PART I

STSM REPORT

COST STSM Reference Number: COST-STSM-BM1205-26638
STSM Reference Code: COST-STSM-ECOST-STSM-BM1205-120415-058492
STSM Grantee: Dr. Andres Udal, Dept. of Computer Control, Tallinn Univ. of Technology, Tallinn (EE)
STSM title: Modeling of THz radiation amplification devices
Home Institution: Tallinn University of Technology, Tallinn (EE)
Host Institution: Prof. Gintaras Valusis, State research institute Center for Physical Sciences and Technology, Vilnius (LT)
STSM period: 12.April - 01.May 2015
STSM purpose:
Main goal of the STSM was to move forward with previously outlined joint Vilnius-Tallinn-Leeds idea of the quantum wells based compact solid-state amplifiers of THz or sub-THz radiation for biooptical sensing/imaging tasks. Planned intensive cooperation period with Vilnius partners (in parallel with intensive internet-based negotiations with Leeds University) was necessary to move forward in the following directions:
- discussion of the device structures for the following research, - planning of experimental realizations, - formulation and agreement of the physical models, - development of the numerical algorithms, - development of the software tools, -outlining the joint publications, -planning the future dense trilateral and wider COST-networks based cooperation.

Description of the work carried out during the STSM:
The main work carried out was the detailed planning of the activities of the future cooperation in the field of research of semiconducting nanostructures for the terahertz amplification relying on dense trilateral cooperation of COST BM1205 network partners from Tallinn University of Technology, State research institute Center for Physical Sciences and Technology in Vilnius and the Leeds University. During the STSM, a draft of cooperation program was formulated considering the rational designs of terahertz amplification media – the resonant tunneling diodes, superlattices and quantum cascade structures – for efficient gain in sub-THz frequencies for application in imaging systems. In more detail the following questions were discussed:

- The general theoretical background considering the current state of development of sources and detectors for "THz gap" frequency range, showing limitations of quantum cascade lasers (QCL) and the remaining need for compact sources for 0.5 – 2 THz with indicating the resonant tunneling diode (RTD) type structures as the most promising candidate;
- Analysis of the recent results of the RTD structures development showing the possibilities to reach the 2-3 THz frequency range, also possibilities to increase power to 0.1 mW at 1 THZ and respectively one order higher at lower sub-THz frequencies;
- Modeling approaches of RTD structures from analytical models to more fundamental numerical quantum mechanics based approaches;
- Review of new design approaches of RTD based generators and amplifiers, analysis of other amplification approaches based on superlattices and quantum cascade structures;
- Earlier prework performed in Tallinn Univ. of Technology of different high-frequency semiconductor devices design, research of different semiconductor materials and quantum superlattice based devices research like quasiparabolic source and QCLs, also prework on development of computationally effective simulation tools for quantum cascade structures;
- The main objectives, hypotheses and methods and draft timeschedule of the planned research, also expected results and their potential applicability;
- Overview of literature considering the usage and development nanostructures for THz amplification (60 publications);
- Auxiliary figures showing the recent progress of development of sources in "THz gap" including new power records from Leeds Univ. (Feb. 2014), Vienna TU (Oct. 2013) and MIT (2006), also overall rise of THz research publications in the world;
- Related earlier and ongoing research projects in TUT that could support the planned research, also description of research infrastructure (mostly computational resources);
- Possible involvement of additional international cooperation partners (networks BM1205 and MP1204, in particular Warsaw, Wroclaw and Helsinki partners from those two networks, also

proposed extending of contacts with IC1208 and MP1403);

Other activities carried out in the Terahertz Lab. of Optoelectronics Dept. of the State research institute Center for Physical Sciences and Technology included detailed discussions of possibilities for new devices design for the sub-THz frequencies amplification, discussion of available technological facilities of the Vilnius center, intensive work with fresh literature for the possible new joint project applications, the participation in scientific seminars twice a week and analysis of recently published papers by Vilnius center.

Description of the main results obtained:

1. The further activities for THz and sub-THz quantum cascade amplification devices research and design in cooperation between Vilnius and Tallinn and Leeds were discussed;
2. Formulation of the written trilateral cooperation plan was completed;
3. The work with the joint manuscript presented as abstract for MP1204 and SMMO2015 conference (Prague, April 8-11, 2015) was continued;
4. The work towards the improvement of the previously developed in Tallinn software tool for resonant tunnel diodes simulation was continued (see Fig.1 below).

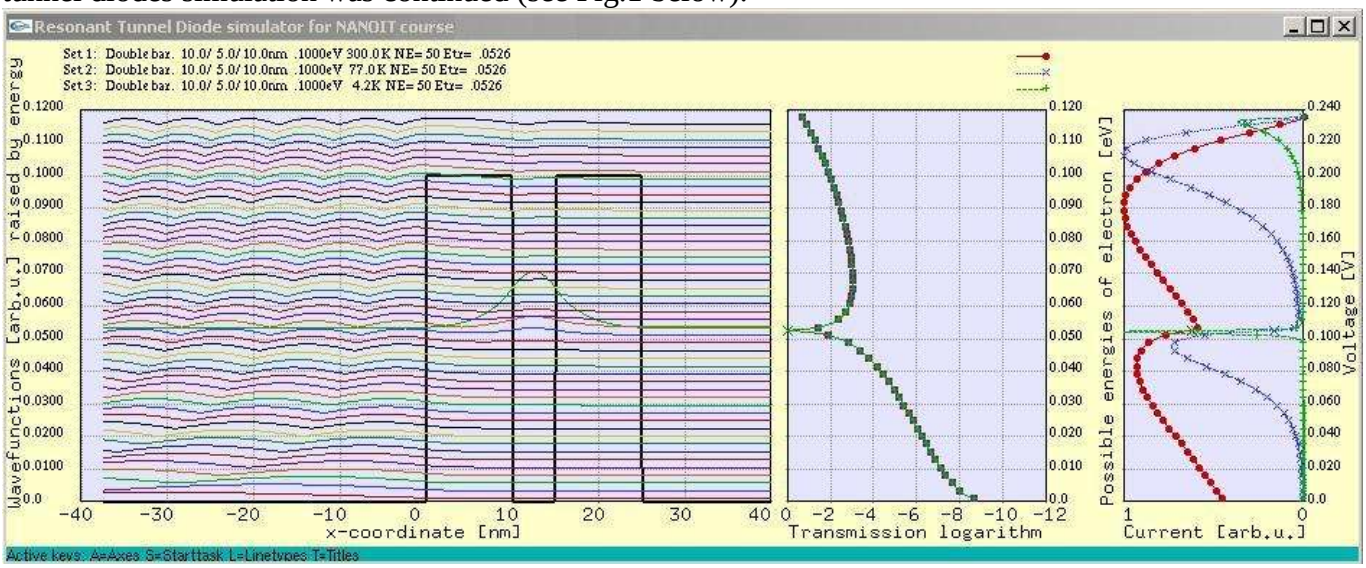

Fig.1 Screenview of the RTD simulator under development.

Mutual benefits for the Home and Host institutions: It may be estimated that this STSM improved remarkably the Home institution R&D level and also somewhat the Host institution R&D level due to intensive joint analysis and planning of new solutions of quantum cascade amplification devices for sub-THz and THz regions. The main actual result of the STSM is the detailed cooperation plan that can be used for a joint project application that assumes dense cooperation and improvement of R&D level of Home and Host institutions during the next years.

Future collaboration with the Host institution (if applicable): STSM was dedicated to the planning of the joint development of quantum cascade amplification devices for sub-THz and THz regions assuming modeling activities in Tallinn with support from Leeds and possible technological realizations in Vilnius. The actual intensity and possibility of the realization of the cooperation plans depends on obtaining the supporting funding.

Foreseen journal publications or conference presentations expected to result from the STSM (if applicable): There was discussed the possibility to improve and extend the joint abstract presented for MP1204 and SMMO2015 conference (Prague, April 8-11, 2015) for publication in special issue of "Optical and Quantum Electronics" or elsewhere.

PART II
THE STSM OUTCOME FORM

STSM application number	**Home institution & country**	**Host institution & country**	**BM1205 WG**	**Objective of the collaboration**	**Results of the collaboration**
COST-STSM-BM1205-26638	Tallinn University of Technology, Tallinn (EE)	State research institute Center for Physical Sciences and Technology, Vilnius (LT)	**WG3**	Modeling of THz radiation amplification devices	Formulating a detailed plan for joint research of semiconductor nanostructure devices for THz amplification

Hereby we confirm the successful execution of the STSM

Director of the Center for Physical Sciences
and Technology, Vilnius, Lithuania

Prof. Dr. Gintaras Valušis