Integrated Optics
- Sensors, Sensing Structures and Methods
IOS'2017

PROGRAMME
and
ABSTRACTS

<u>Organizers of IOS 2017</u>

Photonic Society of Poland,

Upper Silesian Devision of
the Polish Acoustical Society

and

Committee of Electronics and Telecommunication
at the Polish Academy of Sciences

27th February to 3rd March 2017,
Hotel "META"
Szczyrk - Beskidy Mountains, POLAND

http://ogpta.pl

Dear participants of
"The 12th Conference Integrated Optics - Sensors, Sensing Structures and Methods - IOS 2017"

Organizers welcome All of You very cordially in Szczyrk, in the beautiful scenery of the Beskidy Mountains.

We wish all Participants of the Conference IOS’2017 plenty of scientific satisfactions and many professional and social impressions.

Organizers

President of the Conference: Prof. Tadeusz Pustelny
Treasurer: Dr eng. Aneta Olszewska
Secretary: Dr eng. Przemysław Struk
Members: Prof. Marek Blahut
Dr eng. Sabina Drewniak
Dr eng. Kamil Barczak

This book includes the Program of the IOS’2017 conference as well as abstracts of presentations and posters sent by their Authors.

CONFERENCE PROGRAMME

27.02.2017 Monday	
13:00	***Dinner***
14:15-14:30	**OPENING CEREMONY of the Conferences:** **12th IOS'2017, 45th WSEA&V and 46th WSW&QA**
14:30-15:00	**45th anniversary of the** **Winter School on Environmental Acoustics and Vibroacoustics**
15:00-16:20	**The Session Dedicated to the MEMORY of** **PROFESSOR EUGENIUSZ JAN DANICKI**
15:00-15:20	**MEMORIES**
15:20-15:40	**An advanced technology for radar signal processing - the review** Adam KAWALEC
15:40-16:00	**Determination of Some Kinetic Parameters of Fast Surface States in Semiconductors by Means of the Surface Acoustic Wave Method** Tadeusz PUSTELNY
16:00-16:20	**Seismometer based on Surface Acoustic Waves transducers** Jerzy FILIPIAK
16:20-17:00	***Coffee break***
17:00-17:30	*Invited lecture:* **Novel photonic and quantum devices exploiting nonlinear and coherence phenomena in color centers in diamond** Wojciech GAWLIK, M. FICEK, M. MRÓZEK, R. BOGDANOWICZ
17:30-17:50	**Micro-cavity in-line Mach-Zehnder interferometers for small-volume and high-sensitivity refractive-index sensing** Marcin KOBA, A. K. MYŚLIWIEC, M. JANIK, W. J. BOCK, M. ŚMIETANA
17:50-18:10	**Last advances in integrated planar optical waveguide interferometers** Kazimierz GUT

18:30	***Regional supper***
19:30-20:30	**Sleigh ride – group 1**
20:30-21:30	**Sleigh ride – group 2**
	28.02.2017 Tuesday
13:00	***Dinner***
14:30-15:00	*Invited lecture:* **Linear and nonlinear waveguide structures in nematic liquid crystal cells for routing and switching** Mirosław A. KARPIERZ ,U. A. LAUDYN, M,.KWASNY, B. KLUS, P. JUNG, I. OSTROMECKA, M. URBANOWICZ
15:00-15:20	**Photonic crystal fibers infiltrated with azobenzene liquid crystals** Daniel BUDASZEWSKI, M. SMYL, T. R. WOLIŃSKI
15:20-15:40	**Functional sensing materials based on graft combcopolymers for applications in optoelectronics and microelectronics chemical gas sensors** Erwin MACIAK
15:40-16:00	**Next generation distributed sensing systems based on microstructured optical fibers** Łukasz SZOSTKIEWICZ, A. PYTEL, A. KOŁAKOWSKA, M. JÓŹWIK, T. NASIŁOWSKI
16:00-16:15	**Fiber optic shape sensor based on multicore fiber technology and Brillouin scattering effect** Anna PYTEL, Agnieszka KOŁAKOWSKA, Michalina JÓŹWIK, Łukasz SZOSZKIEWICZ, Zhisheng YANG, Michał MURAWSKI, Marek NAPIERAŁA, Luc THÉVENAZ, Paweł MERGO, Tomasz NASIŁOWSKI

16:15-16:30	**Radiation effects in distributed optical fiber sensors** Michalina JÓŹWIK, Marta FILIPOWICZ, Tomasz NASIŁOWSKI
16:30-17:00	***Coffee break***
17:00-17:30	*Invited Lecture* **Recent developments in gas sensing using laser-based dispersion spectroscopy** Michał NIKODEM
17:30-17:45	**Brillouin distributed sensing in birefringent optical fibers** Agnieszka KOŁAKOWSKA, Anna PYTEL, Michalina JÓŹWIK, Łukasz SZOSZKIEWICZ, Zhisheng YANG, Michał MURAWSKI, Marek NAPIERAŁA, Luc THÉVENAZ, Paweł MERGO, Tomasz NASIŁOWSKI
17:45-18:00	**Application of graft comb copolymers of poly(3-hexylthiophene as a receptor materials for gas sensors** Marcin PROCEK, A. STOLARCZYK, E. MACIAK
18:00-18:20	**Study of MIR photoluminescence from Pr^{3+} doped chalcogenide fibers pumped at near-infrared wavelengths** Sławomir SUJECKI, L. SOJKA, E. BERES-PAWLIK, R. PIRAMIDOWICZ, H. SAKR, Z. TANG, E. BARNEY, D. FURNISS, T.M. BENSON, A.B. SEDDON
19:30	***Festive Supper (Banquet)***
01.03.2017 Wednesday	
13:00	***Dinner***
14:30-14:50	*Invited lecture*: **Non-invasive assessment of thromboembolism in rotary blood pumps** Maciej GAWLIKOWSKI, M. GŁOWACKI, R. KUSTOSZ, P.

	PUDZIŃSKI
14:50-15:10	*Invited lecture*: **The wireless programmable optical sensor to protect the works of art** Krzysztof MURAWSKI, M. MURAWSKA
15:10-15:30	**Technique of accuracy measurement of membrane shape mapping of the artificial ventricle** Wojciech SULEJ, L. GRAD, K. MURAWSKI
15:30-15:50	**Method of laser beam coding for control the system of augmented reality** Tomasz PAŁYS, A. ARCIUCH, A. WALCZAK, K. MURAWSKI
15:50-16:10	**Research of using wavelet transform to improve the accuracy of determining the stroke volume of artificial ventricle** Leszek GRAD, W. SULEJ, K. MURAWSKI
16:10-16:30	**Long-period grating biosensor for detection of very low DNA concentration** Karolina H. CZARNECKA, M. DOMINIK, M. JANCZUK-RICHTER, J. NIEDZIÓŁKA-JONSSON, E. ROŹNIECKA, M. ŚMIETANA
16:30-17:00	***Coffee break***
17:00-17:30	*Invited lecture*: **Self-organization of light in media with competing nonlocal nonlinearities**

	Wiesław KRÓLIKOWSKI, F. MAUCHER, T. POHL, S. SKUPIN,
17:30-17:45	**Cross spectral, active and passive approach to face recognition for improved performance** Marcin KOWALSKI, A. GRUDZIEŃ, M. SZUSTAKOWSKI
17:45-18:00	**Optoelectronic technologies for Virtual Reality systems** Marcin MACIEJEWSKI, M. PISZCZEK, M. POMIANEK, M. SZUSTAKOWSKI
18:00-18:15	**Application of continuous optical fiber measurements for strain and deformation state determination within building structures** Jakub KORYCIŃSKI, R. SIENKO, Ł. BEDNARSKI, T. HOWACKI
18:15-18:30	**Hollow-core fibers for multiphoton spectroscopy application** Hanna STAWSKA, M.POPENDA , E. BERES- PAWLIK
19:00-19:30	***Supper***
19:30-21:30	**Poster Session**

02.03.2017 Thursday

13:00	***Dinner***
14:30-15:00	*Invited lecture*: **Fiber microprobe with integrated electrodes for single cell electroporation** Ryszard BUCZYNSKI, J. KULBACKA, J. SACZKO, D. PYSZ, A. FILIPKOWSKI, M. DUBIŃSKA-MAGIERA, R. KASZTELANIC, R. STĘPIEŃ, M. KOTULSKA
15:00-15:15	**Special magnetooptic glasses** Kamil BARCZAK, R. BUCZYŃSKI

15:15-15:35	**ZnO semiconductor for applications in optoelectronics sensors structures** Przemysław STRUK, T. PUSTELNY, M. A. BORYSEWICZ, K. GOŁASZEWSKA
15:35-16:00	*Invited lecture*: **Polymer-assisted formation of waveguiding structures in liquid crystalline materials** Katarzyna A. RUTKOWSKA, M. CHYCHŁOWSKI, U. A. LAUDYN
16:00-16:20	**Modulators for MWIR detectors with liquid crystal** Urszula CHODOROW, A. KOWALEWSKI, J. HERMAN, R. MAZUR, P. MORAWIAK, W. PIECEK, P. KULA, W. GAWRON
16:20-16:40	**MIR emission from Tb^{3+} doped chalcogenide glass** Łukasz SÓJKA, Z. TANG,D. FURNISS, H. SAKR, Y. FANG, E. BERES-PAWLIK, T.M. BENSON, A.B. SEDDON, S. SUJECKI
16:40-17:00	***Coffee break***
17:00-17:20	*Invited lecture*: **Development of active optical fibers technology** Pawel MERGO, K. POTURAJ, R. LYSZCZEK, P. BORTNOWSKI, K. ANDERS, A. JUSZA, J. PEDZISZ, A. WALEWSKI, R. PIRAMIDOWICZ
17:20-17:40	**High birefringent microstructured polymer optical fibers with frozen stresses** Grzegorz WOJCIK, A. WALEWSKI, L. CZYZEWSKA, J. PEDZISZ, J. KOPEC, P. MERGO
17:40-18:00	*Invited lecture*:

	Detection of optical signals in selected sensing applications Jacek WOJTAS, Z. BIELECKI, J. MIKOŁAJCZYK, B. RUTECKA, D. SZABRA, K. KŁOS
18:00-18:20	**Metrology and gas sensors in business processes of the Company Atest-Gaz** Aleksander PACHOLE
18:20-18:40	**Selected gas sensors designed for IS and Automotive applications** Grzegorz KONIECZNY
18:40	**Closing ceremony of the IOS'2017 Conference**
19:00	**Supper**
03.03.2017 Friday	
8:00	***Breakfast***

IOS'2017 - Poster Session

01.03.2017 Wednesday: 18:45 – 21:30

Optical sensors based on multimode interference
Marek BŁAHUT

Influence of Fe3O4-doped LC on photonic liquid crystal fibers
Miłosz CHYCHŁOWSKI, Nina ZATKA, Sławomir ERTMAN, Bartosz BARTOSEWICZ, Bartłomiej JANKIEWICZ, Tomasz WOLIŃSKI

Thermo-optical properties of active polymers
Lidia CZYZEWSKA, Renata LYSZCZEK, Grzegorz WOJCIK, Janusz PEDZISZ, Paweł MERGO

Combined optical and electrochemical detection of isatin by its electro-polymerization on ITO-coated lossy-mode resonance optical sensor
Magdalena DOMINIK, Michał SOBASZEK, Dariusz BURNAT, Robert BOGDANOWICZ, Vitezslav STRANAK, Petr SEZEMSKY, Mateusz ŚMIETANA

Protein detection using long-period fiber gratings with nanocrystalline boron-doped diamond coating
Mateusz FICEK, P. NIEDZIAŁKOWSKI, M. ŚMIETANA, M. KOBA, R. BOGDANOWICZ

Boron doped diamond nanosheets – graphene nanostructures for electronic devices and biosensors
Mateusz FICEK, Michał SOBASZEK, Jakub KARCZEWSKI, Łukasz GOŁUŃSKI, Paweł NIEDZIAŁKOWSKI, Adrian NOSEK, Marc BOCKRATH, William A. GODDARD, Marcin GNYBA, Tadeusz OSSOWSKI, Robert BOGDANOWICZ

Special luminescent materials used in POF technology
Malgorzata GIL, Wieslaw PODKOSCIELNY, Beata PODKOSCIELNA

The Hall mobility measurement of the highly-doped, low bandgap HgCdTe epitaxial layers
Kinga GORCZYCA, Jarosław WRÓBEL, Paweł MADEJCZYK, Piotr MARTYNIUK

Calculations of dark current in mid-wavelength infrared type-II InAs/GaSb superlattice interband cascade photodetectors
Klaudia HACKIEWICZ, Piotr MARTYNIUK, Jarosław RUTKOWSKI, Andrzej KOWALEWSKI

InAs/GaSb superlattice quality investigation
Aleksandra HENIG, Kacper GRODECKI, Krzysztof MURAWSKI, Krystian MICHALCZEWSKI, Łukasz KUBISZYN, Djalal BENYAHIA, Piotr MARTYNIUK, Bartłomiej JANKIEWICZ, Bogusław BUDNER, Antoni ROGALSKI

Experimental elaboration and analysis of various low cost dye-sensitized TiO2 solar cell structures
Piotr KAŁUŻYNSKI, Erwin MACIAK, Agnieszka STOLARCZYK

Experimental determination of leakage current occurring in HgCdTe infrared detectors operating in the mid-infrared
Olga MARKOWSKA, Małgorzata KOPYTKO, Jarosław RUTKOWSKI, Andrzej KOWALEWSKI, Piotr MARTYNIUK

Theoretical simulation of the long-wave HgCdTe detector for ultra fast response - operating under zero bias and room temperature condition
Piotr MARTYNIUK, Paweł MADEJCZYK, Jarosław RUTKOWSKI

Raman and photoluminescence investigation of InAs/GaSb and InAs/InAsSb superlattices
Krzysztof MURAWSKI, Kacper GRODECKI, Aleksandra HENIG, Krystian MICHALCZEWSKI, Djalal BENYAHIA, Piotr MARTYNIUK, Bartłomiej JANKIEWICZ, Bogusław BUDNER, Antoni ROGALSKI

Optoelectronics sensors of hydrocarbons based on NDIR technique
Artur PROKOPIUK, Jacek WOJTAS

Spectroelectrochemical sensing with Mach–Zehnder interferometer - route toward extreme sensitivity of biomolecules detection
Michał SOBASZEK, Marcin STRĄKOWSKI, Łukasz SKOWROŃSKI, Jerzy PLUCIŃSKI, Robert BOGDANOWICZ

The photonic sensor measuring the exchange of gases, in particular CO2 in the area of the forest atmosphere
Piotr SOBOTKA, Marcin BIEDA, Tomasz WOLIŃSKI

Straight and bended high refractive index channel waveguides – theoretical analysis
Cuma TYSZKIEWICZ

Optical skin phantoms for calibration medical lasers
Michal WĄSOWICZ, Anna SĘKOWSKA, Maciej WRÓBEL, Marcin Mrotek, Stanisław GALLA, Adam CENIAN, Małgorzata JĘDRZEJEWSKA-SZCZERSKA

Long-range network formation in nematic liquid crystals doped with gold nanoparticles in 1D photonic structure
Karolina BEDNARSKA, Piotr LESIAK, Kamil ORZECHOWSKI, Miłosz CHYCHŁOWSKI, Michał WÓJCIK and Tomasz WOLIŃSKI

Thermal face recognition on the move
Artur Grudzień, Marcin Kowalski, Mieczysław Szustakowski

PRESENTAIONS ABSTRACTS

An advanced technologies for radar signal processing - the review

Adam KAWALEC

Institute of Radioelectronics, Military University of Technology, 2 Kaliskiego Str. 00-908 Warsaw, Poland

e-mail address: adam.kawalec@wat.edu.pl

The selected applications of the surface acoustic wave devices in the area of the signal processing are presented. The analysis of the surface acoustic wave (SAW) filter is described in the paper. In the analysis based on the spectral theory is taken into account. The analysis of the effective surface permittivity significantly simplifies the theoretical analysis of the interdigital transducer. The calculation of the complex effective surface permittivity can be used to estimate the band of the possible (undesirable) bulk waves. The synthesis of the dispersive line based on the theoretical analysis results is presented. The experimental characteristics for the quartz based dispersive line as an application for the radar signal processing is demonstrated. Dispersive delay lines can be applied in chirp pulse compression system characterized low side-lobe level and in SAW spectrum analyser as well.

The paper is dedicated to the memory of Professor Eugeniusz Danicki.

Determination of Some Kinetic Parameters of Fast Surface States in Semiconductors by Means of the Surface Acoustic Wave Method

Tadeusz PUSTELNY
Department of Optoelectronics, Silesian University of Technology, 2 Krzywoustego St., 44-100 Gliwice, POLAND;
e-mail address: Tadeusz.Pustelny@polsl.pl

Among the methods of investigations of semiconductor surfaces, there are no methods of investigating the kinetic properties of electrical carries in fast and very fast surface states. The existing methods allow only investigations of the surface sates with a carrier life-time τ of above 10^{-8} s. In the case of extrinsic semiconductors the surface states may, however, be considerably faster (the carrier life-time in surface traps is usually less than 10^{-8} s). In such cases the existing methods of determining the parameters of fast surface states allow only to estimate these parameters, since the obtained results exhibit a considerable uncertainty. For this reason, investigations of the kinetic properties of fast surface states are not popular and there aren't any new results concerning their determination.

For some years attention has been paid to the influence of the physical state of the near-surface region of a semiconductor on the results of investigations of the acoustoelectric effects in piezoelectric-semiconductor systems. The attention has been paid to the possibility of applying Rayleigh's surface acoustic waves SAWs for investigations of various surface parameters of solid states.

The theoretical and experimental results of the application of acoustoelectric effects (longitudinal and transverse) for the determination of carrier properties in near surface region (e.g. the surface electrical potential, carrier concentration, electrical conductivities,…) have been presented. Problems connected with the determination of the chemical and mechanical means of surface treatments in the first step of preparation of semiconductor plates for technology on their kinetic properties have not often been taken up. The quantitative data concerning the effective life-time τ and the velocity of carrier trapping g are very seldom presented in literatures of semiconductor surfaces. Presented results are new and original.

Seismometer based on Surface Acoustic Waves transducers

Jerzy FILIPIAK

Institute of Electronic and Control Systems, Technical University of Czestochowa, Al. Armii Krajowej 17, 02-240 Częstochowa, Poland

e-mail address: filipiak1947@gmail.com

The paper will be presented the concept of a seismometer based on surface acoustic waves (SAW). The base of the system design are three SAW transducers arranged along three orthogonal axes. Each transducer is composed of two SAW delay lines. The seismometer consists of high frequency generator, phase detector and three SAW transducers. It allows to measure constant and time dependent accelerations in three orthogonal directions with the operating band up to 150Hz. We will show an analysis of main system parameters i.e. amplitude frequency response, resonant frequency and sensitivity including cross-sensitivity. We will discuss temperature influence on these parameters, also. We will present experimental results of the seismometer transducer and compare them with theory.

Currently used seismometers in seismology, mine seismology and reflection seismology are design based on system of mechanic pendulums. We will compare these systems with presented above in terms of technical performance, prices and installations.

Novel photonic and quantum devices exploiting nonlinear and coherence phenomena in color centers in diamond

Wojciech GAWLIK[1*], Mateusz FICEK[2], Mariusz MRÓZEK[1] and Robert BOGDANOWICZ[2]
[1]Institute of Physics, Jagiellonian University, Łojasiewicza 11, 30-348 Kraków, Poland
[2]Faculty of Electronics, Telecommunications and Informatics, Gdańsk University of Technology, 11/12 Narutowicza St., 80-233 Gdansk, Poland
e-mail address: gawlik@uj.edu.pl

The color center may couple an electron to become negatively charged (SiV– or NV–) with spin S=1. The nonzero spin is responsible for paramagnetic properties of the center. The vacancies may be created in diamond powders or in a bulk CVD or HTHP diamond. Due to photo-conversion between the charged and neutral forms of the center and its light-power dependence, the NV centers are very attractive for applications in various quantum devices. However, there is a serious problem of their coupling with photonic cavities or other devices. These issues are investigated by research teams in Oxford, Berkeley, MIT, Melbourne, Ulm, Mainz. Recently the Oxford - Grenoble-Alpes group demonstrated efficient coupling between the NV centers in open Fabry-Perot cavities at 77 K [1]. Recently. the Melbourne team demonstrated coupling of NV spherical micro-resonator of a high Q-factor with nanodiamond integrated in tellurite glass [2]. The main objectives of this study is development of new technological solutions for the creation of photonic structures and quantum devices based on color centers in diamond (Figure 1) and to develop novel dedicated spectroscopic methods for studying their optical and microwave properties. Moreover, we intend to investigate the application perspectives of the achieved results and technological potential for development of novel sensors based on nonlinear and quantum optics (biosensors/biomarkers, quantum information processing and quantum cryptography).

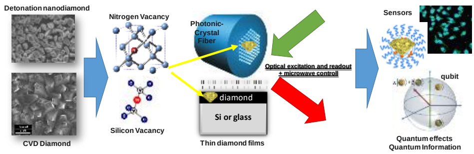

Fig. 1. The photonic and quantum devices based on color centers in diamond.

The proposed method relies on synthesis of diamond with integrated color centers and/or synthesis of photonic fibers with NV centers and has not been used by any other team. It will be developed in two directions: (i) filling the PCF fiber with DND-NV suspensions and (ii) synthesis of PCF fiber precoated with DND-NV suspensions (empty PCF and NVs in the fiber walls) [3]. The sample characterization will be based on optical (absorption, emission, Raman) and microwave spectroscopy with high spatial (confocal, ~µm3) and spectral (sub-Hz) resolution. The measurements will be performed using a technique of optical detection of magnetic resonance (ODMR) improved by development of the microwave hole burning technique [4]. The development and applications of quantum technologies and nonlinear spectroscopy for studies of color centers in diamonds is very fast. Thanks to the stable crystallographic and electron structure of diamond, NV-color centers exhibit very stable electronic spectra, not much sensitive to various perturbations. Their excellent optical and spin properties (paramagnetism) allow one to use different resonance and spintronic methods of and enable precision metrology.

This work was supported by the Polish National Science Centre (NCN) under the Grants No. 2014/14/M/ST5/00715 and 2016/21/B/ST7/01430. The DS funds of Faculty of Electronics, Telecommunications and Informatics of the Gdansk University of Technology are also acknowledged.

Reference

[1]. R.N. Patel, T. Schröder, N. Wan, L. Li, S.L. Mouradian, E.H. Chen, D.R. Englund, Efficient photon coupling from a diamond nitrogen vacancy center by integration with silica fiber, Light Sci. Appl. 5 (2016) 11486.

[2]. Y. Ruan, H. Ji, B.C. Johnson, T. Ohshima, A.D. Greentree, B.C. Gibson, T.M. Monro, H. Ebendorff-Heidepriem, Nanodiamond in tellurite glass Part II: practical nanodiamond-doped fibers, Opt. Mater. Express. 5 (2015) 73 .

[3]. R. Bogdanowicz, M. Śmietana, M. Gnyba, M. Ficek, V. Straňák, Ł. Goluński, M. Sobaszek, J. Ryl, Nucleation and growth of CVD diamond on fused silica optical fibres with titanium dioxide interlayer, Phys. Status Solidi A. 210 (2013) 1991–1997.

[4]. M. Mrozek, A. Wojciechowski, D.S. Rudnicki, J. Zachorowski, P. Kehayias, D. Budker, W. Gawlik, Coherent population oscillations with nitrogen-vacancy color centers in diamond, Phys.Rev. B, B 94, 035204 (2016).

Micro-cavity in-line Mach-Zehnder interferometers for small-volume and high-sensitivity refractive-index sensing

Anna K. MYŚLIWIEC[1], Monika JANIK[3], Marcin KOBA[1,2*], Wojtek J. BOCK[3], Mateusz ŚMIETANA[1*]

[1]Institute of Microelectronics and Optoelectronics, Warsaw University of Technology, Koszykowa 75, 00-662 Warsaw, POLAND

[2]National Institute of Telecommunications, Szachowa 1, 04-894 Warsaw, POLAND;

[3]Centre de recherche en photonique, Université du Québec en Outaouais, 101 rue Saint-Jean-Bosco, Gatineau, QC J8X 3X7, CANADA

e-mail address: (M.Koba@elka.pw.edu.pl, M.Smietana@elka.pw.edu.pl)

High refractive index (RI) sensitivity typically requires large sensing surface and does not allow for spatially high-definition sensing. A solution to this instance may be sought in highly sensitive in-fiber RI sensors capable of investigating possibly small volumes of liquids. To meet these needs many sensors based on the Mach-Zehnder Interferometer (MZI) principle have been proposed, where the cavity is most commonly micro-machined using femtosecond laser. Generally, in such a micro-cavity in-line MZI (µIMZI) structure, a beam of light in the fiber core encounters two optically different regions at which it tends to superpose. In the sensing configuration, the two regions might be looked at as two paths where one is a sensing path (the micro-cavity path), and the other one is a reference path (the fiber core path) [1].

The structures in a form of cylindrical micro-cavities were fabricated in standard Corning SMF28 fibers with a Solstice Ti:sapphire femtosecond laser operating at 795 nm (Fig. 1). The fibers were irradiated by 80 fs-long pulses, with repetition rate of 10 kHz. In order to make the micro-cavity, the laser beam was directed to suitably designed micromachining setup based on the Newport's uFab system. The micro-cavities were then examined under the Olympus LEXT OLS3100 confocal laser scanning microscope. The physical dimensions of the micro-cavities obtained from the microscopic scans were about 30 to 80 µm and 30 to 100 µm in depth and width, respectively. The optical transmission of the µIMZI was monitored in the spectral range of 1150-1650 nm using Leukos SM30 supercontinuum source and Yokogawa AQ6370B optical spectrum analyzer. The RI sensitivity measurements were performed using a set of liquids (mixtures of water and glycerin) of nD varying in the range of 1.333-1.440 RIU. The nD was measured using Rudolph J57 automatic refractometer working with the accuracy of 2·10-5 RIU.

The obtained structures show constant sensitivities in specific RI ranges depending on the traced interference fringe and span from 12,000 (nD between 1.333 and 1.360 RIU), to over 23,000 nm/RIU (nD between 1.420 and 1.440 RIU), which is according to the best of the authors' knowledge the highest value reported for any µIMZI structures (Fig. 2) [2].

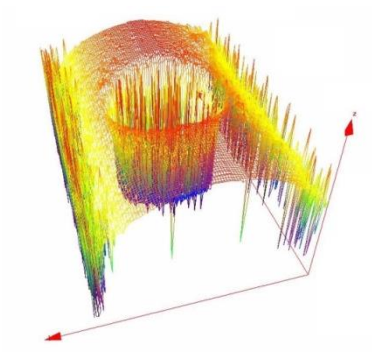

Fig. 1. Microscopic visualization of one of the fabricated µIMZI structures

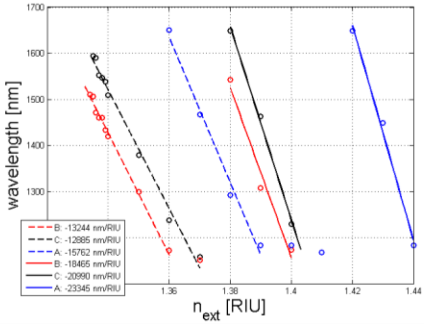

Fig. 2. Sensitivity plots of three differing in size µIMZI structures

This work was supported by the Polish National Science Centre (NCN) as a part of 2014/13/B/ST7/01742 project and Polish Ministry of Science and Higher Education in years 2014-2017 as a research project under "Diamentowy Grant" program.

Reference

1. X. Sun, X. Dong, Y. Hu, H. Li, D. Chu, J. Zhou, C. Wang, J. Duan, Sensor. Actuat. A-Phys. **230**, 111 (2015).
2. Y. Liu, G. Wu, R. Gao, S. Qu, Appl. Optics **56**, 847 (2017).

Last advances in integrated planar optical waveguide interferometers

Kazimierz GUT

Institute, Department of Optoelectronics, Silesian University of Technology, Akademicka 2, 44 100 Gliwice, POLAND

e-mail address: kazimierz.gut@polsl.pl

In the group of optoelectronic application of planar waveguide structures in metrology with respect to the possibility of realizing metrological system a high, and even very high sensitivity considerable role is played by interference systems [1]. According to the opinion of one of the leaders of modern optoelectronics (photonics) - prof. Paul Lambeck in terms of practical applications interferometers can be divided into the following [2] :

- Mach–Zehnder interferometer;
- Young interferometer;
- Michelson interferometer;
- difference interferometer.

In all these systems, we are dealing with overlapping (interference) of two electromagnetic waves with a visible spectral range, propagate through the waveguides. Changing the conditions of propagation of optical circuits revealed a change in velocity - as a result of the change of the phase difference of interfering beams.

Relatively recently it proposed distribution a division of waveguide interferometers system into common and double path ones [3] (single channel and two channel ones [4]). In his paper differential interferometers I consistently described as common path interferometers.

In a typical double path waveguide interferometer mode of the same order and polarization propagates along two laterally separated path: measured path (where the measuring agent affects the phase) and the reference path (which is isolated of this effect). The recorded signal inform about a change in the phase affected by factor of measurements (cover).

In a common path interferometer the waveguide mode propagate along one path and the measurement factor affects the phase of all the guided modes. The modes may differ in the state of polarization (TE, TM) or the order (TE0, TE1, TM0, TM1, ..). In such systems, it is important that there be as large as possible a difference in sensitivity between modes selected for interference.

Interferometers of this type constitute the base of constructing many kinds of sensors of physical, chemical and biological [3] quantities. Usually in investigations the waveguide structure is optimized in order to get the highest differential sensitivity.

An interesting solution permitting a magnification of even some hundred times is the application of an additional layer with a thickness of some scores of nanometers (with a high index of refraction), deposited on the waveguide

As described above, the structures it analyzed phenomenon of common path interference for one wavelength. The signal recorded by the detector is a function of the sine of the phase difference between modes (because it is a periodic function, there are such differences in the phase at which the light intensity at the output is the same). In 2008 published a work in, which describes spectropolarimetric common path interference in planar waveguide structure [5]. In the waveguide was excited mode both polarizations of the entire range of visible wavelengths and at the output of the spectrometer recorded broadcast spectrum.

Monotonic change of phase (between mods) causes monotonic shift of the recorded the spectral distribution. This method of detection also used in planar double path interferometers [6,7].

Reference

1. McDonagh C. et al. Optical chemical sensors, CHEMICAL REVIEWS Vol. 108 (2), pp.400-422, (2008).

2. Lambeck, P. V. Integrated optical sensors for the chemical domain, MEASUREMENT SCIENCE & TECHNOLOGY Vol.17 (8), pp. R93-R116, (2006).

3. Kozma P. et al. Integrated planar optical waveguide interferometer biosensors: A comparative review BIOSENSORS & BIOELECTRONICS Vol. 58, pp. 287–307, (2014)

4. Campbell D. Interferometric Biosensors, chapter in the book: Principles of Bacterial Detection, Springer (2008).

5. Qi Z. et al. Spectropolarimetric interferometer based on single-mode glass waveguides OPTICS EXPRESS Vol. 16 (3) pp.2245-2251(2008).

6. Kitsara M. et al. Integrated optical frequency-resolved Mach-Zehnder interferometers for label-free affinity sensing., OPTICS EXPRESS Vol.18 (8) pp. 8193-8206 (2010).

7. Misiakos K. et al. Broad-band Mach-Zehnder interferometers as high performance refractive index sensors: Theory and monolithic implementation, OPTICS EXPRESS Vol.22 (8) pp. 8856-8870 (2014).

Linear and nonlinear waveguide structures in nematic liquid crystal cells for routing and switching

Urszula A. LAUDYN, Michał KWASNY, Bartłomiej KLUS, Paweł JUNG, Iga OSTROMECKA, Magda URBANOWICZ, and Mirosław A. KARPIERZ
Faculty of Physics, Warsaw University of Technology, Koszykowa 75, 00-662 Warsaw, POLAND
e-mail address: karpierz@if.pw.edu.pl

The huge availability of liquid crystals mixtures with a variety of parameters (including optical birefringence, sign of electrical and optical anisotropy, thermal stability, etc.) allows easy customization of the designed device for specific conditions and allows for an operation in a variable range. Additionally, the use of nonlinear beam propagation of the light allows for the construction of an all-optical waveguide switch. In this work we present a specially designed and performed liquid crystal micro waveguide structures for optical signal guiding and switching. To produce the optical waveguide a precisely design alignment layer is applied to the boundary plates of liquid crystal cell providing the desired distribution of the nematic liquid crystal molecules. In such a manner, a well-defined regions with variable refractive index distribution in both, transverse and longitudinal directions are created. This enables to obtain a precisely designed structures with desired geometry (size and shape) that are able to curve the beam trajectory. Thus, created in such a way liquid crystal waveguides enable to control optical signal trajectory both for low intensities (linear propagation) as well as for high intensities regime, thus inducing nonlinear effects related to the interaction of the optical signal with nematic liquid crystal molecules. In both cases, the direction of light beam propagation is determined by the shape of the created waveguide. Such realized structures provide an opportunity to create of reconfigurable optical circuits for all optical signal guiding, switching and routing

Acknowledgment:
Effort sponsored by the National Centre for Research and Development by the grant agreement LIDER/018/309/L-5/13/NCBR/2014.

Reference

1. G. Assanto, Nematicons, Wiley (2012).
2. M. Peccianti and G. Assanto, Phys. Rep. 516, 147 (2012).
3. A. Piccardi, et al., Appl. Phys. B, 104, 5 (2011).
4. U. A. Laudyn and M. A. Karpierz, Appl. Phys. Lett., 103, 221104 (2013).
5. I. Ostromęcka, M. Kwasny, P. Jung, B. W. Klus, U. A. Laudyn, Phot. Lett. Poland, 8, 1 (2016).

Photonic crystal fibers infiltrated with azobenzene liquid crystals

Daniel BUDASZEWSKI, Maciej SMYL, Tomasz R. WOLIŃSKI
Faculty of Physics, Warsaw University of Technology, Koszykowa 75, 00-662 Warszawa, POLAND
e-mail address: danielb@if.pw.edu.pl

In this paper, we investigate spectral properties of photonic crystal fibers (PCFs) partially infiltrated with azobenzene liquid crystals (azo-LC). This group of liquid crystals gives the possibility to design a new class of fiber-optic devices that can be tuned by low-power laser pulses. Due to the high efficiency of photoisomerization process between trans- and cis- states it is possible to optically tune spectral properties of PCF infiltrated with azo-LC. As it was reported [1, 2] trans-cis and cis-trans photoisomerization process of azo-LC molecules can take place with very short times, even below picoseconds.

In case of systems where azo dyes serves as dopant in
a non-photoresponsive host liquid crystals, only a small amount of molecules take part in photoisomerization process [3]. As a result, photoisomerization is not directly responsible for optical properties of such system. The changes observed in such system emerge in a slow process, where LC molecules adapt to the new alignment of dopant.

On the contrary to these systems, all molecules of azobenzene liquid crystals take part in photoisomerization process and as a result, the reorientation of molecules can be achieved in a very short time [4]. Moreover, by illuminating PCF infiltrated with azo-LC with the appropriate wavelength, it is possible to generate a large optical anisotropy of the system.

In our work, preliminary results of PCF infiltrated with azo-LC is reported. A commercially available azo-LC mixture 5721 manufactured by BEAM CO. was used in research. The 5721 azo-LC is a multi-component compound based on a series of 4-n-alkyl-4'-n-alkoxy azobenzenes. The molecules of this mixture can be aligned in cis- or trans- states depending on illumination with UV or blue light.

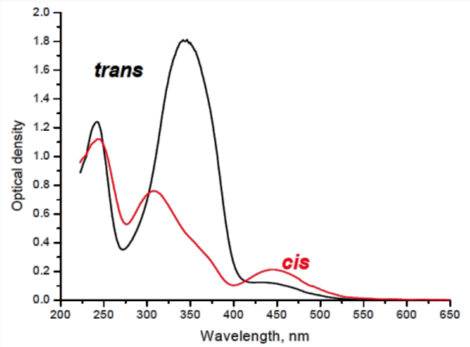

Fig.1. The absorbance spectrum of azo-LC 5721 (BEAM CO) in trans- and cis- forms.

We have infiltrated a single microcapillary and next
LMA-10 PCF (NKT Photonics) with the azo-LC 5721 and investigated its alignment in both hosts materials under the microscope with crossed polarizers. Moreover, an

influence of temperature and an electric field was also studied.

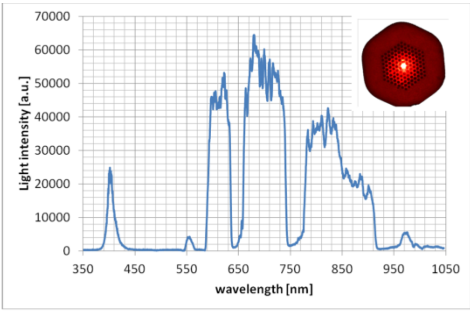

Fig. 2 Halogen lamp spectrum in LMA-10 PCF infiltrated with 5721 azo-LC after illumination with UV light (*cis*-isomerization)

The results indicate that PCFs infiltrated with azo-LCs can act as a new type photo-tunable filters and attenuators.

Reference

1. I. C. Khoo, M. V. Wood, M. Y. Shih, P. H. Chen, "Extremely nonlinear photosensitive liquid crystals for image sensing and sensor protection," Optics Express 4, 431-442 (1999).
2. 9. I. C. Khoo, M. Y. Shin, A. Shishido, "Supra optical nonlinearities of photosensitive nematic liquid crystals," Mol. Cryst. Liq. Cryst. 364, 141-149 (2001).
3. L. Deng, H.-K. Liu, "Nonlinear optical limiting of the azo dye methyl-red doped nematic liquid crystalline films," Opt. Eng. 42, 2936-2941 (2003).
4. J. Si, J. Qiu, J. Guo, M. Wang, K. Hirao, "Photoinduced birefringence of azodye-doped materials by
a femtosecond laser," Appl. Opt., 42, 7170-7173 (2008).

Functional sensing materials based on graft combcopolymers for applications in optoelectronics and microelectronics chemical gas sensors

Erwin MACIAK

Department of Optoelectronics, Silesian University of Technology, 2 Krzywoustego St., 44-100 Gliwice, POLAND

e-mail address: erwin.maciak@polsl.pl

Present work fit into the current development trends of modern micro- and nanoelectronics, which concerns the application of organic materials in the construction of electronic elements and devices.

Obtaining of the dedicated sensing structure is a multi-step process, which is schematically presented in the Fig. 1. The process started from the synthesis of the function groups which are affinitive to the target gas analyte (very effectively interacts with it), what results in the very significant changes in the properties of such material. The changes of its colour, electrical conductivity, thickness, refractive index etc. can be observed. This stage of process undergoes the simulations. The process of the synthesis is strictly controlled. What is more, on this stage aside of the sorption properties, the solubility level of the material is modified. It causes the problems and limits in the reproducible technologies of the production of final microelectronic devices and components. The method of the joining of the active function groups into the structure (chain) of different stable polymer seems to be solution of mentioned problems.

This process is called "grafting" of this matrix polymer. Besides the function groups, some addition groups which improves hydrophobicity or film-formation properties are usually grafted to the core chain. On this stage the well-defined functional sensing material, which can be built into optimal opto(electro)chemical transducer (sensing structure), is obtained. In this way we will obtain the new class of the effective sensing structure which can be applied in chemical gas sensors with high sensitivity and selectivity [1-3]. Off course in every single stage of the process the feedback in the form of multi-parameter nanocharacterization and nanoindentation is necessary.

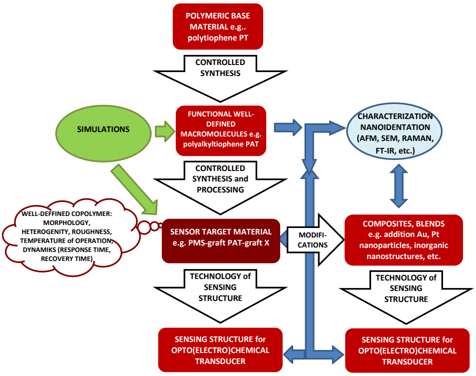

Fig. 1. Scheme of the process of the obtaining of sensing structures with adjustable properties.

This work presents an investigation on innovative graft comb copolymer of polymethylsiloxane (PMS) with phthalocyanine (Pc) side group and polymethylsiloxane (PMS) with poly(3-hexylotiophene) (P3HT) and poly(ethylene) glycol (PEG) as functional side groups. Those segmented copolymers were investigated as gas sensing materials in various sensor configurations. Gas sensing, optical and electrical properties of thin films of graft polymers are tested and compared.

Acknowledgements
Syntheses of graft combcopolymer material was performed with the support from the Foundation for Polish Science grant POMOST 2011-3/8. This work is partially financed within Grant no. BKM/563/Re4/2016.

Reference

1. Kamil Staszek, Artur Rydosz, Erwin Maciak, et al., Sensors and Actuators B, 245, 882 (2017).
2. Erwin Maciak, Marcin Procek, et al., Thin Solid Films 618, Part B, 277 (2016).
3. Artur Rydosz, Erwin Maciak, et al., Sensors and Actuators B, 237, 876 (2016).

Next generation distributed sensing systems based on microstructured optical fibers

Łukasz Szoszkiewicz[1,2] , Anna Pytel[1,2,] Agnieszka Kołakowska[1,2,] Michalina Jóźwik[1,2,]
Tomasz NASIŁOWSKI[1]

1 InPhoTech Sp. z o. o., 17 Slominskiego St 31, Warsaw, 00-195, Poland
2 Faculty of Physics, Warsaw University of Technology, Warsaw 00-662, Poland'
e-mail address: ppisiewicz@inphotech.pl

Fiber optics distributed sensors now offer great detection range[1], high spatial resolution[2] and almost instant response[3]. On the other hand every sensor based on Brillouin Frequency Shift (BFS) detects only strain and temperature over the fiber length. It is mainly caused by the fact that the ITU G.652 compliant single mode fiber which is, due to its low volume price and availability, examined toughly in terms of Brillouin Gain Spectra dependence to abovementioned quantities. However recent advancements in microstructured fibers allow to utilize more sophisticated distributed sensing techniques like C-OTDR, which combined with birefringent fibers allow to perform distributed pressure sensing. During presentation we will discuss feasibility of specialty fibers in terms of their usability to the next generation distributed sensors.

Reference

[1] Marcelo A. Soto, Gabriele Bolognini, and Fabrizio Di Pasquale, "Optimization of long-range BOTDA sensors with high resolution using first-order bi-directional Raman amplification," Opt. Express 19, 4444-4457 (2011)

[2] Tom Sperber, Avishay Eyal, Moshe Tur, and Luc Thévenaz, "High spatial resolution distributed sensing in optical fibers by Brillouin gain-profile tracing," Opt. Express 18, 8671-8679 (2010)

[3] Javier Urricelqui, Ander Zornoza, Mikel Sagues, and Alayn Loayssa, "Dynamic BOTDA measurements based on Brillouin phase-shift and RF demodulation," Opt. Express20, 26942-26949 (2012)

Fiber optic shape sensor based on multicore fiber technology and Brillouin scattering effect

Anna PYTEL[1,2], Agnieszka KOŁAKOWSKA[1,2,] Michalina JÓŹWIK[1,2], Łukasz SZOSZKIEWICZ[1,2,] Zhisheng YANG[3], Michał MURAWSKI[4], Marek NAPIERAŁA[1], Luc THÉVENAZ[3], Paweł MERGO[5], Tomasz NASIŁOWSKI[1]

[1] InPhoTech Sp. z o. o., 17 Slominskiego St 31, Warsaw, 00-195, Poland
[2] Faculty of Physics, Warsaw University of Technology, Warsaw 00-662, Poland
[3] EPFL Swiss Federal Institute of Technology, Institute of Electrical Engineering, SCI STI LT, Station 11, CH-1015 Lausanne, Switzerland
[4] Polish Centre For Photonics And Fibre Optics, 312 Rogoznica, 36-060 Glogow Malopolski, Poland
[5] Laboratory of Optical Fibers Technology, Faculty of Chemistry, Maria Curie-Sklodowska University, Maria Curie-Sklodowska Sq. 5, 20-031 Lublin, Poland
e-mail address: ppisiewicz@inphotech.pl

The subject of performing shape measurements attracts a lot of interest in the past few years [1,2] due to its possible application in medical engineering as well as in robotics and civil engineering. Shape sensing is a measurement the deformation of a structure is monitored, e.g. a flexible arm, where the exact bend radius, its location and orientation must be evaluated all along the structure. Experts have proposed a design of a shape sensor which takes advantage of the effect of Brillouin scattering in multicore fibers [3]. The Brillouin frequency shift (BFS) which is strain dependent allows distinguishing the amount of strain in each core separately, thus enabling to evaluate the differential strain in the fiber transverse section due to bending and to eventually extract the shape information. The location of the bending is identified thanks to the BOTDA distributed measuring technique, which is an optical-time domain method. The theoretical analysis of the design and experimental results of the distributed fiber optic shape senor based on the multicore fiber are reported.

Reference

[1] Roger G. Duncan ; Mark E. Froggatt ; Stephen T. Kreger ; Ryan J. Seeley ; Dawn K. Gifford ; Alexander K. Sang ; Matthew S. Wolfe; High-accuracy fiber-optic shape sensing. Proc. SPIE 6530, Sensor Systems and Networks: Phenomena, Technology, and Applications for NDE and Health Monitoring 2007, 65301S (2007).
[2] J. P. Moore and M. D. Rogge, "Shape sensing using multi-core fiber optic cable and parametric curve solutions," Opt. Express 20(3), 2967–2973 (2012).
[3] Z. Zhao, M. A. Soto, M. Tang, and L. Thévenaz, "Distributed shape sensing using Brillouin scattering in multi-core fibers," Optics Express 24, 25211-25223 (2016).

Radiation effects in distributed optical fiber sensors

Michalina JÓŹWIK[1,2], Marta FILIPOWICZ[1], Tomasz NASIŁOWSKI[1]
[1] InPhoTech Sp. z o. o., 17 Slominskiego St 31, Warsaw, 00-195, Poland
[2] Faculty of Physics, Warsaw University of Technology, Warsaw 00-662, Poland
e-mail address: ppisiewicz@inphotech.pl

Optical fibers can be successfully used in the field of distributed sensing [1]. Changes of such parameters like temperature, strain, humidity, strain etc. have direct impact on the optical wave propagating in the fiber [2]. Due to the linearity of the fiber geometry, system can determine the value of the measured parameter at any point along the length of the sensor, replacing thousands of point sensors. Fiber-optic distributed sensors can work in almost any environment – even where, for example, temperature is very high and there is no possibility of placing electronic sensors. Moreover optical fibers have the potential of application in places where there is a significant radiation. It is important that in the presence of radiation a time dependent increase of loss in the core is involved due to the effect called radiation induced attenuation (RIA). Taking this into account, there is a possibility to design a fiber for distributed sensing which is resistant to radiation. It can be realized by appropriate fiber doping which reduces RIA effect. Optimization of the core composition gives possibility to prevent the increase of loss in the optical fiber and furtherly increase the range and reliability of distributed fiber sensor in harsh nuclear environment.

Reference

[1] Bao, Xiaoyi, and Liang Chen. "Recent progress in distributed fiber optic sensors." Sensors 12.7 (2012): 8601-8639.
[2] Thévenaz, Luc. "Review and progress on distributed fibre sensing." Optical Fiber Sensors. Optical Society of America, 2006.

Recent developments in gas sensing using laser-based dispersion spectroscopy

Michał NIKODEM

Laser Sensing Laboratory, Wroclaw Research Centre EIT+, Stabłowicka 147, 54-066 Wrocław, POLAND

e-mail address: michal.nikodem@eitplus.pl

Laser technology became a very useful tool in non-invasive chemical sensing, and plays an important role in various applications, such as industrial monitoring and emission control, environmental sensing, or exhaled breath analysis for medical diagnostics. Methods typically used for sensitive and selective laser-based molecular spectroscopy include direct laser absorption spectroscopy [1], wavelength modulation spectroscopy [2], photoacoustic spectroscopy [3], cavity ring-down spectroscopy [4] or integrated cavity output spectroscopy [5]. All of them target absorption fingerprints of selected molecules located in mid-infrared, near-infrared, THz or UV spectral regions. In 2010 a new technique for trace gas detection was introduced: chirped laser dispersion spectroscopy, CLaDS [6]. In contrast to typically used methods, in CLaDS analyte concentration is retrieved through measurement of optical dispersion, not absorption.

In CLaDS optical waves separated in frequency by Ω propagate through the gas sample and are focused onto square-law photodetector where they produce a heterodyne beatnote. Phase of this beatnote is affected by the molecular dispersion which is proportional to the target molecule concentration. When these optical waves are frequency chirped across the molecular transition signal encoded in phase domain can be conveniently detected as frequency modulation of the carrier Ω (which is additionally enhanced by the factor proportional to the chirp rate) [6]. The biggest advantage of CLaDS is its immunity to amplitude noise and transmission fluctuations. Because spectroscopic information is encoded in frequency of the beatnote (not in its amplitude) signal in CLaDS does not require any power normalization even when significant optical power fluctuations are present [7, 8]. This makes it particularly suitable for open-path sensing [9]. CLaDS and its derivatives also enable new capabilities in gas spectroscopy, such as extended dynamic range of concentration measurements [10], or capability of direct processing of spectroscopic signals in optical domain [11].

During my talk a molecular dispersion spectroscopy for laser-based gas sensing will be presented. Current state of the art and an overview of recently developed CLaDS configurations will be demonstrated. I will present several experimental configurations based on near-infrared laser diodes and mid-infrared quantum cascade lasers. Strategies towards compact, integrated, robust and field deployable CLaDS-based sensing instrumentation will be discussed.

Reference

1. B. McManus, M. S. Zahniser, J. D. D. Nelson, J. H. Shorter, S. Herndon, E. Wood, and R. Wehr, Opt. Eng. 49, 111124-111111 (2010).
2. G. B. Rieker, J. B. Jeffries, and R. K. Hanson, Appl. Opt. 48, 5546-5560 (2009).
3. A. A. Kosterev, Y. A. Bakhirkin, and F. K. Tittel, Appl. Phys. B 80, 133-138 (2005).
4. T. Stacewicz, J. Wojtas, Z. Bielecki, M. Nowakowski, J. Mikołajczyk, R. Mędrzycki, B. Rutecka, Opto-Electron. Rev. 20, 53-60 (2012).
5. M. R. McCurdy, Y. A. Bakhirkin, and F. K. Tittel, Applied Physics B 85, 445-452 (2006).
6. G. Wysocki, and D. Weidmann, Opt. Express 18, 26123-26140 (2010).
7. M. Nikodem, G. Wysocki, Sensors 12, 16466-16481 (2012).
8. M. Nikodem, G. Plant, D. Sonnenfroh, G. Wysocki, Applied Physics B 119, 3-9 (2015).
9. G. Plant, M. Nikodem, P. Mulhall, R. Varner, D. Sonnenfroh, G. Wysocki, Sensors 15, 21315-21326 (2015)
10. M. Nikodem, G. Wysocki, Optics Letters 38, 3834-3837 (2013).
11. M. Nikodem, G. Wysocki, IEEE Journal of Selected Topics in Quantum Electronics 23, Article 9000405 (2017).

.

Brillouin distributed sensing in birefringent optical fibers

Agnieszka KOŁAKOWSKA[1,2] Anna PYTEL[1,2], Michalina JÓŹWIK[1,2], Łukasz SZOSZKIEWICZ[1,2], Zhisheng YANG[3], Michał MURAWSKI[4], Marek NAPIERAŁA[1], Luc THÉVENAZ[3], Paweł MERGO[5], Tomasz NASIŁOWSKI[1]

[1] InPhoTech Sp. z o. o., 17 Slominskiego St 31, Warsaw, 00-195, Poland
[2] Faculty of Physics, Warsaw University of Technology, Warsaw 00-662, Poland
[3] EPFL Swiss Federal Institute of Technology, Institute of Electrical Engineering, SCI STI LT, Station 11, CH-1015 Lausanne, Switzerland
[4] Polish Centre For Photonics And Fibre Optics, 312 Rogoznica, 36-060 Glogow Malopolski, Poland
[5] Laboratory of Optical Fibers Technology, Faculty of Chemistry, Maria Curie-Sklodowska University, Maria Curie-Sklodowska Sq. 5, 20-031 Lublin, Poland
e-mail address: ppisiewicz@inphotech.pl

Distributed fiber optic sensors have been intensively studied and reported in scientific literature [1], [2], due to the fact that among advantages, such as immunity to electromagnetic fields and resistance to hazardous chemicals, the whole fiber length is a sensing element in distributed sensing along which events can be localized. The working principle of this kind of sensors is based on the measurement of scattered light due to Rayleigh, Raman or Brillouin scatterings. The most attractive sensing method is probably the one based on Brillouin scattering, where the Brillouin peak gain frequency is shifted under temperature and strain changes.

The Brillouin response of the fiber can be measured using Brillouin Optical Time Domain Analysis (BOTDA). Depending on the spatial resolution and the fiber length this process can be quite time-consuming. In standard single mode fibers, typically used in Brillouin distributed sensing, due to the random state of polarization, one the measurements must be performed successively using two polarization states, consequently increasing the measurement time significantly [3,4]. It turns out that the implementation of birefringent optical fibers as sensing element enable two times faster measurements in BOTDA systems.

In this paper we present results of the microstructured highly birefringent fiber examined with Brillouin Optical Time Domain Analysis.

Reference

[1] A. Motil, A. Bergman, and M. Tur, "State of the art of Brillouin fiber-optic distributed sensing," Opt. Laser Technol., vol. 78, pp. 81–103, Apr. 2016.

[2] L. Thévenaz, "Brillouin distributed time-domain sensing in optical fibers: state of the art and perspectives," Front. Optoelectron. China, vol. 3, no. 1, pp. 13–21, Mar. 2010.

[3] M. O. van Deventer and A. J. Boot, "Polarization properties of stimulated Brillouin scattering in single-mode fibers," Journal of Lightwave Technology 12, 585-590 (1994).

[4] S. Diaz, S. Mafang-Foaleng, M. Lopez-Amo, and L. Thevenaz, "A High-Performance Optical Time-Domain

Brillouin Distributed Fiber Sensor," IEEE Sensors Journal 8, 1268-1272 (2008).

Application of graft comb copolymers of poly(3-hexylthiophene) as a receptor materials for gas

Marcin PROCEK[1*], Agnieszka STOLARCZYK[2], Erwin MACIAK[1]

[1]Department of Optoelectronics, Silesian University of Technology, 2 Krzywoustego St., 44-100 Gliwice, POLAND
[2]Department of Physical Chemistry and Technology of Polymers, Silesian University of Technology, 9 Strzody St., 44-100 Gliwice, POLAND;
e-mail address: Marcin.Procek@polsl.pl

Conducting and semiconducting polymer materials are increasingly using as a gas sensing structures. Most popular conducting polymers are polypyrrole, polyaniline and polythiophene (PT). Due to poor processability of the PT more popular and wide used are its derivates such as poly alkylthiophenes (PAT) including poly(3-hexylothiophene) (P3HT) [1,2].PTs and P3HT can be a p-type (doped via oxidation) wide-gap semiconductor. It could have regio-regular (rr) and random-regular (nr) structure [1-4]. The rr P3HT are very attractive due to its high chemical stability and good electrical properties. Unfortunately it have poor mechanical properties and week adhesion to the surfaces. One of the methods of its functionalization and improving of properties of such materials is a grafting method [1-4].

In this work a thin films of the novel comb copolymers of rr-P3HT grafted on the poly methylsiloxane chains are investigated as a gas sensing structure. The changes of their electrical and optical properties due to reaction with gases shows huge potential to apply them as a gas receptors in chemical sensors. The resistance changes of grafted P3HTs and standard rr-P3HT and nr-P3HT indicated by small concentrations of NO2 at relatively low temperature (50˚C) are compared. Method of applying of a thin film of the polymers on the transducers and investigations of its morphology (AFM) and chemical composition are presented. The mechanism of the interaction of NO2 and tested materials are discussed. Temperature and UV radiation impact of the polymers are also mentioned in this work.

Aknowledgements:
Syntheses of combcopolymer material was performed with the support from the Foundation for Polish Science grant POMOST 2011-3/8. This work is partially financed by the Polish National Science Centre (NCN) within Grant no. 2012/ 07/B/ST7/01 471.

Reference

1. E. Maciak, M. Procek, K. Kepska, A. Stolarczyk, Thin Solid Films 618B, 277–285 (2016).
2. R. S. Dudhe, J. Sinha, D.S. Sutar, A. Kumar, V. R. Rao Sensors and Actuators A: Physical 171, 12-18 (2011).
3. M. Procek, E. Maciak, A. Stolarczyk, T. Pustelny, Frontiers in Optics 2015 OSA Technical Digest (online) (Optical Society of

America, 2015), paper FM3B.3, doi:10.1364/FIO.2015.

4. A.Stolarczyk, R. Turczyn, A. Januszkiewicz-Kaleniak, K. Kepska, Polish patent application no. P.407784 RR10.

A study of MIR photoluminescence from Pr3+ doped chalcogenide fibers pumped at near-infrared wavelengths

S. SUJECKI[1,2], L. SOJKA[1], E. BERES-PAWLIK[1], R. PIRAMIDOWICZ[3], H. SAKR[2], Z. TANG[2], E. BARNEY[2], D. FURNISS[2], T.M. BENSON[2], A.B. SEDDON[2]

[1]Department of Telecommunications and Teleinformatics, Faculty of Electronics, Wroclaw University of Science and Technology, Wyb. Wyspianskiego 27, 50-370 Wroclaw, Poland
[2]George Green Institute for Electromagnetics Research, The University of Nottingham, University Park, NG7-2RD, Nottingham, UK
[3]Institute of Microelectronics and Optoelectronics, Warsaw University of Technology Nowowiejska 15/19, 00-665 Warsaw, Poland

e-mail address: Slawomir.Sujecki@pwr.edu.p

Mid infrared (MIR) light chalcogenide fiber based photoluminescence sources find increasingly many applications in the sensor technology. So far dysprosium and praseodymium doped sulfide chalcogenide glass based sources were used for gas [1] and water pollutant [2] sensing. In this contribution we explore the luminescence properties of selenide-chalcogenide glass fibers doped with praseodymium ions for potential application as MIR spontaneous emission sources for MIR light based sensors. For pumping purposes we consider an application of near infrared laser diodes, which are robust, reliable and low cost. For the purpose of this study we fabricated several samples of selenide-chalcogenide glass doped with praseodymium ions and performed absorption and photoluminescence spectrum measurements. From the experimental results using the standard procedures we extracted the relevant modelling parameters.

The population inversion in Pr3+ ion doped selenide-chalcogenide glass can be studied using a rate equations model [3]. Here we considered 4-level system corresponding to the pump wavelength of approximately 1.5 μm.

Figure 1 shows the energy level diagram relevant for praseodymium ions when a near-infrared pump operating around 1.5 μm is used to populate the higher energy levels. Due to a fairly small energy gap when compared with the maximum phonon energy of the chalcogenide-selenide glass host the level 4 is depopulated mainly non-radiatively.

Figure 2 shows the dependence of the relevant level populations on the pump intensity for the considered 4 level system. The pump wavelength was set at the 1480 nm. The signal wavelengths were set to 3700 nm and 4890 nm. The assumed luminescence life time of level 3 is 4 ms while for the level 2 is 12 ms. The multiphonon transition lifetime for the levels 4, 3 and 2 is 5 μs, 9 ms and 9 ms, respectively. Fig.1 shows that a significant inversion of the level 3 and 2 populations with respect to the ground state is achieved for pump intensity exceeding 1 MW/m2. It can be also observed that due to fairly high multiphonon transition rate level 4 is nearly empty.

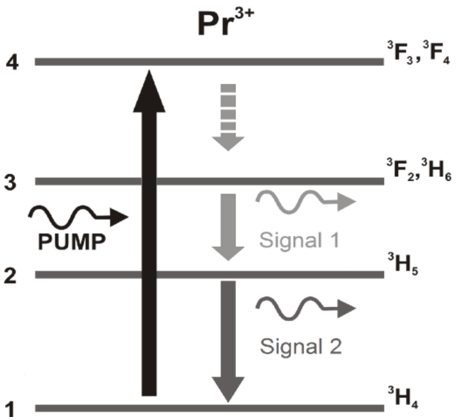

Fig. 1. Energy level diagram.

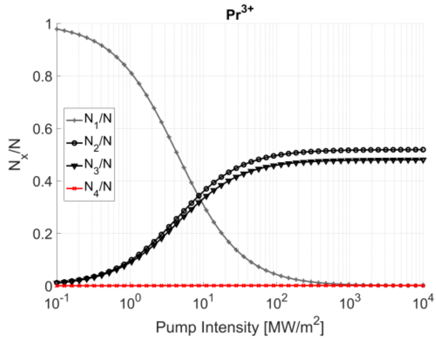

Fig. 2. Dependence of level populations on the pump intensity at pump wavelength of 1480 nm.

Reference

1. F. Starecki et al., Sensors and Actuators B: Chemical 207 518-525 (2015).
2. R. Chahal et al., Sensors and Actuators B: Chemical 229 209-216 (2016).
3. S. Sujecki et al., Optical and Quantum Electronics 42 69-79 (2010).

Non-invasive assessment of thromboembolism in rotary blood pumps

Maciej GAWLIKOWSKI, Maciej GŁOWACKI, Roman KUSTOSZ, Paweł PYDZIŃSKI
Foundation of Cardiac Surgery Development, Wolnosci 345a, 41-8000 Zabrze, POLAND
e-mail address: mgawlik@frk.pl

Background: Mechanical circulatory support by means of ventricular assist device (VAD) is routine treatment of serious heart failure. Nowadays the most widely used VADs are implantable rotary blood pumps (RBP) – axial (HeartMate II/Thoratec – ap. 20.000 cases) and centrifugal one (HVAD/HeartWare Inc. – ap. 12.000 cases and HeartMate III/Thoratec – the latest device, still in clinical trials).

Due to the contact of biomaterial (titanium alloy covered by TiN layer) with blood and non-physiological shear stress the coagulation system is activated. In spite of anticoagulation and antiplatelet therapy in some cases it leads to growth of larger embolus and – in consequence – to serious complication like ischemic stroke or even death. Therefore one of the challenges facing mechanical circulatory support is to put into routinely use effective and non-invasive methods of early thromboembolism detection in RBS systems.

Goal: the goal of our work was to assess the practical suitability of selected measurements to predication the risk of RBP embolization.

Material and methods: our studies have been carried out based on clinical and technical data collected from patients treated by RBP (HVAD and HeartMate II) in three hospitals in Poland. No agreement of Ethical Committee was needed.

We analyzed following data: long-term (30 days) trends of electrical power consumption by motor of the pump, acoustic signal produced by the pump collected during patients' physical examination by means of electronic stethoscope, clinical symptoms of embolization like lactate dehydrogenase (LDH) level, plasma-free hemoglobin concentration (fHB) and urine coloration (which indicates degree of blood hemolysis) as well as echocardiographic examination.

HVAD system allows technical data registration (pump speed, power, estimated flow) every 15 minutes. Based on this data we build the power trend.

For acoustic physical examination we used Littmann 3200 electronic stethoscope (with built-in ambient noise reduction and cut-off frequency 4kHz). We calculated FFT of this signal before pump embolization (reference examination during routinely patients' control visit), during embolization and after thrombus lysis by means of heparin and/or tissue plasminogen activator (tPA).

Results: totally we found and analyzed 5 cases of pumps embolization (4 cases of HVAD and 1 case of HeartMate II). The power trend of patient with high LDH (2100U/l) and brown-colored urine (typical symptoms of hemolysis resulting from blood flow disturbances caused by thromboembolic material adhered to the pump) has been presented in Fig.1. The gradual and sudden power spike recognized as pump embolization has been labeled as 1. The inadequate thrombolytic treatment by administer of heparin has been labeled as 2. Next sudden clot growth and thrombolytic treatment by tPA administer has been labeled as 3. Back to the normal power value after tPA treatment has been labeled as 4. The spectrum of acoustic signal from physical examination has been presented in Fig. 2. Comparing with reference (before embolization) we found 2nd and 3rd harmonics in signal collected during sudden power spike labeled at 3 in Fig. 1.

Similar examinations have been carried out for HeartMate II system. Due to poor access to technical data (especially power trend) and different construction of the pump, obtained results were no specific.

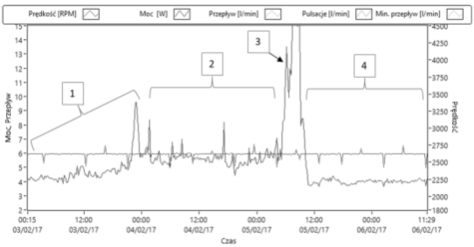

Fig. 1. Power trends during pump embolization and thrombolytic treatment (description provided in the text)

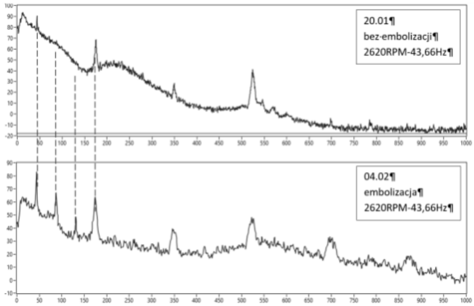

Fig. 2. Acoustic spectrum before and during embolization

Conclusions: power trends analysis gives information about pump embolization after incident occurrence. Acoustic analysis of pump operation prospectively allows earlier detection of clots growth, however specificity and sensitivity of this method has to be confirmed in more complex examinations which takes into account specific construction of various RBP.

It is recommended to introduce remote monitoring of RBP systems in order to make currently analysis of technical data and detect rising trend of power before power spike will appear.

Acknowledgements: this work has been supported by NCBiR (grant no. RH-ROT/266798/STRATEGMED-II)

Technique of accuracy measurement of membrane shape mapping of the artificial ventricle

Wojciech SULEJ, Leszek GRAD, Krzysztof MURAWSKI
Institute of Teleinformatics and Automatics, Military University of Technology, Kaliskiego 2, 01-489 Warsaw, POLAND
e-mail address: krzysztof.murawski@wat.edu.pl

The paper the research results which are a continuation of work on the use of image processing techniques to determine of the membrane shape of the artificial ventricle were presented. The studies focused on developing
a technique for measuring the accuracy of the shape mapping. It is important in view of ensuring the required accuracy of determining the instantaneous stroke volume controlled pneumatic artificial ventricular. Experiments were carried out on the model of the pump membrane developed within the Polish Artificial Heart Program.

The purpose of the research was to obtain a numerical indicator, which will be used to analyze the options to improve mapping techniques shape of the membrane.

Wireless programmable optical sensor to protect the works of art

Krzysztof MURAWSKI[1], Monika MURAWSKA[2]

[1] Institute of Teleinformatics and Automatics,
[2] Institute of Organization and Management,
Military University of Technology, Kaliskiego 2, 01-489 Warsaw, POLAND
e-mail address: krzysztof.murawski@wat.edu.pl

In the paper we present the wireless programmable non-contact optical sensor to protect the works of art. Sensor detects the danger situations by analyzing the variability of the image of work of art registered by miniature camera.

Method of laser beam coding for control the system of augmented reality

Tomasz PAŁYS[1], Artur ARCIUCH[1], Andrzej WALCZAK[2], Krzysztof MURAWSKI[1]

[1] Institute of Teleinformatics and Automatics, [2] Institute of Information Systems, Military University of Technology, Kaliskiego 2, 01-489 Warsaw, POLAND

e-mail address: krzysztof.murawski@wat.edu.pl

The article presents the method of encoding a laser beam for control the system of augmented reality.
The experiments were performed using a red laser emitting a wavelength of L = 640 nm and a power of P = 5 mW. The aim of the study was to develop the methods of modulation and demodulation of the laser beam. In the paper is also shown the result of research in which we determined the effect of selected camera parameters, such as image resolution, number of frames per second on the result of demodulation of optical signal. The results showed that the adopted coding method provides sufficient information encoded in a single laser beam (not less than 36 codes with the efficiency of decoding at 99.9%).

Research of using wavelet transform to improve the accuracy of determining the stroke volume of artificial ventricle

Leszek GRAD, Wojciech SULEJ, Krzysztof MURAWSKI

Institute of Teleinformatics and Automatics, Military University of Technology, Kaliskiego 2, 01-489 Warsaw, POLAND

e-mail address: krzysztof.murawski@wat.edu.pl

In the article we were presented results obtained during research, which are the continuation of work on the use of artificial neural networks to determine the relationship between real view of membrane and the stroke volume of the blood chamber of the mechanical prosthetic heart. The purpose of the research was to increase the accuracy of determination the volume of the blood chamber. Therefore, the study were focused on the technique of the features extraction from the image. During research we used the wavelet transform. Received results we compared to the results obtained previously by other methods. Tests were conducted on the same model of mechanical prosthetic heart, which have been used in previous experiments.

Long-period grating biosensor for detection of very low DNA concentration

Karolina H. CZARNECKA[1,2,] Magdalena DOMINIK[1,] Marta JANCZUK-RICHTER[3],
Joanna NIEDZIÓŁKA-JÖNSSON[3], Ewa ROŹNIECKA[3], and Mateusz ŚMIETANA[1]

[1] Institute of Microelectronics and Optoelectronics, Warsaw University of Technology, Koszykowa 75, 00-662 Warszawa, Poland;

[2] Department of Molecular Bases of Medicine, Medical University of Lodz, Pomorska 251, 92-213 Lodz, Poland;

[3] Institute of Physical Chemistry, Polish Academy of Sciences, Kasprzaka 44/52, 01-224 Warszawa, Poland;

e-mail address: Karolina.czarnecka@umed.lodz.pl

In molecular biology and analytics the detection of nucleic acids with expected DNA sequences, i.e., detection of viral DNA, DNA from cancer cells or pathologically changed tissues, especially recognition of mutated or altered DNA sequences requires the amplifying and/or labeling stage and lastly specific laboratory equipment. Optical fiber sensors with long-period gratings (LPGs) can be used in label-free model of different size molecules detection f.ex.: nucleic acids, specific bacteria, proteins or antigens [1-4]. The periodic modulation of LPG (inducing coupling of the core mode with a series of cladding modes) enables observation of DNA binding to fiber surface by monitoring the kinetics of reactions taking places on the sensor's surface [5]. Thanks to interactions between the cladding modes and the external medium, the LPGs are sensitive to variations in surrounding refractive index (RI) or formation of thin, high-RI overlay on its surface.

In this study we present an application of LPG sensors working near the dispersion turning point (DTP) for detection of very low concentrations of DNA ligands. LPG sensors were manufactured using germanium-doped Corning SMF-28 single-mode optical fiber and UV-irradiated with 226.8 µm period amplitude mask. In order to achieve DTP and enhanced the RI sensitivity LPGs were etched in hydrofluoric acid [6]. The optical transmission of the LPG in the range of λ=1100-1700 nm was monitored using a supercontinuum white light laser source (Leukos SM30) and spectrum analyzer (Yokogawa AQ6370B). All the measurements were conducted under constant tension and in stable ambient temperature (T = 25°C). In order to functionalize the fiber surface LPG underwent silanization process, incubation in probe solution (EDC-activated DNA oligonucleotide in PBS) and 3 turns of ligand hybridization in increasing concentration (DNA sequences binding specifically to the DNA probe). After every step the steps fiber was immersed/stabilized in PBS and changes in external spectral response were monitored.

We have demonstrated that LPG optic sensor functionalized with a DNA probe can detect hybridization of nucleic acids to the LPG surface. The resonance wavelength shift observed after binding the probe layer was 1.8 nm. Specific DNA were hybridized to DNA-coated LPG in concentrations: 0.1 pM, 1 pM, 10 pM, causing the resonance wavelength shifts 0.2 nm; 1.4nm and 1.6 nm, respectively.

The biofunctionalization process allowed capture of specific DNA oligonucleotides in concentration dependent manner. We have proved that LPG can be successfully applied for label free detection of DNA molecules in very low concentration – f.ex. nucleic acids in range 0.1 - 1 pM.

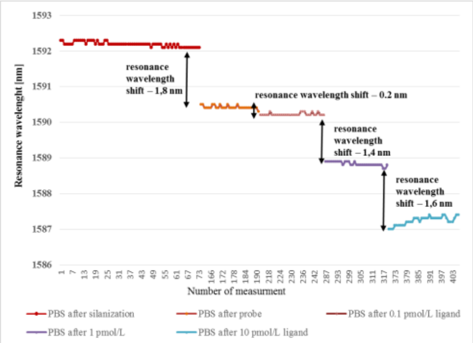

Fig. 1. Evolution of resonance the wavelength during each step of the biofunctionalization process, where: PBS – PBS after each step, probe – DNA ctivation step, specific DNA with concentrations: 0.1 pM, 1 pM, 10 pM.

Acknowledgements:

This work was supported by the Polish National Science Centre (NCN) under the Grant No.2014/13/B/ST7/01742.

Reference

[1] Chen, X., Zhang, L., Zhou, K., Davies, E., Sugden, K., Bennion, I., Hughes, M. and Hine, A., "Real-time detection of DNA interactions with long-period fiber-grating-based biosensor," Opt. Lett. 32(17), 2541-2543 (2007).

[2] Tian, Y., Wang, W., Wu, N., Zou, X. and Wang, X., "Tapered optical fiber sensor for label-free detection of biomolecules," Sensors 11(4), 3780–3790 (2011).

[3] Jensen, J., Pedersen, L., Hoiby, P., Nielsen, L., Hansen, T., Folkenberg, J., Riishede, J., Noordegraaf, D., Nielsen, K., Carlsen, A. and Bjarklev, A., "Photonic crystal fiber based evanescent-wave sensor for detection of biomolecules in aqueous solutions," Opt. Lett. 29(17), 1974-1976 (2004).

[4] Kim, D. W., Zhang, Y., Cooper, K. L. and Wang, A., "Fibre-optic interferometric immuno-sensor using long period grating," Electron. Lett. 42(6), 324 (2006).

[5] Chen, X., Liu, C., Hughes, M.D., Nagel, D.A., Hine, A.V. and Zhang, L., "EDCMediated Oligonucleotide Immobilization on a Long Period Grating Optical Biosensor," J. Biosens. Bioelectron. 6, 173 (2015).

[6] Śmietana, M., Koba, M., Mikulic, P. and Bock, W.J., "Towards refractive index sensitivity of long-period gratings at level of tens of µm per refractive index unit: fiber cladding etching and nano-coating deposition," Opt. Express 24(11), 11897-11904 (2016).

Self-organization of light in media with competing nonlocal nonlinearities

F. MAUCHER, T. POHL, S. SKUPIN, Wiesław KROLIKOWSKI
Texas A&M University at Qatar
e-mail address: wzk111@gmail.com

We study light propagation in media with competing nonlocal nonlinearities.We demonstrate that such system can give rise to self-organization of light into stable states of trains or hexagonal arrays of light filaments, depending on the transverse dimensionality. This long-range ordering can take place in mere unidirectional propagation of light. We discuss the dynamics of long-range ordering and the crucial role which phase plays for this phenomenon. Furthermore we discuss how transverse dimensionality affects the order of the phase-transition.

Cross spectral, active and passive approach to face recognition for improved performance

Artur GRUDZIEŃ, Marcin KOWALSKI, Mieczysław SZUSTAKOWSKI
Institute of Optoelectronics, Military University of Technology, Gen. S. Kaliskiego 2, 00-908 Warsaw, POLAND
e-mail address: marcin.kowalski@wat.edu.pl

Biometrics refers to metrics related to human characteristics. Biometric identifiers are the distinctive, measurable characteristics used to label and describe individuals. One of the identifiers is face. Face recognition in visible range of light is a very active area of research and is widely applied [1]. Thermal infrared imagery seems to be a promising alternative or complement to visible range imaging due to its relatively high resistance to illumination changes.

Despite its advantages this modality has some limitations including that it is opaque to glass. Since infrared and visible imagery capture different types of characteristics of the observed faces we would like to focus on utilizing complimentary information present in the two spectra.

Thermal-to-thermal and thermal-to-visible face recognition are the two possible schemes of utilizing spectral properties of face [2]. Both types of biometric modalities are very challenging, because of the initial difference between imaging in the thermal and visible spectrums.

Imaging in visible light spectrum relies on the fact that the objects are illuminated. Illumination may come from the sun light or other light source. Long-wavelength infrared (LWIR) and mid-wavelength infrared (MWIR) sensor acquires the radiation emitted by the body, while visible range imaging is reflection dominated, acquiring light reflected from the surface of the face. Sensors operating in MWIR and LWIR do not require illumination to acquire image [3]. These specific properties of MWIR and LWIR sensors may be efficiently utilized for face recognition.

Thermal imaging has potential for low-light or night-time acquisition of facial images. Emission dominated, passive imaging does not require additional illuminator and is independent from illumination non-uniformities. It also helps to perform the liveness detection of the scanned person. The face image captured in infrared range is always monochrome and presents the distribution of values of temperature on the surface of the face [4].

We present our investigations on both thermal-to-thermal and thermal-to-visible face recognition as methods for performance improvement of identity verification systems. We propose a method for automatic face recognition in IR images, a preprocessing algorithm for detecting facial elements, and show the applicability of commonly used face recognition methods in the visible light domain We propose a cross-spectral face recognition scheme where different facial features are extracted for verification purposes.

Examples of complementary images of faces in two different as well as the same spectrums are presented in Fig. 1 and Fig. 2 respectively.

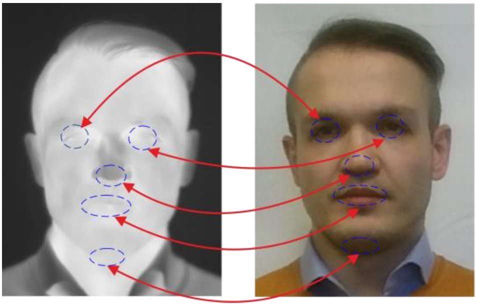

Fig. 1. Cross-spectral face recognition. Images in two different parts of spectrum and corresponding face features, (a) thermal infrared image, (b) visible image.

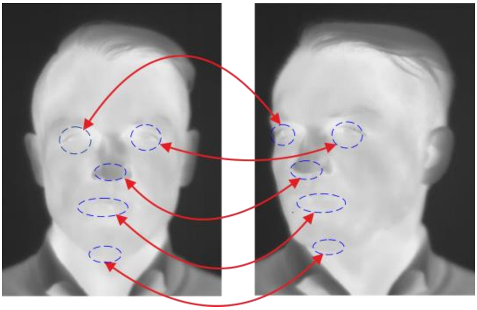

Fig. 2. Uni-modal, infrared-to-infrared face recognition. Images of the same spectrum and corresponding face features.

Recognition or 1:1 verification of faces requires to extract facial features before the matching process. We present two various approaches for extraction of feature points in two presented spectrums.

Acknowledgements:

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 700259.

Reference

1. M. Turk, A. Pentland, J. Cog. Neuroscience, 3 (1), (1991).
2. R. Chellappa, C. Wilson, and S. Sirohev, Proc. of IEEE, 83 (1995).
3. B. Moghaddam, A. Pentland, IEEE Pattern Analysis and Machine Intell., 19(7), (1997).
4. D. Reisfeld, Y. Yeshurun, Com. Vis. and Im. Underst., 71 (3), (1998).

Optoelectronic technologies for Virtual Reality systems

Marek PISZCZEK, Marcin MACIEJEWSKI, Mateusz POMIANEK, Mieczysław SZUSTAKOWSKI
Institute of Optoelectronics, Military University of Technology
2 S. Kaliski St., 00-908 Warsaw, POLAND
e-mail address: marek.piszczek@wat.edu.pl

Virtual reality is most commonly associated with entertainment industry. However, in the past few years it often appears in applications such as education, medicine and military [1]. Practically speaking, only the imagination of the designers of virtual systems sets the boundaries of their applicability.

This field of knowledge could not develop without the support of other technologies. One of them are optoelectronic devices and systems. It concerns both the solutions of measurement and data visualization.

This article presents selected solutions in the field of optoelectronics, without which it is difficult to imagine the functioning of modern virtual reality system.

One of the issues specific to virtuality is digital three-dimensional modeling. Objects can be modeled by means of the special graphics programs. However, for complex objects it is possible to use a 3D optoelectronic scanner (fig. 1).

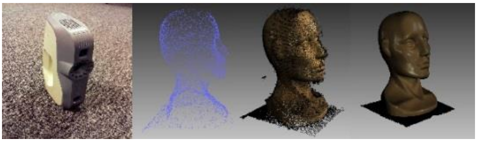

Fig. 1. 3D Scanner and example of object modeling

The needs of the virtual world are not limited to static objects. Many of the applications require visualization of moving objects. In this group of topics, we can speak about two types of solutions. The first is post processing visualization of pre-recorded animation. As in the case of static objects modeling, dedicated software can be used for this purpose which unfortunately can be very time consuming. Another option supported by the optoelectronic technology is called Motion Capture. This solution consisting in capturing movement of the selected characteristic points and is often used for modeling the human figure (fig. 2).

Fig. 2. Motion capturing using optoelectronic system

More advanced VR applications requires real time tracking movements of user [2]. For this purpose, optoelectronic MoCap systems may be used. Not without significance are complexity and cost of such systems. For the moment, therefore, better solutions to this issue are still being researched, discussed and developed.

Virtuality is best experienced by immersion that is perception of being physically present in a non-physical world This is possible thanks to another optoelectronic technology, namely HMD (Head Mounted Display). (fig. 3).

Fig. 3. VIVE HMD and the image that they generate.

The article presents the results of current work on design sensors for active tracking system for VR. The summary also presented selected application solutions implemented by a team in the field of virtual reality. They concern, among others, the so-called. VR trainers, design and testing of systems using VR environment and finally the ability to create virtual HMI (fig. 4).

Fig. 4. Examples of virtual environments

Reference

1. C. S. Lanyi, Applications of Virtual Reality, InTech, Chapters published May 02, 2012

2. M. Piszczek, Positioning of objects for real-time application of virtual reality, PRZEGLĄD ELEKTROTECHNICZNY, ISSN 0033-2097, R. 92 NR 11/2016, str. 79-82.

Application of continuous optical fiber measurements for strain and deformation state determination within building structures

Jakub KORYCIŃSKI, Łukasz BEDNARSKI, Rafał SIEŃKO, Tomasz HOWIACKI
Interlab, Kosiarzy 37 paw. 20, 02-953 Warsaw, POLAND
SHM System, Jana Pawła II 82A, Libertów, 30-444 Cracow, POLAND
e-mail address: jakub@interlab.pl

In recent years fiber optic measurement technology is intensively developed in Poland and worldwide in terms of its applicability to geometrically continuous (see Fig. 1.) measurements of building structures strain and deformation.

However, there are a lot of scientific and technical issues which still remain to deal with, relating, inter alia, the way of strain transferring from structural member under test to measuring fiber, protection against damage during installation and operation, introduction of thermal compensation and development of effective methods for measurement data acquisition and processing.

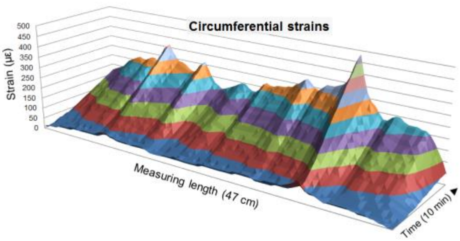

Fig. 1. A sample graph of obtained tensile strains of concrete specimen under test, in the time and distance domains [SHM System]

This article presents examples of researches and measurements carried out in this field by SHM System company, currently working on the research project POIR.01.01.01-00-0550/15 called "Development of a new fiber optic sensor allowing the determination of profiles of vertical and horizontal displacements of objects under study at lengths up to 120 km". This project is funded by the grant won at the National Center for Research and Development within the framework of Intelligent Development Operational Program 2014-2020.

Fiber optic measurements of strains and temperature within the pilot research were performed using optical reflectometer, in cooperation with Interlab company, an official Polish distributor of equipment made by Luna Technologies. The application of the Rayleigh dispersion phenomenon and the fiber optic strands up to 70 m long with spatial resolution reaching several millimeters, allowed for successful replacement of large number of single traditional strain sensors. The obtained strains Δε are analyzed in two domains: time t and distance l measured from the end of the fiber optic strand (Eq. 1). In traditional experiments the analysis is simplified, as the measurement is a function of time only (Eq. 2):

$$\Delta\varepsilon_{distributed\ measurements} = f(t,l) \quad (1)$$

$$\Delta\varepsilon_{spot\ measurements} = f(t,l) \quad (2)$$

The studies presented in this article included, among other things, bending of aluminum flat bar, tensile of reinforced concrete rod, compress of concrete cylindrical specimen, bending of brick wall and strain measurements within bridge structure in the natural scale.

Reference

1. A. Barrias, J. R. Casas, S. Villalba, A Review of Distributed Optical Fiber Sensors for Civil Engineering Applications, Sensors 2016, 16.

2. A. Barrias, J. R. Casas, S. V. Herrero, Review of Civil Engineering Applications with Distributed Optical Fiber Sensors, 8th European Workshop On Structural Health Monitoring (EWSHM 2016), Spain, Bilbao, 5-8 July 2016.

3. W. Derkowski, T. Zych, Nowoczesne materiały kompozytowe do wzmacniania konstrukcji budowlanych, Czasopismo Techniczne, Wydawnictwo Politechniki Krakowskiej, 2004, ISSN 0011-4561.

4. W. Li, X. Bao, High Spatial Resolution Distributed Fiber Optic Technique for Strain and Temperature Measurements in Concrete Structures, International Workshop on SMART MATERIALS, STRUCTURES NDT in Canada 2013Conference & NDT for the Energy Industry, October 7-10, 2013.

5. J. López-Higuera, L. Cobo, A. Incera, A. Cobo, Fiber Optic Sensors in Structural Health Monitoring, Journal of Lightwave Technology, 2011, Vol. 29, no. 4.

6. D. Samiec, Distributed fibre-optic temperature and strain measurement with extremely high spatial resolution, Photonic International, 2012.

7. R. Sieńko, T. Howiacki, R. Szydłowski, M. Maślak, M. Pazdanowski, Application of distributed optical fiber sensor technology for strain measurements in concrete structures, COST TU1402: Quantifying the Value of Structural Health Monitoring. Copenhagen, 24th August 2016.

8. M. Skłodowski, Współczesny monitoring obiektów budowlanych, Przegląd Budowlany, 3/2009: 37-46.

Hollow-core fibers for multiphoton spectroscopy application

H.STAWSKA[1], M.POPENDA[1] , E. BERES- PAWLIK[1]

[1]Telecommunications and Teleinformatics Department, Wroclaw University of Technology, Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, Poland

During design process of the miniature two-photon endoscope it is important to select appropriate fiber. Because of the occurring dispersion phenomena in the standard, solid core fibers, it is undesirable to use them for the multiphoton excitation signal transmission. In this paper we present the numerical studies of several new structures of hollow core fibers for two-photon endoscopic systems. Construction of proposed fibers is based on the hypocycloid-core Kagome hollow core photonic crystal fiber but cores of these fibers contain additional lateral areas. We show that introducing such distortion to the structure allows a significant improvement of optical parameters, such as losses or bandwidth, without reducing the temporal quality of the transmitted pulses, such as the initial pulse width. In addition to the performed calculations, we present initial measurements of the fluorescence spectra with a custom designed fiber probe, employing good fluorescence collection parameters of the solid-core, POF fibers, and the superior pulse transmission parameters of the hollow-core, photonic crystal fibers.

Fiber microprobe with integrated electrodes for single cell electroporation

Ryszard BUCZYŃSKI[1,2], Julita KULBACKA[3], Jolanta SACZKO[3],
Dariusz PYSZ[1], Adam FILIPKOWSKI[1], Magda DUBIŃSKA-MAGIERA[4], Ryszard STĘPIEŃ[1],
Rafał KASZTELANIC[1] and Małgorzata KOTULSKA[5]

[1] Institute of Electronic Materials Technology, Wolczyńska 133, Warsaw, POLAND.
[2] Microelectrocell sp. z .o.o., Rostafinskich 4, 02-593, Warsaw POLAND.
[3] Department of Medical Biochemistry, Wroclaw Medical University, Chalubinskiego 10, 50-368, Wroclaw, POLAND.
[4] Department of General Zoology, Zoological Institute, University of Wroclaw, Sienkiewicza 21, 50-335 Wroclaw, POLAND
[5] Institute of Biomedical Engineering and Instrumentation, Wroclaw University of Technology, Wyb. Wyspiańskiego 27, POLAND
e-mail address: ryszard.buczynski@itme.edu.pl

Optical fibers technology plays a key role in development of modern photonic systems in area of optical sensors, laser machining and telecommunications. Recently this technology starts playing more and more important role in biomedical applications e.g. compact minimum-invasive sensing systems, laser ablation and cosmetic surgery. In this paper we report on application of optical fiber technology for development of microprobes for single cell electroporation.

Application of electric field with adequately high energy can lead to formation of short-lived nanopores in lipid cell membranes of cells. This method is named electroporation. The phenomenon of temporary membrane permeabilization enables transport of hydrophilic molecules into the cell, which has been used in medicine and biotechnology for introduction of DNA, anticancer drugs and other small molecules [1]. The studies of electroporation are mainly performed in bulk - on cell culture population or in vivo. Observation of a single cell electroporation is highly demanded since it could extend our knowledge concerning the mechanisms of electroporation and its effects. Therefore new tools for single cell electroporation is highly demanded.

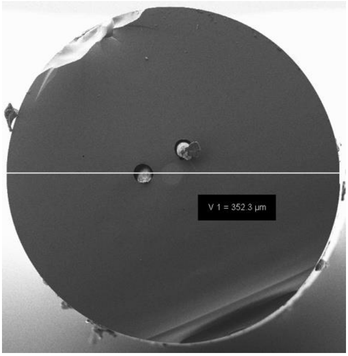

Fig. 1. Glass fiber with two low-resistant silver-copper microelectrodes, separated 31 µm from each other, each with a diameter of 23 µm.

In this work we demonstrate a new fiber microprobe which can be used for a single-cell studies requiring application of an electrical field. We use a standard stack-and-draw technology commonly used for photonic crystal fiber development [2]. The microprobe consists of two low-resistant silver-copper microelectrodes, separated 31 µm from each other, each with a diameter of 23 µm. The microelectrodes were covered with a glass fiber which was 352 µm in diameter (Fig. 1). For experiment some glass was removed at the end of the fiber to open 2 mm long electrodes. The open ends of the electrodes were further mechanically separated 210 µm form each other (Fig. 2). The fiber microprobe total longitudinal dimension of 10-30 cm allows for an easy penetration into a biological sample and its convenient manipulation as previously reported.

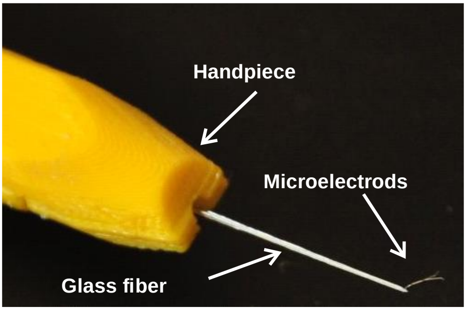

Fig. 2. Thin microprobe for electroporation of single cells.

We applied the probe to single-cell electroporation on two normal cell lines – CHO-K1 hamster ovarian fibroblasts – lacking ion channels, H9C2 rat myocardial cells and to two human cancer cell lines: LoVo (colon adenocarcinoma) and A431 (squamous carcinoma). For verification of microprobe efficiency there were used two stages of the experiments: constant and pulsed electric field with the voltage up to 10 V was used (which corresponds to voltage-to-distance ratio of 476 V/cm). It allowed a successful electroporation of a small, selected group of cells, as well as of single selected cells.

Reference

1. G. Serša, J. Teissié, M. Čemažar, E. Signori, U. Kamenšek, G. Marshall, D. Miklavčič, Cancer Immunol. Immunother. 64, 1315-1327 (2015).
2. R. Stępień, J. Cimek, D. Pysz, I. Kujawa, M. Klimczak, R. Buczyński, Opt. Eng. 53, 071815 (2014).

Magnetooptic properties of special optical glasses

Kamil BARCZAK*, Ryszard BUCZYŃSKI**

* Silesian University of Technology, Department of Optoelectronics, ul. Krzywoustego 2, 44-100 Gliwice, POLAND

** Institute of Electronic Materials Technology, ul. Wólczyńska 133, 01-919, Warszawa, POLAND

e-mail address: kamil.barczak@polsl.pl

The presented work is concentrated on investigation of Verdet constants of a series of heavy metal oxides glasses developed in-house: PBG-08, CS-1030, SPB-N12 and TWPN/1/6. These glasses was made by Prof. Buczyński group from ITME [1-3]. They have the highest nonlinear properties in oxide glasses group dedicated to multiple thermal processing. They are unique on a global scale because of this. The most important feature is that from these glasses optical fibers, especially photonic crystal fibers (PCF), can be produced [4-5].

The table 1 presents the optical and geometrical properties of investigated glasses.

Tab. 1. Optical and geometrical properties of investigated glasses.

No	*name*	*diameter d [mm]*	*refractive index n_d (587,6nm)*
1	CS-1030	1,89	2.026
2	PBG-08	2,04	1.938
3	SPB-N12	3,4	1.879
4	TWPN/1/6	3,35	2.136

The investigations on determination of the Verdet constant were carried out at room temperature. Finally Verdet constant dispersion characteristics for visible wavelength range were obtained. This was the main goal of this work, which was determination of magnetooptic properties of these glasses and expansion of a knowledge about them was obtained.

The results of the investigations are presented in the Fig.1. We can see results for SF6 and SF57 glasses too. They were measured and compared with data obtained from Schott. The good agreement proves the correctness of the measurement method.

Obtained results show very high Verdet constant, especially for PBG-08 glass. This value is 50% higher than for commercially SF57 glass which is characterized by high Verdet constant value. These properties are very promising from the point of view of application in magnetooptic sensors [6].

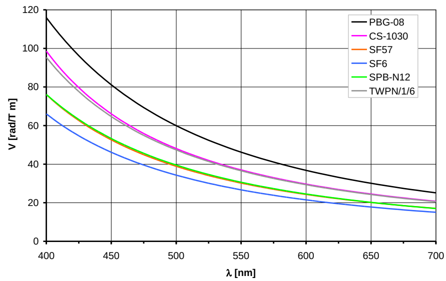

Fig. 1. Dispersion characteristics of investigated glasses.

Reference

1. R. Stępień, J. Cimek, D. Pysz, I. Kujawa, M. Klimczak, and R. Buczyński, Soft glasses for photonic crystal fibers and microstructured optical components, Opt. Eng. 53 (7), 071815, 2014
2. R. Stepien, D. Pysz, I. Kujawa, R. Buczynski, Development of silicate and germanate glasses based on lead, bismuth and gallium oxides for midIR microstructured fibers and microoptical elements, Opt. Mater., 35(8), 1587-1594 (2013).
3. J. Cimek, R. Stępień, G. Stepniewski, B. Siwicki, P. Stafiej, M. Klimczak, D. Pysz, R. Buczyński, High contrast glasses for all-solid fibers fabrication, Opt. Mat. 62, 159-163 (2016).
4. G. Sobon, M. Klimczak, J. Sotor, K. Krzempek, D. Pysz, R. Stepien, T. Martynkien, K. M. Abramski, R. Buczynski, Infrared supercontinuum generation in soft-glass photonic crystal fibers pumped at 1560 nm, Opt. Mat. Express, 4, 2147-2155 (2014)
5. M. Klimczak, G. Soboń, R. Kasztelanic, K. M. Abramski and R. Buczyński, Direct comparison of shot-to-shot noise performance of all normal dispersion and anomalous dispersion supercontinuum pumped with sub-picosecond pulse fiber-based laser, Sci. Rep., 6, 19284 (2016)
6. Kamil Barczak, Optical fiber current sensor with external conversion, Proc. SPIE 10034, 11th Conference on Integrated Optics: Sensors, Sensing Structures, and Methods, 100340A (September 2, 2016);

ZnO semiconductor for applications in optoelectronics sensors structures

Przemysław STRUK[1], Tadeusz PUSTELNY[1], Michał A. BORYSIEWICZ[2], Krystyna GOŁASZEWSKA[2]

[1]Department of Optoelectronics, Silesian University of Technology, 44-100 Gliwice, Poland.
[2]Institute of Electron Technology, Al. Lotnikow 32/46, 02-668 Warsaw.
e-mail address: Przemyslaw.Struk@polsl.pl

The development of civilization is nowadays inspired by development of semiconductors materials and their applications in electronics, optoelectronic devices, photonics structures as well as sensors structures. One of the most interesting semiconductor material which can be applied in mentioned above devices and structures is a zinc oxide (ZnO). The ZnO semiconductor is characterized by a wide energy band-gap at the level of Eg~3.3eV [1]. This semiconductor is also transparent for light above edge of absorption which is at the level of λ~380nm [2,3].

The paper shown applications of the ZnO semiconductor material in optoelectronics sensors structures. The principle of operations of presented optoelectronics sensors is based on changing of optical properties of ZnO semiconductor under influence of external environments.

The first part of paper presents experimental results focused on applications of ZnO semiconductor for detection of selected gas such as: NH_3, NO_2, H_2. Under influence of selected gaseous environments on ZnO semiconductor layer the optical properties - spectral transmittance is changing. Experimental studies shown that the biggest changes of optical transmission of ZnO is in the range of light absorption edge. The experimental setup using during experiments contain: light source UV-VIS-NIR, gas dosing system, measurement chamber, test sample, temperature controller and spectrometer Fig. 1.

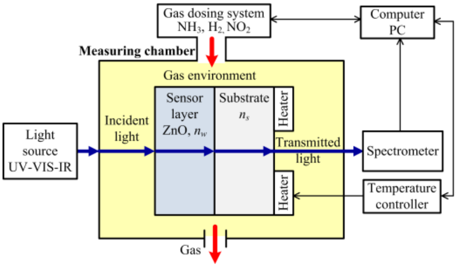

Fig. 1. Scheme of measurement setup.

The changes of spectral transmission under influence of NO_2 is presented in Fig.2

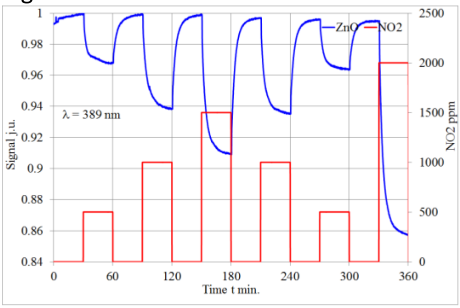

Fig. 2. Spectral transmission of ZnO under influence of NO_2 gas environment.

The second part of paper presents experimental results of the temperature sensors based on ZnO semiconductor. The investigation was focused on investigation of changing the optical properties of ZnO for different temperatures in the range of T = 25-200^{o}C.

Acknowledgments

The work was partially sponsored by the grant: WND-POIG.01.03.01-00-159/08-00 InTechFun and by grant "Badania Młodych Naukowców" financed by Faculty of Electrical Engineering, Silesian University of Technology Poland.

Reference

1. P. Struk, T. Pustelny, K. Gołaszewska, M. A. Borysiewicz, A. Piotrowska. „Optical investigations of ZnO layers affected by some selected gases in the aspect of their application in optical gas sensors". Bulletin of the Polish Academy of Sciences: Technical Sciences, 63 (4), pp. 829-836, 2015.

2. P. Struk, T. Pustelny, Z. Opilski "Researches on the spectral transmittance of zinc oxide ZnO semiconductor layers", Acta Physica Polonica A, Volume 118, Issue 6, pp.: 1239-1241, 2010.

3. P. Struk, T. Pustelny, K. Gołaszewska, M. A. Borysiewicz, E. Kamińska, T. Wojciechowski and A. Piotrowska, „ZnO - wide bandgap semiconductor and possibilities of its application in optical waveguide structures" Metrology and Measurement Systems, vol. XXI, no. 3, pp. 401 – 412, 2014.

Polymer-assisted formation of waveguiding structures in liquid crystalline materials

Katarzyna A. RUTKOWSKA, Miłosz CHYCHŁOWSKI, Urszula A. LAUDYN
Faculty of Physics, Warsaw University of Technology, Koszykowa 75, 00-662 Warsaw, POLAND
e-mail address: kasia@if.pw.edu.pl

Unique properties of liquid crystals (LCs), combining specific features of isotropic liquids and anisotropic crystals, cause that they are successfully applied in modern photonic devices, including these for integrated optic systems (IOS) [1-4]. In this communication we present possibility of formation of waveguiding structures in liquid crystalline materials by means of photo-orientation [5-6] and photo-polymerization [7-8] process, independently. In the first method, a polymer material exposed to linearly polarized UV radiation allows to create sections of planar alignment in NLC cell with varying angular orientation with respect to propagation axis. In the second one, thanks to the photo-polymerization process applied, it is possible to create LC regions with mutually orthogonal molecular orientation (i.e. planar and homeotropic, see Fig. 1). In addition LC:PDMS photonic structures [9], in which PDMS is used as a cladding for micro-channels to be infiltrated with liquid crystalline material, are presented. All mentioned methods can be potentially applied to obtain light guiding structures with accessible spatial resolution of single micrometers, as well as periodic waveguiding structures (e.g. to study discrete light propagation).

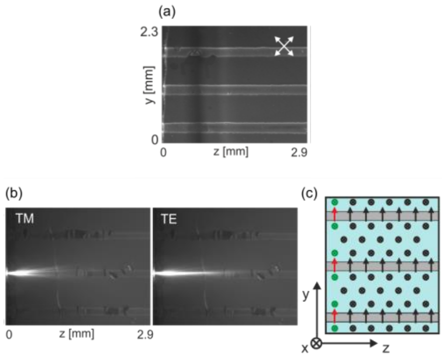

Fig. 1. a) Periodic structure obtained in NLC cell due to photo-polymerization process for the special mask applied and after irradiating the cell with UV light, as observed trough crossed polarizers. (b) Propagation of low power beams with orthogonal polarizations when launched in the channels of planar orientation. (c) The scheme of photonic structure obtained thanks to the photo-polymerization process taking place in NLC layer.

Acknowledgment: This work was supported by the Polish National Science Center under the grant no. DEC-2013/11/B/ST7/04330 (Integrated optical circuits in novel liquid crystalline structures and materials).

Reference

1. L. Vicari, Optical applications of liquid crystals, CRC Press, 2016,
2. D. Yang, Fundamentals of liquid crystal devices, John Wiley & Sons, 2014,
3. I. Khoo, Liquid crystals: physical properties and nonlinear optical phenomena, John Wiley & Sons, 2007,
4. J. Whinnery, C. Hu, and Y. Kwon, IEEE J. Quant. Electron. 13, 262 (1977),
5. K. Takatoh, M. Sakamoto, R. Hasegawa, M. Koden, N. Itoh, and M. Hasegawa, Alignment technology and applications of liquid crystal devices, CRC Press, 2005,
6. O. Yaroshchuk and Y. Reznikov, Journal of Materials Chemistry 22, 286 (2012),
7. A. De Souza Gomes, Polymerization (InTech, Croatia, 2012),
8. V. Presnyakov, K. Asatryan, T. Galstian, and A. Tork, Optics Express 10, 865 (2002),
9. R. Asquini, L. Martini, and A. d'Alessandro, Molecular Crystals and Liquid Crystals 614, 11 (2015).

Modulators for MWIR detectors with liquid crystal

Urszula CHODOROW[1], Andrzej KOWALEWSKI[1], Jakub HERMAN[2], Rafał MAZUR[1], Przemysław MORAWIAK[1], Wiktor PIECEK[1], Przemysław KULA[2], Waldemar GAWRON[1,3], Piotr MARTYNIUK[1]

[1]Institute of Applied Physics, Military University of Technology, Kaliskiego 2, 00-908 Warsaw, POLAND
[2]Institute of Chemistry, Military University of Technology, Kaliskiego 2, 00-908 Warsaw, POLAND
[3]Vigo System S.A., Poznańska 129/133, 05-850 Ożarów Mazowiecki, Poland
e-mail address: urszula.chodorow@wat.edu.pl

The interest of liquid crystal (LC) materials with low absorption of infrared radiation (IR) is steadily increasing as evidenced publications appearing in recent years [1-3]. At present, LC-based tunable optical modulators are commonly used in the visible range, therefore, these materials can also find application in the infrared range, e.g. as shutters [4,5].The possibility of fast switching of IR radiation by using LC transducers would allow to replace mechanical choppers currently used in IR detectors. Mechanical choppers themselves are a source of IR radiation, which interferes with the signal read by the detector. Mechanical chopper has large size and during operation consumes much more power than LC device. The liquid crystal chopper has a much smaller size compared with the mechanical, making it easier to integrate it with detector, requires lower drive voltages and is insensitive to vibrations of the environment in contrast to the mechanical chopper. Aperture of liquid crystal transducer can also be arbitrarily large, and it does not have any moving parts which makes the maintenance easy.

We present two liquid crystal modulators working in Mid-Wave Infrared Radiation (MWIR) range. Two electro-optical effects were used: cholesteric nematic (ChLC) transition and twisted nematic (TN) effect. The modulators were constructed of ZnSe windows coated by thin film of indium tin-oxide (ITO) as an electrode and polyimide as an alignment layer. The thickness of LC layer was 53 µm.

In the case of cholesteric nematic LC the modulation was done by switching of a focal conic structure to homeotropic one under a 120 V pulse of AC voltage. The reverse switching was induced by 50 V. The modulation of the IR radiation (see Fig.1) of wavelength λ = 4 µm was between 19% (focal conic texture) to 35% (homeotropic texture).

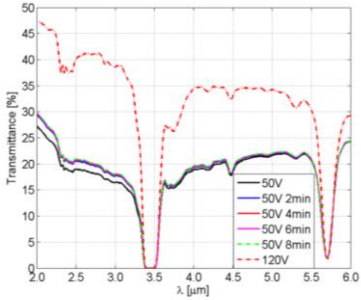

Fig. 1. Transmittance of ChLC modulator switched between focal conic and homeotropic texture by using 50 V and 120 V respectively

The switching-on time t_{on} = 1.5 s, and the switching-off time t_{off} = 150 ms at 24°C. In Fig. 1 one can see there is some transmittance drift in time for focal conic texture which is higher for lower wavelengths. In visible range transmittance in focal conic state was stabilized after 40 s. Anyway, the transmittance drift in MWIR range is negligible.

In the case of TN effect the transmittance switching was done between a twisted nematic structure to homeotropic structure and was between 26% (0 V) and 0.2% (100 V) respectively at λ = 3.6 µm (see in Fig.2). This effect gives a satisfactory dark state. The switching-off time toff to bright state is very long (several minutes) because this process is driven by elastic forces only.

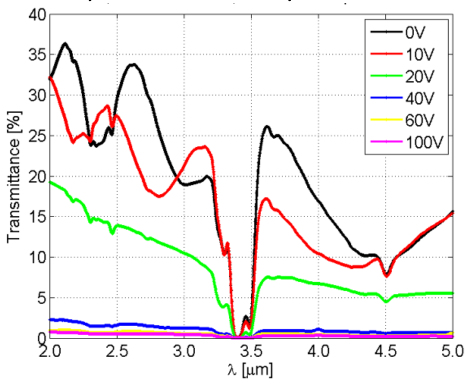

Fig. 2. Transmittance of TN modulator for different voltages.

The TN effect requires two linear polarizers in contrast to cholesteric nematic transition and thus the total transmittance of TN transducer is lower. In both effects by using different voltages one can change the transmittance modulation depth.

Acknowledgments

We acknowledge support by PBS 653.

Reference

1. Y. Chen, H. Xianyu, J. Sun, P. Kula, R. Dabrowski, S. Tripathi, R.J. Twieg, S.-T Wu, Opt. Exp. 19(11), 10843-10848 (2011),
2. M. Hu, Z. An, J. Li, H. Chen, F. Peng, S.-T. Wu, X. Wang, M. Li, J. Mat. Chem. C 4, 4939-4945 (2016),
3. J. Herman, P. Kula, RSC Adv. 6, 84231 (2016),
4. J.L. West, R. Ondris-Crawford, J. Appl. Phys. 70(7), 3785-3790 (1991),
5. G.J. Choi, H.M. Jung, S.H. Lee, J.S. Gwag, Appl. Opt. 55(16), 4436-4440 (2016).

MIR emission from Tb^{3+} doped chalcogenide glass

L. SOJKA[1,2], Z. TANG[1], D. FURNISS[1], H. SAKR[1], Y. FANG[1], E. BERES- PAWLIK[2], T.M. BENSON[1], A.B. SEDDON[1], S. SUJECKI[1,2*]

[1]Mid-infrared Photonics Group, George Green Institute for Electromagnetics Research, Faculty of Engineering, University of Nottingham, University Park, Nottingham NG7 2RD, UK

[2]Telecommunications and Teleinformatics Department, Wroclaw University of Technology, Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, Poland

Recent publications focus on rare-earth doped chalcogenide glasses that can emit light in the spectral region spanning between 3 and 6 µm [1-4]. The majority of the results reported in the literature were achieved for chalcogenide glasses doped with dysprosium and praseodymium. However, the mid-infrared laser (MIR) action from these glasses has not yet been demonstrated. A major reason for this is the existence of self-terminating levels in these glasses. Thus, a better solution is to use a laser host that does not suffer from this problem. In this paper we show that in Tb3+ doped selenide-chalcogenide glass the transitions from the $^7F_4$, $^7F_3$, $^7F_2$, $^7F_1$, and 7F0 levels are expected to be strongly quenched. Mid-infrared 3-level laser action (at a wavelength of 4.7 µm) may thus be possible from the $^7F_5$ level to the $^7F_6$ level transition whilst pumping into the $^7F_4$ level. A set of bulk and fiber samples made of Tb^{3+} doped chalcogenide glass has been fabricated. For the fabricated samples the room temperature emission spectrum at 4.7 µm wavelength and the photoluminescence decay characteristics corresponding to the laser transition $^7F_5 \rightarrow {}^7F_6$ were measured. These measurements confirm that the $^7F_4$ transition is depopulated in a non-radiative way in Tb^{3+} doped selenide glass, which leads to the conclusion that terbium can be used for the realization of a true 3-level system laser operating at the mid-infrared (MIR) wavelength of 4.7 µm. Further, FTIR (Fourier transform infrared spectroscopy) was used to measure the absorption cross-section spectrum. From measured absorption spectra the contributions of glass matrix impurity bands due to OH and Se-H were removed in order to perform Judd-Ofelt (J-O) analysis. The radiative transition rates calculated from J–O theory are compared with measured lifetimes. Using the experimentally extracted parameters, a numerical model of a Tb^{3+} doped fiber laser was developed. The model was used to analyze the dependence of the laser performance on the fiber length, output coupler reflectivity, pump wavelength, signal wavelength and fiber background loss. The modeling results show that an efficient 3-level mid-infrared fiber laser operating at 4.7 µm may be realised when pumping at a wavelength of either 2.013 µm or 2.95 µm.

Funding. European Commission (MINERVA 31783), EPSRC (RDF/0312), COST (MP1401), Polish Ministry of Science and Higher Education (IP0441/IP2/2015/73)

Reference

1. Z. Tang, D. Furniss, M. Fay, H. Sakr, L. Sójka, N. Neate, N. Weston, S. Sujecki, T. M. Benson, and A. B. Seddon, "Mid-infrared photoluminescence in small-core fiber of praseodymium-ion doped selenide-based chalcogenide glass," Opt. Mater. Express 5, 870-886 (2015).

2. Ł. Sójka, Z. Tang, H. Zhu, E. Bereś-Pawlik, D. Furniss, A. B. Seddon, T. M. Benson, and S. Sujecki, "Study of mid-infrared laser action in chalcogenide rare earth doped glass with Dy3+, Pr3+ and Tb3+," Opt. Mater. Express 2, 1632-1640 (2012).

3. J. Hu, C. R. Menyuk, C. Wei, L. Brandon Shaw, J. S. Sanghera, and I. D. Aggarwal, "Highly efficient cascaded amplification using Pr3+-doped mid-infrared chalcogenide fiber amplifiers," Opt. Lett. 40, 3687-3690 (2015).

4. Falconi, M. C., Palma, G., Starecki, F., Nazabal, V., Troles, J., Taccheo, S., Ferrari, M., Prudenzano, F., "Design of an Efficient Pumping Scheme for Mid-IR Dy3+:Ga5Ge20Sb10S65 PCF Fiber Laser," Photonics Technology Letters, IEEE, 28, 1984-1987 (2016).

Development of active optical fibers technology

Pawel MERGO[1], Krzysztof POTURAJ[1], Renata LYSZCZEK[2], Paweł BORTNOWSKI[3], Krzysztof ANDERS[3], Anna JUSZA[3], Janusz PEDZISZ[1], Aleksander WALEWSKI[1], Ryszard PIRAMIDOWICZ[3]

[1] Laboratory of Optical Fibers Technology, Maria Curie-Sklodowska University, Sklodowska SQ 3, 20-031 Lublin, POLAND

[2] Department of General and Coordination Chemistry, Maria Curie Sklodowska University, Sklodowska SQ 2, 20-031 Lublin, POLAND

[3] Institute of Microelectronics and Optoelectronics, Warsaw University of Technology, Koszykowa 75, 00-662 Warsaw

e-mail address: Pawel.Mergo@umcs.lublin.pl

In this work we report the first results on development of modified technology of doped active SiO2 fibers manufactured at Maria Curie-Skłodowska University. Active silica glass with different doping rare-earth elements (Nd^{3+}, Er^{3+}, Yb^{3+} and Tm^{3+}) doping levels (from 1300ppm up to 6100ppm) has been fabricated with MCVD method complemented by a modified impregnation from liquid phase method. From the manufactured preforms three different kinds of optical fibers with different cross-sections (standard single mode, circular shape double-clad, stadium shape double-clad or octagon shape double-clad) have been drawn. Absorption, transmission and Raman characteristics have been recorded, allowing assessment of optical quality of developed glasses, as well as maximum phonon energies. Measurements of emission characteristics and fluorescence dynamics profiles have proved the presence of rare-earth ions and confirmed acceptable luminescent properties of both preforms and drawn fibers. Performed characterization provided also important feedback for technological team enabling further optimization of both bulk glasses and optical fibers.

High birefringent microstructured polymer optical fibers with frozen stresses

Grzegorz WOJCIK, Aleksander WALEWSKI, Lidia CZYZEWSKA, Janusz PEDZISZ, Jaroslaw KOPEC, Pawel MERGO

Laboratory of Optical Fibers Technology, Maria Curie-Sklodowska University, Sklodowska SQ 3, 20-031 Lublin, POLAND

e-mail address: grzegorzwojcik@poczta.umcs.lublin.pl

Studies on polymer optical fibers (POF) and their applications are in progress since the early eighties [1]. Polymer optical fibers have many advantages which make their technology still intensively developed. Among of the particularly important properties of POF fibers we can point out their flexibility and production in relatively low temperatures. This involves low manufacturing costs and allows for doping the polymer structure with various organic and inorganic compounds during the preform preparation process and also after the fiber drawing, which is not possible in the technology of silica glass optical fibers. As in the case of silica glass fibers an important step in the development of polymer fibers technology was manufacturing in 2001 the first microstructured polymer optical fiber (mPOF) made of polymethyl methacrylate (PMMA) [2, 3].

Polymethyl methacrylate (PMMA), which is currently the most popular basic material of microstructured polymer optical fibers is formed in the polymerization process consisting in the combination of grate number independent particles of monomer (MMA) in a singular molecule of very large molecular weight and length [4, 5]. During the PMMA fiber drawing in the fixed temperature conditions and non-zero stress the internal structure of the polymer is changing. Under the influence of the external force molecular chains in the polymer are forced to a partial orientation along the fiber axis. Then, during the cooling phase PMMA chains are "freezing" in the new state of the polymer alignment. Generation of a new state of molecules order introduce large additional stress in the fibers cross-section and cause disturbances in the regular distribution of the refractive index. In effect in such fibers we can observe the appearance of residual birefringence [6]. Additionally an extremely disadvantageous is the fact that after a certain time the "frozen" internal stress undergoes relaxation process and causes a significant change in optical properties of polymer fibers. Relaxation effect is particularly enhanced when an optical fiber is exposed to higher temperatures [7, 8, 9, 10].

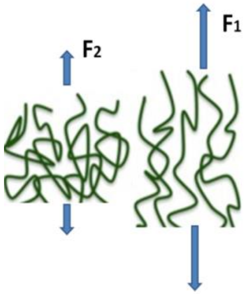

Fig. 1 Mechanism of "stretching" PMMA chains during the fiber drawing process (F2>>F1).

Stresses generated in the polymer structure during the processing are essential because of two reasons. First of all is an influence on the process stabilization, particularly important during the phase of preform preparation, which has a major impact on the stability of microstructure cross-section characteristics (e.g. fluctuations: outer diameter, hole diameter and pitch distance) [3, 11]. The second reason is related to the effect of stress in the optical fiber, which is changing during the fiber work as a result of the polymer relaxation process [12, 13].

The main goal of the research is to analyze the mPOF drawing conditions influence on stress generation mechanisms in polymer fibers. The general research hypothesis is that according to the drawing conditions - mainly the force of drawing it is possible to control the level of internal stresses in microstructural fibers. At present there is no a literature references describing this mechanisms typically from the technology side. Information about the influence of drawing conditions on the internal material structure is very important because knowledge about stress generation mechanisms in mPOF fibers will strongly improves the quality and stability of manufactured fibers.

Reference

1. Y. Koike, , Journal of Polymer Science Part B: Polym. Phys., Vol. 49, No. 1, 2011
2. M. A. van Eijkelenborg, Optics Express, Vol. 9, No. 7, 2001
3. M. Large, "Microstructured Polymer Optical Fibers", 2008, Springer
4. Wilczyński K. "Przetwórstwo tworzyw sztucznych", Oficyna Wydawnicza PW, Warszawa, 2000
5. P. Mergo, Photonic Letters of Poland, Vol. 5, No. 4, 2013
6. A. A. Hamza, Journal Physics D: Applied Physics, Vol. 20, No. 7, 1987
7. P. Ji, Proceedings of SPIE, Vol. 5212, 2003
8. P. Stajanca, Optical Fiber Technology, Vol. 28, pp. 11–17, 2016
9. G. Woyessa, Optics Express, Vol. 24, No. 2, 2016
10. A. Pospori, Proceedings of SPIE, Vol. 9886, 98860V-1, 2016
11. M.A. van Eijkelenborg, Optical Fiber Technology, Vol. 9, No. 4, 2003
12. Johnson I. P., Proceedings of SPIE, OFS21, Vol. 7753, 2011
13. D.J. Webb, Measurements Science and Technology, Vol. 26, No. 09, 2015

Detection of optical signals in selected sensing applications

Jacek WOJTAS, Z. BIELECKI, J. MIKOŁAJCZYK, B. RUTECKA, D. SZABRA, K. KŁOS
Institute of Optoelectronics, Military University of Technology, 2 Kaliskiego Str., Warsaw 00-908, POLAND
e-mail address: jacek.wojtas@wat.edu.pl

The optical signals are registered with the photoreceivers, which should be matched to the application requirements. Photoreceivers are characterized by spectral responsivity, gain, linear dynamic range, photosensitive area, frequency bandpass, dark current and signal-to-noise ratio (SNR) [1]. There are two types of detectors, which can be applied in photoreceiver construction: thermal (e.g., thermopile, bolometer and pyroelectric) and photon (e.g., photomultiplier, photodiode and photoresistor). The first group is characterized by an almost constant value of spectral responsivity, long response time, and low detectivity. They are commonly used in low-cost non-dispersive infrared technique (NDIR). Photon detectors with higher responsivity and speed find applications in trace matter laser absorption spectroscopy (LAS). To achieve better performance they can be extra cooled, especially in IR range of the wavelengths. In the case of ultraviolet (UV), visible (VIS) and near infrared (NIR) ultrasensitive spectroscopy the most popular are photomultiplier tubes (PMT). They are characterized by high gain, high speed and low dark current. Because of high resistance, transimpedance preamplifiers are usually used to amplify PMT signal in wide dynamic range [2]. In Figure 1 spectral detectivity of multi-anode photomultiplier tubes (Multi PMT) is presented. There are also available types of PMT's with spectral response up to 1.7 µm, e.g.: H10330A or R5509 [3].

Mid-infrared (MIR) spectral region is attractive for LAS because of fundamental absorption bands of molecular absorbing transitions located there. For MIR radiation detection, the most popular are InSb photodiodes, PbSe photoresistors as well as MCT photoresistors and photodiodes (Fig. 1). These detectors are characterized by high speed, low noise and good linearity and stability. They can operate in the photovoltaic and photoconductive mode . To achieve the best properties, InSb detectors have to operate at low temperatures, such as 77 K. PbSe photoconductive detectors are able to detect radiation in the wavelength range from 2.0 µm to 6.0 µm (77 K). Their main virtues are low cost, high efficiency and compact design. Thanks to thermoelectric cooling it is possible to provide better sensitivity, wider spectral range and higher stability of operation temperature [1,2].

An alternative detectors for the middle and long wavelength IR region are also quantum well infrared photodetector (QWIPs) and super-lattice (SL) photodiodes. QWIP cannot compete with MCT photodiode because of relatively low quantum efficiencies, typically less than 10%. The spectral response band is also narrow for this detector. In comparison, the SL structures provide high responsivity, as already reached with MCT. But for these detectors, fabrication of high quality photodiodes is technologically challenging. The detectors are typically DC coupled with transimpedance preamplifier or AC coupled with voltage ones. The AC coupling allow to alleviate problems with 1/f noise.

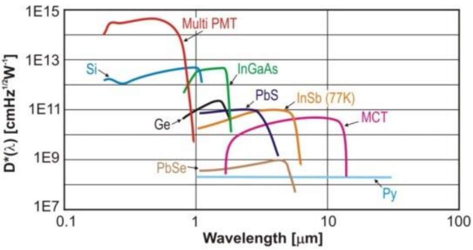

Fig. 1. Example of photodetectors detectivity [4]

The signal from the photoreceiver is digitized using an A/D converter. Dedicated software provides procedures of data processing and gas concentration determination. These procedures depend on applied LAS techniques: multipass spectroscopy (MUPAS), cavity enhanced or cavity ringdown spectroscopy (CEAS, CRDS), open path monitoring (e.g.: using retro-reflector), tunable laser spectroscopy (TLAS) and wavelength modulation spectroscopy (WMS). To improve SNR and the lowest detection limit (LDL), signal averaging, phase-sensitive algorithms including so called 2f detection accompanied by wavelength modulation are commonly used.

Above mentioned LAS techniques and optical signal detection schemes will be described in the presentation. Particular attention will be given to practical aspects related to conducted research.

Acknowledgments: works carried out in the laboratory of Institute of Optoelectronics MUT, supported by project "Laser systems of directed-energy weapons, laser systems of non-lethal weapons", DOB-1-6/1/PS/2014.

Reference

[1] A. Rogalski, Z. Bielecki, Detection of Optical Radiation. In Handbook of Optoelectronics; Taylor & Francis: New York, NY, USA, pp. 73–117, 2006.

[2] A. Piotrowski, P. Madejczyk, W. Gawron, K. Klos, M. Romanis, M. Grudzien, A. Rogalski, J. Piotrowski, MOCVD growth of Hg1xCdxTe heterostructures for uncooled infrared photodetectors. Opt. Electron. Rev. 12, pp. 453–458, 2004.

[3] http://sales.hamamatsu.com

[4] J. Wojtas, J. Mikolajczyk, Z. Bielecki. Aspects of the Application of Cavity Enhanced Spectroscopy to Nitrogen Oxides Detection. Sensors, 13(6), pp. 7570-7598, 2013.

Metrology and gas sensors in business processess of the Company Atest-Gaz

Aleksander PACHOL

Atest-Gaz A. M. Pachole sp. j. ul. Spokojna 3, 44-109 Gliwice, Polska

e-mail address: biuro@atestgaz.pl

Selected gas sensors designed for IS and Automotive applications

Grzegorz KONIECZNY

SGX Europe Sp. z o.o.
e-mail address: grzegorz.konieczny@sgxsensortech.com

POSTER SESION ABSTRACTS

Optical sensor in planar configuration based on multimode interference

Marek BŁAHUT
Optoelectronics Department, Silesian University of Technology, ul. Krzywoustego 2, 44-100 Gliwice, POLAND
e-mail address: Marek.Blahut@polsl.pl

In recent years, there have been many papers on the use of multimode interference structures (MMI) in waveguide sensor technology [1, 2]. In this paper the model of optical sensor is proposed which is based on step-index planar multimode structures. Optical configuration of examined sensor is shown in Fig.1. It consists of single-mode waveguide, MMI section of the length equal to 1-fold image formation distance, and single-mode output waveguide. The MMI section is covered by a dielectric sensing layer which changes its optical properties in contact with measured external surrounding. The refractive index variation of dielectric layer affects the modal properties of multimode waveguide and the output image position. The image variations are registered by single-mode output waveguide. Material parameters shown in the Fig.1 concerns to polymer SU8 waveguide on SiO2 substrate. It is assumed that the optical system described will be used to the analysis of biological substances. Hence the suggested refractive index changes for initial research characteristics are in the limit of 1.3317-1.3327.

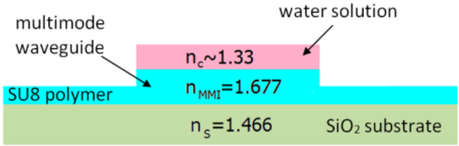

Fig.1. The geometry of one dimensional MMI structure in step-index configuration

The initial numerical simulations are performed for the special configuration of MMI section which guides only two modes. The thickness of the input waveguide for single-mode operation amounts to 400nm and the thickness of two-mode multimode section is equal to1000nm. The length of the structure is equal respectively to 1cm for single-mode input, 1cm for the multimode section and 1 cm for the output single-mode waveguide. In Fig.2 there are presented the amplitude distributions at the output of MMI section, for the refractive index of the cover changing in the limit of 1.3317-1.3327. Dotted lines determine the multimode waveguide thickness. The signal variations at the output of single-mode waveguide which respond these amplitude distributions are presented in next Fig.3. Results of simulations indicate the sensitivity of the optical system to refractive index changes in the range of 10-5.

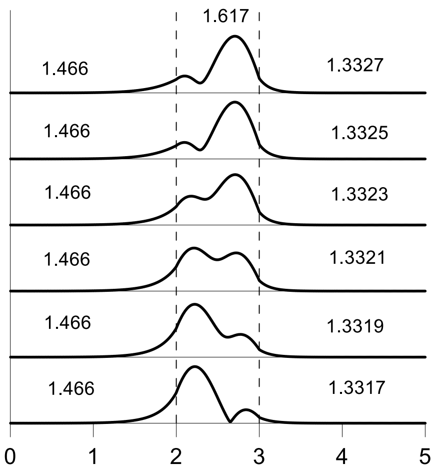

Fig.2. Amplitude distributions at the output of MMI section for the refractive indices of the cover in the limit of 1.3317-1.3327. Dotted lines denote the borders multimode waveguide.

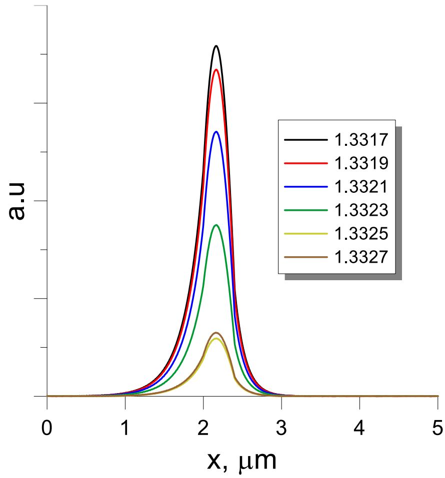

Fig.3. Optical signal at the output of single-mode waveguide for the refractive indices of the cover in the limit of 1.3317-1.3327.

Reference

1. Szewczuk A., Błahut M., MMI structures covered by bromocresol purple for amonia detection, Acta Physica Polonica A 124 (3), pp. 570 – 573 (2013)

2. Blahut M., Szewczuk A., Multimode interference in sensors application, Proc. SPIE 9816, Optical Fibers and Their Applications 2015, 98160Q, (2015)

IOS'2017, Szczyrk 27.02-03.03.2017

Influence of doping LC with Fe_3O_4 on photonic liquid crystal fibers

Miłosz CHYCHŁOWSKI, Nina ZATKA, Sławomir ERTMAN, Bartosz BARTOSEWICZ*, Bartłomiej JANKIEWICZ*, Tomasz WOLIŃSKI

Warsaw University of Technology, Koszykowa 75, 00-662 Warszawa, POLAND
*Military University of Technology, gen. S. Kaliskiego 2, 00-908 Warszawa, POLAND
e-mail address: piccoro@if.pw.edu.pl

The recent studies in liquid crystals (LCs) are focused on blue-phase, THz applications or doping LCs [1-3]. Wide variety of materials are used for LCs doping such as: polymers, dyes, or carbon nanotubes. Lately, there has been a growing interest in LCs with dispersed nanopatricles (NPs). Additions of even 1% of NPs can change transition temperature for a few degrees or value of LC order parameter [4]. For doping with NP liquid crystals typically are used metallic NPs due to their plasmonic properties. In this paper we focus on another type of NPs – ferromagnetic NPs such as Fe_3O_4 [5]. The ferromagnetic NPs dispersed in LCs reduce magnetic field needed to reorient LCs molecules. Typically magnetic field of 1T is needed for reorientation of pure LC, but for LCs doped with ferromagnetic NPs the threshold is reduced to less than 10 mT. It opens up a great range of new potential applications, including new class of magnetic field optical fiber sensors or magnetically tuned all-in-fiber devices.

In this paper, preliminary results of photonic crystal fibers infiltrated with nematic LCs doped with ferromagnetic NPs are reported. Two types of nematic LCs: 6CHBT and 5CB LCs were used to compare an influence of the doping on propagation parameters of the PLCFs and their magneto-optical response to external magnetic field. Preliminary studies of magnetic field influence on PCF show changes in transmission intensity for longer wavelength (fig. 1).

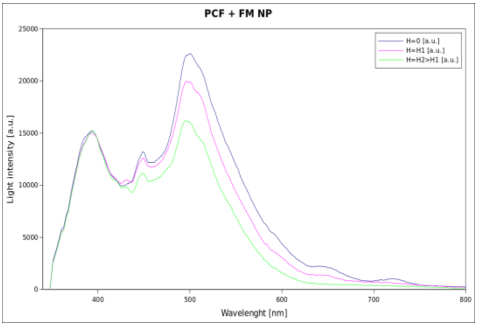

Fig. 1 Propagation spectras for photonic crystal fiber filled with ferromagnetic particles under infuence of external magnetic field

Studies of PCF infiltrated with undoped LC present small photonic band gaps shift and shortening (fig. 2).

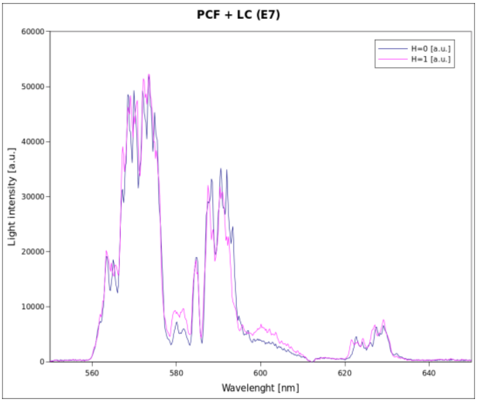

Fig. 2 Propagation spectras for photonic crystal fiber filled with liquid crystal under infuence of external magnetic field

Reference

1. Ge ZHU, et al., "Polarization independent blue phase liquid crystal gratings driven by vertical electric field", Journal of the Society for Information Display, 20.6: 341-346, 2012

2. R. Dąbrowski, P. Kula, J. Herman, "High birefringence liquid crystals", Crystals, 3(3), 443-482, (2013)

3. M. D. Lynch, D. L. Patrick, "Organizing carbon nanotubes with liquid crystals", Nano letters, 2(11), 1197-1201, (2002)

4. A. Siarkowska, M. Chychłowski, T. R. Woliński, A. Dybko, "Titanium nanoparticles doping of 5CB infiltrated microstructured optical fibers", Photonics Letters of Poland, 8(1), 29-31, (2016)

5. P. Kopčanský, et al., „Structural changes in the 6CHBT liquid crystal doped with spherical, rodlike, and chainlike magnetic particles", Physical Review E, 78(1), 011702, (2008)

Thermo-optical properties of active polymers

Lidia CZYZEWSKA[1], Renata LYSZCZEK[2], Grzegorz WOJCIK, Janusz PEDZISZ, Pawel MERGO[1]
[1]Laboratory of Optical Fibers Technology, Maria Curie-Sklodowska University, Sklodowska SQ 3, 20-031 Lublin, POLAND
[2]Department of General and Coordination Chemistry, Maria Curie Sklodowska University, Sklodowska SQ 2, 20-031 Lublin, POLAND
e-mail address: Pawel.Mergo@umcs.lublin.pl

Polymer luminescent materials containing rare earth elements, are used in fast-growing areas of the industry such as optoelectronics and photonics [1-3]. An important element of active polymers technology is doped polymers with chemical compounds containing rare earth elements [4,5]. In the literature you can find lots of information about active optical fibers doped with rare earth elements, made of different materials. Most of their concerns ions Yb^{3+}, Er^{3+}, Nd^{3+}, Tm^{3+}.

The paper presents results of thermal-optical characteristics of new nonorganic-organic hybrid materials containing in its structure admixture of rare earth elements (Tb^{3+} and Eu^{3+}), which can be successfully used in the technology of new types of active fibers. Thanks to its nearly linear dependence of the temperature on the luminescence characteristics fabricated active polymers can be used in temperature sensors.

Reference

1. D.Y. Kim, H.N Cho, C.Y. Kim, Prog Polym Sci. 11 (2000) 4450.
2. J.M. Hong, H.N. Cho, D.Y. Kim, C.Y. Kim, Synthetic Met. 102 (1999) 933.
3. S. V. Eliseeva, J.-C. G. Bünzli, New J. Chem. 35 (2011) 1165–1176.
4. T. Kobayashi, S. Nakatsuka, T. Iwafuji, K. Kuriki, N. Imai, T. Nakamoto, C. D. Claude, K. Sasaki, Y. Koike, Appl. Phys. Lett. 71 (2016) 2421.
5. C. Koeppen, S. Yamada, G. Jiang, A. F. Garito, L. R. Dalton, JOSA B 14 (1997) 155.

Combined optical and electrochemical detection of isatin by its electro-polymerization on ITO-coated lossy-mode resonance optical sensor

Magdalena DOMINIK[1], Michał SOBASZEK[2], Dariusz BURNAT[1], Robert BOGDANOWICZ[2], Vitezslav STRANAK[3], Petr SEZEMSKY[3], Mateusz ŚMIETANA[1*]

[1]Institute of Microelectronics and Optoelectronics, Warsaw University of Technology, Koszykowa 75, 00-662
[2]Warsaw, POLAND 2Department of Metrology and Optoelectronics, Gdansk University of Technology, Narutowicza 11/12, 80-233 Gdansk, POLAND
[3]Institute of Physics and Biophysics, University of South Bohemia, Branisovska 1760, 370 05 Ceske Budejovice, CZECH REPUBLIC
e-mail address: M.Smietana@elka.pw.edu.pl

This work presents an optical fiber sensors based on lossy–mode resonance (LMR) phenomenon [1] supported by indium tin oxide (ITO) thin overlay for investigation of electro-polymerization effect on ITO's surface. The ITO overlays were deposited on 2 cm-long section of exposed core of polymer-clad silica (PCS) fibers using reactive magnetron sputtering (RMS) method. Since ITO is electrically conductive and electrochemically active it can be used as a working electrode in 3-electrode cyclic voltammetry setup. In this work we investigate possibility for optical Isatin detection when it electro-polymerizes on ITO surface. Isatin (1H-indole-2,3-dione) is a versatile heterocyclic compound and it is well known as one of the most important indole present in mammalian tissues and brain [2]. Isatin is a strong endogenous neurochemical regulator in humans as it is a metabolic derivative of adrenaline [3]. Control of the Isatin level in humans and rats urine can be used as marker for Parkinson's disease [4]. For fixed potential applied to the electrode current flow decrease with time what corresponds to polymer layer formation on the ITO surface. Since LMR phenomenon depends on optical properties in proximity of the ITO surface, polymer layer formation (isatin electro-polimerization) can be monitored optically in real time.

In the measurement configuration, the ITO-based LMR sensor has been used as a working electrode in cyclic voltammetry (CV) 3-electrode configuration (Fig. 1). When constant potential is applied to the ITO-LMR sensor, the electro-polymerization takes place and the effect can be monitored by observation of changes in the sensor optical transmission spectrum. The electro-polymerization effect monitored electrically is shown in Fig. 2. During the first cycle a thin film formation process took place resulting in deposition of Isatin oxidation product at surface of the ITO electrode. Furthermore, the effect of electro-polymerization can also be seen by changes in relative optical transmission (RT) (Fig. 3). The proposed novel sensing approach provides a promising strategy for both optical and electrochemical detection of various bio-compounds and monitoring of their concentration.

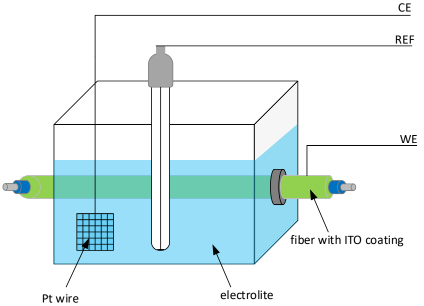

Fig. 1. Schematically shown cell allowing for combined electrochemical and optical measurements.

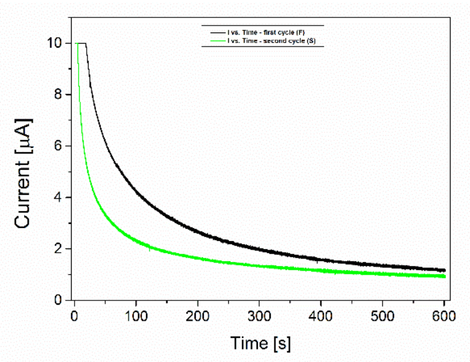

Fig. 2. Electrochemical measurements for chronoamperometry cycle resulting in Isatin electro-polymerization.

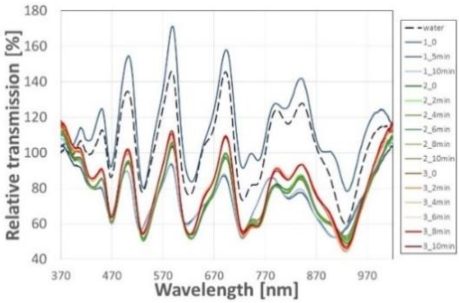

Fig. 3. Effect of the thin film electro-polymerization process on transmission of the sensor: transmission referred to response in air at different stage of the experiment and process time

Acknowledgements
This work was supported by the Polish National Science Centre (NCN) as a part of 2014/14/E/ST7/00104 project.

Reference

[1] Hernaez, M., Del Villar, I., Matias, I.R., Arregui, F.J., Zamarre, C.R., "Chemical Tunable humidity sensor based on ITO-coated optical fiber," Sensors Actuators B Chem. 146, 414–417 (2010).
[2] Medvedev, A.E., Clow, A., Sandler, M., Glover, V., "Isatin: A link between natriuretic peptides and monoamines?," Biochem. Pharmacol. 52(3), 385–391 (1996).
[3] d'Ischia, M., Palumbo, A., Prota, G., "Adrenalin oxidation revisited. New products beyond the adrenochrome stage," Tetrahedron 44(20), 6441–6446 (1988).
[4] Medvedev, A., Crumeyrolle-Arias, M., Cardona, A., Sandler, M., Glover, V.,

"Natriuretic peptide interaction with [3H]isatin binding sites in rat brain," Brain Res. 1042(2), 119–124 (2005).

Protein detection using long-period fiber gratings with nanocrystalline boron-doped diamond coating

M. FICEK[1,2], P. NIEDZIAŁKOWSKI[3], M. ŚMIETANA[4], M. KOBA[4], R. BOGDANOWICZ[1]

[1]Department of Metrology and Optoelectronics, Faculty of Electronics, Telecommunications and Informatics, Gdansk University of Technology, 11/12 G. Narutowicza St., 80-233 Gdansk, Poland

[2]Institute for Materials Research (IMO), Hasselt University, Wetenschapspark 1, B-3590 Diepenbeek, Belgium

[3]Department of Analytical Chemistry, Faculty of Chemistry, University of Gdansk, 63 Wita Stwosza Str., Gdansk, Poland

[4]Institute of Microelectronics and Optoelectronics, Warsaw University of Technology, Koszykowa 75, 00-662 Warszawa, Poland

e-mail address: mateuszficek@gmail.com

Growth processes of diamond thin films on the fused silica optical fibres with induced LPG (long-period gratings) and their biosensing applications were investigated towards detection of bovine serum albumin (BSA) used as a model protein which is the most important protein in the circulatory system. Boron nanocrystalline diamond (B-NCD) films appear to be a promising material for optical transparent electrodes in opto-electrochemical devices (Fig. 1).

B-NCD films were deposited on the fibres using the linear antenna microwave plasma enhanced chemical vapor deposition system (LA MW CVD), which can grow the diamond layers at low temperatures (below 300°C). High quality B-NCD thin films with thickness ranging from 70 nm to 150 nm were deposited on silicon, glass and optical fibre substrates. Substrate pretreatment by dip-coating and spin coating process with a dispersion consisting of detonation nanodiamond (DND) in dimethyl sulfoxide (DMSO) with polyvinyl alcohol (PVA) has been applied. During the deposition process the continuous mode of operation of the LA MW CVD system was used.

The samples were characterized by scanning electron microscopy (SEM) to investigate the morphology of B-NCD films. The film growth rate, film thickness, and optical properties in the VIS-NIR range, i.e., refractive index (n) and extinction coefficient (k) were measured on reference quartz plates using spectroscopic ellipsometry (SE). The samples exhibited relatively low deviations of n (2.4±0.3) and k (0.02±0.01), as estimated at a wavelength of 550 nm. The results of transmission measurements have demonstrated that the B-NCD overlay exhibits higher refractive index than the one for optical fiber and that is why it allows for tuning LPG response to variation in optical properties of external medium. Moreover, the low-temperature deposition process has a negligible effect on the fibre transmission properties.

As the external medium the bovine serum albumin (BSA) was studied. BSA plays a key role in the transport of metabolites, fatty acids, hormones and other components which are delivered to the cellular. The modification of the optical fiber was performed on the oxidized carbon surface by BSA using an activating compound commonly used in peptide chemistry. The activation of the carboxyl groups present on the surface of fiber initiated the coupling reaction with the amino groups present in the structure of BSA, which in consequently led to the modification of the fiber. The concentration of BSA used as modification agent was on the level of 0.15 nmol. The changes in B-NCD-coated LPG transmission spectrum as a result of immersion in liquids with different optical properties prove that the structure is suitable for label-free biosensing applications. As a response to BSA binding and formation of thin biofilm on B-NCD surface, the LPG resonances slightly split and shift towards lower wavelength. The shift is higher for higher BSA concentration

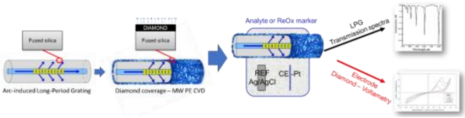

Fig. 1. Schema of developed sensing device

This work was supported by the Polish National Science Centre (NCN) under the Grants No. 2014/14/M/ST5/00715 and 2014/14/E/ST7/00104. The DS funds of Faculty of Electronics, Telecommunications and Informatics of the Gdansk University of Technology are also acknowledged

Boron doped diamond nanosheets – graphene nanostructures for electronic devices and biosensors

Mateusz FICEK[1], Michał SOBASZEK[1], Jakub KARCZEWSKI[2], Łukasz GOŁUŃSKI[1], Paweł NIEDZIAŁKOWSKI[3], Adrian NOSEK[4], Marc BOCKRATH[4], William A. GODDARD[5], Marcin GNYBA[1], Tadeusz OSSOWSKI[3] and Robert BOGDANOWICZ[1,5*]

[1]Faculty of Electronics, Telecommunications and Informatics, Gdańsk University of Technology, 11/12 Narutowicza St., 80-233 Gdansk, Poland

[2]Faculty of Applied Physics and Mathematics, Gdansk University of Technology, 11/12 G. Narutowicza St., 80-233 Gdansk, Poland

[3]Department of Analytical Chemistry, Faculty of Chemistry, University of Gdansk, 63 Wita Stwosza St., 80-952 Gdansk, Poland

[4]Department of Physics and Astronomy, University of California, Riverside, CA 92521, USA

[5]Materials and Process Simulation Center, California Institute of Technology, Pasadena, CA 91125, USA

e-mail address: robbogda@pg.gda.pl

Various carbon layered materials are of considerable interest as potential electronic materials for future diverse electronic and optoelectronic devices, including transistors, photodetectors or optical modulators. In that sense, it is also worth noting that applications are limited by nature of CVD growth of diamond. To overcome that drawbacks, the freestanding diamond foils and thin diamond nanosheets could be utilized. The boron-doped diamond nanosheets were synthetized in the MW PA CVD system (SEKI Technotron AX5400S). The diamond foils were synthesized on mirror polished molybdenum substrates. Substrate temperature was kept at 500°C during the deposition process. The growth time was 2h, producing film of a thickness ca. 500 nm1–3. The large area (up to 5 mm x 5 mm) diamond sheets have been exfoliated from the substrate using mechanical techniques and transferred to other substrates (e.g. polymers, Si/SiO2 or Si/Si3N4). The growth producing film of avg. thickness 550 nm (4.6 nm min-1) and roughness 96 nm as revealed by AFM. The molecular structure was investigated with micro-Raman Spectroscopy at both sides of diamond foil revealing strong diamond peak 1331 cm-1, while "D" and "G" band and boron doping peaks were also recorded (sp3/sp2 ratio = 0.721). The morphology judged by means of scanning electron microscopy reveals a uniform, conformal and continuous polycrystalline structure along with avg. crystallite size of 52 nm. In summary, the fabrication procedure and parameters of novel freestanding diamond nanosheets has been studied. The phenomena of unique low adhesion and delamination from substrate is under investigation (e.g. lattice mismatch, temperature stress, bonding energies). The investigations of diamond – graphene FET transistor design, as displayed in Fig. 1, will be also discussed.

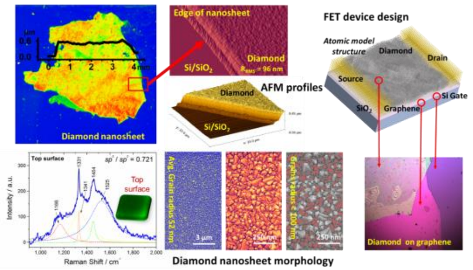

Fig. 1. Morphology and structure of diamond nanosheets

The authors gratefully acknowledge financial support from the Polish National Science Centre (NCN) under Grant No. 2015/17/D/ST5/02571. The DS funds of the Faculty of Electronics, Telecommunications and Informatics of the Gdansk University of Technology.

Reference

R. Bogdanowicz, A. Fabiańska, L. Golunski, M. Sobaszek, M. Gnyba, J. Ryl, K. Darowicki, T. Ossowski, S. Janssens, K. Haenen, and others, Diam. Relat. Mater. 39, 82 (2013).

[2]. R. Bogdanowicz, M. Śmietana, M. Gnyba, J. Ryl, M. Gardas, and others, Appl. Phys. A 116, 1927 (2014).

[3]. R. Bogdanowicz, M. Sobaszek, J. Ryl, M. Gnyba, M. Ficek, \Lukasz Go\luński, W.J. Bock, M. Śmietana, and K. Darowicki, Diam. Relat. Mater. 55, 52 (2015).

Special luminescent materials used in POF technology

Małgorzata GIL, Wiesław PODKOŚCIELNY, Beata PODKOŚCIELNA
Faculty of Chemistry, Maria Curie-Skłodowska University, Maria Curie-Sklodowska Sq. 3, 20-031 Lublin, POLAND
e-mail address: malgorzata.gil@poczta.umcs.lublin.pl

Recently, dye-doped polymers got attention because of their low cost, light weight, flexibility and processsability into thin films and optical fibers for nonlinear and linear optical applications such as photonic devices (sensors, laser diodes, data recording, wavelength conversion, light amplification, optical computing four wave mixing and optical telecommunication) [1-2].

The most important advantage of dye-doped polymers is that their properties can be optimized for high mechanical, thermal and temporal stabilities. Photoluminescent optical materials are used in different optical applications. According to Kyung Jin Lee et.al. photoluminescent dye-doped (Rhodamine B and Coumarin 6) nanofibers can be used for polymer-based nanodevices [3]. For optical telecommunication purposes difunctional dopants are especially useful as they can participate in polymerization typical for thermoplastics.

In this study synthesis and characterization of the new methacrylic derivatives of naphthalene-2,7-diol are presented. This reaction was performed in the three stages. In first stage 2,7-NAF was reacted with dimethyl sulfate in the NaOH solutions at 0oC. Next, the obtained 2,7-NAF.Me was modified by epichlorohydrine leading to epoxide compound (2,7NAF.MeEP). Finally, the reaction of opening oxirane rings by methacrylic acid was carried out.

The chemical structures of all derivatives were confirmed by ATR-FTIR, ^{1}H ^{13}C NMR and elemental analysis. New monomer (2,7-NAF.MeM) possesses only one double bond and can be used as a dopant in polymeric optical fibers (POF) technology. Their thermal, optical and luminescent properties are compared with previously obtained dimethacrylate derivatives of naphthalene-2,7-diol (2,7-NAF.DM) [4,5].

Reference

1. S. S. Gaur, K. Ghawana, V. K. Sharma and K. N. Tripathi, J. Opt. A-Pure. Appl. Op. 6, 312 (2004),
2. M. A. Diaz-Garcia, S. Fernandez De Avila, R. Dubois and R. Jerome. Appl. Phys. Lett. 80, 4486 (2002),
3. K. J. Lee, J. H. Oh, Y. Kim and J. Jang. Adv. Mater. 18, 2216 (2006),
4. B. Podkościelna, J. Therm. Anal. Calorim. 116, 785 (2014),
5. B. Podkościelna, A. Lipke, B. Gawdzik, M. Majdan, Polym. Adv. Tech. 26, 176 (2015).

The Hall mobility measurement of the highly-doped, low bandgap HgCdTe epitaxial layers

Kinga GORCZYCA, Jarosław WRÓBEL, Paweł MADEJCZYK and Piotr MARTYNIUK
Institute of Applied Physics, Military University of Technology, Gen. Sylwestra Kaliskiego 2, 00-908 Warsaw, POLAND
e-mail address: kinga.gorczyca@wat.edu.pl

Mercury cadmium telluride material is used in high performance infrared detectors. Its extremely beneficial properties such as: very good compatibility of lattice constants between HgTe and CdTe and its thermal expansions, the possibility of linear modification of energy bandgap with molar composition x, the high values of absorption coefficient, quantum efficiency, carriers mobility and carriers lifetime and low dielectric constant make that such material is considered to be the best for infrared detection aplications for more than 40 year [1].

Currently one of the main object of interests of Solid State Physics Department in the Institute of Applied Physics Military University of Technology – in the Hg1-xCdxTe research context – is the verification of models of charge carriers transport in highly-doped layers. It is connected with the theory of formation of additional bands originating from wave functions of doping atoms. In such theory bands are assumed to change the nature of charge carriers transport for multi-channel one [2].

In our researches two photoresistors made of Hg1-xCdxTe have been used. It have been grown by metaloorganic chemical vapour deposition - MOCVD. The first photoresistor has been made from the layer marked by the number: 3704. It parameters was the following: thickness – 4.5 µm, the molar composition x = 0.315 and the donor doping level is equal 3.0×1017 cm-3. The second photoresistor has been made from the layer with the no. 3916. It thickness was 8.84 µm, x = 0.173 and acceptor doping level 4.0×1017 cm-3. In order to find an arguments for multi-channel transport, we have made electrical characterization of the two samples in the function of constant magnetic field and temperature.

The characterization has been performed using the Cryogenic Ltd company system – CFMS 16 T. Its main part consists of superconducting electromagnet, which the highest values of the magnetic field induction (B) placed in the center of the magnet can be adjusted up to ± 16 T. The built in cryostat stabilizes the temperature of the sample in the range of 1.6 K-325 K and makes possible the measurement in the two relative to the field lines orientations: perpendicular and parallel [3]. The presented results refers in our case to only one orientation – perpendicular. It contains resistivity measurements made by van der Pauw method and the Hall effect data. The examples of Hall mobility data for the sample number 3704 has been presented on the Fig. 1.

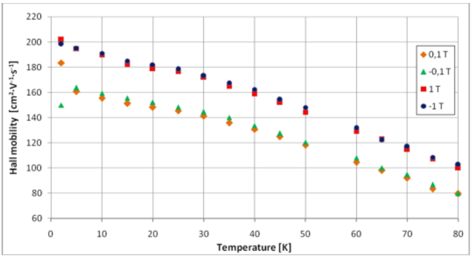

Fig. 1. The examples of temperature dependence of the Hall mobilities for the sample number 3704 for four values of magnetic field

Preliminary measurement results indicate that the behavior of the samples conductivity is difficult to explain relying on the simple two-band model. This may indicates on the existence of expected doping bands.

Acknowledgments
This study was carried out with the financial support from the National Science Center (grant no. TANGO1/266576/NCBR/2015).

Reference

1. A. Rogalski, Infrared Detectors, Second Edition, CRC Press. 2010,
2. E. Finkman, Y. Nemirovsky, J. Appl. Phys. 53, 1052 (1982),
3. Cryogenic Ltd, Cryogen-Free Magnet System User Manual, London 2014,

Calculations of dark current in mid-wavelength infrared type-II InAs/GaSb superlattice interband cascade photodetectors

Klaudia HACKIEWICZ, Piotr MARTYNIUK, Jarosław RUTKOWSKI, Andrzej KOWALEWSKI
Institute of Applied Physics, Military University of Technology, 2 Kaliskiego Str., 00–908 Warsaw, POLAND
e-mail address: klaudia.hackiewicz@wat.edu.pl

Interband (IB) cascade type II mid wavelength infrared (MWIR) InAs/GaSb superlattice detector in temperature range from 200K to 300K is investigated.

A single stage in the cascade is a double heterostructure with the absorber sandwiched between electron and hole barriers. The conduction bands and the valence bands of adjacent absorbers are connected in series using an interband tunneling heterostucture.

This structure exhibited a cutoff wavelength in the midwave infrared domain, near 4.8 µm at 200K. The absorber region is non-intentionally doped and is made of MWIR 9ML InAs/9ML GaSb T2SL [1] (see Fig. 1). At low temperatures structure has a residual doping of p-type, but at room temperature the SL is n-type with n(300K) = 1016cm-3 [2].

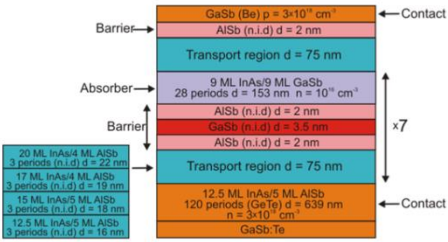

Fig. 1. Structural schematic of the MWIR T2SL cascade detector [after Ref. 1]

We present detailed studies of the temperature dependence characteristics (current responsivity and I-V characteristics) of seven-stage device. These measurements were useful for the calculations of dark current treated as a sum of two currents: average bulk current Ib and average surface current Is, which flow through the device. Average bulk current Ib was theoretically calculated [3], while the average surface current Is resulted from a comparison of theoretically bulk current and measured current.

We show that it is possible to fit our experimental data to theoretical model (Fig.2), assuming that transport in absorber is determined by the dynamics of the intrinsic carriers. Based on the fit we estimated lifetime of carrier greater than 100 ns in temperature range 200K - 300K.

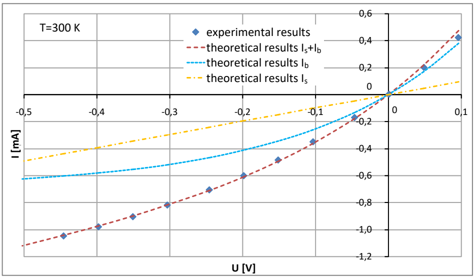

Fig. 2. Measured and modeled dark current versus bias voltage of T2SL InAs/GaSb cascade detector at 300K

Acknowledgments
We acknowledge support by The National Science Centre - the grant no. OPUS/UMO-2015/19/B/ST7/02200 and PBS 653.

Reference

1. N. Gautam, S. Mayers et al., Appl. Phys. Lett. 101, 021106 (2012),
2. P. Christol, C. Cervera et al., Proc. SPIE 7608, 76081U (2010),
3. R.T. Hinkey, R.Q. Yang, J. Appl. Phys. 114, 104506 (2013).

InAs/GaSb superlattice quality investigation

Aleksandra HENIG[1], Kacper GRODECKI[1], Krzysztof MURAWSKI[1], Krystian MICHALCZEWSKI[1,2], Łukasz KUBISZYN[2], Djalal BENYAHIA[1,2], Piotr MARTYNIUK[1], Bartłomiej JANKIEWICZ[3], Bogusław BUDNER[3]

[1]Institute of Applied Physics, Military University of Technology, 2 Kaliskiego Str., 00–908 Warsaw, POLAND
[2]VIGO System S.A., 129/133 Poznanska Str., 05–850 Ozarow Mazowiecki, POLAND
[3]Institute of Optoelectronics, Military University of Technology, 2 Kaliskiego Str., 00–908 Warsaw, POLAND
e-mail address: aleksandra.henig@wat.edu.pl

InAs/GaSb superlattices are widely used in mid-wavelength infrared (MWIR) and long-wavelength infrared (LWIR) optoelectronic devices due to their narrow, direct bandgap, as well as an ability to tune to the entire mid and long wave infrared spectrum [1, 2].

n this work we compare two InAs/GaSb superlattice samples {(A) grown in 3950C and (B) grown in 3150C} grown in MBE VIGO/MUT laboratory on 2 inch (001) GaAs substrate. Both samples were obtained using MBE technique [3].

The photoluminescence measurements were performed at 30 K. For the sample A there is no photoluminescence signal, while spectrum for the B sample consists of two peaks: bandgap peak at 0.5 eV and deep state peak at 0.25 eV (fig. 1). X-Ray Diffraction (XRD) measurements show that sample A has better crystallographic quality than sample B.

Raman Spectroscopy results are shown in fig. 2. Low energy peaks (20-100 cm-1) indicate the existence of superlattice for both samples [4]. Additionally, for sample A there are peaks related to Sb precipitates (fig. 2) [5]. It suggests that except the InAs/GaSb superlattice there is an additional Sb layer which may disturb band structure of superlattice and cause the disappearance of photoluminescence for sample A.

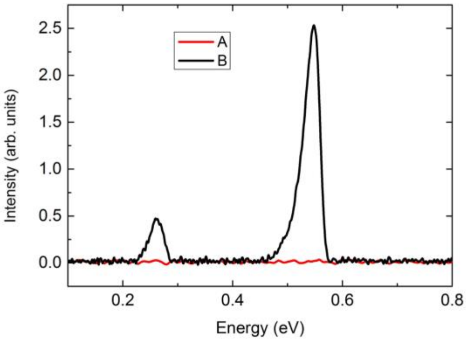

Fig. 1. Photoluminescence spectra of InAs/GaSb superlattice

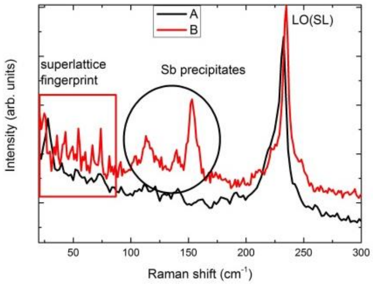

Fig. 2. Raman spectra of InAs/GaSb superlattice. For both samples superlattice fingerprint is marked by red rectangle, for

sample A Sb precipitates bands are marked by black circle

Acknowledgements

We acknowledge support by The National Science Centre - the grant no. OPUS/UMO-2015/19/B/ST7/02200 and PBS 653.

Reference

1. M. Razeghi, S. Abdollahi Pour, E. K. Huang, G. Chen, A. Haddadi, B. M. Nguyen, Opto-El. Rev. 19, 261 (2011),

2. C. Jagadish, S. Gunapala, D. Rhiger, Advances in Infrared Photodetectors, Elsevier 2011,

3. R. Hao, Y. Xu, Z. Zhou, Z. Ren, H. Ni, Z. He, Z. Niu, J. Phys. D: Appl. Phys. 40, 6690 (2007),

4. N. Herres, F. Fuchs, J. Schmitz, K. M. Pavlov, J. Wagner, J. D. Ralston, P. Koidl, C. Gadaleta, G. Scamarcio, Phys. Rev. B. 53, 15688 (1996),

5. B. Arpapay, S. Şahin, B. Arıkan, U. Serincan, Thin Solid Films, 564, 110 (2014).

Experimental elaboration and analysis of various dye-sensitized TiO_2 solar cells (DSSCs)

P. KAŁUŻYŃSKI*, E. MACIAK

Department of Optoelectronics Silesian University of Technology, Akademicka 2A, Gliwice, 44-100, Poland

*e-mail address: *piotr.kaluzynski@polsl.pl*

Dye-sensitized solar cells (DSSCs) which are combination of unique properties of both the organic compound and inorganic semiconductor compound (TiO_2) have attracted the attention of optoelectronics engineers and interdisciplinary scientists. Nowadays scientific works on solar cells are focused in efficiency increasing and finding novel materials and technology for overall solar cell improvements. On the market, there are plenty conventional solar cells such as silicon solar cells or cells based on compounds like Cadmium Tellurium (CdTe) or Sulphur Tellurium (CdS), which are the most widespread and utilized by scientist and end-users, although these solutions are high cost in the process of manufacturing and implementation on the market, so they still do not represent competition for energy sources based on fossil fuels. [1]

In this paper we propose low cost and easy in development, fully working dye-sensitized solar cell module (Fig 1.) made with use of a different sensitizing dyes (anthocyanins for DSSC and conductive polymers like P3HT for hybrid-cells), semi-transparent condictive substrates (vaccum spattered gold), nanometer sized TiO_2 film, iodide or Viologen electrolyte, and a counter electrode (vaccum spattered platinum or carbon) [2, 3, 4]. Moreover, some of the different technologies, such as adding a thin layer of nanoparticles of graphite oxide or optimization of manufacturing processes, were elaborated for energy efficiency increase and were presented in this project [3].

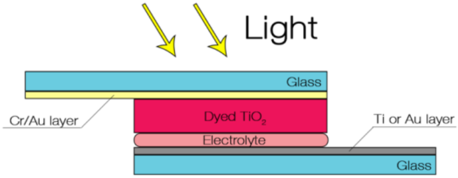

Fig. 1. Structure of elaborated DSSC.

Reference

[1]. Junghänel Matthias: Novel aqueous electrolyte films for hole conduction in dye sensitized solar cells and development of an electron transport model, 2007

[2]. Carbó-Vela Pablo C. et al.: Construction of dye-sensitized solar cells (DSSC) with natural pigments, Advances in Functional Materials (Conference 2015), AFM 2015

[3] P. Kałużyński; E. Maciak; T. Herzog; M. Wójcik.: Experimental elaboration and analysis of dye-sensitized TiO_2 solar cells (DSSC) dyed by natural dyes and conductive polymers, Proc. SPIE 10031, Photonics Applications in Astronomy, Communications, Industry, and High-Energy Physics Experiments 2016

[4]. H. M. Smith and N. J. Ekins-Daukes: Blueberry Electricity: An Experimental

Introduction and Analysis of Fruit and Chlorophyll based Dye-Sensitised Solar Cells, Fruit and Chlorophyll Based DSSC, ANZSES Solar 07

Theoretical simulation of the long-wave HgCdTe detector for ultra fast response - operating under zero bias and room temperature condition

Piotr MARTYNIUK, Paweł MADEJCZYK, Jarosław RUTKOWSKI
Institute of Applied Physics, Military University of Technology, 2 Kaliskiego Str., 00–908 Warsaw, POLAND
e-mail address: piotr.martyniuk@wat.edu.pl

There are many applications to include gas sensing where HgCdTe long-wave (8–12 μm) infrared radiation (LWIR) detector reaching ultra fast response < 1 ns operating under zero bias condition (1/f noise contribution is limited) and room temperature are implemented [1, 2].

The multilayer detector's architecture for zero bias condition, where recombination decay in p type absorber region, transport by diffusion and drift transit time across the depletion areas to collection contacts is presented in the paper [3].

Detector structure was simulated with software APSYS by Crosslight Inc. [4]. The response time was calculated as photocurrent's ~ 1/e decay from its maximum value using
Li et al. model implemented in APSYS platform [5]. The dependence of response time characteristics for selected active layer compositions corresponding to the cut-off wavelength ~ 8.05–11 μm at T = 300 K was simulated. The presented structure exhibits response time within the range $\tau_s \approx$ 400–440 ps operating under zero bias voltage and no extra series resistance (R_{Series}).

Example of energy band profile of the simulated heterostructure for unbiased condition operating at room temperature and exhibiting ultra fast response time is presented in Fig. 1. Absorber thickness was assumed d = 1 μm, while doping $N_A = 10^{17}$ cm^{-3}. Both contact layers are highly doped $N_D = 5\times10^{17}$ cm^{-3}. The barrier's composition and doping were assumed at the level x_{Cd} = 0.25 and $N_A = 5\times10^{17}$ cm^{-3}.

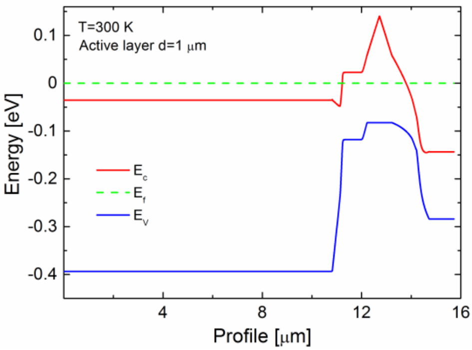

Fig. 1. Energy band diagram of the structure for ultra fast response time at 300 K

Device resistance/diffusion capacitance was calculated at the level of ~3.5–3.8 Ω/~ 80–95 pF assuming absorbers x_{Cd} = 0.17–0.19 while ambipolar diffusion coefficient was assessed Da = (1.58–2.94)×10^{-3} m2/Vs. Response time analysis versus extra RSeries being dependent on processing is presented in Fig. 2 respectively. The highest contribution of the R_{Series} is visible in the range up to 5 Ω. Fig. 3 depicts response time versus active layer composition showing optimal xCd dependence on extra R_{Series}.

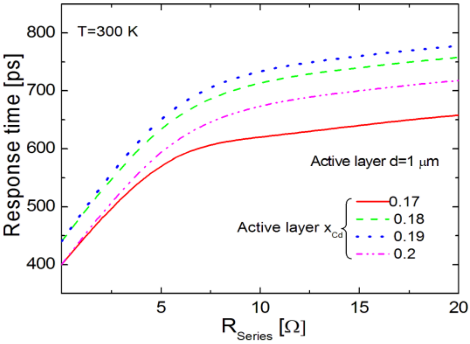

Fig. 2. Response time versus extra R_{Series} for selected active layer x_{Cd} at 300 K

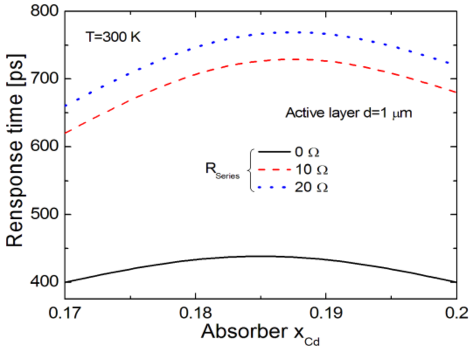

Fig. 3. Response time versus active layer x_{Cd} at 300 K

Acknowledgments We acknowledge support by The National Centre for Research and Development-the grant no. TANGO1/2665576/NCBR/2015.

Reference

1. J. Piotrowski, A. Rogalski, High operation temperature photodetectors, SPIE, Bellingham 2007,
2. J. Wojtas, et. al., Opto-Electron. Rev., 20, 26–39 (2012),
3. J. Pawluczyk, et al., J. Electron. Mater., 44, 3163–3173 (2015),
4. APSYS Macro/User's Manual ver. 2011. Crosslight Software, Inc. (2011),
5. Q. Li, et al., IEEE Trans. Electron Devices, 38, 1285–1288 (1991).

Raman and photoluminescence investigation of InAs/GaSb and InAs/InAsSb superlattices

Krzysztof MURAWSKI[1], Kacper GRODECKI[1], Aleksandra HENIG[1], Krystian MICHALCZEWSKI [1,2,] Łukasz KUBISZYN[2], Djalal BENYAHIA[2], Piotr MARTYNIUK[1], Bartłomiej JANKIEWICZ[3], Bogusław BUDNER[3]

[1] Institute of Applied Physics, Military University of Technology, 2 Kaliskiego Str., 00–908 Warsaw, POLAND

[2] VIGO System S.A., 129/133 Poznanska Str., 05–850 Ozarow Mazowiecki, POLAND

[3] Institute of Optoelectronics, Military University of Technology, 2 Kaliskiego Str., 00–908 Warsaw, POLAND *e-mail address: krzysztof.murawski01@wat.edu.pl*

InAs/GaSb and InAs/InAsSb superlattices (SL) are attractive materials for infrared technology, especially for fabrication of infrared photodetectors [1,2].

In this work we compare two superlatices: InAs/GaSb (sample A) and InAs/InAsSb (sample B) grown in laboratory MBE VIGO/ MUT on 2 inch (001) GaAs substrate. Both samples were grown using MBE technique[3].

The photoluminescence spectrum (fig.1) of the sample A consists of two peaks: bandgap peak at 0.5 eV and deep state peak at 0.25 eV. Spectrum for the sample B (fig.1) consists of one bandgap peak at 0.17 eV. The results are in agreement with ref 1 and 4. X-Ray Diffraction (XRD) measurements show low crystal quality for both samples.

Raman spectrum for the sample A (fig.2) shows LO superlattice peak and two low energy peaks, which are the superlattice fingerprints. They confirm existence of superlattice for this sample.

For the sample B (fig.2) there is also LO superlattice peak, as well as low energy superlattice peaks for some of the obtained spectra. It suggests the existence of inhomogeneous superlattice in sample B. Superlattice period of both samples was calculated from low energy Raman bands with method presented in ref 5.

For sample A the obtained period is 5.8 Å[5]. For sample B its value was calculated using the speed of sound in InAs/InAs0.65Sb0.35 superlattice obtained through numerical calculations based on the material parameters[6,7]. The obtained period is 8.3 Å. Values obtained for both samples are in agreement with XRD measurements.

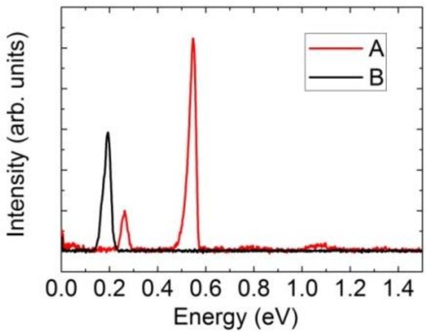

Fig. 1. Photoluminescence spectra of samples A and B

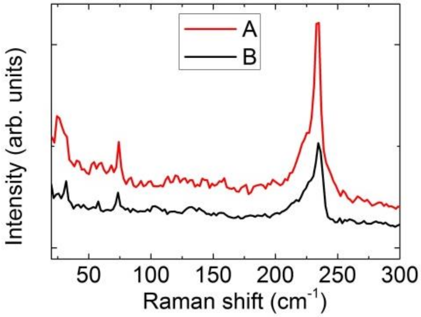

Fig. 2. Raman spectra of samples A and B

Acknowledgments We acknowledge support by The National Science Centre - the grant no. OPUS/UMO-2015/19/B/ST7/02200 and PBS 653.

Reference

1. E. H. Steenbergen, J. A. Massengale, G. Ariyawansa, Y. H. Zhang, J. Lumin. 178, 451 (2016),
2. Y. Wei, A .Gin, M.Razeghi, G. J. Brown, Appl. Phys. Lett. 81, 3675 (2002),
3. R. Hao, Y. Xu, Z. Zhou, Z. Ren, H. Ni, Z. He, Z. Niu, J. Phys. D: Appl. Phys. 40, 6690 (2007),
4. J. Huang, W. Ma, Y. Wei, Y. Zhang, K. Cui, Y. Cao, X. Guo, J. Shao, IEEE J. Quant. Electron. 48, 1322 (2012),
5. B. Aslan, M. Korkmaz, Appl. Surf. Sci. 362, 244 (2016),
6. U. Rössler, D. Strauch, Group IV Elements, IV-IV and III-V Compounds. Part a-Lattice Properties, Springer Berlin Heidelberg (2001),
7. A. Belabbes, A. Zaoui, M. Ferhat, Mater. Sci. Eng. B 137, 210 (2007).

Optoelectronics sensors of hydrocarbons based on NDIR technique

Artur PROKOPIUK, Jacek WOJTAS
Institute of Optoelectronics, Military University of Technology, 2 Kaliskiego Str., Warsaw 00-908, POLAND
e-mail address: artur.prokopiuk@wat.edu.pl

Saturated hydrocarbons are mainly nontoxic, but as extremely flammable gases forming explosive mixtures with air. The Lower Explosive Level (LEL) for methane is 4.4%, which is very dangerous in mining industry [1]. Methane is also an asphyxiant gas causing coma or death. The serious hazardous problem is also propane due to its commonly application as domestic and industrial fuel. The LEL of the propane is 2.37%, thus very small gas leaks may cause explosions. Therefore, continuous monitoring of the hydrocarbons concentration is very important.

Optoelectronic methods are very attractive for this applications, especially nondispersive infrared (NDIR) technique. The principle of operation such sensors consist in infrared radiation absorption by gas at a specific wavelength [2]. It enables a direct, fast and selective measurements of different gas concentration. NDIR technique is low-cost and perspective thanks to intensive advances in optoelectronic technology, especially technologies of photodetectors and radiation sources.

A typical NDIR setup includes IR source, absorption cell equipped with gas, two optical filters and two detectors. One of the detectors is designed for background radiation monitoring (Fig. 1).

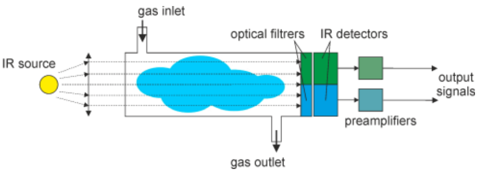

Fig. 1 NDIR sensor scheme.

NDIR sensors have many advantages, which make them very promising for use as hydrocarbons detectors:

• long-term use; when using miniature lamp bulb as an infrared radiation source, typical lifetime of the sensor is up to 5 years maximum, but using LED radiation source lifetime can be even more than 15 years;

• there is no problem with poisoning if NDIR sensor is exposed to high gas concentrations, H_2S or chlorinated atmosphere impact;

• they can be used to fast and continuous monitoring the high concentration of measured gases without loses of sensitivity and without reduction of lifetime.

Despite a lot of benefits, common used NDIR sensors have some disadvantages as well:

• needs periodic calibration, but less frequently than other type of gas sensors (e.g.: one per year);

• limited detection range, in practical application from ~100ppm up to 100% LEL.

These parameters can be improved thanks to modernization detection scheme and use of newest IR sources and detectors [3]. During analyses selected IR sources (e.g.: LEDs, miniature bulbs, thin film sources) and different IR detectors (pyroelectric, thermocouple, photodetector) were taken into account. Furthermore, absorption spectra of analyzed hydrocarbons were studied to minimize adverse impact interfering gases like carbon dioxide and water.

Acknowledgments: works carried out in the laboratory of Institute of Optoelectronics MUT, supported by project "Laser systems of directed-energy weapons, laser systems of non-lethal weapons", DOB-1-6/1/PS/2014.

Reference

[1] H. Kucuker, "Occupational fatalities among coal mine workers in Zonguldak, Turkey", 1994-2003, Occup Med (Lond). 2006 Mar;56(2):144-6.

[2] J. Wojtas, J. Mikolajczyk, M. Nowakowski, B. Rutecka, R. Medrzycki, Z. Bielecki, "Applying CEAS method to UV, VIS, and IR spectroscopy sensors", Bulletin of the Polish Academy of Sciences, Technical Sciences, Vol. 59, No. 4, pp. 1-10 (2011).

[3] M. Kwaśny, K. Kopczyński, M. Miczuga, M. Kopica, Z. Mierczyk, J. Mierczyk, "Optyczne metody wykrywania metanu w powietrzu", Ochrona przed skutkami nadzwyczajnych zagrożeń. Tom 3, Warszawa 2012

Spectroelectrochemical sensing with Mach–Zehnder interferometer - route toward extreme sensitivity of biomolecules detection

Michał SOBASZEK[1], Marcin STRĄKOWSKI[1], Łukasz SKOWROŃSKI[2], Jerzy PLUCIŃSKI[1] and Robert BOGDANOWICZ[1]

[1]Department of Metrology and Optoelectronics, Faculty of Electronics, Telecommunications and Informatics, Gdansk University of Technology, 11/12 G. Narutowicza St., 80-233 Gdansk, Poland

[2]Institute of Mathematics and Physics, University of Technology and Life Sciences, Kaliskiego St 7, 85-789 Bydgoszcz, Poland

e-mail address: michal.sobaszek@pg.gda.pl

Boron-doped nanodiamond layers (B-NCD) can be used in marker free electrochemical sensors[1], electronics (high power switches, high temperature electronics)[2,3], photovoltaics[4] and those areas that demand of transparent protective coating. Diamond layers due to its biocompatibility, can be used to identify a wide variety of proteins, cancer cells, viruses, and analysis of the blood and the levels of heavy metals in the body. In addition, diamond layers can be used in the food industry for detecting impurities like organic compounds, e.g. toxins. In order to detect important biologically organic compounds and the assessment of the modification nanodiamond layers was built a measuring system using interferometry. Change of the refractive index is correlated with the electrochemical process taking place.

The paper shown the optically transparent B-CNW layers applied to measurement system based on the Mach-Zehnder interferometer. Parameters of B-CNW layers such as surface morphology, molecular structure, optical indices or electrochemical performance are discussed. The synthesis of the B-CNW layers was carried out in the MWPACVD process using a special truncated cone-shape shim. This procedure allowed for change of the geometrical plasma excitation with form bubble-like to a spherical ring (O-ring). This modification has a significant impact on the growth rate of diamond and crystalline structure of the layer. B-CNW films achieved low surface roughness of surface equal to 10 nm, refractive index n = 2.15 at a wavelength of 632 nm, and the optical transmittance at 65%. In addition, synthesized layers are characterized by electrochemical window equal to 1.85 V vs. Ag/AgCl/3 KCl and very good reversibility of the reaction redox ions $Fe(CN)_6^{3-/4-}$ equal to $\Delta E = 101$ mV.

The construction of the detection system based on the Mach-Zehnder interferometer was developed. The representative organic compounds melamine and isatin was described. Melamine is a representative organic compound of amine group used for surface modification to obtain an organic link between the electrode and the detected organic compound e.g. linker of nucleic acid. Isatin is an organic compound that is a derivative of adrenaline, and also is considered to be a potential marker of stress. This particular compound is difficult to sense using electrochemical detection. Thus, the electrochemical, spectroelectrochemical and interferometry analysis is shown utilizing these compounds as reference analytes.

The result of the this study is a new approach of the spectroelectrochemical measurements involving interferometry. Obtained results confirm that the presented in situ interferometric diagnostic of electrode modification is efficient enough to substitute *ex situ* complex measurement techniques like X-ray Photoelectron Spectroscopy. Furthermore, Isatinu detection was performed for concentrations of 500, 100 and 10 μM. The achieved level of detection allows for recognition of much lower concentrations. Such a sensing system could be applied for the study of the concentration of this stress marker in body fluids such as blood or urine.

Acknowledgments

This work was supported by the Polish National Science Centre (NCN) under the Grants No. 2014/14/M/ST5/00715 and 2014/14/E/ST7/00104. The DS funds of Faculty of Electronics, Telecommunications and Informatics of the Gdansk University of Technology are also acknowledged.

Reference

[1] Fortin, E., Chane-Tune, J., Mailley, P., Szunerits, S., Marcus, B., Petit, J.-P., Mermoux, M.., Vieil, E., "Nucleosides and ODN electrochemical detection onto boron doped diamond electrodes," Bioelectrochemistry 63(1–2), 303–306 (2004).

[2] Achard, J., Silva, F., Issaoui, R., Brinza, O., Tallaire, A., Schneider, H., Isoird, K., Ding, H., Koné, S., et al., "Thick boron doped diamond single crystals for high power electronics," Diam. Relat. Mater. 20(2), 145–152 (2011).

[3] Yoneda, H., Tokuyama, K., Ueda, K., Yamamoto, H.., Baba, K., "High-power terahertz radiation emitter with a diamond photoconductive switch array," Appl. Opt. 40(36), 6733–6736 (2001).

[4] Polyakov, V. I., Perov, P. I., Rossukanyi, N. M., Rukovishnikov, A. I., Khomich, A. V., Prelas, M. A., Khasawinah, S., Sung, T.., Popovici, G., "Photovoltaic effects in metal/semiconductor barrier structures with boron-doped polycrystalline diamond films," Thin Solid Films 266(2), 278–281 (1995).

The photonic sensor measuring the exchange of gases, in particular CO2 in the area of the forest atmosphere

Piotr SOBOTKA, Marcin BIEDA, Tomasz WOLIŃSKI
Faculty of Physics, Warsaw University of Technology, Koszykowa 75, 00-662 Warszawa, POLAND
e-mail address: sobotka@if.pw.edu.pl

Currently, the most widely used scale of ecosystem is an eddy covariance method . It allows the measurement of any gas stream that goes between the surface of the ecosystem and the atmosphere. In the past, this method was limited by the lack of sufficiently fast and accurate analyzers, that could measure the concentration of trace gases in the free atmosphere.
In Poland there are currently several research stations using the EC method.

The network of photonic CO2 sensors is based on a distributed sensing elements, which are spread around the tested volume ecosystem. Each sensing element is connected to a wireless network with the adjacent sensing elements and the base station, which collects, archives and analyzes the results of measurements. The composition of each sensing element includes a CO2 sensor module for data transmission as well as power supply module, that analyzes the speed and direction of flow of the air mass within the specified measurement point.

Reference

1. B. Chojnicki, M. Urbaniak, A. Danielewska, P. Strzeliński, J. Olejnik, Pomiar wymiany dwutleku węgla oraz biomasy w ekosystemach leśnych-stacja pomiarowa w Tucznie, Studia i Materiały Centrum Edukacji Przyrodniczo-Leśnej, 11(2), 247-256, 2009
2. K .Ziemblińska, M. Urbaniak, A. Danielewska, M. Baran, R. Juszczak, B. Chojnicki, J. Olejnik, Sezonowy przebieg wskaźnika wykorzystania wody (WUE) w lesie sosnowym, Rocznik Ochrona Środowiska., 2013,Vol. 15.

Straight and bended high refractive index channel waveguides – theoretical analysis

Cuma TYSZKIEWICZ, Paweł KARASIŃSKI
Department of Optoelectronics, Silesian University of Technology, Krzywoustego 2, 44-100 Gliwice, POLAND
e-mail address: cuma.tyszkiewicz@polsl.pl

Planar evanescent wave sensors (EWS) are being used for detection of the presence of (bio)chemical compounds as well as for studying kinetics of biochemical reactions [1]. Their spectrum of application includes biomedicine, pharmaceutical industry, biotechnology, diagnostics as well as in-situ environmental monitoring. Comparing to other types of transducers, e.g. resistive transducers, planar EWS can have very high sensitivities especially if a phase detection scheme is used. Achievement of high sensitivities is conditioned by application of a single mode slab, rib or channel waveguides having high refractive index contrast [2]. Achievement of EWS parameters stability is conditioned by application of chemically resistant waveguide films [3]. We have developed fabrication technology of silica-titania rib waveguides characterized by high refractive index (~1.81 for λ=635 nm), very high homogeneity and smoothness, chemical resistance and stability of their parameters over long time period [4]. In the first part of this work there is presented the theoretical analysis of an influence of silica-titania rib waveguides geometric parameters - rib height *t*, width w and thickness of a parent slab waveguide *H* on their single mode behavior and on homogeneous sensitivity characteristics. The schematic view of the rib waveguide cross-section is shown in Fig.1. In the second part, there is presented the theoretical analysis of the influence of rib height and radius of bended silica-titania rib waveguides curvature on their bend losses.

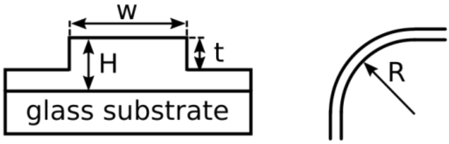

Fig. 1. Schematic of the rib waveguide, *t* - rib height, *w* - rib width, *H* - base slab thickness, R - radius of curvature.

Effective indices of straight rib waveguides were calculated using a FMM method implemented in the FIMMWAVE 6.3 solver, whereas effective indices and bend losses of curved rib waveguides were calculated in two steps. In the first step a complex FDM solver with transparent boundary conditions was used. An initial mode list obtained this way was polished using the FMM method. A range of values of rib height *t* in which the rib waveguide is single mode for a given value of width *w* was derived from a set effective index characteristics of rib waveguide and its base slab waveguide There were extracted characteristic values of *t*, for which for given polarization, rib waveguide modes are cut-off, t_{cff}, and the rib waveguides have the same effective index as its parent slab, t_{sst}. It was shown that there is a range of rib width values in which there are two ranges of rib height values in which the rib is single mode for quasi-TM polarization separated by a range in which the first order TM_{10} mode is guided. It was shown that if a thickness *H* of the base slab is chosen so that a homogeneous sensitivity, for given polarization, is maximized, than formation of rib results in decrease of rib waveguide homogeneous sensitivity. It was shown how to choose a thickness of the base slab in order to maximize a sensitivity of the rib waveguide.

Analysis of bend losses characteristics in function of rib height have shown that silica-titania bended rib waveguides are appropriate for design of planar integrated optical circuits.

Reference

1. P. Kozma et. al., Integrated planar optical waveguide interferometer biosensors: A comparative review. Biosens. Bioelectron., 58, pp. 287–307 (2014)
2. P. Karasiński, R. Rogoziński, Characterization and sensor properties of sol-gel SiO2:TiO2/ion-exchange glass waveguide, Opt. Commun., 281, pp. 2472-2480 (2008)
3. J.J. Ramsden, Review of new experimental techniques for investigating random sequential adsorption, J. Stat. Phys., 73, pp. 853-877 (1993)
4. P. Karasiński, C. Tyszkiewicz, A. Domanowska, A. Michalewicz, J. Mazur, Low loss, long time stable sol-gel derived silica-titania waveguide films, Mater. Lett., 143, pp. 5-7 (2015)

Optical skin phantoms for calibration medical lasers

Michal WĄSOWICZ[1], Anna SĘKOWSKA[1], Maciej WRÓBEL[2], Marcin Mrotek[2], Stanisław GALLA[2], Adam CENIAN[3], Małgorzata JĘDRZEJEWSKA-SZCZERSKA[2]

[1]Warsaw University of Life Sciences, Faculty of Veterinary Medicine Address: ul. 02-776 Warsaw
[2] Faculty of Electronics, Telecommunications and Informatics, Gdańsk University of Technology, 11/12 Narutowicza St., 80-233 Gdansk, Poland
[3] Institute of Fluid Flow Machinery Polish Academy of Science, Fiszera 14 st. Gdańsk 80-231, Poland

e-mail address: michal_wasowicz@sggw.pl, mjedrzej@eti.pg.gda.pl

Extensive research in the area of optical sensing for the medical diagnostics requires the development of tissue phantoms with optical properties similar to those of living human tissues. Development and improvement of in vivo optical measurement systems requires the use of stable tissue phantoms with known characteristics, which are mainly used for calibration of such systems and testing their performance over time. In this paper, we focus on the development of phantoms with optical properties (reduced scattering coefficient $\mu s'$ and absorption coefficient μa) corresponding to the human skin. Those phantoms were used for calibration of a new dermatological laser with central wavelength 975 nm. These studies were carried out to test the laser interaction with the skin. The temperature distribution in the phantom after laser radiation was examined to determine the optimal and safe laser parameters (power, pulse duration, and its repetition rate) during treatment. The interaction of the 975-nm laser radiation with tissue phantoms was studied as a preclinical trial of laser treatment effects.

Long-range network formation in nematic liquid crystals doped with gold nanoparticles in 1D photonic structure

Karolina BEDNARSKA[1*], Piotr LESIAK1, Kamil ORZECHOWSKI[1], Miłosz CHYCHŁOWSKI[1], Michał WÓJCIK[2] and Tomasz WOLIŃSKI[1]

[1]Faculty of Physics, Warsaw University of Technology, Koszykowa 75, 00-662 Warszawa, POLAND
[2]Faculty of Chemistry, University of Warsaw, ul. Pasteura 1, 02-093 Warszawa, POLAND
e-mail address: bednarska@if.pw.edu.pl

Recent advances in microfluidics and nanophotonics have led to a newly emerging field known as optofluidics, which in a complementary way merges both photonics and fluidics. In optofluidic systems fluids give fine adaptability, mobility, and accessibility to nanoscale photonic devices that otherwise could not be realized by using conventional devices [1-2]. There has been a significant activity in the field of optofluidics based on micro-channels filled with liquid crystal (LC) colloids. This fluid consisting of colloidal particles or liquid droplets dispersed in nematic liquid crystals. Many experiments have shown that mixtures of a colloidal particle and a nematic liquid crystal solvent have a variety of phase separations [3–10] and 2D crystalline structures. Coupling to the LC orientational elasticity tends to expel the colloids and the suspension shows a phase separation into an almost pure nematic phase coexisting with a colloidal rich phase [5]. In this work we have investigated the use of colloidal particles and a nematic liquid crystal solvent to create a network in the form in a 1D photonic structure. We have focused on structures formed by high concentrations of Au NPs in the 5CB nematic phase byusing polarized optical microscopy. Upon heating from the nematic phase to the isotropic liquid, the NPs reversibly self-assemble into highly regular networks whose morphologies and associated LC patterns are controlled by the heating rate, concentration, and elastic properties of the LC.

Reference

1. D. Psaltis, S. Quake, C. Yang, Nature 442, 381–386 2006
2. C. Monat, P. Domachuk, B. Eggleton, Nat Photonics 1, 106–114 2007
3. S. P. Meeker, W. C. K. Poon, J. Crain, and E. M. Terentjev, Phys. Rev. E 61, R6083 2000
4. J. Yamamoto and H. Tanaka, Nature London 409, 321 2001
5. V. J. Anderson, E. M. Terentjev, S. P. Meeker, J. Crain, and W. C. K. Poon, Eur. Phys. J. E 4, 11 2001
6. J. Cleaver and W. C. K. Poon, J. Phys.: Condens. Matter 16, S1901 2004
7. D. Vollmer, G. Hinze, W. C. K. Poon, J. Cleaver, and M. E. Cates, J. Phys.: Condens. Matter 16, L227 2004
8. V. J. Anderson and E. M. Terentjev, Eur. Phys. J. E 4, 21 2001

9. M. Caggioni, A. Giacometti, T. Bellini, N. A. Clark, F. Mantegazza, and A. Maritan, J. Chem. Phys. 122, 214721 2005

10. J. C. Loudet, P. Barois, P. Auroy, P. Keller, H. Richard, and P. Pouling, Langmuir 20, 11336 2004

Experimental determination of leakage current occurring in HgCdTe infrared detectors operating in the mid-infrared

Olga MARKOWSKA, Małgorzata KOPYTKO, Jarosław RUTKOWSKI, Andrzej KOWALEWSKI, Piotr MARTYNIUK

Institute of Applied Physics, Military University of Technology, 2 Gen. Sylwestra Kaliskiego Street, 00-908 Warsaw, POLAND

e-mail address: olga.markowska@wat.edu.pl

Photon detectors for long-term sensitivity limit of more than 3 microns must be cooled to a temperature below 300 K to reduce thermal generation processes of carrier. The narrow band gap IR detectors requires cryogenic cooling to suppress the dark current, which is typically limited by Auger generation-recombination (G-R) and Shockley-Read-Hall (SRH) processes. The necessity of the IR detectors' cryogenic cooling is a major obstacle preventing their widespread applications. Among the mechanisms generating the dark current in detector's structure the following must be enumerated: diffusion and G-R mechanisms, band-to-band (BTB) tunnelling, trap assisted tunnelling (TAT), and surface leakage currents [1-4].

Most of the HgCdTe devices in the p-on-n, n-on-p, or multilayer architecture are fabricated by mesa geometry using wet chemical or plasma etching techniques. The mesa definition etch process induces undesirable changes in HgCdTe surface properties. In narrow bandgap materials these surface changes could deteriorate a device performance. Uncontrolled band bending (dangling bonds) occurred on the slopes of the active layer increase of the recombination velocity causing surface leakage current which is a serious problem that affects infrared detectors. Adequate passivation is essential to minimize the effects from the surface states by saturating them. This process consists in covering the slopes of the mesa layer of insulating material from external conditions.

The work presents processing steps proposed for HgCdTe $n^+B_pnN^+$ and $n^+B_ppN^+$ barrier detectors based nBn-design detectors for the mid-wave infrared (MWIR) spectral region. Test structures with a round mesa geometry with different diameters from 200 to 600 µm were defined by a standard optical photolithography and wet chemical etched with Br:HBr (1:100) solution to the N+ bottom contact layer.

The bulk current (J_{bulk}) and surface leakage current (J_{surf}) are components of the dark current. The main objective was to estimate the ratio of bulk current to parasitic leakage currents - usually flowing on the mesa slope. Analysis of the current characteristic measured for detectors of different sizes allows specify value of bulk and surface current. The relationship between parameters J_{surf} and J_{bulk} can be approximated as:

$$J_{dark} = J_{bulk} + J_{surf} \cdot \frac{P}{A} \qquad (1)$$

where J_{bulk} is the bulk current density contribution (A/cm2), J_{surf} is the surface current parametr (A/cm), P is the diode’s perimeter and A is the diode’s area. The slope of the function given by equation (1) is directly proportional to the surface-dependent leakage current of the diode.

The HgCdTe barrier detectors were investigated for unpassivated and passivated devices. As shown in the Fig.1, for the unpassivated $n^+B_ppN^+$ HgCdTe structure the experimental value of J_{bulk} (at -0.2 V bias and a temperature of 170 K) was found at the level of 63 % of the total dark current for devices with large diameters (above 600 µm). In the case of detectors with small diameters, the dark current is dominated by the surface leakage current. For a detector with a diameter of 200 µm, the bulk current consists only 27% of the total dark current. Therefore, additional passivation processes are required following the mesa definition process to eliminate dangling bonds as much as possible. After passivation the level of bulk current increase to 80% in cause of the smallest mesa diameter (200 µm) and almost 100% in cause of large diameter.

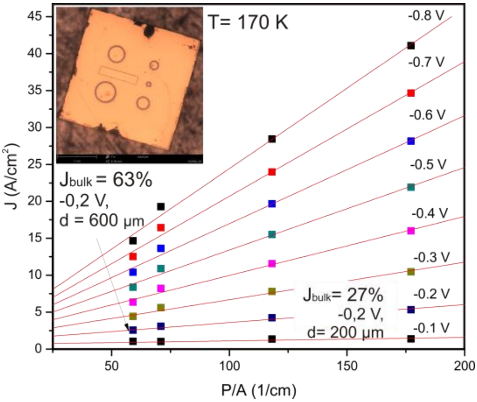

Fig. 1. The surface impact analysis on the unpassivated $n^+B_ppN^+$ HgCdTe structure

Acknowledgements We acknowledge support by The Polish National Centre for Research and Development TANGO1/2665576/NCBR/2015

Reference

1. A. Rogalski, Rep. Prog. Phys., 68(10), 2267–2336 (2005),
2. P. Martyniuk and A. Rogalski, Bull. Pol. Acad. Sci. Tech. Sci., 61 (1) (2013),
3. A. Rogalski and P. Martyniuk, Infrared Phys. Technol., 48 (1), 39–52 (2006),
4. M. Kopytko et al., Proc. SPIE, 945117 (2015).

Table of contents