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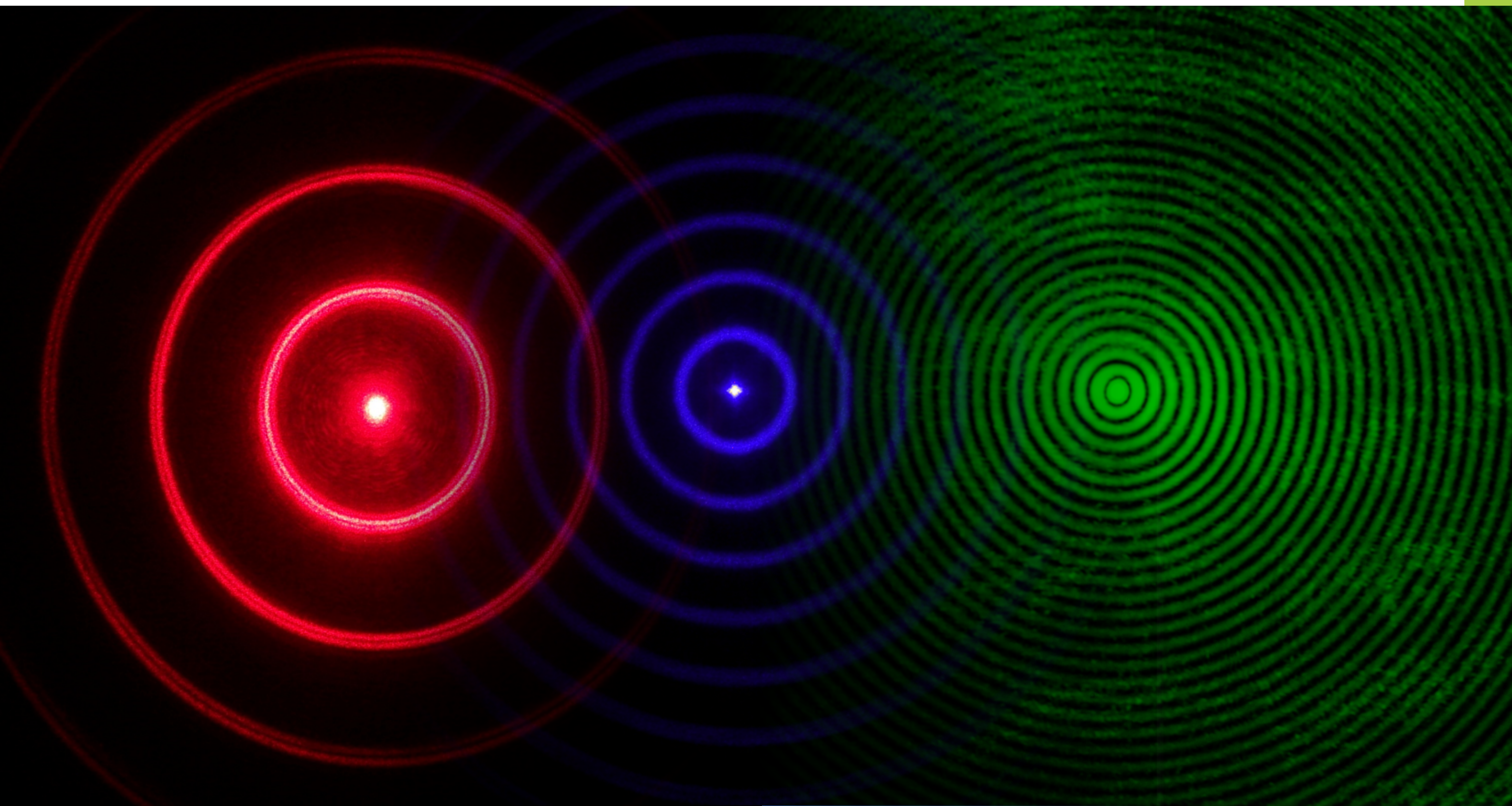

14th School
on
Acousto-Optics and Applications

Toruń, Poland | June 24-27, 2019

# Book of Abstracts & Conference Guide

NICOLAUS COPERNICUS UNIVERSITY IN TORUŃ
Faculty of Physics, Astronomy and Informatics

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14th
SCHOOL on ACOUSTO-OPTICS AND APPLICATIONS
24-27 June 2019 Toruń, Poland

# Book of Abstracts
# &
# Conference Guide

Edited by
Grzegorz Gondek
Piotr Ablewski
Bogumił B.J. Linde
Antoni Śliwiński
Ireneusz Grulkowski

Toruń 2019

**14th School on Acousto-Optics and Applications**

**Book of Abstracts & Conference Guide**

**Editors:**

Grzegorz Gondek
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**Hard copy:**

**On-line version:**

# Welcome Letter from the Organizers

Dear Participants,

It is our pleasure to welcome you to the conference ***14th School on Acousto-Optics and Applications***, which is held on June 24-27, 2019 in Toruń, Poland. The tradition of the Schools dates back to 1980's when the international meetings were organized by the Institute of Experimental Physics of the University of Gdańsk in different places in Pomeranian region (Jurata, Wieżyca, Gdańsk, Sopot), and the last two editions of the conference were organized together with Vilnius University in Druskininkai, Lithuania (2014) and with the National University of Science and Technology MISIS in Moscow, Russia (2017). This time we meet in Toruń – a place known from its original Gothic architecture and a hometown of the astronomer Nicolaus Copernicus. The conference has attracted 53 senior and young scientists, engineers and specialists from all over the world to disseminate their results, to exchange ideas and forge new or strengthen and consolidate ongoing collaborations.

Monday (24 June) through Thursday (27 June) will feature keynote lectures (3), invited talks (3) and regular oral presentations (39). The conference will focus on all physical aspects of light and sound interaction and will provide an insight into recent technology developments of both pure and applied acousto-optics. The topics covered by the School span from traditional acousto-optic research to novel applications of optics and acoustics (ultrasonics) with a special attention to modern imaging technologies. Most of the results presented at the 14th SAOA will be published in the SPIE Proceedings.

During the conference there will be also time to enjoy social events such as a visit to the Astronomical Observatory of the Nicolaus Copernicus University with the biggest radio telescope in the Central Europe, a welcome barbecue and the conference dinner in the heart of the Old Town of Toruń.

We would like to thank the members of Scientific and Organizing Committees for their efforts to make this meeting successful and the employees of the Aleksander Jabłoński Foundation for their operational support. We acknowledge the partners of the conference including Committee on Acoustics of the Polish Academy of Sciences and SPIE Student Chapter at the NCU, which participates in the SPIE Visiting Lecturer Program. We also express our sincere thanks to the organizations that provided financial support: Institute of Experimental Physics at the University of Gdańsk, Polish Ministry of Science and Higher Education, The Optical Society (OSA), International Commission on Acoustics (ICA), and SPIE – The International Society for Optics and Photonics.

We do believe that you will find 14th SAOA a stimulating and fruitful event.

Antoni Śliwiński
Bogumił B.J. Linde
Ireneusz Grulkowski

# General Information

The **14th School on Acousto-Optics and Applications** follows nearly 40-year-old tradition of the international acousto-optic meetings organized in different places in Poland and abroad. The conference focuses on all physical aspects of light and sound interaction and provides an insight into recent technology developments of both pure and applied acousto-optics.

The aim of the 14th SAOA is to exchange ideas and forge new or strengthen and consolidate ongoing collaborations among early stage researchers and experts. The conference serves as a platform that brings together senior scientists, engineers and specialists as well as young researchers (students, PhD students, post-docs etc.) from all over the world to disseminate recent scientific and technology results on trans-disciplinary fields such as optics and acoustics. Another aims of this international conference include discussion on current challenges of the development of acousto-optics and photo-acoustics, integration of the acousto-optic community, and enabling young researchers to participate in a meeting with renown experts in those fields. In particular, the Organizers encourage scientists from the Eastern Europe to attend the conference.

The conference obtained external support from the International Commission on Acoustics (ICA), The Optical Society (OSA) and by the Polish Ministry of Science and Higher Education. SPIE supported the conference via Visiting Lecturer Program coordinated by SPIE Student Chapter at the Nicolaus Copernicus University.

The program will include keynote lectures, invited talks and regular presentations. Topics covered by the School include:

- theoretical and experimental studies of light diffraction by ultrasonic waves,
- acousto-optic devices and instruments,
- new materials and structures for acousto-optics signal processing,
- acousto-optic imaging and tomography,
- ultrafast and femtosecond acousto-optics,
- photoacoustic imaging and spectroscopy,
- optoacoustics and thermoacoustics,
- novel applications in biomedicine.

## Organizers

bio-optics & optical engineering lab at NICOLAUS COPERNICUS UNIVERSITY IN TORUŃ

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## Partners

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# Committees

**Scientific Committee**

- Antoni Śliwiński (Poland, Chair)
- Bogumił B.J. Linde (Poland, Vice-Chair)
- Laszlo Adler (USA)
- Adriano Alippi (Italy)
- Vladimir Balakshy (Russia)
- Erik Blomme (Belgium)
- Daumantas Ciplys (Lithuania)
- Sergey Egerev (Russia)
- Vitali Goussev (France)
- Jean-Claude Kastelik (France)
- Sergey Kulakov (Russia)
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- Oswald Leroy (Belgium)
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- Justyna Cembrzyńska (Invoices, Conference Office)
- Agnieszka Górska-Pukownik (Events, Conference Office)
- Piotr Ablewski (Book of Abstracts)

# Time & Venue

The 14th School on Acousto-Optics and Applications will take place at the Institute of Physics of the Nicolaus Copernicus University in Toruń, Poland, on **June 24-27, 2019**. The lectures are given in the lecture hall (room 2.10) of the Center for Quantum Optics

Institute of Physics

Nicolaus Copernicus University in Toruń

ul. Grudziądzka 5

87-100 Toruń, Poland


Photos: www.fizyka.umk.pl

# Social Events

**Visit to Astronomical Observatory & Welcome BBQ Reception – Monday, June 24, 4:30-9:00 pm**

The Astronomical Observatory of the Toruń Center for Astronomy of the Nicolaus Copernicus University is located in Piwnice – the village situated ca. 14 km from Toruń.

Toruń Center for Astronomy

87-148 Piwnice, Poland

http://www.ca.umk.pl/en

The bus will departure at 4 pm from the Institute of Physics, and will come back from the Observatory at 9 pm.

Photo: www.web.astro.umk.pl

**Conference Dinner – Wednesday, June 26, 7:00-9:00 pm**

Hotel Nicolaus****

ul. Ducha Świętego 14-16

87-100 Toruń, Poland

www.nicolaus.com.pl

HOTEL NICOLAUS****

Photo: www.nicolaus.com.pl

# Practical Information

**Complimentary Internet at the Conference (wireless internet)**

network: konferencja

login & password: provided with the badge

**Presenter Information**

- Conference room has a computer workstation / laptop, projector, screen, laser pointer, and a white board with markers.
- All presenters are requested either to upload their presentations to the computer in the lecture room or to come to lecture room with their laptops or memory devices to confirm their presentation display settings.
- The presenters are asked to adjust timing of their presentations to allow the audience to ask questions after their talks.
- Regular presentations: 12 minutes (+3 minutes for discussion)
- Invited presentations: 30 minutes (+5 minutes for discussion)
- Keynote lectures: 40 minutes (+5 minutes for discussion)

# Program

# Program-At-A-Glance

| | Monday, 24 June, 2019 | Tuesday, 25 June, 2019 | Wednesday, 26 June, 2019 | Thursday, 27 June, 2019 |
|---|---|---|---|---|
| 08:30 – 09:00 | Registration | Registration | Registration | Registration |
| 09:00 – 10:00 | | Session III (9:00 am - 10:15 pm)<br>**Acousto-Optic Instrumentation** | Session VII (9:00 am - 10:15 pm)<br>**Acousto-Optics in Waveguides/Photonic Structures** | Session X (9:00 am - 10:00 am<br>**Novel Applications of Acoustics / Optics** |
| 10:00 – 11:00 | Opening Ceremony and Opening Talk<br>Session I (10:30 am - 12:00 pm)<br>**Photoacoustic Imaging and Spectroscopy** | Tea / Coffee Break<br>Session IV (10:45 am - 12:30 pm)<br>**Light & Sound in Biology and Medicine** | Tea / Coffee Break<br>Session VIII (10:45 am– 12:05 pm)<br>**Fundamentals of Acousto-Optic Interaction II** | Summary and Closing Ceremony |
| 11:00 – 12:00 | | | | |
| 12:00 – 13:00 | Lunch and Tea / Coffee | Lunch and Tea / Coffee | Lunch and Tea / Coffee | |
| 13:00 – 14:00 | Session II (1:00 pm - 2:05 pm)<br>**Fundamentals of Acousto-Optic Interaction I** | Session V (1:30 pm – 2:50 pm)<br>**Acousto-Optic Materials and Structures (Dedicated to the Memory of Prof. L. Kulakova)** | Session IX (1:00 pm – 2:45 pm)<br>**Acousto-Optic Devices** | |
| 14:00 – 15:00 | | Tea / Coffee Break | Scientific Committee Meeting | |
| 15:00 – 16:00 | | Session VI (3:20 pm -4:35 pm)<br>**Acousto-Optics for Spectroscopy, Metrology and Imaging** | | |
| 16:00 – 17:00 | Visit to the Toruń Center for Astronomy (Piwnice) and Welcome BBQ Reception | | | |
| 17:00 – 18:00 | | | | |
| 18:00 – 19:00 | | | | |
| 19:00 – 20:00 | | | Conference Dinner (Discussions at Round Tables) | |
| 20:00 – 21:00 | | | | |
| 21:00 – 22:00 | | | | |

# Monday, June 24, 2019

| | |
|---|---|
| 08:30 – 10:00 | **Registration and Welcome Tee / Coffee** |
| 10:00 – 10:30 | **Opening Ceremony** |
| | **Welcome Addresses** |
| | Dean, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University in Toruń |
| | Director, Institute of Experimental Physics, University of Gdańsk |
| | **Opening Talk** |
| | A. ŚLIWIŃSKI, Acousto-optics as a field of current interest in research and application |
| | **Session I: Photoacoustic Imaging and Spectroscopy**<br>Chair: I. Grulkowski |
| 10:30 – 11:15 | X.L. DEÁN-BEN, D. RAZANSKY, Interrogating Rapid Biological Dynamics with Volumetric Multi-Spectral Optoacoustic Tomography [Keynote] |
| 11:15 – 11:30 | B.B.J. LINDE, N. PONIKWICKI, E. SKRODZKA, Photoacoustics as a tool for studying the aqueous mixtures of non-electrolytes |
| 11:30 – 11:45 | P. ROCHOWSKI, S.J. POGORZELSKI, M. GRZEGORCZYK, Drug permeation through a skin-mimicking system studied by means of the photoacoustic depth-profiling method |
| 11:45 – 12:00 | V. ZARUBIN, A. BYCHKOV, E. CHEREPETSKAYA, A. KARABUTOV, Broadband real-time laser ultrasound tomography of composites |
| 12:00 – 13:00 | **Lunch and Tea / Coffee** |
| | **Session II: Fundamentals of Acousto-Optic Interaction I**<br>Chair: V. I. Balakshy |
| 13:00 – 13:35 | P. KWIEK, Interaction of two coherent light beams with ultrasonic wave [Invited] |
| 13:35 – 13:50 | M.V. MARUNIN, V.B. VOLOSHINOV, Physical Properties of $\alpha$-$BaB_2O_4$ and $\beta$-$BaB_2O_4$ Crystals Promising for Application in Acousto-Optic Devices |
| 13:50 – 14:05 | V.YA. MOLCHANOV, K. YUSHKOV, V. GUROV, A. CHIZHIKOV, A. DARINSKY, Novel method of the unscattered phonons energy removal from acousto-optical devices |
| 16:00 – 21:00 | **Visit to the Toruń Centre for Astronomy (Piwnice)<br>and Welcome BBQ Reception** |
| 16:00 | Coach Departure from the Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University, ul. Grudziądzka 5 |

# Tuesday, June 25, 2019

| | |
|---|---|
| 08:30 – 09:00 | **Registration and Morning Tea / Coffee** |
| | **Session III: Acousto-Optic Instrumentation**<br>Chair: B.B.J. Linde |
| 09:00 – 09:15 | J.-C. KASTELIK, S. Dupont, J. Champagne, Multi-electrode array for spectral bandwidth control |
| 09:15 – 09:30 | K.B. YUSHKOV, Acousto-Optic Programmable Filters and the Sampling Theorem |
| 09:30 – 09:45 | G. SLINKOV, V.I. BALAKSHY, S.N. MANTSEVICH, L.N. MAGDICH, Effects of Electric Matching Circuit Parameters on the Acousto-optic Mode Locker Functioning |
| 09:45 – 10:00 | M.M. MAZUR, L.I. MAZUR, YU.A. SUDDENOK, V.N. SHORIN, Adaptive change of AOTF instrumental function at frequency modulation of ultrasonic wave |
| 10:00 – 10:15 | A.I. CHIZHIKOV, K. YUSHKOV, V. MOLCHANOV, Acousto-optic modulator based on crystal $NaBi(MoO_4)_2$ |
| 10:15 – 10:45 | **Tea / Coffee Break** |
| | **Session IV: Light and Sound in Biology and Medicine**<br>Chair: P. Saggau |
| 10:45 – 11:30 | M. DUOCASTELLA, Toward ultrafast volumetric microscopy with acoustic liquid lenses [Keynote] |
| 11:30 – 11:45 | S.J. POGORZELSKI, P. ROCHOWSKI, M. GRZEGORCZYK, Photosynthetic energy storage efficiency in biofilms determined by photoacoustics |
| 11:45 – 12:00 | A. JIMÉNEZ-VILLAR, D. RUMIŃSKI, G. GONDEK, I. GRULKOWSKI, Scanning Laser Ophthalmoscope Integrated with Tunable Lens: Imaging and Ophthalmic Applications |
| 12:00 – 12:15 | A. MACHIKHIN, V. BATSHEV, A. GOREVOY, D. KHOKHLOV, V. POZHAR, Improvement of endoscopic imaging systems by means of acousto-optic filtration of light |
| 12:15 – 12:30 | A. JIMÉNEZ-VILLAR, E. MĄCZYŃSKA, K. KARNOWSKI, M. JANNESARI, B. KAŁUŻNY, M. WOJTKOWSKI, I. GRULKOWSKI, Non-contact Optical Probing of Ocular Biomechanics |
| 12:30 – 13:30 | **Lunch and Tea / Coffee** |

# Tuesday, June 25, 2019 (cont'd)

| | |
|---|---|
| | **Session V: Acousto-Optic Materials and Structures**<br>**SESSION DEDICATED TO THE MEMORY OF PROF. LUDMILA KULAKOVA**<br>Chair: V.Ya. Molchanov |
| 13:30 – 13:45 | V.B. VOLOSHINOV, Tribute to the Memory of Professor Lyudmila Kulakova |
| 13:45 – 14:20 | V.B. VOLOSHINOV, N.V. POLIKARPOVA, Acousto-Optic Probing of Acoustic Beams Generated by Multiple Reflections in Paratellurite Crystal [Invited] |
| 14:20 – 14:35 | W. JEON, J. AN, Enhancement of Acousto-Optic Interaction by Using Two-Scale Phoxonic Crystals |
| 14:35 – 14:50 | V.S. KHORKIN, V.B. VOLOSHINOV, M.S. KUZNETSOV, Anisotropic Acousto-Optic Interaction in KRS-5 Cubic Crystal Possessing Induced Optical Anisotropy |
| 14:50 – 15:20 | **Tea / Coffee Break** |
| | **Session VI: Acousto-Optics for Spectroscopy, Metrology and Imaging**<br>Chair: M. Delgado-Pinar |
| 15:20 – 15:35 | Y. DOBROLENSKIY, O. KORABLEV, A. FEDOROVA, S. MANTSEVICH, Y. KALINNIKOV, N. VYAZOVETSKIY, A. TITOV, A. STEPANOV, A. SAPGIR, I. DZYUBAN, N. EVDOKIMOVA, R. KUZMIN, Y. IVANOV, I. SYNIAVSKYI, Acousto-Optic Spectrometer ISEM for ExoMars-2020 space mission: ground measurements and calibrations |
| 15:35 – 15:50 | A. NAUMOV, A. GOREVOY, A. MACHIKHIN, V. BATSHEV, V. POZHAR, M. MAZUR, Calibration features of a stereoscopic AOTF-based hyperspectral imager |
| 15:50 – 16:05 | S.N. MANTSEVICH, K.B. YUSHKOV, A.S. VOLOSHIN, Applications of Collinear Acousto-optic Diffraction for Optical Frequency Combs Generation |
| 16:05 – 16:20 | C. ISAZA, K. ANAYA, J. PAUL ZAVALA, A. RIZZO, J.C. MOSQUERA, Semiautomatic Acousto-optical Tunable Filter Calibration from Spectrometry in the Visible Range with Deep Learning |
| 16:20 – 16:35 | G. KOWZAN, Selected applications of acousto-optic modulators in high-precision spectroscopy |

# Wednesday, June 26, 2019

| | |
|---|---|
| 08:30 – 09:00 | **Registration and Morning Tea / Coffee** |
| | **Session VII: Acousto-Optics in Waveguides / Photonic Structures**<br>Chair: J.-C. Kastelik |
| 09:00 – 09:15 | S. ROSALES-MENDOZA, M. DELGADO-PINAR, A. DÍEZ, M.V. ANDRÉS, Characterization of sensitivity of in-fiber acousto-optic interaction |
| 09:15 – 09:30 | H. HAN, YU. LI, L. HUANG, L. GAO, M. LIU, T. ZHU, All-fiber dual-wavelength narrowband acousto-optic tunable bandpass filter based on vector mode coupling |
| 09:30 – 09:45 | I.M. SOPKO, G.A. KNYAZEV, D.O. IGNATYEVA, V.I. BELOTELOV, Application of layered structures for mid-infrared acousto-optics |
| 09:45 – 10:00 | A. TWAROWSKI, P. WCISŁO, Setup for noise cancellation in optical fiber |
| 10:00 – 10:15 | M. PAWLAK, Toward Laser Induced Photothermal Infrared Radiometry Spectroscopy |
| 10:15 – 10:45 | **Tea / Coffee Break** |
| | **Session VIII: Fundamentals of Acousto-Optic Interaction II**<br>Chair: V.B. Voloshinov |
| 10:45 – 11:20 | V.I. BALAKSHY, M.I. KUPREYCHIK, S.N. MANTSEVICH, Anisotropic Light Diffraction in Spatially Periodical Acoustic Field [Invited] |
| 11:20 – 11:35 | D.L. POROKHOVNICHENKO, J. RYU, D.V. ZINKIN, V.B. VOLOSHINOV, Analysis of Wide-Angle Acousto-Optic Interaction Geometry in Single Crystal Mercury Bromide |
| 11:35 – 11:50 | D. ČIPLYS, R. RIMEIKA, A Novel Configuration for Effective Acousto-Optic Diffraction by IDT-radiated Bulk Waves in Lithium Tantalate |
| 11:50 – 12:05 | M.I. KUPREYCHIK, V.I. BALAKSHY, Investigation of Close to Collinear Anisotropic Acousto-Optic Interaction in a Biaxial Crystal of Alpha-Iodic Acid |
| 12:05 – 13:00 | **Lunch and Tea / Coffee** |

# Wednesday, June 26, 2019 (cont'd)

| | |
|---|---|
| | **Session IX: Acousto-Optic Devices**<br>Chair: S.J. Pogorzelski |
| 13:00 – 13:45 | P. SAGGAU, Review of Acousto-Optical Devices in Advanced Microscopy: from 3D Scanning via Super-Resolution to Encoded Multi-Beams [Keynote, SPIE Visiting Lecturer] |
| 13:45 – 14:00 | J. VANHAMEL, E. DEKEMPER, V.B. VOLOSHINOV, E. NEEFS, D. FUSSEN, Comparison between the electrical bandwidth performance of a transducer and the diffraction efficiency of an AOTF |
| 14:00 – 14:15 | A.V. RYABININ, M.M. MAZUR, L.I. MAZUR, V.N. SHORIN, Two-crystal acousto-optic modulator of high-power laser radiation |
| 14:15 – 14:30 | S. VALLE, K.C. BALRAM, High-frequency ($f_{RF}$ >1GHz) Acousto-Optic modulation using a doubly resonant cavity in a MEMS foundry platform |
| 14:30 – 14:45 | A. ZUNINO, S. SURDO, M. DUOCASTELLA, Acousto-Optofluidic Multi-spot Generation for High-throughput Laser Material Processing |
| 14:45 – 15:40 | **Scientific Committee Meeting** |
| 19:00 – 21:00 | **Conference Dinner (Discussions at Round Tables)**<br>**Venue: Hotel Nicolaus, ul. Ducha Świętego 14-16, Toruń** |

# Thursday, June 27, 2019

| | |
|---|---|
| 08:30 – 09:00 | **Registration and Morning Tea / Coffee** |
| | **Session X: Novel Applications of Acoustics / Optics**<br>Chair: M. Duocastella |
| 09:00 – 09:15 | E. DEKEMPER, J. VANHAMEL, J.-C. KASTELIK, N. PEREIRA, D. BOLSÉE, G. CESSATEUR, H. LAMY, D. FUSSEN, AOTF-based instrumental concepts for atmospheric science |
| 09:15 – 09:30 | R. BIELAS, A. JÓZEFCZAK, Z. ROZYNEK, Acoustical and optical control of Pickering emulsions formation in electric field |
| 09:30 – 09:45 | R. HODÉ, S. RAETZ, V. GUSEV, F. JENSON, N. CUVILLIER, M. DUCOUSSO, V. TOURNAT, Laser ultrasonics for non-destructive evaluation of adhesively bonded joints |
| 09:45 – 10:00 | M. URBAŃSKA, S.M. KOLENDERSKA, F. VANHOLSBEECK, Optical Coherent Elastography of the vitreous humour |
| 10:00 – 10:30 | **Summary and Closing Ceremony** |

# Keynote Lecturers

DANIEL RAZANSKY is Full Professor of Biomedical Imaging at the University and ETH in Zurich, Switzerland. He studied Electrical and Biomedical Engineering at the Technion - Israel Institute of Technology and received postdoctoral training in bio-optics at the Harvard Medical School in Boston, USA. He was previously Professor of Molecular Imaging Engineering at the Technical University and Helmholtz Center in Munich, Germany. His lab pioneered a number of novel bio-imaging technologies successfully commercialized worldwide, among them the multi-spectral optoacoustic tomography (MSOT) and hybrid optoacoustic ultrasound (OPUS). Prof. Razansky's research has been awarded the German Innovation Prize and multiple recognitions and awards from the ERC, NIH, DFG and HFSP. He is also an elected Fellow of the OSA and SPIE.

MARTI DUOCASTELLA received his PhD degree in Physics from the University of Barcelona in 2010. His thesis focused on studying the ejection dynamics of a laser additive manufacturing technique. Hereafter, he joined Princeton University as a Postdoctoral Research Associate. For over three years, he worked with Prof. Craig B. Arnold on the development of sound-driven liquid lenses for laser materials processing and imaging. During this time, he was involved with the creation of a US-based start-up company, TAG Optics Inc., first as an external consultant and later as the Vice-president of Research and Development. Since 2014, he is a researcher of the Department of Nanophysics at Istituto Italiano di Tecnologia (IIT). His research focuses on combining acousto-optics with fluidic systems for fast imaging and high-throughput laser fabrication. Dr. Duocastella has authored over 50 peer-reviewed publications, including 3 book chapters and 2 patents. He has been an invited speaker at more than 20 international conferences in the fields of laser processing and optical microscopy. He is also the recipient of several awards, including the R&D 100 Award, the PRISM Award, the Siemens Innovation Award or the Laser Focus World-OSA Technology Innovation Award.

# SPIE Visiting Lecturer

PETER SAGGAU is an Adjunct Professor of Neuroscience at Baylor College of Medicine in Houston, TX, and was a Principal Investigator and Lab Director from 1990-2014. He was a Senior Director at the Allen Institute for Brain Science in Seattle, WA. As Head of Research Engineering, he was responsible for Technology Development from 2014-2018. Dr. Saggau holds degrees from the Technical University Munich, School of Engineering, and Ludwig-Maximillians University, Medical School, Germany. His research interest is Instrumentation for Neuroscience Research, specifically Advanced Optical Techniques for imaging living brain tissue. He is a member of many professional organizations and an Elected Fellow of the Institute of Physics. He was a Nikon Fellow at the MBL (Woods Hole, MA), and is a Visiting Scientist at the Italian Institute of Technology (Genoa, Italy).

SPIE Toruń STUDENT CHAPTER

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# Abstracts

Opening Talk

# Acousto-optics as a field of current interest in research and application

**A. ŚLIWIŃSKI***

*University of Gdańsk, Institute of Experimental Physics, Wita Stwosza 57, 80-308 Gdańsk, Poland*
**fizas@ug.edu.pl*

Some personal recollections on the acousto-optics as an interesting field of physics and its applications will be shared with the participants in a short welcome address. The consecutive number of the present Spring School on AO&A, 14-th, indicates a long history of events (39 years) initiated in 1980 by the University of Gdańsk as the triennial international meeting of specialists of science and technology over the world, being continued till now.

The fundamentals of the acousto-optics domain covering light (photons) and ultrasonics (phonons) interactions originally come from works of L. N. Brillouin whose anniversaries the 130 years of his birthday and the 50 years of his death are being celebrated during the current year.

The next principles were widely developed by many others in 1930's after essential two independent papers by P. Debye & F. W. Sears (USA) and R. Lucas & P. Biquard (France), then fundamentals by C. V. Raman & N. S. Nagendra Nath, followed by many papers and applications after the II World War. The wide and rich literature of the subject of the last 100 years built up a branch of knowledge to which a piece of contribution of the AO&A Schools has its own place. The further development of the branch is prospective, too. Recently, such problems as very short time (pico- and femtoseconds) acousto-optic interactions, nonlinear processes in bio- and nano-structures and their applications in acousto-optic and optoelectronic instrumentation as well as many others are subjects of the current interest and promising topics for the future.

# Interrogating Rapid Biological Dynamics with Volumetric Multi-Spectral Optoacoustic Tomography

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Optoacoustic imaging is increasingly attracting the attention of the biomedical research community due to its excellent spatial and temporal resolution, centimeter scale penetration into living tissues, versatile endogenous and exogenous optical absorption contrast. State-of-the-art implementations of multi-spectral optoacoustic tomography (MSOT) are based on multi-wavelength excitation of tissues to visualize specific molecules within opaque tissues. As a result, the MSOT technology can noninvasively deliver structural, functional, metabolic, and molecular information from living tissues [1]. Our recent efforts in the field of optoacoustic functional and molecular imaging have established new technological platforms employing spherical matrix arrays, parallel acquisition hardware, GPU-based data processing and fast-tuning laser systems in order to enable acquisition and visualization of spectroscopic information from entire tissue volumes at video rates [2]. This has set the stage for the so-called five dimensional (real-time three-dimensional multi-spectral) optoacoustic imaging that offers unparalleled capabilities among the existing bio-imaging modalities. Biomedical applications are explored in the areas of functional neuro-imaging, fast tracking of agent kinetics and biodistribution, cardiovascular research, monitoring of therapies and drug efficacy as well as targeted molecular imaging studies. Handheld optoacoustic systems are further transforming optical imaging by offering novel precision in clinical observations of patients, demonstrating high diagnostic efficacy in a number of indications, such as breast cancer, inflammatory bowel disease and lymph node metastases.

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Session I: Photoacoustic Imaging and Spectroscopy

# Photoacoustics as a tool for studying aqueous mixtures of non-electrolytes

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In this paper we would like to show that photoacoustic methods can be successfully used to study aqueous mixtures of non-electrolytes.

It is known that the physical and chemical properties of binary liquid mixtures may vary significantly by changing their composition. The dependence of many properties on concentration often reveal characteristic maxima, minima, or inflection points, which can be discussed in terms of interactions between components of a mixture.

It has been shown that the obtained positive deviations of the effusivity from linearity in aqueous solutions of alcohols at low concentrations can be assigned to hydrophobic interactions.

The thermal effusivity was determined using a photoacoustic method. The excess molar volume was found from measured densities, while the isentropic compressibility coefficient was calculated based on density and ultrasound velocity measurements. The procedure applied by A. Sikorska et.al., [1] allows determination of an absolute value of the so-called thermal effusivity, numerically equal to the root of the product of the above quantities, i.e. $\rho$, $c_p$ and $\lambda$.

It has been proven that the dependence of the effusivity on concentration, expressed in mass fraction units, is nonlinear in the case of all the alcohols used. Moreover, the location of extreme deviations from linearity for the thermal effusivity, e, agrees well with that of characteristic points for the isentropic compressibility coefficient, $\kappa_S$, and the excess molar volume, $V^E_m$, as a function of the concentration.

Presenting the investigations of such mixtures by ultrasonic methods, we conclude that the photoacoustic method applied to study thermal dependence of effusivity on the molar concentration of the investigated substance is a powerful tool, complementary to other ultrasonic techniques commonly used to examine structural changes of liquid mixtures [2, 3].

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# Drug permeation through a skin-mimicking system studied by means of the photoacoustic depth-profiling method

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Studying transdermal transport mechanisms and accompanying interactions provides valuable information on the skin properties as an outermost body barrier as well as on optimal drug formulation for transdermal delivery systems.

The objective of the work was to characterize processes driving the drug permeation through the skin outermost layer – stratum corneum. The model system considered here consisted of a drug – dithranol in a pharmaceutical form (drug/Vaseline suspension) penetrating stratum corneum-mimicking nitrocellulose membrane.

Photoacoustic measurements provide a valuable tool for non-destructive studies of the systems under consideration. By means of a simple modulation of the excitation beam, various depths of the sample can be monitored. Here, the photoacoustic depth profilometry measurements at 20$^{o}$C for the drug/membrane system were performed in a wide range of modulation frequencies (15-350Hz) corresponding to a variable thickness of layers scanned inside the sample during the drug permeation process. The evolution of the frequency-dependent signal intensities were assigned to the increment of the drug concentration inside the membrane.

The collected data set allowed for testing mathematical models of different complexity, for the drug transport dynamics. The models were based upon the Fickian diffusion as a primary driving mechanism of the drug transport, but also included other processes affecting the permeation like: chemical reactivity (depletion) of the drug, the drug/membrane interactions and advection (under creeping-flow approximation of the Navier-Stokes model). Eventually, the permeation schemes were analyzed by fitting the models to the collected data set, allowing for the diffusion, advection, and reaction rate coefficients to be evaluated. The results indicate, that for the purely diffusion model, the diffusion coefficient obtained remains in a good agreement with results obtained by means of other method. However, statistical analysis of the more complex models underlined significance of the advection and reaction processes accompanying the diffusion [1].

In the future studies, a sequence of similar measurements will be performed for a wide range of physiologically significant temperatures. There is an evidence, that rheological behavior of semisolid ointment base affects the drug transport phenomenon, and such a signature will be included in a novel version of the model.

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# Broadband real-time laser ultrasound tomography of composites

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Laser ultrasound tomography (LUT), like photoacoustic tomography, uses pulsed laser radiation for excitation of short ultrasonic pulses. In LUT, the light is absorbed in a dedicated light-absorbing plate [1]. Probe pulse propagates through immersion liquid, undergoes scattering by a surface of an object and by internal inhomogeneities. Scattered waves are recorded by a wideband multi-element acoustic array, and then used for reconstruction of the object image. In comparison with traditional tomography, LUT provides images with better quality and resolution due to short duration and smooth shape of laser-excited probe pulse. A wide spectral band (0.1-15 MHz) of the pulse well suites a problem of inspection of carbon fiber reinforced composites, allowing visualizing of individual layers of carbon fiber, delaminations of thickness about 100 µm, etc. [2].

In this talk, an experimental setup for real-time LUT inspection of composites and reconstruction algorithms will be presented. The algorithms account for refraction of waves at the sample surface, as well as for anisotropic propagation of acoustic waves inside the sample. Results of tests on numerically and experimentally obtained data show that resolution in isotropic (example on Fig. 1) and anisotropic media is up to 100 µm in the direction of the probe pulse propagation [3, 4].

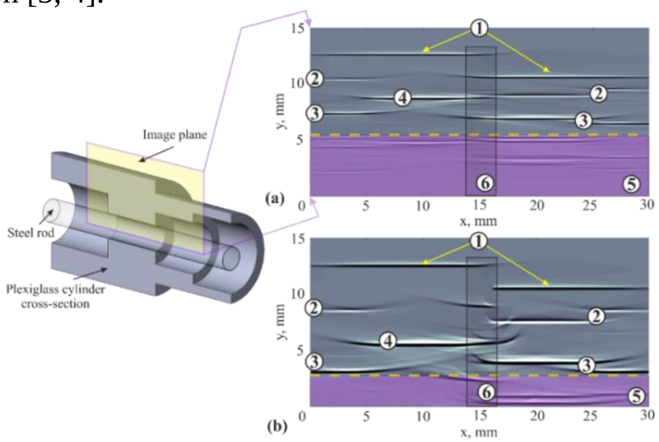


Fig. 1. The example of numerically simulated LUT of a plexiglass cylinder. Left: 3D model of the sample. Right: images (a) with and (b) without refraction-correction. 1, 2, 4 – external and internal boundaries; 3 – reflection from the steel rod; 5 – reverberations; 6 – image artifacts.

*This work was supported by the Ministry of Education and Science of the Russian Federation grant № K2-2019-004.*

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# Interaction of two coherent light beams with ultrasonic wave

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The accurate theory describing interaction of two coherent light beams with ultrasonic wave where one of the light beam is incident at positive Bragg angle while the other at negative was developed by Leroy and Blomme in 1984 [1].

The assumed geometry in this theory is resembling an interferometer wherein ultrasonic beam plays a role of the output beam splitter of the light. The output light intensity is modulated with ultrasonic frequency as a result of interference between the light in diffraction orders in which the frequency is changed due to the Doppler effects with those diffracted with unchanged frequency.

Temporal modulation of the light intensities in diffraction orders, that was foreseen by Leroy and Blomme, was confirmed experimentally and the results will be presented.

Although many years have passed Leroy and Blomme theory was not verified experimentally to the author's best knowledge.

This theory could be applied to the quantum optics phenomenon when pairs of entangled photons are incident on ultrasonic wave instead of two coherent light beams [2]. The geometry of interaction of two coherent light beams with ultrasonic wave in Leroy-Blomme theory is the same as for Hong-Ou-Mandel interferometer wherein a beam splitter is replaced by the ultrasonic wave. Similarities and differences between Leroy-Blomme and Hong-Ou-Mandel interferometers will be presented.

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# Physical Properties of α-$BaB_2O_4$ and β-$BaB_2O_4$ Crystals Promising for Application in Acousto-Optic Devices

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We examined optic, acoustic and acousto-optic properties of materials belonging to the borate family of trigonal crystals α-$BaB_2O_4$ and β-$BaB_2O_4$. The analysis was carried out in order to evaluate a possibility of using the materials in acousto-optic deflectors and filters operating in the visible light and also in the ultraviolet region of spectrum [1]. As known, acousto-optic devices are widely used in optics, spectroscopy, laser technology and optical information processing for control of optic beams. The devices have proved their advantages of fast and reliable operation in the visible light and in the near infrared region of spectrum. On the other hand, development of the instruments operating in the ultraviolet region of spectrum is limited by lack of crystals showing high acousto-optic efficiency and good transparency in the ultraviolet [2]. In the majority of known ultraviolet materials, it is not possible to observe the "anisotropic diffraction" of light by sound because the media are not birefringent.

Based on data found in scientific literature [2, 3], we examined physical characteristics of the materials α-$BaB_2O_4$ and β-$BaB_2O_4$. Carrying out the analysis, we calculated magnitudes of acoustic phase velocities in the materials in three basic planes of the crystals XY, XZ and YZ. We also evaluated directions of acoustic polarization and energy walk-off angles in the crystalline materials. In this way, we got the required information on the acoustic properties of the materials. As for the acousto-optic parameters of the crystals, they were calculated in the XZ and YZ planes. In the calculation, we used data on photoelastic coefficients also found in literature [2, 3]. Our analysis showed that the anisotropic diffraction in XZ plane of the crystals, especially in the deflector and filter regimes, is characterized by very low magnitudes of the acousto-optic figure of merit. The analysis also demonstrated that the large birefringence resulted in a sufficient increase of driving electric frequencies. These features of the crystals should be considered as a disadvantage.

A similar analysis carried out in the plane YZ of the crystals revealed a possibility of using the materials in acousto-optics. The required regimes of the anisotropic diffraction may be realized in the crystals if a pure shear and a quasi-shear acoustic wave is sent at an angle to the Y or Z axes. As found, the acousto-optic figure of merit of the crystals in the YZ plane exceeds the corresponding value in the XZ plane. A geometry of interaction is examined suitable for the application in an acousto-optic modulator. We also found a configuration of a cell to be used as a deflector. A possibility to design an imaging filter is also discussed in the presentation. It makes the borate crystals rather attractive for the application in the acousto-optic devices.

*The work was supported by the grant of the Russian Foundation for Basic Research, project 17-07-00369.*

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# Novel method of the unscattered phonons energy removal from acousto-optical devices

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This work is devoted to the research of a new principle of active absorption of BAW for acousto-optical Q-modulators with high energy consumption in the lasers of the mid-IR range in order to reduce thermal gradients and remove of thermal sources from the laser resonator.

Recent years there has been the creation of new high-power pulsed lasers of the mid-IR range (Ho3+:YAG, 2 µm range; Fe2+:ZnS, 3-5 µm range [1, 2]) operating in Q-switching mode. Acousto-optic (AO) laser Q-switches based on fused or crystalline quartz with an efficiency of about 50% on mid-IR require extremely high RF power consumption of 50-100 W. The usual solution is water cooling of laser gates or conductive with Peltier elements. In any case, the passive power absorber BAW is located on the shutter housing inside the laser resonator, and can cause temperature instability of the latter due to AO crystal overheating.

We proposed a new method to remove absorber from the resonator and place it in a structurally acceptable zone outside the laser system using cable and matched load. The method is based on the conversion of BAW into electrical energy in the $LiNbO_3$ piezoelectric absorber.

In the plane waves approximation, it is shown that with a certain choice of complex load, the BAW reflection from the $LiNbO_3$ absorber at the central frequency tends to zero (Fig.1).

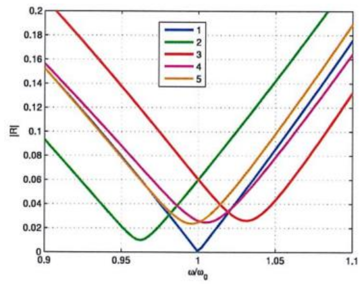


Fig.1. Frequency dependence of the reflection coefficients at different values of the electrical load. Curve 1 corresponds to the optimal load complex value.

Theoretical calculations are confirmed by experiment. We designed and fabricated custom laser Q-switch based on $SiO_2$ with an active absorber of $LiNbO_3$. The electrical load has active value 50 Ohm. It is transformed by the matching circuit to the optimal complex value (curve 1, Fig.1). The electrical load is located outside the laser resonator using the cable. This study demonstrated the effectiveness of the proposed method.

*The research was supported in parts by the RFBR (Project 18-29-20019 мк) and the Ministry of Science and Higher Education of the Russian Federation (Project 02.A03.21.0004 / Grant K2-2017-079).*

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Session III: Acousto-Optic Instrumentation

# Multi-electrode array for spectral bandwidth control

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Acousto-optical tunable filters (AOTFs) are well used for practical applications and are most often based on the classical anisotropic non-collinear configuration in tellurium dioxide crystals. Any product sheet of such a commercially available AOTF presents two main features: the tuning range and the spectral bandwidth $\Delta\lambda$. The spectral transmission bandwidth [1] is proportional to the ratio $\lambda^2/(bW)$ where $\lambda$ is the optical wavelength, b the dispersive constant and W the length of the transducer. The dispersive constant b is a rapidly decreasing function of the wavelength in the blue visible spectrum. As for examples: for a one octave tuning range starting from 400 nm to 800 nm, the spectral bandwidth is multiplied by ~10. For a tuning range in the infrared band 1250-2500 nm, the spectral bandwidth is multiplied by ~4.

We present the design of a filter operating in the visible region from 450 nm to 650 nm. A double anisotropic interaction [2] is considered allowing the simultaneous diffraction of the two optical modes propagating into the crystal by a single ultrasonic wave. A multi-electrode array of three identical consecutive electrodes $W_{i:1\text{-}3}$ = 3 mm is deposited on the transducer leading to a more precize control of the spectral bandwidth. The acoustooptic device has been fabricated by the AA-Opto company. Experimental results are summarized in Fig. 1.

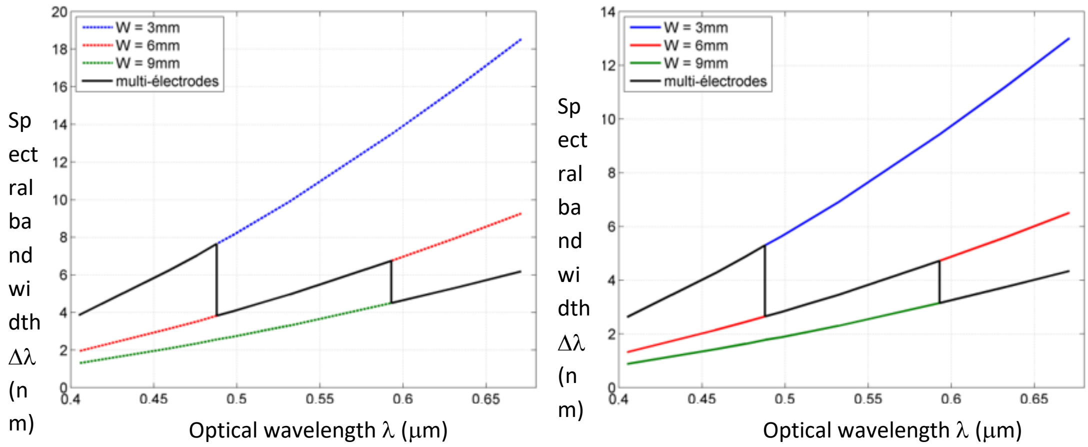


Fig. 1 Spectral bandwidth $\Delta\lambda$ as a function of the optical wavelength in multi-electrode configurations for the two simultaneous anisotropic interactions.

By a proper choice of the multi-electrode configuration, the variation of the spectral bandwidth over the optical tuning range can be significantly reduced by a factor 3 for the two anisotropic interactions.

*This work was supported by National Grant ANR SPIT-FIRE 2017.*

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# Acousto-Optic Programmable Filters and the Sampling Theorem

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One of the major breakthroughs in acousto-optical signal processing during the last decade is programmable controlling of tunable filters [1]. Arbitrary tailoring of broadband complex-valued transmission functions for both collinear and orthogonal types of acousto-optic interaction has been demonstrated. Ultrafast pulse shaping is the main application of programmable acousto-optic filters. The emerging applications are spectrally matched filtering and adaptive spectroscopy.

The transmission function of the AO filter is determined by the spectrum of RF waveform fed to the piezoelectric transducer. Digital arbitrary waveform generators are used for signal synthesis. Dispersive algorithm of waveform synthesis uses the Fourier transform to find the required RF waveform [2]. In calculations, both the RF spectrum and the waveform are considered as discrete functions. According to the generalized sampling theorem (Kotel'nikov's fifth theorem), the sampling interval in time domain is inversely proportional to the RF signal bandwidth, $\delta t_s = 1/(2\Delta f)$ [3]. Since the duration of the waveform $T_0$ is determined by the geometry of the AO filter, the total number of points in the sample can be found $N_s = T_0/\delta t_s = 2T_0\Delta f$. The sampling interval in the frequency domain $\delta f_s = 1/(2T_0)$ corresponds to the finest features in the spectrum. Discrete Fourier transform of a given complex-valued spectrum results in a periodic waveform with the period $T_{per} = N_s/\Delta f = 2T_0$. Thus, the RF waveform calculated from the discrete Fourier digitally truncated before being synthesized. This is equivalent to convolution of the defined RF spectrum with the instrument function of the AO filter having the FWHM $\delta f_{ao} = 0.8/T_0$ under condition of high diffraction efficiency.

A practical issue is matching the calculated waveform with the sampling frequency of the arbitrary waveform generator. Typically, the sampling rate of the generator, $\delta t_{awg}$ is much greater than the bandwidth-determined interval $\delta t_s$ that requires resampling of the waveform before its uploading to the generator memory. The straightforward way for proper waveform sampling is using explicit form of the discrete Fourier transform for calculation of the output waveform data array consisting of $N_{awg} = T_0/\delta t_{awg}$ points from the initial array of $N_s$ spectral samples. Alternatively, fast Fourier transform and zero-padding can be used for the waveform resampling and reducing required computation time by 2-3 orders. The improvements in accuracy and processing time discussed in this report are aimed at developing instrumentation for adaptive spectroscopy with multi-kHz operation rates.

*This work was supported by Russian Foundation for Basic Research (Project 18-29-20019) and the Ministry of Science and Higher Education of Russia (Project 02.A03.21.0004 / Grant K2-2017-079).*

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# Effects of Electric Matching Circuit Parameters on the Acousto-optic Mode Locker Functioning

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Acousto-optic methods of optical radiation control are widely applied in optoelectronics. One of the applications of acousto-optic modulators (AOM) is active synchronization of longitudinal laser modes, which allows to acquire an evenly spaced train of short and powerful pulses from a conventional CW laser [1].

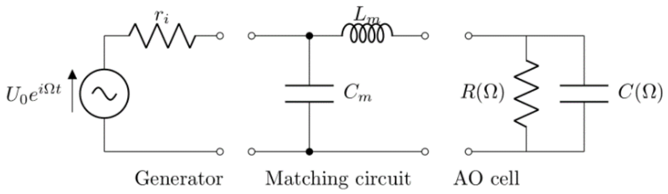


Fig. 1. Equivalent electrical scheme of the AO mode locker.

Mode locking can be implemented through amplitude modulation of a laser radiation inside its cavity with frequency $f$ equal to intermodal distance of the laser $c/2L_l$ ($c$ – speed of light $L_l$ – cavity length). AOM used for mode locking usually operate in a standing wave mode, since it is a simpler and much more power-effective way than driving the AOM with a modulated RF signal. Therefore, ultrasound frequency $f$ must also meet standing wave condition for an acoustic wave in AOM's crystal ($f = f_a = (V_s n)/(2L_s)$, $n \in \mathbb{Z}$, $V_s$ being the speed of sound and $L_s$ the length of the crystal). This way, heating of the crystal due to absorption of acoustic energy becomes a problem of an AO mode locker: thermal expansion of the crystal breaks that standing wave condition by increasing $L_s$, which decreases modulation effectiveness. This problem we address in terms of acoustic resonance frequency $f_a$ shifting with temperature deviation. Complicated AO cell temperature stabilization systems are usually applied to reduce this effect.

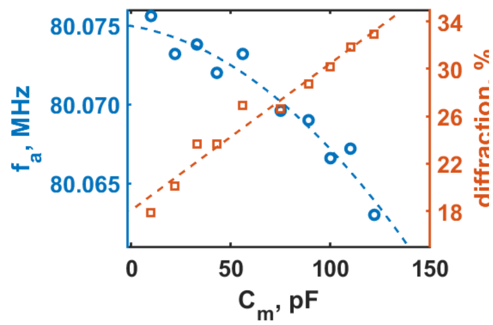


Fig. 2. Acoustic resonance frequency and AO diffraction efficiency at acoustic resonance frequency plotted against matching circuit capacity.

However, another method for compensating thermal shift exists [2, 3]. It is based on the dependence of acoustic resonance frequency $f_a$ on parameters of the electrical matching circuit $(L_m, C_m)$ of a modulator (Fig. 1), first reported in [2]. In this study we examine the effects of matching circuit topology and electrical characteristics on the parameters of acoustic resonances and AO diffraction in the AO cell (Fig. 2) and outline the ways to utilize it for compensating that thermal frequency shift both theoretically and experimentally. Our analysis allows broadening of the temperature and power domains of an AO mode locker's reliable operation without temperature stabilization system.

*This work was supported by Russian Science Foundation (RSF) under Project 18-72-00036.*

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# Adaptive change of AOTF instrumental function at frequency modulation of ultrasonic wave

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The paper presents the results of an experimental study of the hardware function of a non-collinear acousto-optic filter at the frequency modulation of an ultrasonic wave. Depending on the scope of the frequency deviation, an extension of the hardware function in the range from 1.5 nm to 105 nm, an increase in the angular aperture of the acousto-optic filter from ~2.5° to ~ 20°, while maintaining a transmittance of more than 70%. It is shown that the luminous flux can be increased by 2000 times. It is shown experimentally that the modulation period corresponding to a single interaction with all frequency components of the modulated ultrasonic beam is optimal. It is shown that with the increase of the acousto-optic filter band due to the linear frequency modulation, the contribution of the side lobes of the hardware function decreases. It is concluded that it is possible to create spectrometers and spectrometers of images with adaptive hardware functions, in particular multi-window hardware functions.

Session III: Acousto-Optic Instrumentation

# Acousto-optic modulator based on crystal $NaBi(MoO_4)_2$

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The work is devoted to investigation of the properties of the $NaBi(MoO_4)_2$ crystal and manufacturing an acousto-optic (AO) modulator based on it. Despite the rather long interest in $NaBi(MoO_4)_2$ crystals as possible AO material, there is no information about their practical use in acousto-optics.

Some properties of the $NaBi(MoO_4)_2$ crystal important for design of AO devices previously were reported [1-3]. Among them are photoelastic constants and a number of acoustic and optical parameters. Physical properties of $NaBi(MoO_4)_2$ crystals make them suitable and perspective for application in acousto-optics.

We investigated the acoustic and AO properties of the $NaBi(MoO_4)_2$ crystal. The values of phase velocities, slowness, drift angles and $M_2$ were calculated, depending on the direction of propagation of the elastic wave. Based on obtained information Z cut selected for manufacturing an AO modulator. Several experiments were conducted with different types of piezoelectric transducers, with shear and with longitudinal acoustic waves. A longitudinal acoustic wave was selected for the device. The custom made modulator was tested at two wavelengths: at $\lambda = 532$ nm for visualization of the effect and at $\lambda = 1064$ nm for measuring diffraction efficiency. The diffraction efficiency measurements at $f = 120$ MHz; SWR $< 1.2$; $\lambda = 1064$ nm were carried out for two mutually perpendicular polarizations of the laser beam. The diameter of the waist - 0.4 mm at the level of intensity $1/e^2$. The diffraction efficiencies for two orthogonal polarizations of the laser beam differ by less than 10%, as shown in Table 1 and Fig. 1.

Table 1 Diffraction efficiency of the AO modulator.

| RF power, W | Diffraction efficiency at different polarizations of the laser beam, % | |
|---|---|---|
| | □ Vertical (ordinary) | △ Horizontal (extraordinary) |
| 0.5 | 25 | 28 |
| 1.0 | 44 | 50 |
| 1.5 | 65 | 62 |
| 2.0 | 71 | 78 |
| 2.5 | 80 | 87 |

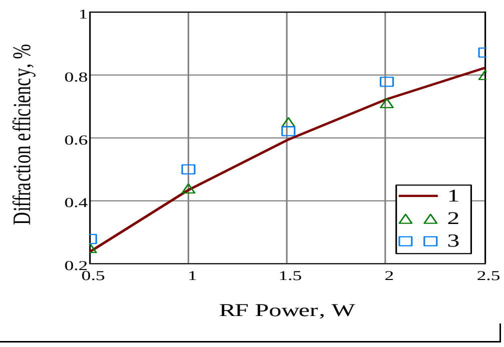


Fig. 1 Diffraction efficiency of the AO modulator: calculated curve (1) and experimental data corresponding to vertical (2) and horizontal (3) polarization.

Preliminary results of research presented in the paper illustrate that the $NaBi(MoO_4)_2$ crystal can be used as an alternative to $TeO_2$ in a specific area of system applications. In Z cut $NaBi(MoO_4)_2$ has nearly the same $M_2$ as the classic Z cut $TeO_2$ used for isotropic interaction AO modulators and low ultrasound attenuation.

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Session IV: Light and Sound in Biology and Medicine

# Toward ultrafast volumetric microscopy with acoustic liquid lenses

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In the quest for a fundamental understanding of biological processes, the development of non-invasive tools that maximize the amount of spatiotemporal information retrieved from a sample is key. Advances in this direction include novel optical architectures such as laser scanning microscopy (LSM) or light-sheet fluorescence microscopy (LSFM), capable of characterizing, with subcellular resolution, the dynamics of fast-evolving phenomena as relevant as neuronal signaling or embryogenesis. However, these systems suffer from suboptimal volumetric imaging rates. Specifically, three-dimensional (3D) microscopes require the sequential acquisition of sections from different focal planes by mechanical translation of sample or objective, a normally tedious and time-consuming task. In this talk, I will discuss our efforts to enhance 3D imaging speed in LSM and LSFM. Our strategy consists of axially scanning the focus at kHz rates using an acoustic liquid lens. By obviating the need for mechanically moving parts, the lens enables unprecedented z-focus control, offering novel opportunities for tailored extension of the depth of field [1, 2], simultaneous multiplane imaging [1, 2] or user-selectable 3D-sampling [3]. It also renders possible the implementation of light-sheet microscopes that rely solely on sound for light focusing and scanning, capable of imaging at unsurpassed rates of hundreds of volumes per second [4]. I will provide a detailed description of this acousto-optic technology and illustrate its potential in various example applications, ranging from functional brain imaging to imaging flow cytometry.

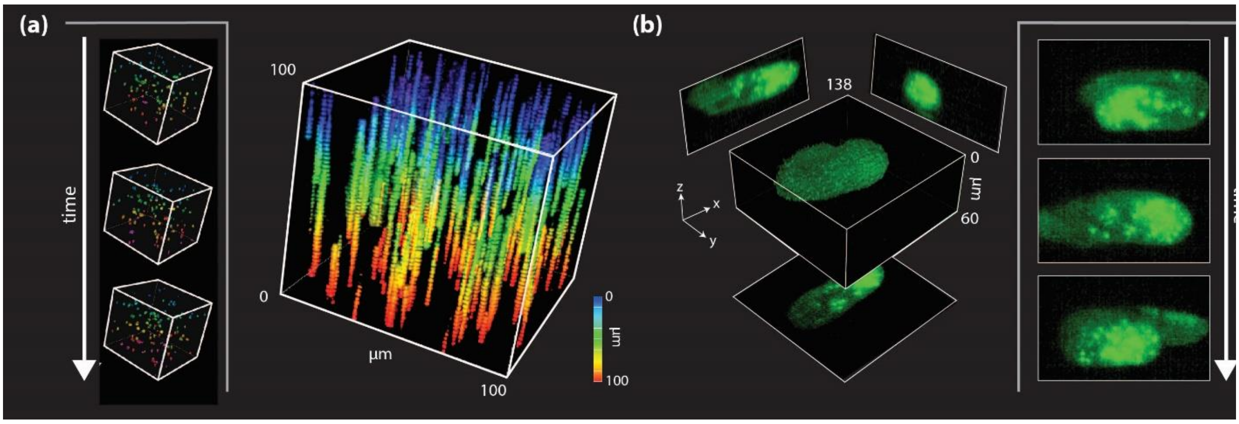


Fig. 1. Examples of high-speed 3D-LSFM using an acoustic liquid lens. (a) Imaging at 200 volumes/second of 100 nm beads flowing through a microchannel. (b) Sub-cellular resolution imaging of a living Paramecium. Adapted from [4].

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# Photosynthetic energy storage efficiency in biofilms determined by photoacoustics

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Biofilms formed on solid biotic and abiotic substrata, deployed for a certain time period in the coastal waters of the Baltic, were studied with a photoacoustic spectroscopy (PA) technique. PA signal amplitude and phase spectra were recorded using the phase-sensitive mode system with a novel closed-cell type photoacoustic spectroscopy (PAS) system [1]. Periphyton is a mixture of algae, cyanobacteria, heterotrophic microbes and detritus, stand for a photosynthetic system with a mixture of pigments, being attached to submerged surfaces in most aquatic ecosystems. Moreover, periphyton appears to be an effective indicator of water quality [2]. Biofilm colony photosynthetic apparatus properties (photosynthetic energy storage (ES), PA amplitude and phase spectra) exhibited a seasonal variability. The aim of the study was to follow the temporal evolution of marine biofilm structural stages with the photoacoustic spectroscopy (PA) technique as a novel tool of water body bioassessment monitoring. The photoacoustic parameters (ES and PA signal amplitude) turned out to be unequivocally related to the biofilm structural signatures (thickness, volume, number of cells, surface energy of biofilm, fractal dimension etc.), as learned from confocal scanning microscopy and wettability measurements [1]. The peak values in PA signal amplitude spectra maximum at ~ 680 nm were found highest for a biotic substratum (wood), lower for filtered planktonic phase, and lowest for metallic abiotic surfaces. *Chl. a* was determined by photoacoustic method, based on the proportionality of the photoacoustic signal to the amount of pigment.

ES could be an indicator of water pollution; they were lower than or equal to those measured for samples in a pollution-free environment. Nutrient limitation and antrophogenic eutrophication are among the most important factors determining the overall status of water bodies which can be followed by ES efficiency of biofilm cultures. ES values were higher for a season of high primary production, and increased by a factor of 1.5-2, for biofilm settled on biotic substrata. The effect of nutrient limitation on relative photosynthetic ES efficiency was exhibited as a significant drop in ES (by 50 %) in P-limited, and (by 60 %) in N -limited biofilm colonies. ES turned out to be inversely correlated to biogenic elements concentrations (N (R= -0.76); P (R= -0.81); O (R= -0.67)), and positively correlated to primary production (R= 0.86) and *Chl. a* concentration (R= 0.82) in the Baltic (seawater parameters data available at http://satbaltyk.iopan.gda.pl). To sum up, photoacoustics can be used to reliably estimate the concentration of photosynthetic pigments in biofilm cultures, the efficiency of ES by periphyton photosynthesis can be determined directly by photoacoustics, the effects of any environmental stressor, such as temperature, nutrient limitation, high/dim light and pollutants on the photosynthetic capacity of biofilm colony can be evaluated.

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# Scanning Laser Ophthalmoscope Integrated with Tunable Lens: Imaging and Ophthalmic Applications.

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The eye is considered as a complex optical system that allows to generate the image on the retina, thus initiating the visual process. Examination of the eye is a common clinical procedure in the diagnosis and therapeutic management of the ocular disorders like age-related macular degeneration or glaucoma [1].

Different imaging techniques have been developed and improved during the last 30 years to enable diagnostics and management of ocular pathologies. One example of those technologies is Scanning Laser Ophthalmoscopy (SLO), an imaging technique commonly used to visualize the fundus of the eye. In SLO, a light beam is scanned across the retina, and the reflected / back-scattered light is coupled back and detected by a photodetector [2]. Confocal SLO (cSLO) is a confocal microscope that enables generation of retinal image with high contrast and high resolution in real time.

Focus tunable lenses are active optical components which allow to modify the focal plane of an optical system time by applying the signal, e.g. voltage. Currently, implementation of tunable optics in optical systems has shown a significant impact on the imaging performance. In particular, using acousto-optic effect to shape the wavefront enable ultra-fast focus tuning [3].

In this work, we report a confocal prototype SLO system integrated with a high-speed acousto-optic tunable lens to image different eye compartments. The confocal SLO prototype was designed by an optical engineering software in order to achieve the best configuration for a field of view of 15º and an afocal telescope M=1.75x. A superluminescent diode emitting the light of a wavelength of 840 nm was used to illuminate the retina. A customized acousto-optic lens (AOL) with a focus tuning frequency of 275 kHz was integrated into the system in order to make a rapid depth scanning. We performed full characterization of the developed system, i.e. the point spread function (PSF), field of view (FOV) and sensitivity were determined depending on the time-resolved state of the AOL. Finally, in-vivo retinal images from myopic and hyperopic patients were acquired.

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# Improvement of endoscopic imaging systems by means of acousto-optic filtration of light

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Endoscopic imaging systems are widely used for non-invasive diagnostics of inner tissues in medical applications [1] as well as for non-destructive testing of various hard-to-reach industrial objects [2]. Contrast visualization of the inspected surface using wide-band illumination and, therefore, localization of the specific elements and their quantitative characterization is not effective or is even impossible [3]. In last cases, fluorescence, Raman and other narrow-band spectral imaging techniques may be helpful to increase the effectiveness of endoscopic inspection. Acousto-optic filtration of light is a very promising technique for implementing such spectral imaging capabilities. In this paper, we discuss the specificity and benefits of acousto-optical tunable filters (AOTF) conjugation with rigid boroscopes, flexible fiberscopes and video endoscopes. We analyze and compare imaging and spectroscopy capabilities of two alternative technical solutions: AOTF-based tunable light sources and AOTF-based add-on modules. The results of this analysis are confirmed by multiple experiments. Additionally, we show that spectral filtration with use of stereoscopic video endoscopes can improve the accuracy of geometrical measurements.

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Session IV: Light and Sound in Biology and Medicine

# Non-contact Optical Probing of Ocular Biomechanics

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The human eye represents a complex dynamic system whose properties can be considered from both optical and mechanical points of view. Whereas the optics of the eye has been explored for centuries, the biomechanical aspects of the eye have recently caught attention since biomechanics plays role in many physiological ocular effects and corresponding diseases, e.g. accommodation (presbyopia), development of myopia, glaucoma, keratoconus, vitreo-retinal diseases, as well as in the outcome of refractive surgery. Current measurement paradigms for the probing of ocular biomechanics include application of the mechanic force in a non-contact way, and simultaneous non-invasive visualization of the tissue reaction to such a stimulus.

In this paper, we will review current optical methods for extraction of the biomechanical properties of ocular tissues. Different macro- and microscopic scenarios of mechanic stimulation including application of the air puffs, acoustic waves or air-borne ultrasound will be demonstrated. In particular, we will focus on air-puff stimulation of the eye and the deformation analysis of the main ocular structures under different conditions using swept source optical coherence tomography (SS-OCT).

We developed two prototype air-puff SS-OCT instruments operating at the central wavelengths of 1050 nm and 1310 nm. The interface of each SS-OCT system was integrated with an air-puff chamber in order to image the eye dynamics during the air-puff stimulus. The prototype device was tested in 61 porcine eyes ex vivo and 20 eyes of 20 Caucasian healthy subjects in vivo. The intraocular pressure level was controlled by a special pomp (in ex vivo study) or by administration of IOP-reducing drops (in vivo study). Information of the dynamics of all ocular elements during air-puff allowed to visualize the eye retraction and the crystalline lens wobbling. Air-puff induced eye reaction was quantified by defining several parameters, which were correlated with the intraocular pressure (IOP). The rheological model was developed to describe the reaction of the eye to mechanical stimulus. This approach may potentially provide comprehensive information on the biomechanics of ocular components.

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**Prof. Lyudmila Kulakova**

**17.09.1942 – 26.10.2018**

# Tribute to the Memory of Professor Lyudmila Kulakova (17.09.1942 – 26.10.2018)

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It was with deep sorrow that we learned of the sad event: our colleague and good old friend Professor Lyudmila A. Kulakova passed away on October 26, 2018. She died of cancer in Saint-Petersburg after half a year struggle with the awful disease.

Lyudmila Kulakova belonged to the International community of scientists engaged in Acousto-electronics, Acousto-optics, Solid State Physics and Physics of Semiconductors. She was a unique scientist capable of combining deep theoretical background and perfect skills in experimental research.

If we overview milestones of her life, we have to note that her biography is not so typical as compared to biographies of other scientists from Russia. She was born during the Second World War in the Ural town Nizhny Tagil. This peripheral town is situated 1400 km to the East of Moscow in between Europe and Asia. Very soon in her childhood, Lyudmila lost her father who in 1942 was arrested by the Stalin regime. Later it was the reason for the family to leave Ural and move to the town of Yeisk on the southern shore of the Azov Sea. Again it was a small town far away from Moscow or Saint-Petersburg.

In Yeisk, Lyudmila Kulakova entered and in 1960 graduated from the Technical College of Agricultural Machinery. Being educated in Mechanical Technology, she moved to Leningrad where she entered and later in 1967 graduated from the Faculty of Electronics at one of the best Russian technical institutes, i.e., the Polytechnic Institute. Her subject of research belonged to the modern branch of Physics - Quantum Electronics. In 1967 she joined the Russian Academy of Sciences. In Ioffe Physical-Technical Institute, she got a position of a Junior Research Fellow. Later on she got her Ph.D. degree and in 1978 she became a Senior Research Fellow. Finally in 1998 she got her Dr. Sci. degree and the position of a Professor at the Division of Microelectronics in the Saint-Petersburg Polytechnic University.

Lyudmila Kulakova was an outstanding scientist and published more than 120 scientific papers. Her name was included in the Encyclopedia of Biographies “Golden Fund of Great Masters in Saint-Petersburg”. For many years, Lyudmila Kulakova has been a Member of the Acoustic Board at the Russian Academy of Sciences. She was awarded many Certificates of Honor and Excellence issued by the Physical-Technical Institute and the Russian Academy of Sciences. As a winner of an International competition, she got a Certificate of Honor issued by the Russian and Polish Academies of Sciences.

Her participation in dozens of Scientific Conferences all over the world was really sounding. Lyudmila Kulakova made perfect scientific contributions at International Conferences in the USA, France. Belgium, Germany, Italy, Poland, Check Republic, Russia, China, Singapore, Chile and other countries. During the recent decades, she regularly used to participate in the traditional Spring Schools on Acousto-optics organized in Poland, Lithuania and Russia.

The International community of scientists remembers Lyudmila Kulakova as an open minded, friendly, kind and enthusiastic person. It was a pleasant thing for all of us to work with her and to know about her real achievements and well-earned success in Physical Science.

# Acousto-Optic Probing of Acoustic Beams Generated by Multiple Reflections in Paratellurite Crystal

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We studied propagation and multiple reflections of bulk acoustic waves in a tellurium dioxide crystal. The crystal was chosen for the analysis due to the extremely strong elastic anisotropy and the high acousto-optic figure of merit of the crystalline material [1]. The acoustic propagation of the waves was carried out by means of the laser probing method and also by the optic Schlieren method providing direct imaging of acoustic beams [2]. The multiple reflections of the acoustic waves from two free facets separating the crystal and the vacuum were examined in details. The crystal was specially cut in form of a tetragonal prism having two parallel and two mutually inclined facets. An X-cut piezoelectric transducer generated in the prism, a quasi-shear acoustic wave having the walk-off angle 74° between the acoustic phase and group velocity. The initial wave was incident on one of the inclined facets and then reflected from the facet. As much as two reflected waves were registered in the crystal after the incidence and the first acoustic reflection. The two reflected waves were further on incident on the other two facets of the prism and then reflected for the second time. In total, as much as five reflected waves were observed in the crystal. It should be noted that the initial and the five reflected waves propagated in the plane (001) of the crystal.

We calculated and then measured basic parameters of the reflected waves. Special attention was devoted to precise registration of directions of the wave propagation. We also evaluated the phase velocities and the acoustic walk-off angles of the waves. Finally, we measured the reflection coefficients and the attenuation coefficients of the waves. All these parameters were determined by the acousto-optic methods at the wavelength of light 532 nm. For the purpose, the prism was illuminated by an expanded collimated laser beam about 2.5 cm in diameter. The illumination provided visualization of the acoustic columns by the Schlieren method. Laser probing of the acoustic beams was carried out at the mentioned optic wavelength but using laser beams about 0.3 cm in diameter [3, 4].

Based on the obtained results, we proposed a new modification of a quasi-collinear tunable acousto-optic filter. As compared to traditional quasi-collinear filters, the proposed instrument was an optic multichannel device capable of a simultaneous operation with a few optic beams.

*The work was supported by the grant of the Russian Foundation for Basic Research, project 17-07-00369.*

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# Enhancement of Acousto-Optic Interaction by Using Two-Scale Phoxonic Crystals

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In this study, we propose a two-scale phoxonic crystal consisting of Si and $SiO_2$ for the purpose of enhancing the acousto-optic interaction in the presence of material loss. In previous studies, researchers investigated the interaction between the light and sound which have similar wavelength scale, so infrared light was controlled by high frequency acoustic wave in GHz range. [1-4] Because the attenuation coefficient of acoustic wave increases as the frequency increases [4], the acousto-optic coupling rate is largely reduced in GHz range. In this study, the mechanical displacement field is increased by using low frequency acoustic wave, but wavelength scale of the acoustic wave is different from infrared wave. In order to enhance the interaction between two waves, we insert a structure of different scale into the phoxonic crystal. The two-scale phoxonic crystal shows the enhanced acousto-optic couple rate about 100% increase after optimizing the unit cell size and its geometrical parameters.

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# Anisotropic Acousto-Optic Interaction in KRS-5 Cubic Crystal Possessing Induced Optical Anisotropy

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We investigated acoustic, optic and acousto-optic properties of KRS-5 cubic crystal based on thallium, chlorine and iodine [1, 2]. This crystal belongs to the cubic class of crystalline materials *m3m* [2] and it is transparent in the wide range of electromagnetic spectrum. The range of transparency starts in the visible light at the wavelength $\lambda = 0.61$ μm and it is extended to the long infrared region at the wavelength $\lambda = 45$ μm. Unfortunately, the material is optically isotropic, therefore it is not possible to develop on base of it, various acousto-optic devices applying the so-called «anisotropic interaction» of light by sound.

In this paper, we present results of theoretical and experimental investigation of the crystal. In particular, we examined a possibility to induce birefringence in the cubic material using an external static pressure. In our analysis, we determined acoustic properties of this material solving the Christoffel equation [3]. In the carried out investigation, we concentrated on three directions of acoustic wave propagation [100], [110] and [111]. We calculated the values of acoustic phase velocities for the three acoustic modes propagating along the chosen directions. In addition, we determined the acouso-optic figure of merit [1]. In the experiment, we chose the slow shear acoustic wave propagating along the direction [100] and having the phase velocity value $V_{SS} = 886$ m/s. The measured magnitude of the figure of merit was equal to $M = 1250 \cdot 10^{-18}$ $s^3g^{-1}$. This magnitude was registered at the wavelength of light $\lambda = 0.63$ μm close to the short wavelength edge of transparency in the material. At the short wavelengths, the material demonstrates a very strong dispersion of its optical parameters For example, the index of refraction at the wavelength $\lambda = 0.63$ μm is equal to $n = 2.57$ while it is $n = 2.42$ at $\lambda = 1.15$ μm. These results of our calculation agreed with data found in literature [2].

We present results of calculations in the case of the induced optical birefringence. The experiment proved that the static pressure about 100 atmospheres resulted in the birefringence about $\Delta n = 2 \cdot 10^{-5}$. Using data obtained from the theoretical investigation, we developed an acousto-optic cell based on the KRS-5 crystal cut along the crystallographic axes. In the plane (001) of the cell, we observed the Schaefer-Bergmann diagram. Finally, we performed the experiment in the cell subject to the regulated static pressure. Influence of the pressure on the Bragg matching condition was registered. The required anisotropic diffraction in the deflector regime of operation at the frequency of ultrasound $f = 60$ MHz was also observed in the cell.

*The work was supported by the grant of the Russian Foundation for Basic Research, project 17-07-00369.*

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# Acousto-Optic Spectrometer ISEM for ExoMars-2020 space mission: ground measurements and calibrations

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Since 1980s, acousto-optic instruments have become popular type of scientific payload in space missions because of their high optical performance (especially in visible and near-infrared light) as well as robust design, small dimensions and mass, the absence of moving parts and low power consumption [1]. Among current projects, a number of spectrometers on the base of acousto-optic tunable filters (AOTFs) are being developed for Russian Lunar and Martian missions [2, 3]. In particular, for Russian-European mission ExoMars-2020, an AOTF-based spectrometer ISEM (Infrared Spectrometer for ExoMars) is developed for context assessment of the surface mineralogy in the vicinity of a planetary probe or a rover analyzing the reflected solar radiation in the near infrared range [3]. The instrument is to be deployed on the mast of ExoMars Rover planned for launch in 2020.

The instrument covers the spectral range of 1.15–3.3 μm with the spectral resolution of ~25 $cm^{-1}$ and is intended to study mineralogical and petrographic composition of the uppermost layer of the regolith and to estimate H2O/OH content and behavior in this layer. The instrument is able to detect the most important water-bearing minerals (i.e. phyllosilicates, sulfates, opal) and other minerals formed in the aqueous environments. Besides, it will help in real-time assessment of surface composition in selected areas, in support of identifying and selection of the most promising drilling sites. A study of variations of the atmospheric dust properties and of the atmospheric gaseous composition is also of interest.

The instrument consists of two parts: Optical Box and Electronic Box. The optical scheme includes entry optics, the AOTF, focusing optics, and a Peltier-cooled InAs detector. A wide-angle acousto-optic tunable filter manufactured on the base of $TeO_2$ crystal is used. Incident optical radiation has ordinary polarization and the diffracted optical beam has the extraordinary polarization. The angle between the passing and diffracted optical beams is 6° at the output of the AO crystal. A pair of polarizers with crossed polarizing planes is used to filter out the non-desired zero diffraction order.

In 2018, flight model of the instrument was manufactured, tested and delivered to ESA. At present, instrument integration and test campaign at rover level has started. Flight spare model of the instrument is being manufactured. We present here also spectra of different materials measured by ISEM in laboratory conditions.

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# Calibration features of a stereoscopic AOTF-based hyperspectral imager

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Hyperspectral imaging is an effective technique for non-contact and non-destructive inspection of various objects. This technique provides a spatial-spectral data $I(x, \mathrm{y}, \lambda)$ which can be used for classification and identification of the elements with determined physical or chemical properties. In many cases, the volume shape of the inspected object is also an important characteristic, which has to be determined or even measured together with spectral properties. In these cases, spectral three-dimensional images are to be collected. For such applications, a dual-channel AOTF-based stereoscopic imager was developed [1, 2], which supplies information related to the shape $z(x, \mathrm{y})$ and the luminance $I(x, \mathrm{y}, \lambda)$ of the object surface. To provide accurate and reliable data, the instrument must be properly calibrated. However, the standard geometrical calibration procedure for machine vision systems is not suitable for AOTF-based systems because of the influence of specific image distortions, chromatic aberrations, temperature variations and other factors, so new techniques are necessary. In this paper, we describe the developed dual-channel stereoscopic acousto-optical imager for the spectral range 450-650 nm and describe the algorithm for its geometrical calibration in the operation range.

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# Applications of Collinear Acousto-optic Diffraction for Optical Frequency Combs Generation

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Optical frequency combs (OFC's) have become nowadays a very important measurement toot in optics that has found the great variety of practical applications in high-precision measurements. OFC's may be produced by a variety of methods depending on the application. Acousto-optic (AO) devices, mainly AO frequency shifters (AOFS) have found applications in OFC's generation systems. They are either used as the element of complex system devoted to the OFC phase stabilization [1] or they play the role of the key element responsible for obtaining OFC [2]. The latter case is much less common.

When applying AO devices to obtain optical comb it is necessary to introduce an optical feedback circuit, feeding the part of the light beam intensity from the output to the optical input of the system. Commonly if the comb is generated by multiple successive amplitude modulation of the light beam intensity then the AO modulator is used as the main element. If the comb is obtained by single-side band (SSB) modulation the AOFS is usually used as main element.

We propose here the new AO system devoted for OFC generation. The main element of this system is the collinear AO filter. The application of collinear AO diffraction geometry gives several advantages. All spectral components of light propagate strictly along the same direction in this case. Also the peculiarities of collinear AO diffraction give the possibility to generate optical combs by several methods [3]. The selection of the method is realized simply by choosing mutual orientation of the pair of polarizers between which the AO cell is located and half-wave plate displaced in the optical feedback circuit after the polarizer.

We have examined two possible AO systems. The first one driven by external RF generator contains only optical feedback. The second one contains in addition the electronic feedback and may be treated as the AO generator [4].

The examination of closed-loop optical system has shown that the shape of OFC depends on the AO mismatch being set by the RF generator frequency. The most effective way to obtain the OFC in this system is the SSB modulation realized when the polarization planes of polarizers are crossed. The spectral interval between the OFC components is defined by the RF generator frequency. The OFC band in this system is determined mainly by the spectral selectivity of collinear AO filter.

The optoelectronic system with both optical and electronic feedback doesn't require the external RF generator for functioning. In this system, due to the electronic feedback, the spectral selectivity of the AO cell doesn't influence on the OFC band. Due to the dependence of AO interaction phase matching frequency on the optical wavelength the spectral interval between OFC components in this system is chirped. It is possible to obtain OFC in wide spectral band in this case that will be determined by the spectral characteristics of photodetector used in the electronic feedback and AO cell characteristics.

*This work was supported by Russian Science Foundation (RSF) under Project 18-72-00036.*

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# Semiautomatic Acousto-optical Tunable Filter Calibration from Spectrometry in the Visible Range with Deep Learning

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Acousto-optical filters are well-known devices that offer a phenomenon of dispersion that occurs in a translucent material in which light as an electromagnetic field interacts with a sound-induced spatially distributed over its refractive index. In fact, the diffracted light can then be analyzed for different purposes. Even if the general theory of the physics of Acousto-Optics has been studied during the last decades, some experimental setups are still required in order to get a useful device. Here, for example, several calibration procedures should be regularly used, in order to get the transfer function of the filter. In-depth, the reflectance response at a given wavelength must be measured and adjusted from a color pattern. Typically, the reflectance value is manually set up.

Considering the above, we propose in this work a semiautomatic strategy to calibrate as a single black box all components of the system that includes: the source of light, the power of the signal generator with its frequency-amplitude deviation from the full radio frequency set point; the radio-frequency amplifier; the transmission lines; the impedance of the piezoelectric; the own transfer function of the filter, among others.

As a framework, we explore the capability of neural networks with deep learning. The input of the system is all reflectance values measured with a spectrophotometer at wavelengths from 400 to 700 nm with a step of 10 nm. We used a Ceramic tile set - CERAM Research as a pattern. After that, an acousto-optical system was used to gather reflectance values from color tiles from 400 to 700 nm with a step of 1nm. Considering the above, both reflectance values were adjusted by using a neural network with deep learning.

Experimental results show that it is possible to calibrate an acousto-optic system by using ceramic tile color patterns and measuring some reference reflectance values gathered with a spectrophotometer in the visible range. Furthermore, a neural network can be trained to learn the compensation values, deriving trustable spectral information with a better wavelength resolution.

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Session VI: Acousto-Optics for Spectroscopy, Metrology and Imaging

# Selected applications of acousto-optic modulators in high-precision spectroscopy

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I will present several measurement techniques in high-precision spectroscopy and experimental setups located in Institute of Physics, NCU, which were either enabled or greatly simplified by the usage of acousto-optic modulators (AOMs). In the case of cavity mode-width (CMWS) [1] and mode-dispersion spectroscopies (CMDS) [2], an AOM is used to scan the laser frequency over few-kHz-wide cavity modes while the undiffracted beam is tightly locked to an adjacent mode, enabling precise control of the relative detuning between the light source and the probed cavity modes. In our broadband implementation of these techniques with an optical frequency comb (OFC) [3], an AOM is utilized to simultaneously couple a continuous-wave (cw) laser and an OFC to an optical cavity while retaining the ability to precisely control the frequency difference between the OFC and the cw laser.

In our ongoing effort to enable broadband cavity-enhanced spectroscopy in the mid-infrared molecular fingerprint region, a mid-IR optical frequency comb is generated through difference-frequency generation process. In this process the offset frequency of the OFC is removed, which prevents the OFC from being resonant with a cavity in a broad spectral range. An AOM provides a simple way to recover this degree of freedom through frequency shifting and obviates the need for more technically difficult nonlinear frequency conversion schemes.

In the recently published most accurate to date measurements of the isotope shift of $^1S_0$-$^3P_1$ transition in mercury [4] the usage of AOMs increased the tuning of the UV fourth-harmonic laser and enabled probing the same transition in four bosonic isotopes. The digital locking technique, which was utilized in the Hg measurements and is routinely utilized in the operation of the two $^{88}$Sr optical lattice clocks in Toruń [5], stabilizes a laser to a resonance with an AOM by rapidly switching between opposite sides of the resonance and frequency tuning the laser to minimize difference signal between the sides.

Finally, fiber transfer of optical frequency references requires active stabilization of the phase. For this goal, fast phase detection combined with AOMs as phase actuators [6] enables making atomic clock comparisons [7, 8] at precision levels of $10^{-19}$.

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Session VII: Acousto-Optics in Waveguides / Photonic Structures

# Characterization of sensitivity of in-fiber acousto-optic interaction

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In this abstract, we present the broadband characterization of the sensitivity of in-fiber acousto-optic interaction (AOI), for the fiber SM2000 and the spectral range 1.0-1.6 μm. We measured the tuning curves of AOI for the coupling $LP_{01}$-$LP_{1,1\text{-}4}$ modes, and calculated the correspondent sensitivity of the technique. Its maximum was achieved at the surroundings of the turning point of the phase-matching condition, $\lambda_I$, for the coupling $LP_{01}$-$LP_{11}$.

When a flexural acoustic wave of frequency *f* propagates along an optical fiber, it induces a resonant, tunable coupling between the fundamental mode $LP_{01}$, and modes $LP_{1m}$. The energy carried by the fundamental mode is transferred to higher order modes at some given wavelengths, $\lambda_R$, which are determined by the AOI phase-matching condition, $\lambda_R = (n_{01}-n_{1m})\cdot\Lambda$ ($\Lambda$: acoustic wavelength, $n_{lm}$: refractive indices of the modes). As $\Lambda$ (or *f*) is varied, the resonances shift in wavelength. Fig 1 (a) shows the tuning curve of the couplings $LP_{01}$-$LP_{1,1\text{-}4}$ for the fiber SM2000 (Thorlabs). The experimental setup used to perform the experiments is that one reported in [1]. By adjusting our simulations (dashed lines) to the experimental results (dots), we determined the cut-off wavelength of the fiber, 1.66±0.03 μm, its numerical aperture, 0.1196±0.0005, and its core radius, 5.12±0.10 μm. The sensitivity of the technique allows determining the different parameters with high accuracy [1].

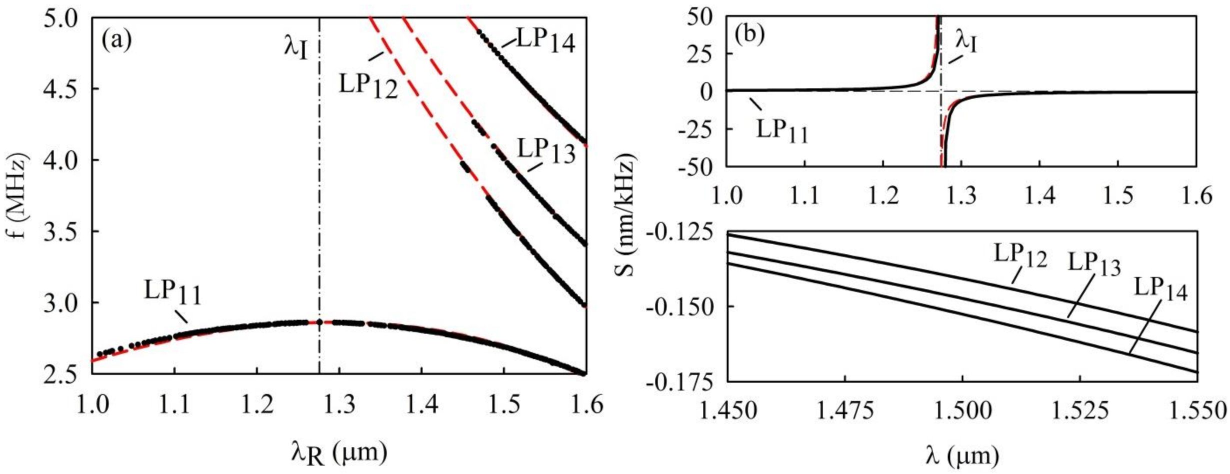


Fig. 1 (a) Tuning curves and (b) sensitivity of AOI resonances $LP_{01}$-$LP_{1,1\text{-}4}$. Interaction length: 80 cm.

The sensitivity of the AOI, $S = d\lambda_R/df$, is shown in Fig. 2(b) (dashed: simulations, solid: experiments). It increases sharply around $\lambda_I$ for the coupling $LP_{01}$-$LP_{11}$, 1.276 μm. achieving a maximum value of ~30 nm/kHz. For couplings $LP_{01}$-$LP_{1,2\text{-}4}$, is lower than 0.2 nm/KHz. Thus, when using AOI for sensing, it results of great interest to work in the surroundings of $\lambda_I$.

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# All-fiber dual-wavelength narrowband acousto-optic tunable bandpass filter based on vector mode coupling

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An all-fiber dual-wavelength narrowband acousto-optic tunable bandpass filter (AOTBF) was proposed and fabricated via the vector mode coupling between the $LP_{01}$ and $LP_{11}$ groups in dispersion compensation fiber (DCF) by the acoustic flexural wave. In the experiment, the resonant dual wavelengths and coupling efficiencies could be tuned simultaneously with a wavelength range from 1526 nm to 1565 nm and the lowest 3-dB bandwidth of 0.92 nm.

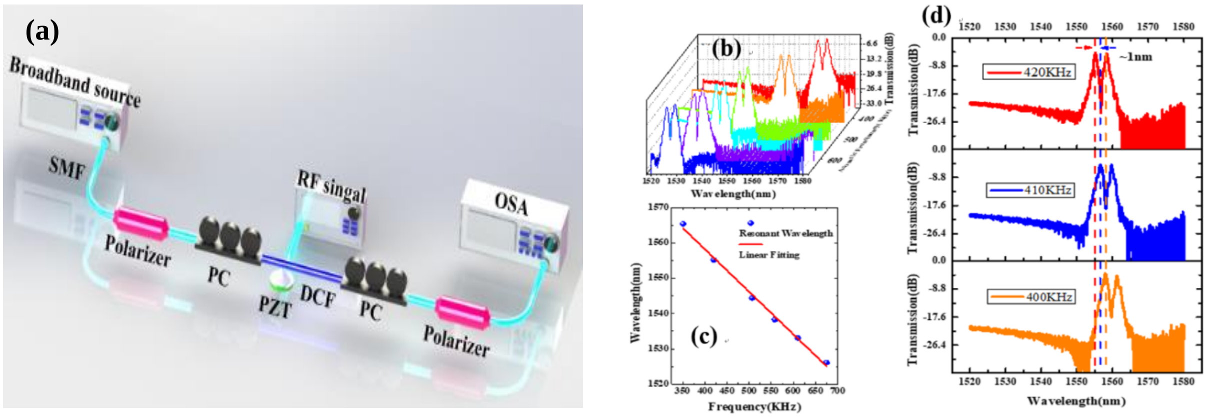


Fig. 1 (a) Experimental setup for the all-fiber dual-wavelength narrowband acousto-optic tunable bandpass filter. PC: polarization controller; PZT: piezoelectric transducer; OSA: optical spectrum analyzer. DCF: dispersion compensation fiber; SMF: single-mode fiber. (b) Transmission spectra with the resonant wavelength tuned. (c) Tuning relationship between the resonant wavelength and the RF driving frequency. (d) The fine tuning of resonant wavelength.

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Session VII: Acousto-Optics in Waveguides / Photonic Structures

# Application of layered structures for mid-infrared acousto-optics

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Majority of the acousto-optic devices are intended for use in visible and near-infrared ranges. Development of acousto-optics in mid and far-infrared range is obstructed by the quadratic law of efficiency drop with the growth of the light wavelength and the necessity to use materials of infrared optics [1, 2]. We proposed several methods of light modulation at 10.6 μm using longitude acoustic wave in Otto configuration of prism coupling. Several approaches to constructing multilayered photonic structures were analyzed. Schemes of the proposed devices are shown on Fig. 1.

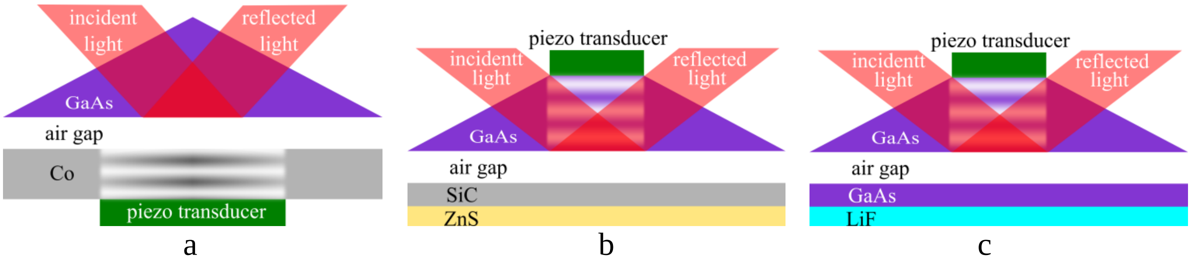


Fig. 1. Schematics of the proposed acousto-optic modulator constructions. (a)-metal based structure, (b) – silicon carbide based structure, (c) – all-dielectric waveguide structure.

We propose a structure that uses GaAs prism for surface plasmon coupling, air gap with thickness about several wavelengths and semi-infinite cobalt medium, as shown on Fig. 1a. The difference of dielectric permittivity for majority of metals in mid-infrared range is less noticeable than in visible light, however application of cobalt results in most noticeable change in Fabry-Perot resonance depth. The air gap thickness is comparable to the wavelength of light with modulation depth of several percent.

Fig. 1b shows the second design based on using silicon carbide phonon structure. Silicon carbide was chosen due to its absorption resonance at 10.6 μm wavelength. The structure consists of GaAs prism, several microns air gap, 570 nm silicon carbide film and ZnS substrate. Implementation of ZnS provides the possibility to achieve zero reflection minimum, what is impossible for semi-infinity SiC crystal. Calculations predict maximum modulation depth at 91%, while the thickness of the structure is just several microns. Phonon resonance strongly depends on coupling efficiency defined by the air gap thickness.

The third design is based on all-dielectric waveguide structures as sown on Fig. 1c. All-dielectric solutions make use of both s-polarized and p-polarized light. We propose the following waveguide solution: GaAs prism, air gap, GaAs guiding layer and LiF substrate. All dielectric waveguides provide the possibility to achieve 100% modulation depth with structure several microns thick at the cost of extremely narrow resonances.

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# Setup for noise cancellation in optical fiber

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One of the main physical quantities that determine the accuracy of measurements is the frequency. A laser light for further spectroscopy or as an optical laser reference is transmitted between rooms by optical fibers. The disadvantage of such light transmission is the fact that a phase noise modulation appears what prevents very precise applications that use laser light frequency. Such frequency differences are in order of hundreds or thousands of hertz. To be able to use ultrastable laser radiation in other rooms, use an active system to compensate for these noises.

This work focuses on discussing theoretical foundations regarding the issue of propagation of electromagnetic waves and polarization of light. Used optical, electronic and optoelectronic elements was described. The experimental part of the work consisted primarily of research on the acousto-optic modulator. Single and double laser beam transitions through the modulator were examined, and the future system for noise compensation in optical fiber was discussed.

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# Toward Laser Induced Photothermal Infrared Radiometry Spectroscopy

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In this presentation, I will show the new approach for measurement of the infrared absorption coefficient in the solid state materials (bulk and thin films). Compared to the optical methods, which measured reflected or transmitted light, the photothermal signal depends only absorption of the light in the sample. When the IR range is observed as the case of the PTR (photothermal radiometry) method, the measured signal depends on (usually) thermal, infrared and optical properties of the sample. In this presentation, I will show the application of the PTR method for investigation of the infrared absorption coefficient of thick heavily Zn doped GaAs [1] and later two undoped and C doped thin AlGaAs layer epitaxial grown on thick heavily Zn doped GaAs substrate [2, 3]. In the same time, it is also possible to measure the recombination lifetime of infrared photoluminescence for certain type of the materials like in ZnSe:Cr and ZnTe:Cr crystals [4, 5]. The obtained results demonstrate that a new laser induced photothermal infrared radiometry spectroscopy (after increasing the spectral resolution) can become a valuable research tool.

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Session VIII: Fundamentals of Acousto-Optic Interaction II

# Anisotropic Light Diffraction in Spatially Periodical Acoustic Field

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Acousto-optic (AO) interaction is one of basic effects used for optical radiation controlling. There exists a large amount of AO devices which find wide applications in laser physics, spectroscopy, optical information processing, ecology, medicine and other areas of science and technology [1, 2]. Characteristics of the devices depend essentially on the structure of the acoustic field excited in the AO cell. Conventionally, the acoustic beam in the cell is created by means of a flat homogeneous piezoelectric plate attached to an AO crystal. However, contemporary technologies allow making a wide diversity of transducer structures, improving, by doing so, AO instrument characteristics.

In this work, we present results of theoretical analysis of AO interaction peculiarities in a spatially periodical acoustic field created by a phased array transducer with antiphase excitation of adjacent sections. Such a field can be realized by different means: sectioning the flat transducer, using interdigital electrodes deposited on a piezoelectric crystal, or applying a ferroelectric crystal (like lithium niobate) with periodical domain structure. A detailed analysis has shown that this type of AO interaction possesses a number of interesting regularities which can be useful at designing AO devices. Contrary to the homogeneous transducer, the transfer function of the AO cell with the phased array transducer contains two main maxima situated on the opposite sides in regard to the Bragg angle $\varphi_B$. At this, light diffraction is absent when the optical beam falls on the cell at the Bragg angle. Nevertheless the diffraction appears when the incidence angle is chosen equal to $\varphi_{opt} = \varphi_B \pm V/2fd$, where $f$ is the frequency of ultrasound, $V$ is its velocity and $d$ is the period of the transducer structure. Our calculations have shown that the diffraction efficiency can reach 100% at these optimal angles $\varphi_{opt}$ in spite of AO phase mismatch. However, this requires somewhat larger acoustic power [3, 4].

Numerical calculations are performed for anisotropic Bragg diffraction in a paratellurite ($TeO_2$) crystal in the case when a shear acoustic mode propagates at the angle $3^0$ to the crystal plane (001). AO interaction domains are found for different periods of the transducer structure. It is established their essential difference from the case of the homogeneous (non-sectioned) transducer. A number of unusual features of AO light scattering is revealed, which can be useful at the development of AO devices of a new type. In particular, the possibility of implementing a non-polarized light modulator with significantly better characteristics than the currently known devices is shown [5].

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# Analysis of Wide-Angle Acousto-Optic Interaction Geometry in Single Crystal Mercury Bromide

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It is known that crystalline compounds on base of mercury and tellurium find wide applications in acousto-optic devices providing control of parameters of radiation in the visible light as well as in the infrared region of electromagnetic spectrum [1, 2]. The single crystals such as tellurium (Te), paratellurite ($TeO_2$), calomel ($Hg_2Cl_2$), mercury bromide ($Hg_2Br_2$), etc., are known for the extremely high magnitudes of their acousto-optic figure of merit. The high magnitudes of the figure of merit sufficiently decrease requirements on the level of driving electric power in the instruments developed on base of mercury and tellurium [1-3]. Therefore, analysis of physical properties of the crystals is an urgent task. The goal of the present research is related to evaluation of acousto-optic characteristics of the mercury bromide crystal in the case of a wide-angle acousto-optic interaction geometry.

We present results of calculation of acoustic phase velocities in the planes (010) and (1-10) of the material. Our analysis proved that the phase velocity of the slow shear acoustic wave in the crystal strongly depends on direction of the acoustic propagation. The velocity in the plane (1-10) may reach the extremely low value $V$ = 282 m/s. In the planes (010) and (1-10) of mercury bromide, we calculated Bragg angle dependences on the acoustic frequency $\theta(f)$ for different directions of the acoustic propagation. The analysis was carried out at the optical wavelength $\lambda$ = 633 nm in the visible light as well as at the wavelength $\lambda$ =10.6 μm in the infrared range. As a result of the carried out calculations, we determined optimal angles of light incidence and also magnitudes of the acoustic frequencies corresponding to the wide-angle regimes of light and sound interaction.

Basic parameters of acousto-optic imaging filters were determined on base of the carried out research. It is expected that the instruments to be developed on base of the found interaction geometry in mercury bromide crystal will provide a possibility to process images in the middle infrared and long infrared regions of electromagnetic spectrum. Requirements on levels of driving power in the filter were predicted. As proved, the driving power depended on wavelengths of optical radiation, linear dimensions of piezoelectric transducers generating ultrasound in the crystals and also on directions of acoustic and optic propagation in the efficient birefringent material.

*The research was supported by the grant of the Russian Foundation for Basic Research, project 17-07-00369.*

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Session VIII: Fundamentals of Acousto-Optic Interaction II

# A Novel Configuration for Effective Acousto-Optic Diffraction by IDT-radiated Bulk Waves in Lithium Tantalate

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In recent years, there was a growing interest in using bulk acoustic waves (BAWs) radiated by an interdigital transducer (IDT), which is usually designed for the excitation and reception of surface acoustic waves (SAWs) [1]. Such an approach offers certain advantages related to both the surface and bulk wave technologies. Due to excellent optical and acoustic properties, lithium tantalate ($LiTaO_3$) is very attractive material for acousto-optic applications [2]. In this paper, we report on the effective acousto-optic diffraction, which is obtained using IDT- radiated BAWs in single-crystal YX- $LiTaO_3$ plates. To our best knowledge, such a study has not been conducted before.

The experimental configuration is shown in Fig. 1. The IDT is fabricated on the Y-face of the plate with electrodes normal to the crystal X-axis. The BAW is radiated into the crystal volume at the angle of about 30$^o$ with respect to the X-axis. The light beam from He-Ne laser with the wavelength of 633 nm penetrates the acoustic beam and is diffracted in the plane containing the crystal Z-axis and the acoustic wave vector $\boldsymbol{K_a}$. The waveforms of zero- and first diffraction orders at acoustic frequency 37.42 MHz are shown in Fig. 2.

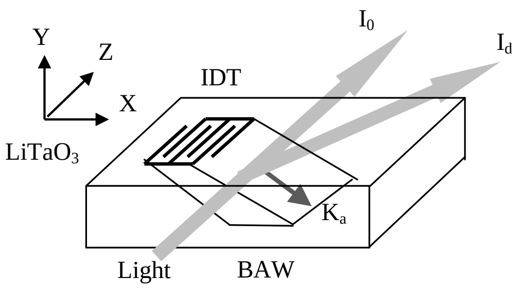


Fig. 1. Experimental configuration.

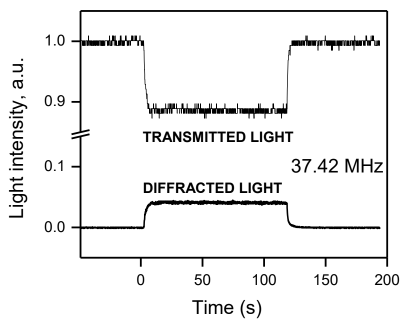


Fig. 2. Waveforms of transmitted and diffracted light.

The anisotropic diffraction with polarization rotation takes place. Since the ordinary and extraordinary refractive indices of $LiTaO_3$ are very close (2.180 and 2.175 at 633 nm, respectively [3]), relatively low acoustic frequencies on the order of a few tens megahertz are required. The diffraction efficiency is determined by the IDT aperture. In our experiments, it attained 10 % with the 1 W electrical power oscillator. The measured dependences of diffraction angles on the acoustic frequency are in good agreement with theoretical calculations. One of the possible applications of the proposed configuration is an acousto-optic probing of the IDT-radiated bulk acoustic waves. In particular, the radiation angle can be easily measured.

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# Investigation of Close to Collinear Anisotropic Acousto-Optic Interaction in a Biaxial Crystal of Alpha-Iodic Acid

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Methods of optical radiation control based on the acousto-optic (AO) interaction find wide applications in many areas of modern science and technology. Using this effect, we can effectively change any characteristics of optical waves: amplitude, phase, frequency, polarization, and direction of propagation. Such AO devices as modulators, deflectors, and filters find application not only in laser physics and spectroscopy, but also in ecology, medicine, telecommunication systems, and military science [1, 2]. Currently, uniaxial crystals with large anisotropy of physical properties are used predominantly in acousto-optics. However, biaxial crystals, despite their physical and technological complexity, also may exhibit high values of AO figure of merit that makes them very interesting for studying their properties.

Presently, non-collinear AO filters are widely used at spectral analysis of optical images. The non-collinear geometry of AO interaction makes it possible to provide a large angle range of filtration. At the same time, collinear filters with optical and acoustic waves, propagating in the same direction, represent another class of AO devices. These instruments possess significantly higher spectral resolution and find application in modern telecommunication systems. The distinctive feature of the pure collinear variant of AO interaction consists in a greater interaction length which enables reaching high spectral resolution. On the other hand, in this case there exists a problem with electromagnetic radiation introducing into the acoustic beam. This problem is solved by implementing a scheme with ultrasonic beam reflection from a crystal face that imposes special requirements on the accuracy of AO device manufacturing [3].

This work is devoted to the analysis of a special, close to collinear variant of AO interaction, when the light beam is introduced into the interaction region through the side boundaries of the acoustic column. In this scheme, the important point is the acoustic energy walk-off. A detailed analysis has shown that this type of AO interaction may also possess high spectral resolution, which is comparable to spectral resolution of pure collinear AO filters having the same interaction length. Herewith, it turned out that the sign of the walk-off angle in the interaction plane may give a significant effect on spectral characteristics of the AO cell [4].

Numerical calculations are performed for anisotropic Bragg diffraction in a biaxial crystal of alpha-iodic acid ($\alpha$-$HIO_3$), for which all components of elastic and photoelastic tensors, as well as gyration tensor are known. Our calculations have shown that the fast quasi-shear acoustic mode is characterized by maximal AO efficiency for the considered variant of anisotropic interaction. It is established that some departure from the purely collinear variant leads to a significant AO figure of merit increase and, as a consequence, to a substantial reduction of consumed electrical power without loss in spectral resolution compared to the pure collinear AO filter having the same interaction length.

*This work was supported by Russian Foundation for Basic Research (RFBR), Grant No. 17-07-00369.*

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Session IX: Acousto-Optic Devices

# Review of Acousto-Optical Devices in Advanced Microscopy: from 3D Scanning *via* Super-Resolution to Encoded Multi-Beams

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An important application of acousto-optic devices uses them as tunable diffraction gratings. Such use allows us to directly manipulate illumination patterns at the Fourier plane of an objective lens, thereby controlling desired illumination patterns at the focal plane of a light microscope.

We have designed and constructed several advanced microscopes employing these properties of AODs, and have applied them to various tasks, mainly in experimental Neuroscience. In this lecture, I will review established and novel ADO-based designs such as the 3D Random-Access Multi-Photon Microscope and the Standing-Wave Super-Resolution Microscope, as well as new designs including the Random-Access STED Microscope and Frequency-Encoded Multi-Beam/Multi-Light-Sheet Microscopes.

- 3D Random-Access Multi-Photon Microscope [1, 2]. Chirped acoustic waves are used in four sequential AODs to independently control collimation and angle of an ultra-fast laser beam to create a single focus positioned inertia-free in three dimensions.
- Standing-Wave Super-Resolution Microscope [3]. Position, separation, and phase of two diffraction-limited Fourier plane foci are controlled by AODs to generate dynamic standing wave patterns with adjustable orientation, frequency, and phase.
- Random-Access STED Microscope [4]. A pair of excitation patterns, i.e., Gaussian focus and fluorescence-depleting annulus, are precisely registered with AODs to provide super-resolution with inertia-free random-access positioning.
- Frequency-Encoded Multi-Beam Microscope [5]. A variable number of separate laser beams with individually controlled frequency-encoding are AOD-generated for simultaneous multi-site imaging.
- Multi-Light-Sheet Microscope [6]. Multiple position-encoded light-sheets are produced with AODs for advanced volume imaging.

All these AOD-based designs have advanced microscopy by overcoming limitations of previously used light microscopy.

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# Comparison between the electrical bandwidth performance of a transducer and the diffraction efficiency of an AOTF

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The performance of an AOTF can be measured in different ways. One of the key parameter is the diffraction efficiency (DE). The ideal situation would be to have a DE as high as possible over a broad band. To make the AOTF perform, the AOTF is activated by applying an RF signal to a transducer. The latter is responsible for the conversion of RF energy into sound waves inside the crystal. The transducer has an optimal electrical bandwidth in which the RF signal is efficiently converted.

The purpose of the experiment is to compare the optical transmission curve to the power transfer curve as a function of frequency. It is expected that at the edges of the RF bandwidth the power transfer ratio is high, but the DE is low. First the VSWR-curve of an AOTF of Gooch & Housego [1] was measured and converted into a power transfer curve P/P0 (Fig. 1). The DE was measured using two laser beams: 633 nm for the upper edge of the frequency band and 1523 nm for the lower edge. Both beams were applied to the AOTF, by working in the region of small Bragg angles [2]. Hence, a single laser wavelength allows to explore the DE over a broad frequency range. The 633 nm laser beam was used to explore the 115 to 165 MHz region, while the 1523 nm laser was used to investigate the 57 to 75 MHz area (Fig. 1). A calibrated 500 mW RF signal was applied to the transducer for each measurement. The combined graph in Fig. 1 reveals that the DE decreases faster at the edges of the frequency range, compared to the power ratio. This means that at the boundaries of the frequency range, the correlation between the DE and the electrical matching can fail. This was also verified by measuring the heat generation in the crystal at different frequencies (not shown here). A notable feature of the device under test is the peak at 153 MHz (good matching), while having a low DE. Temperature measurements revealed that indeed a large part of the electrical energy is converted into sound, while the DE is low. The hypothesis for this phenomena is the existence of another mode inside the crystal, besides the slow shear wave. As a conclusion, the experiment confirms that a mismatch can occur between the DE and the power transfer ratio.

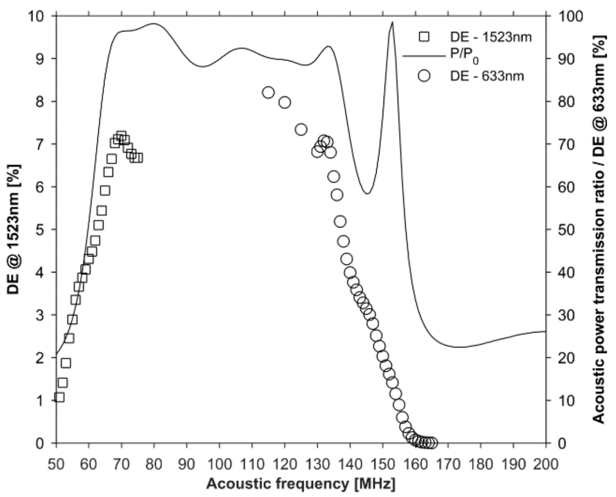


Fig 1. Power transfer curve and DE.

*This work was funded through the PRODEX contract 4000110400.*

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Session IX: Acousto-Optic Devices

# Two-crystal acousto-optic modulator of high-power laser radiation

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Using an AO modulator as an intracavity modulator of high-quality laser radiation a man should know that the most important requirements are radiation resistance of the crystal and antireflection coatings of the faces, simplicity and convenience of adjustment.

The use of modulators with input and output radiation at the Brewster angle solves the problem of losses on the optical faces. There is no need to use anti-reflective coatings of high radiation resistance. However, this solution entails a significant shift of the laser beam. The return of the laser beam to its original position is solved using an additional acousto-optic cell, which is mirrored first.

It is known that crystals of the group $KMe(WO_4)$, where Me is a Y atom or Gd or Yb or Lu, have high radiation resistance [1] and are effective acousto-optic crystals [2-3] and they can serve as AO modulators for controlling high-power laser radiation.

We have developed and investigated a two-crystal acousto-optical $KGd(WO_4)$ modulator for operation with high-power laser radiation with a wavelength of 2–3 µm.

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# High-frequency ($f_{RF}$ >1GHz) Acousto-Optic modulation using a doubly resonant cavity in a MEMS foundry platform

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Acousto-Optic Modulators (AOM) have been used for a wide variety of signal processing application. Traditionally, they have been built with bulk materials such as quartz, Tellurium Dioxide [1], which has limited their operational frequency to < 300MHz. In addition, the absence of a CMOS foundry-compatible process has prevented the scalable integration, mass production, and design complexity achieved by integrated photonic devices. An efficient high-frequency AOM can be the building block for different applications, such as a high-speed spatial light modulator with tens of MHz bandwidth, or a viable free space optical interconnect link between processors and memory that meets the stringent energy and bandwidth constraints [2]. We report the operation of an AOM with operation frequency between 300 MHz and 3.5 GHz realized by MEMS foundry platform [3]. The structure is a suspended AlN transducer sandwiched between an electrode made of Al and a p-doped Silicon substrate. The device is configured as collinear acousto-optic cavity, where the optical cavity is between the bottom layer of the silicon and the top electrode (Al), and the acoustic cavity is between the top layer of the electrode and the bottom layer of the Silicon. The efficiency of the modulation is enhanced by the co-localisation of the acoustic and optical cavity modes. The acoustic cavity modes are high overtone bulk acoustic wave modes [4], and the optical modes are the eigenmodes of a planar Fabry-Perot cavity. We measured modulation up to 4 GHz on a single device, which is the highest frequency acousto-optic modulation and the broadest frequency range (from 300 MHz up to 4.5 GHz) on a single device. Traditional AOMs rely on the elasto-optic effect, in this case the modulation is achieved by the movement of the cavity boundaries. We believe this platform will be promising for several application from low cost modulation to spatial light modulation and detection of RF signal for radio astronomy.

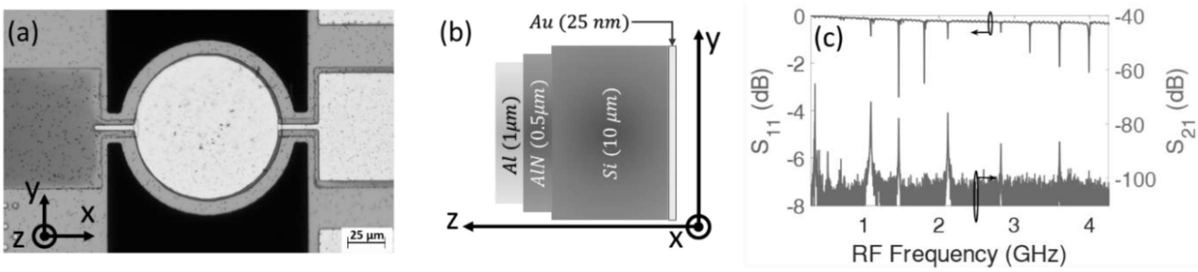


Fig.1 Microscope of the image (a), Stack of the structure (b), measured acousto-optic modulation (c).

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Session IX: Acousto-Optic Devices

# Acousto-Optofluidic Multi-spot Generation for High-throughput Laser Material Processing

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Laser Direct Writing (LDW) systems have become the tool of choice for the maskless digital processing of materials at the micro scale [1]. However, their point scanning nature can seriously constrain fabrication throughput, thus limiting the potential of LDW in both scientific and industrial applications. A simple and widely extended solution is to split light into several beamlets, but existing technologies can suffer from aberrations, limited response time, low damage threshold or pixelization. Here, we present a new Acousto-Optofluidic (AOF) device that overcomes these issues and is capable of dynamic multi-spot generation at ease and at sub-microsecond time scales, faster than the inter-pulse period of many commercial laser systems. It consists of a water-filled cavity with two independent pairs of piezoelectric plates aligned along orthogonal directions [2]. On resonance, standing acoustic waves are established inside the cavity that periodically modulate the refractive index of the liquid. Because the typical driving frequencies are $\nu \approx 1\ \mathrm{MHz}$, the acousto-optic interaction is in the Raman-Nath regime and the device acts as a tunable phase grating, generating a comb of beamlets as shown in Fig. 1a. Specifically, modifying the driving parameters allows real-time selection of the main features of the diffraction pattern, namely number, separation, and intensity of the beamlets. We combine our AOF device with a LDW system to achieve parallelization of laser processing, and demonstrate tailored and fast micromachining of various materials, including metal and glass (Fig. 1b). Furthermore, we show various writing methods by synchronizing our system with a pulsed laser, including discrete, averaged, synchronized scanning and a brush-like mode. As a proof of concept, we fabricated complex micro-patterns for locally modifying the wettability of a surface. Our AOF-enabled LDW system can achieve an unprecedented combination of throughput, speed and ease of use. These unique features will help overcome the intrinsic tradeoff between flexibility and throughput of LDW systems, paving the way for the further expansion of laser manufacturing in both subtractive and additive modalities.

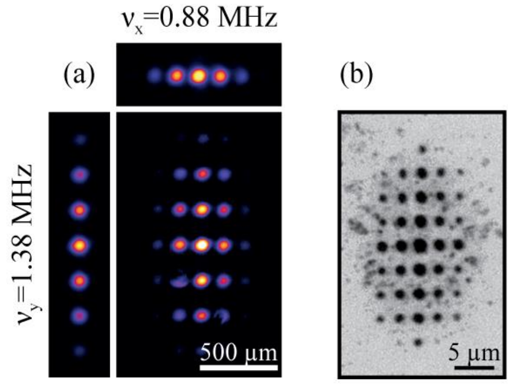


Fig. 1: (a) Experimental Fraunhofer diffraction pattern after the AOF device when driven along the x, y and x-y axes. (b) Optical micrograph of an ablated pattern on metal generated with the AOF-enabled LDW system.

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# AOTF-based instrumental concepts in atmospheric science

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Remote sensing instruments play an important role in advancing the understanding of our environment. In many cases, the capability to resolve fine structures in the spectrum of the light emitted, transmitted, or scattered by the atmosphere is needed. Some applications also require the measurement of the polarization state revealing hints about scattering and electronic excitation processes.

Whereas AOTFs can offer the needed spectral and polarization sensitivity, their potential does not seem to have been fully grasped by the geoscience community. BIRA-IASB has a long expertize in AOTF integration and driving for spaceborne atmospheric instruments (SOIR/Venus-Express [1, 2], NOMAD [3], ALTIUS [4]), and more recently also on ground-based pollution monitoring sensors (NO2 camera [5]).

New concepts are also being investigated: a small payload for the monitoring of the solar irradiance variability (UV-VIS), an instrument for the measurement of the SO2 fluxes of volcanoes (UV), and a spectro-polarimetric imager for the measurement of the linear degree of polarization of northern lights (VIS) [6].

In this contribution, we will present the design and the performance of the existing NO2 camera, and see how it can be tailored to the specific needs of the three abovementioned instrumental concepts.

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Session X: Novel Applications of Acoustics / Optics

# Acoustical and optical control of Pickering emulsions formation in electric field

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Pickering emulsions have become very interesting class of colloidal systems in last decades. In these systems, particles adsorbing at droplet interfaces provide a mechanical barrier against coalescence and caused its kinetic stabilization. Particle-stabilized emulsions are believed to exhibit better stability in comparison these using surfactants. Despite of plenty of papers and industrial patents, there is still a need to develop methods to characterize these emulsions, especially the process of their formation. Optical microscopy imaging is often used to show appearance of emulsion droplets. However, because of limitations linked to the optical path length, it cannot be utilized for non-diluted systems, *in situ*. Acoustical methods, on the contrary, are able to travelled by even optical opaque medium. They are thus utilized to characterize emulsions e.g. droplet size distribution. It is worth pointing out that they are not yet commonly used to characterize particle-stabilized emulsions.

In the presentation, the method of such stable emulsions preparation by using ultrasonic homogenization and electric field will be described. Stabilization under electric field caused here a controlled coalescence of emulsion droplets and, as a result, a change in droplets size during the process of formation [1]. This change can be correlated with a change in acoustical attenuation coefficient and, immediately, with optical data [2]. The results show that combination of ultrasonic and optical measurements provides a comprehensive insight into emulsion structure, in particular – the dynamic of Pickering droplets formation.

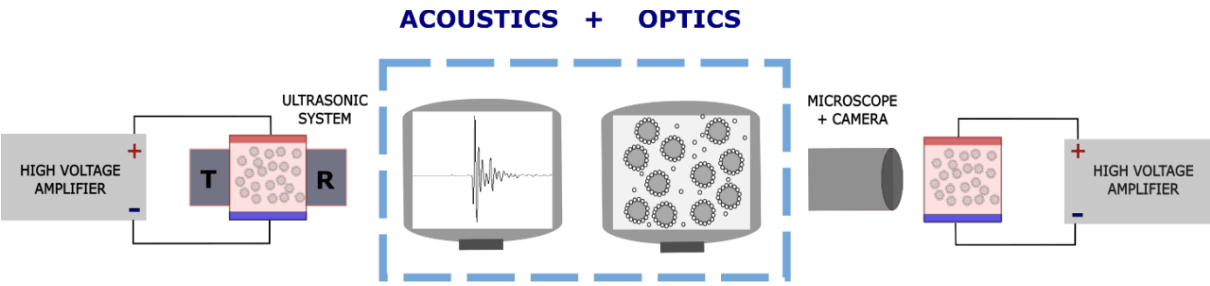


Fig. 1 The schematic illustration of acoustical and optical system used to follow changes in Pickering emulsion during the stabilization in electric field.

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Session X: Novel Applications of Acoustics / Optics

# Laser ultrasonics for non-destructive evaluation of adhesively bonded joints

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The non-destructive evaluation of adhesively bonded joints is a major issue in the aeronautical industry. Indeed, this assembly technique has got a lot of advantages compared to more conventional ones (riveting): it allows lighter aircraft structures and therefore reduced fuel consumption and emissions. Furthermore, a better stress distribution can be achieved between assembled parts. Nevertheless, the significant deployment of this assembly technique is currently limited by the nonexistence of a method to quantify the practical adhesion without damaging the structure. In the past 50 years, a large number of non-destructive ultrasonic methods have been investigated to measure bond strength quantitatively [1, 2]. However, up to now, none of these methods allow to quantify the mechanical strength of an industrial bonded joint. Thus, the goal of this work is to propose a new non-destructive technique to face this issue.

In order to evaluate the practical adhesion of an adhesively bonded joint, a laser ultrasonic method can be considered as a good candidate. Two main reasons can explain this choice. First, the propagation of ultrasounds in a bonded assembly may give relevant information concerning the practical adhesion. Indeed, these elastic waves will interact mechanically with the bonded joint and then the presence of an adhesive defect should lead to a signature in the received ultrasonic signals. Secondly, a contactless method for the non-destructive evaluation of bonded joints is really interesting in an industrial context. For these reasons lasers are used to generate and to detect ultrasonic waves on the same free surface of the assembly. The laser generation remains in the thermo-elastic regime in order to stay non-destructive.

The aim of this research project is to quantify the practical adhesion of a bonded assembly: aluminum/epoxy/aluminum. To investigate this issue, samples with different conditions of interface have been prepared. The experimental set-up is composed of a pulsed laser (Nd:YAG, Q-switched, nanoseconds pulses) to generate the ultrasonic waves in the sample and an interferometer to measure the normal displacement of the free surface as a function of time. The reflection of bulk waves at an imperfect interphase or the propagation of guided waves in the bonded assembly may contain an information concerning the practical adhesion, since these elastic waves interact mechanically with the bonded joint. The experimental data are then compared with semi-analytical simulations [3]. A uniform distribution of normal and transversal springs $(K_N, K_T)$ is used to model the bonding interface [4]. These numerical models will allow us to understand and to analyze the experimental signals in order to identify the key parameters which characterize the practical adhesion of a bonded joint.

## References

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[2] S. Mezil, F. Bruno, S. Raetz, J. Laurent, D. Royer, C. Prada, *J. Acoust. Soc. Am.*, **138**(5), 3202 (2015).
[3] H. Meri, *Ultrasonic radiation generated by laser in anisotropic medium; effects of the optical penetration, the thermal diffusion and the electronic density diffusion*, Doctoral Dissertation, Université Bordeaux I, Bordeaux 2004.
[4] J.P. Jones, J.S. Whittier, *J. Appl. Mech.*, **34**(4), 905 (1967).

Session X: Novel Applications of Acoustics / Optics

# Optical Coherent Elastography of the vitreous humour

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The aim of my PhD research is to establish an all-optical experimental method for mapping the elastic properties of the vitreous humour in the eye. Our method can be useful for early diagnosis and monitoring of eye-related diseases that change the elastic properties of the vitreous humour like diabetic retinopathy or age-related macular degeneration (AMD). If successful, our research will lead to development of a cost effective device allowing for measurements to be made in an optometry practice rather than in a hospital.

Employing Optical Coherence Tomography (OCT) in Elastography, a technique referred as Optical Coherence Elastography (OCE), is increasingly popular due to its cost efficiency, and its micrometre spatial as well as nanometre longitudinal resolution [1]. To measure elasticity using OCT, it is necessary to apply stress on the sample that triggers different elastic waves: compressional waves, shear waves and surface waves. Shear waves provide information about the tissue shear modulus and hence its stiffness [2]. For an isotropic, linear, elastic material, shear modulus can be determined from the formula [2]:

$$G=v^2\rho, \tag{1}$$

where G is the shear modulus, v is the shear wave velocity and ρ is the density of the sample.

In our research, to obtain the shear modulus we will calculate the shear wave velocity from the OCT images. We are currently performing preliminary measurements which we will use as a reference for the target study. In our experimental set-up we use a Spectral domain OCT system to detect shear waves in polydimethylsiloxane (PDMS) samples which we use as a phantom of the vitreous humour. To induce the shear waves we apply loading using a contact, mechanical method. Eventually, we will conduct *in-vitro* experiments for the vitreous humour in rat eyes with different pathologies. For these experiments we will use a non-contact, all-optical method to trigger the shear waves. To image the shear waves induced in these samples and get the best possible results we will use an ultra-fast OCT system especially designed for this OCE research. These experiments will allow us to correlate different diseases with the shear modulus of the vitreous humour.

In our preliminary, study we imaged elastic waves in non-scattering PDMS samples with different shear modulus. Further experiments with higher temporal resolution and better time response of the OCE system are needed to confirm velocities of the shear waves propagating in our samples. These velocities where extracted by spectral analysis from obtained OCE data.

*This work was supported by the Marsden grant UOA-1509 from the Royal Science society of New Zealand.*

**References**

[1] Y. Wang, S.G. Adie, S.A. Boppart, M.F. Insana, *Handbook of Imaging in Biological Mechanics*, C.P. Neu, G.M. Genin, eds., CRC Press, Taylor & Francis Group, Boca Raton, Florida, USA (2015).
[2] A.P. Sarvazyan, A.R. Skovoroda, S.Y. Emelianov, J.B. Fowlkes, J.G. Pipe, R.S. Adler, R.B. Roemer, *Acoust Imaging*, **21**, 223 (1995).

# Conference Proceedings


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# History

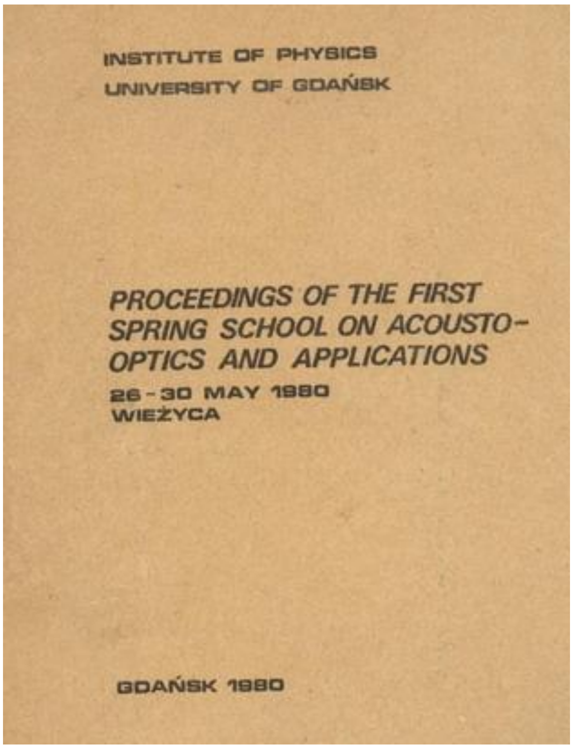
Photos courtesy of: A. Śliwiński, B.B.J. Linde, G. Gondek, J. Gondek, D. Čiplys, K. Yushkov

# 1st Spring School on Acousto-Optics and Applications Gdańsk – Wieżyca, 26-30 May 1980

The 1st Spring School on Acousto-Optics and Applications was organized in Wieżyca (village in Cashubian region) in 1980. The main organizer was the University of Gdańsk and the Polish Acoustical Society (Section of Quantum Molecular Acoustics and Sonochemistry). The conference was supported by the Institute of Fundamental Technological Research of the Polish Academy of Sciences. The program of the meeting included 22 oral presentations, 10 posters and a round table discussion. The papers were published in the proceedings released by the Institute of Physics of the University of Gdańsk. The report from the conference was published in: A. Śliwiński, First spring school on acousto-optics and its application: Gdańsk — Wieżyca, Poland, 26–30 May 1980, *Ultrasonics* **19**(1), 44-45 (1981).


Participants and organizers of the 1st School in front of the building of the Faculty of Mathematics, Physics and Chemistry of the University of Gdańsk.
From the left: B. Linde, I. Gabrielli, A. Śliwiński, R. Mertens and P. Kwiek

Excursion to Gdańsk. Conference participants at the Faculty of Mathematics, Physics and Chemistry of the University of Gdańsk. From the left: J. Narkiewicz-Jodko, P. Kwiek, A. Markiewicz, S. Kryszewski, I. Wojciechowska, K. Dałek and M.A. Breazeale

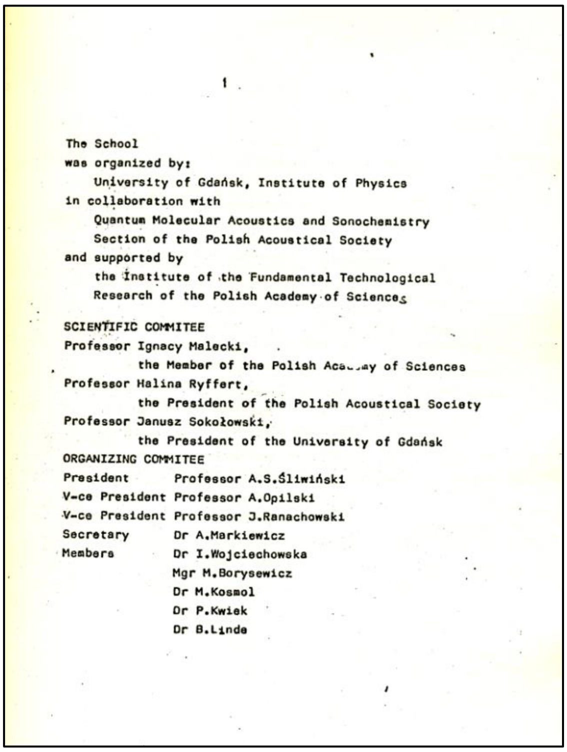


INSTITUTE OF PHYSICS
UNIVERSITY OF GDAŃSK

PROCEEDINGS OF THE FIRST SPRING SCHOOL ON ACOUSTO-OPTICS AND APPLICATIONS

26 - 30 MAY 1980
WIEŻYCA

GDAŃSK 1980



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The School
was organized by:
University of Gdańsk, Institute of Physics
in collaboration with
Quantum Molecular Acoustics and Sonochemistry Section of the Polish Acoustical Society
and supported by
the Institute of the Fundamental Technological Research of the Polish Academy of Sciences

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Professor Halina Ryffert,
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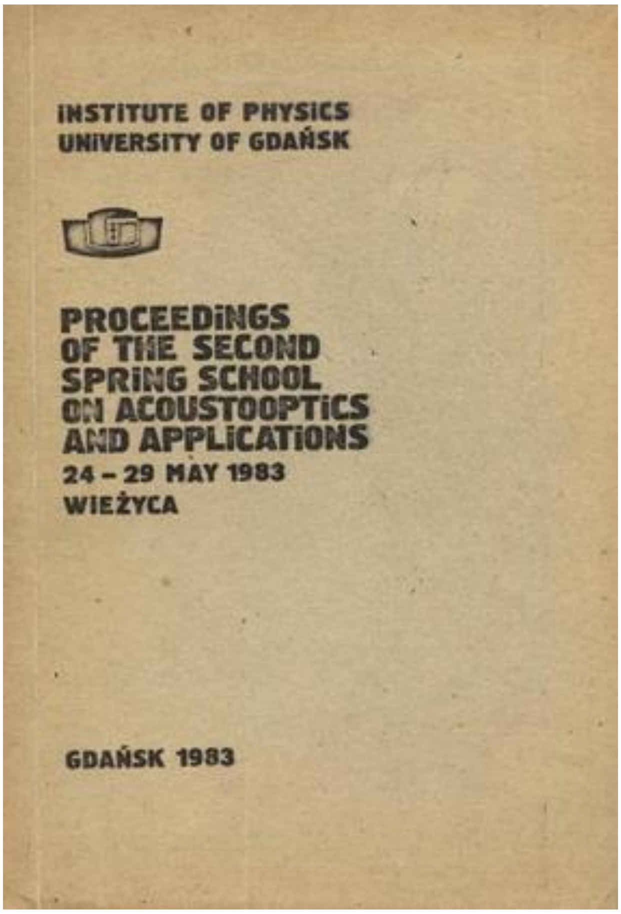
# 2nd Spring School on Acousto-Optics and Applications Gdańsk – Wieżyca, 24-29 May 1983

The 2nd Spring School on Acousto-Optics and Applications took place in Wieżyca in Cashubian region in 1983. The program consisted of 28 invited and regular talks as well as 12 posters. Discussion at the round table was devoted to the criteria of Raman-Nath and Bragg regime of light diffraction on ultrasound. The conference proceedings were issued by the Institute of Physics of the University of Gdańsk. The report about the conference was published in: A. Śliwiński, Second spring school on acousto-optics and applications: 24–29 May 1983, Gdańsk-Wiezyca, Poland, *Ultrasonics* **22**(1), 45-46 (1984).

In front of the conference venue in Wieżyca.
From the left: J. Zieniuk, A. Śliwiński and Z. Pajewski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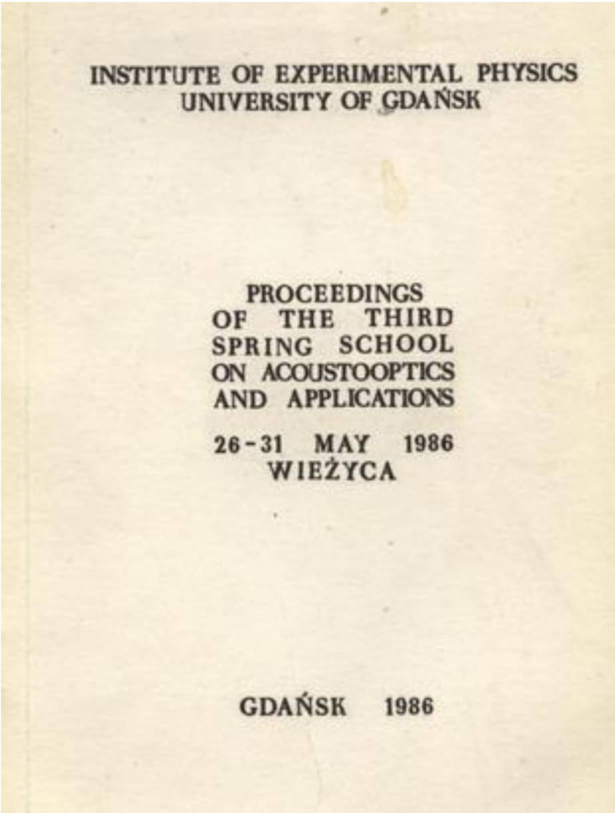
PROCEEDINGS
OF THE SECOND
SPRING SCHOOL
ON ACOUSTOOPTICS
AND APPLICATIONS
24 – 29 MAY 1983
WIEŻYCA
GDAŃSK 1983

# 3rd Spring School on Acousto-Optics and Applications Gdańsk – Wieżyca, 26-31 May 1986

It was the third time when the Spring School on Acousto-Optics and Applications was held in Wieżyca. The third edition of the meeting attracted ca. 60 researchers from all over the world. The program included 27 presentations. Additionally, two round table discussions entitled ‘On light and ultrasonic pulses interaction’ (W.G. Mayer) and ‘Possibilities of acousto-optics in material examination’ (H.W. Jones) were organized. The conference proceedings were published by the University of Gdańsk. The conference information was published in: A. Śliwiński, Third spring school on acousto-optics and its applications: Gdańsk-Wieżyca, Poland, 26–31 May 1986, *Ultrasonics* **25**(3), 182-183 (1987).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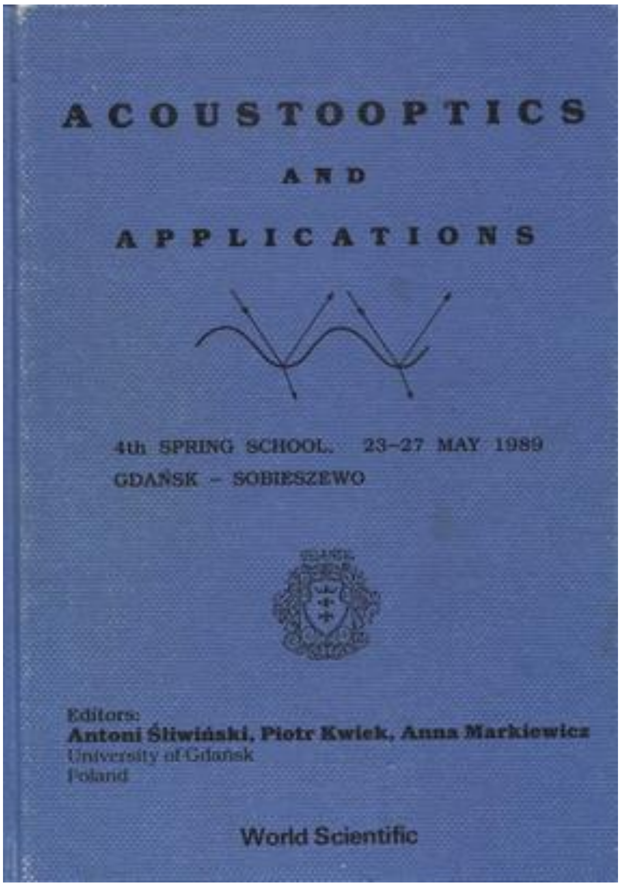
PROCEEDINGS
OF THE THIRD
SPRING SCHOOL
ON ACOUSTOOPTICS
AND APPLICATIONS

26-31 MAY 1986
WIEŻYCA

GDAŃSK 1986

# 4th Spring School on Acousto-Optics and Applications Gdańsk – Sobieszewo, 23-27 May 1989

The 4th Spring School on Acousto-Optics and Applications took place on Sobieszewo island in Gdańsk and brought together 51 participants, who presented 36 papers (including 19 invited lectures, 6 oral presentations and 11 poster presentations). The discussions during round table session were moderated by A. Korpel and V. Proklov, and were devoted to acousto-optics and photoacoustics. The proceedings were published in: A. Śliwiński, P. Kwiek, A. Markiewicz (eds.), Acousto-Optics and Applications, World Scientific, Singapore-New Jersey–London-Hong Kong 1990.



# 5th International Spring School on Acousto-Optics and Applications Gdańsk – Jurata, 25-29 May 1992

The 5th Spring School on Acousto-Optics and Applications took place in Jurata in Hel Peninsula, 70 km away from Gdańsk. The meeting was sponsored by the Polish Ministry of Education as well as by SPIE The International Society for Optical Engineering. The conference was attended by 46 specialists from Europe and North America who delivered 34 presentation (16 invited lectures, 11 oral contributions and 7 posters). The proceedings were published by SPIE in: A. Śliwiński, P. Kwiek, B. Linde, A. Markiewicz (eds.), Acousto-Optics and Applications, *Proc. SPIE* **1844** (1992). The report about the conference was published in: A. Śliwiński, 5th International Spring School on Acousto-Optics and Applications, Gdańsk-Jurata, 25-29 May 1992, *Arch. Acoust.* **18**(1), 171-174 (1993).

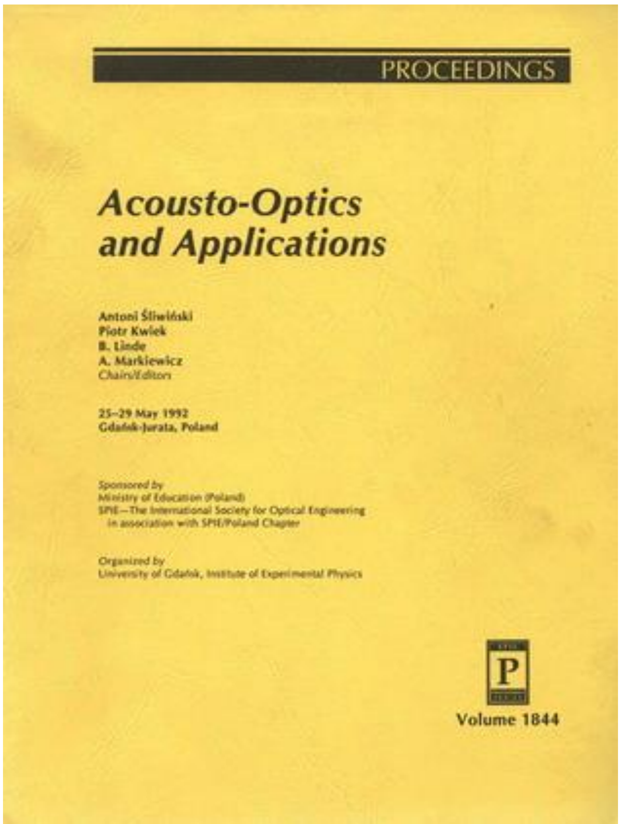
Participants of the 5th School on Acousto-Optics and Applications

The first day of the conference

From the left: R. Briers, O. Leroy, E. Blomme, Z. Grzonka (Rector of the UG, sitting back)

Group of participants during excursion to Hel Peninsula.
From the left: (1st row) R. Reibold, E. Soczkiewicz, O. Leroy, A. Śliwiński, M. Januszewska (kneeling), J. Gondek, G. Gondek, M. Borysewicz, D. Konderska, (2nd row) D. Čiplys, I. Gabrielli, M. Kosmol, B. Linde, T. Katkowski, E. Blomme

S. Boseck during the excursion to Hel Peninsula. J. Sapriel behind S. Boseck.


PROCEEDINGS
Acousto-Optics and Applications
Antoni Śliwiński
Piotr Kwiek
B. Linde
A. Markiewicz
Chairs/Editors
25–29 May 1992
Gdańsk-Jurata, Poland
Sponsored by
Ministry of Education (Poland)
SPIE—The International Society for Optical Engineering
in association with SPIE/Poland Chapter
Organized by
University of Gdańsk, Institute of Experimental Physics
Volume 1844

# 6th International Spring School on Acousto-Optics and Applications Gdańsk – Jurata, 22-26 May, 1995

The 6th International Spring School on Acousto-Optics and Applications was organized again in the resort of Jurata. The conference was attended by 71 participants. The program included 17 invited lectures, 25 contributed papers and 15 posters. A very interesting discussion about the perspectives of acousto-optics was moderated by B. Cook. The papers were published in SPIE Proceedings Series: A. Śliwiński, P. Kwiek, B. Linde, A. Markiewicz (eds.), Acousto-Optics and Applications II, *Proc. SPIE* **2643** (1995). Information about the conference was published in: A. Śliwiński, Chronicle - 6-th International Spring School on Acousto-optics and Applications, Gdańsk-Jurata, 22-25 May 1995, *Arch Acoust.* **21**(1), 109-113 (1996). Another report was also published in: A. S. Śliwiński, Conference report: 6th International Spring School on Acousto-optics and applications Gdańsk-Jurata, 22–25 May 1995, *Ultrasonics* **34**(1), 79 (1996).

School attendees in front of the military resort 'Jantar' in Jurata


From the left: B.B.J. Linde (side in the 1st row), T. Pustelny, V.B. Voloshinov, V.Ya. Molchanov (2nd row), A. Śliwiński (standing), I. Gabrielli (3rd row), N.V. Parygin (4th row)

Session of the 6th School on Acousto-Optics and Applications: P. Banerjee in the first row, V.Ya. Molchanov and A. Korpel in the second row

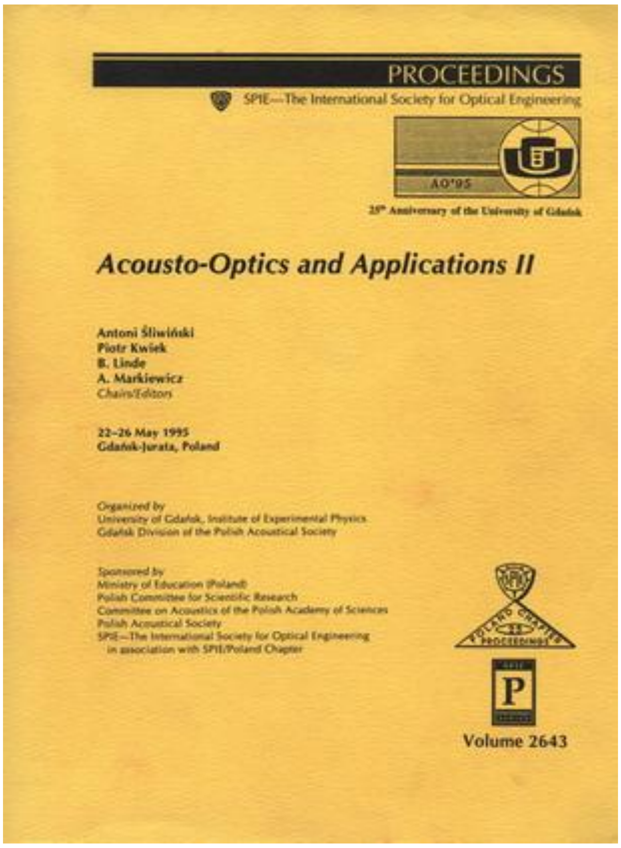
Session of the 6th School on Acousto-Optics and Applications

Organizing Committee of the School. From the left: B. Linde, M. Borysewicz, T. Katkowski, A. Sikorska, G. Gondek and B. Dałek

Meeting in the evening. From the left: T. Katkowski, G. Gondek, V.N. Parygin, A. Korpel, V.Ya. Molchanov, V.I. Balakshy, V.B. Voloshinov

Conference dinner. From the left: R. Reibold, B.D. Cook and his wife D. Scott, H.W. Jones, A. Śliwiński. Sitting back: A. Christ and H.J. Hein


B.D. Cook visiting lighthouse in Rozewie



# 7th International Spring School on Acousto-Optics and Applications Gdańsk – Jurata, 18-22 May, 1998

The 7th International Spring School on Acousto-Optics and Applications was held in Jurata for the third time. The meeting was joint with the 3rd Advances in Acousto-Optics Symposium. The conference attracted 74 scientists from Europe, America, Asia and Africa. The program consisted of 22 invited lectures, 25 contributed papers, a poster session (18 posters), and a round table discussion. Plenary session (chaired by A. Korpel) was dedicated to the memory of Professor Bill. D. Cook who passed away in 1997. The proceedings were published in: A. Śliwiński, B. B. J. Linde, P. Kwiek (eds.), Acousto-Optics and Applications III, *Proc. SPIE* **3581** (1998). The report about the conference was published in: A. Śliwiński, Conference report on the 7th International Spring School on Acousto-Optics and Applications joint with the 3rd Advances in Acousto-Optics Symposium, Gdańsk-Jurata, 18-22 May 1998, *Opto-Electron. Rev.* **6**(4), 299-300 (1998). Another report can be found in: A. Śliwiński, 7-th International Spring School on Acousto-optics and Applications joint with the 3rd Advances in Acousto-optics Synposium, Gdańsk – Jurata, 18-22 May 1998, *Acustica-Acta Acustica* **85**(1), 145-146 (1999).

Participants of the conference in front of the military resort 'Jantar' in Jurata


From the left: V.B. Voloshinov, V.I. Balakshy, V.N. Parygin,
V.Ya. Molchanov, V.V. Proklov, V.I. Pustovoit

B.D. Cook’s Memorial Session. From the left: A. Śliwiński and A. Korpel

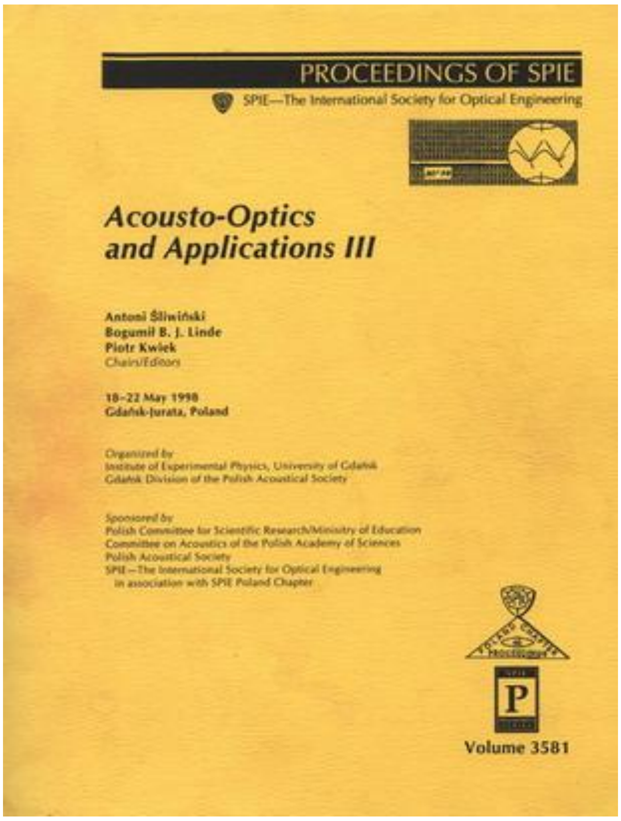
O. Leroy recalling his common work with B.D. Cook during special session dedicated to the memory of Prof. B.D. Cook

M.A. Breazeale during special session dedicated to the memory of Prof. B.D. Cook. A portrait of B. Cook was prepared by the organizers and was later sent to Donna Scott, Cook’s wife.


Visit to the Acousto-Optic Laboratory of Prof. P. Kwiek at the University of Gdańsk. Prof. P. Kwiek presenting the equipment. From the left: T.C. Poon, V.N. Parygin, T. Pustelny (1st raw), V.I. Balakshy, T. Błachowicz, V.B. Voloshinov (behind P. Kwiek), J.L. Katz, E. Soczkiewicz


Visit to the Acousto-Optic Laboratory of Prof. P. Kwiek at the University of Gdańsk. Prof. P. Kwiek presenting the equipment. From the left: E. Blomme, V.N. Parygin, T.-C. Poon, P. Banerjee, T. Pustelny, V.I. Balakshy

Group of participants in front of the Faculty of Mathematics and Physics of the University of Gdańsk. From the left: I. Gabrielli, P. Banerjee, V.I. Balakshy, V.B. Voloshinov, V.N. Parygin, P. Kwiek, A. Śliwiński, G. Gondek, T. Katkowski, V.Ya. Molchanov



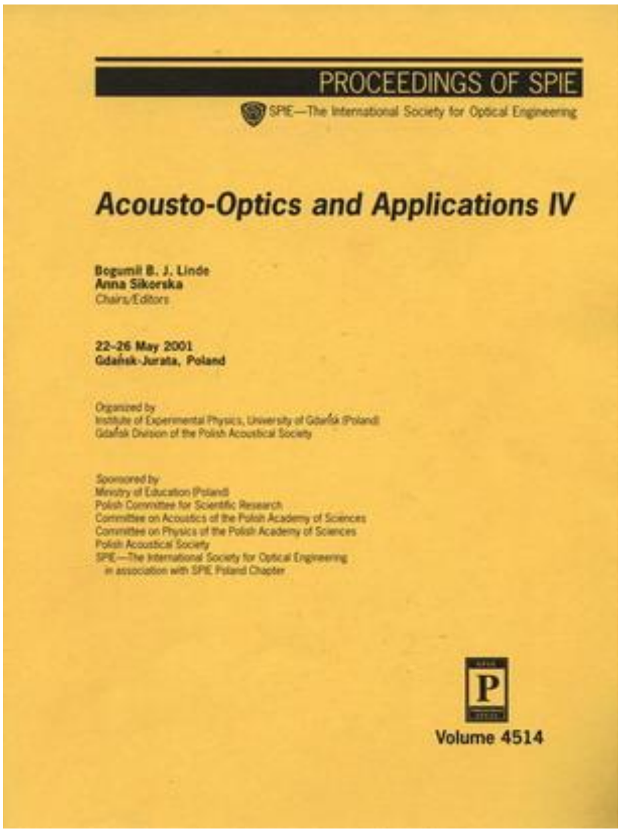
# 8th International Spring School on Acousto-Optics and Applications Gdańsk – Jurata, 22-26 May 2001

The 8th International Spring School on Acousto-Optics and Applications in Jurata was organized with 6th Advances in Acousto-Optics Symposium. Both joint events attracted 37 acousto-opticians. Twenty eight oral presentations were delivered. The papers were published as SPIE Proceedings: B. B. J. Linde, A. Sikorska (eds.), Acousto-Optics and Applications IV, *Proc. SPIE* **4514** (2001).

A. Korpel


Cz. Lewa and J. Sapriel


N. Mbamou


PROCEEDINGS OF SPIE
SPIE—The International Society for Optical Engineering
Acousto-Optics and Applications IV
Bogumil B. J. Linde
Anna Sikorska
Chairs/Editors
22–26 May 2001
Gdańsk-Jurata, Poland
Organized by
Institute of Experimental Physics, University of Gdańsk (Poland)
Gdańsk Division of the Polish Acoustical Society
Sponsored by
Ministry of Education (Poland)
Polish Committee for Scientific Research
Committee on Acoustics of the Polish Academy of Sciences
Committee on Physics of the Polish Academy of Sciences
Polish Acoustical Society
SPIE—The International Society for Optical Engineering
in association with SPIE Poland Chapter
Volume 4514

# 9th International School on Acousto-Optics and Applications Gdańsk – Sobieszewo, 6-10 September 2004

The 9th International School on Acousto-Optics and Applictions took place in the island of Sobieszewo (15 km from the center of Gdańsk). The event was joint with the 51st Open Seminar on Acoustics, Polish-German Structured Session and Symposium on Applications of Ultrasound in Bio-measurements, Diagnostics and Therapy ABIOMED. The congress was organized by the Polish Acoustical Society (Gdańsk Division), Gdańsk University of Technology, Institute of Experimental Physics of the University of Gdańsk, Polish Naval Academy in Gdynia, Committee on Acoustics of the Polish Academy of Sciences, and Institute of Oceanology of the Polish Academy of Sciences. The conferences obtained support of the Polish Ministry of Education, Polish Committee for Scientific Research, International Commission on Acoustics, Polish Academy of Sciences and Polish Chapter of SPIE. The joint meeting was attended by 191 participants who gave 154 presentations. The papers of the School were published in: T. Klinkosz, B. B. J. Linde, A. Sikorska, A. Śliwiński (eds.), Acousto-Optics and Applications V, *Proc. SPIE* **5828** (2004).

Opening ceremony of the 51st Open Seminar on Acoustics at the Gdańsk University of Technology

Opening ceremony of the 51st Open Seminar on Acoustics at the Gdańsk University of Technology. From the left: B.B.J. Linde, A. Ceynowa (Rector of the University of Gdańsk), A. Stepnowski (speaking, Vice-Rector of the GUT), A. Rakowski, J. Blauert, M. Vorlander

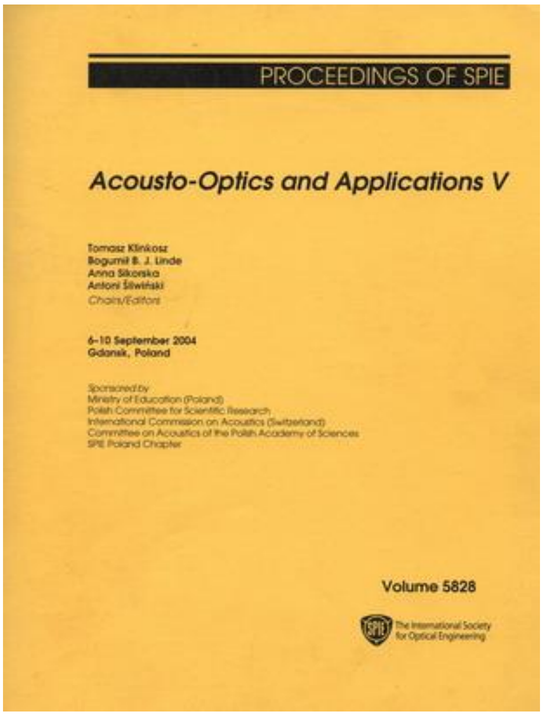
Participants of the 51st OSA and 9th School on Acousto-Optics and Applications in front of the conference venue in Sobieszewo

Acousto-optic session.
From the left: Y. Dobrolenskiy, V.Ya. Molchanov, T. Katkowski, D. Bogomolov, J. Smirnova, R. Bukowski, V.I. Balakshy

From the left: V. Rysakov, M. Ćwieczkowski, M. Aleksiejuk, N. Declercq, F. Reimund, P. Kozłowski, D. Wojaczek, A. Śliwiński

From the left: R. Bukowski(1st row), A. Opilski (2nd row), V. Balakshy (3rd row),
J. Pączkowski (4th row) and T. Katkowski (last row)

S. Egerev during his talk



# 10th School on Acousto-Optics and Applications Sopot, 12-15 May 2008

The 10th School on Acousto-Optics and Applications was held in Sopot in 2008. The conference was organized by the Institute of Experimental Physics at the University of Gdańsk in cooperation with Polish Acoustical Society (Gdańsk Division) and the Committee of Acoustics of Polish Academy of Sciences. Honorary patronage of the conference came from the Marshal of the Pomeranian Voivodeshift. Special support was provided by the International Commission for Acoustics (ICA) and the Polish Ministry of Science and Higher Education. The program included 7 invited lectures, 33 contributed oral presentations, and 6 poster presentations. Special tribute to the memory of Prof. V. N. Parygin was paid. The conference was attended by 50 participants (including 4 accompanying persons and 7 PhD. students) from four continents (Europe, North America, South America, Africa). Twenty three papers presented at the School were published in the feature issue of Applied Optics in honor of Prof. A. Śliwiński on his 80th birthday and Prof. A. Korpel on his 75th birthday: *Applied Optics* **48**(7), C1-C181 (2009). The issue was edited by T.-Ch. Poon, Ch. S. Tsai, V. B. Voloshinov and M. Chatterjee.


Participants of the 10th SAOA in Sopot

Participants entering the lecture room

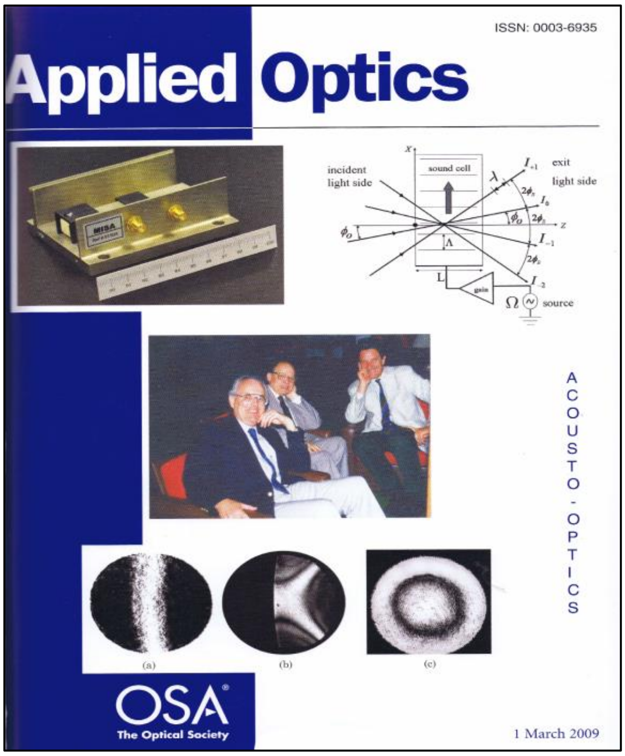
Opening of the 10th School by B.B.J. Linde

Prof. B.B.J. Linde congratulates Prof. A. Śliwiński on his 80th birthday

Unofficial meeting and discussions in the evening

Antoni and Alina Śliwińscy during conference dinner

A. Śliwiński with Agnes and Oswald Leroy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Applied Optics
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(c)
ACOUSTO-OPTICS
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The Optical Society
1 March 2009

# 11th International School on Acousto-Optics and Applications Gdańsk, 5-6 September 2011

The 11th School on Acousto-Optics and Applications was held during the first two days of the International Congress on Ultrasonics ICU 2011 in Gdańsk (5-9 September 2011). The School was regarded as one of the six structured sessions. The entire congress attracted ca. 300 participants, and about 60–80 people attended the sessions on acousto-optics where 16 papers (including 3 invited lectures) were presented by the scientists from Algeria, Belgium, Brazil, France, Japan, Lithuania, Poland, and Russia. The participants had an occasion to visit Acousto-Optic Laboratory at the University of Gdańsk (head: Prof. P. Kwiek) and discuss acousto-optical applications. The proceedings of the ICU 2011 were published in the AIP Conference Proceedings Series: B. B. J. Linde, J. Pączkowski, N. Ponikwicki, International Congress on Ultrasonics, Gdańsk 2011, *AIP Conference Proceedings* **1433** (2012). The report about the ICU was published in: A. Śliwiński, B. Linde, International Congress on Ultrasonics Gdańsk, Poland, September 5–8, 2011, *Arch. Acoust.* **36**(4), 975-980 (2011). The report about the School was published in: B.B.J. Linde, A. Śliwiński, 11th International School on Acousto-optics and its Applications Gdańsk, Poland, September 5 – 6, 2011, *Arch. Acoust.* **37**(1), 121 (2012).


Opening ceremony of the International Congress on Ultrasonics ICU 2011 in Gdańsk

D. Gužas and A. Śliwiński chatting at the official banquet


W. Sachse, A. Śliwiński and J. Gallego


INTERNATIONAL CONGRESS
ON ULTRASONICS
Gdańsk 2011
Gdańsk, Poland 5 – 8 September 2011
ICU
2011
POLAND
GDAŃSK
EDITORS
Bogumił B. J. Linde
Jacek Pączkowski
Nikodem Ponikwicki
AIP
AIP | CONFERENCE PROCEEDINGS 1433

# 12th School on Acousto-Optics and Applications Druskininkai, 29 June – 3 July 2014

The 12th School on Acousto-Optics and Applications took place in the cozy Lithuanian resort town Druskininkai on the Nemunas river bank. The School was organized by Vilnius University in cooperation with the University of Gdańsk under the auspices of the Division of Mathematics, Physics and Chemistry of the Lithuanian Academy of Sciences, Committee on Acoustics of the Polish Academy of Sciences, Lithuanian Acoustical Society, and Polish Acoustical Society. The School was supported by Acoustical Society of America and International Commission for Acoustics, Research Council of Lithuania, and SPIRE Norway. The 2nd Workshop on Micro-Acoustics in Marine and Medical Research was held as a special session at the 12th School on Acousto-Optics and Applications. Another interesting special session was devoted to the acoustic properties of wood. During the School, 55 talks (13 plenary lectures, 3 workshop lectures, and 39 regular presentations) were given by both advanced scientists and young researchers from 15 countries. The proceedings from the conference were published in Acta Physica Polonica A (37 articles from the plenary lectures and regular presentations): *Acta Physica Polonica A* **127**(1), 1-137 (2015). The issue was edited by E. Skrodzka, D. Čiplys and B. B. J. Linde.


Participants of the 12th SAOA in front of conference venue in Druskininkai (Lithuania)

Session of the 12th SAOA in Druskininkai

Discussions during the break. The chairs of the conference: D. Čiplys and B.B.J. Linde


V.B. Voloshinov chairing the session. B.B.J. Linde, D. Gužas, D. Čiplys


L. Adler preparing to the talk

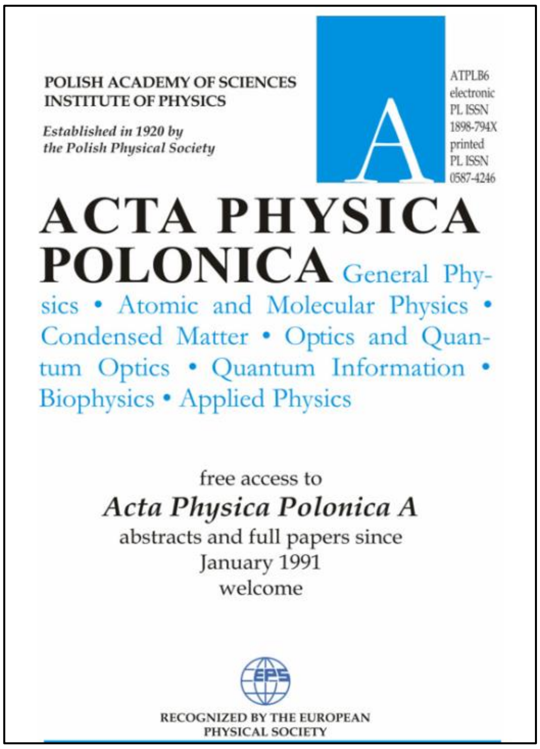

N. Polikarpova presenting her paper

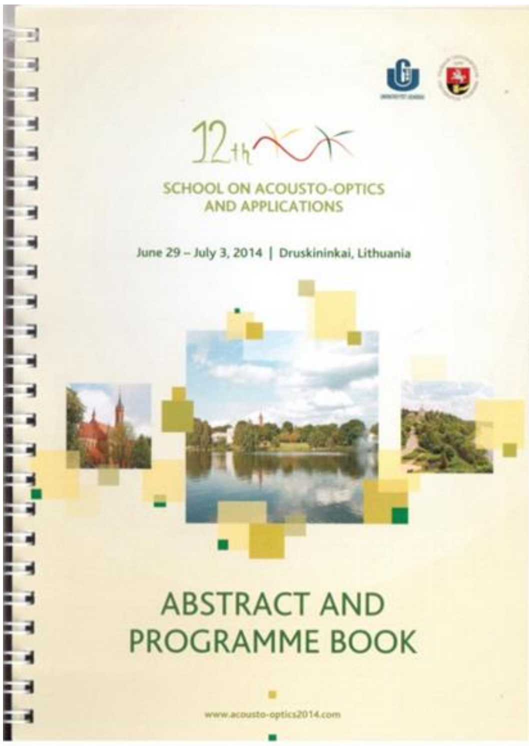
The structured session on ‘Acoustic Properties of the Wood’ organized by E. Skrodzka

Organizing Committee of the 12th SAOA. From the left: D. Čiplys, J. Zmitrulevičiūtė, E. Skrodzka, R. Giriūnienė and B.B.J. Linde

Boat trip to Liškiava with magnificent views of the banks of Nemunas River

Boat trip to Liškiava. From the left: V.V. Proklov, L. Kulakova, N. Polikarpova



# 13th School on Acousto-Optics and Applications Moscow, 19-23 June 2017

The 13th School on Acousto-Optics and Applications was organized in Moscow (Russia) in 2017 by the National University of Science and Technology MISIS and the University of Gdańsk. The meeting was supported by the Ministry of Education and Science of the Russian Federation, Russian Foundation for Basic Research (RFBR), Polish Acoustical Society, Committee on Acoustics of the Polish Academy of Sciences and by the Increase Competitiveness Program of NUST MISIS. The program of the 13th School contained 11 invited and 35 regular lectures from 8 countries. A representative selection of topics presented at the 13th School was published in a feature issue of Applied Optics edited by T.-C. Poon, V. Molchanov, M. Chatterjee, V. Gusev and B. B. J. Linde: *Applied Optics* **57**(10), AO1-C127 (2018).

Group photo at the conference venue (National University of Science and Technology MISIS)

Presentation of B.B.J. Linde. The session is chaired by (from the left): V.I. Pustovoit, M. Chatterjee, V.Ya. Molchanov, M. Filonov (vice-rector of NUST MISIS), Y. Gulyaev

V.I. Balakshy and V.B. Voloshinov (during discussion)

B.B.J. Linde visiting Gagarin Cosmonaut Training Center, Zvyozdny Gorodok (Star City)

K. Yushkov during his talk

# List of Registered Participants

Vladimir I. Balakshy
Rafał Bielas
Oksana Bibikova
Alexander I. Chizhikov
Daumantas Čiplys
Xosé Luís Deán-Ben
Emmanuel Dekemper
Martina Delgado-Pinar
Yury Dobrolenskiy
Marti Duocastella
Grzegorz Gondek
Ireneusz Grulkowski
Ashish Gupta
Romain Hode
Ligang Huang
Haonan Han
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Wonju Jeon
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Demid Khokhlov
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Vladimir Ya. Molchanov
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Ewa Skrodzka
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Ivan M. Sopko
Antoni Śliwiński
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Magdalena Urbańska
Stefano Valle
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# 14th SCHOOL on ACOUSTO-OPTICS AND APPLICATIONS

## 24-27 June 2019 Toruń, Poland

## organized by

bio-optics & optical engineering lab

at

NICOLAUS COPERNICUS UNIVERSITY IN TORUŃ

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