is assumed to be 100. The basic advantages of LEDs for illumination purposes are: long lifetime – above 50000 h, and high efficiency – over 50-150 [lm/W]. The relevant parameters for a tungsten bulb are around ten times smaller.

A considerable progress is also observed in the development of organic LEDs. OLEDS are build of organic semiconductors of two categories – polymer and molecular. The principle of work is similar as in classical LEDs.The carriers are passing between the two molecular orbits HOMO and LUMO. These orbits play the role analogous to valence and conduction bands in a semiconductor. The electrons are injected from the cathode to LUMO and the holes are injected from the anode to HOMO. OLEDs promise for building flexible planar light sources with tuned colors, transparent light sources, effective screens and displays of high dynamic and static contrast.

V. Optical Supercontinuum

Generation of optical supercontinuum is photonic optical fibers serves for building broadband sources of light. The laser is a very bright source but narrowband. Natural source of light is broadband but dim. A supercontinuum fiber source is broadband (for example 400-1600nm), very bright and white. During the nonlinear process of broadband excitation of high intensity in a fiber, there are generated new optical frequencies. This phenomenon is combined with electron reaction in the glass. The refraction depends on the intensity of excitation. The photons are interacting strongly with phonons. Typical excitation conditions for a dispersive optical fiber with an intense laser pulse are: pulse duration 100 fs, pulse energy 1nJ, peak Power 10 kW. The resulting peak intensity of the electric field in fiber core is 1kW/μm^2.

The dispersion in a fiber, which is required to generate the optical supercontinuum, causes that different frequency components of the exciting pulse propagate in the fiber with different group velocities. Simultaneously, there are many nonlinear effects present at the same time: self-shifting of the Raman frequency, solitonu fusion, and self-phase modulation.

During the pulse propagation along the fiber, there are continuously generated short wavelength (blue) and long wavelength (red) components, thus broadening of the pulse envelope. The dispersion causes that the high frequency components are slower than the low frequency ones. Due to the nonlinear refraction, for the top of the pulse, the low frequency (red) components are slower than the high frequency (blue) ones – and the pulse is subject to narrowing, degeneration, collapse and change to a solitonu. Very intense pulses generate many solitons and continuously loose energy on behalf of THz phonons (f>10THz). Frequency of a strong excitation pulse decreases during the propagation and the pulse continuously slows down, lagging behind self-generated solitons. Due to a strong statistical nature of these processes, the coherence path of the optical supercontinuum is very small and is equal to 10μm.

VI. Sensors, Photonic Instrumentation, Metrology

Optoelectronic and optical fiber sensors, photonic instrumentation systems and metrology are traditionally developed at several academic centers in this country. Early work was done at the Faculty of Chemistry WUT on chemical optrodes. This work is intensely continued till now [39]–[43]. The works on optical fiber were extended to Białystok, Gdańsk (imaging and displays), Lublin (industrial, observation of combustion processes), Wrocław and Warsaw (polarization and Bragg fibers), Warsaw (novel sCCD sensing systems) [44], [45], etc. The conference featured a few papers from these centers on various kinds of optical fiber sensors for industrial applications.

VII. Passive Optical Networks

Passive optical networks PON are a kind of optical distribution networks ODN. ODN is usually connected to the ISP operator via an optical line terminal OLT. Multimode, passive optical fiber networks, with time division multiplexing TDM, also with wavelength division multiplexing CWDM, are increasingly widely used because of low costs of the components and installation, much lower than for single mode networks. The multimode bandwidth, despite it is confined in comparison with the singlemode solution, is sufficient for many applications in LANs and access links. PON may have a structure of a local loop, an access star (point to multipoint) or a tree.

PON does not possess any active components, electronic like repeaters, transceivers, and multiplexers. There are used passive, not powered couplers, optical branchers, distributing the signals to subscribers and summing the signals from subscribers. A few kinds of PONs are standardized. APON uses ATM for transport. It belongs to the class of full services access networks FSAN. It is described by the standard G.983.1 ITU-T. The PON network components have strictly standardized names and functions. These are: OLT-optical line terminal (optical distribution node), ONT – optical network terminal (at a subscriber), ONU – optical network unit (distribution component). The network connected to a common OLT is called as OAN – optical access network.

BPON – a Broadband PON (described by standard G.983) includes APON, Ethernet transport and Video transport, and is the oldest standard for a broadband PON. GPON – a Gigabit PON (described by standard G.984 ITU-T) uses SONET GPF frames and may transport packet traffic as well as TDM. EPON is the IEEE standard for Ethernet based PON (IEEE 802.3). The name GEPON is used for Gigabit Ethernet PON. The name 10GEPON is used for 10GbE PON. Other PON terms are used: CPON for CDMA PON, WPON for WDM PON. The ONUs (splitters) are in the network beginning of a fiber leading to the vicinity (FTTC, FTTN) or directly to the subscriber (FTTH, FTTP).

The PON bases on a few simple principles. The OLT and ONU units consist of the Layer 2 (Ethernet, MAC, ATM adapter, etc), optical transceiver (optoelectronic Tx/Rx, two side converter O/E and E/O) using two different wavelengths for sending to the subscriber (1530$\pm$50nm, 1530-1580nm) and to receive from the subscriber (1310$\pm$50nm, 1260-1360nm), as well as optionally a WDM multiplexer (precisely CWDM). Tor both transmission directions to the subscriber and from the subscriber an equal bandwidth of 100nm is reserved, with exception of additional CWDM band applied for the direction to the subscriber (1490$\pm$10nm and extension band 1550-1560nm for video transmission, 1539-1565nm for digital data transmission). Transmission towards the subscriber, of broadcasting nature, is provided from OLT to all ONUs in a single ODN. ONU receives data destined to the particular address and omits the rest of data. Data are coded in order to provide privacy. Transmission from the subscriber (multi-access) is provided by multiplexing of the bandwidth by the ONU using TDMA (Ethernet).

PON is neither using directly the CSMA/CD protocol (multipoint to multipoint) nor the ATM (point-to-point). OLT manages the time slots of ONU. The length of optical link is determined in order to set the propagation time needed for covering the distance ONU-OLT. PON has additional functionalities like: management of the physical layer, network auto-discovery, link length measurements to set the latencies for TDMA access signals, dynamic bandwidth allocation, network recovery after failure, etc. Exemplary PON data is: maximum splitting losses around 15dB, optical power splitting homogeneity 1dB, total losses 15dB, range of used wavelengths 1250-1650nm, range 5-20 km, fiber losses 0,35dB/km, connector losses 2dB.

VIII. Petabit Photonic Internet

The applications of optoelectronics, photonics and in particular optical fiber communications in the Internet are still fast developing [19], [20], [46]–[50]. The main research areas on the photonic Internet concern two major areas: increase of the transmission rate and buildings of a human – global network interface. One conception of such an interface is an extremely wideband electromagnetic cloud embracing RF bands, IR and optical. The cloud is fully interactive, identifies a person, reads his/her well being, reads gestures, traces eye globe movements, recognizes speech, executes orders, but also displays/conveys information to the human being.

Concerning the optical channel throughput, the industrial standards embrace 40Gbit/s systems. Standards for 100Gbit/s and 160Gbit/s Ethernet are under preparation and will be ready soon (IEEE 802,3ba). Modulation methods of optical carrier are under development, adapting the RF technologies like OFDM and extending purely optical ones like UDWDM. Concatenation of these methods will allow, in the near future, to close the gap to the Shannon-Hartley transmission rate boundary. For typical working conditions of an ultra broadband transmission channel WDM-COOFDM (coherent optical orthogonal frequency division multiplexing), with two-fold polarization multiplexing, it mens the spectral efficiency close to 10bit/s/Hz, at SNR=30dB and the aggregated throughput on the level of 1Pb/s, for the optical band 1,3-1,7μm. In such conditions, the subscriber has an access to the network via a 1Gbit/s fiber. The Internet exchanges IX are connected with hundreds Tbit/s or single Pb/s, and the links IX – ISP provides throughput on the level from 1 to a few Tbit/s.

Transmission systems with ultra-dense wavelength multiplexing UDWDM are subject of research leading to more effective usage of the optical bandwidth. A standard interchannel WDM slit of 100GHz in width (for example in frequenct band 193-193.1 THz), there are inserted 32 optical carriers (colors), using a multi-wavelength source, with a new inter-channel separation equal to 3,125GHz. Such a dense transmission system must provide a suitable stability of the channel separation on the level of single MHz. At a large spectral efficiency of the used modulation system for a single color, it is possible to obtain effectively even 10Gbps throughput in the access networks with the UDWDM method.

IX. Optical Fibers and Their Applications 2012

The next XIVth conference on Optical Fibers and Their Applications will be organized in autumn 2012 in Lublin and Krasnobród. The co-organizers are Lublin University of Technology and UMCS, Laboratory of Optical Fiber Technology.

The Proceedings of the XIIIth Conference on Optical Fibers and Their Applications, Białowieża 2011, are usually printed as a volume in the Proceedings of SPIE . The proceedings of the previous conferences from this series were published there [51], [52].

Acknowledgment

The authors would like to acknowledge all the persons involved in the organization of the conference on 'Optical Fibers and Their Applications', Białowieża 2011, in particular the Program and Organization Committees.

References

[1] J. Modelski, "Electronics and Telecommunications in Poland, Issues and Perspectives: Part I. Society and Education," *Proceedings of SPIE*, vol. 7745, pp. 1–16, 2010, paper 774504.

[2] ——, "Electronics and Telecommunications in Poland, Issues and Perspectives: Part II: Science, Research, Development, Higher Education," *Proceedings of SPIE*, vol. 7745, pp. 1–21, 2010, paper 774505.

[3] ——, "Electronics and Telecommunications in Poland, Issues and Perspectives: Part III: Innovativeness, Applications, Economy, Development Scenarios, Politics," *Proceedings of SPIE*, vol. 7745, pp. 1–16, 2010, paper 774506.

[4] R. S. Romaniuk, "Photonics Letters of Poland – A New Peer Reviewed Internet Publication of the Photonics Society of Poland," *Photonics Letters of Poland*, vol. 1, no. 1, pp. 1–3, 2009.

[5] J. Gajda, "Development of Laser Technology in Poland," *Proceedings of SPIE*, vol. 7745, pp. 1–9, 2010, paper 774507.

[6] R. S. Romaniuk, "POLFEL – Free Electron Laser in Poland," *Photonics Letters of Poland*, vol. 1, no. 3, pp. 103–105, 2009.

[7] ——, "Advanced Photonic and Electronic Systems, WILGA 2010," *Elektronika*, vol. 52, no. 1, pp. 94–108, 2011.

[8] ——, "Wilga Photonics and Web Engineering 2010," *Proceedings of SPIE*, vol. 7745, 2010, art no. 774503.

[9] ——, "Photonics Applications and Web Engineering SPIE – PSP Wilga Symposium Series," *Proceedings of SPIE*, vol. 7745, 2010, art no. 774502.

[10] ——, "Photonics and Web Engineering in Poland, Wilga 2009," *Proceedings of SPIE*, vol. 7502, 2009, art no. 750202.

[11] ——, "Photonics Applications and Web Egineering SPIE – PSP WILGA Symposium Series," *Proceedings of SPIE*, vol. 7745, 2010, art no. 774502.

[12] ——, "WILGA Photonics and Web Engineering 2010," *Photonics Letters of Poland*, vol. 2, no. 2, pp. 55–57, 2010.

[13] ——, "WILGA Symposium on Photonics Applications," *Photonics Letters of Poland*, vol. 1, no. 2, pp. 46–48, 2009.

[14] J. Dorosz, "Technology of Optical Fibers," *Ceramika, Polish Ceramic Bulletin*, vol. 86, 2005.

[15] ——, "Optical Fibers and Their Applications, Proceedings of the XI Conference 'optical fibers and their applications'," *Ceramika, Polish Ceramic Bulletin*, vol. 108, 2008.

[16] J. Dorosz and R. S. Romaniuk, "Fiber Optics Department of Biaglass Co. Twenty Years of Research Activities," *Optica Applicata*, vol. 28, no. 4, pp. 267–291, 1998.

[17] W. Wójcik, "Optical Fiber Technology Development in Poland," *Proceedings of SPIE*, vol. 7745, 2010, art no. 774508.

[18] J. Rayss, J. Wójcik, and W. Wójcik, "Optical Fibers and Their Applications," in *XII TAL Conference Proceedings, Plenary and Contributed Papers*, Lublin, 2009.

[19] R. S. Romaniuk, *Optical Terabit Internet*. Warsaw: PAN Publications, 2001.

[20] ——, *DWDM, Technology, Measurements, Exploitation, Development*. Warsaw: PAN Publications, 2001.

[21] A. Rogalski, *Infrared Detectors*. CRC Press, 2010.

[22] R. S. Romaniuk and J. Dorosz, "Technology of Soft-Glass Optical Fiber Capillaries," *Proceedings of SPIE*, vol. 6347, 2006, art no. 634710.

[23] R. S. Romaniuk, "Two Classes of Capillary Optical Fibres: Refractive and Photonic," *Proceedings of SPIE*, vol. 7124, 2008, art no. 71240D.

[24] ——, "Capillary Optical Fiber – Design, Fabrication, Characterization and Application," *Bulletin of the Polish Academy of Sciences*, vol. 56, no. 2, pp. 87–102, 2008.

[25] ——, "Applications of Capillary Optical Fibers," *Proceedings of SPIE*, vol. 6347, 2006, art no. 63470Z.

[26] ——, "Optical Fiber Capillaries in Trunk Telecommunications," *Proceedings of SPIE*, vol. 6347, 2006, art no. 634712.

[27] R. S. Romaniuk and J. Dorosz, "Mechanical Properties of Hollow Optical Fibres," *Proceedings of SPIE*, vol. 6347, 2006, art no. 634711.

[28] ——, "Multicore Single-Mode Soft-Glass Optical Fibres," *Optica Applicata*, vol. 29, no. 1, pp. 15–49, 1999.

[29] J. Dorosz, "Multicrucible Technology of Tailored Optical Fibres," *Optica Applicata*, vol. 28, no. 4, 1998, 293–322.

[30] R. S. Romaniuk, "Tensile Strength of Tailored Optical Fibres," *Opto-Electronics Review*, vol. 8, no. 2, pp. 101–116, 2000.

[31] R. S. Romaniuk and J. Dorosz, "Measurement Techniques of Tailored Optical Fibres," *Proceedings of SPIE*, vol. 5064, pp. 210–221, 2003.

[32] R. S. Romaniuk, "Manufacturing and Characterization of Ring Index Optical Fibres," *Optica Applicata*, vol. 31, no. 2, pp. 425–444, 2001.

[33] ——, "Nonlinear Glasses and Metaglasses for Photonics – A Review Part I – Nonlinear Electrical Susceptibility and Refractive Index," *Proceedings of SPIE*, vol. 6937, 2008, art no. 693716.

[34] ——, "Nonlinear Glasses and Metaglasses for Photonics – A Review Part II – Kerr Nonlinearity and Metaglasses of Positive and Negative Refraction," *Proceedings of SPIE*, vol. 6937, 2008, art no. 693717.

[35] ——, "Modal Structure Design in Refractive Capillary Optical Fibers," *Photonics Letters of Poland*, vol. 2, no. 1, pp. 22–24, 2010.

[36] ——, "Geometry Design in Refractive Capillary Optical Fibers," *Photonics Letters of Poland*, vol. 2, no. 2, pp. 64–66, 2010.
[37] D. Dorosz, "Active Specialty Optical Fibers," *Ceramika, Polish Ceramic Bulletin*, vol. 110, 2010.
[38] S. Ertman, "Light Polarization in Liquid Crystal Photonic Fibers," Ph.D. dissertation, Faculty of Physics, Warsaw Univeristy of Technology, 2009.
[39] A. Dybko and W. Wróblewski, "Polymer Track Membranes as a Track Support for Reagent in Fiber Optic Sensors," *Journal of Applied Polimer Science*, vol. 59, no. 4, pp. 719–723, 1996.
[40] A. Dybko, "Fiber Optic Probe for Monitoring of Drinking Water," *Proceedings of SPIE*, vol. 3105, pp. 361–366, 1997.
[41] ——, "Efficient Reagent Immobilization Procedure for Ion-Sensitive Optomembranes," *Sensors and Actuators, B: Chemical*, vol. 39, no. 1, pp. 207–211, 1997.
[42] ——, "Assessment of Water Quality Based on Multiparameter Fiber Optic Probe," *Sensors and Actuators, B: Chemical*, vol. 51, no. 1-3, pp. 208–213, 1998.
[43] ——, "Application of Optical Fibres in Oxidation-Reduction Titrations," *Sensors and Actuators, B: Chemical*, vol. 29, no. 1-3, pp. 374–377, 1995.
[44] G. Kasprowicz, "CCD Detectors for Wide Field Optical Astronomy," *Photonics Letters of Poland*, vol. 1, no. 2, pp. 82–84, 2009.
[45] P. Obroślak, "Digital Techniques for Noise Reduction in CCD Cameras," *Photonics Letters of Poland*, vol. 2, no. 3, pp. 134–136, 2010.
[46] A. Kalicki, "Ultrabroadband Photonic Internet: Safety Aspects," *Proceedings of SPIE*, vol. 7124, 2008, art no. 712410.
[47] K. T. Poźniak, "FPGA and Optical Network Based LLRF Distributed Control System for Tesla-Xfel Linear Acelerator," *Proceedings of SPIE*, vol. 5775, pp. 69–77, 2005.
[48] R. S. Romaniuk, "Optical Network and FPGA/DSP Based Control System for Free Electron Laser," *Bulletin of the Polish Academy of Sciences: Technical Sciences*, vol. 53, no. 2, pp. 123–138, 2005.
[49] T. Janicki, "Integration of Multi-Interface Conversion Channel Using FPGA for Modular Photonic Network," *Proceedings of SPIE*, vol. 7745, 2010, art no. 77451H.
[50] R. S. Romaniuk, "Optical Fiber Transmission with Wavelength Multiplexing – Faster or Denser?" *Proceedings of SPIE*, vol. 5484, pp. 19–28, 2004.
[51] J. Dorosz, R. S. Romaniuk, and T. Woliński, "Optical Fibers and Their Applications," *Proceedings of SPIE*, vol. 7120, 2008.
[52] J. Dorosz and R. S. Romaniuk, "Optical fibers and their applications," *Proceedings of SPIE*, vol. 3731, 1999.
[53] W. Wójcik and R. S. Romaniuk, "Development of Optical Fiber Technology in Poland," *Elektronika*, vol. 51, no. 40, pp. 140–144, 2010.
[54] ——, "Development of Optical Fiber Technology in Poland," *International Journal of Electronics and Telecommunications*, vol. 56, no. 1, pp. 99–104, 2010.
[55] J. Dorosz and R. S. Romaniuk, "Optical Fibers and Their Applications," *Proceedings of SPIE*, vol. 5028, 2003.