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BOOK OF ABSTRACTS

Poster presentations

Development of optical frequency comb generator based on a whispering gallery mode microresonator and its applications in telecommunications

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The project proposal (No 1.1.1.1/18/A/155)[1] has been developed in response to the European Regional Development Fund in Latvia measure 1.1.1.1. *Industry-Driven Research* of the specific objective 1.1.1. *To increase the research and innovation capacity of scientific institutions of Latvia and their ability to attract external funding by investing in human resources and infrastructure*. The project was ranked as the second best and has been implemented form 16 May 2019 to 15 May 2022 at a total cost of EUR 643 960.14, from which ERDF funding is 57.8%, state budget contribution is 34.7%, other public funding – 1.5%, private costs – 6%.

The project was implemented in collaboration of three organisations: University of Latvia (LU, lead organisation), Riga Technical University (RTU) and AFFOC Solutions, Ltd (AFFOCS). The involved personnel: LU – Jānis Alnis (project coordinator, Assoc. Professor, leading researcher), Aigars Atvars / Rita Veilande (leading researcher), Inga Brice (researcher), Arvīds Sedulis (laboratory assistant) and the project manager Dina Bērziņa; RTU – Jurģis Poriņš (Professor, leading researcher), Tamara Sharashidze (research assistant), Armands Ostrovskis (research assistant); AFFOCS – Ilya Lyashuks / Sandis Spolitis (leading researcher), Artūrs Ciniņš / Toms Salgals (researcher), Kristians Draguns (technical specialist). The budget allocation among the partners was distributed as follows: University of Latvia (40%), Riga Technical University (20%), AFFOC Solutions, Ltd. (40%).

Main activities (work packages) of the project were:

A1. Development, modelling, testing and optimisation of WCOMB,
A2. The development, construction, and testing of portable WCOMB for application in fibre optical communication systems,
A3. The adjustment and validation of the portable WCOMB prototype in commercial fibre optical communication system,
A4. Dissemination of the project results.

Project results

All the expected project results and the project monitoring indicators have been achieved and some even exceeded. The novelty level of the obtained results can be estimated as high since a prototype of new WGMR-based OFC light source, capable to provide sustainable operation was constructed, and a new approach for data transmission in fibre optical telecommunication networks has been developed and successfully validated. The project developed new smart materials (WGM resonators), technologies and engineering systems (WCOMB system), contributed and after its completion continues contributing to the ICT sector (application of WCOMB in telecommunication solutions).

The main results of the project

- ***7 scientific publications*** cited in SCOPUS (3 of them in journals with the citation index at least 50% of the average citation index in the sector) [1–7];

[1] https://www.lu.lv/en/wcomb/

- ***3 know-how descriptions*** (WGM resonator fabrication and testing; Computer modelling of WCOMBs; Technology and test results of WCOMB application into telecommunications);
- ***3 prototypes*** with descriptions (WGM microsphere resonator & WGM microrod resonator; Optimised advanced WCOMB system prototype; portable WCOMB prototype adjustment for field tests in commercial fibre optical communication system infrastructure);
- ***1 patent*** [8] related to the telecommunications sector, particularly the multi-wave light sources, which generate optical frequency combs (OFC) used for data transmission in fibre optical wavelength division multiplexed (WDM) telecommunications systems.

Other significant achievements

- ***Microsphere (400 GHz)*** and ***microrod (90-100 GHz) WGM resonator prototypes with excellent performance***. Research visit to Max Plank Institute of Light in Erlangen, Germany contributed to the further collaboration with P. Del'Haye research group, which allowed us to fabricate and test microrod and microdisc resonators.
- Multiple ***setups have been constructed for testing the resonators***. The experimental setup is based on tapered fibre coupling that was applicable for WCOMB generation. Research visit to Max Plank Institute of Light in Erlangen and the Swiss Federal Institute of Technology in Lausanne, Switzerland significantly contributed to the optimisation and advancement of the experimental setup.
- Successful ***field tests and validation of the experimentally developed portable WCOMB multi-wavelength laser source prototype*** in an existing fibre optical transmission line infrastructure.
- ***Modelling activities*** resulted in ***determining precise resonance frequencies, the best simulation parameters for creating a soliton regime***. For better understanding of the physical processes related to the light propagation in micro-resonators, a theory of the photon mathematical model has been developed.
- ***Achieved record 50 Gbps per λ transmission of NRZ-OOK modulated signals with a novel silica microsphere WGMR-based Kerr-OFC as a light source*** operating in the optical C-band, surpassing the previously demonstrated data rate record by five times. In terms of data transmission speed for silica microsphere WGMR-based Kerr-OFC light sources is a data transmission rate record of 50 Gbps per λ.
- During the project implementation 1 ***bachelor's thesis***, 2 ***master's theses***, 1 ***PhD thesis*** have been developed and defended. By the end of 2022 another PhD thesis has been defended.

Future plans

The sustainability of the project results is ensured and further developed in farther projects, thus increasing the competitiveness of involved partners (scientific institutions – LU ASI, RTU TI, and enterprise – AFFOCS). Further research improvement of the prototype will allow to offer it for the production as a more mature technology; a potential innovation-oriented spin-off company may arise from this activity. Some directions for the future studies and applications:

- research staff from scientific institutions (LU ASI and RTU TI) have become a part of the Latvian Quantum Initiative[2] focused on thematic directions based on

[2] https://www.quantumlatvia.lu.lv/en

the perspective of the future development of Latvian quantum technologies and already existing applications in science and industry (quantum algorithms and software, quantum sensors and devices, quantum communication and communication security);

- studies on microresonator frequency combs and its applications are continued at the University of Latvia (e.g., the project *Development of Quantum Optics and Photonics at the University of Latvia*, PhD studies of the project participant Kristians Draguns, etc.);
- applications of WCOMBs into telecommunications is continued at the Riga Technical University Telecommunications Institute and newly established Communication Technologies Research Center (e.g., the project *Development of optical frequency combs for fiber optic communication systems*, PhD studies of the project participant Armands Osrovskis, etc.);
- the enterprise AFFOCS is gaining new market opportunities based on the experience and knowledge acquired on new portable WGMR-OFC generator construction, adjustment, testing, and validation;
- the patent application has been approved and a technology reducing the number of light sources needed in the transmitter part of the multi-channel WDM fibre optical telecommunication systems without reducing the number of channels used for data transmission and, by using multi-level pulse amplitude modulation (M-PAM) where multiple bits are encoded in one signal level, providing spectrally efficient data transmission between the transmitter side of the fibre optical telecommunication system and its optical network terminals (ONT) will soon enter the market;
- developed prototypes is a starting point for further collaboration and new project proposals: e.g., Laboratory of Organic Materials at Institute of Solid State Physics developing polymer photonics is a new collaboration partner for WCOMB development on polymer chips (project proposals for national funding have been already submitted);
- academic research partners (LU and RTU) are investing in the implementation of new study course modules and developing of new research directions on whispering gallery mode microresonators and optical frequency comb generators for master and PhD students in the field of atomic and quantum physics & telecommunications thus creating high-level specialists in Latvia among both students and specialists;
- experience and contacts obtained through the dissemination of the results at the scientific conferences and workshops have encouraged international mobility and resulted in project proposals with new partners and institutions worldwide: e.g., Center for Soft Nanoscience, Münster University; Quantum Science and Technology Laboratory, University of Trento (project proposals for Horizon Europe funding have been already submitted).

Project evaluation by independent experts

Overall evaluation of the level of achievement of the project aims and the planned results was appraised at 95% (Quality of the research – 90%, Economic and social impact of the research – 90%, Implementation quality and efficiency – 100%).

Regarding the scientific quality the experts highlighted: the project since the very beginning has clearly stated its objectives and goals and during its implementation it has followed a clear route to achieve the goals as stated – research activities have included both theoretical and experimental efforts that the research team has developed with

a rigorous scientific method working also in collaboration with eminent foreign research institutes. The activities performed includes testing of commercial devices, as well as modelling, design fabrication and testing of novel prototypes of the microresonator. However, regarding the development of the prototype for portable WGMR COMB, even though it is quite compact, it's still far from being portable. The project has obtained clear and evident results whose scientific value is clearly assessed also by the number of scientific papers published after peer review; dissemination has been performed very well with a high number of publications (in highly ranked journals); outreach activities done witness a high commitment of the whole team.

As for economic and social impact, the project was assessed as addressing a problem of strong public need: the demand for high quality, reliable, and secure telecommunication, involving the transmission of spoken words, video signals and data. The project has positively contributed to the economic impact: the prototype realised has significant potential for a future development to a market level maturity. Regardless global epidemiologic situation distribution and dissemination of the project results has been performed in accordance (in some cases outperforming) with the initial plans – the project team has developed significant collaborations both within Latvia and abroad; future more intense collaborations are foreseeable. However, regarding the prototype and the new product to be patented, optical-frequency combs in monolithic WGM microresonators have already been demonstrated and the technology level is high, which may diminish the potential impact of the designed prototype, it could even hinder the outcome of the patent.

Implementation quality was the most highly rated: a wise and accurate planning, distribution and management of both financial and human resources has been done throughout the whole project. The inclusion of a small enterprise increases the impact of the results and ensures future development after the project completion. The personnel is quite balanced regarding gender equal opportunities. The Emergency Health situation was not helping in certain activities such as exchange of researchers or scientific dissemination, but from the midterm, there has been an increment of both, in a way that the team overreached the proposed research products.

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