Dear Participants
of 17th Conference: INTEGRATED OPTICS - Sensors, Sensing Structures and Methods, IOS'2023

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

Honorary auspices of the Conference are taken over by Professor Wiesław Woliński – Full Member of the Polish Academy of Sciences.

We wish all Participants of the Conference IOS'2023 plenty of scientific satisfactions and many professional and social impressions.

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This book includes the Program of IOS'2023 and Abstracts of presentations and posters sent by their Authors

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PROGRAMME
of the IOS'2023 Conference -
Integrated Optics - Sensors, Sensing Structures and Methods
Szczyrk, 27 February – 03 March 2023

27.02.2023 Monday	
14.00	***Lunch***
16.00 – 16.10	**OPENING CEREMONY of the Conferences** **50th Jubilee WSEA&V** **51th WSW&QA** **17th IOS'2023**
16.10 – 16.45	**„Akustyczne" Szkoły zimowe w fotografiach.** **60 LAT Oddziału Górnośląskiego PTA** (in Polish) "Acoustic" Winter Schools in photos. 60 years of the Upper Silesian Division of the PAS (in Polish) R. BUKOWSKI
17.00 – 17.45	**Reduction of device noise** Redukcja hałasu urządzeń M. PAWEŁCZYK
17.45 – 18.20	***Coffee Break***
18.30 – 19.30	**MUSIC GLANCE** - SILESIAN CULTURAL CENTER
19.30	***Supper***

28.02.2023 Tuesday	
8.00	***Breakfast***
13.00	***Lunch***
14.30 – 15.00	**MEMORIES about:** **prof. Mieczyslaw Szustakowski;** **prof. Grażyna Grelowska**
	Photonic Integrated Circuits - Technologies, Platforms and Applications
15.00 – 15.30	Plenary lecture **Photonic Integrated Circuits – technologies, platforms, and applications** R. PIRAMIDOWICZ, S. STOPIŃSKI, K. ANDERS, A. JUSZA, A. PAŚNIKOWSKA, M. LELIT, A. POŁATYŃSKI, A. KAŹMIERCZAK, M. A. BUTT, P. WIŚNIEWSKI, M. SŁOWIKOWSKI, M. JUCHNIEWICZ, K. PAVŁOV, M. ŻBIK, J. JUREŃCZYK, M. LIEBERT, K. PIERŚCIŃSKI, D. PIERŚCIŃSKA
15.30 – 16.00	**Indium Phosphide generic platform**
15.30 – 15.45	**InP-based integrated photonic interrogators** S. STOPIŃSKI, K. ANDERS, A. JUSZA, M. SŁOWIKOWSKI, A. BIENIEK, R. PIRAMIDOWICZ
15.45 – 16.00	**Integrated light sources for telecom, datacom and sensing applications** K. ANDERS, S. STOPIŃSKI, A. JUSZA, A. PAŚNIKOWSKA, A. BIENIEK, R. PIRAMIDOWICZ

16.00 – 16.30	**TiO_2/SiO_2 HYPHA platform**
16.00 – 16.15	**HYPHa – innovative photonic integration platform for sensing applications** A. KAŹMIERCZAK, M. A. BUTT, Ł. KOZŁOWSKI, M. SHAHBAZ, A. JUSZA, K. ANDERS, S. STOPIŃSKI, J. OLSZEWSKI, T. MARTYNKIEN, Ł. DUDA, K. CZYŻ, J. PAWŁÓW, K. PROKOP, M. ZDOŃCZYK, K. ROLA, M. GUZIK, J. CYBIŃSKA, M. ZIĘBA, C. TYSZKIEWICZ, P. KARASIŃSKI, R. PIRAMIDOWICZ
16.15 – 16.30	**Library of fundamental photonic components of HYPHa platform** J. OLSZEWSKI, E. ŚRODA, P. PALA, K. GEMZA, A. ŚLIPEK, M. ŁUKOMSKI, A. GAWLIK, P. MROWIŃSKI, D. HLUSHCHENKO, R. KUDRAWIEC, K. KOMOROWSKA, T. MARTYNKIEN
16.30 – 17.00	***Coffee Break***
17.00 – 17.20	**Silicon nitride platform at CEZAMAT WUT**
17.00 – 17.20	**Silicon-nitride based generic platform – current status and perspectives** M. SŁOWIKOWSKI, M. LELIT, M. JUCHNIEWICZ, B. STONIO, B. MICHALAK, K. PAVŁOV, M. FILIPIAK, M. MYŚLIWIEC, M. GOLAS, P. WIŚNIEWSKI, K. ANDERS, S. STOPIŃSKI, R. B. BECK AND R. PIRAMIDOWICZ
17.20 – 18.40	**MIRPIC platform - VIGO, WUT & Łukasiewicz IMiF alliance**
17.20 – 17.40	**Waveguiding components for MIRPIC platform – design and modelling** A. POŁATYŃSKI, M. LELIT, K. ANDERS, S. STOPIŃSKI, R. PIRAMIDOWICZ

17.40 – 18.00	**Waveguiding components for MIRPIC platform – progress in technology** M. JUCHNIEWICZ, M. SŁOWIKOWSKI, B. STONIO, B. MICHALAK, K. PAVŁOV, M. FILIPIAK, M. MYŚLIWIEC, M. LELIT, P. WIŚNIEWSKI, K. ANDERS, S. STOPIŃSKI, R. B. BECK AND R. PIRAMIDOWICZ
18.00 – 18.20	**Mid-IR light sources for MIRPIC platform – technologies and applications, Institute of Microelectronics and Photonics, Łukasiewicz Research Network** K. PIERŚCIŃSKI, D. PIERŚCIŃSKA, G. SOBCZAK, K. PIENIAK, A. BRODA, I. SANKOWSKA, A. KUŹMICZ, P. GUTOWSKI
18.20 – 18.40	**Mid-IR detectors for MIRPIC platform – current status and perspectives** J. JUREŃCZYK, Ł. KUBISZYN, M.ŻBIK, B. SEREDYŃSKI, A. KRAWCZYK, P. ROPELEWSKI, K. ANDERS, S. STOPIŃSKI, R. PIRAMIDOWICZ
18.40 – 19.10	**Integration and Packaging**
18.40 – 19.10	Invited lecture **Packaging technologies for photonic integrated circuits** K. GRADKOWSKI, P. O'BRIEN
20.00	***Festive Supper***

01.03.2023 Wednesday	
8.00	***Breakfast***
13.00	***Lunch***
15.00 – 15.30	**Optoelectronic sensors**
15.00 – 15.30	Invited lecture **Military optoelectronic sytems** K. KOPCZYŃSKI
15.30 – 16.30	**Biomedical Engineering**
15.30 – 15.50	**OCT imaging using a MOEMS endomicroscopy probe with Mirau micro-interferometer and 2-axis electrothermal micro-scanner** P. STRUK, S. BARGIEL, B. MIRECKI, M. JÓŹWIK, Q. TANGUY, R. CHUTANI, N. PASSILLY, P. LUTZ, H. XIE, M. WOJTKOWSKI AND C. GORECKI
15.50 – 16.10	**Functionalized photonic silicon-nitride-based integrated circuits operating in visible wavelengths for biosensing applications** M. LELIT, M. SŁOWIKOWSKI, M. JUCHNIEWICZ, B. STONIO, B. MICHALAK, K. PAVŁOV, M. FILIPIAK, M. MYŚLIWIEC, P. WIŚNIEWSKI, K. ANDERS, S. STOPIŃSKI, A. DUSZCZYK, S. KAROŃ, R. B. BECK AND R. PIRAMIDOWICZ,
16.10 – 16.30	**Bearingless impeler suspension in rotatory pumps – challenge for biosngineers** M. GAWLIKOWSKI, P. URTYKA, J. ZALEWSKI
16.30 – 17.00	***Coffee Break***

17.00 – 19.20	**Photonics Metrology**
17.00 – 17.20	**Metrology aspects of wavelength and illumination scanning holographic tomography** P. OSSOWSKI, A. KUŚ, W. KRAUZE, S. TAMBORSKI, M. ZIEMCZONOK, Ł. KUŚBICKI, M. SZKULMOWSKI, M. KUJAWIŃSKA
17.20 – 17.40	**Fiber-optic CRP sensor supported by machine learning** M. SZCZERSKA, K. CIERPNIAK, M. KOSOWSKA, R. VITER, P. WITYK
17.40 – 18.00	**Entropy source of optical fiber-based quantum true random numer generator – modeling and measurements** M. DUDEK, G. SIUDEM, G. KWAŚNIK, W. ŻOŁNOWSKI, M. ŻYCZKOWSKI
18.00 – 18.20	**Automatic detection of defects in composites using terahertz imaging** N. PAŁKA, K. KAMIŃSKI, M. MACIEJEWSKI, K. DRAGAN, P. SYNASZKO
18.20 – 18.40	**Polymer nanocomposites evaluation by optical coherence tomography** M. R. STRĄKOWSKI, J. PLUCIŃSKI
18.40 – 19.00	**Broadband differentia interference in a planar waveguide with a gradient refractive index profile** K. GUT

19.00 – 19.20	**Fabrication of infrared detectors with monolithic micro-lenses manufactured by a thermal reflow process** J. CHRZANOWSKA-GIŻYŃSKA, O. ŚLĘZAK, P. NYGA, M. WANKIEWICZ
19.00	***Supper***
20.00	**Poster Session**

02.03.2023 Thursday	
8.00	***Breakfast***
13.00	***Lunch***
14.30 – 16.30	**Photonic Sensors and Their Applications**
14.30 – 14.50	Plenary lecture **Nanoparticles-doped blue-phase liquid crystalline photonic microstructures for promising sensing and tunable devices applications** T. R. WOLIŃSKI, K. ORZECHOWSKI, J. DZIURKO, M. TUPIKOWSKA, W. LEWANDOWSKI, O. STRZEŻYSZ, W.-Y. CHEN, W.-H. HUANG, CH.-T. WANG
14.50 – 15.10	Invited Lecture **Microphantoms for validation of 2D/3D quantitative phase imaging system** M. KUJAWIŃSKA, M. ZIEMCZONOK
15.10 – 15.30	Invited Lecture **FOSREM – from sky through ground up to underground application** L.R. JAROSZEWICZ, A.T. KURZYCH, P. MARĆ, M. DUDEK, K. STASIEWICZ, J. K. KOWALSKI, T. WIDOMSKI
15.30 – 15.50	**Poly(3-hexylthiophene) graft copolymers and their organic-inorganic blends activated by UV light for NO2 gas sensing applications** M. PROCEK, P. KAŁUŻYŃSKI, A. STOLARCZYK, T. JAROSZ, K. GŁOSZ, E. MACIAK, M. KRUPA

15.50 – 16.10	**Monitoring temperature changes of the active layer of the permafrost across varied grounds in the Arctic with fiber-optic distributed measurement system** A. PAŹDZIOR, Ł. FRANCZAK, W. BERUS, K. MISZTAL, K. KULTYS, P. ZAGÓRSKI, R. DOBROWOLSKI, A. BIEGANOWSKI, P. MERGO
16.10 – 16.30	**PhotonHub Europe - making photonics innovation more available** M. J. NOWAKOWSKI
16.30 – 16.40	IOS'2023 Closing Ceremony
16.40 – 17.10	***Coffee Break***
17.30	Panel Session **„Optoelectronics.PL – which way further?"**
19.00	***Supper***

03.03.2023 Friday	
8.00	***Breakfast***

Poster Session

- **InP-based photonic integrated circuits of EEDH WUT**
  K. ANDERS, S. STOPIŃSKI, A. JUSZA, A. PAŚNIKOWSKA, M. SŁOWIKOWSKI, R. PIRAMIDOWICZ

- **Two-channel fluorescence microscope for imaging diamonds with nitrogen vacancies**
  M. BABIŃSKA, M. FICEK, A. MAZIKOWSKI

- **Research on temperature dependence of optical fiber current sensor with external conversion**
  K. BARCZAK, J. JURASZEK

- **Development of miniaturized optical gyroscopes using photonic integration technologies**
  A. BIENIEK, S. STOPIŃSKI, T. SZLETER, S. SZOSTAK, R. PIRAMIDOWICZ

- **AWG components for HYPHA integrated photonic platform – design and applications**
  P. BORTNOWSKI, M. LELIT, A. POŁATYŃSKI, M. A. BUTT, S. STOPIŃSKI and R. PIRAMIDOWICZ

- **Room Temperature NO_2 sensor based on reduced graphene oxide**
  Ł. DREWNIAK, S. DREWNIAK, R. MUZYKA

- **The influence of platinum substrate in hydrogen sensor based on reduced graphene oxide**
  S. DREWNIAK, Ł. DREWNIAK, R. MUZYKA, M. PROCEK

- **Boron-doped diamond electrodes rich in nitrogen vacancies**
  M. FICEK, S. KUNUKU and R. BOGDANOWICZ

- **Application of Faraday mirror for phase coding of information in the optical fiber sensor**
  S. FIDERKIEWICZ, M. ŻYCZKOWSKI, A.PAKUŁA

- **Development and study of plasma etching in fabrication of TiO_2 waveguides**
  M. FILIPIAK, K. PAVŁOV, M. JUCHNIEWICZ, B. MICHALAK, M. MYŚLIWIEC, M. SŁOWIKOWSKI, B. STONIO, P. WIŚNIEWSKI, P. KARASIŃSKI

- **Analysis of rib waveguide geometry on operation of a 2x3 planar Mach-Zehnder interferometer based on silica-titania waveguides on glass substrates**
  A. GALIK, A. ŚLIPEK, K. ROLA, C. TYSZKIEWICZ, J. OLSZEWSKI, P. KARASIŃSKI

- **Fiber-optic water salinity sensor**
  M. JÓZWICKI, W. JÓZWICKA, P. MERGO

- **Integrated photonics for free-space optical communication**
  A. JUSZA, S. STOPIŃSKI, K. ANDERS, Ł. KUSTOSZ, K. PIERŚCIŃSKI, D. PIERŚCIŃSKA, R. PIRAMIDOWICZ

- **Influence of UV light activation on ppb NO_2 sensing of P3HT-bearing graft copolymers**
  P. KAŁUŻYŃSKI, M. PROCEK, A. STOLARCZYK, T. JAROSZ, K. GŁOSZ, E. MACIAK, M. KRUPA

- **Against Blue Light - investigation of eye protection strategies used by mobile phone manufacturers**
  P. KAŁUŻYŃSKI, Ł. WOŹNIAK, D. DZIADEK, M. MIETŁA, P. NOWAKOWSKI, M. KUBANEK, Z. GRUSZCZYŃSKA ,P. SMOŁKA, A. SŁABOŃ, W. ŁUKASZEWICZ-SZMYTKA

- **UnVisible Sunguard – UVA imaging system for cross-polarized reflectance photography for sunscreen SPF analysis**
  P. KAŁUŻYŃSKI, Ł. WOŹNIAK, P. NOWAKOWSKI, Z. GRUSZCZYŃSKA, K. TARNAS, M. KRUPA

- **New D-shaped fiber fabrication approach for SPR sensor**
  R.KASZTELANIC, G. STEPNIEWSKI, A. FILIPKOWSKI, D. PYSZ, R. BUCZYNSK

- **SiO_2:TiO_2 Integrated Photonic 1x2 DEMUX based on Y-splitter for telecom and sensing applications**
  Ł. KOZŁOWSKI, M. SHAHBAZ, M. DUDEK, M. A. BUTT, A. KAŹMIERCZAK, R. PIRAMIDOWICZ

- **Development of integrated optical interfaces for silicon-nitride-based photonic platform**
  M. LELIT, K. ANDERS, M. SŁOWIKOWSKI, M. JUCHNIEWICZ, B. STONIO, K. PAVŁOV, S. STOPIŃSKI, R. B. BECK and R. PIRAMIDOWICZ

- **Design and optimization of stepped interference filters for mid- and long-wave infrared spectral sensing applications**
  F. ŁABAJ, J. KALWAS, R. PIRAMIDOWICZ

- **An optomechanical transducer based on FBG sensors to measure of the compensator expansion on gas transmission pipelines**
  E. MACIAK, W. KOSTOWSKI, D. ADAMECKI, K. BARCZAK, G. GŁUSZEK, Z. OPILSKI, R. ROLF, J. PIETRUSZEWSKI, W. GRZEGORZEK, P. SZUFLEŃSKI

- **High-speed THz-TDS imaging system with ECOPS scheme**
  M. MACIEJEWSKI, M. PISZCZEK, P. ZAGRAJEK, M. WALCZAKOWSKI, E. CZERWIŃSKA, N. PAŁKA.

- **Terahertz spectroscopy of ceramics for high-frequency applications**
  N. PAŁKA, D. SZWAGIERCZAK, E. CZERWIŃSKA, B. SYNKIEWICZ-MUSIALSKA, J. KULAWIK

- **Exposure optimization procedure for grayscale lithography in photonic applications**
  K. PAVŁOV, J. SUSZEK, M. SYPEK, M. FILIPIAK, M. SŁOWIKOWSKI, P. WIŚNIEWSKI

- **Four-channel Stokes polarimeter with a division of amplitude.**
  E. PAWLIKOWSKA, M. ŻYCZKOWSKI, A. PAKUŁA, P. MARĆ

Fiber-optic distributed sensing probes for vertical profiling of temperature changes in the active layer of the permafrost in the Arctic
A. PAŹDZIOR, Ł. FRANCZAK, W. BERUS, K. MISZTAL, K. KULTYS, P. ZAGÓRSKI, R. DOBROWOLSKI, A. BIEGANOWSKI, P. MERGO

- **Influence of the electrolyte used in carbazole electro-polymerization on the response of the hydrogen sensor**
  M. PROCEK, M. KRUPA, K. GŁOSZ, P. KAŁUZYŃSKI, A. STOLARCZYK, T. JAROSZ

- **Tunable LC:PDMS periodic waveguiding structures**
  K.A. RUTKOWSKA, P. SOBOTKA, SZ. BACZYŃSKI, A. IGNACIUK

- **Tuning optoelectronic properties of semiconducting diamond sheets for microfluidic devices**
  M. RYCEWICZ, A. NOSEK, M. FICEK, J. G. BUIJNSTERS, R. BOGDANOWICZ

- **Numerical evaluation of silica-titania-based reverse rib waveguide and standard rib waveguide structures**
  M. SHAHBAZ, Ł. KOZŁOWSKI, M. A. BUTT, A. KAŹMIERCZAK, R. PIRAMIDOWICZ

- **The structure and preparation method of spectrally shifted double-comb Tilted Fiber Bragg gratings.**
  K. SKORUPSKI, S. CIĘSZCZYK, P. PANAS

- **Optical monitoring of electrodegradation of water micropollutants**
  M. SOBASZEK, M. PIERPAOLI, I. KACZMARZYK, R. BOGDANOWICZ

- **Virus deactivation with UV-C LEDs**
  P. SOBOTKA, M. PRZYCHODZKI, T. WOLIŃSKI, M. STANISZEWSKA

- **Numerical analysis of grating coupler shape for optimization of integrated optics biosensor structure**
  P. STRUK

- **Technology of MIM diode rectifiers for THz rectennas**
  P. WIŚNIEWSKI, B. STONIO, M. SŁOWIKOWSKI, M. FILIPIAK, K. PAVŁOV, M. HARAS, T. SKOTNICKI

- **Mesoporous TiO_2 films – optical properties and photocatalytic activity**
  K. WOJTASIK, M. ZIĘBA, J. WIECZOREK, E. CABAJ, P. KARASIŃSKI

- **Active planar waveguides based on erbium doped silica-titania films for photonic applications**
  M. ZIĘBA, K. WOJTASIK, K. MATUS, C. TYSZKIEWICZ, D. DOROSZ, P. KARASIŃSKI

- **QKD system synchronization using the ARTIQ Sinara platform**
  W. ŻOŁNOWSKI

LECTURES

Photonic Integrated Circuits – technologies, platforms, and applications

R. PIRAMIDOWICZ[1,2,3], S. STOPIŃSKI[1,2,3], K. ANDERS[1,2,3], A. JUSZA[1,3], A. PAŚNIKOWSKA[1], M. LELIT[1,4], A. POŁATYŃSKI[1,5], A. KAŹMIERCZAK[1], M. A. BUTT[1], P. WIŚNIEWSKI[4], M. SŁOWIKOWSKI[1,4], M. JUCHNIEWICZ[4], K PAVŁOV[4],M. ŻBIK[2], J. JUREŃCZYK[2], M. LIEBERT[2], K. PIERŚCIŃSKI[6], D. PIERŚCIŃSKA[6],

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Global changes and dangers, like the unprecedented COVID-19 pandemic as well as Russian aggression against Ukraine, dramatically influence the economy, politics, and way of life, modify priorities, and define new challenges to be faced.

As one of the results, crucial from the European and Polish perspective, a pressing need appears to develop a more resilient and autonomous technological potential in all critical fields of technology.

Integrated photonics is undoubtedly among them - photonic integrated circuits (PICs) are one of the most intensively developed ICT technologies of the 21st century, providing unique, highly efficient and highly reliable solutions in telecommunication, data-communication and sensing. The latter one covers impressively broad range of specific application areas, like environmental monitoring, agriculture, automotive, space, digital health monitoring, security and defense, as well as broadly understood internet of things (IoT).

European integrated photonics, although undergoing severe pressure from the global competition (mainly Chinese and US), still represents a strong technological and economic potential to develop products of unique, strategic value.

In this presentation, the major technological platforms of integrated photonics will be presented and discussed together with major fields of applications, analyzed from the perspective of the present and future market needs and demands, as well as development trends. Specific attention will be given to generic indium phosphide platform available via external commercial foundries like SMART Photonics [1,2] and non-standard platforms developed in Poland (like SiN, MIRPIC, and HYPHA), enabling the extension of the spectral range of operation towards VIS and mid-IR and therefore providing additional functionalities not available to telecom-originated technologies of indium phosphide or silicon photonics.

Also, the exemplary PICs and/or PIC components designed and developed jointly by the authors' team will be presented, illustrating the progress in technology and addressing current application trends and demands

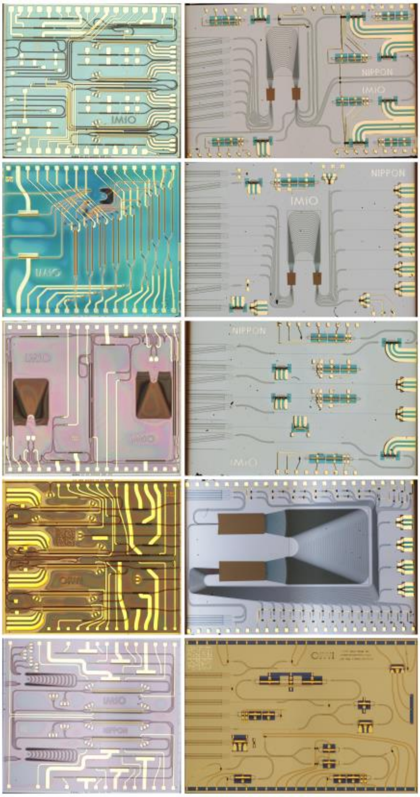

Fig. 1. Exemplary ASPICs (InP technology) designed and developed in EEDH, WUT and manufactured in external generic foundries.

The key elements of the supply chain of integrated photonics will be discussed in the context of HyperPIC projects, the biggest investment initiative in Poland in the field of photonic integrated circuits for mid-IR spectral range (MIRPIC).

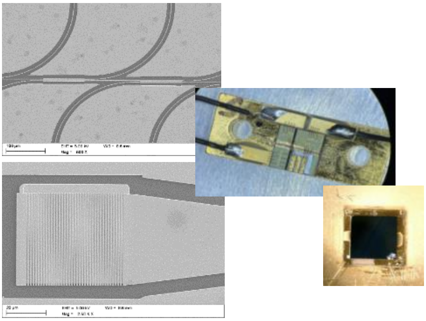

Fig. 2. Selected components of the new mid-IR technological platform (MIRPIC)

Finally, the major challenges and perspectives faced by integrated photonics in Poland will be analyzed and discussed in detail.

Acknowledgments:

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[1] L. Augustin et al., IEEE Journal of Selected Topics in Quantum Electronics, vol. 24, no. 1, 2018

[2] F.M. Soares et al., *Applied Sciences* 2019, *9,* 1588.

InP-based integrated photonic interrogators

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The InP-based photonic integration platform enables the monolithic integration of active and passive photonic components in a single semiconductor chip [1,2]. This, in turn, allows realizing sophisticated, highly miniaturized photonic systems capable of generation, modulation, processing, and detection of optical signals.

The main fields of application so far have been telecom and datacom systems. Numerous high-speed, multi-channel transmitters, receivers, switches, and routers have been successfully developed. Some of them have also been already implemented as fully functional commercial products.

In recent years, however, a constantly increasing interest in sensing applications of InP-based photonic integrated circuits has been observed. This is also caused by the rapid development of fiber-optic-based sensing techniques, as the InP platform is fully compatible with the III telecom window (i.e., around 1550 nm), in which the standard single-mode fibers have minimal attenuation.

Among many different fiber-optic sensors and sensing systems, these based on fiber Bragg gratings (FBGs) provide excellent performance in terms of sensitivity and the capability of channel multiplexing in the wavelength domain. Generally, FBGs can be used as sensors of strain and/or temperature, which makes them suitable for application in industries such as civil engineering, aviation, automotive, energy, medicine, and many others. FBG-based systems require efficient interrogation devices capable of simultaneously reading out the data from multiple gratings with a high frequency.

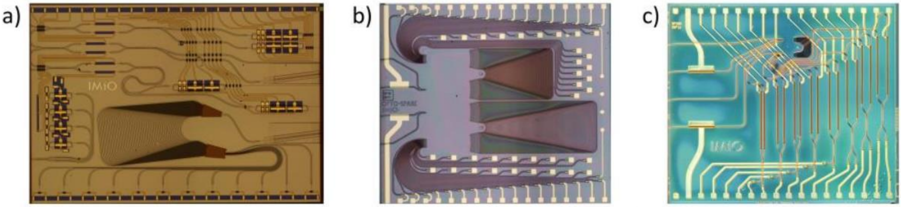

Fig. 1. Integrated photonic interrogators based on a matrix of tunable DBR lasers (a), an AWG demultiplexer (b) and asymmetric Mach-Zehnder interferometers (c)

In this work, we present and discuss a series of integrated FBG interrogation units designed by the team of the Eastern Europe Design Hub of Warsaw University of Technology and fabricated in generic InP foundries. The microscope pictures of the fabricated devices are presented in Fig. 1. We demonstrate a solution with a matrix of tunable distributed Bragg reflector (DBR) lasers, a spectrometer based on an arrayed waveguide grating (AWG) with a matrix of PIN photodiodes, and a device comprising an array of asymmetric MachZehnder interferometers (AMZI). The obtained measurement results are compared with respect to applicability in FBG-based sensing systems.

Acknowledgments:

The results presented in this work were supported under the OPTO-SPARE (PBS3/B9/41/2015) project financed by the National Center for Research and Development.

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Integrated light sources for telecom, datacom, and sensing applications

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Photonic integrated circuits (PICs) play a constantly increasing role in the telecom, datacom, and sensing markets. Furthermore, new application fields such as medicine, agriculture, automotive and space industry, defense, and security are currently being intensively explored.
Among multiple integration platforms currently available in the European and worldwide technology landscape, the indium phosphide (InP), silicon on insulator (SOI) and silicon nitride (SiN) are the most mature and are nowadays offered commercially in the framework of generic, to some extent even standardized processes. Considering these mainstream technologies, the most significant advantage of the InP platform is the capability of monolithic integration of light sources, which is necessary for the operation of any photonic system.
Since 2009 Warsaw University of Technology has been participating in the development of an indium phosphide generic integration technology platform in cooperation with key European partners such as Technische Universiteit Eindhoven, SMART Photonics, and Fraunhofer Heinrich Hertz Institute [1,2]. This effort is reflected in the number of one hundred application-specific photonic integrated circuits (ASPICs) designed by the IMiO WUT team (Eastern Europe Design Hub), all of which were later fabricated by generic foundries.
In this work, we present and discuss selected examples of laser light sources that have been developed and tested in the framework of realizing complex, ASPIC-based systems for a variety of applications, including telecom, datacom, and optical sensing.
Contemporary, telecom-grade multi-channel transmitters, regardless of the fabrication technology, require compact laser light sources operating on a single and stabilized frequency and generating sufficiently high output power.
Fig. 1 presents microscope pictures of two wavelength division multiplexed (WDM) integrated transmitters,

realized using the generic processes of two photonic foundries.

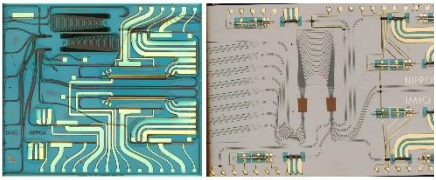

Fig. 1. Multi-channel WDM transmitters with integrated DBR lasers realized in InP generic processes.

Both devices use DBR (distributed Bragg reflector) lasers as the CW signal sources. The lasers comprise a section of a semiconductor optical amplifier and two DBR mirrors that define a resonator. The rear grating is long (300-500 µm) to provide maximum reflectivity, while the front one is much shorter (50-75 µm) to couple the light out of the cavity. The digital transmission is provided either by using electro-absorption or Mach-Zehnder modulators. All channels are multiplexed using an arrayed waveguide grating (AWG) to a single output waveguide.

The transmitters have been characterized with respect to applicability in fiber-optic communication systems and short-range datacom connections. Multi-channel laser emission has been achieved, open eye diagrams and error-free operation have been recorded for the digital signals up to 10 Gb/s.

Optical gyroscope systems are also a field of the potential implementation of photonic integrated circuits. Several devices have already been proposed to be used in the interferometric fiber-optic or ring laser (RLG) configuration [3-5].

The laser light source for RLG applications has to fulfill several requirements – single-frequency operation, linewidth below 1 MHz, combined with a cavity length above 10 mm, and sufficient output power. Another key issue is a bi-directional operation, as typical ring lasers tend to operate unidirectionally.

In Fig. 2, two InP-based photonic integrated circuits comprising ring lasers are presented. They use an SOA as the active medium, while the resonator is formed by racetrack-shaped passive waveguides. AWG and Mach-Zehnder interferometers provide wavelength filtering within the laser cavity, which enables single-mode operation.

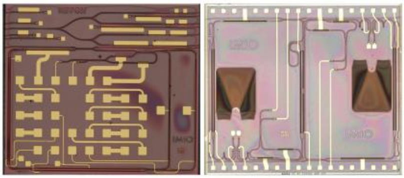

Fig. 2. Integrated ring lasers fabricated in InP generic processes.

The basic characterization results obtained so far confirm the very good performance parameters of the light sources and their usefulness in ring laser gyroscopes.

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Acknowledgments:

The results presented in this work were supported under the NIPPON (PBS3/A3/21/2015) project financed by the National Center for Research and Development and through POB Photonic Technologies from the funds of the Warsaw University of Technology under the Program Initiative of Excellence - Research University (IDUB).

HYPHa – innovative photonic integration platform for sensing applications

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The tremendous development of Photonic Integrated Circuits (PICs) technology has been observed over the last two decades. These compact structures based on integrated waveguides contain a number of optical functionalities in a single photonic chip (in a similar way as it is known from classical electronic ICs). PICs technology has been investigated by a vast number of companies, research centers, and universities. As a result, a mainstream of PIC technologies has been formed, including the three most significant ones that have reached technological maturity, namely: indium phosphide (InP), silicon-on-insulator (SOI), and silicon nitride (SiN). InP technology offers the possibility of direct integration of active optoelectronic components, SOI offers very dense circuit integration, while SiN allows operation in both visible (VIS) and near-infrared (NIR) wavelength ranges. It has to be underlined, however, that all the above-mentioned technologies require expensive and effort-demanding fabrication techniques, including (i) gaseous phase waveguide (WG) film deposition, (ii) electron-beam or deep UV lithography, and (iii) dry plasma etching as well. This results in limited accessibility of these technologies for small and medium enterprises (SMEs) or research centers.

In this work, we present a potentially attractive alternative to these technologies with respect to costs and platform flexibility. The HYPHa platform, based on silica-titania integrated optical waveguides technology, potentially promises a low-cost fabrication. It is possible due to the prospect of avoiding the expensive fabrication steps and replacing these with (i) liquid phase deposition with dip-coating sol-gel derived waveguide films, followed by (ii) direct nano-imprint (NIL) or two steps processing including optical lithography and (iii) chemical wet-etching. The prosperous properties of HYPHa platform include: (i) possible operation in both VIS and NIR wavelength range, (ii) adjustability of WG core refractive index in the range of 1.5 – 1.9, (iii) WG film thickness ranging from 200 nm (single-step deposition) up to more than 400 nm (two-step deposition), (iv) high chemical resistance (inherent feature of oxides) and (v) optical propagation loss in WG film as small as 0.3 dB/cm [1].

The development of this technology is the primary goal of the HYPHA project funded by the Foundation for Polish Science in the framework of the Team-NET program, which is being executed by the project consortium (Łukasiewicz Research Network – PORT Polish Center for Technology Development, Silesian University of Technology, Wrocław University of Science and Technology and Warsaw University of Technology).

In the presentation, the recent achievements of our project consortium will be discussed in details including the development of the material platform [2], proposed layouts of integrated photonics devices and systems [3-5], and the current state of development of two demonstrators of the integrated sensor system and integrated light source.

Acknowledgments: The work was funded with the project "Hybrid sensor platforms of integrated photonic systems based on ceramic and polymer materials" carried out within the TEAM-NET program of the Foundation for Polish Science financed by the European Union under the European Regional Development Fund, POIR.04.04.00-00-14D6/18-01.

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Library of fundamental photonic components of HYPHa platform

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Several dozen platforms for photonic integrated circuits (PICs) currently exist [1, 2]. They differ in essential aspects from a usability point of view, including technological maturity, availability, price-per-component, and environmental friendliness, but above all, they differ in optical properties. The choice of a specific PIC platform determines the contrast of refractive indices of the materials used, the spectral range of operation, and through available technologies, also defines the general characteristics of fabricated PIC components. For these purposes, each new material platform, like the HYPHa ("Hybrid sensor platforms of integrated photonic systems based on ceramic and polymer materials") platform, requires a set of essential PIC components to be designed that are specific to this platform but realize the standard functions.

The HYPHa platform is based on a SiO_2:TiO_2 sol-gel waveguide layer deposited on a soda-lime or SiO_2 glass substrate using the dip-coating technique, selectively masked by the optical photolithography and then ion etched. Already manufactured components belong to the class of rib and ridge waveguides [3,4]. The refractive index contrast for such waveguides equals 0.31-0.35 in the spectral range of 0.6 µm - 1.6 µm. Such contrast imposes the minimum SiO_2:TiO_2 layer thickness of 0.2 µm, 0.40 µm, and 0.6 µm, respectively, for visible light (approx. 0.635 µm), second (1.31 µm) and the third (1.55 µm) telecom window, assuming a single-mode operation [4].

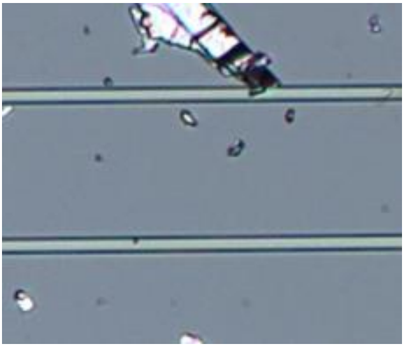

Fig. 1. Image of 10 µm width waveguides with and without MoS_2 layer.

Our component library contains designs of straight and bent rib, ridge, strip-loaded, and reverse-rib waveguides with geometries adjusted for operation in the 0.6 µm - 1.6 µm spectral range. We also included designs of basic input/output, basic active components, and signal-processing passive components, i.e., tapers interconnecting waveguides of different widths, splitters/combiners, ring resonators, multimode interference devices, and grating couplers [5].

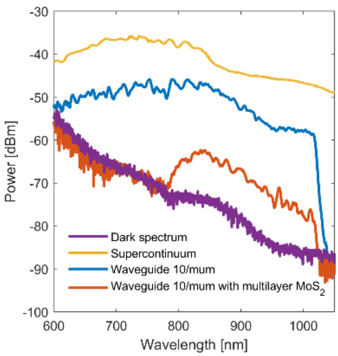

Fig. 2. Measured spectra for both waveguides from Fig. 1.

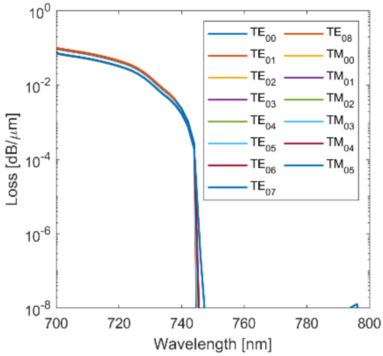

Fig. 3. Calculated propagation loss for the first 15 modes of the SiO_2:TiO_2 waveguide with deposited MoS_2 monolayer.

In addition, we designed and numerically characterized the unique components dedicated to the SiO_2:TiO_2 platform but having optical properties resembling that of high-contrast platforms. For instance, we proposed a waveguide with a two-step-like thickness variation that reduces bending loss and increases tolerance to technological imperfections [6] and optical ring resonators without a spatial gap between the ring and bus waveguide. Similarly, we proposed (Fig. 1) and characterized (Fig. 2, Fig. 3) the waveguide covered with highly absorbing multilayers of MoS_2 that can serve as the optical signal detector below the wavelength of 750 nm. Nevertheless, work on developing PIC components, and their implementation in the HYPHa platform is still being carried out. In this presentation, we will summarize the present state of the HYPHA building blocks library and discuss the perspectives of its further development.

Acknowledgments: The “Hybrid sensor platforms of integrated photonic systems based on ceramic and polymer materials” project is conducted under the TEAM-NET program of the Foundation for Polish Science financed by the European Union under the European Regional Development Fund. Calculations have been carried out using resources provided by Wroclaw Centre for Networking and Supercomputing (http://wcss.pl).

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Silicon-nitride based generic platform – current status and perspectives

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Generic photonic technology applies the paradigm of integrating a variety of functionalities using the limited number of building blocks fabricated in the same technological run [1]. Standardization of building blocks and technological processes enable easy implementation of the concept of multi-project wafer (MPW) runs, where layouts of different customers can be fabricated on a common substrate, with the costs shared among the ordering parties. That model makes integrated photonics available for small and medium-sized enterprises (SME) or scientific institutions [2].

In this work, the current status of the silicon-nitride-based integrated photonic platform developed in the Centre for Advanced Materials and Technology CEZAMAT of Warsaw University of Technology is reported and discussed in the context of current and prospective technology readiness level (TRL), building blocks availability and standardized fabrication processes.

Silicon nitride (Si_xN_y) is, along with silicon and indium phosphide, a third major candidate for a base material of a photonic platform [3]. Its features, like a wide transparency window extending from the visible to the mid-infrared range, CMOS processing compatibility, and low losses, indicate an attractive complement to the silicon-on-insulator (SOI) and indium phosphide platforms. Additionally, relatively high refractive indices contrast of Si_xN_y/SiO_2 results in small footprints.

A number of fabrication cycles have been performed in an iterative approach to achieve stable functional parameters of the building blocks planned to be offered within the process design kit (PDK). Passive elements developed and verified so far include:

(1) deeply etched multimode and single-mode waveguides, bends, and tapers;
(2) multi-mode interferometers;
(3) arrayed waveguide gratings;
(4) ring resonators;

(5) grating couplers;
(6) Mach-Zehnder interferometers.

The standard technological process developed for manufacturing photonic integrated circuits in CEZAMAT consists of the following steps:

(1) wafer surface cleaning;
(2) high-temperature oxidation of silicon to obtain SiO_2;
(3) Low-Pressure Chemical Vapor Deposition (LPCVD) of Si_XN_Y layer;
(4) Lithography to transfer the pattern to the material;
(5) Reactive Ion Etching (RIE) - pattern transfer into Si_XN_Y layer;
(6) Plasma Enhanced Chemical Vapor Deposition (PECVD) of SiO_2 layer.
(7) chips separation.

A picture of a fabricated SiN PIC exposed to optical characterization is presented in Fig. 1.

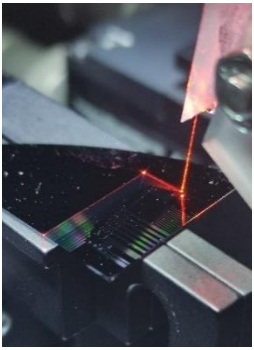

Fig. 1. PIC equipped with a grating coupler on the optical characterization setup.

Recently, there have been investigated the first shallow structures, complex low-loss optical interfaces for edge and vertical coupling, thermo-optic modulators, and microfluidic elements as well. The results confirm the high quality of the developed elements. The major optical features and parameters are comparable to those offered by commercial foundries.

Further optimization and standardization of the library of elements and technological processes are in progress, enabling the launching of commercial PDK and MPW run services in the near future.

Acknowledgments: This work was supported by „Development of optical interfaces for photonic platform based on silicon nitride„ project, agreement no. 1820/339/Z01/POB1/2021, realized within the framework of the competition FOTECH-3 announced by Scientific Council of the Research Centre POB Photonic Technologies, financed in the framework of the program Excellence Initiative - Research University, implemented at the Warsaw University of Technology.

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Waveguiding components for MIRPIC platform – design and modeling

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Recent advances in versatile photonic integrated circuit (PIC) technologies and hybrid integration processes offer a flexible and cost-optimized way of developing complex photonic components and systems for various applications. The fast and efficient test, verification, and optimization of new ideas and innovative solutions require an automated and reproducible simulation and design processes and environment, thus supporting flexible layout-aware schematic-driven methodologies [1]. When considering very complex designs, even small fabrication tolerances of one building block could make a significant difference in the performance and manufacturability of the whole structure [2]. To reduce the risk of failure and to make performance predictions by virtual prototyping reliable, the simulation model of each single building block needs to work correctly based not only on the appropriate mathematical and physical equations but also on adequate information provided by the foundry, where the final structure will be manufactured.

The MIRPIC project, aimed at establishing an entirely new platform operating in the mid-infrared (MIR) spectral range (λ = 3.0–5.5 µm), not available to any alternative generic platform, faces these design challenges in a particular way [3].

In this work, we present recent advances in the development of a process design kit (PDK) and a building block library for this germanium-on-silicon (Ge-on-Si) MIRPIC platform. It will enable realizing passive photonic circuits with which active photonic devices (quantum and interband cascade lasers, III-V MIR photodetectors) can be integrated in a hybrid way. We also discuss the methodology of numerical modeling and prototyping of optical elements and simulation techniques for optimizing their crucial parameters.

The obtained simulation results are presented for the following passive building blocks: deeply and shallowly etched planar waveguides, waveguide bends, tapers, multi-mode interference (MMI) splitters, couplers, grating couplers and arrayed waveguide gratings (AWGs). Fig. 1. presents the transmission spectra of a designed AWG, which is one of the most complex passive elements of photonic integrated circuits.

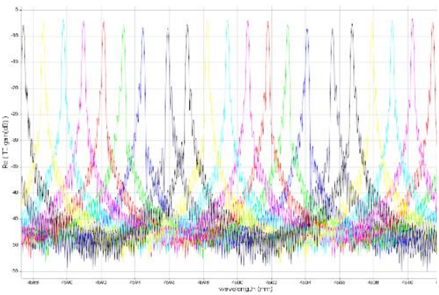

Fig. 1. A transmission spectrum of an 8-channel AWG designed for the central wavelength λ_c = 4.6 µm and channel spacing $\Delta\lambda$ = 50 nm.

The designed elements are arranged into test cells for planned fabrication and characterization. A mask layout of a cell comprising designed structures of multi-mode interference couplers is presented in Fig. 2.

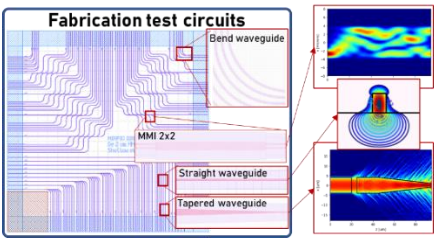

Fig. 2. An exemplary test circuit including developed PDK building blocks.

To sum up, we have designed several fundamental building blocks for the MIRPIC platform, thus defining the foundation for technological experiments, optimization of the designs and further development of the PDK.

Acknowledgment:
This work has received support from the National Centre for Research and Development through project MIRPIC (TECHMATSTRATEG-III/0026/2019-00).

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Waveguiding components for MIRPIC platform – progress in technology

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In recent years, a lot of research efforts have been put onto photonic integrated circuits (PICs). It is due to the number of possible fields of application: telecom, datacom [1], computing, and sensing [2,3], to show only the most emblematic examples. Although the majority of PICs operate in the near-IR spectral range (below 1.7 µm), there is an observable increase of interest in extending this range towards the mid-IR band (2-20 µm). This part of the spectrum often denoted as MIR is specifically attractive for all applications related to gas-sensing [4].

In this work, the current status and future plans for the development of two technological platforms will be presented. Both are designed for MIR applications and intensively developed by the Institute of Microelectronics and Optoelectronics (IMO) and the Centre for Advanced Materials and Technologies CEZAMAT PW, within the framework of the MIRPIC project. The first is based on germanium on silicon, while the second makes use of suspended silicon waveguides on SOI (silicon on insulator) substrates.

For both platforms, the development cycle involves three main stages:

1. numerical simulation of photonic structures
2. fabrication of structures
3. characterization of the fabricated structures.

The presentation will focus on the most significant issues regarding the key technological processes of each platform.

Such a key process for both platforms is lithography. Therefore, all issues, including the selection of the resist, a number of aspects relating to the exposure processes, and the development processes, will be discussed in detail.

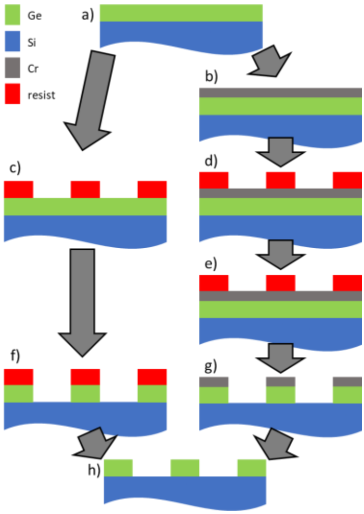

Fig. 1. Process flow for Ge-based PICs. Two paths are possible: with soft mask (a, c, f, h) or with hard mask (a, b, d, e, g, h): a) Si wafer with Ge layer; b) hard mask - Cr deposition; c) & d) e-beam lithography; e) hard mask etching; f) & g) Ge etching; h) mask removal (final structure).

For the Ge platform, an example process flow using a hard mask includes (Fig. 1 a, b, d, e, g, h):

- substrate preparation;
- application of material for hard mask;
- lithography of the pattern using electron beam lithography;
- dry etching of hard mask;
- dry etching of germanium including cryogenic etching process;
- removal of the hard mask.

This is one of the possible paths for the fabrication of this type of structures. The other, using a soft mask (Fig. 1 a, c, f, h), is less complicated, but comes with limitations on the etching capabilities of the structures. Regardless of the process path chosen, the important issues are:

- optimization of lithography processes for a given material stack;
- determination of the type of plasma and optimal parameters for the dry etching process and selection of a suitable etch mask;
- compatibility problems of certain processes with germanium;

Regarding the silicon platform with suspended waveguides, the following steps will be discussed (shown in Fig. 2):

- fabrication of pattern by electron beam lithography;
- cryogenic etching of silicon;
- release of suspended waveguides by etching in HF vapours.

For both platforms, the processing of structures with different etching depths and possible options for simplifying the technological procedures will be discussed.

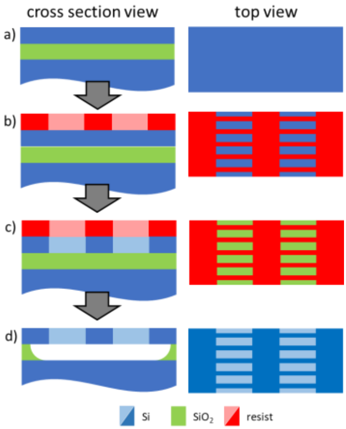

Fig. 2. Process flow for PICs with suspended Si waveguides: a) SOI wafer; b) lithography of waveguide with suspending supports; c) dry etching of Si; d) structures by etching of SiO_2 in HF vapours.

Acknowledgments: This work received support from the National Centre for Research and Development through the project MIRPIC (TECHMATSTRATEG-III/0026/2019-00).

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Mid-IR light sources for MIRPIC platform – technologies and perspectives

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Quantum Cascade Lasers [1] are essential sources for IR-photonics: narrow linewidth and wavelength tunability can serve high-end and upcoming applications. Prominent examples are monitoring and sensing in fabrication, bio-sensing, monitoring the integrity of civil structures, laser ranging (LIDAR) for autonomous traffic or sensing of rotation with optical gyros.

The progress that photonic integration is currently undergoing may be compared to that of electronic integration nearly half a century ago. Its development will not only enable the transmission of huge amounts of information – particularly in optical data communication – but will also pave the way for large scale fabrication, the minimization of assembly processes, and the reduction in energy consumption.

The purpose of the mid-IR PIC component integration technology is to enable the integration of individual components of the PIC system - in particular the Quantum Cascade Lasers with passive structures integrated on PIC. There are several challenges facing horizontal hybrid integration. One of the problems is matching the waveguide mode size of the integrated waveguide structures on the PIC chip with the waveguide mode size of QCL. One of the solutions is decreasing the divergence of the output beam of QCLs.

In this work we present results of optimization of Quantum Cascade Laser (QCL) active region toward efficient Photonic Integrated Circuits. Large Optical Cavity AlInAs/InGaAs/InP Quantum Cascade Lasers with different thick of active region were calculated, grown by Molecular Beam Epitaxy (MBE) [2] and fabricated. The devices were characterized to extract the key information regarding the heterostructures and device parameters. We have performed the HR XRD measurements to confirm reduced structure strain.

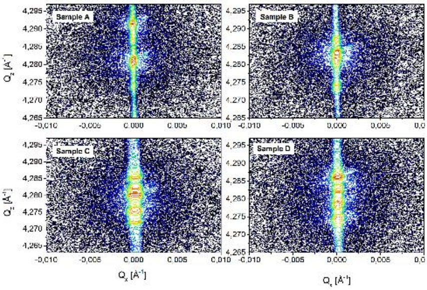

Fig. 1. The reciprocal-space maps along the [110] direction for structures A, B, C and D/series of QCLs with different waveguide width and number of periods.

Far field emission patterns were registered to confirm vertical (fast-axis) narrowing due to extended cavity height. Thermal problems related to increasing the thickness of the active area and higher voltage operations was investigated by non-invasive optical technique: CCD-thermoreflectance. [3]

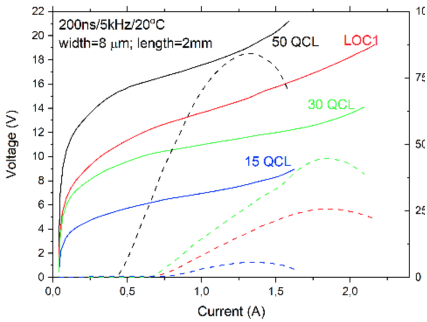

Fig. 2. Light-current-voltage characteristics in pulsed operation of series of QCLs with different waveguide width and number of periods

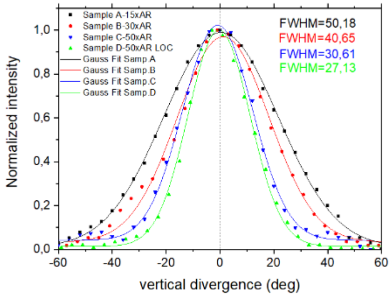

Fig. 3. Far-field of a series of QCLs with different waveguide width and number of periods.

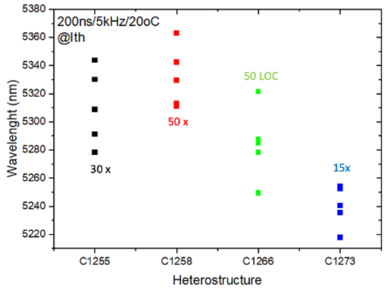

Fig. 4. Dependence of the wavelength (at threshold) for series of QCLs with different waveguide width and number of periods.

Acknowledgments: This work was financially supported by National Center for Research and Development (Poland) grant no. TECHMATSTRAEG-III/0026/2019-00.

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Mid-IR detectors for MIRPIC platform – current status and perspectives

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Photonic integrated circuits (PICs) have been present in the market since the beginning of the 21st century. Initially, their development was mainly driven by telecommunication applications. PICs' potential was quickly noticed, and significant progress was observed in this field over the last twenty years. It should be noted, however, that the development was to some extent limited by technology constraints – most mature platforms, silicon-on-insulator (SOI) and indium phosphide (InP), are limited spectrally to ca 2 um (when the features of all building blocks, like light sources, modulators, waveguides, detectors, etc. are of concern). Nevertheless, PICs operating within the telecom spectral range are currently commercial products, confirming the maturity and market readiness of the technologies. However, it is clearly seen in the market trends that the potential of integrated photonics is also evident in the field of sensing-related applications, especially when longer wavelengths are of concern.

Mid-infrared (mid-IR) spectroscopy provides the possibility of detecting various gas and liquid substances, which is illustrated in Fig.1.

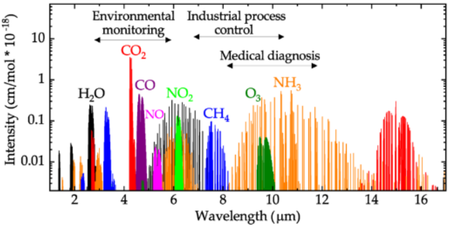

Fig. 1. Main absorption lines of selected gases in mid-infrared spectral range [1].

Furthermore, there are also atmospheric windows, around 4.5 μm and 9 μm, suitable for free-space optical communication (FSOC). However, this spectral range is challenging in terms of the technological platform since most materials strongly attenuate mid-infrared radiation. Currently, only several platforms, such as SOI, Ge-on-Si, or GaAs/AlAs, show the capability to realize efficient waveguides and other passive components in an integrated form.

In this work, the development of detectors optimized for integration with photonic integrated circuits based on the MIRPIC platform, developed by VIGO Photonics, Łukasiewicz Institute of Microelectronics and Photonics, and Warsaw University of Technology and optimized for a spectral range between 3 µm and 5 µm, are presented and discussed. The detectors are developed and optimized to obtain the highest normalized detectivity and/or bandwidth while operating at 300 K. Additionally, sufficiently large resistance (>100 ohms) for the active area of $100 \times 100\ \mathrm{um}^2$ needs to be achieved, together with reduced capacitance and parasitic serial resistance. As there is no possibility of realizing monolithic light sources and detectors using the Ge-on-Si or SOI platforms, a heterogenous integration approach is implemented. In such a case, the detectors must show immunity to high temperatures or specific chemistry needed for integration processes. These conditions limit the material of choice to III-V compounds, especially antimony-based. In this work the J-V and current spectral response characteristics of detectors optimized for 5.2 µm, 4.8 µm and 4.4 µm cutoff wavelength are presented and analyzed. Also, the C-V, response time and linearity characteristics are discussed. Finally, different integration methods such as gluing, flip-chip bonding and transfer printing are presented and further development possibilities are shown and discussed.

Acknowledgments: This work was supported by the National Centre of Research and Development through project MIRPIC (TECHMATSTRATEG-III/0026/2019).

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Packaging Technologies for Photonic Integrated Circuits

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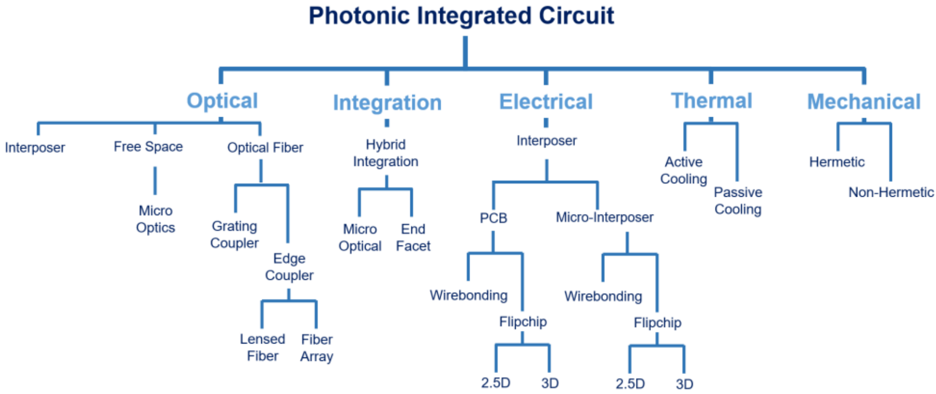

Fig. 1. Overview of photonic packaging technologies.

The development of photonic integrated circuits (PICs), especially those based on silicon wafer substrates is motivated by the potential of these devices to drive an industrial revolution in the domain of light. They are a central element of established and newly emerging technologies in areas such as in optical communications, sensing (e.g. LIDAR, chemical sensing), biomedical and quantum. As these devices and systems go beyond their research and development stage, manufacturing and scalability must be considered for them to become cost-effective and ubiquitous in the market. Both of these requirements are currently bottlenecks that prevent the widespread deployment of photonic technologies, as there is a high cost-to-market price.

Photonic packaging builds on the legacy of several decades of exceptionally successful engineering discipline of electronic packaging, which developed methods for mechanical housing ruggedness, thermal management and electrical connectivity; and expands it to include an additional domains of optical source integration and optical connectivity (Fig. 1).

Key to realizing low-cost, affordable photonics is the development of chip packaging and optical coupling technologies that enable manufacturing at low cost and can provide reliable low optical loss in practical application environments. The development of such technologies is complicated by the fact that silicon photonic waveguide devices are intrinsically single-mode. As a result, coupling of fiber to the PICs requires high-precision (few micron tolerance) and highly-stable mechanical alignment.

A typical photonic package requires a wide variety of different assembly technologies and processes, which are shown in Fig. 1. In this presentation, we focus on what is considered to be the most challenging aspect: connectivity with optical interfaces of the PIC. The techniques discussed range from standard fiber butt-coupling to emerging free-space micro-optic couplers that enable pluggable operation of the device [1].

The development of new emerging packaging strategies is highly complex and novel methods for prototyping, automation and scaling are required. In this work, we will present our vision for Assembly Design Kits (ADKs) and how they can be implemented using reference PICs for packaging process development and standardization [2]. These standardization efforts lead to a much more streamlined packaging process and allow for automation to take over, with the ultimate goal of automatic, wafer-level packaging and testing, which will be a key in scaling-up of photonic device manufacturing.

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OCT imaging using a MOEMS endomicroscopy probe with Mirau micro-interferometer and 2-axis electrothermal micro-scanner.

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The authors would like to present a new type of micromachined MOEMS/MEMS-type endo-microscopy probe. The connection of the MOEMS Mirau micro-interferometer and MEMS two axis electrothermal micro-scanner with swept source optical coherence (SS-OCT) imaging techniques enables construction of cost-effective, high level integration and hence small size as well as high quality endo-microscopy probe for application in vivo medical imaging. The presented endo-microscopy probe is designed for early diagnostics of cancer in human upper digestive tract as well as stomach tissue.

Authors would like to present the results of the study of an optical properties and scanning properties of the endo-microscopy probe. An important part of presented experiment results will be SS-OCT tomograms and images of test samples obtained by the endo-microscopy probe which using Lissajous scanning trajectory.

Acknowledgments:

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Functionalized photonic silicon-nitride-based integrated circuits operating in visible wavelengths for biosensing applications.

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Biosensing is a novel research area for photonic integrated circuits (PICs). This is largely enabled by silicon nitride properties whose transparency window extends from below 450 nm up to beyond 8 µm [1]. Transparency of silicon nitride (SiN) in the visible pass-band (400–700 nm) is of particular interest for biomedical applications due to low photo-induced damage to the living cells, low water absorption, and high availability of fluorescent markers. Furthermore, the SiN platform fabrication flow is compatible with the standard CMOS process.

The general purpose of the investigated biosensors is the detection of biological and chemical substances with high spatial and concentration resolution [2]. Such biosensors are based on evanescent field detection via refractive index modification.

The results and the development flow for two main types of PICs are presented as a basis for the developed integrated photonic biosensors.

The first discussed type are ring resonator-based (RR) circuits, most commonly realized with the use of microring resonators. In such a structure, the light guided via an input waveguide is coupled into a resonant cavity via the evanescent field. As only resonant modes can propagate in RR, in the presence of analyte binding to this structure, there is a shift in resonance wavelength, which can be measured as an analytical signal correlated with a number of elements bound to the surface [3].

The second type are interferometer-based PICs which are most widely reported in the literature. The working principle of this type of sensor is based on the interference of two phase-shifted signals propagating in the interferometer arms, one of which is regarded as the sensing arm and the second as the reference arm. The sensing arm comprises a cavity where the evanescent field interacts with the analyte, which results in a change of the refractive index of the cladding in the vicinity of the waveguide core [4].

On the basis of the preliminary development of a domestic SiN-based integrated photonic platform at Warsaw University of Technology [5], two types of sensing structures have been designed, fabricated, and tested:

(1) micro-ring resonators (RRs)

(2) Mach-Zehnder interferometers (MZIs)

Both types of PICs operate at visible wavelengths and have been tested for reference (SiO_2), air, water and glycerin claddings. Introduction of fluidic claddings is possible due to the additional technological processes performed during fabrication. The openings in the upper SiO_2 claddings are etched in selected areas to create sensing chambers. Images of MZIs and RRs with sensing windows are presented in Fig. 1.

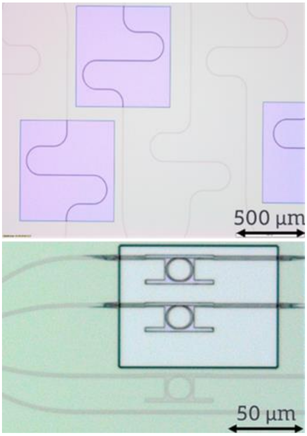

Fig. 1. Microscopic picture of MZIs and RRs with microfluidic interfaces.

The obtained measurements results confirm the sensing capabilities of the developed circuits. A device mounted in the characterization setup with visible input and output interface is presented in Fig. 2.

Additional tests with a bio-functionalized surface of the waveguides have been performed and the ability to detect concentration levels of a protein has been confirmed. 6405 anti-CRP antibodies have been immobilized on the waveguide surface exposed within the sensing window. Preliminary results onconcentration-selective detection of CRP protein will be presented during the conference.

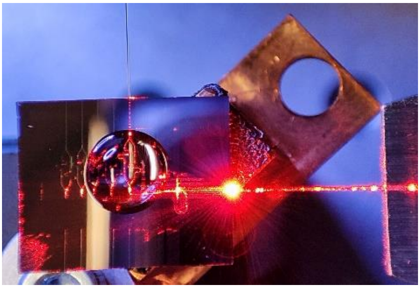

Fig. 2. PICs comprising biosensing elements in the characterization setup.

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Bearingless impeler suspension in rotary blood pumps - challenge for bioengineers

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Mechanical heart support is one of the recognized forms of treatment for end-stage heart failure. Rotary blood pumps, mainly centrifugal, have been used for this purpose for about 15 years. The technical problem in such pumps is the suspension of the impeller, which must operate without failure for at least several years.

Two concepts are used for the bearingless suspension of the impeller in the blood pump housing. The passive concept is characterized by the least degree of technical complexity, but it has numerous disadvantages. The most important of these is the negative impact on the blood, which leads to the formation of life-threatening blood clots. The active concept makes it possible to reduce the negative impact of the impeller on the blood at the expense of high technical complexity.

Active rotor suspension requires the use of sensors of its position in space as well as an advanced control system. Its task is to keep the rotor in a given position and to set it in rotation. Position sensors must work in the optically opaque blood environment, be accurate and reliable.

The paper presents considerations related to technological challenges encountered during the construction of systems of active levitation of the centrifugal blood pump rotor.

Fiber-optic CRP sensor supported by machine learning

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Abstract: We present a fiber optic biosensor for the detection of CRP (C-reactive protein) level, which is based on low coherence interference. According to preliminary investigations, The sensor's sensitivity is 5.65 µg/L, the measurement time is only 10 minutes and the volume of the sample is 10 µL. This makes our sensor one of the most prospective solutions for CRP monitoring. 27 machine learning classifiers were investigated for labeling the samples as usual or with high CRP levels. ExtraTreesClassifier showed an accuracy of 94.68% for the validation dataset.

Keywords: biosensors, fiber optic sensor, biomarkers, CRP detection

C-reactive protein is one of the most significant biomarkers used to assess inflammation (CRP). When it falls within the range that does not indicate inflammation, its level provides information about the likelihood of cardiovascular events. The CRP level can grow 1,000 times in a matter of hours if the norm is surpassed and inflammation is found in the body. The degree of raised CRP can also be used to diagnose the type of infection. Due to all of these factors, CRP is a crucial component of diagnosis. A 1310 nm-centered broadband light source (SLD-1310-18-W, FiberLabs Inc., Fujimi) was utilized to conduct the tests. The biofunctionalized end-face of the optical fiber received the light after it passed through the fiber optic coupler (G657A, CELLCO, Kobylanka, Poland). The wave then traveled to the detector, which was a spectrum analyzer (Ando AQ6319, Yokohama, Japan), after being reflected from the fiber's end-face (Fig.1)

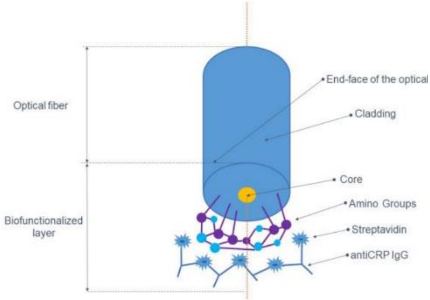

Fig. 1. The fiber optic biofunctionalized sensor head.

Because only commercially accessible components were used to construct the system, production costs could be kept to a minimum. Additionally, because of how simple it is to use, even non-technical individuals can use it. These characteristics make our technology a possible substitute for commercially available ELISA, which calls for skilled staff to carry out laborious measurement methods.

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Entropy source of optical fiber-based quantum true random number generator – modeling and measurements

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Well defined source of randomness (entropy) is crucial for physical true random number generator used e.g. to secure quantum communication. It can be realized based on measurements of external physical phenomena
(e.g. β-decay) or within a dedicated hardware (e.g. based on its electric noise).

In this work we presented a short description of a stochastic model of an entropy source for quantum true random number generator based on optical fiber system. The model was developed in order to properly describe the entropy source according to the regulations BSI AIS20/31 [1] and NIST SP800-90B [2]. The final results of the model are entropy of the system (determining its randomness) and probability of success, meaning the probability of obtaining either state 01 or state 10. The model also allows to predict the influence of changes in the input parameters on the final results and the behavior of the system. Finally, the results obtained numerically can be compared with the measured ones, which can lead to determination if the system is functioning properly. According to the AIS20/31 [1], the entropy of the system to be considered a proper entropy source should be at least 7.976 bits per byte (0.997 per bit). The measurement setup consisted of laser source (Laser), variable optical attenuator (VOA), optical fiber splitter (BS 50/50), two single-photon detectors (DET1 and DET2) and control device (PC), as shown in Fig. 1.

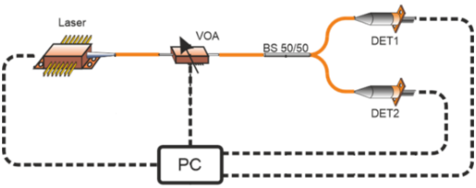

Fig. 1. Scheme of the measurement system

The number of photons in the system (generated by a pulsed laser source and attenuated with variable optical attenuator) can be described by Poisson distribution with attenuation being the expected value. The main parameters of optical fiber splitter used during modeling are distribution of transmission loss between two paths and additional attenuations of these paths. The two detectors can be described by their efficiency, afterpulsing, dark counts rate and detection frequency.

All of the aforementioned parameters were used as an input to the developed stochastic model in order to confirm its usability by comparing its results with the results of measurements performed on our system, as presented in Fig. 2.

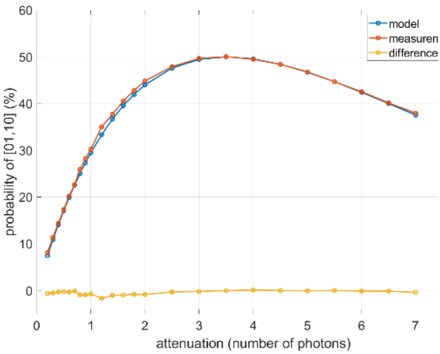

Fig. 2. Comparison of probability of success in the model and measurements

As it can be seen in Fig. 2, the results of the model were in good agreement with the measurement results. Some small differences (below 2%) might originate e.g. from environmental conditions during the measurements and in no way they change the overall characteristics of success probability (obtaining states 01 or 10).

Additionally, we studied the influence of the relation of additional attenuation in both paths (s_1 and s_2) on the final entropy value, which is presented in Fig. 3.

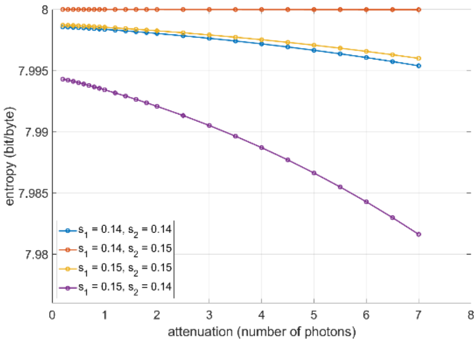

Fig. 3. Influence of the additional attenuation parameters on the system's entropy

From analysis of Fig. 3 it is evident that even small changes (at the level of single percentage point) in the relation of one of the input parameters (in this case the additional attenuations in both paths) can lead to drastic changes in the entropy value. Therefore, a proper control of the subsystem's properties is necessary to obtain high entropy values, even though it might prove to be difficult in some cases (e.g. losses in both optical paths).

To conclude, we demonstrated that the developed stochastic model of the entropy source of quantum true random number generator is appropriate for our optical fiber-based system and can be used for its evaluation. Additionally, with the stochastic model it is possible to determine the tolerances of parameters of each part in the system, in order for it to be properly functional – to provide true random numbers as an output.

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Automatic detection of defects in composites using terahertz imaging

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A histogram-based method for automatic defect detection in glass composites based on the terahertz system was developed. We arranged a high-speed TDS reflective scanner with an electronically controlled optical sampling scheme for testing the method. Two samples with two kinds of round defects (delaminations and inclusions) of different sizes were prepared. In the beginning, the algorithm acquired a series of C-scans, which were pre-selected to find only those likely to have defect-related characteristics. The thresholding method is based on Gaussian fit to C-scan histogram. For the sample with delaminations, 100% of defects were detected, while for the sample with inclusions - 87%. The algorithm also provided information about the depth of the defects, because each C-scan is assigned to a time slice. The results prove that a terahertz TDS-based system with the histogram-based method can be used for automatic defect detection in composites.

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Polymer nanocomposites evaluation by optical coherence tomography

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Optical Coherence Tomography (OCT) is a modern non-destructive and non-invasive visualization method of optically scattering materials and objects. The OCT delivers the 2D cross-sectional images or 3D volumetric data of the tested device's inner structure with a resolution of a few micrometers. The method is based on spatially resolved detection of backscattering light from each point inside the evaluated sample with the aid of low-coherence interferometry. The OCT features and abilities have been appreciated especially in medical diagnosis, mainly in ophthalmology. Furthermore, some beyond medical applications like polymer composites evaluations or strain field mapping have been noticed [1,2].
Standard OCT imaging is based on backscattered intensity calculations, which is useful for most OCT applications. However, this approach neglects other important material features, which relate to, i.e., spectral characteristics or state of polarization of light [3-6]. They are of interest in the presented study in a frame of evaluation of polymer composite materials infilled with nanoparticles. Some examples of standard OCT imaging of PMMA matrix filled with TiO_2 nanoparticles at volume concentrations of 0.1%, 0.2%, and 1.0% were presented in Fig. 1-3.

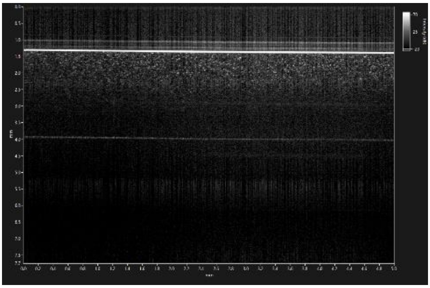

Fig. 1. The PMMA matrix with TiO_2 volume concentration of 0.1%

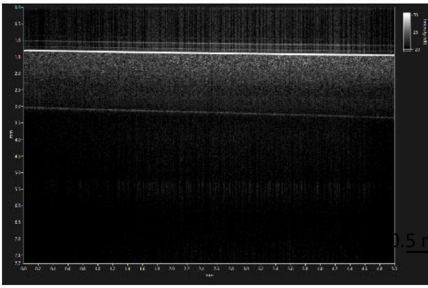

Fig. 2. The PMMA matrix with TiO_2 volume concentration of 0.2%

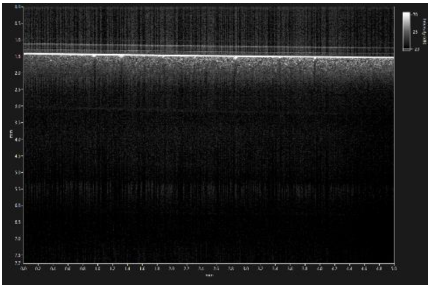

Fig. 3. The PMMA matrix with TiO_2 volume concentration of 1.0%

It is going to be shown that the fast and reliable evaluation of concentration and dispersion of the nanofiller in the polymer matrix can be performed based on OCT imaging by retrieving the spectral information of the backscattered light.

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Measurements of the spectral interferogram for single-mode waveguide layers

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In recent years, first there have been proposals [1], and then the implementation of broadband planar optical interferometric sensors. The broadband Mach-Zhender [2] and Young [3] interferometers are presented. In sensors of this type, waveguide modes are excited in the visible or near infrared range in the wavelength range of several hundred nanometers. The spectrometer records the interference spectrum at the output of the optical path.

Changing the parameters of the optical path causes a change in the interference spectrum. The papers [4, 5] present the theoretical description of broadband differential interference in planar waveguides. In this interferometric system, fundamental waveguide modes with TE and TM orthogonal polarization in the visible range are excited. The phase change between the TE and TM modes (usually caused by a change in the refractive index of the coverage of the waveguide layer) causes a change in the recorded spectral signal.

A stand was built for introducing light into the waveguide layer and recording the output interference signal. Spectral measurements at the output of the structure allow to determine the derivative of the spectral dependence of the birefringence of the modal waveguide layer.

The work will present the test stand and measurement methodology.

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Fabrication of infrared detectors with monolithic micro-lenses manufactured by a thermal reflow process

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An infrared detector is a semiconductor electronic device that is used in many areas such as: temperature measurement systems, gas analysis, military detection system, people counting and fire or smoke detection. The most important parameters defining the usefulness of the detector include the intensity of current noise I_n, current sensitivity R_i, and spectral detectivity. While the sensitivity depends mainly on the parameters of the semiconductor photosensitive structure, the current noise depends, among others, on the photosensitive surface area.

This means that the detection of weak optical signals requires a detector with a small photosensitive area. Therefore, in applications requiring high sensivity as well as large analysis area, multi-element detectors are used. Unfortunately, the design of a flat multi-element detector causes distortion of the recorded signal due to optical crosstalk [1, 2] and blind spots. An alternative solution is to use an immersion detector, i.e. monolithic integration of the detector element with a microlens. This makes the optical size of the detector larger compared to its physical size, thus increases the normalized detectivity D* by a factor of $(A_0/A)^{1/2}$, where A_0 is optical area and A is physical area.

Immersion lenses were already fabricated by machining process [3, 4]. However, this solution is expensive due to the need to process each workpiece separately, ensuring high centering and machining accuracy and low processing temperature, so as not to damage the photosensitive structure. All these factors contribute to the high cost and long production time of the detectors. Therefore, it is proposed to replace the hyper-hemispherical lens with integrated micro-lens produced in a thermal reflow technology followed by dry etching. The proposed solution offers benefits such as the automation of the production process, higher accuracy of manufactured elements, reduction of manufacturing time and thus a reduction in the unit price.

In this paper, we report the results of experiments with the fabrication of monolithic immersion micro-lenses for III-V materials infrared detectors. This technique allows obtaining the uncooled detectors with improved detectivity and overcoming the problem of low resistance and low signal-to-noise ratio (SNR) at higher temperatures. The research was carried out based on InAsSb molecular beam epitaxy (MBE) growth materials with photosensitive structures located on the front side of the detector. The shape of micro-lenses was determined by the thermal reflow process of cylindrical photoresist structures on the back side. Immersion was assured by transferring shape into GaAs substrate by Inductively Coupled Plasma Reactive Ion Etching (ICP RIE) (see Fig. 1).

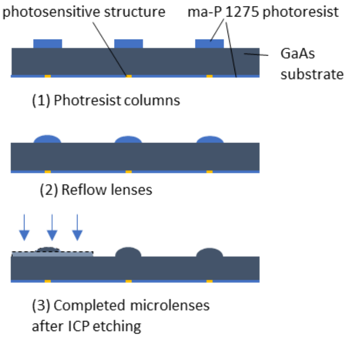

Fig. 1. Fabrication of GaAs lenses by thermal reflow and ICP etching

Implementation of micro-lenses enables to increase in the optical area of a photodetector while maintaining the electrical area dimensions. The measured aperture of the flat and immersed detector was 100x100 µm and 330±10 µm, respectively.

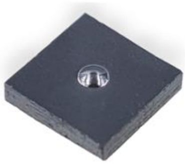

Fig. 2. Picture of the manufactured detector chip.

The fabricated detector with micro-lens structure enabled obtaining three times higher normalized detectivity D* (see Fig. 3) than obtained for flat detector and preserve a similar level of resistance and current sensitivity.

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Nanoparticles-doped blue-phase liquid crystalline photonic microstructures for promising sensing and tunable devices applications

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Blue Phase Liquid Crystal (BPLC) is composed of liquid-crystalline molecules with a specific arrangement creating self-assembling cubic structures in the two phases BP I and BP II or occurring as an isotropic-like 'fog phase' BP III [1]. All three structurally distinct types of the BPLC appear in order of decreasing temperature from the isotropic to cholesteric phase and naturally exist in a relatively narrow temperature range (0.1-5.0 K). BPLCs are characterized by outstanding properties such as 3D Bragg reflections, optical isotropy, no need any alignment layers, ultra-fast switching reaction times (less than 1 ms), and polarization insensitivity in a macroscopic scale for the wavelengths outside their resonance bands [2,3]. Notably, the optical properties of BPLCs can be modified by external factors such as temperature, external electric or magnetic fields, as well as mechanical deformations. Moreover, the use of BPLCs in fiber-optic systems can contribute to the creation of advanced and flexible systems, operating in the visible spectrum, that control the propagation properties and simultaneously detect selected external physical factors [4,5].

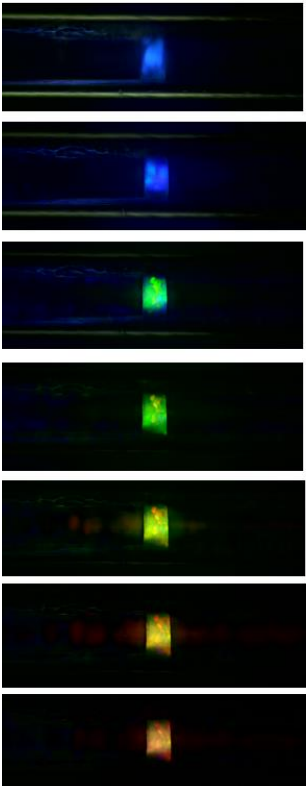

Fig. 1. BPLC-based photonic microstructure with fiber probes on both sides sensitive to temperature

In this work, optical properties of the selected photonic microstructures based on BPLCs (Fig. 1) doped with gold nanoparticles (Au NPs) are investigated. It has been shown that the examined photonic microstructures can provide promising tunable optical properties, simultaneously enhancing temperature stability of the LC-system. This is due to the presence of Au NPs with an appropriate organic coating in the LC matrix [6]. It has been demonstrated that the investigated BPLC-based photonic microstructures seem to be very promising materials for realizing electro-optical modulation and switching as well tunable filter applications and sensing capabilities providing better transmission properties due to the existence of inherent optical isotropy in BPLCs.

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FOSREM – from sky through ground up to underground applications

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FOSREM – Fiber Optic System for Rotatio-nal Events Monitoring is conception of in-novative system secures continuum moni-toring any kinds of the rotational moving without reference frame.

It uses von Laue-Sagnac effect [1] in a special configuration of a fiber-optic inter-ferometer (Fig. 1) which detects rotation without reference frame in axes perpen-dicular to sensor loop [2]. The main system parameters such as: sensitivity (dependent on white noise), stability (connected with bias drift), required dynamic range mainly depends on applied fiber optic length (0.1 –15 000 m) and loop diameter (0.08-0.60 m). Applied suitable broadband high power source as well as digital signal processing secures suitable scale factor accuracy. All above directed such system for wide range of different grade system listed in Tab 1.

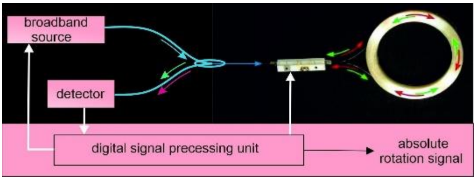

Fig. 1. So-called minimum configuration

Technical implementation in 3- axis system (see Fig. 2) with additional three linear motion sensors based on accelero-meters is a main key for construction 6DoF-IMU (Six-Degree-of-Freedom Inertial Measurement Unit) [3].

Tab. 1. The main parameter for different system grade.

System Grade	**ARW (white noise)**	**Bias Drift**	**Scale Factor accuracy**
	[(o/h)*/$\sqrt{Hz}$]	[°/h]	[ppm]
Rate	> 0.5	1 000 ÷ 10	1 000 ÷ 10 000
Tactical	0.5 ÷ 0.05	10 ÷ 1	100 ÷ 1 000
Intermediate	0.05 ÷ 0.005	1 ÷ 0.01	1 ÷ 100
Inertial	0.005 ÷ 0.0003	0.01 ÷ 0.001	5
Strategic	< 0.0003	< 0.001	1

*For rotation rate system 1 [°/h] = $4.81 \cdot 10^{-6}$ [rad/s]

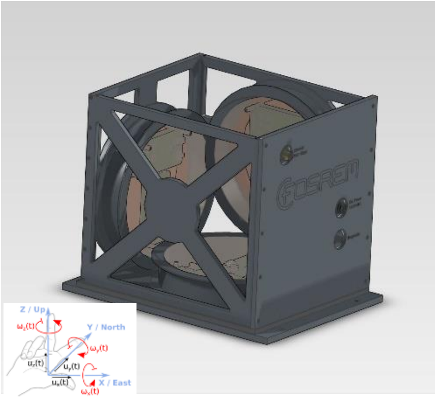

Fig. 2. 6DoF IMU of FOSREM with 6-axis identification

Such implementation is base for any application as rotational rate [4, 5] or angular moving unit [2, 6]. Additional equipment 6DoF-IMU in PCU (Power Com-munication Unit) secures such functio-nality as: independent power supply from additional sources, data time s tamping based on GPS for set of IMUs synchroni-sation as well as data converting on angle, their resample, processing and continuum transfer for given server via telecommu-nication system gives FOSREM as a system from sky through ground up to under-ground applications.

The sky (or space) FOSREM application has three fundamental functions. The well-known is IMU gyro navigation including air-crafts (military and civile), rockets as well as drones. However calibrating RF instru-ments in space, and relativistic time trans-fer are the two other area possible for applications.

The ground FOSREM applications is also very attractive. As gyro implementa-tion is used for car and autonomous cargo-ships IMU navigation, for platform stabili-sation as for tank as in radiotherapy and MRI/PET (nuclear medicine). The rotatory monito-ring includes investigation Earth rotation fluctuations, space-time research (investigation gravitational waves) as pro-bably the most important development the system for protecting people, complex civil structure, business and peace. In the last rotatory IMU are investigated for pipe damage control systems, monitoring sky-scrapers, tunnels, fast trains as well as sensing rotatory force at wind towers, and nuclear plants. They will be very attractive for industry asset monitoring and manage-ment.

Finally FOSREM underground applica-tions is design for measurement the rotational components in natural and arti-ficial earthquakes, searching by microseis-mic reflection such minerals as carbon, thermal water gas and oil, and monitoring underground activity of mines.

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Poly(3-hexylthiophene) graft copolymers and their organic-inorganic blends activated by UV light for NO2 gas sensing applications

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The detection of nitrogen oxides (NOx) plays a crucial role in air quality monitoring and in nitric explosives detection [1]. The concentrations of NO2 should be monitoring in the sub ppm range because according to the European standards continuous average exposition to NO2 should be below 200 ppb in outdoor air[2].

In this work poly(3-heylthiophene) based conducting graft copolymers [3,4,5] and their blends with ZnO nanostructures [6] for gas sensing applications will be presented. The influence of near UV irradiation (390-400 nm) on gas sensing properties of such materials will be shown. The fabrication process of receptor structures in interdigitated transducers and their sensing properties at low concentrations of NO2 in ppb and sub-ppm range will be presented. The materials will be compared in terms of their sensing properties and long-term stability. The sensing mechanisms of presented structures will be discussed. The selectivity to other gases and the influence of humidity will be also shown. The influence of UV on sensing dynamics of polymer based structures and their potential photodegradation in long term operation are investigated. The organic-inorganic heterostructures made of P3HT based polymers mixed with ZnO nanostructures are proposed to achieve more stable sensing performance.

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Monitoring temperature changes of the active layer of the permafrost across varied grounds in the Arctic with fiber-optic distributed measurement system

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Gathering spatially and temporally dense large amounts of data on temperature changes in the active layer of permafrost is of importance as an input for modelling climate changes and predicting their consequences. However, conventional methods of performing temperature measurements of permafrost – analogue mercury thermometers and thermistor strings – do not provide such abundance of data. On the other hand, fiber-optic distributed sensors, especially those interrogated by the means of optical frequency-domain reflectometry, are known to permit spatial resolutions of the order of even few millimeters and can be easily automated to perform measurements with time interval of few seconds.

In the summer of 2022 we have installed and tested a fiber-optic distributed measurement system based on commercial optical frequency-domain reflectometer LUNA OBR4600 in genuine Arctic environmental conditions near Calypsobyen on the island of Spitzbergen in the Svalbard archipelago (Fig. 1.). The sensing fiber-optic cable has been buried in varied grounds comprising tundra, solifluction slope and sandy beach.

Fig. 1. Sensing optical fiber on the tundra before installation in the ground.

We present the installation of the sensors according to the strict regulations for environment and cultural heritage protection as wells as the results from the summer measurement session. We compare the obtained readouts with reference temperature measurements from thermistor strings installed in nearby locations as well as meteorological stations and discuss the influence of the strain-temperature cross-sensitivity.

Acknowledgments: This work was supported by the projects National Laboratory for Photonics and Quantum technologies – NLPQT (POIR.04.02.00-00-B003/18-00) and Autonomous Quasi-Distributed Optical Fiber Temperature Sensor for Ground Temperature Measurements – SPILOD (POIR.04.01.01-00-0031/19).

POSTERS

InP-based photonic integrated circuits of EEDH WUT

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The progress in integrated photonic circuits technology enables the design and development of innovative, complex, highly efficient, and reliable miniaturized optoelectronic systems with the use of standardized design tools, libraries of building blocks, as well as manufacturing and packaging processes. The last two decades observed the growing interest in application-specific photonic integrated circuits (ASPIC) for application in next-generation telecommunications, datacom, and sensing systems. This, in turn, resulted in the rapid development of numerous start-up and spin-off companies operating in the fabless formula, commercializing the knowledge gained in the field of integrated photonics systems.

The monolithic integration of light sources, amplifiers, modulators, detectors, and a wide range of passive components on the indium phosphide platform, enables the implementation of photonic systems of practically any kind. Good examples are multichannel transceivers for telecom and datacom systems (provided by such companies as Infinera, Intel, Effect Photonics, Miraex, etc.), as well as interrogators of fiber-optic sensors (developed by PhotonFirst or Amazec Photonics).

In 2011, at Warsaw University of Technology (WUT), the team of young scientists led by dr. R. Piramidowicz and prof. P. Szczepański, with the significant knowledge support from Technische Univeristeit Eindhoven (TU/e), established Eastern Europe Design Hub (EEDH) - the first design house in Eastern Europe, capable of designing and characterizing photonic integrated circuits of any kind.

Since then, the team grew up, gaining new experience and systematically extending the scope of operation. So far, more than 100 different PICs have been designed in EEDH, based mainly on generic InP technology, including multi-channel transceivers, interrogator units for FBG sensors, ring lasers for optical gyroscope systems, optical time domain reflectometers, optical switches, lossless power splitters, and so on. The most emblematic examples are shown in Fig. 1.

a)

b)

c)

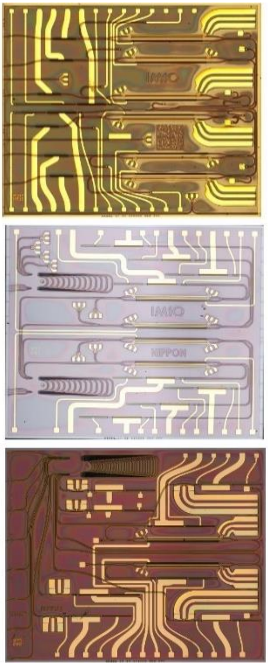

Fig. 1. Exemplary implementations of PIC systems with integrated laser structures a) transmitter for the system Few Mode Fiber, b) four-channel WDM transceiver, c) eight-channel WDM transmitter

All of these were manufactured in European ASPIC foundries – mainly in SMART Photonics, but also in Fraunhofer Heinrich-Hertz-Institut, COBRA Research Institute, Oclaro, and LioniX International. All designed circuits were comprehensively characterized in the Photonic Integrated Circuits Laboratory at WUT. Due to the great interest of companies seeing the market potential of the designed solutions, confirmed by the successes of several large applied research projects, the first commercial Polish design house, Light**House,** was established, offering support in the design and technical guidance in ASPIC technologies. Light**House** is a spin-off company of WUT, providing not only support in the ASPICs designing process but also access to unique research equipment allowing versatile characterization of photonic chips, operated by an experienced team of engineers eager to help you find your way to success on integrated photonics market.

In this work, we present examples of the ASPICs designed and developed by EEDH so far, together with the current capabilities and technical support offered by EEDH and Light**House** to research institutions and industrial partners (including startups and SMEs).

Acknowledgments:
The results presented in this work were supported under the NIPPON (PBS3/A3/21/2015), OPTO-SPARE (PBS3/B9/41/2015) and NMKM+ (TECHMATSTRATEG/1348438/16/NCBR/2018) projects financed by the National Center for Research and Development and through POB Photonic Technologies from the funds of the Warsaw University of Technology under the Program Initiative of Excellence - Research University (IDUB).

Two-channel fluorescence microscope for imaging diamonds with nitrogen vacancies

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We have constructed measuring system for observing the fluorescence of diamonds and standard fluorescent powders.

The system is multifunctional and allows observation of samples in two ways as it utilizes two independent optical channels – through the standard image and the fluorescence spectrum. A photo of the optical system is shown in Figure 1.

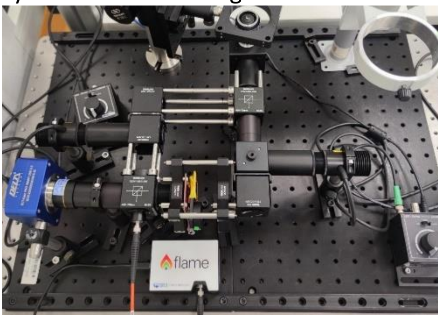

Fig. 1. Photo of the optical system for fluorescence imaging

The two-channel system enables the observation of various substances having their response in the form of the fluorescence phenomenon to excitations of two wavelengths. In addition, in the proposed configuration it is possible to make measurements with a camera and a spectrometer in the same measurement conditions, simultaneously or quasi-simultaneously. Assuming the use of only one-channel system, such measurement would be possible sequentially, however, it would time-consuming and requiring re-alignment of the entire system after each change. Examples of observation of nano-diamonds are shown in Figure 2.

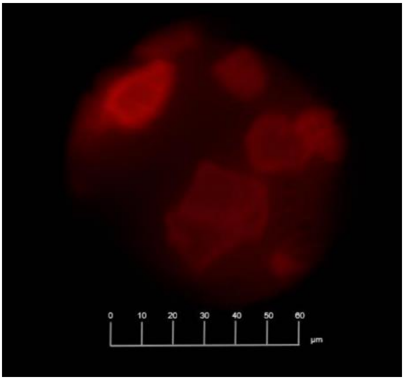

Fig. 2. Image of diamonds with nitrogen vacancies

Acknowledgments: The research was carried out within the TEAM NET program of the Foundation for Polish Science co-financed by the European Union under the European Regional Development Fund, project POIR.04.04.00-00-1644/18.

Research on temperature dependence of optical fiber current sensor with external conversion

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The measurement of electrical quantities in the power industry is very important. The measurement methods used in the system by means of direct and indirect methods of electrical quantities, e.g. current, have their limitations. A particular imperfection of the measurement concerns the use of traditional instrument current transformers in the measurement, and the sensitivity of measurement and the transmission speed of measurement data, which are important in some areas.

An alternative to conventional instrument current transformers are optical instrument transformers based on the magneto-optical effect. These sensors are characterized by high insulation, insensitivity to electromagnetic interference, high response speed and small size. In addition, they are resistant to exceeding the range, current surges, and in the event of damage caused by e.g. physical influence of current (e.g. high temperature) they minimize the risk of people and property.

The paper presents the research of a optical fiber current sensor with external conversion (OFCS-EC) as a function of temperature. The sensor was developed in the Department of Optoelectronics. The sensor was tested in the temperature range from 20 - 75 ^{0}C. For each of the temperatures, the sensitivity was determined on the basis of a sinusoidal waveform. Thus, the linearity of the transfer characteristics was checked. The main purpose of the experiment was to check the limits of sensitivity changes in changing thermal conditions and whether the sensor meets the standards used in the power industry.

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Development of miniaturized optical gyroscopes using photonic integration technologies

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In current sensing devices, there is a need to develop miniaturized optical systems, optimized with respect to power consumption, reliability, and cost. Among a variety of sensing systems specifically interesting from the application point of view are integrated optical gyroscopes [1, 2], considered as an attractive, low-cost solution for various kinds of navigation systems, and everyday electronic devices like smartphones or smartwatches.

Basically, two main types of optical gyroscopes can be distinguished: ring laser gyroscopes (RLG) and fiber optic gyroscopes (FOG) [3]. The principle of operation of the first type is based on the detection of the rotation-induced frequency shift between two modes of the ring laser - clockwise (CW) and counter-clockwise (CCW). The second type is based on the detection of the phase difference between two signals propagating in opposite directions through a long optical fiber loop.

In this work both abovementioned approaches will be discussed in the context of implementing the solutions based on photonic integrated circuits (PICs) generic technology. In particular, several designs of integrated optical

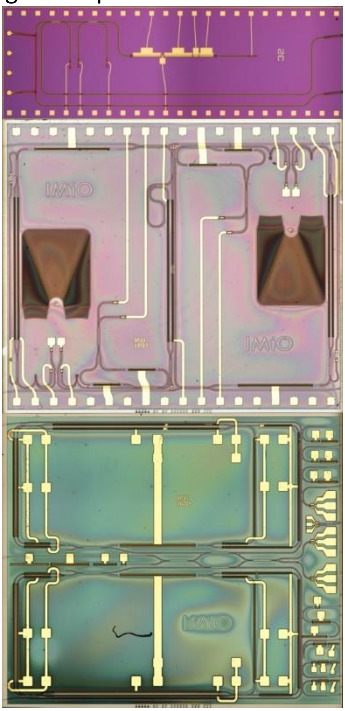

Fig. 1. Selected designs of RLG and FOG photonic integrated circuits.

gyroscopes (both RLGs and FOGs) will be presented and compared with respect to the performance parameters and perspectives of market applications.
All of these devices (Fig. 1) were designed and manufactured using the generic indium phosphide-based integrated photonic platform, provided by SMART Photonics and OCLARO foundries. All of these were subjected to versatile electrical and optical characterization, both at the element and system level, which, in turn, enabled optimization of the designs and analysis of the commercialization perspectives. The best-performing devices were developed up to packaged systems level, equipped with dedicated electronics and tested in the close-to-real exploitation conditions.
In general, the performed tests confirmed the initial assumptions and applicability of the developed photonic integrated circuits to the detection of angular velocity. As a result, the roadmap of the further development of integrated photonic gyroscopes has been defined, with the most important milestones and application fields defined.

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AWG components for HYPHA integrated photonic platform - design and applications

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Telecommunication, data communication, and sensing are currently the most important application fields of modern fiber-optic systems and photonic integrated circuits. In particular, technologies of integrated photonics provide the unique potential for designing and manufacturing complex, highly efficient, reliable, and compact telecom, datacom, and sensing systems. Therefore, dynamic progress is observed in the development of new technological platforms extending the spectral range of operation and/or functionality of the integrated systems. One of these is the HYPHA platform, based on TiO_2/SiO_2 material system, developed jointly by Warsaw University of Technology, Wroclaw University of Technology, Silesian University of Technology, and Łukasiewicz Research Network – PORT Polish Center for Technology Development.

The progress in technology development might be, to some extent, measured by a number of available building blocks (designed and manufacturable), among which the most advanced is arrayed waveguide grating (AWG) [1, 2], often considered as proof of the maturity of the platform. An example of AWG is presented in Fig. 1.

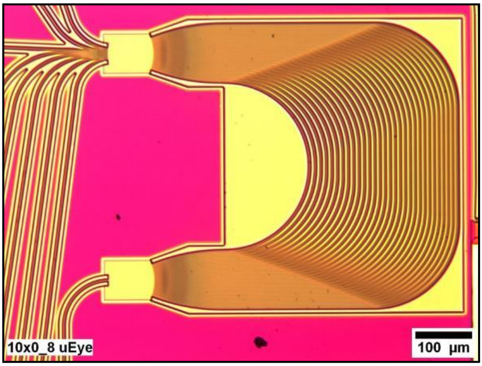

Fig. 1. Exemplary structure of AWG component on the indium phosphide platform.

It should be noted that apart from their complexity, these elements are crucial for all applications related to the multiplexing/demultiplexing of signals of different wavelengths, monitoring the changes in the optical spectra, and so on.

The most typical application of AWG components is modern telecommunication, using multiple multiplexing methods. One of these is the Dense Wavelength Division Multiplexing (DWDM) technique, which can be easily implemented using integrated AWG components.

In this work, we show the first results of designing AWGs building blocks for the silica-titania technological platform (aka HYPHA). In particular, the designing tools and designed components will be briefly presented, together with the first results of simulations and modeling, discussed in the context of major challenges and opportunities provided by the platform.

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Room Temperature NO_2 sensor based on reduced graphene oxide

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Nitrogen dioxide belongs to dangerous gases because it causes irritation of the respiratory system even at 10-20 ppm concentrations. Moreover, NO_2 at 150 ppm concentration it could even cause death. It is generated through combustion of fossil fuels and it is responsible for acid rain. It has not only a direct impact on human life and health, but also on the surrounding environment [1-5]

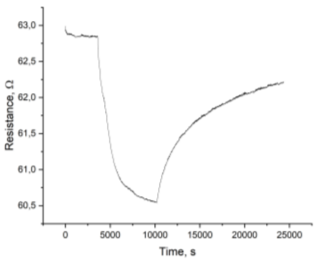

Fig. 1. Resistance vs. time (atmosphere of different NO_2-N_2 concentration, room temperature)

One of the sensing material, which can be used in NO_2 detection is reduced graphene oxide (rGO). We presented that nitrogen dioxide detection using sensors based on reduced graphene oxide is possible at room temperature.

The resistance vs. time is showed at Fig. 1 (carrier gas: nitrogen, concentration of NO2 in N2: 10 ppm, RT) Interestingly, sensitivity of rGO is the highest at room temperature and decreases with increasing temperature (Tab. 1).

Tab. 1. Dependence of sensitivity (S) from temperature (T).

S, %	T,ºC
3,67	27
2,16	50
1,76	70
1,28	90
0,91	110
0,55	130
0,26	150

Acknowledgments: This work was supported by Dotation of Polish Ministry of Science and Higher Education (BK-270/Re4/2023).

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The influence of platinum substrate in hydrogen sensor based on reduces graphene oxide

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Hydrogen should be classified as a dangerous gas because it is explosive in concentrations between 4 and 75 % in air [1]. Due to this, it is very important to detect it in a fast and reliable way. Despite the fact that many ready-made solutions are available commercially, faster, more accurate and characterized by lower energy consumption solutions are still being sought.

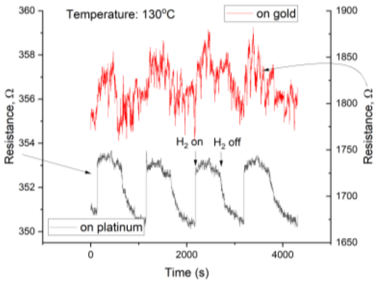

Fig. 1. Resistance of structure with reduced graphene oxide on gold and on platinum substrate (electrodes) vs. time during hydrogen detection

One of the sensing materials which is investigated as a hydrogen sensing layer is reduced graphene oxide. It reacts quite quickly to the appearance of hydrogen in the atmosphere, unfortunately, its sensitivity is not very high [2]. For this reason, we decided to use it on platinum electrodes (acting as a catalyst). As it turned out, we were able to achieve better sensitivity with comparable times of reaction of the sensor structure (Fig. 1).

Acknowledgments: This work was supported by Dotation of Polish Ministry of Science and Higher Education (BK-270/Re4/2023).

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Boron-doped diamond electrodes rich in nitrogen vacancies

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The development and applications of quantum technologies and nonlinear spectroscopy for studies of color centers in diamonds are very fast. Thanks to the stable crystallographic and electron structure of diamond, NV-color centers exhibit very stable electronic spectra, resistant to various perturbations [1]. Their excellent optical and spin properties allow one to use different resonance and spintronic methods of and enable precision metrology [2].

The properties of diamond can be changed by doping. In this work, changes in the optical and electrical properties of thin diamond layers doped with boron and nitrogen will be presented. Doping with boron allows to change the electrical parameters in a wide range. On the other hand, nitrogen admixtures allow you to create vacancies. Both admixtures simultaneously allow for tuning the optical and electrical parameters of the obtained electrodes.The SEM analysis, Raman spectroscopy, and electrochemical properties were particularly presented.

The in-situ co-doping induces synergistically crystal defects, which are even pronounced at average boron levels. The increase of B/ N co-doping ratios was also responsible for the reduction of nitrogen precipitation in CVD diamond promoting the formation of increased density of NV centers displayed in PL spectra. Nevertheless, an efficient NV emission was achieved after thermal treatment of samples attributed to the migration vacancies to form the NV centers. Doping by boron decreases the work function down to 4.47 eV saturation level followed by its increase for larger doping levels attributed to the growth of sp2 degenerated diamond and formation of boron-clusters, which influences the NV emission due to quenching. The boron doping introduces impurities band revealed surficial conductivity in the range of a few Ohms, which is enhanced additionally by nitrogen co-doping particularly benefiting at low boron-doping. The tailoring of B/N co-doping CVD diamond at fused silica substrates allowed to achieve high quality and low resistivity layers attractive in the frame of joint quantum/electronic or electrochemical applications.

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Application of Faraday mirror for phase coding of information in the optical fiber sensor

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Globalization enabled tremendous access to information - nowadays every human living in developed country has common access to the information with fast and high capacity transferring. However with raise of common access to the information and the infrastructure enabling it, the risk of any eavesdropping of information and hacker attack also raised substantially. Thus the need of proper protection of all kinds of communication systems also have raised. This is extremely important in the critical areas of life, i.e. military, banking or personal data protection. Modern data transmission systems are based mainly on optical fiber technology. Therefore, various types of optical fibers cable protection were developed to protect such systems from eavesdropping [1-3]. One of such systems was developed in the Institute of Optoelectronic at Military University of Technology in recent years [4].

This work is about upgrading system mentioned above, by adding another phase modulator (PM) – in shorter arm of Mach-Zender Interferometer (MZI) and changing silver mirror to Faraday Mirror (FMIR) placed at the end of the setup. Moreover both PMs were manufactured without polarizers on the input or output.

The additional phase modulator enables switching between coding bases making our system similar to Quantum Key Distribution (QKD) systems and enabling usage of different coding protocols such as BB84. The FMIR was at first used to desensitize the system and making it better transmission system – since the rotation of polarization on FMRI makes the system self-compensating on the polarization changes. However we found out that changed construction of phase modulators and use of FMIR causes polarization mismatch big enough to create the pulse residue – additional small intensity pulse after the modulated signal. This residue can be canceled by polarization controller. However, if we let it propagate within the system the difference between its intensity and the intensity of the original pulse changes whenever there is mechanical disturbances of the transmission single mode fiber. Those changes are big enough to use them as an alarm signal for the user.

After upgrading system is now double-secured; firstly by the ability of changing coding bases and secondly by the sensitive nature of transmission whenever the telecom fiber is disturbed.

Acknowledgments:

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Fiber-optic water salinity sensor

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Water salinity caused by various means, e.g. through industrial waste discharged into rivers or the use of road salt for road infrastructure near water reservoirs, has a negative impact on the natural environment. It can cause, among others: increased mortality of organisms by reducing their mass and life activity, inhibition of plant growth, reduction in size and number of leaves and roots, releases of heavy metals (Cu, Cr, Pb and Ni) from colloids and organic substances.

In order to determine the concentration of salt in water, a fiber optic sensor based on a D-shape fiber (working on the principle of an evanescent wave sensor) was designed.

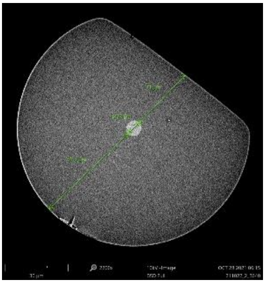

Fig. 1. SEM photo of the D-shape fiber used this work.

Sea and rock salt solutions of various concentrations were prepared and then spectroscopic measurements were carried out to determine the analytical wavelength. The next step was to make the sensor by splicing together the SMF fiber with the measuring section of the D-shape fiber with a length of 30mm and the SMF fiber.

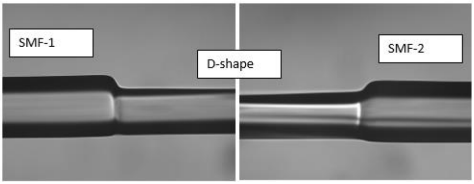

Fig. 2. Photo of the SMF-D-shape-SMF splice.

The last step in the above work was to carry out spectrum measurements using an optical spectrum analyzer. After the measurements, the results were compared with the results of spectroscopic measurements.

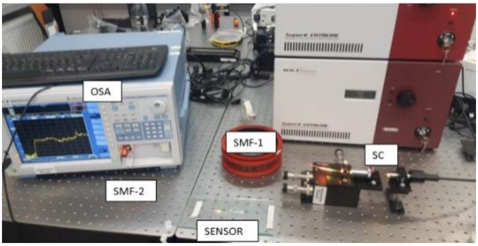

Fig. 3. photo of the measuring system.

Integrated photonics for free-space optical communication

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Wireless optical communication (WOC) is considered the next frontier for high-speed broadband connection due to its unique features: extremely high bandwidth, relative easiness of deployment, tariff-free bandwidth allocation, lower power, less mass, and smaller size compared to RF systems [1]. WOC can be divided into two main broad categories: indoor and outdoor systems, while outdoor wireless optical communication is also termed free-space optical communication (FSOC). FSOC requires a line-of-sight connection between the transmitter and receiver. The optical information signal propagates through the atmosphere, space, or other specific gas environments, whose characteristics determine the conditions for its transmission and detection, which, in turn, define the requirements for designing reliable and efficient communication systems.
The wavelength selection of the FSOC system is crucial, as it affects the overall performance of the link. The choice of the proper spectral range

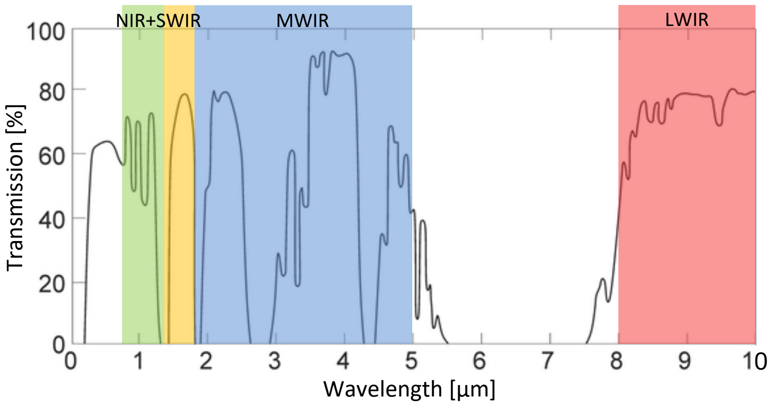

Fig. 1. Transmission windows in the atmosphere as a function of wavelength.

mainly depends on atmospheric effects and transmission windows (see Fig. 1), attenuation, and background noise power, but also on the availability and cost of the components. Last but not least, eye safety regulations have to be fulfilled.
Nowadays, almost all commercially deployed FSOC systems use near-infrared (NIR, 0.7-1.4 µm) and short-wavelength infrared (SWIR, 1.4-1.7 µm) spectral bands [2]. This is mainly caused by the maturity and broad availability of transmitters and receivers since they are also used in state-of-the-art fiber-optic communication systems.
It should be noted, however, that turbulence and aerosol (diffusion) effects significantly influence transmission over the atmosphere within the NIR/SWIR spectral range. Therefore, shifting the transmission to longer wavelengths is considered to mitigate the turbulence-related effects [3,4].
In this work, we present and discuss our first attempts to design and develop photonic integrated circuits (PICs) for application in free-space optical communication systems. Fig. 1. presents a microscope picture of one of the series of realized multi-channel WDM transmitters fabricated in generic indium phosphide technology [5]. The design and initial characterization results of the realized transmitters are discussed with respect to their applicability in free-space optical communication systems.

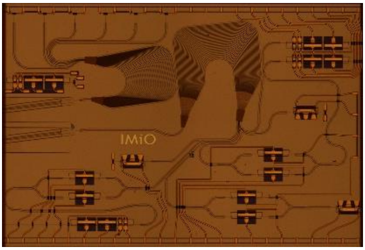

Fig. 1. Multi-channel photonic integrated transmitter for free-space communication systems.

We also propose and discuss the concept of integrated transmitters and receivers based on the new MIRPIC platform, making use of the germanium on silicon technology, which is tailored for the spectral range between 3.0 µm and 5.5 µm. The transmitter design will be based on several quantum cascade lasers (QCLs) or interband cascade lasers (ICLs) operating around 4.5 µm (MWIR), integrated in a hybrid way on a passive photonic integrated circuit with an arrayed waveguide grating (AWG) to multiplex optical signals into a single output. Also, the concept of moving the transmission band to longer wavelengths (above 9 µm) will be presented and discussed.

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Against Blue Light - investigation of eye protection strategies used by mobile phone manufacturers

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The use of portable mobile devices providing instant communication and access to various resources of knowledge and information has become a part of our everyday life, because these devices integrate many other types of devices (telephones, cameras and video cameras, notebooks, computer functionality). According to recent data, the average person spends 3 hours and 15 minutes on their mobile phone each day. And 1 in 5 smartphone users spends upwards of 4.5 hours on average on their phones every day, and this amount of time will increase year by year. The light emitted by the screens of mobile devices, the spectrum of which directly depends on the technology used (e.g. LED / OLED) for the production of displays, affects the function of the photoreceptor present in the retina (melanopsin), which is directly related to the production of melatonin. This photoreceptor is directly related to the production of melatonin, and the main stimulus to its operation is the range light emission around 450 nm (blue light). For these reasons, manufacturers of mobile devices over time began to introduce the possibility of enabling the so-called. night mode for displays in which the perceived colors are characterized by the so-called warming of the color temperature, significantly reducing the percentage of blue light in the spectrum emitted by the screen. In the presented study, we analyzed the strategies used by mobile device manufacturers related to eye protection and human health. We examined the spectrum of light emitted by the tested devices with different ranges of program eye protection using spectroscopic methods. Both LCD screens and screens based on organic compounds (OLED, POLED) were analyzed (Fig. 1). The obtained results show a significant reduction in blue light emissions (as much as 90%) compared to the initial values for the default settings of mobile devices. The obtained results made it possible to determine eye protection methods used by leading manufacturers of mobile devices. They also showed differences in the adopted conventions in relation to the image display technology used.

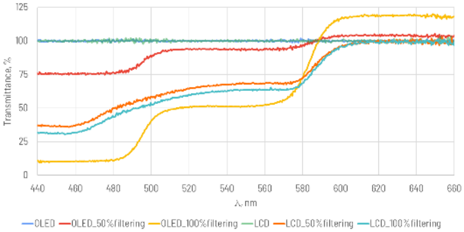

Fig. 1. Effectiveness of blue light filtration for LCD and OLED displays.

Influence of UV light activation on ppb NO_2 sensing of P3HT-bearing graft copolymers

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Performance parameters of nitrogen dioxide (NO2) sensors using graft copolymers containing poly(3-hexylothiophene) chains were developed and tested using different carrier gases (N2 or air) and under dark or UV irradiation conditions. Interestingly, sensor performance improved when switching from N2 to air, with most NO2 sensors doing the opposite. Moreover, the introduced structural modifications of the copolymers allow not only better use of radiation energy, but also allow the detection of much lower concentrations of NO2 - in the ppb range. UV irradiation both improved the dynamics of the sensor and stabilized the sensor's electrical baseline (Fig. 1), enabling SilPEG-based sensors to meet the requirements of industrial sensing solutions (less than 10% baseline deviation once sensors reach saturation), making them promising candidates for further development and usage.

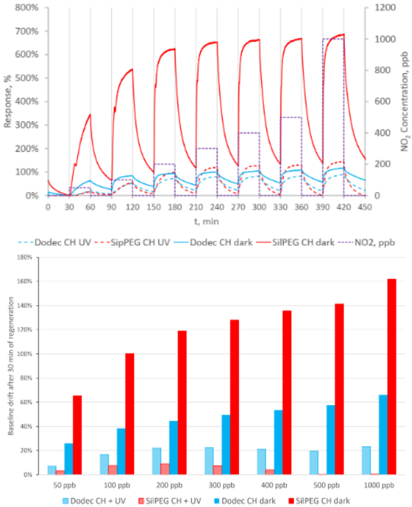

Fig. 1. Response to 50-1000 ppb NO2 in dark conditions and with UV in air at RT, b) baseline drift in air conditions.

On the basis of the multivariate experiments carried out, a preliminary mechanism underlying the interaction of exposure to oxygen (present in the air) and UV radiation was postulated. The proposed mechanism better explains the obtained experimental results and is more consistent with the properties of conjugated polymers than the most commonly postulated mechanism based on the properties of inorganic semiconductors, consisting of photo stimulated desorption of oxygen from the sensor structure.

UnVisible Sunguard – UVA imaging system for cross-polarized reflectance photography for sunscreen SPF analysis

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Solar radiation, in particular ultraviolet radiation, is one of the main sources of skin cancer. About 80% of the most damaging effects, such as sunburn, increased risk of skin cancer through DNA point mutations, are attributed to UVB (280 to 315 nm) and the remaining 20% to UVA (315 to 400 nm), which in turn accelerates aging. In areas with very strong sun exposure, there are a large number of reports of first and second degree sunburn, most of which are correlated with previous activity in the water. These data directly underscore the importance of adequate coverage as well as reapplying SPF sunscreens when the skin is exposed to the sun. Regular use of sunscreen has also been shown to reduce the incidence of squamous cell carcinoma and melanoma. It also blocks the damaging molecular effects of UV radiation on skin cells in vivo. SPF filters can be divided into two types: 1) physical filters, such as titanium dioxide (TiO2) or zinc oxide (ZnO), which work mainly by scattering sunlight from the surface of the skin, or 2) chemical filters, which convert the sun's energy into molecular conformational changes. Thanks to these features, it becomes possible to visualize the operation of SPF filters by registering the absorption of UV radiation on the surface of the skin with the applied sunscreen (Fig. 1). This student project consisted in building a stand for visualization and assessment of skin coverage with protective SPF filters along with image acquisition. In addition, the use of cross-polarization in the system allowed the elimination of light reflections and enabled the comparative analysis of skin protective products with different SPF levels.

Fig. 1. Images acquired using the UnVisible Sunguard system, a) VIS, b) UVA, c) UVA – sunscreen applied.

New D-shaped fiber fabrication approach for SPR sensor

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SPR is used to detect small amounts of chemicals and biologicals in solution. Conventionally, SPR sensors are based on a prism. However, to miniaturize sensors and make analysis easy, fast, and inexpensive in non-laboratory conditions, SPR sensors based on optical fibers are increasingly being used. In an optical fiber, surface resonance occurs at the core-cladding interface. For effective excitation, it is necessary to expose the core, which is most commonly achieved by grinding the side of the fiber. This approach results in a single sensor of limited size (a few centimeters), requires high precision and is time-consuming. As a result, the technology for fabricating fiber SPR sensors is expensive, which has a significant impact on their limited availability and scope of applications.
Therefore, we have proposed a new D-shaped fiber fabrication method for mass-produced SPR sensors. With this method, it is possible to fabricate a D-shaped fiber (Fig. 1) with a length of several hundred meters. The fiber has the same core diameter, the same core distance from the flat surface of the fiber, and the same optical properties along its length. Thanks to its structure, it can also be easily spliced with standard telecommunication fibers.

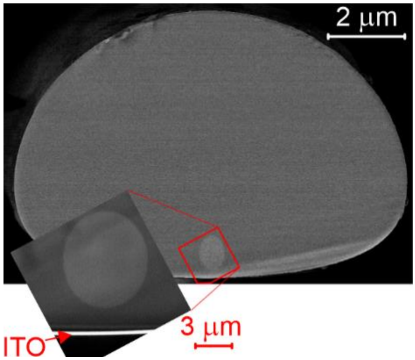

Fig. 1. Fabricated D-shape fiber.

In the poster, we present the results of our work on the fabrication of a D-shaped fiber, an example of a sensor based on such a fiber using ITO layer, and the results of measurements (Fig. 2).

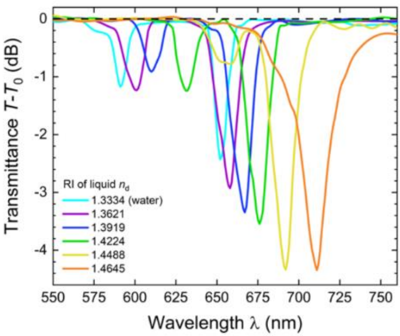

Fig. 2. An example of the results of measuring solutions with different refractive indexes.

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SiO_2:TiO_2 Integrated Photonic 1x2 DEMUX based on Y-splitter for telecom and sensing applications

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Photonic integrated circuits (PICs) are a fast-developing branch of the field of optoelectronic devices. They are compact devices containing various waveguide (WG) structures and other passive and/or active optical and photonic components. The size of a single PIC, being a fully functional optoelectronic system, can even be as small as a human nail. PICs find use in more and more innovative solutions. The most common applications for PICs are telecommunication and sensing. In this latter field, they allow for achieving more sensitive and significantly smaller components than conventional electronic counterparts. Among the most interesting areas that PIC-based sensors might cover are environmental monitoring, biology, medicine, and pharmaceutical applications, to enumerate a few. Regarding telecom, PICs offer the possibility of super-fast data transfer, together with compact size, high energy efficiency, and high reliability as well. An exemplary telecommunication system realized using PICs-based solutions is wavelength division multiplexing (WDM) [1]. WDM technology enables multiple optical channels to be simultaneously transmitted over a single optical fiber, thus dramatically increasing the information capacity of the fiber link. One of the key elements of optical fiber networks enabling the launching and extracting of optical signals of different wavelengths is (de)multiplexer. In PIC-oriented technology WDM (de)multiplexer – (DE)MUX is mainly implemented by using arrayed waveguide gratings (AWGs). Nevertheless, also other approaches can be considered. In this paper, we propose a 1×2 DEMUX structure based on a Y-branch optimized for the two most important telecommunication wavelengths, i.e. 1310 nm and 1550 nm (so1called 2nd and 3rd communication windows). The idea of a PIC-based 1×2 DEMUX making use of a Y-splitter with subwavelength gratings (SWGs) [2] in both arms differing in grating period is shown in Fig. 1.

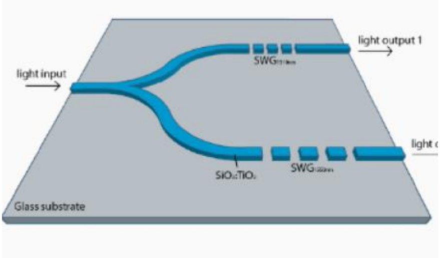

Fig. 1 Y-splitter DEMUX based on SiO_2:TiO_2 platform

By tailoring the optical properties of the SWG structure, the photonic bandgap (PBG) for 1310 nm and 1550 nm can be designed for arm 1 and arm 2, respectively. As a result, signal at 1310 nm can be collected at output port 1 only, while signal at 1550 nm can be collected at output port 2 with minimum crosstalk. The presented solution would be a novel idea for a DEMUX that could work not only in telecom devices but also might be useful for biosensing applications. A proposed material platform is silica-titania (SiO2:TiO2), potentially offering combination of low-cost of manufacturing processes and satisfactory optical properties. Our group is currently working on the development of this platform for the realization of eye-catching photonic devices. It not only can be manufactured by low-cost methods but also provides the possibility of manipulating the refractive index of the material during the fabrication process, which could open even more attractive perspectives for this technology [3].

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Development of integrated optical interfaces for silicon-nitride-based photonic platform

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Photonic integrated circuits (PICs) are considered one of the most promising photonic technologies for applications in the areas of telecom and datacom, biological and environmental sensors, as well as quantum engineering. Among different technologies, the silicon nitride platform provides the possibility of covering a very broad spectral range, extending from the visible up to mid-infrared wavelengths. In this work, we present the recent achievements in the development of the optical input/output interface components for the SiN platform developed at Warsaw University of Technology [1]. The platform is currently optimized for operation in the visible, spectral range.

In principle, the optical interface between a photonic integrated circuit and optical fibers can be realized using an edge-coupling scheme [2] or by application of a grating coupler [3]. In both cases, the main challenge faced by the designers is the efficient spatial matching between the guided mode of the planar waveguide, typically of the sub-micron dimensions, and the mode of the optical fiber, with a diameter of several microns. Therefore, dedicated waveguiding components need to be designed to convert the size of the mode and thus optimize the coupling efficiency.

The designed and investigated elements for the edge coupling interface are schematically depicted in Fig. 1. and Fig. 2.

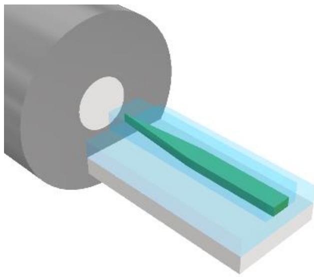

Fig. 1. Visualization of the spot size converter realized with an inverted taper structure.

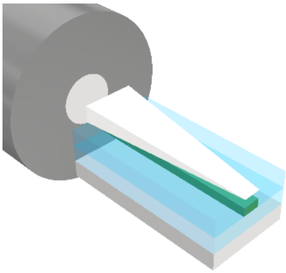

Fig. 2. Visualization of the spot size converter with a 3D gray-scale polymer taper.

The first structure uses an inverted taper, i.e. the waveguide width gradually decreases towards the edge of the chip. The second type that is being investigated is a 3D taper, i.e. extending not only within the chip plane but also in the perpendicular direction, which allows to expand the mode in two dimensions simultaneously. Such structures are manufactured with the assistance of gray-scale E-beam lithography. The third analyzed type is a 3D polymer-assisted taper. In such a structure, an intermediate layer (i.e. PMMA, SU8, or SiO_2) is placed on top of the waveguide, preferably with a refractive index lower than that of the waveguide core but higher than the substrate and cladding refractive indices.

The investigated low-loss vertical coupling scheme is realized with advanced grating couplers. The standard grating is assisted with additional light leakage shielding by using metallic mirrors or Bragg reflector structures in the substrate, which provide increased light coupling efficiency with respect to classical couplers. Visualization of such a structure is presented in Fig. 3.

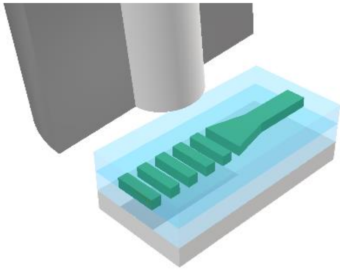

Fig. 3. Visualization of the designed grating coupler with metal shielding.

The obtained simulation results show a decrease of the coupling losses to below 5 dB with the potential for further improvement.

In this work, we will discuss in detail the features of all designed interface elements, with a specific focus on efficiency features and all technological aspects of manufacturability. This will be followed by the manufacturing of these devices in CEZAMAT technological facilities and experimental validation of design parameters in the Institute of Microelectronics and Optoelectronics laboratories, the results of which will be presented during the conference.

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An optomechanical transducer based on FBG sensors to measure of the compensator expansion on gas transmission pipelines

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The objective of the work is to develop an effective and safe system for measurement extension and/or shortening expander in natural gas transmission pipelines by applying a non-invasive measurement and data transmission system based on fiber optic sensing technique, Fiber Bragg Grating (FBG) sensors.

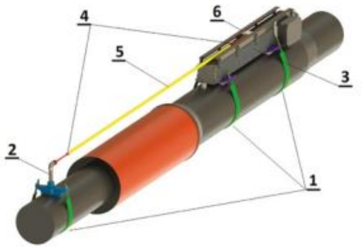

Fig. 1. Fixing and motion transmission system for the maintenance-free DN300 pipeline expansion joint: 1 – mounting band, 2 – vertical distance pivot, 3 – IP68 casing, 4 – ball joint, 5 – connecting rod , 6 – magnetic slide.

The elaborated transducer is based on FBG sensors, providing high quality of measurments with an experimentally demonstrated accuracy no worse than 0.93%. Beyond the optical part, the transducer is also equipped with a mechanical system and an ingress protection system against the soil and water environment. The application of a fiber optic sensor technology enables the operator to easily multiply the measurement points and to carry out remote reading of even several dozen expansion joints at once.

Fig. 2. Fixing he general view of the testing site – transducer mounted on the DN300 gland-type pipeline expansion joint.

The optomechanical measuring transducer changes the characteristics of the light signal under the influence of deformation of the FBG sensors in the order of fractions of a mm. In order to be able to use this type of solution to measure large displacements, it was necessary to use mechanical gears of the first and second degree, thanks to which it was possible to detect displacements of hundreds of mm.

In the developed solution, a second-stage transducer was used, in which the movement of the measuring rod has a range of ±25 mm. The second stage transducer has an internal system that reduces rectilinear motion to a sub-millimeter scale, in which small deformations of fiber optic FBG sensors are realized.

Transitioning the movement of the compensator, with the range of changes of moving elements ±630mm or ±400mm, to the range of movement of the second stage transducer, required the design of an appropriate mechanical system. Fig. 1 schematically shows the method of transferring a large displacement to the movement of an optomechanical transducer with FBG sensors. On the other hand, Fig. 2 presents the real research object.

This system consists of an internal part (reduction of the range) and an external part (kinematic drive transmission between the parts of the compensator).

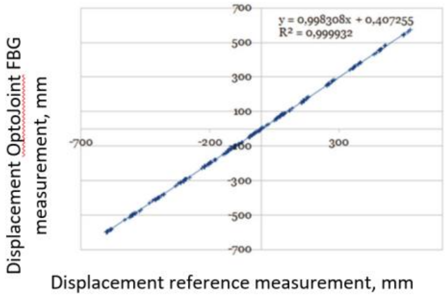

Fig. 3. An example of the output-input response function for the designed and constructed optomechanical transducer

As part of the tests, a total of 66 measurement series were carried out, in each of them the compensator extension was recorded using the reference method (using a laser rangefinder) and the compensator extension obtained from the interpretation of the transducer output signal. An example of the transducer characteristics is shown in Fig. 3.

Acknowledgments: The project "Development of a system for measuring the degree of elongation of compensators based on fiber optic technology" was carried out on request and with financial support Gas Transmission Operator GAZ-SYSTEM S.A.

High-speed THz-TDS imaging system with ECOPS scheme

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We present fast terahertz time domain spectroscopy (TDS) imaging system for flat samples. It Operates in reflection configuration with use of electronically controlled optical sampling scheme (ECOPS). We employ Toptica Teraflash Smart platform with fibre optic fed photoconductive switches (transmitter and receiver) based on InGaAs. The device can measure up to 1600 pulse traces per second. The fast movement of the sample was provided by three high-speed motorized linear stages. Synchronization of the data reading system with the engine controller was achieved by using a dedicated marker. The system with the developed software can scan the 50 x 50 cm sample with resolution of 1.3 mm in less than 10 minutes.

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Terahertz spectroscopy of ceramics for high-frequency applications

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The rapid development of modern communication systems is associated with the growing demand for new dielectric substrate materials, which should ensure a higher speed of signal transmission and miniaturization as well as the possibility of integrating passive elements. Using ceramic-ceramic or glass-ceramic composites effectively adapts the microstructure and functional materials' electrical and thermal properties to microwave substrates. In particular, this approach enables the fabrication of sandwich structures with buried passive electronic components using advanced LTCC technology, which offers relatively low cost, design, and manufacturing flexibility, and a high degree of miniaturization and integration. Here we present the terahertz time-domain characteristics of several selected materials, including their refractive indices and absorption coefficients.

Acknowledgments: This research was funded by the National Science Centre, Poland, grant number 2019/35/B/ST5/02674

Exposure optimization procedure for grayscale lithography in photonic applications

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Grayscale lithography (mostly performed by direct laser or electron beam writing) is widely used to manufacture thin 2,5D optical structures ina a single process. [1] In the latter method, electron scattering diffuses the delivered energy dose and causes undesired deformations of the depth profile.

A process of determining the point spread function (PSF) and introducing corrections is called Proximity Effect Correction (PEC). In this work, a series of exposures with different double Gaussian PSF parameters were performed. Obtained profiles were then measured by white light interferometry (WLI) (Fig. 1 and 2).

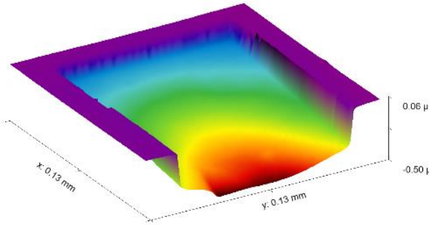

Fig. 1. Profile cross-section before optimization

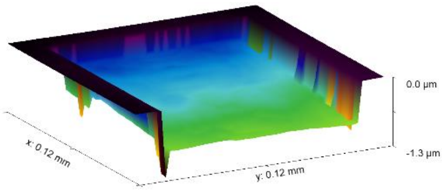

Fig. 2. Profile cross-section after optimization

PSF correction resulted in much flatter and stable depth profile, as shown in Fig. 3. and Tab 1.

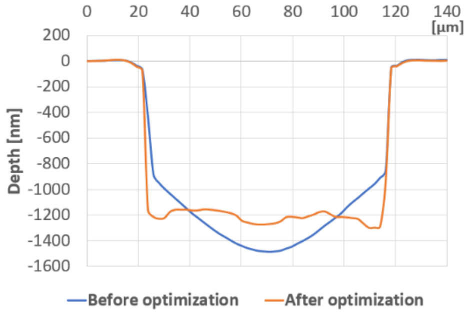

Fig. 3. Resist depth profile before and after optimization

	Before	**After**

Average depth [nm]	1227.50	1207.14
Standard deviation	228.40	59.47

Tab. 1. Depth deviation comparison

Optimized PSF correction enables larger control of depth profile, higher pattern fidelity and better quality of manufactured optical structures.

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Four-channel Stokes polarimeter with a division of amplitude.

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Polarimetric systems are widely developed in many applications. Exemplary to determine the beam's state of polarization Stokes polarimeters are often used. This type of device is based either on a division of amplitude or a variable state of the analyzer in time.

The main advantage of devices from the first group is simultaneous Stokes vector measurement and the possible characterization of variable in time-domain signals. In the literature, there are presented examples like in-line fiber polarimeter using blazed fiber gratings [1], Stokes roll-angle sensor [2], or full Stokes polarimeter with polarization-preserving beams splitters [3].

We present the proof of concept of a polarimeter with a division of amplitude dedicated to the telecommunication band 1550 nm.

The state of polarization is provided by the division of the beam into four channels. Each channel of the setup is responsible for analyzing different components of the polarization state. Our solution provides a full calculation of the state of polarization described by the Stokes vector, which is extracted from intensities measurements.

The main advantage of this system is that division of amplitude provides calculation of the polarization state for pulse signals, in contrast to time-domain devices, where the state of polarization is calculated along with, for example, a rotating waveplate. The rate of measurement is determined by the measurement rate of detectors.

According to the authors' assumptions, this kind of solution in the optimized version could be used to measure and clearly define the state of polarization of the radiation in fiber optic systems, where polarization constantly changes, also in pulse signals.

The use of our system is a state of polarization monitoring sensor in fiber optics, particularly in QKD systems based on faint pulses. The concept of work assumes that it may be introduced into the QKD system in a place, where a signal is not yet attenuated to the single-photon level.

Acknowledgments: This project has received funding from the National Center for Research and Development research and innovation programme under grant agreement DOB-SZAFIR/01/A/023/01/2020.

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Fiber-optic distributed sensing probes for vertical profiling of temperature changes in the active layer of the permafrost in the Arctic

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Precise monitoring of the changes in the depth of the active layer is of utmost importance for protection of the fragile arctic ecosystem as well as for modelling climate changes and predicting their consequences. However, conventional methods of performing profiling of permafrost – thermistor strings and electrical resistivity tomography – provide spatially sparse data. On the other hand, fiber-optic distributed sensors, especially those interrogated by the means of optical frequency-domain reflectometry, are known to permit spatial resolutions of the order of even few millimeters.

In the summer of 2022 we have installed and tested fiber-optic sensing probes interrogated by the commercial optical frequency-domain reflectometer LUNA OBR4600 in genuine Arctic environmental conditions near Calypsobyen on the island of Spitzbergen in the Svalbard archipelago. The sensing probes based on few different optical fibers have been installed in varied grounds comprising tundra, solifluction slope and sandy beach.

We present the installation of the sensors according to the strict regulations for environment and cultural heritage protection as wells as the results from the summer measurement session. We compare the obtained readouts between different optical fibers and with reference temperature measurements from thermistor strings installed in nearby locations and discuss the influence of the strain-temperature cross-sensitivity.

Acknowledgments: This work was supported by the projects National Laboratory for Photonics and Quantum technologies – NLPQT (POIR.04.02.00-00-B003/18-00) and Autonomous Quasi-Distributed Optical Fiber Temperature Sensor for Ground Temperature Measurements – SPILOD (POIR.04.01.01-00-0031/19).

Influence of the electrolyte used in carbazole electro-polymerization on the response of the hydrogen sensor

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High quality polymer films can be easily electrodeposited directly on transducer by low-potential anodic oxidation of carbazole in solution of electrolyte dissolved in acetonitrile [1]. As a result of electro-polymerization, we obtain a polymer doped with electrolyte anions. In our research, we demonstrated the effect of changing the electrolyte using in electrosynthesis of carbazole on the sensor's response to hydrogen. tetrabutylammonium tetrafluoroborate [BF_4] the counterion will be the large organic tetrafluoroborate anion (fig 1) and lithium perchlorate [$LiClO_4$] in the case of the counterion will be the lithium anion. were selected for the tests.

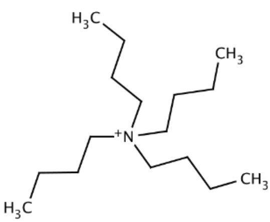

Fig. 1. Tetrabutylammonium anion

in the first stage, the thermal resistance of the obtained materials was tested, which
allowed to assess the maximum working temperature of the sensor. In the case of PCZ-BF4, the DSC (fig.2) thermograms can be observed already at the temperature of 65°C and the decomposition of the electrolyte takes place already from 90°C. In the case of PCZ-Li, the system is stable and the degradation occurs at about 300°C and is identical to the PCZ degradation described in literature [2]. The measurements of the resistance of the sensors in the temperature function are combined with the DSC results and when the sensor is heated above 90°C, there is a drastic increase in the resistance of the receptor layer, which resistance does not decrease after cooling down the sensor (fig 3).

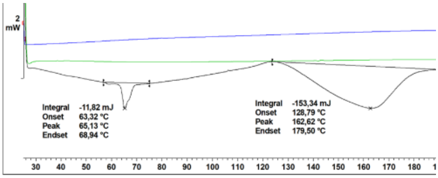

Fig. 2. DSC thermogram PCz-BF4 (black and green) PZC-Li blue line

The obtained results confirm the occurrence of complete degradation of the anion doping PCZ and allow to set the limit of the sensor's operation at 80°C.

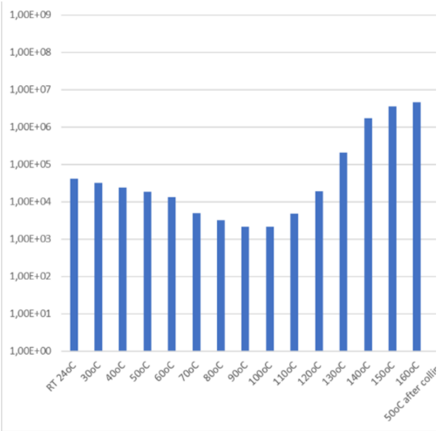

Fig. 3. Change of resistance of PCZ-BF_4 sensors as a function of temperature

In the case of PCZ-BF4, the presence of moisture improves the dynamics of the sensor's work. The change of the electrolyte from BF_4 to $LiClO_4$ differentiates the sensor's responses and in the case of $LiClO_4$ makes it insensitive to moisture, while reducing the size of the response and causing deterioration of the dynamics of its work.

Acknowledgments: M-ERA.NET 3 Joint Call 2021 Project 9150

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Tunable LC:PDMS periodic waveguiding structures

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PDMS is a high-performance material belonging to polymeric organic silicones. The most common application of this elastomer is in microfluidics, including lab-on-a-chip and sensing devices. The physical and chemical properties of PDMS allow for low-cost and reliable fabrication technology based on soft lithographic molding. The LC:PDMS structures explored in a research work reported here are optofluidic systems in the form of microchannels formed in PDMS and filled with liquid crystalline material [1-2].

The proposed structure gains advantages related to the characteristic features of LCs, such as a significant anisotropy of their physical properties and high sensitivity to external fields and factors, combined with low cost and low energy consumption. Such features allow for easy tunability and reconfiguration. Indeed, LC:PDMS photonic systems are perfect candidates for sensing applications while offering electrically, magnetically, and optically controlled cores of easily switchable and reconfigurable waveguides (also with spatial periodic refractive index distribution along propagation direction [2]).

The design, fabrication, and testing methods for tunable LC:PDMS structures are discussed in this communication. Emphasis was particularly placed on determining their optical properties after applying an external electric field, depending on the geometrical parameters of the systems with periodic electrodes.

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Tuning optoelectronic properties of semiconducting diamond sheets for microfluidic devices

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Diamond is a promising material for optoelectronic and microfluidic devices due to its high thermal conductivity, extreme wear resistance, high breakdown voltage, possible doping and low absorption in the visible range [1-3]. Unfortunately, there is a significant lack of knowledge regarding the effects of boron incorporation on the electrical, morphological and optical properties of free-standing, nanocrystalline diamond sheets.

In this study, we analyze the optoelectronic properties of boron-doped diamond sheets as a function of boron doping. For this purpose, we use free-standing diamond films delaminated from a mirror-polished tantalum substrate. Each sample has been grown with a different [B]/[C] ratio in the gas phase using a chemical vapor deposition process. The growth time was 3h resulting in a thickness of 1.3 µm.

The lower doped samples present p-type semiconductor behavior (variable-range and nearest-neighbor hopping are observed), while the resistance of the most heavily doped sample ([B]/[C] = 20,000 pm in the gas phase) is virtually constant versus temperature (153K-473K).

Increasing doping reduces the mobility of the holes to 0.12 $cm^2V^{-1}s^{-1}$ at room temperature. Moreover, boron incorporation into the diamond lattice shifts the position of the sp^3 peak towards lower frequencies and a lowering of the optical band gap is observed based on UV-VIS measurements.

Our findings could be a stepping stone in the future production of optoelectronic devices based on diamond sheets for microfluidic applications.

Acknowledgments: M.R. acknowledges the financial support of the National Agency for Academic

Exchange under the Iwanowska Programme (PPN/IWA/2019/1/0009 1/U/00001). The financial support from the National Center for Research and Development under the UPTURN grant (NOR/POLNOR/UPTURN/0060/2019-00) is also acknowledged.

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Numerical evaluation of silica-titania-based reverse rib waveguide and standard rib waveguide structures

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The use of optical waveguide (WG) devices in integrated optical circuits for optical communication networks and sensing applications is the subject of the current study. High bandwidth, minimal loss, and immunity to electromagnetic interference are only three of the many benefits that optical WGs offer over conventional electrical wires. They also have the potential to be merged with other components on a single chip, which would allow for the construction of compact and efficient optical integrated circuits. The expansion of the microelectronics sector was directly attributable to the development of thin-film technologies, and this pattern is observed today in the field of optoelectronics. Silicon (Si) photonics has emerged as one of the most productive technology platforms for the development of a diverse range of functional optical components as a direct result of the rapid pace of technological advancement over the past decade [1]. On the other hand, silica (SiO_2), titania (TiO_2), and silica-titania (SiO_2:TiO_2) materials obtained by the sol-gel technique have gained a lot of attention due to their potential optical applications [2-3]. The deposition of thin-films can be achieved using a variety of processes, including RF-sputtering, magnetron sputtering, chemical vapor deposition (CVD), plasma-enhanced CVD, pulsed laser deposition, and sol-gel coating. The simplicity of the operation, which is extremely cost-effective, and the fact that it can be carried out in laboratories with limited resources makes the sol-gel method combined with the dip-coating process a very appealing option.

The paper is divided into two sections. In the first part, the reverse rib waveguide (RRW) with rounded side walls is designed, and its modal characteristics are compared with RRW with vertical side walls. Whereas in the second part of the paper, the modal analysis of a standard rib waveguide is conducted, and a method to mitigate its bending losses is proposed.

The silica-titania WG films can be deposited using a low-cost sol-gel method and dip-coating technique and are structured via wet-chemical etching or reactive ion etching (RIE). The WG architecture with rounded side walls (which can be obtained via wet chemical etching) is modeled to represent RRW, and the modal conditions and bending loss are compared to those of RRW with vertical side walls (which can be obtained via RIE). This research aims to apprehend the fundamental modal conditions of WGs with both vertical and rounded side walls. Fig. 1 (a, b) depicts the geometry of the silica-titanium-based RRW structures investigated in this study.

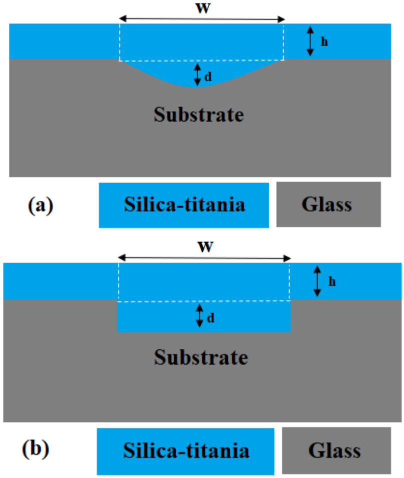

Fig. 1. Silica-titania RRW shown graphically with (a) rounded side walls and (b) vertical side walls.

Standard rib WGs made of silica-titania are examined numerically with an emphasis on the analysis and optimization of bending losses. A modal analysis is conducted for various geometric parameters of the WG, including wavelength-based modal analysis. The potential for minimizing bending losses by adding an upper cladding (UC) layer of refractive index c.a. 1.3 to the rib WG is also discussed. The graphical representation of a standard rib WG structure based on SiO_2:TiO_2 material deposited on a glass substrate is shown in Fig. 2.

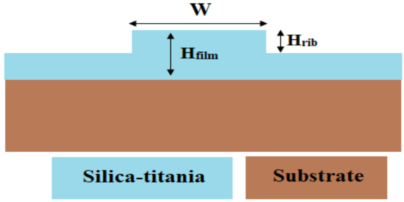

Fig. 2. Schematic representation of SiO_2:TiO_2 based standard rib WG.

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The structure and preparation method of spectrally shifted double-comb Tilted Fiber Bragg gratings.

K. SKORUPSKI, S. CIĘSZCZYK, P. PANAS

Tilted fiber Bragg gratings (TFBGs) have peaks in the transmission spectrum associated with cladding modes. The spectral distances between these peaks depend on the geometry of the optical fiber including the cladding, tilt angle and structure period. In this paper we propose to increase the number of peaks in the spectrum without changing the geometry of the optical fiber. Such effect can be achieved by producing two structures on the same section of optical fiber, one of which has shifted spectral peaks relative to the other. The spectral shift occurs as a result of a change in the period of the structure obtained by stretching the optical fiber during its writing. We show here the properties of such a method for increasing the number of modes by analysing both simulated and experimental spectra.

Optical monitoring of electrodegradation of water micropollutants

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Currently in the world and in Poland, a growing emphasis on environmental protection by increasing awareness in society, developing and implementing new technologies and legal regulations. The Council Directive of the European Union 91/271/EEC regulates the issues of municipal sewage treatment (UWWT) in Europe and is one of the most important driving forces on the market of sewage treatment devices.

The electrochemical advanced oxidation process (EAOPs) is a treatment process that involves the generation of highly reactive ·OH. The ·OH is the second strongest oxidizing species with a relative oxidation power of 2.8 eV. The generation of radicals is done by passing an electric current between two electrodes anode and cathode.

Porous glassy carbon was used as the electrode namely Reticulated vitreous carbon (RVC). RVC is an open-pore vitreous carbon foam material of honeycomb structures, which has a wide range of applications such as: electrochemical water and wastewater treatment [1,2].

However, there is a need to monitor such a process. A sensitive, fast and, most importantly, test that can be carried out during the oxidation process is the measurement of UV-VIS absorption. The decrease in the characteristic peaks will be associated with a decrease in the concentration of the given compounds.

We demonstrate usage of optical methods for to monitor the change in the concentration of micropollutants in water during electrochemical oxidation. The UV–Vis absorbance spectra of paracetamol, caffeine and PFOA was during electrolysis had been analyzed for the 200–1200 nm range.

Acknowledgments: This work was This research was supported by The National Centre for Research and Development in the framework of the NOR/POLNOR/i-CLARE/0038/2019 project.

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Numerical analysis of grating coupler shape for optimization of integrated optics biosensor structure.

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The paper presents a numerical analysis of a biosensor structure based on an integrated optics circuit. The presented biosensor structure including prism coupler, planar waveguide as well as grating coupler. The biosensor is designed to determine selected physical properties of biological liquid such as: real part of refractive index n and imaginary part of refractive index k. Detection of the real part of the refractive index n is carried out by a grating coupler, where the angle α of uncoupled of light beam from the structure to cladding depends on the effective refractive index N_{eff} [1-3]. Changes of refractive index of the biological liquid n_{CH} causes changes in the effective refractive index N_{eff}, and thus causes changes in the angle α of uncoupled light beam from the sensor structure [1-5].

$$\alpha = arcsin\left[\frac{1}{n_c}\left(N_{eff} - \frac{m_o\lambda}{\Lambda}\right)\right] \quad (1)$$

where: λ_0 - wavelength, N_{eff} - effective refractive index, m_0 – diffraction order,
Λ spatial period.

The imaginary refractive index k is detected by means of the evanescent field of the guided waveguide mode, which penetrates the layer of biological liquid in waveguide area [5]. The analysis was focused on optimization of selected geometrical properties of grating coupler such as: shape of ridges and grooves for obtain maximum efficiency of uncoupling of light from the sensor structure P_{out}. The analysis were carried out for three type of ridges and grooves shape in grating coupler:

- rectangular,
- triangular,
- sinusoidal.

The scheme of analyzed structure is presented in fig. 1. The shapes of grating coupler ridges and grooves are presented in Figs. 2a, 2b, 3c.

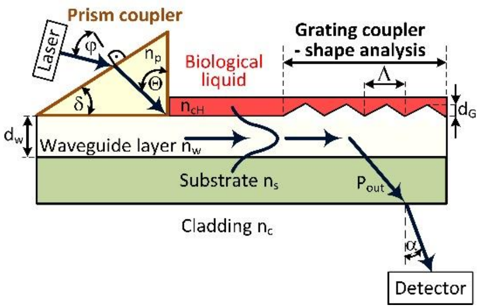

Fig. 1. Scheme of the biosensor structure.

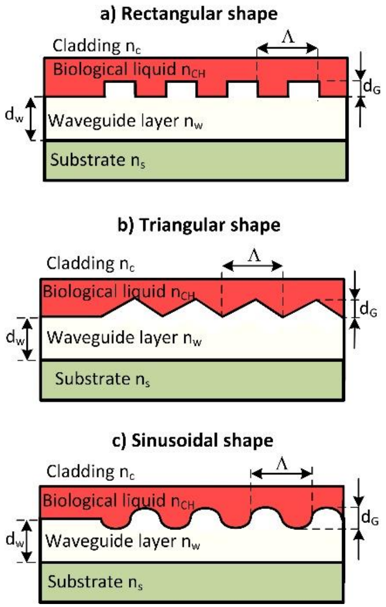

Fig. 2. Shape of ridges and grooves in grating coupler.

The presented numerical analyzes of the biosensor structure with grating coupler were carried out using the Finite difference time domain method (FDTD) method.

Acknowledgments:

The numerical analysis were carried out on PC computer financed by Silesian University of Technology Rector's pro-quality grant: 05/040/RGJ20/2003.

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Technology of MIM diode rectifiers for THz rectennas

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Metal-Insulator-Metal (MIM) tunnel diodes, due to their speed of operation [1], are interesting from the point of view of detection of high-frequency signals (e.g., terahertz radiation) [2][3][4] and construction of rectennas [5]. The transport of carriers in the ideal MIM structure occurs as a result of electron tunneling from the metal electrode region through a thin dielectric to the other electrode under the influence of the applied voltage. The tunneling process is by nature a very fast phenomenon.

By applying a voltage, we change the shape of the potential barrier in the dielectric region, which affects the current flowing through the structure. The RC time constant of such a device is determined by the resistance of the junction R (and the antenna that is connected to the device) and its capacitance C. The choice of metal electrode materials and the dielectric between them is essential in terms of device parameters. Appropriate selection of materials allows tuning the I-V characteristics of the device and its responsivity. In Fig. 1, we show the schematic sketch of the investigated MIM structures integrated with antennas.

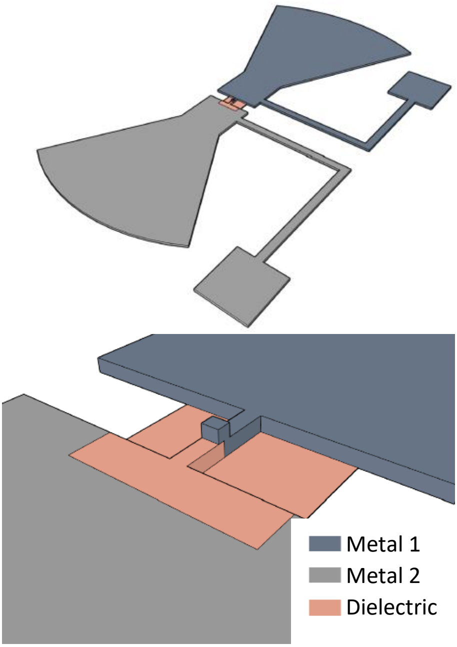

Fig. 2. Schematic sketch of the investigated MIM structures integrated with antennas.

The MIM structures were fabricated on high-resistivity silicon wafers. The first stage was the cleaning of substrates and their oxidation. The fabricated silicon dioxide acts as a layer separating the MIM structure from the silicon substrate. A first metal electrode was fabricated using metal deposition, e-beam lithography, and plasma etching. Next, the dielectric layer was deposited, and a second metal electrode was fabricated on top of the stack.

In this work, we present the technology of manufacturing sub-micrometer MIM structures for the construction of tunnel diodes for THz rectennas. Fig. 2 shows a SEM picture of fabricated MIM structure. We discuss the technological aspects of the fabrication of THz rectennas, preliminary measurement results, and possible applications of this technology.

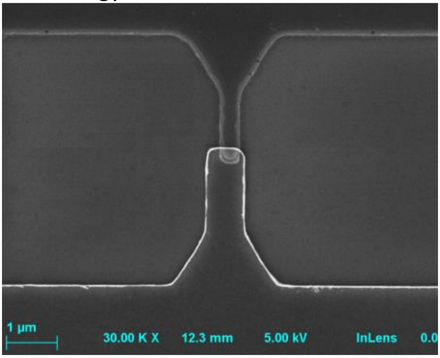

Fig. 2. SEM picture of fabricated $Al/Al_2O_3/Au$ MIM structures.

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Mesoporous TiO_2 films – optical properties and photocatalytic activity

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Water pollution is one of the environmental pollution problems and poses a serious threat to flora, fauna and humans. The most common wastewater contaminants are dyes, microplastics, pharmaceuticals and others. Currently, the problem of their removal is one of the main challenges intensively developed [1]. Conventional methods such as biological methods, chemical precipitation and membrane filtration are expensive and have limitations. Therefore, photocatalysis shows a high degradation potential of water environment pollutants [2].

Titanium dioxide is the most popular material with photocatalytic properties. Due to its non-toxicity and thermal and chemical stability, TiO_2 is used for photocatalytic degradation of organic pollutants [2]. TiO_2 is used in powdered form but also in the form of an immobilized carrier in a layer or coating. This way of preparing the photocatalyst is useful for the recovery and reuse of the material. The photocatalytic activity of TiO_2 is affected by its concentration and the surface of the layer: thickness, roughness, grain size, pore size distribution and porosity of the layer material [3], [4].

The sol-gel method is a very good method of producing solid materials from the liquid phase. Combined with layering methods, it is an excellent way to produce layers with controlled parameters. By selecting a precursor, solvent, stabilizing agent, catalyst or surfactant, layers with different morphological parameters can be obtained [5].

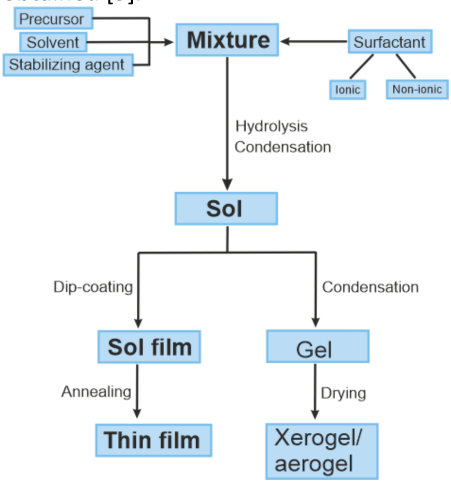

Fig. 1 Scheme of the production of films using the sol-gel method and dip-coating technique.

The dip-coating technique is one of the most popular methods of applying layers on substrates. It is characterized by low cost, simplicity and the ability to control the thickness by the rate of ascent of the substrates from the sol [6]. Fig. 1 shows a schematic diagram of the sol-gel and dip-coating process. In our experiments, we used titanium (IV) *tert*-butoxide as a TiO_2 precursor, diethanolamine (DEA) as a stabilizing agent, and ethanol as a solvent. In addition, a non-ionic surfactant - poly(ethylene glycol) with an average molecular weight of 400 g/mol (PEG 400) and a cationic surfactant - hexadecyltrimethylammonium bromide (CTAB) were added.

In our presentation, we will present preliminary studies on the effect of surfactants on the optical properties of thin TiO_2 films. We will present the technological characteristics, i.e. the dependence of the thickness and refractive index on withdrawal speed of the substrates from the sol. We will compare the transmission and reflection characteristics of the TiO_2 layers obtained and the values of the energy gap width determined by the Tauc method. We will determine the porosity of the layers from the Lorentz-Lorenz equation. We will evaluate the influence of the presence of a surfactant on the photocatalytic activity of TiO_2 layers.

The presented results show the potential of TiO_2 layers to be used in the removal of organic pollutants in aqueous solutions.

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Active planar waveguides based on erbium doped silica-titania films for photonic applications

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Rare-earth doped materials have been studied in the past few years due to a growing interest in their applications in optoelectronic technology [1]. For instance, erbium-doped waveguides become one of the key components of the planar lightwave circuits. The trivalent erbium ions (Er^{3+}) exhibit excellent up and down conversion properties. In up-conversion two or more low-energy photons are absorbed in the IR range and then one higher-energy photon in the Vis range is emitted. In down-conversion, the higher-energy photon is absorbed and the lower-energy photon is emitted [2].

Amongst the materials used for planar waveguides, SiO_2-based ones were distinguished due to their physical, mechanical and chemical properties, as well as the ability to adjust optical and spectroscopic properties [3]. Also, silica-based systems such as SiO_2-TiO_2, SiO_2-HfO_2, SiO_2-ZrO_2, SiO_2–Ta_2O_5, SiO_2–Al_2O_3, SiO_2–TiO_2–Al_2O_3 are excellent host materials for rare-earth doping [3-8].

The choice of a host material with the desired optical, structural, morphological, and luminescent properties is one of the most important factors in the development of photonic devices.

The sol-gel method has several significant advantages among the various technologies used to develop materials suitable for photonics such as the low synthesis temperature, high homogeneity, and the possibility of producing materials with controlled refractive indexes. Also, the alkoxide precursors can be homogeneously mixed at the molecular level, allowing a wide range of compositions, including multi-components, wherein some of them cannot be obtained by other methodologies [9].

The sol-gel method combined with the dip- coating technique is a suitable method for the production of waveguide films.

The dip-coating technique is an inexpensive and relatively easy method of obtaining high-quality and uniform layers on various types of substrates. This technique can be used in both industrial and laboratory applications [10].

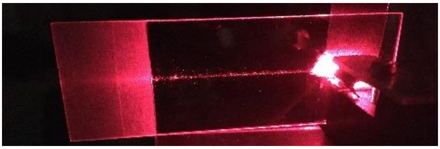

Fig.1. Scattered light streak from an erbium-doped waveguide film (n=1.65)

In this presentation, we extend our focus on the study of the optical, structural, morphological and photoluminescence properties of Er^{3+}-doped SiO_x-TiO_y optical planar waveguides prepared by sol-method and dip-coating technique. The effect of erbium concentration in the layer on propagation losses will be shown.

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QKD system synchronization using the ARTIQ Sinara platform

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In today's world, securing data can be crucial to both the security of individuals and entire organisations. This applies to both databases created and data transferred between users. One branch of this issue is quantum cryptography, which uses the effects of quantum mechanics to achieve accepted goals. One example in this discipline is Quantum Key Distribution (QKD) circuits, which enable the creation of a secret key between partners.

QKD-type systems use two types of channels when communicating: quantum channel and authenticated public classical channel [1]. While the purpose of the quantum channel is to ensure the transmission of qubits in the system, the classical channel can be used for multiple purposes as post-processing the exchanged information of the protocol. The basic idea is that the sender and receiver communicate to agree on a distributed key.

Due to the fact that a QKD-type system requires a high time synchronisation between sender and receiver and that it is a space-distributed system, it is necessary to provide an identical time base during the operation of the system. The Advanced Real-Time Infrastructure for Quantum physics (ARTIQ) SINARA system [2], which is an open source ecosystem designed for the control of quantum experiments, can be used for this purpose. A dedicated FPGA chip, it provides nanosecond resolution with sub-nanosecond latency, along with master-satellite capability. The SINARA chip has interchangeable modules that perform specific tasks.

The purpose of using SINARA in the laboratory QKD system under construction is to ensure synchronised system operation by triggering individual system components with high timing accuracy. Due to the specifics of the system, Alice and Bob are controlled by two separate Kasli modules, operating in a master-satellite arrangement, where the master is responsible for controlling the satellite and is located on Bob's side and the satellite on Alice's side.

The system described here uses a SINARA system consisting of the following modules:

- Kasli core device, being the control module [3],

- DIO 8 channel TTL I/O, providing 8 digital input-outputs [3].

Acknowledgments: This work was supported by ….

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