The 4th International Conference
Quantum Optics and Photonics 2021

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IEGULDĪJUMS TAVĀ NĀKOTNĒ

Book of Abstracts

Riga, 22-23 April 2021

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The 4th International Conference “Quantum Optics and Photonics 2021”

The conference was supported by ERDF project No. 1.1.1.5/19/A/003
"The Development of Quantum Optics and Photonics at the University of Latvia"

Conference Scientific Committee

Rashid A. Ganeev – Conference Chair

Aigars Atvars – Coordinator of the ERAChair project

Arnolds Ūbelis – Scientific secretary of the NSP FOTONIKA-LV

Conference Secretariat

Dina Bērziņa – Head of the Conference Secretariat

The 4th International Conference "Quantum Optics and Photonics 2021“ Riga, 22–23 April 2021

Agenda

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09.30 - 10.00 Arnolds Ūbelis, *University of Latvia* National Science Platform FOTONIKA -LV - dynamics of growth and future prospects.

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13.20 – 13.40 Katarina Svanberg , *South China Normal University, Lund University,* Laser spectroscopy to meet some challenges in medicine

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16.20 – 16.40 Vyacheslav V. Kim, *American University of Sharjah,* Investigating laser plasma dynamics with high - order harmonics generation in carbon -containing nanomaterials

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17.05 – 17.15 J. R. Ek-Ek, *Instituto Politecnico Nacional, Mexico,* Optical fibre taper simulation and manufacture: from standard to micro size
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17.35 – 17.45 Viesturs Silamiķelis, *University of Latvia,* Development of next generation technology for ultra purity crystal growth based on MHD semi levitation
17.45 – 17.55 Kaspars Zaķis, *Riga Technical University,* Modelling of cladding-pumped erbium/ytterbium Co-doped fibre amplifier for C-band operation
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Arnolds Ūbelis	National Science Platform FOTONIKA-LV, University of Latvia, Latvia	NSP FOTONIKA-LV on the upwards track
Aigars Atvars[1], Rashid A. Ganeev[1], Dina Bērziņa[2]	1. Institute of Astronomy, University of Latvia, Latvia 2. Institute of Atomic Physics and Spectroscopy, University of Latvia, Latvia	The progress of the ERDF project "The Development of Quantum Optics and Photonics at the University of Latvia" (refinanced Horizon 2020 ERA Chairs project)
Kalvis Salmiņš	Institute of Astronomy, University of Latvia, Latvia	Space sciences and technologies at NSP FOTONIKA-LV
10.50 – 12.20	***Plenary session II*** *Future challenges in photonics and laser spectroscopy*	*Chair:* ***Arnolds Ūbelis***
Sune Svanberg	South China Academy of Advanced Optoelectronics, South China Normal University, China, Department of Clinical Sciences, Lund University, Sweden	Laser spectroscopy applied to the environmental, ecological, and agricultural areas
Lorenzo Pavesi	Nanoscience Laboratory, Department of Physics, University of Trento, Italy	Quantum Silicon Photonics
Henrik Hartman	Department of Materials Science and Applied Mathematics, Malmö University, Sweden	High-Accuracy Laboratory Atomic Astrophysics
13.30 – 15.25	***Session*** *Advances in photonics*	*Chair:* ***Aigars Atvars***
Katarina Svanberg	South China Academy of Advanced Optoelectronics, South China Normal University, China, Department of Clinical Sciences, Lund University, Sweden	Laser Spectroscopy to Meet Some Challenges in Medicine
Natalia V. Kamanina	Vavilov State Optical Institute, Russian Academy of Sciences, Russia Saint Petersburg Electrotechnical University, Russia Kurchatov Institute - Nuclear Physics Institute, Russia	Nanotechnology in optics, electronics and biomedicine: Advantages of the optical materials surface structuration with the carbon nanotubes
Emilio Fiordilino	Department of Physics and Chemistry, University of Palermo, Italy	Testing Quantum Mechanics Foundations with a Laser Field
Ivan A. Shuklov	Moscow Institute for Physics and Technology, Russia	Chalcogenide colloidal quantum dots of lead and mercury for near-/mid-IR-applications
Dag Hanstorp	Department of Physics, University of Gothenburg, Sweden	Photodetachment Studies of Negative Ions
15.40 – 16.40	***Session*** *Developments in nonlinear optics I*	*Chair:* ***Rashid A. Ganeev***
Rashid A. Ganeev	Institute of Astronomy, University of Latvia, Latvia, Saitama Medical University, Japan	Resonance processes during high-order harmonics generation in atomic and molecular plasmas

Authors	***Affiliations***	***Title of presentation***
Thursday, 22 April 2021		
Pavel V. Redkin[1], Rashid A. Ganeev[2], Wei Li[1]	1. Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, China 2. Institute of Astronomy, University of Latvia, Latvia	Coupled oscillations in enhancement of high-order harmonics generation
Vyacheslav V. Kim, Rashid A. Ganeev	Institute of Astronomy, University of Latvia, Latvia	Investigating laser plasma dynamics with high-order harmonics generation in carbon-containing nanomaterials
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Jānis Blahins, Uldis Bērziņš, Valdis Avotiņš, Arnolds Ūbelis	Institute of Atomic Physics and Spectroscopy, University of Latvia, Latvia	Technological challenges for next generation boron ion implantation device
Artūrs Ciniņš[1], Kaspars Mičulis[1], Nikolai Bezuglov[2]	1. Institute of Atomic Physics and Spectroscopy, University of Latvia, Latvia 2. Saint Petersburg State University, Russia	Two-photon selection rules of HF structure for Rydberg atomic states
Inga Brice[1], Toms Salgals[2,3], Vjaceslavs Bobrovs[2], Roman Viter[1], Jānis Alnis[1]	1. Institute of Atomic Physics and Spectroscopy, University of Latvia, Latvia 2. Institute of Telecommunications, Riga Technical University, Latvia 3. AFFOC Solutions Ltd., Latvia	Whispering gallery mode silica microsphere resonator applications for biosensing and communications
Jānis Blahins, Arnolds Ūbelis	National Science Platform FOTONIKA-LV, University of Latvia, Latvia Institute of Atomic Physics and Spectroscopy, University of Latvia, Latvia	Small size Boron ion implanter concept

Authors	***Affiliations***	***Title of presentation***
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Michael Wöstmann, Helmut Zacharias	Center for Nanotechnology and Center for Soft Nanoscience, University of Münster, Germany	Control of Quasi-Phase-Matched High Harmonic Generation in Structured Plasmas
Sergey Yu. Stremoukhov	Faculty of Physics, Lomonosov Moscow State University, Russia National Research Centre "Kurchatov Institute", Russia	Quasi-Phase Matching of High-Order Harmonics in Mid-IR Laser Fields
Elena A. Anashkina, Alexey V. Andrianov	Institute of Applied Physics, Russian Academy of Sciences, Russia	Nonlinear optical and laser effects in microresonators based on silica and non-silica tellurite and chalcogenide glasses

Authors	***Affiliations***	***Title of presentation***
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Jānis Alnis, Aigars Atvars, Roberts Berķis, Dina Bērziņa, Uldis Bērziņš, Inga Brice, Artūrs Ciniņš, Kristians Draguns, Kārlis Grundšteins, Viesturs Ignātans, Pauls Kristaps Reinis, Lāse Mīlgrāve, Arvīds Sedulis, Alma Ūbele	Institute of Atomic Physics and Spectroscopy, University of Latvia, Latvia	From ultra-stable laser resonators for atomic spectroscopy and fiber-based femtosecond optical frequency combs to whispering-gallery-mode microresonator sensors and microsphere optical frequency combs for telecommunication data transfer
Arseny A. Sorokin[1], Aleksey V. Andrianov[1], Gerd Leuchs[1,2], Elena A. Anashkina[1]	1. Institute of Applied Physics, Russian Academy of Sciences, Russia 2. Max Planck Institute for the Science of Light, Germany	Theoretical analysis of limiting factors for quantum noise squeezing of ultrashort pulses in optical fibers
Aigars Atvars[1], Alexander Narbut[2,3]	1. Institute of Astronomy, University of Latvia, Latvia 2. Institute of Atomic Physics and Spectroscopy, University of Latvia, Latvia 3. COMCON*TRIZ & FRT corporation, Ukraine	TRIZ forecast of the development of research on optical microresonators
Artūrs Ciniņš[1], Kaspars Mičulis[1], Nikolai Bezuglov[2]	1. Institute of Atomic Physics and Spectroscopy, University of Latvia, Latvia 2. Saint Petersburg State University, Russia	The Optimal (Tom and Jerry) pairs of cold Rydberg atoms in Penning Ionization processes
13.15 – 14.55	***Session*** *Spectroscopy and space sciences*	*Chair:* ***Arnolds Ūbelis***
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Uldis Bērziņš, Arnolds Ūbelis, Armans Bžiškjans, Andris Vanags	Institute of Atomic Physics and Spectroscopy, University of Latvia, Latvia	Oscillator Strengths of Arsenic Resonance Lines
Javed Iqbal[1,2,4], François Vidal[1], Rashid Ganeev[2,3]	1. National Institute of Scientific Research, Center for energy, materials and telecommunications, Canada 2. Institute of Astronomy, University of Latvia, Latvia 3. Voronezh State University, Russia 4. Department of Physics, University of Azad Jammu and Kashmir Muzaffarabad, Pakistan	Laser Induced breakdown spectroscopy as an Emerging technique for Mineral and Space Exploration
Vidvuds Beldavs	Riga Photonics Centre, Latvia	Moon-Earth: A concept for building a space-resources based economy
Igmārs Eglītis, Ilgonis Vilks, Anna Bule, Adelaida Sokolova	Institute of Astronomy, University of Latvia, Latvia	Some results of three projects of the Institute of Astronomy of UL
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Vladimirs Gostilo, Anna Bulycheva, Rais Nurgalejevs, Igors Krainjukovs	Baltic Scientific Instruments Ltd., Latvia	Radiation Detection Materials and Detector Technologies for Radiation Detectors

Authors	Affiliations	Title of presentation
Friday, 23 April 2021		
Oleg Dimitriev[1], Petro Smertenko[1], Olexander Gridin[1], Eduard Manoilov[1], Vadym Naumov[1], Arnolds Ubelis[2]	1. Institute of Semiconductor Physics, National Academy of Sciences of Ukraine, Ukraine 2. National Science Platform FOTONIKA-LV, University of Latvia, Latvia	Towards Energy-Efficient Technologies with Smart Optical Sensing and Shape-Assistant Trapping of Infrared Emission
Serhii Pohuliai, Aleksandrs Sokolovs, Aleksandrs Kipluks	Baltic Scientific Instruments Ltd., Latvia	Monitoring of Radioactive Waste on Nuclear Industry
Boriss Janins, Jurijs Antonovs	SLICKER Ltd., Latvia	Small form-factor supermultiview 3D display using Gabor superlens
16.45 – 18.05	**Poster session II**	Chair: **Jānis Alnis**
Janis Braunfelds[1,2], Jurģis Porins[1], Sandis Spolītis[1,2], Vjačeslavs Bobrovs[1]	1. Institute of Telecommunications, Riga Technical University, Latvia 2. Communication Technologies Research Center, Riga Technical University, Riga, Latvia	FBG sensors for structural health monitoring of road infrastructure
Kristians Draguns[1,2], Inga Brice[1], Aigars Atvars[1], Jānis Alnis[1]	1. Institute of Atomic Physics and Spectroscopy, University of Latvia, Latvia 2. AFFOC Solutions Ltd., Latvia	Dispersion engineering of whispering gallery mode resonators
Jaime R. Ek-Ek[1,2], Fernando Martinez-Piñon[1], Frans Segerink[2], Jeroen P. Korterik[2], Raúl Castillo Perez[3], Carlos Jacome-Peñaherrera[3], Herman L. Offerhaus[2], Jose A. Alvarez-Chavez[3]	1. National Polytechnic Institute, Center of Technologic Innovation and Investigation, Mexico 2. Optical Sciences Group, University of Twente, The Netherlands 3. National Polytechnic Institute, Postgraduate in Telecommunications, ESIME Zacatenco, Mexico	Optical Fibre Taper Simulation and Manufacture: from Standard to Micro Size
Lāse Mīlgrave, Pauls Kristaps Reinis, Kristians Draguns, Inga Brice, Jānis Alnis, Aigars Atvars	Institute of Atomic Physics and Spectroscopy, University of Latvia, Latvia	Liquid whispering gallery mode humidity sensor and its applications
Toms Salgals[1,2], Jānis Alnis[3], Rihards Mūrnieks[1,4], Inga Brice[3], Jurģis Poriņš[1], Alexey V. Andrianov[5], Elena A. Anashkina[5], Sandis Spolītis[1,2], Vjačeslavs Bobrovs[1]	1. Institute of Telecommunications of the Riga Technical University, Latvia 2. AFFOC Solutions Ltd., Latvia 3. Institute of Atomic Physics and Spectroscopy, University of Latvia, Latvia 4. Communication Technologies Research Center, Riga Technical University, Riga, Latvia 5. Institute of Applied Physics, Russian Academy of Sciences, Russia	Microsphere-based OFC-WGMR multi-wavelength source and its applications in telecommunications
Viesturs Silamiķelis, Aigars Apsītis, Valdis Avotiņš, Arnolds Ūbelis	Institute of Atomic Physics and Spectroscopy, University of Latvia, Latvia	Development of next generation technology for ultra purity crystal growth based on MHD semi levitation

Authors	*Affiliations*	*Title of presentation*
Friday, 23 April 2021		
Kaspars Zaķis[1], Andis Supe[1], Sandis Spolītis[1,3], Sergejs Olonkins[1,2], Aleksejs Udaļcovs[2], Jurģis Grūbe[4], Edgars Elsts[4], Oskars Ozoliņš[1], Vjačeslavs Bobrovs[1]	1. Institute of Telecommunications, Riga Technical University, Latvia 2. AFFOC Solutions, Ltd., Latvia 3. Communication Technologies Research Center, Riga Technical University, Latvia 4. Institute of Solid State Physics, University of Latvia, Latvia	Modelling of Cladding-Pumped Erbium/Ytterbium Co-Doped Fibre Amplifier for C-Band Operation
Roberts Berķis, Kristians Draguns, Jānis Alnis, Inga Brice, Aigars Atvars	Institute of Atomic Physics and Spectroscopy, University of Latvia, Latvia	Wavelength measuring for optical telecommunications, using tapered fiber, image analysis and PMMA WGM micro resonators

NSP FOTONIKA-LV on the upwards track

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The Association of research institutes of the University, FOTONIKA-LV, formed April 24, 2010 was designated to National Science Platform FOTONIKA-LV in quantum sciences, space sciences and related technologies by the decree of the University of Latvia No.1/215 on June 18, 2018. In early spring, just 10 years ago, directors of three institutes signed an agreement unique in the history of Latvian science, to create a framework where research communities, continuing to keep, in history based national scale, responsibility in relevant areas, joined forces to undertake larger cross-disciplinary research projects under the umbrella of photonics – the driving technology of the 21st century. FOTONIKA-LV received special notice in the report of international evaluators of Latvian science led by TECHNOPOLIS group[1]: "*In April 2010, three institutions of the University of Latvia (Atomic Physics and Spectroscopy, Astronomy and Geodesy and Geoinformatics) established the association FOTONIKA–LV with the aim to take responsibility for sustainable advancement of the sector of photonics in Latvia. The association submitted an ambitious FP7 project of basic and applied research in traditional and innovative fields of photonics: REGPOT–2011-1 which was eventually granted € 3.8 million. Other laboratories should follow this example*".

Six years passed since the report was published, but NSP FOTONIKA-LV still is unique phenomenon in research landscape in Latvia. NSP FOTONIKA-LV is open for new partnerships and is prepared to expand across borders of the University.

NSP FOTONIKA-LV face the problems typical to the whole research community in Latvia precisely highlighted in the already cited TECHNOPOLIS report from 2014:

- acute shortage of institutional funding *(see page #27[2])* is the case also in 2021;
- evidence shows that *low political priority of innovation and research* 3 in Latvia is going to be the problem for years to come.

Nevertheless NSP FOTONIKA-LV in the Year 2021 is on hard, but convincingly upwards going, promising track scaling up fundamental and applied research activities and cooperation with industry on national level, inside European Research Area and worldwide.

The foundation of the Association FOTONIKA-LV followed by NSP FOTONIKA-LV, evidently, was strategically decisive step and structural change, granting survival of national research community within the frame of photonics despite exclusively unfavourable to RTD and innovation policy in Latvia. The idea was inherited in the outstanding achievements of researchers and collected intellectual capital of the laboratories and observatories currently forming NSP FOTONIKA-LV at the University since the early 1960s in following fields:

- Quantum optics, laser spectroscopy, VUV, UV and visible light spectroscopy;

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[1] Arnold, E., Knee, P., Angelis, J., Giarraca, F., Griniece, E., Jávorka, Z., Reid, A. 2014. Latvia - Innovation System Review and Research Assessment Exercise: Final Report. TECHNOPOLIS, April 20, 2014: DOI: 10.13140/RG.2.2.21960.52489. https://www.researchgate.net/publication/312593088_Latvia_Innovation_System_Review_and_Research_Assessment_Exercise

[2] Only 17% of research funding is institutional (ERAWATCH Country Report, 2011), making Latvia's one of the most highly 'contested' systems in the world. While there is no clear international benchmark for what the proportion of institutional funding should be, there is some consensus that 50% is the minimal viable level. The Finnish Research and Innovation Council recently observed that the share of competitive funding in the university research system has recently approached that value and that to do any further would be dangerous, citation from page 27.

[3] The difficult financial climate, short-term planning within the state, insufficient administrative capacity and the low political priority of innovation and research and a heavily bureaucratic tradition all make it hard to implement research and innovation policy in Latvia, citation from page 38.

- Atomic, molecular and optical physics, molecular beam and ion beam physics; ICP plasma devices;
- Optical fibres technologies, in particular UV fibre optics;
- Vacuum-sputtering, quartz, glass and vacuum technologies;
- Atmosphere physics and photochemistry; development of atmospheric remote sensing devices;
- Observational astronomy and astrophysics of galactic carbon stars, research on late evolution stars (MS, S type);
- Observation, and monitoring of small objects (asteroids) of the Solar System and Near Earth Objects with wide field Ø1.2 metres Schmidt type telescope in Baldone (Code 0.69);
- Terrestrial geodesy and geodynamics measurements with the world class laser telescope LS-105 with which Latvian astronomers have served for decades as a node of the International Laser Ranging Service (ILRS code name RIGL-1884, Riga);
- Advancement of satellite laser ranging (SLR) instruments, including software and hardware components;
- During the last decade contribution in various areas of applied research is on the agenda basing on cooperation with research driven SMEs in Latvia and looking forward across the national borders.

The isolation from international research community came to the end when “iron curtain” was removed in 1990. A lot of various strategic international partnerships emerged due to very supportive attitude of international research community to recognized researchers in Latvia (The Baltic state which restored independence after 50 years of Soviet occupation).

Incorporation in European Research Area via association to EU Framework Research programmes and participation of implementation of work programmes of FP5, FP6, FP7 and HORIZON 2020 EU Framework programmes for RTD and innovation was exclusive chance for the survival of FOTONIKA-LV research community when national funding was cut down drastically. Availability of resources coming from EU Regional development funds when Latvia joint EU was another valuable asset despite awful bureaucratic burden wasting time and suppressing creativity.

The Fig. 1 provides insight in the budget dynamics since 2001 of research community from which NSP FOTONIKA-LV emerged. The budget is result of intensive project life. National budget funding (institutional funding) formed for years only 10 % of the sum needed to sustain full scale research activities.

Unique ERA Chair project is the best one from the point of view of “academic freedom” available to 6 highly qualified researchers which means new opportunities to be successful with new project proposals up to the level of Future Emerging Technologies projects and European Research Council grants in Horizon Europe programme (2021-2027) and to attract experienced researchers and students from diaspora and to recruit researchers from abroad via Marie-Curie fellowships, Post Doc Grants and ERASMUS projects.

The absence of institutional funding “de facto” still is very painful problem, but now research community of NSP FOTONIKA-LV has capacity to influence and to change RTD policy in Latvia via authority of recruited ERA Chair supported by International Scientific Council of FOTONIKA-LV representing strategic partnership institutions in European Research Area.

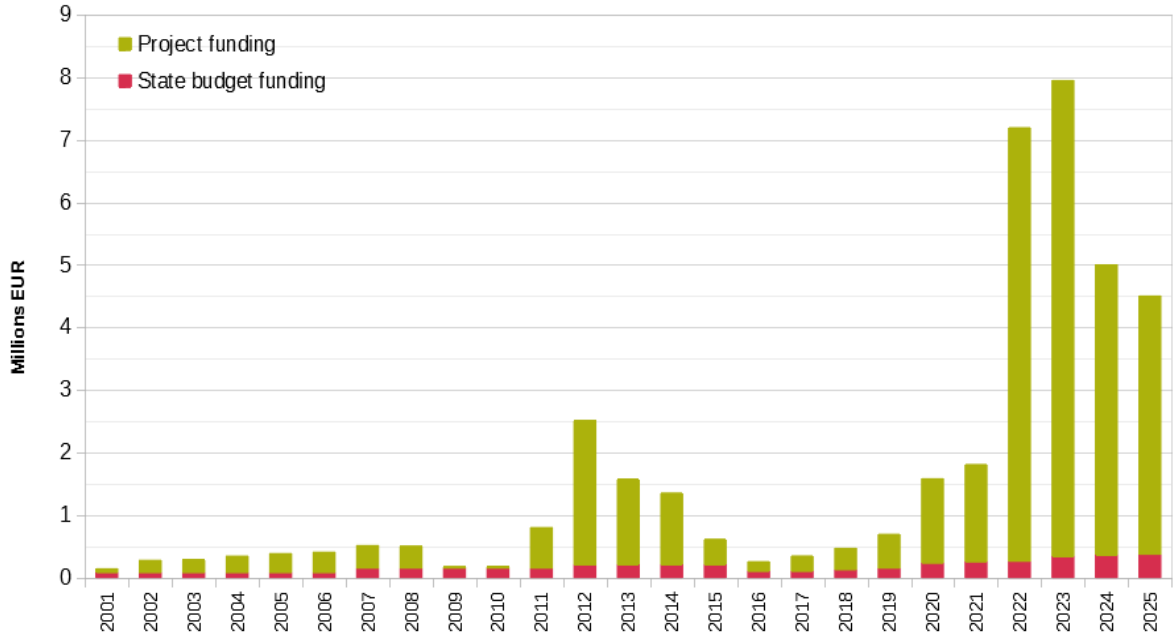

***Fig. 1**. Financial history and project life since 2001 of research institutes and researchers' community related to NSP FOTONIKA-LV.*

The progress of the ERDF project "The Development of Quantum Optics and Photonics at the University of Latvia" (refinanced Horizon 2020 ERA Chairs project)

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The University of Latvia (UL) implements European Regional Development Fund Project No. 1.1.1.5/19/A/003 "The Development of Quantum Optics and Photonics in University of Latvia" (Project) [1]. The realisation period of the project activities is 01.05.2019 – 30.11.2023. The budget of the Project is EUR 2.5 million (85% covered by European Regional Development Fund and 15% covered by State budget). The Project was initially submitted to the Horizon 2020 call "WIDESPREAD-04-2019: ERA Chairs" and was scored above the threshold.

The objective of the Project is to attract a high-level research leader (ERA Chair) who will develop quantum optics and photonics at the University of Latvia and thus will raise the research quality and international recognition of UL. Project has the following work packages: WP1. Selection and Recruitment of an ERA Chair; WP2. Selection, recruitment, and personnel management of an ERA Chair's research team; WP3. Research activities of an ERA Chair and his/her team; WP4. Preparation of competitive project proposals; WP5. Strategy development and implementation of structural changes; WP6. Communication, Networking, and Dissemination; WP7. Management. The main expected results of the Project and their achievements so far are summarized in Tab.1.

Tab. 1. *Main expected results of Project No. 1.1.1.5/19/A/003 and achievements as of 25.03.2021*

Expected result	***To be achieved during the Project, by 30.11.2023***	***Achieved till 25.03.2021***	***Achieved till 25.03.2021 %***	***Planned to be achieved by the end of 2021***
ERA Chair holder recruited (agreement)	1	1	100%	1
ERA Chair scientific group recruited (agreements)	4	2 + 3 (selected)	50%	5
Publications submitted	24	8 (5 published)	33%	> 20
Project proposals submitted	6	5 (1 funded)	83%	> 7
Patents applied	2	0 in progress	0%	0 in progress
Lecture course prepared	1	0 in progress	0%	0 draft version
Human Resources Strategy for Researchers prepared	1	0 in progress	0%	0 in progress
Strategy for the Development of Quantum Optics and Photonics at the University of Latvia prepared	1	0 in progress	0%	0 preliminary draft version prepared
International conferences organized	2	0 in progress	0%	1

The Project has an international Advisory Board who, within a Selection Committee, launched an international open-competition for the ERA Chair position [2] and evaluated candidates.

Finally, Dr. Rashid Ganeev was selected and recruited as an ERA Chair in Quantum Optics and Photonics at the University of Latvia. R. Ganeev is a highly productive researcher with a total number of publications (SCOPUS) 504 and H-index (SCOPUS) 47. He is the author of 8 monographs. His research topics cover quantum optics and photonics, including research on resonance-induced processes of single high-order harmonic enhancement in different metal plasmas, time-resolved plasma characterization with spectral, morphological, and harmonic issues, studies of the nonlinear refraction, and nonlinear absorption in nanoparticles suspensions. The ERA Chair's main tasks are to develop quantum optics and photonics at UL, lead the ERA Chair research group, prepare new project proposals, develop Strategies, and implement structural changes at the UL to achieve excellence on a sustainable basis. For implementing research activities of R. Ganeev, a Laboratory of Nonlinear Optics at UL was established.

The core research team of the ERA Chair has been selected in an international competition and is formed by Janis Alnis (Latvia; whispering gallery mode resonator sensors), Uldis Bērziņš (Latvia; atomic spectroscopy), Javed Iqbal (Canada, Pakistan; laser-produced plasma), Vyacheslav Kim (United Arab Emirates, Uzbekistan; high-order harmonic generation) and Claudio Conti (Italy; machine learning in photonics). R. Ganeev leads this research group and supports the career development of its members.

During the Project, various new project proposals are prepared. In 2020, two project proposals were submitted to Horizon 2020 FET Open and RISE calls, two project proposals in the Latvian Science Council call, and one project proposal for ERDF Activity 1.1.1.1. call. The former project No. 1.1.1.1/20/A/070 "Next generational technology for high purity crystal growth using MHD pseudo levitation "was approved for funding. In 2021, an ERC Advanced grant proposal is being prepared by R. Ganeev (submission deadline August 2021), Horizon EUROPE Teaming project (expected submission deadline Fall 2021), and Latvian Council of Science projects (submission deadline August 2021) are under preparation. Horizon EUROPE Teaming Project (6 years, 15 million EUR from the European Commission + 15 million from National funding) is seen as a proper continuation of an ERA Chair project.

The Project aims to implement structural changes at UL that will allow to form and keep research excellence on a sustainable basis. For this, the "Strategy for the Development of Quantum Optics and Photonics at the University of Latvia" and "Human Resource Strategy" will be developed. Project members are involved in the working groups to prepare "Strategy of the University of Latvia 2021-2027". R. Ganeev is providing his competence on research article preparation. Actions are taken to mobilize the research community of UL in the field of quantum optics and photonics. Joint research seminars in the House of Science of UL will be launched. New partnerships with foreign research institutions - Center for Soft Nanoscience, Muenster University (Germany), and Sapienza University of Rome (Italy) – were created for joint research and project preparation.

R. Ganeev is preparing a lecture course "Nonlinear Optics of Plasmas" to present to physics students of UL. It is expected that this course, together with other publicity activities of ERA Chair, will raise the attractivity of the field of quantum optics and photonics, and will grow human resources in this field for the benefit of research and industry. National Science Platform (NSP) FOTONIKA-LV as an initiator of the Project, holds a network of photonics companies in Latvia. This network will be employed to launch industry-driven research topics and new technologies.

Actual information is on the Project web page - https://www.erachair.lu.lv/.

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Laser spectroscopy applied to the environmental, ecological, and agricultural areas

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An overview of the possibilities of laser spectroscopy applied to the environmental, ecological, and agricultural areas is given, based on the experience of the author within these fields at LU, Lund and SCNU, Guangzhou.

Optical probing of the atmosphere using active remote sensing techniques of the laser-radar type will be discussed, but also some passive techniques employing ambient radiation. Atmospheric objects of quite varying sizes can be studied. Mercury is the only pollutant in atomic form in the atmosphere, while other pollutants are either molecular or in particle form. Light detection and ranging (Lidar) techniques provides three-dimensional mapping of such constituents. Recently, the techniques have been extended to the ecological field. Monitoring of flying insects and birds is of considerable interest, and several projects have been pursued in collaboration with biologists.

Fluorescence lidar also allows remote monitoring of vegetation and historical building facades. In agricultural applications, e.g., the fertilization levels of crops can be assessed. Drone-based techniques are now also augmenting the possibilities of fluorescence mapping of the environment.

Laser spectroscopy also allows for non-intrusive quality control of pharmaceutical preparations and foods, now mostly employing the gas in scattering media absorption spectroscopy (GASMAS) technique.

The talk emphasizes the value of cross-disciplinary work to help solving important societal issues. Some background material is provided as Refs [1-10].

Acknowledgements

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Quantum Silicon Photonics

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We are on the dawn of the second quantum revolution, where single particles, quantum superposition and quantum entanglement are used to enable new technologies and devices. In this talk, I will review few devices, which are based on these concepts. In addition, I will show that Silicon Photonics is the proper platform to integrate quantum photonics. Indeed, Silicon Photonics is the technology to fabricate photonics devices with standard silicon microelectronics processing. By using Silicon Photonics, I will discuss:

1. a tiny, low cost, high performance fully silicon device to generate random numbers for security applications,
2. a source of single photon entanglement which can be used as a resource for quantum information applications such as quantum key distribution or as certified quantum random number generator,
3. a heralded single photon sources which works in the MIR and can be used for ghost imaging or undetected photon spectroscopy,
4. a near-ideal spontaneous photon sources in silicon quantum photonics which could enable a silicon quantum computer.

High-Accuracy Laboratory Atomic Astrophysics

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Analyses of astronomical spectra rely on detailed knowledge of the structure of the atomic species involved. Furthermore, the line strengths must be accurately known to use astronomical spectra for quantitative analyses, such as determination of stellar and nebular temperature, density or ultimately the chemical abundance. The near-infrared wavelength region, 1-5 µm, is becoming more important thanks to its smaller interstellar extinction and several spectrographs are coming online matching these needs, e.g., the CRIRES+ at VLT and the APOGEE survey. The planned European Extremely Large Telescope (E-ELT) will observe predominantly in the infrared domain, and the lack of data will appear significant also in this case. In addition, the optical region surveys are dependent on accurate atomic transitional data to fully exploit the expensive observations.

Our research program on Laboratory Atomic Astrophysics focuses on meeting the needs for infrared atomic data, both line identification and measurements of intrinsic line strengths, the oscillator strengths.

We will review the branching fraction and lifetime technique to measure line strengths, using the high-resolution Fourier spectrometer at Edlen Laboratory, in combination with radiative lifetimes. The measurements are combined with calculations using the GRASP and ATSP2k codes, providing a high-accuracy data set for astrophysical analysis. We participate in observational programs to identify the relevant problems and priorities in need for atomic data.

In the present contribution, we will discuss infrared transitions from an atomic structure point of view and as a base for the astronomical analysis as well as for laboratory and theoretical priorities. Furthermore, we will discuss the effect of hyperfine structure on the astrophysical analysis. Examples are given from recent and ongoing studies on e.g., Sc I, Mg I, Si I and La I.

New areas include the radiative data for nuclear capture elements and kilonova spectroscopy, which are not available with the existing techniques. We will discuss new developments to measure lifetimes for these important elements and a recent collaboration with the group of Lead researcher Uldis Berzins (University of Latvia) around light sources to access the spectrum of additional elements for spectroscopic analysis.

Laser Spectroscopy to Meet Some Challenges in Medicine

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There are a lot of unmet needs in medicine, such as reliable tools for early tumor detection, objective guidance in therapy decisions in infectious diseases avoiding the alarming development of antibiotic resistance, too few minimal invasive surgical procedures among other challenges. Laser spectroscopy has been shown to be a valuable tool, both in the detection and the therapy of human malignancies. The most important prognostic factor for cancer patients is early tumor discovery. If malignant tumors are detected during the non-invasive stage, most tumors show a high cure rate of more than 90%. Even though there are many conventional diagnostic modalities, very early tumors may be difficult to discover. Laser-induced fluorescence (LIF) for tissue characterization is a technique that can be used for monitoring the biomolecular changes in tissue under transformation from normal to dysplastic and cancer tissue before structural tissue changes are seen at a later stage. The technique is based on UV or near-UV illumination for fluorescence excitation. The fluorescence from endogenous chromophores in the tissue alone, or enhanced by exogenously administered tumor seeking substances can be utilized. The technique is non-invasive and gives the results in real-time. LIF can be applied for point monitoring or in an imaging mode for larger areas, such as the vocal cords or the portio of the cervical area.

Photodynamic therapy is a selective treatment technique for human malignancies. To overcome the limited light penetration in superficial illumination interstitial delivery (IPDT) with the light transmitted to the tumor via optical fibers has been developed. Interactive feed-back dosimetry is of importance for optimizing this modality and such a concept has been developed. The technique has special interest for tumors where there are no other options, such as for recurrent prostate cancer after ionizing radiation. For correct dosimetry it is important to assess the optical properties of tissue; this can be done by time resolving propagation techniques.

Another technique which has been developed for medical application is based on gas in scattering media absorption spectroscopy (GASMAS). The technique is used to detect free gas (e.g., oxygen and water vapor) in hollow organs in the human body and has been applied to the detection of the human sinus cavities in the facial skeleton. The GASMAS technique might also be used for the surveillance of prematurely born infants. As the organs are not fully developed there is a risk of morbidities. In particular, the lung function is limited, and the babies may develop respiratory distress syndrome resulting in decreased oxygen saturation affecting risk organs, such as the brain. GASMAS may also be developed for detection of other diseases, such as middle ear infection in small kids. A certain proportion of these infections are viral induced and in these cases no antibiotics should be prescribed. GASMAS has a potential to discriminate the origin of the disease and thus guide in the decision of appropriate therapy, trying to fight the global problem of antibiotic resistance. Many of these techniques can also be applied to study other organic materials, e.g., foods.

A few references, illustrating laser spectroscopy applied to the medical area, are given in [1-10].

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Nanotechnology in optics, electronics and biomedicine: Advantages of the optical materials surface structuration with the carbon nanotubes

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It is well known that at the present time the nanotechnology approach has been used by different scientific and technical teams in order to optimise the basic physical-chemical properties of the materials. In the current research the comparative study of the spectral parameters, wetting phenomena, as well as of the micro hardness improvement for the large groups of the model optical materials such as: KCl, KBr, LiF, MgF2, BaF2, CaF2, Si, ZnS, Sc, ITO, etc. have been shown via surface structuration. The carbon nanotubes have been chosen as the specific and the effective nano-objects, which permit to modify the materials physical-chemical characteristics with good advantage. The laser-oriented deposition (LOD) technique with an additional procedure to use the surface electromagnetic waves (SEWs) has been shown. The CO2-laser has been used in this case. Some special accent has been given to postulate the nanostructurisation process advantage to modify the ITO conducting coatings and the PVA thin-film polarizers. The resistivity and refractivity change of the ITO coatings have been presented; the improvement of the transmittance of the parallel component of the electromagnetic wave for the PVA polarizers has been shown and explained. Analytical and quantum-chemical simulations have supported the experimental results.

Furthermore, additional data have been received and discussed for the nanostructured organic conjugated materials (polymers, monomers and the liquid crystal ones) via change of their refractive parameters. The fullerenes, shungites, graphene oxides, etc. nano-sensitisers have been used. Nd-pulsed laser has been applied in this case. The area of the structured materials application can be extended from optoelectronics to biomedicine.

Some previously obtained results have been shown in papers [1-3].

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Testing Quantum Mechanics Foundations with a Laser Field

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Our communication presents a systematic theoretical test of the fundamental laws of Quantum Mechanics by means of a laser field that has been demonstrated to be a powerful tool for the investigation of the behaviour of atoms, molecules and nanoparticles because of its versatility to be tuned - in intensity, frequency and duration – according to the requirements of the designed experiment. One important feature is the possibility of setting the laser angular frequency ω_L to resonance with a Bohr transition of a quantum object; in this way the wave function of the object undergoes rapid oscillations and introduce a wealth of effects that would, otherwise, be of difficult observation. Moreover quantum objects driven by a laser field become source of new electromagnetic radiation the spectrum of which contains a large plateau of odd harmonics of ω_L. The diffused radiation carries information on the nature and comportment of the objects; it can be detected and unveil microscopic properties otherwise not observable.

Quantum Physics is based upon postulates which can be checked in their validity by slightly changing the form of the Schrödinger equations and by observing the sort of modifications that are produced by the new form. In the communication we present investigations on two issues: 1. the linearity of Quantum Mechanics and 2. the *constancy* of physical constants.

1. Linearity is a basic axiom of Quantum Mechanics which has been object of investigation [1]. We have introduced in the form of the Schrödinger equation describing an atom-radiation interaction a tiny non linearity and observed that under opportune conditions the dynamics of the object presents traits of non-predictability of chaotic nature. In fact, the population of the quantum states in the non-linear case is very sensitive on the initial atomic state and this fact is a flag of Chaos in the realm of Classical Physics.
2. Since Dirac’s [2] hypothesis that Newton’s gravitational constant *G* is time dependent, a fervid debate has been carried out on the possibility that other constants – dimensionless or not – may be variable. Experimental evidence, although not universally accepted, suggests that the fine structure constant α and Plank’s constant might be time [3] or space dependent [4,5]. We introduce a general form of the Schrödinger equation and two experimental protocols to investigate the behaviour of an atom driven by a laser field under the hypothesis that $\hbar$ is not constant. The form of the new Schrödinger equation assumes a particular simple form if we define a new time standard $\tau = \int_0^t \hbar(t')\, dt'$ that substitutes the ordinary time. The first protocol requires two observations of the time evolution of the population of the ground state of an atom at different moments separated by a gap of one hour. The second one requires the measurement of the harmonic spectrum emitted by the atom. Both experiments are well inside the today’s state of art. We observe again modified chaotic evolution of the atomic dynamics and a redshift of the emitted harmonic lines. The results permit the setting of constraints on the value of $\Delta\hbar/\hbar$ which considerably improve the experimental constraints up to now presented. In Fig. 1 we show the harmonic spectrum emitted by an atom driven by a laser pulse. The spectrum contains hyper-Raman lines which are always predicted but never detected and odd order lines; these are slightly redshifted because of the assumed inconstancy of $\hbar$.

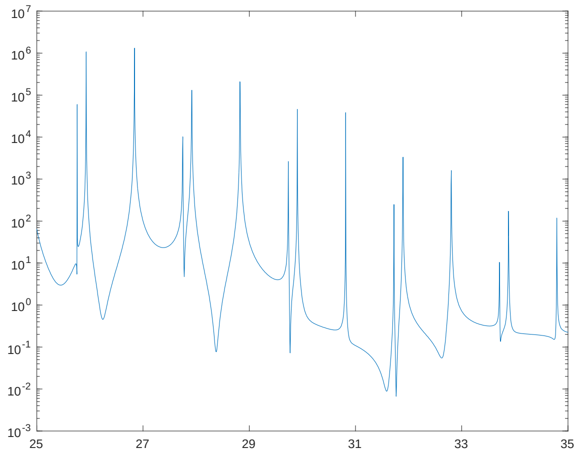

Fig. 1. *Spectrum emitted by an atom driven by a laser field when the Planck constant is dependent upon the coordinates. It is evident a small redshift of the odd order harmonics. The redshift can be measurable.*

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Chalcogenide colloidal quantum dots of lead and mercury for near-/mid-IR-applications

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The use of colloidal quantum dots (CQDs) offers an interesting alternative to the expensive epitaxially-grown structures for the production of low-cost infrared detectors. Technologies based on near-/mid-IR CQDs are not as mature as application of CQDs visible spectral range. Near-IR energies could be achieved with lead chalcogenide CQD. The long wavelength could not be accessed with these CQD due to their bulk band gap. So PbS posses the band gap in bulk (0.41 eV) and the lowest band gap in bulk among lead chalcogenides observed for PbSe (0.28 eV). Semimetals, such as HgTe or HgSe are showing the most promising properties for the creation of CQD devices for the mid wavelength infrared (MWIR).

Significant effort has been invested in the development methods for the synthesis of chalcogenide CQD of lead and mercury [1]. The particular interest was paid to the development of the production of CQDs with narrow size distribution and good stability [2,3]. Nevertheless, even for the most developed lead sulphide CQD is rather difficult to get the broad range of nanocrystals sizes and the narrow size distribution by a single method of PbS synthesis. Another acute problem is lack of understanding of the chemistry involved in the synthesis of chalcogenide quantum dots, that hampers developing efficient methods of chalcogenide CQD production.

Controlled aging of PbS

The joint-application of the lead oleate in the oleic acid as a lead precursor with sulphur-oleylamine reagent was developed for the synthesis of PbS CQDs [4], and the influence of temperature, Pb/S-ratio was studied in detail. The innovative controlled aging approach to the quantum dots of PbS will be described. The combination of this approach with the described synthetic method allows to produce the PbS colloidal quantum dots with first excitonic peak from 1100 to 2050 nanometres. Our controlled aging approach is designed to utilize a larger PbS QDs as a starting material for smaller QDs, and therefore significantly increase the range of accessible QDs.

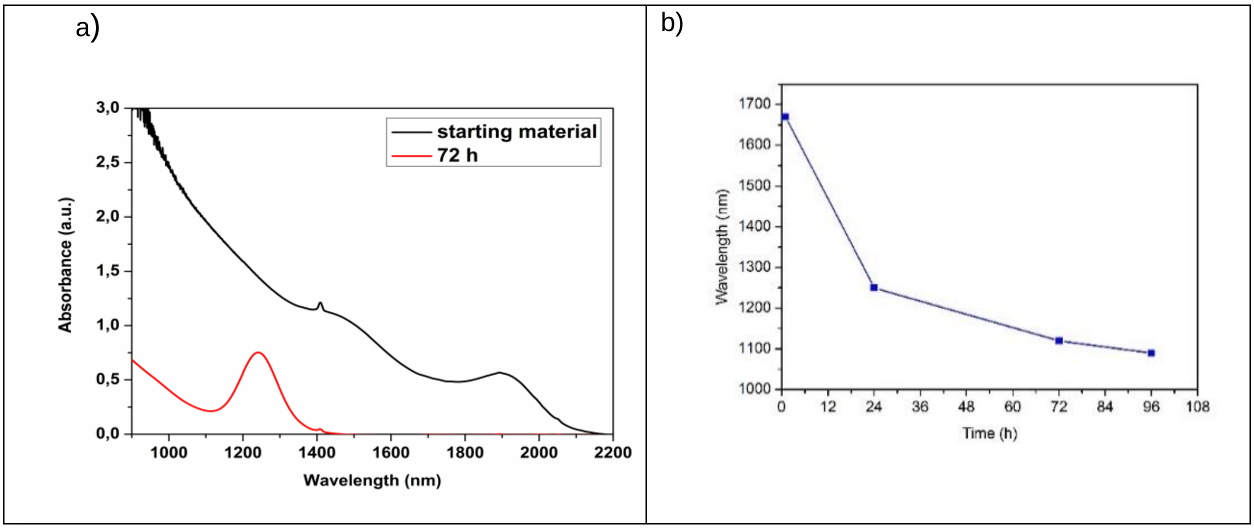

Fig. 1. *Aging of QD PbS by storage of solution CQDs in the presence of oleylamine-oleic acid mixture: a) absorption spectra of samples; b) Dependence of the absorption spectra from the storage time*

Mercury chalcogenides

The solution of elemental tellurium in trioctylphosphine is commonly used reagent for the synthesis of colloidal quantum dots of mercury tellurides as well as CdTe, SnTe, PbTe, Ag_2Te. There is absence of detailed information on this commonly used tellurium precursor. We used ^{125}Te and $^{31}P\{^1H\}$ NMR spectroscopy along with quantum-chemical calculations to study the nature of compounds formed by the dissolution of tellurium in trioctylphosphine.[5] Our NMR study expanded by DFT simulation results revealed the new unforeseen dimeric phosphine telluride-phosphine species dominating in the solution of this key precursor for metal telluride nanocrystals. The quantum chemical calculations suggest also that the nature of species in the tellurium solutions in lower trialkylphosphines should be similar to the solution in trioctylphosphine and therefore should be revised. Acquired knowledge allowed us to improve synthesis of HgTe colloidal quantum dots with absorption in Mid-IR.

a) b)

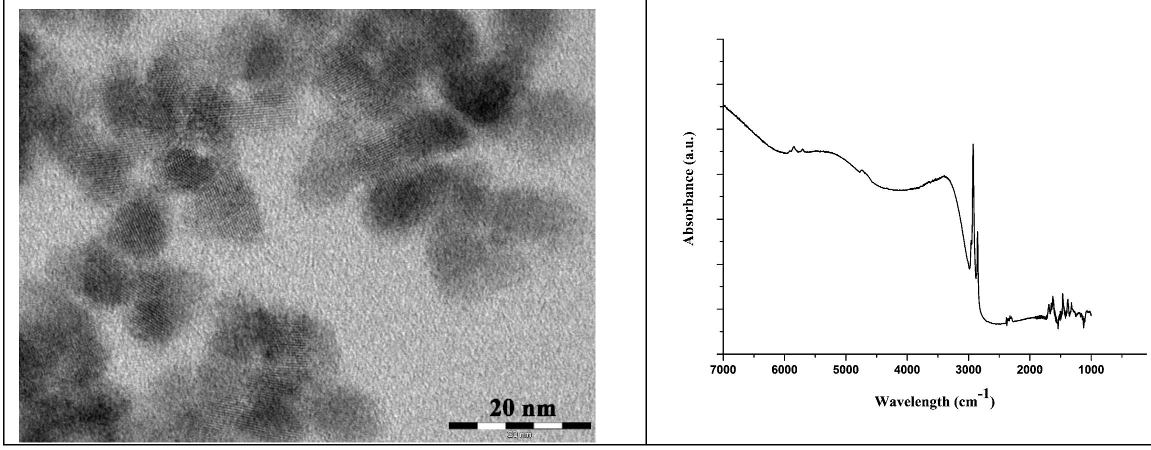

Fig. 2. *(a) TEM Image of HgTe QDs; (b) Absorption spectra of HgTe QDs.*

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Photodetachment Studies of Negative Ions

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The extra electron in a negative ion does not experience the Coulomb force from the nucleus at large distances. Instead, core polarization induced by the extra electron stabilizes the ion. The correlated motion of the electrons requires theoretical models that go beyond the independent particle approximation. Experimental investigations of the structure and dynamics of negative ions can hence lead to an increased understanding of many-electron effects.

I will review various laboratory experiments of negative ions. First, photodetachment experiments at the negative ion beam facility GUNILLA in Sweden and at the ISOLDE facility at CERN, revealing structural properties of various atomic negative ions, will be presented. Thereafter, I will show how the dynamics of negative can be be studied using femtosecond laser pulses in combination with velocity map imaging (VMI) spectrometer in order to visualise the electronic motion in the ground state of an atom. It will also be demonstrated how the 2-dimensional VMI technique can be used to produce complete a 3-dimensional image using a tomographic technique. Third, experimental investigations of lifetimes of excited state in negative ions using the cryogenic electrostatic double storage ring DESIREE will be presented. Finally, possible experiments using the GRIBA facility, located at University of Latvia, will be discussed.

Resonance processes during high-order harmonics generation in atomic and molecular plasmas

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High-order harmonics generation (HHG) is the efficient method for frequency conversion of laser radiation towards the extreme ultraviolet (XUV) region. We re-examine the resonance enhancement of single high-order harmonic during propagation of ultrafast pulses through different chromium-, tin-, and zinc-containing laser-induced plasmas (LIP). We compare the atomic (Cr, Zn, Sn) and molecular (Cr_2O_3, Cr_3C_2, ZnSe), as well as Sn nanoparticle, plasmas to demonstrate a distinction in the enhancement factor of the single harmonic.

Part of amplified uncompressed radiation from Ti:sapphire laser was separated from a whole beam and used as a heating pulse (HP) for LIP formation (Fig. 1). The focused compressed (806 nm, 64 fs) driving pulses (DP) were aligned to propagate through LIP at a distance of ~200 µm above the target surface for HHG. The beta-barium borate (BBO) crystal was inserted into the vacuum chamber in the path of the 806 nm focused radiation to generate second harmonic for the two-colour pump (TCP, 806 nm + 403 nm) of plasma.

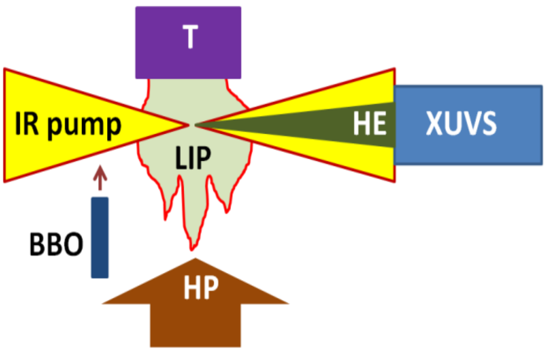

***Fig. 1**. Experimental setup for HHG in LIPs. IR pump: infrared (either 806 nm or tuneable NIR) driving femtosecond pulses; BBO: nonlinear crystal for second harmonic generation; T: solid target; HE: harmonic emission; XUVS: extreme ultraviolet spectrometer*

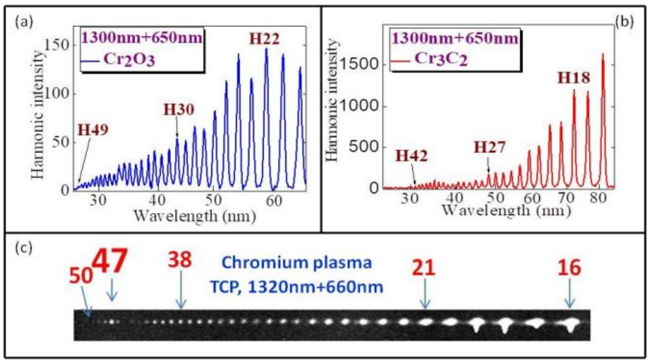

***Fig. 2**. Harmonic spectra from Cr_2O_3, Cr_3C_2 and Cr plasmas using tuneable NIR driving pulses. (a) HHG in Cr_2O_3 LIP using 1300 nm + 650 nm driving pulses. (b) HHG in Cr_3C_2 plasma using 1300 nm + 650 nm driving pulses. (c) HHG in Cr plasma using 1320 nm + 660 nm driving pulses at best conditions of plasma formation*

We also used the optical parametric amplifier pumped by above-described laser to apply the tuneable near infrared (NIR) radiation for HHG in LIP. Most of experiments were carried out using the 1 mJ, 70 fs signal pulses tuneable in the range of 1280–1440 nm. The harmonic radiation was analyzed using an XUV spectrometer.

We re-examine the resonance enhancement of single-harmonic emission during propagation of ultrafast pulses through the chromium-containing plasmas. We show how, in the case of 806 nm pump, the enhancement of 29^{th} harmonic (λ=27.8 nm) in Cr-containing plasma depends on the constituency of the plasma components at different conditions of target ablation. The application of tuneable (1280–1440 nm) radiation from optical parametric amplifier allows demonstrating the notable variations (from 46^{th} to 49^{th} order) of single-harmonic enhancement using two-colour pump of Cr plasma. Meanwhile, no enhancement of harmonics was observed in the case of chromium carbide and chromium oxide plasmas, except for the case of overexcited Cr_3C_2 plasma and 806 nm pump (Fig. 2).

We also reconsider the mechanism of resonant amplification of single harmonic in zinc-containing atomic and molecular plasmas when generating high-order harmonics. The selenides of this metal noticeably reduce the amplification of the single harmonic in comparison with purely atomic plasmas, probably due to the decrease of the oscillator strength of the involved ionic transitions (Fig. 3). The variations of single harmonic enhancement are demonstrated using fixed (806 nm) and tuneable (1280–1440 nm) radiation. Stronger ablation of these molecular targets did not allow the resonant amplification of the single harmonic in ZnSe plasma to be restored using different laser sources, probably due to the insufficient decay and disintegration of molecules leading to the appearance of zinc ions.

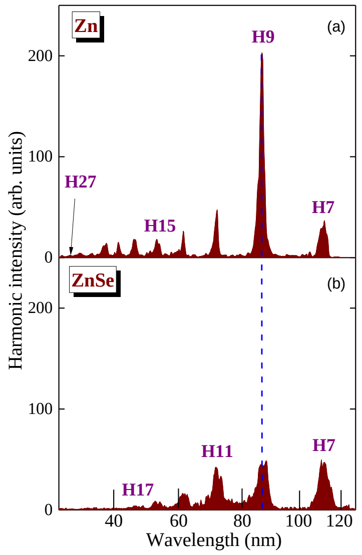

Fig. 3. *HHG from Zn-containing components of LIP using 806 nm driving pulses. (a) Harmonic spectrum generated in Zn plasma. (b) Harmonic spectrum generated in ZnSe plasma.*

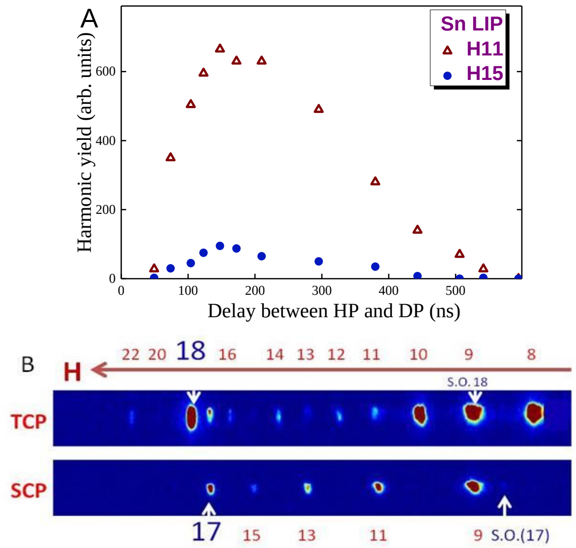

Fig. 4. *(A) Variations of the 11th (open triangles) and 15th (filled circles) harmonic yields at different delays between the heating and driving pulses. (B) Raw images of harmonics in the case of 806 nm and 403 nm pump (upper panel) and 806 nm pump (bottom panel) of tin plasma.*

Finally, we compare the resonance-induced enhancement of single harmonic emissions during propagation of ultrafast pulses through different tin-containing LIPs. The enhancement of the 17^{th} and 18^{th} harmonics of 806 nm pulses was analyzed in the case of single-colour and TCP of atomic tin plasma, showing up to a 12-fold enhancement of even (H18) harmonic compared with the neighbouring orders in the latter case (Fig. 4). We also compare the single-atomic Sn and Sn nanoparticles-containing plasmas to demonstrate a distinction in the enhancement factor of the single harmonic in the case of tuneable near-infrared pulses. We show the enhancement of a single harmonic in the vicinity of the $4d^{10}5s^25p^2P_{3/2} \rightarrow 4d^95s^25p^2$ transitions of SnII ions and demonstrate how this process depends on the constituency of the plasma components at different conditions of the target ablation.

Our research allows us to predict modification of the mechanism of resonant amplification of single harmonics reported in other atomic plasmas (manganese, selenium, tellurium, molybdenum, indium, and arsenic) being presented in the molecular form. This process can also be reconsidered by comparing the atomic and molecular plasmas containing the above elements, as well as by tuning the wavelength of driving radiation along those resonances that are responsible for the observed amplification of harmonics.

Acknowledgements

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Coupled oscillations in enhancement of high-order harmonics generation

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High harmonic generation (HHG) is not only prominent for its ability to provide coherent ultrashort pulses in extreme ultraviolet using tabletop lasers, but also for an opportunity to investigate ultrafast laser-plasma interactions. During the last two decades the main drawback of HHG – low conversion efficiency – has been reduced by using resonant HHG [1-3], HHG in two-color pulses [4], quasi-phase matching (QPM) of HHG in periodic gas [5] and plasma [6] jets. While these experimental approaches are quite simple and misleadingly intuitive, there is still no commonly accepted theoretical explanation of these phenomena. So, our goal is to highlight the current state of theoretical description of these unsolved problems.

Resonant HHG is probably the most theoretically studied problem of these three. Models of resonant HHG that support a sharp resonant line are a variation of the three-step model [7]: pumping of an excited state [8], effective radius model [9], four-step model using autoionizing state [10]. It has been shown [11] that consideration of resonant inelastic scattering and multielectron effects does not change the qualitative predictions of this four-step model. While the nature of this intermediate state is currently not restricted, it is assumed to be Fano resonance [12] - a particular case for coupled oscillations. The main advantage of coupled-oscillator model is the potential ability to explain the difference between efficiency of resonant HHG for different transitions. Despite the intuitiveness of such classical description of resonant HHG and advantages of classical analytic description, some problems are still not addressed. First of all, the considered bound resonant state is not really autoionizing state of an atom, because it considers the transition of one of inner-level electrons to another level not bound into continuum. Then, exchange interactions of electrons may significantly affect the interference of two channels. Finally, the nature of resonant harmonic radiation is not distinguished between stimulated lasing without inversion [13] and stimulated superradiant emission [14]. So, the future of quantitative description of resonant HHG is related to fully quantum mechanical treatment of multi-electron systems.

HHG enhancement in two-color ($\omega+2\omega$ central frequencies) fields, whose polarizations are orthogonal to each other, is still not fully understood. In experiments, a strong driving field of frequency ω is combined with a very small fraction of its second harmonic 2ω ($0.01\ I_\omega < I_{2\omega} < 0.03\ I_\omega$), but that increases non-resonant (and, in most cases, also resonant) HHG strongly for odd and even harmonics. Experiments with three-color and non-integer combinations of fields revealed that only a single high-frequency photon is taken from the weak high-frequency field. Single-active electron (SAE) approximation study [15] of 2 delayed circular fields with equal field strength (so that $I_{2\omega}=4I_\omega$) could explain most of the experimental features, but it fails to predict the enhancement in the case when $I_{2\omega}<<4I_\omega$. Even if the second harmonic has the intensity comparable to the fundamental field, the total enhancement of HHG in fully quantum mechanical SAE approximation turns to be on the order of additional energy of 2ω field.

While symmetry breaking is referenced as the origin of this enhancement, the actual mechanism is still unclear. Here, we propose to consider HHG enhancement in two-color fields as a special case of coupled oscillations that is quite similar to Fano resonances for resonance HHG. It has been shown [16] that parity-time symmetry breaking changes the coupling of oscillators from strong to weak, and the splitting is similar to Rabi splitting during the resonant HHG. While this effect definitely needs a more detailed consideration, it also clarifies why SAE methods are not directly applicable to two-color HHG unless artificial potential barriers are included to represent strong coupling of oscillators.

QPM enhancement of HHG looks intuitive. If we separate sequential plasma jets so that the jet length is smaller or equal to the so called “length of coherence”, aiming to remove negative interference of the propagated and newly generated harmonics, HHG indeed grows. But what reduces the phase mismatch between jets so that HHG in different jets differs from HHG in a single jet? Gouy phase variation has been assumed to compensate phase mismatch, but in typical QPM experiments its variation is not sufficient. Free electrons without ions between jets can explain the enhancement, but this assumption is quite restrictive. While in thin capillaries the influence of positive dispersion is significant to compensate this phase mismatch, this is also not the case for laser plasmas. What if QPM in laser plasmas differs from QPM in gas filled capillary by principle, that is, the ablated surface playing a role in local field enhancement? Here we assume that the collective excitations in periodically modulated laser plasma can also produce an equivalent of Fano resonance in a sequence of Fabry-Perot resonators represented by jets. It has been shown [17] that consecutive Fano resonances have opposite polarity, so this effect makes them equivalent to periodically poled crystals used for quasi-phase matching for low-order harmonics.

To sum it up, we propose that model of coupled oscillations is the universal theoretical description of seemingly very different processes of experimental HHG enhancement.

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Investigating laser plasma dynamics with high-order harmonics generation in carbon-containing nanomaterials

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Introduction

We study high-order harmonics generation from the plasmas produced on the surfaces of the graphite, fullerenes (C_{60}), carbon nanotubes (CNT), carbon nanofibers (CNF), diamond nanoparticles (DN), graphene (Gr) and epoxy resin composed targets. Our approach utilizes a two-laser configuration with heating of targets by nanosecond laser pulses to produce plasmas that serve as the media for subsequent high-order harmonic generation (HHG) from a second femtosecond laser pulse. High-order harmonics are generated at different time delays following the plasma formation, which allows us to analyse the spreading of species with different masses. We analyse the harmonic yields from single carbon atoms, 60 atoms (fullerene), 10^6 atoms (DN), 10^9 atoms (CNTs and CNFs), and even much larger species of graphene sheets. The harmonic yields are analyzed in the range of 100 ns – 1 ms delays between the heating pulses (HP) and driving pulses (DP). The harmonic yields were significantly higher within 200 ns – 0.5 µs range of delays, but no harmonics were observed between 10 µs - 1 ms.

An analysis of the application of longer (nanosecond) pulses for target ablation during HHG in laser-induced plasma (LIP) compared to picosecond pulses, has previously been reported in [1]. Nanosecond laser ablation has been widely used to synthesize various metal and oxide nanoparticles (NPs). However, numerous factors such as duration of the laser pulse, fluence, and characteristics of irradiated targets affect the properties of synthesized NPs. The pulse duration is one of the most important parameters when considering the in-situ synthesis of NPs in LIP. Used approach has already been reported in studies to analyse harmonic's delay dependencies from different ZnO-contained targets, resonance-enhanced harmonics in mixed LIPs, and HHG during propagation of femtosecond pulses through different ablated species [2-4].

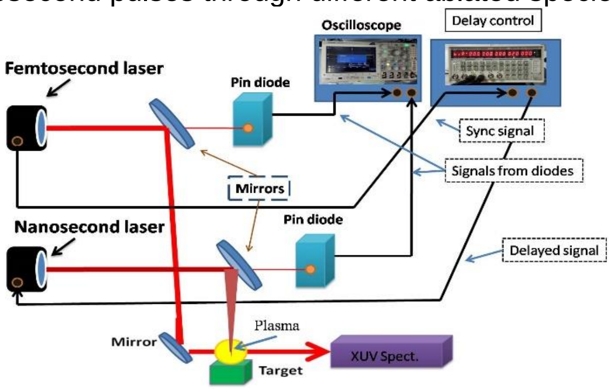

Fig. 1. *Schematic of the experimental setup for two laser HHG experiments with tuneable delay between heating nanosecond pulse and probing femtosecond pulse*

Experiment

For laser plasma formation, the 5 ns heating laser pulses (λ=1064 nm, 5 mJ, 10 Hz) from Nd:YAG laser were used. HP were focused by a 300 mm focal length spherical lens on the target surface. Femtosecond pulses (50 fs, 806 nm, 2 mJ) from Ti:sapphire laser were focused inside the plasma plume to generate harmonics (Fig. 1). The intensity of the driving pulses in the plasma area was maintained to be ~2×10^{14} W cm^{-2}. The delay between HP and DP was tuned using the delay generator. The variable electronic delay range was equal to 0–10^6 ns. The harmonics and plasma emission were detected using a flat field grazing-incidence XUV spectrometer.

Results

The delay dependence for integrated harmonics signal is demonstrated on Fig. 2, panel (a). Fig. 2, panel (b) shows the saturated images of harmonics collected by CCD camera from the phosphorous screen of the microchannel plate of XUV spectrometer at the optimal delays of each studied sample. The purpose of such presentation of harmonics distribution is to define the maximal order of generated harmonics, i.e., harmonic cut-off, and for better viewing of the difference in harmonic intensities from various species.

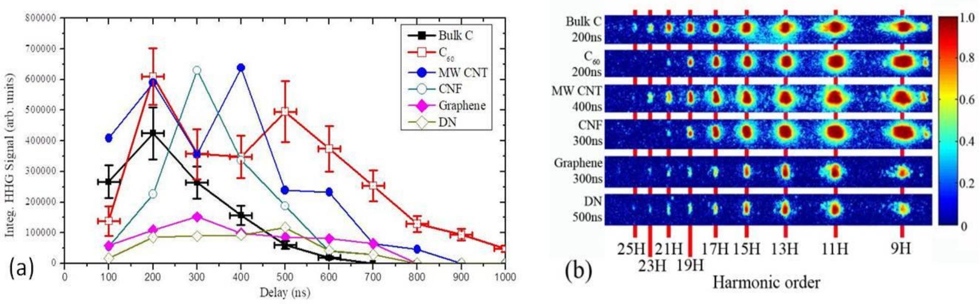

Fig. 2. *Panel (a): Dependences of the integrated yield comprising 9th to 25th harmonics on the delay between nanosecond heating pulse (HP) and femtosecond driving pulse (DP). Panel (b): Raw images of the harmonics at the optimal delay for each plasma sample. Images are normalized and logarithmically scaled. For bulk C, the maximal yield of harmonics is shown at a delay equal to 200 ns. The optimal delays for C60, CNT, CNF, Gr, and DN were 200, 400, 300, 300, and 500 ns, respectively*

We address the importance of considering the above delay-dependent experiments for understanding the dynamics of plasma propagation. The signature, indicating the presence of specific emitters, is the increase in the output of harmonics at certain specific delays from the beginning of ablation. An approximate similarity in the latter parameter led to similarity, to some extent, of the cut-off harmonics, while larger amount of atoms in nanostructures allowed increasing the cross section of recombination of the accelerated electron with the parent particle. The latter peculiarity distinguished the harmonic yields from the single-atomic plasma produced from ablated graphite and the multi-atomic plasma produced from other studied carbon-contained species (fullerenes, nanotubes, nanofibers, diamond nanoparticles, and graphene). Thus, by combining the analysis of delay dependences of integrated harmonic signals and of HHG spectra in the 30 – 100 nm wavelength range the role of the carbon monomers, small-sized carbon molecules, and large nanoparticles in the former process has been revealed.

Acknowledgements
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Technological challenges for next generation boron ion implantation device

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Recently started project is aimed to perform proof of concept and to validate frontier technology for small sized next generation 100 keV Boron ion implantation device in laboratory environment. The project is response to the current demand for user friendly, small-sized and cost-effective ion implantation technology from the research driven SMEs in Latvia and Germany to sustain their global competitiveness. The innovation is based on the use of hollow cathode plasma combined within RF inductively coupled plasma producing Boron ions from pure metallic Boron directed in ion optics track to form high energy ion beam close to 100 kV.

The Project will elaborate and test the following technologies and approaches:

1) boron ion production: use of a hollow cathode RF ICP ion with magnetic plasma rope guiding the plasma to ion optics track;
2) beam acceleration using a linear electrostatic accelerator adjustable depth up to 100 keV;
3) QMS filter for ion beam formation;
4) classical Einzell-lens adapted for ion focusing and guidance systems;
6) quartz/glass technologies advantageous for high vacuum needs and miniaturisation of laboratory device.

The following key characteristics for Boron ion implantation need to be reached: 10 keV – 100 keV ion beam energy with a density of 1xE13 to 1xE16 atoms/cm^2 over ~100 cm^2 target, by exposure time less than 100 sec.

Boron is metalloid complicated substance, characterised by high chemical inertness, hardness and thermal resistance and showing both metallic and non-metallic properties. It condenses at 3927ºC. Current commercial ion implant devices use highly toxic boron fluoride gas to avoid condensation. Use of low toxicity boron rich powder as a target will be key innovation.

The main reason why the classic industrial scale ion implant equipment is in multi-ton weight and high price is mostly the size and weight of magnetic mass-selector (magnet) for purifying the ion beam.

In the last decades a magnet-free device with an outstanding filter efficiency came into the chemical analytical industry under the name of quadrupole mass-selector (QMS). It had never been implemented before because the transmissivity of QMS is harshly dependent on geometry accuracy of QMS rods and positioning. A pencil sized filter has the transmissivity of 10% at 10 micron accuracy and near 90% at 2 micron accuracy. Therefore, application of QMS technology is essential for the winning in size, weight, price, and purity.

Two-photon selection rules of HF structure for Rydberg atomic states

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We described creation of optical dressed states in a multilevel two-state quantum system with essential in experimental situation HF splitting. As example we study sodium systems of levels $3s_{1/2} - 3p - 5s_{1/2}(-4d)$ due to its reach structure that allows us to consider a great number of excitation schemes. When the system interacts with a very strong laser field the coupling operator forms the structure of both bright and dark states. Autler-Townes spectra we observe with weak probe laser (a weak probe field in the first excitation step and a strong coupling field in the second step). We treat the lack of some bright peaks in Autler-Townes spectra as a consequence of a specific architecture of dressed states in HF components, incorporated into independent (orthogonal) ladder excitation schemes. In several cases we reveal as well the modified 2-photon selection rule that in terms of the total angular momentum F is reduced to $\Delta F \equiv 0$. The last is resulted from constructive/destructive interferences of atomic states upon their coupling by a strong laser field at the ladder middle steps. That fact opens practically important perspectives to realise selective addressing to unresolvable HF F-components of atoms and molecules.

Acknowledgements
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Whispering gallery mode silica microsphere resonator applications for biosensing and communications

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Inside whispering gallery mode (WGM) resonators the light beam can be confined in a circular symmetry structure and sustained with small reflection losses. By choosing an appropriate material with a very low absorption, and fabricating a very smooth surface, WGM resonators can reach ultra-high quality (Q) factors. High Q factors allow light to circulate inside longer and have very narrow resonances. This makes them suited as laser cavities, resonant filters, sensitive sensors, generation of nonlinear effects at relatively low powers. The simplest 3D WGM resonator is a sphere. These microsphere resonators are easy to fabricate. The principle is based on melting the tip of an optical waveguide fiber and allowing the surface tension of liquid glass to do all the work to reform the material into a sphere. The sphere has low surface roughness, helping the resonator achieve ultra high Q-factors in the range of $10^6 – 10^9$.

WGM microsphere resonators for biosensing

WGMR sensor operation principles are based on a shift of WGM resonance due to external influence (temperature, pressure, humidity etc.). WGM resonances in the WGMRs are a function of their geometry and refractive index. To enhance optical properties or detect molecules or biomolecules the surface of WGMR has to be functionalized with a nanomaterial layer. Sensing molecule adhesion to the surface is a good step towards biosensor development but not enough to call it a biosensor. One of the requirements for WGMR biosensors, which is often forgotten, is selectivity - the ability to distinguish the desired biomolecules from other molecules. Many enzymes, for example, glucose oxidase (GOx) which oxidizes glucose, or genes/antigens have selective properties and have to be tailored for each biomolecule.

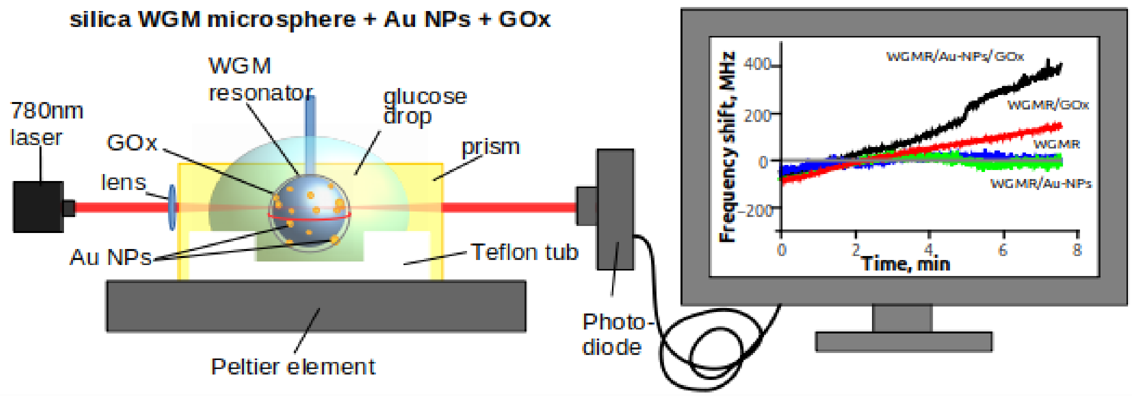

***Fig. 1.** Responses of glucose sensor based on differently modified silica microsphere WGM resonators: bare resonators - WGMR (blue curve), resonators coated with gold nanoparticles - WGMR/Au-NPs- (green curve), resonators coated with glucose oxidase layer – WGMR/GOx (red curve) and both layers to enhance sensitivity and provide selectivity - WGMR/Au-NPs/GOx (black curve)*

Fabricated silica microsphere WGM resonators surface was coated with multiple different functionalising layers. Gold nanoparticles (Au NPs) were used to enhance the sensitivity together with GOx to ensure selectivity (see Fig. 1). The research demonstrated that WGM resonators can be coated with materials, which are increasing sensitivity towards selected analyte - glucose -and to enhance the sensitivity of WGR microsphere based sensor.

Several ZnO structures were tested to increase surface area for protein binding which were selective for analyte/antibody reactions. 3 types of ZnO coating on WGM resonator surface

(WGMR/ZnO) structures were tried. ZnO nanorods had too rough surface for potential application in WGM resonator sensors. ZnO nanolayer coated using atomic layer deposition and 10-15 nm layer thickness showed the best results and highest Q factors [2]. ZnO nanocrystals structure obtained by drop coating zinc acetate solution on WGM microspheres was the easiest and fastest method but only 50% of samples were usable for further modifications. Bovine leukemia virus (BLV) cattle virus and Bovine serum albumin (BSA) was added to WGMR/ZnO structure to test BLV-positive test samples (see Fig. 2.)

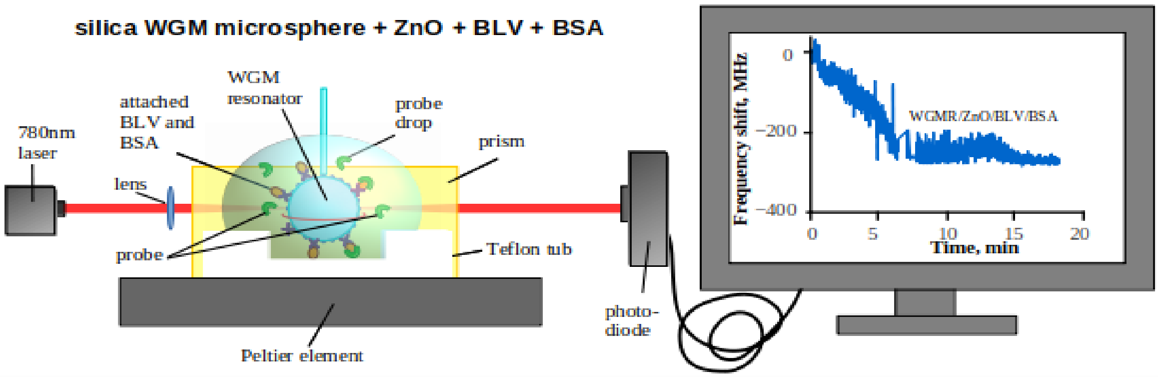

Fig. 1. *Responses of cattle virus sensor based on antigen/antibody reaction modified silica microsphere WGM resonator*

WGM microsphere resonators for communications

An Optical frequency comb (OFC) can be generated using third-order Kerr-nonlinearity induced four wave mixing (FWM) generating the equidistant optical side-bands in the WGM microresonators. The generated equidistant frequencies may allow the substitution of an expensive laser array solution for wavelength-division multiplexing (WDM) data transmission system.

Silica microsphere WGM resonators with 170 µm diameter were used to generate OFCs with ~400GHz repetition rate. Two more intense generated optical carriers (+1) and (-1) were filtered and used to demonstrate data transmission [3]. The stability is an important parameter for telecom data transmission and the long term stability was explored. The temperature influence on the system was deemed crucial as it could affect multiple points, like the coupling position impacting WGM resonator OFC resonances and polarization of the input, which were determined to be integral for the OFC generation [4].

Acknowledgments

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Small size Boron ion implanter concept

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Currently, besides semiconductor manufacturing, ion implantation is used for many purposes, e.g., sensors manufacturing, hardening of metal surface, friction modification, altering of chemical resistance, painting etc. Particularly, boron ion implantation in high purity germanium (HPG) crystals is the key material used for high energy radiation sensors produced at Riga. Therefore, we analyse available technologies and implantation devices in the context of possibility to reach the technology breakthrough of boron implantation in HPG crystals. The key of implantation apparatus is ion source of selected element followed by beam forming ion optics unit and mass filter separating for impurities, ion beam accelerator and raster scanning system combined with moving targeted crystal. The ion sources may differ substantially by approach and used techniques and are adapted and optimized to selected dopant ion (e.g., boron for germanium crystals). Historically the gas-type ion sources were exploited to produce the boron ions, like Penning source, Bernas, Sidenius and Freeman sources or Duoplasmotron. Due to extremely low volatility with melting point 2076°C and boiling point 3927°C obtaining a solid state Boron ion source is technological challenge. Historically boron trifluoride gas BF3 was chosen to be best raw material. Still two aspects cause serious problems: the incandescent cathode of source corrodes in the atmosphere of aggressive gas; and the BF_3 is extremely toxic. All able substitute gases have roughly the same problem, thus the use of solid state boron may miniaturise the source as well make it less poisonous and better serviceable.

The development of hardly volatile ion sources raised after review article describing the possibility of hollow cathode (HC) discharge for various needs**.** Further research exposed the effectiveness could increase if HC discharge is combined with radio-frequency (RF) glow discharge or RF inductively coupled plasma (ICP) sources. Soon the coupling of ICP or CCP (capacitive coupled plasma) actuator with the HC was reported by. Known that HC are in strong demand in analytical spectroscopy, as well for space micropropulsion thruster industry. Detailed studies of published research allowed us to offer new approach in boron ion implantation technologies. The key of emerging disruptive innovation is in the development sophisticated hybrid geometry of ICP–HC–ICP plasma coupling. As a result, we elaborated the following prospective geometry of unique device (fig. 1) substantially different from existing commercial devices for Boron Ion implantation and new for implantation apparatus markets*. Deposit is targeted* 10^{13}*–*10^{16} *atoms/cm*^{2} *thus the beam current should stand over 20 microamperes.*

First, design begins with the carrier gas – argon is laid in the vacuum tract by tiny, adjusted flux. Pressure is kept ~1 Torr and excited by ICP coil thus the flame tail is slight inside the boron insert. Effect of tail may be increased if apply the proper ramp-voltage between ICP ground and HC cathode. Boron insert forms inner surface of hollow cathode cylinder with wide output aperture, where the body of insert may be heated toward 600°C. Between cathode and anode works voltage multiplier circuit, giving semi-constant current self-adjusted high voltage. Ions crowds the space next to anode, where second ICP exciter increases the electron temperature of plasma. Via the narrow aperture (~1 mm) the cone-shaped electrode extracts plasma to the focusing electrodes and QMS mass selector. Vacuum in QMS is ca of micro-Torr or deeper. Then DC accelerator Viderøe tubulus provide positive kinetic energy to the beam, adjustable between 10 and 100 kV, where system`s zero voltage point is entrance of accelerator; voltage is created by means of RF Cockroft-Walton circuit. Vacuum here is order of nano-Torr. Then stay declining system providing x and y scan of target surface by slightly defocused beam. To make the implantation surface ideally uniform, target is slowly rotated in narrow angle to the axis. To avoid the target charge-up preventing further implantation, the anticharge e-gun under the certain angle radiates the defocused e-beam from filament, scanning x and y to form uniform negative surface charge.

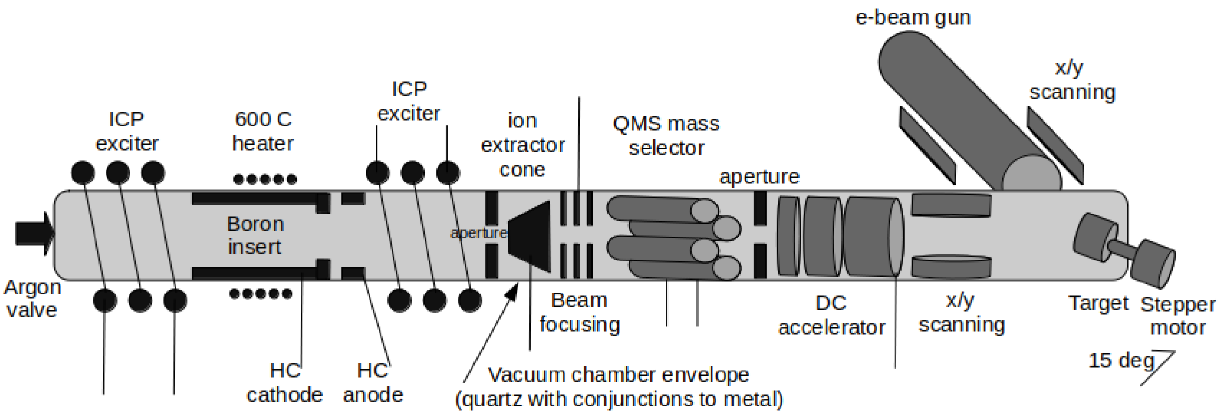

Fig 1. *The boosted combined ICP-HC-ICP ion source in the full proposed implanter concept*

The next alter in the diagram is traditional magnetic mass filter purifying ions. We studied several possibilities including different sector magnet geometries, Wien filter and QMS filter. Among prospective the Quadrupole Mass Selector (QMS) seems realistic and preferable alternative. It seems cheaper and mechanically simpler as sector magnet, high selective with ultra-purity, less weight, less power demand. QMS consists of four cylindrical rods of QMS set ideally parallel to each other and fed by DC and RF voltage superposition. System separates ions by (*m/z*) ratio. The ion-transparency of QMS filter sharply depends on mechanical accuracy having critical jump between good and bad between 1...10 microns of position and shape geometry deviations. Currently the best at the markets advertise accuracy 0.25 microns. The QMS filter demands sophisticated electronics to produce extra stable frequency and voltage, where fresh & simple solution is DDS - Direct Digital Synthesis. Ion beam technologies demand to ensure the vacuum in the device too. Offered approach allows to use glass silica technologies and glass to metal seals based on kovar (iron-nickel-cobalt alloy), having thermal expansion similar to high-borosilicate glass. Graded seals quartz to high-borosilicate glass will be applied.

After optimisation of the developed hybrid plasma source the next innovations are foreseen. *Firstly,* to apply laser ablation technique to intensify atomization of boron in HC by laser ablation technique developed. *Secondly,* reported about of boron cathodic arc ion source. *Thirdly,* another principle of ion source giving excellent ion beam current ca 75 mA is reported, where the LaB_6 tablet was used (what is conductor) and specific two-power-supplies pulse-excitation circuit. *Fourthly,* Boron heated to over 600°C has sharp decrease of electric resistance about 6 orders in comparison with room temperature. The effect was used by various authors in efforts to develop high current boron ion beam source. Success with HC ion source with preheating optimized for production of double-charged ions (yet non-boron) is reported - some applications may benefit by twin-charge.

Discussion/Conclusions

We suggest the use of (and further research on it) at least four possible innovations: (a) For ion source to use the metallic boron filled HC with ICP pre-activated carrier gas, with or without of pulsed power or accelerating ramp-voltage or/and pre-heating of boron. (b) If larger beam currents are mandatory, the vacuum-arc with pulsed power supply are more effective however more tricky to build. (c) For mass separation the use the QMS-MS instead of magnetic-MS may provide the win of size, weight, price, and purity. (d) For vacuum chambers and pipes, where proper and practical, is good to consider the use the quartz as material providing support of extraordinary purity.

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Control of Quasi-Phase-Matched High Harmonic Generation in Structured Plasmas

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High-order harmonic generation (HHG) is an important and versatile method for the generation of ultrashort light pulses in the extreme ultraviolet (XUV) spectral range, in particular for attosecond science [1]. Unfortunately, the conversion efficiency of this process is rather low. Therefore, schemes are sought which bear the promise of a significant enhancement of the yield into a specific harmonic. One successful way is to find in various gaseous materials accidental strong resonances in the vicinity of a certain harmonic. That has been impressively shown, e.g., for In and Sn plasmas [2, 3]. Another scheme builds on the realization of quasi-phase matching, which has been successfully applied in the near-IR spectral range in optically nonlinear solids, in particular in periodically poled $LiNbO_3$ [4]. It has been shown previously also in the field of high-order harmonic generation [5 - 9]. In the present contribution we want to show a system which can easily been used for plasmas to control the harmonic order which is enhanced by quasi-phase matching.

The experimental realisation is based on a physically structured plasma target [10]. Laser ablation of this target leads to a spatially structured plasma with dimensions closely resembling those of the target. Fig. 1 shows schematically the experimental set-up. The target consists of a stack of metallic disks separated by spacers with significantly smaller diameter. Both the width and number of target disks as well as the width of the spacers can easily be adapted to the needs of the experiment. Rotating the target ensures fresh surfaces for each of the 1 kHz ablating pulses (12 ps, 2 mJ). The ablating laser is focused by a cylindrical lens (CL) to a line focus which length can be adjusted by a knife edge. The fundamental (800 nm, 40 fs, 0.22 mJ, 1 kHz) if focused by a f = 500 mm lens. The generated harmonics are spectrally separated by a VLS grating and detected by a MCP/phosphore screen and measured by a CCD camera.

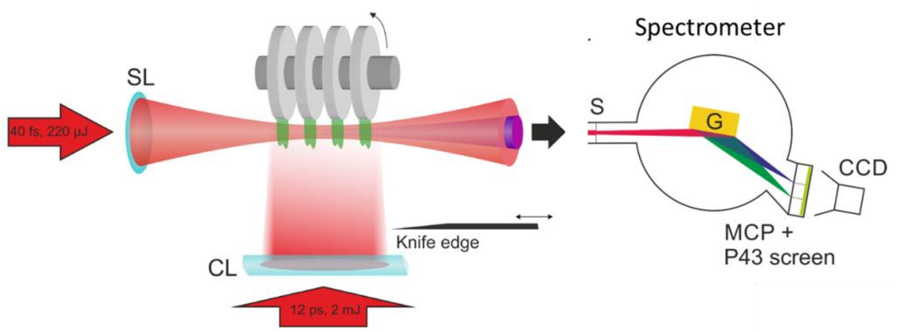

Fig. 1. *Experimental set-up showing the disk target and the XUV spectrometer with a VLS grating*

Fig. 2 shows a comparison of the intensity of the 25th harmonic (hν = 38.75 eV) for a target with four disks with that for an unstructured target (enhanced by a factor of 5). From the first intensity modulations of the unstructured target the coherence length in the plasma for this harmonic can be derived. The intensity rises until one coherence length is reached. As expected, the coherence length decreases with increasing order of the harmonics, from about 0.525 mm at the 13th harmonic to less than 0.35 mm for the 23rd. The optimal spacing of the disks is derived from the geometrical phase of the focused fundamental beam. It is evident that with each new disk the harmonic intensity increases, in fact, the intensity increases quadratically with the effective length of the plasma jets.

Fig. 2b shows the easy control of the harmonic order for which QPM is achieved. By adjusting the width and spacing of the target disks this order can be shifted. For a smaller width and spacing, here 0.4 mm and 0.7 mm, respectively, higher harmonics are phase matched. In the present case that is optimal for the 21st and 23rd harmonic. Increasing both disk width and their spacing yields QPM for lower harmonics, here shown for the 17th and 19th.

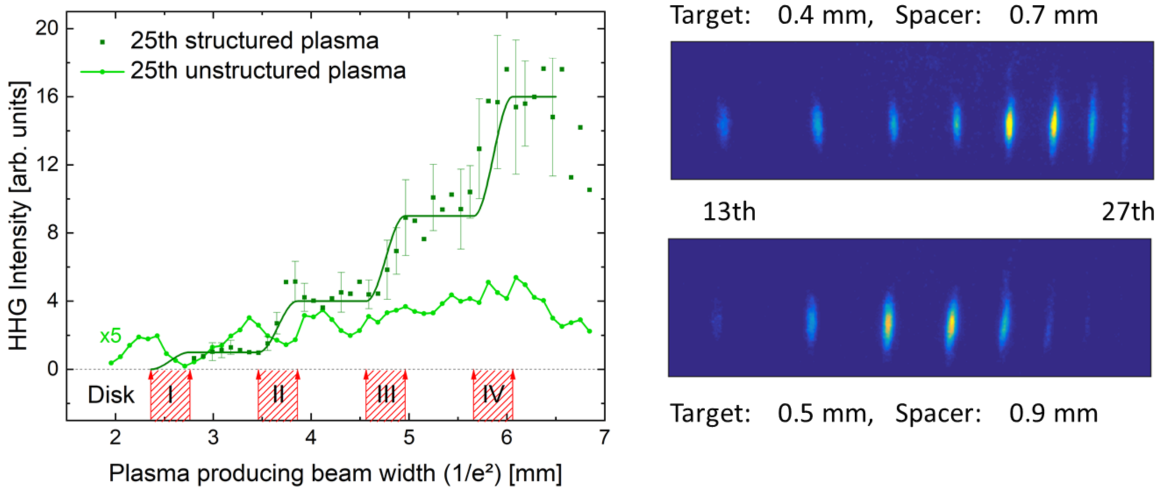

Fig.2. (a) *Stepwise increase of the intensity of the 25th harmonic with the number of plasma jets;* ***(b)*** *control of QPM by choosing the target width and spacing.*

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Quasi-Phase Matching of High-Order Harmonics in Mid-IR Laser Fields

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One of the most effective methods of generating harmonics having high photon energy is to use mid-IR laser systems as a driver of the non-linear processes in gas [1]. However, along with quadratic growth of the maximal number of generated harmonics during the laser field wavelength (λ) increase, the photon flux scales as $\lambda^{-5.5}$ [2]. To overcome the harmonics efficiency drop, the usage of two-colour laser scheme [3], or molecular resonances located near the pump spectrum for enhancement of harmonics yield driven by mid-IR fields was presented [4]. Here, we analyse the other way to increase the harmonics photon flux using the effects of quasi-phase matching (QPM) for high harmonics generated in periodic media [5,6].

In numerical simulations, we suppose that the perforated gas media consists of a number of gas jets having spatial sizes d divided by free spaces forming the multi gas media (MGM). It interacts with a two-colour (w+2w) laser field consisting of two linearly polarised components with zero-degree angle between their polarization directions. Laser field wavelength scales from near IR (800 nm) to far IR (up to 15 mkm) spectral diapason. Macro-parameters of the MGM (total length of the media, pressure of the gas, d and numbers of gas jets) also scales in wide ranges.

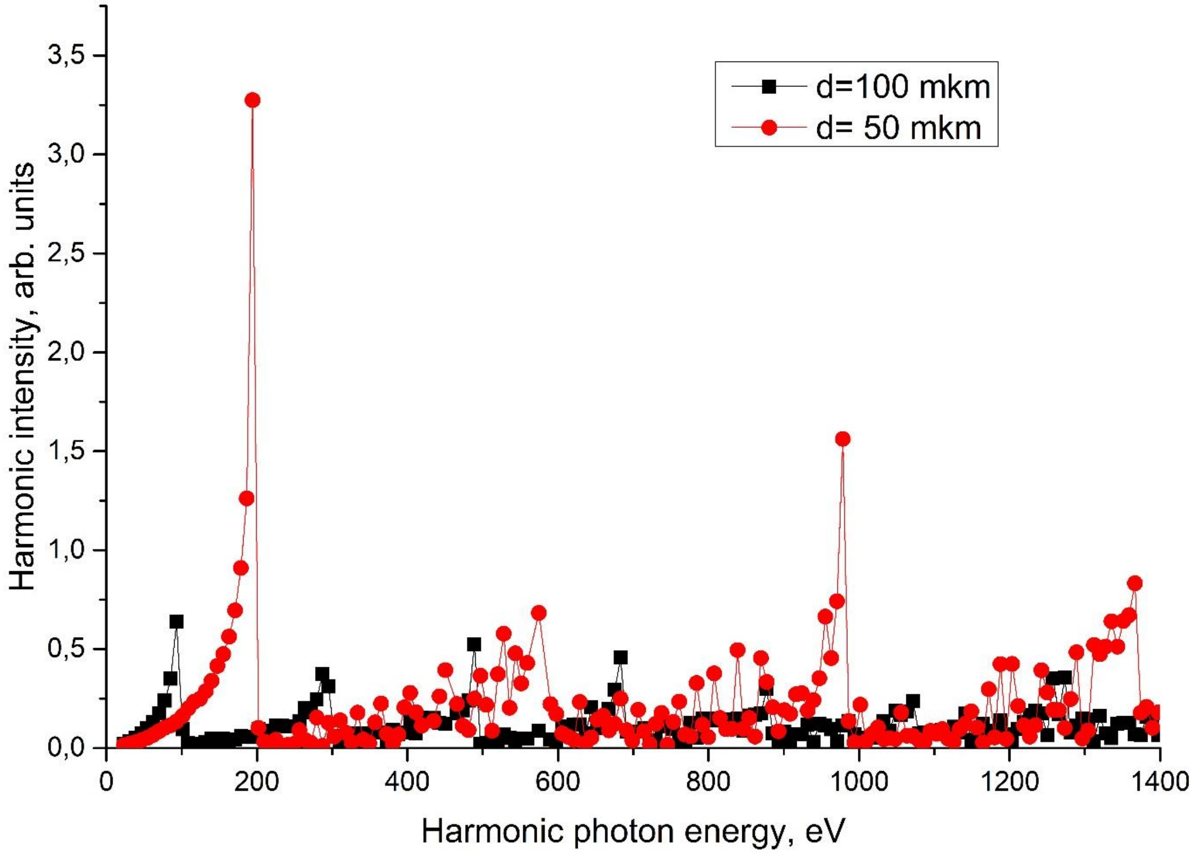

Fig. 1. *The QPM spectra generated by Argon MGM interacting with two-colour laser field formed by the fundamental and the second harmonics of Ti:Sa laser (λ=800 nm). Calculations have been done for pressure 230 mbar and total MGM (25 jets for curve black curve with squares, 50 jets for red curve with circles) length L=0.5 cm*

The numerical calculations based on the interference model of extended gas [7] and the non-perturbative theory of single atom response [8] show that, due to the QPM, the group of harmonics enhanced (please, see Fig. 1). The influence of the gas media parameters and the laser wavelength on the position of enhanced harmonics and its value is analysed. Fig. 1 illustrates the influence of d on the position and efficiency of the QPM harmonics: shorter d shifts the position of the QPM harmonics to the shorter wavelength part of the spectrum and increases its value. The simple relations between the position of the enhanced QPM harmonics, laser wavelength and MGM parameters are introduced. Boundaries of the harmonics enhancement method are discussed.

Acknowledgements
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Nonlinear optical and laser effects in microresonators based on silica and non-silica tellurite and chalcogenide glasses

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One of the trends in modern photonics is the development of miniature devices based on microresonators with whispering gallery modes (WGMs) [1,2]. Such microresonators have huge Q-factors and large nonlinear coefficients, which allows exploiting nonlinear and laser effects at very low pump powers. Promising applications of microresonators are optical filtering and switching, remote sensing, spectroscopy and telecommunication [1-6]. Microresonators can be used to generate non-classical states of light [2], e.g., squeezed light [7] and quantum correlated photon pairs [8]. Active microresonators are used to obtain laser radiation [9]. In nonlinear microresonators, Kerr optical frequency combs (OFCs) can be generated which significantly expands application areas of microresonators [1]. Existing technologies make it possible to produce high-Q microresonators based on various materials including silica and non-silica glasses [3]. Non-silica tellurite and chalcogenide glasses have huge values of cubic Kerr and Raman nonlinearities and mid-IR transparency (up to ~5-5.5 μm for tellurite and up to 8-20 μm for chalcogenide glasses), so their use expands the capabilities of silica microresonators.

Here we present some of recent achievements of our team concerning theoretical and experimental investigation of silica, tellurite, and chalcogenide glass spherical microresonators.

We studied the OFC generation in a silica microsphere for a pump wavelength in a normal dispersion region, in a low anomalous dispersion region, and very close to a zero-dispersion wavelength [10]. Kerr-assisted and Raman-assisted (Stokes) combs as well as anti-Stokes combs emerging due to the four-wave mixing between the Kerr and Raman combs were demonstrated [10]. The mechanisms underlying observed processes were studied [10].

We studied Raman-assisted nested OFCs in two different mode (TE and TM) families with soliton-like spectral envelopes for each mode family in a silica microsphere [11]. We studied the regime in which the pump wavelength (without an OFC nearby) was in the normal dispersion region and Raman-assisted OFCs were generated in the anomalous dispersion region [11].

We demonstrated Raman lasing in an As_2S_3 chalcogenide glass microsphere pumped by a C-band narrow line laser [12]. Single-mode Raman lasing tunable from 1.610 μm to 1.663 μm was attained when tuning a pump laser wavelength in the 1.522-1.574 μm range (Fig. 1) [12]. When the pump power significantly exceeded the threshold, multimode cascade Raman lasing was achieved with the maximum Raman order of four at a wavelength of 2.01 μm (Fig. 1) [12].

We developed theoretical approaches and created a numerical code to investigate lasing in tellurite microspheres, including simultaneously on different radiative transitions of the same rare-earth ion [13]. The models were developed taking into account the mode competition, and the found solutions were checked for stability [13]. For the first time, a detailed theoretical analysis of CW multicolour lasing at different radiative transitions was conducted for Tm-doped tellurite microresonators [13]. It was found that, depending on the Q-factor and pump power, single-color lasing, two-colour lasing, and three-color lasing is possible. We also developed a simple yet efficient analytical model to describe lasing in Er-doped tellurite microspheres [14]. It was theoretically demonstrated that for low Q-factors, generation occurs in the C-band, and for relatively high Q-factors, generation occurs in the L-band, and switching between these regimes occurs with a jump, which agree with experimental observations [14].

A theoretical model was developed to describe thermo-optical effects in silica and tellurite microresonators [15]. First, in the frame of finite element simulation, temperature distributions were calculated. Then, taking into account the found temperature distributions, shifts of the WGM eigenfrequencies were calculated. Within the frame of the developed model, detailed theoretical studies of steady-state and transient thermal effects were carried out in tellurite and silica microspheres. Results for tellurite microspheres agree with experimental results [15].

This work is supported by the Russian Science Foundation, Grant No. 20-72-10188 (study of microresonators based on silica and tellurite glasses) and by the Mega-grant of the Ministry of Science and Higher Education of the Russian Federation, Contract No.14.W03.31.0032 (study of microresonators based on chalcogenide glasses).

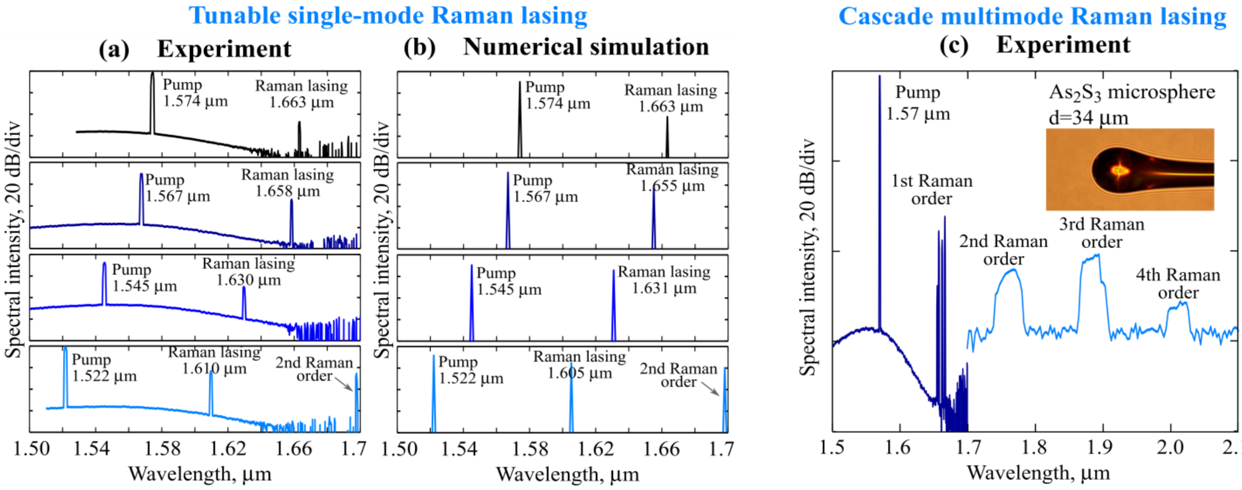

Fig. 1. *Experimental spectra of tunable single-mode Raman lasing (a) and the corresponding numerically simulated spectra (b) in 34-µm As_2S_3 glass microsphere [12]. (c) Experimental spectrum of four-cascade Raman lasing recorded by OSA (dark blue curve) and by PbSe detector plus monochromator (light blue curve) [12]. The inset shows the microphoto of the used home-made As_2S_3 glass microsphere.*

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From ultra-stable laser resonators for atomic spectroscopy and fiber-based femtosecond optical frequency combs to whispering-gallery-mode microresonator sensors and microsphere optical frequency combs for telecommunication data transfer

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Improving precision optical spectroscopy of atomic hydrogen over several decades at the Max Planck Institute of Quantum optics [1] has led to the development of an optical frequency comb method that allows to count the frequency of light and has activated a field of optical atomic clocks. The stability of the laser spectral line has reached the thermal noise limit of sub-Hz linewidth [2]. The thermal noise limit was reached also in optical whispering gallery mode (WGM) microresonators [3]. Ultra-stable laser radiation can be transferred using interferometrically stabilised optical fiber link across the continent between the metrology labs [4].

Fotonika-LV Project [5] in Latvia has allowed establishing a Quantum optics lab in 2013 acquiring a fiber-based optical frequency comb (Menlo Systems 250 MHz) and building a stable laser resonator [6]. In order to learn to use the comb, we re-measured rubidium saturated absorption line frequencies [7]. We built a two-mirror ring-down resonator for acetone measurements in breath [8]. Afterwards we switched from classical two-mirror resonators to so-called whispering gallery mode (WGM) microresonators that circulate the light by total internal reflection and can be used in biosensors [9]. Resonance condition occurs when in a roundtrip fits an integer number of light waves. We make SiO2 microsphere WGM resonators by melting a tip of high purity telecom fiber and reach optical Q factors in the 106-108 range. The most straightforward application is a WGM temperature sensor [10] as both index of refraction and physical dimensions change with temperature. Next application is to coat the microresonator surface with a thin coating, for example, ZnO using atomic layer deposition method [11], and glucose oxidase enzyme for glucose sensing [12]. Sensitivity can be further enhanced by adding to coating gold nanoparticles to excite surface plasmon resonances [13]. Drifts of microsphere resonances can be referenced to atomic rubidium lines [14]. WGM resonances can be excited also in a liquid droplet and we demonstrated glycerol droplet WGM with very high sensitivity to relative humidity [15].

Another application is to induce nonlinear optical phenomena such as four-wave mixing, Kerr and Raman effects by pumping microspheres with several hundreds of milliwatts of CW laser power. Thanks to the high optical Q factor, the circulating power in approximately 10 mm2 mode area can reach GW/cm2. At such high intensities new optical frequencies are generated. Resonator allows generating frequencies that satisfy constructive interference after a roundtrip. This leads to the generation of Kerr frequency comb in microresonator manifesting as equally spaced lines in the optical spectrum [16]. We have demonstrated the use of Kerr frequency comb in a silica microsphere for telecommunications by using comb lines as a carrier for telecom data [17]. Comb use for telecommunications requires only a single comb generator laser instead of separate lasers for each colour.

Acknowledgements
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Theoretical analysis of limiting factors for quantum noise squeezing of ultrashort pulses in optical fibers

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Quantum noise suppression of CW and pulsed light is required for many applications including quantum sensing, quantum communication, and detection of gravitational waves [1]. There are several ways to obtain squeezed light which is a quantum state with a variance of one field quadrature being below the value for a coherent or a vacuum state (whereas the conjugated quadrature variance is above the variance of the vacuum in order to satisfy Heisenberg's uncertainty relation) (see [1] and references therein). One way is Kerr squeezing in optical fibers demonstrated for the first time in [2] and is still actively investigated [3]. For quantum noise suppression of CW radiation, fiber lengths of about a hundred meters are required, and limiting factors are optical loss and guided acoustic wave Brillouin scattering (GAWBS) [4]. For solitons with duration ~100-200 fs and a high peak power, significantly shorter fibers are required (of about ten meters), and instead of loss or GAWBS, Raman effects limit squeezing [5].

Here we analyse the possibility of quantum noise squeezing of solitons with durations of 200 fs, 500 fs, and 1 ps in an optical fiber with realistic parameters using home-made software. The simulation of pulse propagation with allowance for quantum noise entails modelling multimode many-body quantum system dynamics. We achieve this here with a truncated Wigner technique, which provides accurate results for relatively short propagation distances and large photon number. We model the Raman-modified stochastic nonlinear Schrödinger equation [6] with allowance for losses. The initial condition is a fundamental soliton with adding normally distributed stochastic quantum noise. In modelling, we switch on/off Raman effects and loss to find their contributions to squeezing of solitons with different durations. The simulated polarisation squeezing [7] as a function of a fiber length is plotted in Fig. 1(a, b, c) for soliton durations of 200 fs, 500 fs, and 1 ps, respectively.

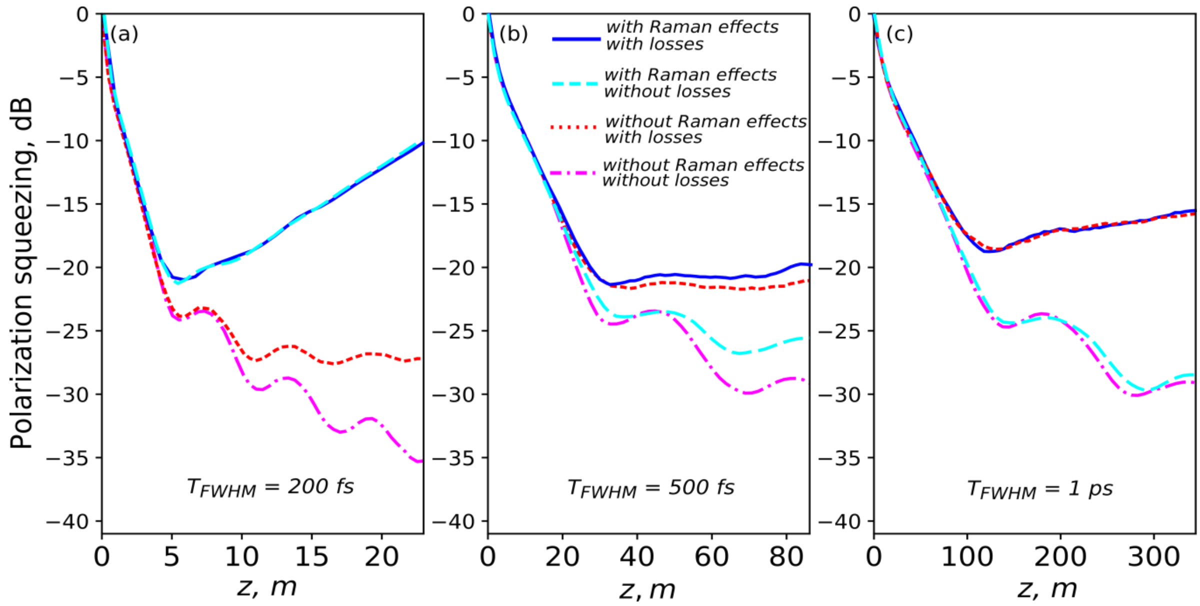

Fig. 1. *Polarisation squeezing simulated for pulse durations of 200 fs (a), 500 fs (b), and 1 ps (c) using sets of 1000 independent realizations. Here the nonlinear Kerr coefficient is 0.093 (W km)$^{-1}$, dispersion is -28.0 ps^2/km, fiber loss is 1 dB/km, central wavelength is 1.5 μm, temperature is 300 K*

For fundamental solitons, the peak power is inversely proportional to the square of the pulse duration, so for longer pulses the required distances are longer and the loss impact is stronger.

For shorter pulses, their spectra are wider, so the overlap with spectrum of the Raman function is larger. When Raman effects are switched on, squeezing of the shortest 200-ps pulses is dramatically decreased, while squeezing of 500-fs and 1-ps pulses is slightly affected. Simulations demonstrate that optimal fiber lengths are the following: <10 m for 200-fs pulses, several tens of meters for 500-fs pulses, and >100 m for 1-ps solitons. Solitons with duration of 500 fs are preferable to attain the strongest quantum noise squeezing (-21 dB), since for them the balance between limiting factors (losses for 1-ps pulses and Raman effects for 200-fs pulses) is satisfied.

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TRIZ forecast of the development of research on optical microresonators

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The research on optical microresonators has attracted significant attention in the last decades [1-3]. The microresonators are optical structures that confine light due to total internal reflection and form an array of optical resonances that can be explored. These objects are used as sensors (temperature, humidity, wavelength, bio-sensing [4], and others) and as tools to study nonlinear effects of optical materials (for example, the generation of microresonator frequency comb [3]). Various aspects of microresonators have already been reported that reveal novelty of the thought; yet forecast of the further development of this research may be of high value. The theory of inventive problem solving (TRIZ) provides various guidelines for such achievements.

TRIZ was developed by G. Altshuller and his colleagues since 1956 to advance the technology [5 - 6]. It contains tools that help to create solutions for technical problems and has underlying concepts that form the theory of this approach. According to TRIZ, technical systems, contrary to natural systems, are created to realise some function. These systems develop according to some laws that can be revealed by analysing the former development of various technical systems. G. Altshuller revealed and described these laws that are applicable for further development of technical systems. The most significant novelty of TRIZ is the use of the concept of contradiction, which inhibits the development of the technical system, but is also the basis for such development. The main instrument of TRIZ is Algorithm for Inventive Problem Solving (recommended version ARIZ-85V), which includes many additional tools, such as the System of Standards-77. Nowadays, TRIZ is used in many areas of technology and science, including patenting process [7-9].

Within TRIZ tools, there are various guidelines that can be used to forecast the development of systems. The description of some of them and application examples within the optical microresonator field are given in Tab. 1.

Tab. 1. *The list of guidelines for system development and their applications seen in microresonator research*

Guideline	***Description of the guideline***	***Example from optical microresonator research***
Use of resources	System can be developed by better use of resources within the system or outside. The use of easily available or cheap resources is recommended. Geometry or space is also a resource	Readily available optical fibres can be used as materials for ball microresonators. Fibre cleaver can be used to melt ball resonators from optical fibres
Trimming	System can be developed by eliminating one of its parts and by redistribution of its functions to other parts	Prism is eliminated and substituted by tapered fibre which fills the functions of prism and laser ray that travelled to prism

Guideline	***Description of the guideline***	***Example from optical microresonator research***
Synchronisation of parameters	System can be developed by synchronisation of its parameters among themselves or with significant external objects	Synchronisation of refraction index of prism and resonator Synchronisation of a wavelength of the system with the requirements of industry (1.5 µm for telecommunication)
The use of internal effects (microsystems)	System can be developed by using internal resources of elements of the system, for example, their physical properties	Resonator is made of dielectric material (for example, SiO2) that has electrostriction properties and can be explored as such
Development in super-system	System can be developed by combining it with similar or other systems. Together they form super-system.	Array of resonators are explored. Microresonators are used for applications in various fields, for example, sensing (temperature, humidity, bio-sensing, and others)
Dynamization	System can be developed by changing its properties in time. For example, system adapts to external environment	Typically, microresonators have static positions of resonance frequencies. Resonators can be heated to change their resonance positions
Expansion over morphological matrix	System can be developed and explored (especially in research) by varying its elements	Various materials of resonators (SiO_2, MgF_2, CaF_2) Various geometries of resonators (ball, ring, toroid, bubble, spiral) Various additional effects (acoustic waves, machine learning) Various wavelengths (visible, IR, UV) Various intensities of laser (average, strong)
The development according to 77 standards	System can be developed by the use of the System of 76 Standard Solutions of TRIZ. This system can be used multiple times to apply for various parts of the system	Standard 1.1.3. – the use of additives to increase the performance of the system. Example: covering the resonator with some layer that is sensitive to bio-molecules to improve the performance of the microresonator

Guidelines given in Table 1 can be used to advance the research field of optical microresonators. The preliminary analyses show that the perspective directions for development are – dynamization, trimming, and joining in super-systems.

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The Optimal (Tom and Jerry) pairs of cold Rydberg atoms in Penning Ionization processes

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We studied Penning ionization (PI) processes involving Rydberg states of alkali atoms in cold gas media. PI analysis has been performed in terms of the autoionization widths $\Gamma_N(R)$ of a quasi-molecule formed by an pair of collision partners with the fix internuclear distance R. Due to a long-range dipole-dipole interaction, one d- atom undergoes a transition from state $N_d = n_d l_d$ to a deeper bound state, while the other i-atom gains the released energy and jumps from state $N_i = n_i l_i$ to the continuum. An important feature of PI is the nontrivial dependence of its efficiency on the effective (n^*) and orbital (l) quantum numbers of the Rydberg states $N = N_i N_d$ of the atoms pair, in particularly, on the size ~ n^{*2} of the particles. We have found optimal $N^{(opt)} = N_i N_d^{(opt)}$, highly asymmetric ($n^{*2}_{d,opt} << n^{*2}_d$) configurations of Rydberg pairs (we call atoms ’Tom’ and ’Jerry’ for ’big’ and ’small’ ones [1]), which lead to explosive intensification (by several orders of magnitude, see Fig. 1) of PI processes. This property makes PI an important source of primary (seed) charged particles when a cold Rydberg medium evolves into cold plasma [1]. We performed systematic calculations and have derived analytical expressions for both the optimal {$n_i l_i$, $n_{d\_opt} l_d$} pairs and the corresponding reduced Penning autoionization widths $\tilde{\Gamma}_N(R) \equiv R^6 \Gamma_N(R)$ for different orbital l_i - l_d configurations of alkali atoms. As an example, the case of s-s states ($l_i = l_d = 0$) of Cs atoms pairs is exhibited in Fig. 1.

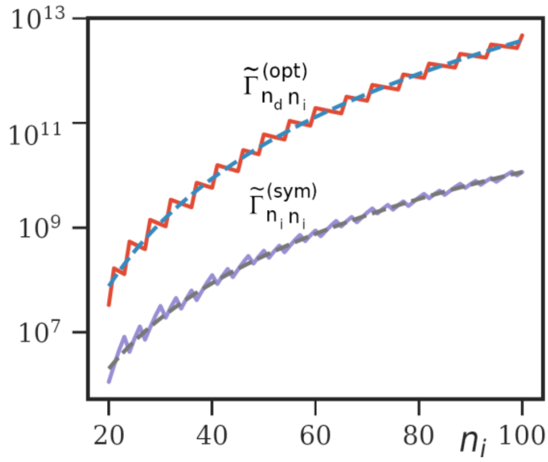

Fig. 1. *Reduced autoionization widths $\tilde{\Gamma}_N^{(opt)}$ (optimal pairs) and $\tilde{\Gamma}_N^{(sym)}$ (symmetric pairs) as functions of the principal quantum number n_i of ionizing i-atoms. Numerical (solid lines) and analytical results (dashed lines)*

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Spectroscopy of atomic Boron

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Research on atomic spectroscopy of hardly volatile chemical elements like Boron (melting point 2076^{o}C, boiling point 3927^{o}C) is an experimental challenge caused by difficulties of atomization. Therefore, the knowledge base of basic properties of B I and B II is not rich at all and need to be improved due to increasing demand from various technology disciplines, atomic physics and astrophysics especially.

On the other side, the implantation of boron ions in high purity germanium crystals [1], remaining the key material used for high energy radiation sensors, currently demands development of more handy and cost effective apparatus. Efforts of our team to respond to such demand resulted in the development of hybrid plasma source coupling together hollow cathode and RF inductively coupled plasma discharge sources ensuring atomization of elemental Boron. Light spectrum coming from such device is dominated by the group of intensive resonance line duplets of B I and several resonance lines of B II. Therefore, we have unique source for more comprehensive investigation of spectroscopy of B I and B II particularly to measure branching ratios and to obtain transition probabilities of B I in spectral region 1600-2500 Å. The latest data on Boron spectroscopy were published in 2009 [2], in 2010 [3] and are collected in worldwide known database [4, 5].

We are going to use mirror/quarz-prisma high dispersion monochromator SPM-2 *(Carl Zeiss Jena)* upgraded with advanced hardware and software. Optical pass between Boron atomic spectra source and the monochromator will be washed by directed flow of nitrogen to ensure branching ratios measurements for the following duplets of B I: 1666.850, 1667.272; 1817.843, 1818.348; 1825.894, 1826.400; 2088.889, 2089.570; 2496.769, 2497.722 and B II resonance lines.

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Oscillator Strengths of Arsenic Resonance Lines

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Introduction

The observation of the absorption lines of neutral arsenic (As I) were firstly reported in the case of the studies of binary star *Chi Lupi* during the first mission of Hubble Space Telescope launched into low Earth orbit in 1990 [1]. Later, arsenic lines were detected in a couple of metal poor stars [2-4], and in interstellar space [5]. The determination of for the oscillator strengths of those transitions would allow the discrimination between different evolution models of those objects. We experimentally determined the oscillator strengths (f) for the As I ($4p^25s$-$4p^3$) transitions (197.3 nm, f = 0.127, and 193.8 nm f = 0.059) evaluated from the branching fraction measurements of the radio frequency inductively coupled plasma by combining them with the selected lifetime values reported in literature [6].

The uncertainty in determination of oscillator strengths depends on the precision in lifetime measurements and from the error bars in branching fraction determination. Since we use the lifetime data from literature, we can not improve them. The accuracy of branching fractions depends on the scattering of measurement data, the calibration error of the spectral response of experimental system, and the influence of the self-absorption of resonance lines.

Experiment

The As I emission lines were obtained from the laboratory-made radio frequency (RF) inductively coupled plasma sources. Two sealed off lamp bulbs were made of high quality Spectrosil type silica of 18 mm diameter spheres filled with As+Xe and As+Xe+KBr. They were placed in the coil of radiofrequency generator, see Fig1.The spectral lines of arsenic were analysed by monochromator SPM-2 (Carl Zeiss Jena) allowing high spectral resolution in the 200-300 nm range. The application of this monochromator allowed us working using a reasonably opened slit in the case of very weak signals from the light source. Intensities of individual spectral lines were detected using photomultiplier tube PMT 39A attached at the exit slit of monochromator. Photocurrent was amplified and measured using the voltmeter. The calibration of spectral response of this system was performed using a hydrogen lamp DBC-25 and a deuterium lamp made and calibrated in Vavilov State Optical Institute The calibration error has estimated not to exceed 15% in the area 190-300 nm.

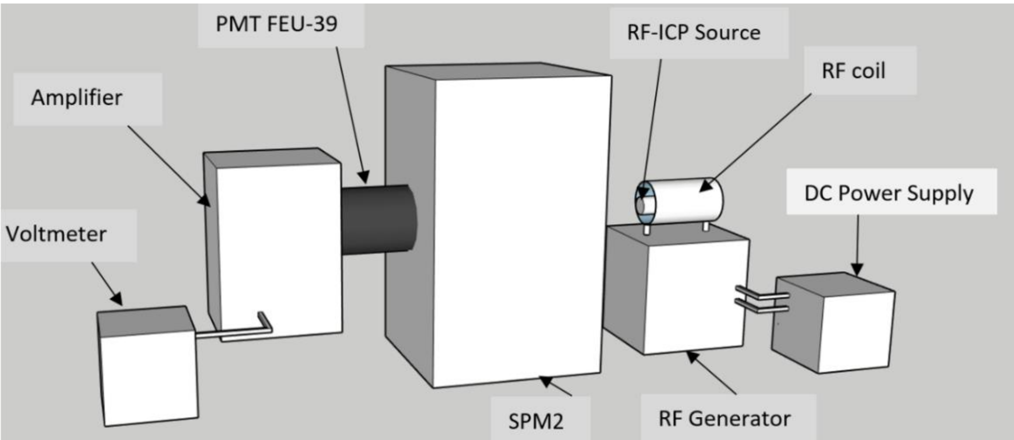

Fig. 1. *Schematic of the experimental sett-up for branching fraction measurements*

The branching fractions were determined for all lines starting from 2 excited levels $^4P_{1/2}$, and $^4P_{3/2}$.levels of $4p^25s$ electron configuration with corresponding to measured resonance lines 197.262 nm and 193.759 nm. and transition to ground state $^4S^o_{3/2}$. Other measured lines are related to the allowed transitions onto metastable states $^2P^o_{1/2}$, $^2P^o_{3/2}$, $^2D^o_{3/2}$, and $^2D^o_{5/2}$ of ground configuration $4p^3$. In order to control the influence of self-absorption we measured the intensity ratios for two spectral lines at different RF generator powers We could observe the influence of self-absorption on line pairs with resonance lines at larger powers.

Results

The branching fractions were determined from intensity ratio measurements at conditions where self- absorption was absent, and they are presented in Tab. 1. The relative uncertainties for the branching fractions were obtained from the errors in the intensity ratio measurements, and they are distributed inversely proportional to the branching fraction values. Thus, for larger fraction the relative error is smaller. Since in our measurements the ratio between the fraction of resonance transition and the fraction of sum for other lines is 0.94/0.06 that means that relative error for branching fraction for resonance line is about 1%. From branching fractions and experimental lifetimes the absorption oscillator strengths were calculated. Together with data from literature they are presented in Tab. 2.

Tab. 1. *The branching fractions from $4p^25s\ ^4P_{1/2}$ and $4p^25s\ ^4P_{3/2}$ states*

Transition $4p^25s\ ^4P_{1/2}$	***λ, nm***	***Branching fraction***	***Transition $4p^25s\ ^4P_{3/2}$***	***λ, nm***	***Branching fraction***
$-^4S^o_{3/2}$	197.262	0.939	$-^4S^o_{3/2}$	193.759	0.943
$-^2D^o_{3/2}$	249.294	0.0569	$-^2D^o_{3/2}$	243.723	0.00998
$-^2P^o_{1/2}$	307.531	0.0016	$-^2D^o_{5/2}$	245.653	0.0426
$-^2P^o_{3/2}$	311.959	0.0024	$-^2P^o_{1/2}$	299.098	0.00093
			$-^2P^o_{3/2}$	303.285	0.0039

From branching fractions and experimental lifetimes the absorption oscillator strengths were calculated. Together with data from literature they are presented in Tab. 2.

Tab. 2. *The oscillator strengths for arsenic resonance lines*

Transition $4p^25s$-$4p^3$	***λ, nm***	***Our data***	***Bengtsson et al 1992 [6]***	***Holmgreen 1975, DV [7]***	***Holmgreen 1975, DL [7]***
$^4P_{1/2}$ -$^4S^o_{3/2}$	197.262	0.127(15)	0.123(17)	0.06	0.11
$^4P_{3/2}$ -$^4S^o_{3/2}$	193.759	0.059(7)	0.059(8)	0.03	0.06

We see good agreement between our data and other experimental data [6]. Theoretical data calculated with dipole lengths approximation DL [7]. We use the experimental set up different from [8] used determination of oscillator strengths in [6]. Our approach allows demonstrating better confidence in determination of the oscillator strengths of arsenic resonance lines resulting in more accurate definition of the arsenic concentration in astrophysical objects.

Acknowledgements

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Laser Induced breakdown spectroscopy as an Emerging technique for Mineral and Space Exploration

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The mineral exploration industry requires new methods and tools to address the challenges of declining mineral reserves and increasing discovery costs. Laser-induced breakdown spectroscopy (LIBS) represents an emerging geochemical tool for mineral exploration that can provide rapid, in situ, compositional analysis and high-resolution imaging in both laboratory and field and settings. LIBS technique for stand-off detection of geological samples for use on landers and rovers to Mars, and for other space applications. LIBS can detect elements with low atomic number (i.e., light elements), some of which are important path finder elements for mineral exploration or are classified as critical commodities for emerging green technologies. LIBS data can be acquired in situ, facilitating the interpretation of geochemical data in a mineralogical context, which is important for unravelling the complex geological history of most ore systems. LIBS technology is available as a handheld analyser, thus providing a field capability to acquire low-cost geochemical analyses in real time. Here using a calibration model built from powdered reference materials doped with gold in solution, the gold concentration of ore samples coming from different gold mines, were determined by LIBS and then compared to those obtained from conventional laboratory techniques. The accuracy of these results base on the in-homogeneity of gold distribution at the sampling scale. The influence of the chemical composition of the calibration samples on the plasma properties was investigated by measuring the plasma electron density and temperature. LIBS has wide potential to be utilized in mineral exploration, prospect evaluation, and deposit exploitation quality control. LIBS is ideally suited for field exploration programs that would benefit from rapid chemical analysis under ambient environmental conditions.

Acknowledgements

We are thankful to the Professor François Vidal from INRS, QC, Canada for his support and the European Regional Development Fund Project No. 1.1.1.5/19/A/003 “Development of Quantum Optics and Photonics at the University of Latvia”.

Moon-Earth: A concept for building a space-resources based economy

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A breakthrough is on the horizon for launch costs to orbit from more than $5,000 / kg. to Low Earth Orbit to potentially $200 / kg. or less by 2040 [1]. SpaceX has driven the push to lower costs with reusable rockets. Elon Musk, the founder of SpaceX even sees costs reaching $10 / kg. Launch costs in this range enable the construction of very large structures in Earth orbits as well as industrial and commercial facilities on the Moon. The recently announced Voyager space hotel by Orbital Assembly Corporation (OAC) with rooms for over 400 guests targets a launch date of 2027[2]. While 2027 appears fantastical to many, the OAC approach is grounded on deep experience with manufacturing with plausible steps for meeting increasingly challenging objectives. The technical feasibility of each step is well grounded. Given progress in reducing launch costs towards $200 / kg, then the driver will become reasons for increasing launch rates. Hotels, space manufacturing and large-scale research facilities in orbit can create targets for launching more and more rockets with costs declining with increased launch reliability and frequency. Much lower launch costs create the potential for dramatically lower costs not only to orbit Earth but to reach the Moon and to develop industrial infrastructure on the Moon. Lunar exploration has barely scratched the surface of revealing the resource base of the Moon, but available data indicates that the Moon has many of the materials required by an industrial civilization. Potentially vast concentrations of valuable metals could exist under the Aitken Basin in the South polar region and elsewhere, but such exploration remains to be done [3]. As use of lunar materials expands the cost of building industrial, scientific and commercial facilities in outer space from lunar resources will drop below the cost of sourcing most types of materials from the Earth. This opens the prospect for a lunar-centric space economy identified as Moon-Earth.

Key assumptions of a lunar centric model for space industrialization are:

- Large structures in space need to be assembled from components manufactured in space. Construction of ISS is not a good model for the future when much larger structures will be built.
- The Moon is the low-cost site for materials for space manufacturing. Many important materials are on or near the surface, and the vacuum and fractional gravity of the Moon promises launch costs from the Moon that are a fraction of launch from Earth.
- Lunar industrial development can make important contributions to developments in Mars orbit. The Δv of shipment to Mars orbit from the lunar surface is less than launch from the surface of Mars [4]. Industrial development in Mars orbit using lunar materials can lower costs and improve effectiveness of operations on Mars.
- It will become increasingly urgent to limit launch of spacecraft to LEO from Earth as congestion from satellite megaconstellations increases and suborbital intercontinental transportation takes off following the model proposed by Elon Musk.
- Climate change is a threat to all countries and urgent action is called for to limit or eliminate large scale resource extraction on Earth, as well as to limit launches through the atmosphere.
- Billionaires can speed up development, but international cooperation is critically needed to demonstrate the feasibility of self-sustaining lunar industrial development.
- The ILD as a framework continues to be relevant to foster vitally important strategically directed international cooperation in outer space development. [5].
- These assumptions could drive the creation of a financial model that would permit the calculation of the size of the space economy by 2040 given these assumptions, and an alternative scenario where the assumptions are not accepted, and the tragedy of the time horizon continues to limit investment in space development. Given that a $10 trillion

space economy could be created by 2040, then the difference in total wealth between the two scenarios could be a compelling argument for international cooperation in the creation of mechanisms to finance accelerated space development.

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Some results of three projects of the Institute of Astronomy of UL

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1. Carbon star survey in the selected zones at the Baldone Observatory

Infrared 2MASS (J – K) colour distribution for C and M-stars differs. Late carbon stars are redder than late M stars. It gives the possibility to complete the checking of potential late carbon star candidates by infrared photometric colours (J-K)>1.3 mag. The potential list of carbon stars contains more than 20000 objects; therefore, the program of observation was planned to cover five-degree delta slices, in each season of observation, beginning from the pole gradually descend to the celestial equator.

Observations were made with a 1.2 m Schmidt system telescope of Baldone Astrophysical observatory with a four degrees objective prism and CCD ST - 10XME from 2006 till early 2017, and CCD STX-16803 from late 2017 till 2019.

49 new carbon stars have been discovered in the constellations Cassiopeia, Perseus, Auriga, Cygnus, Cepheus and Pegasus. Without spectral images of potential C-stars, positions of 347 spectral CCD images of bright standard C-star fields were exposed to study their spectral characteristics.

The distance in kpc can be calculated from the equation Mk - mk + 5lgr + Ak + 10 = 0, where Ak is interstellar absorption, Mk absolute magnitude in K passband, mk observed K magnitude. Mauron (2008) showed that the absolute K magnitude of late carbon stars varies in a small range of magnitude from -8.1 to -7.4 depending on $(J - K)_0$ colour indices in LMC. The interstellar absorption Ak and $(J – K)_0$ can be calculated from interstellar reddening. Ak = 0.302E(B−V) and $(J - K)_0 = (J - K) – 0.405E(B −V)$, where E(B – V) is taken from infrared full-sky dust maps obtained by Schlafly and Finkbeiner, 2011[2].

Comparison of Gaia satellite and Baldone Observatory obtained distances are made. The distances of Gaia satellite and distances obtained at Baldone Observatory correlate within ±0.9 kpc; r(B) = 1.07r(G) - 0.41.

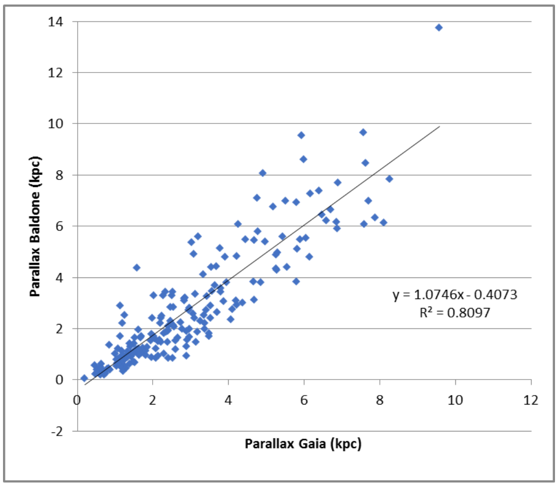

Fig. 1. Comparison of Gaia satellite and Baldone Observatory obtained distances

Carbon star concentrations at distances 2, 4, 6-7 kpc from the Sun are observed. According to distances they are located near Orion, Perseus, and Outer arms, however, in general, carbon stars poorly tied to the galaxy's branches.

2. Observations of asteroids using the Baldone Schmidt telescope

The research was carried out within the project "Complex investigations of small objects of Solar system". In 221 observation nights were obtained 5544 CCD images, which covered 648 square degrees of sky. More than 6000 astrometric positions for 1122 asteroids were published and 49 new asteroids were discovered. Of them 3412 CCD images devoted to studying photometric characteristics of 25 NEO-type asteroids. For asteroids Nr.11508 (Stolte), 6178

(1986 DA), 2014 LJ21, 850 (Altona), 2583 (Fatyanov), 345705 (2006 VB14) and 26724 (2001 HU8) rotation periods were obtained. Photometric data reductions for the images of five Near-Earth Objects were done using the MPO Canopus and MaxIM DL programs. Through experimentation with different rotation periods used Fourier fitting to determine the best size of periods.

Tab. 1. *H20 results (March 2019)*

Nr, Name	***Nights, Observation Nr***	***P(sun, years)***	***P(rotation, h)***
11508, Stolte	9, 167	4.64	3.049
6178, 1986 DA	5, 150	5.10	3.12
2014 LJ21	5, 123	4.91	16.41
850, Altona	7, 264	5.20	11.19
2583, Fatyanov	4, 465	3.38	5.66
345705, 2006 VB14	7, 39	0.67	3.25
26724, 2001 HU8	1, 52	5.50	1.43

The G(RP) photometric magnitudes for reference stars were taken from Gaia DR2 release [3]. For the other 18 asteroids, photometric data reductions are continuing.

3. The results of “Online Observatory” project

ERASMUS+ project “Online Observatory” (KA201-2018-008, 2018-2020) started in the autumn of 2018. The Online Observatory was founded by five European observatories (Baldone Observatory; Brorfelde Observatory, Denmark; Harestua Solar Observatory, Norway; Helsinki Observatory, Finland; Faulkes telescope project, UK) in 2018, all of which with a special interest in communicating astronomy and where visitors get hands-on experiences on how to be an astronomer. Their combined efforts resulted in the Online Observatory, where activities developed at each observatory are made accessible for schools and others for educational purposes (https://onlineobservatory.eu/).

The outcomes contain 71 resources for educational purposes in astronomy beginning from Virtual tours at the five observatories, about the sky observation, Moon, Planets and exoplanets, Sun and stars, and concluding with the Universe. Thirteen of them have been prepared by the staff of the Institute of Astronomy (Baldone Astrophysics Observatory).

Acknowledgements

This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation.

This work uses results from the European Space Agency (ESA) space mission Gaia. Gaia data are being processed by the Gaia Data Processing and Analysis Consortium (DPAC). Funding for the DPAC is provided by national institutions, in particular the institutions participating in the Gaia Multi-Lateral Agreement (MLA). The Gaia mission website is https://www.cosmos.esa.int/gaia. The Gaia Archive website is http://archives.esac.esa.int/gaia.

This research is funded by the Latvian Council of Science, project Complex investigations of Solar System small bodies, project No. lzp-2018/1-0401.

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Radiation Detection Materials and Detector Technologies for Radiation Detectors

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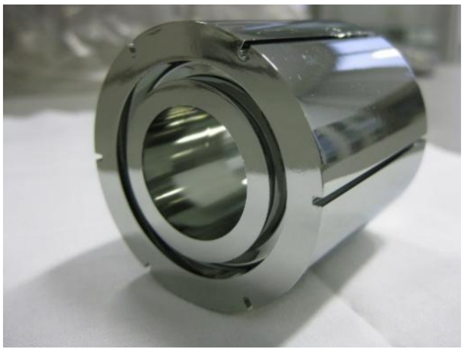
Nuclear radiation detectors are widely used in radiation monitoring equipment for nuclear industry and environmental monitoring, mining industry and medicine, nuclear science and space applications and in many other applications. Radiation detectors based on semiconductor materials surpass all other types of detectors in terms of energy resolution and have a high radiation detection efficiency. Scintillation detectors are superior to other types in terms of radiation detection efficiency, but they are inferior to semiconductor detectors in terms of energy resolution.

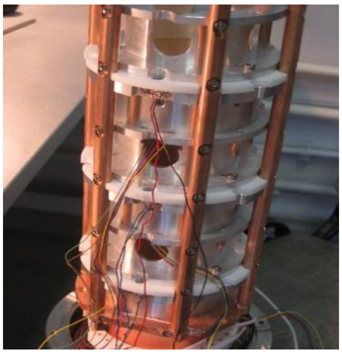
Specialising in the development and manufacturing of precise spectrometric equipment, which allows not only registering nuclear radiation, but also analysing their composition, distribution and activity of emitting radionuclides, Baltic Scientific Instruments carries out research and development in the field of detector materials and technologies that allow creating precise spectrometric detectors for various applications. The main research, development and production are conducted with semiconductor materials HPGe, Si, CdZnTe/CdTe, TlBr, as well as the highest precision scintillation crystals LaBr3, CeBr3, SrI2, whose spectrometric performance has been significantly improved in recent years.

The company has clean boxes, zones and rooms for working in clean conditions and glove boxes to work in special atmospheres, as well as the necessary equipment used in technological operations for cutting, slicing, dicing, polishing, lapping, chemical etching, impurities diffusion and drift, vacuum annealing, materials vacuum evaporation, photolithography, wirebonding, microassembling.

In addition to the release of serial detectors for industrial applications (nuclear industry, environmental monitoring, mining and metallurgical industry), the company provides the development and manufacture of unique ultra low-background detectors for international scientific experiments in the search for dark matter, neutrino-antineutrino research, double beta decay registration, underground investigations.

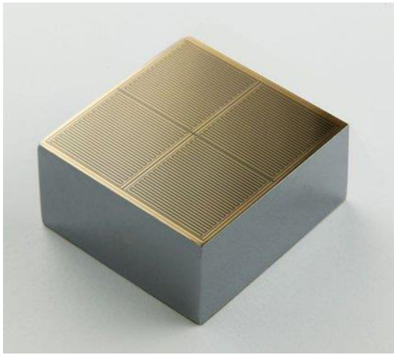
The company has significant experience in the development and manufacture of specialised detectors for imaging systems used in medicine, space and industrial applications. We are continually dedicated to researching, developing and mastering advanced detector technology. All research and development is carried out in close cooperation with international research organisations and foreign universities. The company’s specialists constantly participate in international conferences and publish the results obtained at the highest scientific level. Some of the company’s scientific products are shown in Fig. 1.

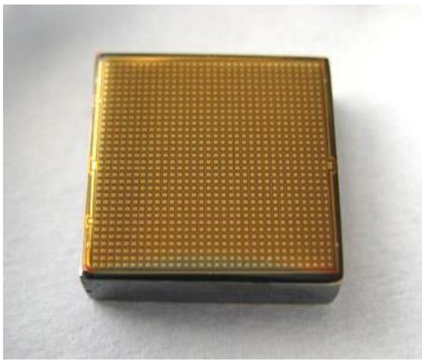




a) *b)*

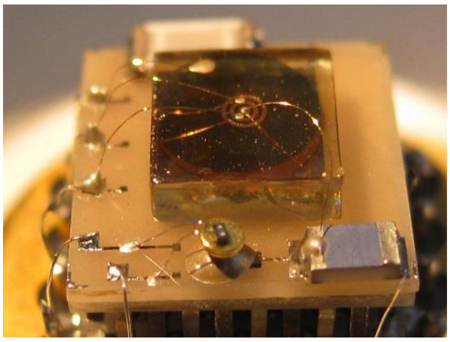
Fig.1. Semiconductor Detectors:
a) segmented HPGe detector for nuclear reactions search;
b) ultra low background HPGe 4-crystals assembly for neutrino registration;





c) *d)*

c) 4-segmented CZT Coplanar Grid detector for HEP;
d) 32x32 pixel CZT detector for medical imaging applications;



e) *f)*

e) CdTe strip detector for position sensitive experiments;
f) prototype of TlBr Ring detector for medical application.

Towards Energy-Efficient Technologies with Smart Optical Sensing and Shape-Assistant Trapping of Infrared Emission

***Oleg Dimitriev*[1], *Petro Smertenko*[1], *Olexander Gridin*[1], *Eduard Manoilov*[1], *Vadym Naumov*[1], *Arnolds Ūbelis*[2]**

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Energy efficiency (EE) is a mainstream for sustainable development and progress in Europe [1]. According to EU statistics, buildings are responsible for almost one third of final energy consumption and up to half of carbon dioxide emissions into the atmosphere. At the same time, 64% of energy consumed in the residential sector is used for heating homes, with renewables accounting for 27% of household space heat consumption. In the last decades, great progress has been made in improving the energy efficiency of households through the development of smart houses, for example, by designing buildings with walls filled with phase-change materials, smart windows that control incoming and outgoing light radiation, programmable sensors that tune the heating, etc. However, little was done with the design of the shape of the buildings, both exteriors and interiors. Most houses still use traditional shapes with rectangular wall joints and box-like structure. Obviously, advanced energy-efficient solutions to improve the EE housing require innovative science-based approaches [2, 3]. A properly designed house shape can help reflect or trap infrared radiation, redistribute thermal fluxes and thus optimize heat emissions. Moreover, such optimization can be carried out during the initial design of a building, as well as during its retrofitting and renovation.

In this work, we have conducted comparative studies of heat distribution in buildings of two shapes: rectangular and circular dome-like. One of the advantages of the dome shape is the following. The minimum surface area with the same usable area as a rectangular one means that less heat is absorbed. Accordingly, the cost of cooling and air conditioning can be reduced. The buildings are of the same height, land area, and inter-building distance (Fig. 1). The angle of the incident light (red arrows) corresponds to the midday sun in summer time. In the case of a rectangular shape, the reflected light (black arrows) is lost between the walls, thus contributing to their heating, while in the case of a circular shape the light is reflected into the environment.

***Fig.1**. Pathways of light propagation in space of rectangular (left) and circular (right) shapes: red arrows - incident radiation, black arrows - reflected radiation*

Figure 2 shows an example of the test survey of two smart houses of rectangular and circular geometry with approximately the same living area (~50 m^2), which are located in the suburban village in the Kiev region (50°10′42″N, 30°18′57″E). The presented data demonstrate the temperature distribution in the interior space, scanned by IR optical sensing throughout the house, beginning from the oven (as shown by red arrows on the plan) as a function of the daytime. The ovens in both houses were turned 'on' in the midday (3 PM local time). One can see that the differences in the temperature gradient in houses are significant. It is almost 2 times higher for the rectangular-shape house with a temperature sweep from 12 to 75^{0}C versus 17 to 38^{0}C for the dome-shape house, which means that a rectangular shape consumes more heat and possesses higher heat losses (according to the Fourier's law of thermal conductivity), and it has less efficient heating of the house area compared to the dome-shapes building. Research is in progress.

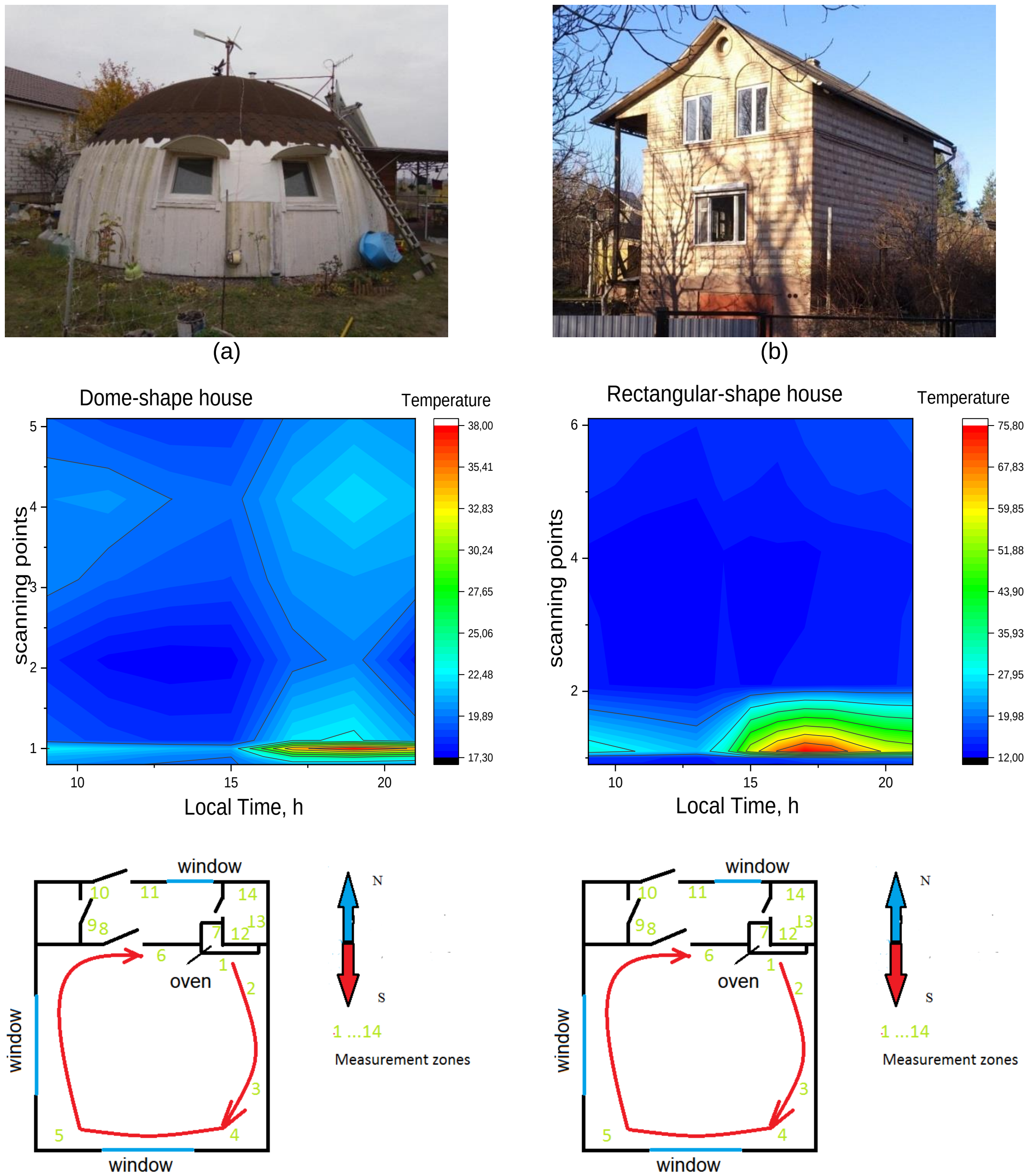

Fig. 2*. Test buildings (photo on the top), temperature distributions (maps in the middle) for houses of different shapes, and plan of IR sensing (at the bottom, red arrows correspond to the measurement steps), as measured on the same day: (a) dome-shape house, (b) rectangular-shape house.*

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Monitoring of Radioactive Waste on Nuclear Industry

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All nuclear facilities (Nuclear Power Plants, reprocessing plants, nuclear laboratories....) in the process of activity generate wastes along with their main product. Due to the specifics of those activities the wastes could be radioactive and dangerous for human beings. Decommissioning and disassembly of nuclear facilities themselves will add to the quantity of radioactive wastes (RAW) which should be recycled in accordance with the existing Standard*[4]. RAW should be characterised according to its physical, chemical, and radiation properties so that the safest and most economically effective variant for the waste treatment can be chosen.

Having own production of radiation detectors, Baltic Scientific Instruments designs and produces Free Release and Waste Assay Monitors for small, medium, and large volumes of RAW for the Nuclear Industry. Some such Monitors are presented on the Fig. 1. Due to specific conditions on all nuclear facilities, all the fabricated Monitors are mostly customized. The main part of fabricated Monitors is based on semiconductor HPGe detectors (10-50% efficiency depending on RAW activity); the most precise types of advanced scintillation detectors (LaBr3, CeBr3, SrI2 with dimensions 2x2” and 3x3”) are used as well.

All monitors that we developed are fully automated and equipped with a software suite that includes the WAM-soft software package for system control and automation, the SpectraLineHandy software package and the EffMaker software package. The WAM-soft package allows the operator to configure the measurement configuration of RAW radiation (place the objects to be measured into the desired position, adjust the shutter opening of the collimators, start the rotation, etc.). The SpectraLineHandy software package executes control of the spectrometer, displays the measured spectra, identifies the radionuclides and determines the RAW activity by applying calculated efficiencies for gamma quanta registration obtained by any calibration method. The EffMaker software package is used for the calibration of the monitors with the Monte Carlo simulation method and for simulation of nonstandard measurement tasks.

All the developed WAMs have metrological assurance. On the basis of existing metrological standards, applicable regulations, and measurement methods accepted in the nuclear industry, we have selected as metrological assurance certain calibration and monitor validation methods, manufactured a set of the volumetric activity reference sources for direct verification of calibration results, and provided a package of application programs to support the measurements and ensure reliable results. The calibration of the monitors’ efficiency is made with standard sources in point geometry as well as with a complex calculation of the effectiveness curves using the Monte Carlo simulation method. The comparison of the calculated dependencies of the registration efficiency on energy and those ones obtained from real measured barrels with sources of calibrated activities demonstrate that the differences in the values do not exceed 20%. To allow direct verification of the monitors’ calibration we have manufactured and certified volumetric activity sources in the form of real 200, 400 and 700 l barrels that contain matrix-fillers.

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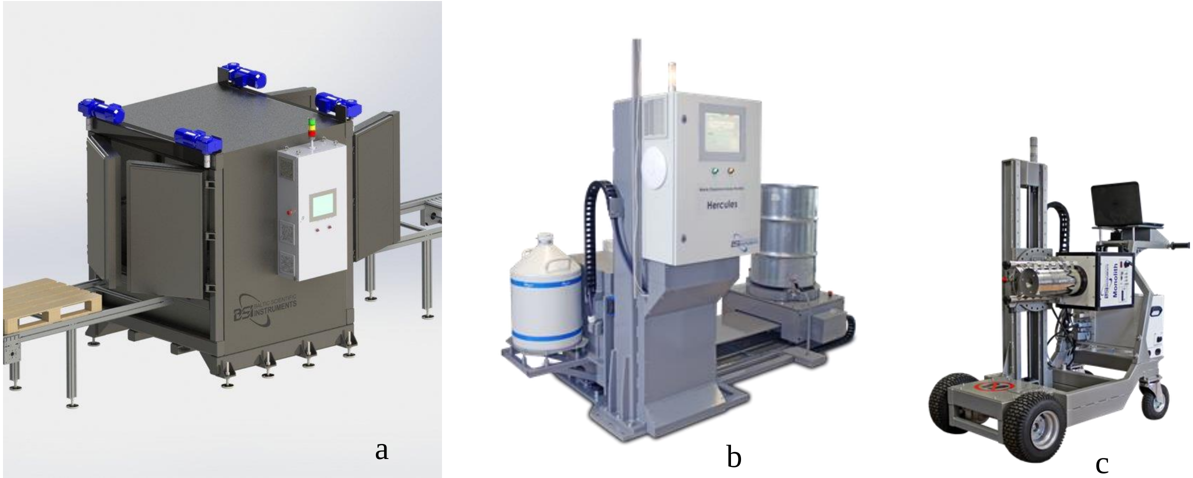

Fig.1. a) Free Release Monitor; b) HERCULES Stationary Waste Assay Monitor; c) Mobile Waste Assay Monitor.

Small form-factor supermultiview 3D display using Gabor superlens

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Stereoscopic two view solutions are not able to provide natural 3D perception. Future-oriented research focuses on glasses-free super-multiview display (SMV), with the viewing angles from 36 and above to overcome vergence-accommodation conflict (VAC).

Slicker's Ltd multi-national team of experienced in the field researchers and entrepreneurs is bringing to the market breakthrough game-changing technology, based on optical nanothickness layers covering square meters of any transparent surface.

The prototype *(TLR≥6)* of the 3D light panel with changeable images as well as working *SLICKER 3D SMV (Super multi-view)* display has been tested. A fundamentally new way to get a 3D image based on very economical film optics containing Gabor superlens array is secured by patent: US9778471B2, published 2017-10-03 [1].

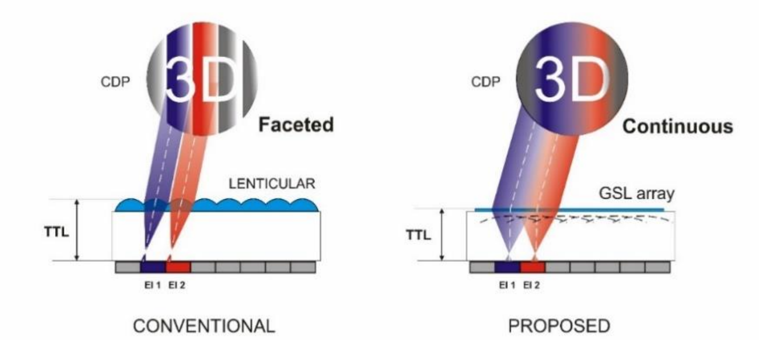

Fig. 1. *Slicker SMV 3D display concept*

European Commission has awarded its *Seal of Excellence* to SLICKER for Horizon 2020 phase 2 proposal "game-Changing 3D".

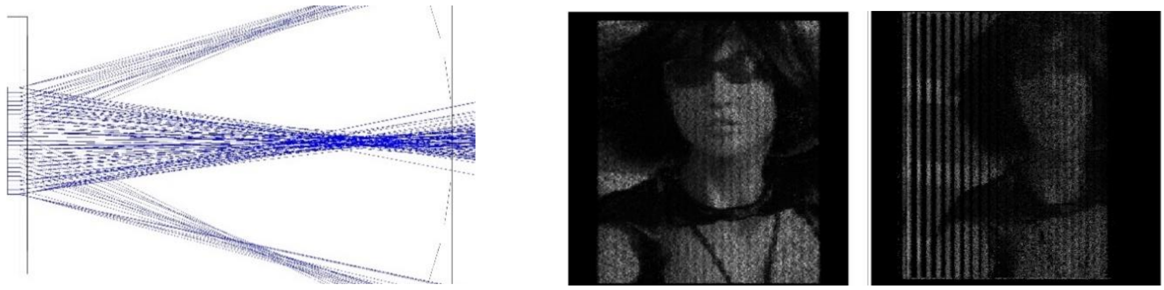

Fig. 2. *Image simulation for 0° and 25° (1/2 of image, black lines are space multiplexion phase)*

The project proposal "968828, Game-Changing3D" of the company to the call H2020-EIC-SMEinst-2018-2020-3 (deadline October 7, 2020) was awarded with European Commission's *Seal of Excellence.*

Ref. Ares(2020)7091180 - 25/11/2020

SEAL OF EXCELLENCE

European Commission

Certificate delivered by the European Commission,
as the institution managing Horizon 2020,
the EU Framework Programme for Research and Innovation 2014-2020

The project proposal
968828, Game-Changing3D
NEXT STEP 3D IMAGING

submitted under the Horizon 2020’s **SME Instrument (grant only and blended finance)**
call **H2020-EIC-SMEInst-2018-2020 (H2020-EIC-SMEInst-2018-2020-3)** of **7 October 2020**
in the area of **EIC-SMEInst-2018-2020**

SME instrument

by
Slicker
Krūzes Street 2B
LV-1046 Riga
Latvia

following evaluation by an international panel of independent experts

WAS SCORED AS A HIGH-QUALITY PROJECT PROPOSAL
IN A HIGHLY COMPETITIVE EVALUATION PROCESS*

This proposal is recommended for funding by other sources, since Horizon 2020 resources available for this specific Call were already allocated following a competitive ranking.

* This means passing all stringent Horizon 2020 assessment thresholds for the 3 award criteria
(excellence, impact, quality and efficiency of implementation) required to receive funding from the EU budget Horizon 2020.

Elisa Ferreira,
Commissioner for
Cohesion and Reforms

Mariya Gabriel,
Commissioner for Innovation, Research,
Culture, Education and Youth

Brussels, 25/11/2020

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FBG sensors for structural health monitoring of road infrastructure

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With every day more and more new roads are being built all around the world. Due to the different aspects like climate, season, weather changes, and high usage of transportation, as well as natural depreciation over time, lead to the need for reconstruction of the older roads that are used on a daily basis. Knowing that the total population of humankind increases, and communication technological aspects develop rapidly, it is safe to say, that infrastructure for a physical connection between places will be needed further on, more than ever. From the previously said - to save resources, ensure public safety, and provide longer-lasting infrastructure, a structural health monitoring (SHM) application for roads should be researched and developed. Asphalt is one of the largest used surface materials for the road building industry. This material also provides a relatively easy fiber optical sensor technology instalment, which can be effectively used for SHM applications - road infrastructure monitoring as well as for resource optimization when road building or their repairs are planned [1-4]. FBG sensor technology, are one of the most promising and are widely used mainly due to their significant advantages like passiveness, size, multiplexing ability, high sensitivity, remote sensing capabilities and resistance to electromagnetic interference, etc. [1,3,5-6].

This paper focuses on the research of the optical (based on fiber Bragg grating (FBG) technology) strain and temperature sensor applications in road SHM. The integration of FBG strain and temperature sensors was realized into road pavement in one of the largest Latvian road sites A2 (Riga-Sigulda) and A8 (Riga - Jelgava). We found the pavement structure in Latvia that is going to be built in the construction seasons 2019-2020 and 2020-2021 for embedding (see in Fig.1) of FBG sensors and measurements (see in Fig. 2). The research was realized in cooperation with SJSC “Latvian State Roads” and contracting companies “Binders” Ltd., JSC “ACB” which are performing the pavement reconstruction projects of main roads A2 and A8.

Fig.1. *FBG strain and temperature sensors integration into road pavement*

Fig.2. *Real-time strain measurements by embedded FBG sensors*

Experiments and measured results are very topical for local and international road pavement designers and road management service to forecast collapsing of the road, permanent deformation, vehicular weight and number of axles, traffic monitoring, and road pavement temperature monitoring.

Acknowledgments

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We thank SJSC “Latvian State Roads”, “Binders” Ltd., and JSC “ACB” for providing us access to the road infrastructure, support during experimental measurements, and valuable advice.

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Dispersion engineering of whispering gallery mode resonators

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Whispering gallery mode resonators (WGMRs) are axisymmetric optically transparent structures with a size of a few hundred micrometres. The light can be confined inside the resonator by total internal reflection. The mode density of the WGMRs is very high, so we can observe strong light-matter interactions. One of the interesting applications is the generation of optical frequency combs using for-wave mixing [1].

Every wavelength of light inside a medium experience a different refractive index n due to material dispersion. But also, the geometry of the resonator contributes to the total dispersion [2]. We can use geometric dispersion to engineer the geometry of the resonator such that the dispersion is desirable. Kerr combs can be generated in anomalous dispersion, so it is important where the zero-dispersion wavelength (ZDW) lays. For optimal comb generation it is good that dispersion line is not steep. For telecommunication applications the pump wavelength is 1550 nm.

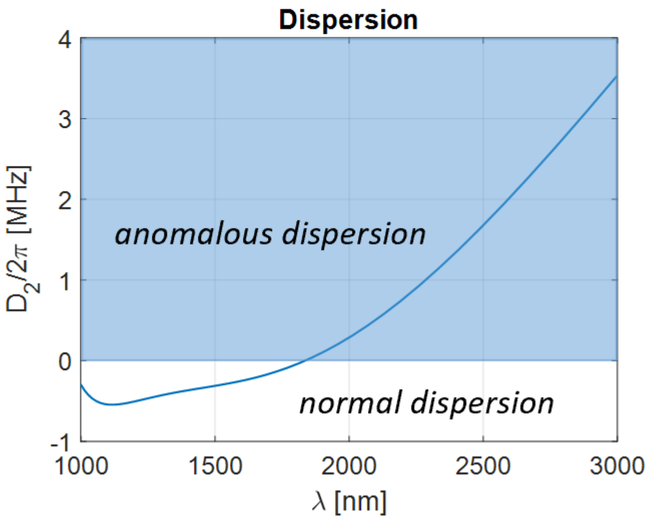

Fig. 1. *Dispersion for R=332 µm belt type WGMR*

Various WGMR geometries are being explored to achieve optimal dispersion for comb generation.

Acknowledgment

This research was funded by the European Regional Development Fund project No. 1.1.1.1/18/A/155.

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Optical Fibre Taper Simulation and Manufacture: from Standard to Micro Size

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The mode field intensity and adiabaticity are calculated for different points along the transition of an optical fibre taper from the standard 125 µm down to 1 µm diameter for low loss operation at 1300 nm wavelength. The first section of the taper is evaluated using a weak guidance approximation. The second section is treated as a three-index layer structure (double-clad) and evaluated with eigenvalue equations for three refractive indices. The third and thinnest section of the taper is studied using an exact mode eigenvalue equation. Tapers ranging from 38 to 40 mm length were fabricated. With this simplified set-up, tapers with the relatively good beam quality, low losses and variable length can be fabricated for applications in sensing and bio-medical applications.

The taper has been assumed to be a symmetrically biconical shape with 19 equidistant points (marked by the letters A-S, 2 mm apart) along the taper from the initial standard size A (125 µm diameter) to the smallest waist diameter of S (440 nm). For obtaining the results, weakly guiding approximation [1], Monerie [2] and exact mode equations [3] were used to evaluate and obtain the shapes of the position o of fundamental mode field in different points along the taper as shown of Fig. 1. It is important to find out if the optical fibre taper is adiabatic, that is the taper has very low loss [4], our first optical fibre taper is shown in Fig. 2 and Fig. 3, show the taper shape obtained.

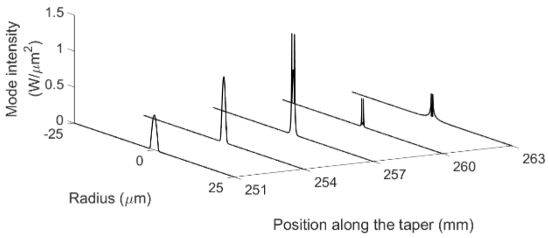

Fig. 1. *Normalized Mode intensity profile along the tapered fibre*

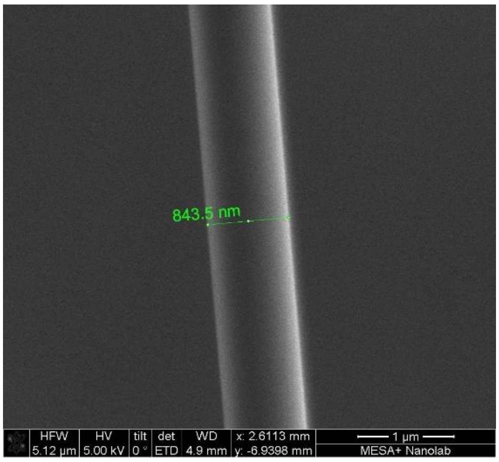

Fig. 2. *Optical Fibre Taper Diameter in SEM*

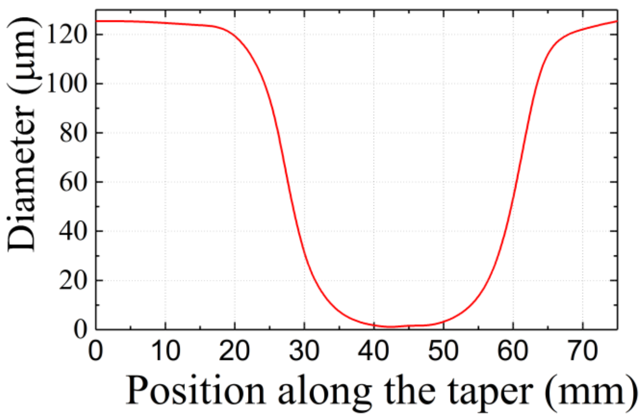

Fig. 3. *Optical Fibre Taper shape.*

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Liquid whispering gallery mode humidity sensor and its applications

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Precise air humidity measurements and control are necessary in many fields: agriculture, industrial manufacturing, scientific research, medicine, and others [1]. To achieve high sensitivity and precision, optical whispering gallery mode (WGM) sensors are widely researched. WGM resonators have high quality (*Q*) factors as they trap light inside them for long periods of time. Other positive qualities include their ability to operate in extreme environments and their electromagnetic immunity [2]. Resonant wavelength λ depends on the refractive index n and the radius R of the resonator: $\lambda m = 2\pi Rn,$ where m is an integer number of optical waves fitting into the parameter [3]. As air humidity changes, the R and n of the resonator change and cause the resonant wavelength to shift. This shift is detected, and the resonator can be used as a humidity sensor.

In this experiment, glycerol microdroplet (R = 370 μm at 50 % RH (relative humidity)) was used as a spherical WGM resonator. Glycerol is highly hygroscopic, transparent, non-toxic, and viscous [4], making it a good choice for the liquid resonator material. Droplet is created at the tip of an optical fiber, which is attached to an XYZ table to change the position of the droplet when necessary. Droplet and other optical components are inside a climate chamber. To excite WGM in the droplet, a 760 nm tenable VCSEL laser was used. Due to the nature of liquids, it was possible to use free space coupling [5], which resulted in a simple set-up (Fig. 1). Photodiode collects the transmission spectrum and data is transferred to an oscilloscope. We used *LabView* and *Python* for data analysis. An original method for data analysis was created – we use Lissajous figure to detect the wavelength shift (change in the radius vector angle) and to tell if the RH is increasing or decreasing (the direction of the Lissajous figure). Data was analysed in real time.

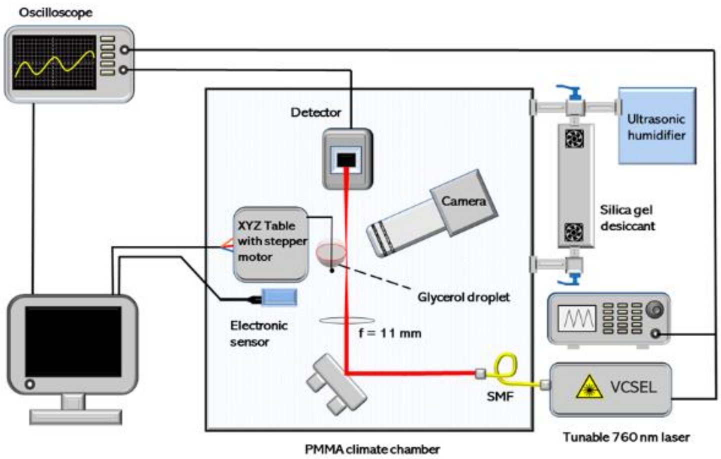
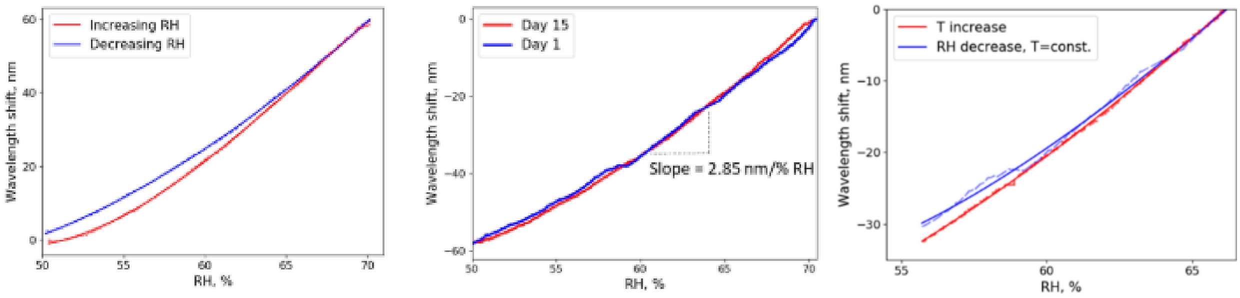


Fig. 1. *Experimental set-up for humidity measurements*

Glycerol droplet as a humidity sensor was tested in the 50–70 % RH region. We tested such parameters as hysteresis, repeatability, lifetime, and temperature independence. From the acquired data sensitivity and resolution were calculated.

Results of this experiment showed that glycerol has great potential as WGM humidity sensor. We achieved the highest reported sensitivity of this type of sensor: 2.85 nm/% RH with the resolution $1{\cdot}10^{-4}$ & RH. It showed high repeatability and stability. One of the benefits, when compared to other WGM sensors, is its temperature independence – small temperature fluctuations in the environment did not cause wavelength shift [6].



(a) (b) (c)

Fig. 2. *Experimental results: (**a**) hysteresis; (**b**) repeatability, stability, sensitivity; (**c**) temperature dependence*

Based on these results, we demonstrate possible applications for our novel humidity sensor and indicate ways for further research. The demonstrated WGM glycerol droplet humidity sensor has qualities to measure and detect very small RH changes. Due to this, one should be able to successfully integrate it into systems where very precise environment control is needed. Chemistry and especially pharmaceutical industries require such precise environment control [7], [8]. Many chemicals need distinct RH conditions for optimal and safe storage. Pharmaceutical compounds often require RH to be in a very narrow region between 50–60 % RH, which coincides with the optimal work range for the demonstrated WGM glycerol droplet humidity sensor. The measured sensitivity, selectivity, and resolution of our sensor could be used in monitoring pharmaceutical and chemical compounds and processes. Further research into creating a portative set-up, calibrating the sensor, and researching the selectivity and response time of the sensor is needed.

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Microsphere-based OFC-WGMR multi-wavelength source and its applications in telecommunications

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The "Development of optical frequency comb generator based on a whispering gallery mode microresonator and its applications in telecommunications" project aims to obtain new knowledge on whispering gallery mode resonator-based optical frequency combs (WCOMBs) and to develop, construct and test a comb generator prototype for telecommunication applications. The planned result of the project is the portable WCOMB prototype for commercial fiber optical communication systems.

Optical frequency combs (OFCs) using different kinds of whispering-gallery-mode (WGMRs) microresonators have a high potential to replace tens of tuneable continuous-wave (CW) lasers with a single laser source in telecom (WDM) optical communication systems. For the first time, the use of silica microspheres (SiO_2) for OFC represents a cheap alternative over the other microcombs. By using arc discharge of a commercially available fusion splicer, it is possible to quickly fabricate microspheres with repeatable parameters such as diameter, and it is easy to control the free spectral range (FSR) which is proportional to the sphere diameter. Our designed microspheres have a high Q-factor (10^7-10^8), where the carrier wavelengths of WGMR-OFC are relatively stable over time and FSR matches the ITU-T spectral grid [1].

One way to enter the light into the resonator is by prism coupling [2]. This scheme is an alternative to the tapered fiber coupling scheme and has some advantages and disadvantages. Advantage – that the setup can be made with standard optical components and the setup does not have fragileness that is present in tapered fiber coupling setup. Disadvantage – coupling efficiency is only about 5 - 40%. Considering the aspect, that the tapered fiber method of microsphere excitation allows to fine-tune the coupling conditions which is not possible for chip-based resonators we have chosen them for OFC generation in optical communication systems.

To the best of our knowledge, we experimentally for the first time present designed silica microsphere whispering-gallery-mode microresonator (WGMR) OFC as a C-band light source where 400 GHz spaced carriers provide data transmission of up to 10 Gbps NRZ-OOK modulated signals over the standard ITU-T G.652 telecom fiber span of 20 km in length.

We search for stable combs on an optical spectrum analyser (OSA) by tuning external cavity CW semiconductor laser in wavelength and found that the most appropriate wavelength (λ = 1552 nm), where a CW laser with a linewidth of about 100 kHz and +6 dBm optical output power can be used as an OFC comb pump source. After OFC generation the carriers (-1) and (+1) are similar but one can be a few dBm more intense than the other if multiple solitons are circling inside the resonator. The optical carriers λ= 1549 nm depicted as (-1) and λ = 1555 nm depicted as (+1) are used further to demonstrate NRZ-OOK modulated 2.5 Gbps and 10 Gbps data transmission, please see Fig.1 (a). The OFC performance over 10 hours period, power stability and power distribution stability over the wavelength of the OFC carriers please see Fig. 1(a) and Fig. 1(b).

The experimental setup of silica microsphere-based WGMR-OFC light source optical communication system, please see Fig.1(c). The light coming from the pump source is further amplified up to +23 dBm by the erbium-doped fiber amplifier (EDFA). The polarization state of the amplified signal is adjusted using the polarization controller (PC1) before coupling the signal into the microsphere. The isolator on the EDFA output is used to prevent back-scattered light from entering the output port of the CW laser. Silica microsphere and tapered fiber are enclosed in a separate box for dust and airflow prevention, providing even further stability to the resulting OFC. The X, Y, and Z micro-translation stage is used to position the microsphere to touch the tapered fiber at a place slightly thicker than the taper waist, which changes such coupling conditions as coupled power and the Q factor of the resonances [3].

We have chosen B2B transmission and a distance of 20 km corresponding to the NGPON2 requirements. The error-free transmission is established during the experiment in both cases of 2.5 and 10 Gbps data rates for OFC comb pump source operating at 1552 nm wavelength. It allows using WGMR-OFC as a light source where 400 GHz spaced carriers provide 2.5 and 10 Gbps NRZ modulated data transmission over 20 km SMF fiber [1].

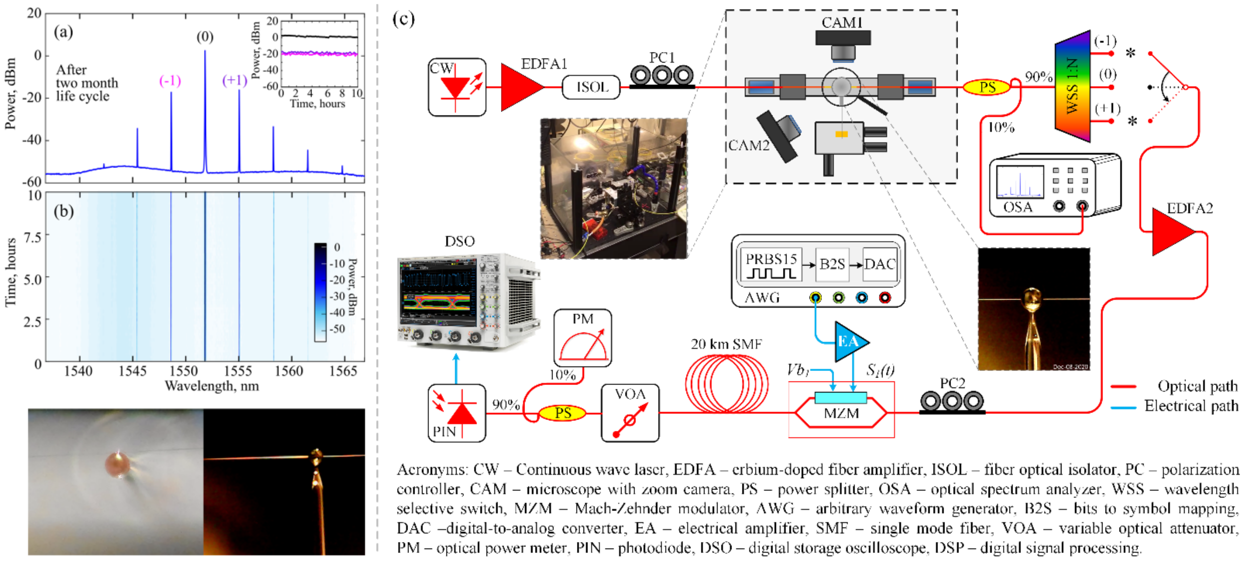

Fig. 1. *Measured OFC performance over a 10-hour period: (a) optical spectrum with inset representing captured power stability, and (b) power distribution stability over the wavelength. (c) The experimental setup of the designed silica microsphere WGMR-OFC as a light source where 400 GHz spaced carriers provide NRZ-OOK modulated 2.5 and 10 Gbps data transmission over 20 km SMF fiber. Insets show tapered fiber and silica microsphere resonator positions of coupling conditions and WGMR-OFC reduced humidity and dust-prevention cover box*

Acknowledgments
This research was funded by the European Regional Development Fund project No. 1.1.1.1/18/A/155 "Development of optical frequency comb generator based on a whispering gallery mode microresonator and its applications in telecommunications" and supported by Riga Technical University's Doctoral Grant programme.

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Development of next generation technology for ultra purity crystal growth based on MHD semi levitation

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The recent papers on unique computer-simulations and experimental results on aluminium magneto-hydrodynamic (MHD) levitation co-authored by scientists from the University of Latvia and Hanover University and followed pilot research highlighted potential for technological innovation leading to remarkable progress in crystal growth technology.

The new 32-month long project supported by Central Financial Contracting Authority is the timeliness response and is going to develop further and to challenge the application of MHD levitation crystal growth technology in semi levitation mode for the Germanium. The project will be implemented by a multi-disciplinary team of physicists, electronic engineers, chemists, and material scientists of the University of Latvia together with two industrial partners – research driven SMEs AGL Technologies, Ltd and Cryogenic and Vacuum Systems, Ltd.

The research efforts during the implementation of the project will result in the proof of concept and custom-made cost-efficient laboratory devices (TLR eventually 3-4) combining in not interrupted sequence: multiple zone purification, Czochralski and melted zone (pedestal) techniques to grow high-purity crystals avoiding their contacts with mechanical parts in the crystal growth zone by application of MHD semi levitation.

Coverless melting techniques in vacuum or in the environment of high-purity gases is going to be performed in a synthetic silica glass-metal assembled device. The core of studies:

a) model simulation of the melted zone hydrodynamic stability under MHD semi levitation.
b) research to find optimum interrelations between the power of MHD inductors, frequency, temperatures profiles and geometry of melted zone.
c) assembling of low temperature (Sn ~300°C) and high temperature (Ge ~1000°C) experimental set-ups for the initial and the final test of semi levitation concept accordingly.
d) experimental studies evaluating the potential of MHD semi levitation concept in HP Ge crystal growth technologies in high vacuum and clean gas environment, surrounded by synthetic silica glass envelop.

Timeliness of our project particularly is evidenced:

- ✓ by short survey performed by research team from South Dakota University, US [1]. The article highlights astrophysical interest to the next generations Germanium based detectors demanding ultra-high purity Ge crystals;
- ✓ the report about the start of the project developing levitation method lead by Dr. Arie van Houselt [2];
- ✓ the article [3] on contactless processing of SiGe-melts in EML under reduced gravity;
- ✓ by the review article of Dieter M. Herlach, Daniel Simons published in 2018 [4].

Presently large germanium single crystals of high purity (reaching 99,99999999999%) are grown by Czochralski techniques, the ingots being subject to repeated cycles (more than 50) of zonal purification in a separate appliance.

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Modelling of Cladding-Pumped Erbium/Ytterbium Co-Doped Fibre Amplifier for C-Band Operation

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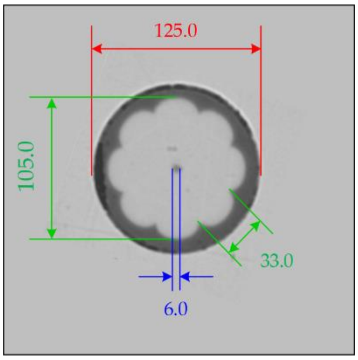
With space-division multiplexing receiving increased attention as a method to exceed bandwidth limitations, compatible schemes for efficient amplification become necessary [1]. Erbium (Er^{3+}) and Ytterbium (Yb^{3+}) co-doping is considered an effective approach for increasing pump power conversion efficiency of cladding-pumped optical amplifiers. The Yb^{3+} ions absorb pump radiation and then resonantly transfer a portion of their energy to Er^{3+} for signal amplification. With the investigation into the effect of various design specifications (e.g., fibre length, pump power, and propagation direction) on amplifier characteristics and their wavelength dependence, our research is dedicated to identifying such a cladding-pumped Er^{3+}/Yb^{3+} co-doped fibre amplifier configuration based on experimentally extracted fibre parameters that provide high, uniform gain with a low noise figure in the optical C-band [2].

As is common practice, the manufacturer of our erbium/ytterbium-doped fibre (EYDF) sample only provides information on its basic geometry and Er^{3+}/Yb^{3+} concentration ratio. The accuracy of the simulation model is primarily dependent on the ion absorption and emission cross-sections and the overlap factor value; thus, it is crucial to determine these values as accurately as possible. The initial overlap factor estimate is calculated as the cross-sectional ratio between the core and inner cladding (as shown in Fig. 1.), which must then be refined by matching the simulation model results to experimental measurements due to the model assuming that the cladding is circular, whereas the physical fibre has a flower-shaped inner cladding. It can be noted that the overlap factor may change as a function of pump power, which should be validated for any particular fibre at the expected operational pump power level [3].

(a)



(b)

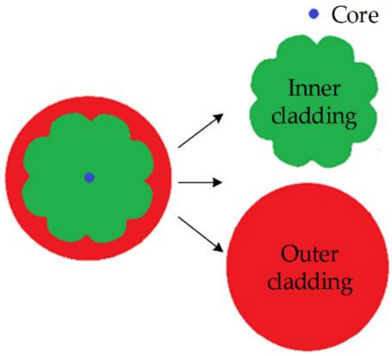


Fig. 1. *(a) Microscope image of the EYDF cross-section with its geometrical measures, and (b) RGB representation of its outer cladding (red), inner cladding (green), and core (blue) used for the overlap factor estimation*

Throughout our analysis, we use an optical pump source operating at $\lambda_P = 975$ nm and $P_P = 3$ W that is based on the specifications of the multimode light diode in our laboratory setup. Higher pump power levels were not considered at this time as a change from 3 W up to 4 W resulted in an insignificant increase in the output signal power of just 0.3 dB. It is determined that the optimal configuration at a per-channel input power of −20 dBm for 40 channels requires a 7 m long EYDF with a co-propagating pump. This results in an output power of 22 dBm, a gain of

19.7–28.3 dB, a noise figure of 3.7–4.2 dB, and a power penalty of 0.1 dB at a bit error rate of 10^{-9} using 40 × 10 Gbps NRZ-OOK signal.

While the highest gain is achieved at a doped fibre length of 8 m, it is only marginally higher than at 7 m, while both the noise figure and gain uniformity are worse, which is a consequence of pump depletion and high signal attenuation within the fibre. It is also seen that both smaller and larger fibre lengths result in worse gain uniformity. At the same optimal length, a counter-propagating pump achieves 1 dB higher gain at the cost of 1 dB higher noise figure, which is not a worthwhile trade-off, thus motivating the choice of a co-propagating pump. Specific to per-channel input power level, a sufficient but limited number of channels must be present to ensure efficient consumption of the generated population inversion and a minimal noise figure, otherwise, the unused portion of the population inversion eventually gives rise to amplified spontaneous emission noise. As a whole, the established dependence of these amplifier characteristics on the input parameters enables the assembly and further development of a cladding-pumped EYDFA in a laboratory setting.

Acknowledgments
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Wavelength measuring for optical telecommunications, using tapered fiber, image analysis and PMMA WGM micro resonators

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Whispering gallery mode

The whispering gallery modes (WGM) micro resonators are based on elliptical objects, which can be made from optically transparent materials, that can enable optical wave circulating inside the ellipse using total internal reflection. If there is a monochromatic light source with constant intensity to the ellipse, constructive interference may be observed which in the case of sphere could be written as [1]:

$$2\pi R n = M\lambda, \qquad (1)$$

where λ is the resonance wavelength, M is azimuthal mode number and R is the radius of the sphere.

The most important parameter of WGM micro resonators is Q (quality) factor. It describes the lifetime of photon that is circulating inside the optical micro resonator. In real life applications there are multiple losses and impurities, that limit the lifetime of photon [2].

PMMA WGM micro resonator characterisation

Poly methyl methacrylate acrylic (PMMA) WGM micro resonators are available with quality factor of 10^3-10^4 [3], while the Q factor is lower than WGM made from SiO_2 or ZnO [4], they are available commercially, solving the main problem for successful WGM micro resonator integration into working sensor system, that is the manufacturing cost.

Using high resolution cameras such as ''Xenics Xs-5049'' it is possible to monitor individual sectors of the micro resonator (Fig.1) and watch each sector intensity changes, based on the wavelength, that is fed to tapered fibber.

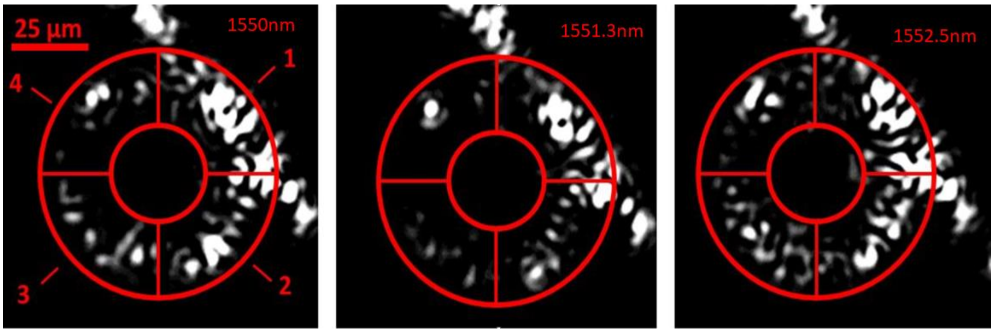

Fig. 1. *45µm PMMA WGM micro resonator attached to tapered fibber waist region, intensity using ''Xenics Xs-5049'' camera, for different wavelengths (1550nm, 1551.3nm and 1552.5nm)*

From each specific region of the micro resonator, normalized intensity map can be obtained (Fig.2), which can be used to navigate specific wavelength. Each region intensity corresponds to different mode interaction with impurities on the WGM PMMA micro resonator surface.

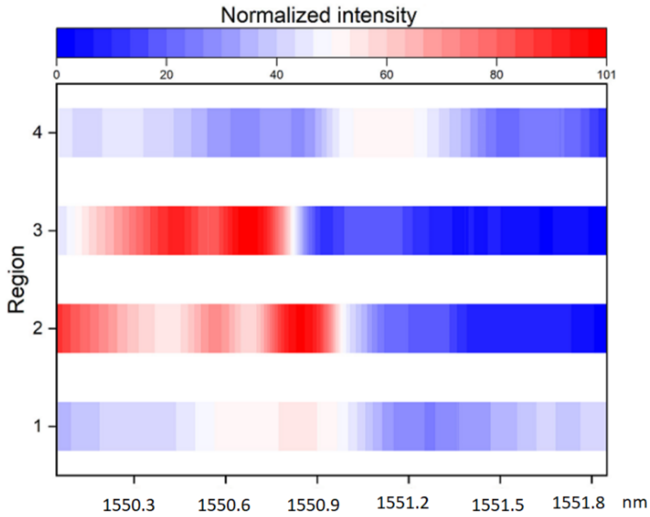

Fig. 1. *Normalized intensity map based on wavelength changes for 50μm PMMA WGM micro resonator*

Conclusions

The following work presents, new type of measuring system, where two main regular problems, that tie with WGM micro resonators – surface impurities and multiple modes, that lead to system improvements where few PMMA WGM micro resonators can be used as an measuring tool for telecommunication purpose [5]. These developed methods are valid not only for wavelength measuring but could be used for different bio measurements as well.

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