2.4 Representative project

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European Centre of Excellence in Microwave, Millimetre Wave and Optical Devices, based on Micro-Electro-Mechanical Systems for Advanced Communication Systems and Sensors-"MIMOMEMS" (www.imt.ro/mimomems)

FP7 Project No 202897 financed (2008-2011) through the "Regional potential" part REGPOT call 2007-1

Coordinator Dr. Alexandru Muller (alexandru.muller@imt.ro)

The overall aim of the **MIMOMEMS project** was to bring research activity in Radio Frequency (RF) and Optical Micro-Electro-Mechanical Systems (MEMS) at the National Institute for Research and Development in Microtechnologies - IMT-Bucharest, Romania, to the highest European level, and create a European Centre of Excellence in microwave, millimetre wave and optical devices, based on Micro-Electro-Mechanical Systems for Advanced Communication Systems and Sensors.

Two laboratories from IMT Bucharest, the RF MEMS Laboratory and the Micro and nano-photonics Laboratory, have joint their efforts to create this European Center of Excellence.

The inspiration for this initiative came from previous successes, including involvement in FP4, FP6 and FP7 EU projects. The two labs have been involved in STREPs (Specific Targeted Research Projects) and IPs (Integrated Projects) and NoE (Network of Excellence):

-The Laboratory of RF-MEMS (lab head Dr Alexandru Muller) has coordinated one of the first European projects in RF-MEMS: Micromachined Circuits for Microwave and Millimetre Wave Applications (***MEMSWAVE***, 1998-2001, FP4-INCO), nominated in 2002 among the top ten European projects for the Descartes Prize. Also, the RF-MEMS Laboratory was a key partner in the FP6 NoE: "Advanced MEMS for RF and Millimetre Wave Communications" (***AMICOM***, 2004-2007 FP6 NoE), and is also partner in the FP7 STREP (call ICT-2007-2) ***MEMS 4 MMIC*** Strep (2008-2011). The group was involved in the ENIAC proposals: "SE2A" where it participated at the design and manufacturing of a ground speed sensor based on a 77 GHz transceiver for SUV cars.

-The Laboratory of Micro and nano-photonics (laboratory head Dr. Dana Cristea – dana.cristea@imt.ro) has participated in several FP6 projects: ***WAPITI***, STREP, 2004-2007, FP6-IST; ***4M***, NoE, 2004-2008, FP6-NMP); ***ASSEMIC***, RTN Marie Curie Trainning Network, 2004-2007 FP6- Mobility , FP 7 IP call NMP-2007-1 ***FlexPAET*** (2008-2010).

The main objectives of the MIMOMEMS project were:

(i) Exchange of know-how and experience with **twining partners, LAAS-CNRS Toulouse** (which has strong expertise in silicon based RF and millimetre wave microsystems, photonic devices, circuits manufacturing and characterization) **and FORTH Heraklion** (which has excellent knowledge of IIIVs (GaAs and related semiconductors) and wideband gap semiconductor processing (GaN, AlN),

(ii) Recruitment of incoming experienced researchers,

(iii) Acquisition, development/upgrading of research equipment,

(iv) Organisation of workshops and conferences,

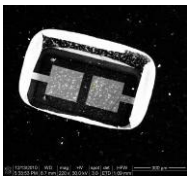
(v) Dissemination and promotional activities.

MIMOMES represents a support action for the developing of microwave, millimetre wave devices and circuits, optical devices and sensors based on MEMS technologies, with applications in modern communication systems. The MIMOMEMS project targeted to support development of:

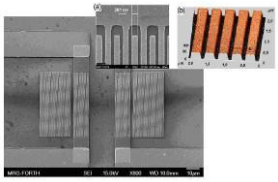
- Millimeter wave reconfigurable filters for millimeter wave applications
- Micro-machined receiving modules based on silicon and GaAs micromachining
- Acoustic devices for GHz applications based on micromachining and nano-processing of Wide band-gap semiconductors
- Polymer-based micro-photonic devices
- Sub-wavelength photonic structures

(i) Together with the twinning partners we have developed state-of-the-art research in each of these fields. Collaborative scientific work and state-of-the-art devices and technologies have been developed in collaboration with the twining partners. Papers in high-ranked journals have been published. In addition, a common European laboratory including IMT-BUCHAREST, LAAS Toulouse and FORTH Heraklion has been created (LEA SMART MEMS). Strong cooperation has also been harnessed with other important European research centers in the field, including VTT Helsinki, Finland, as well as with a number of European industrial partners like Thales TRT (France) and NXP (Netherlands).

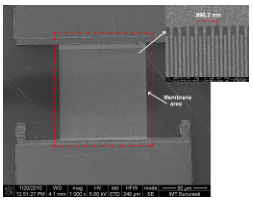
Highlights of the state of the art results obtained in cooperation with twining partners with the support of the MIMOMEMS project



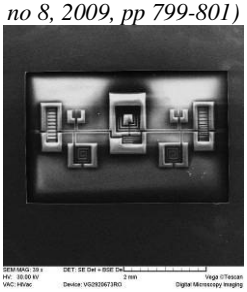
*FBAR structure on 0.5µm GaN membrane resonating at 6.3 GHz (A Muller, D. Neculoiu, G Konstantinidis et al., **IEEE Electron Devices Lett.**, vol 30, no 8, 2009, pp 799-801)*



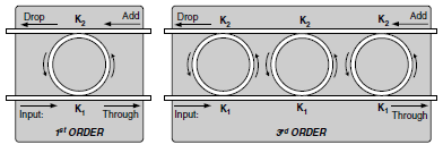
*GaN based 5.3 GHz SAW structure (A Muller,D.Neculoiu G Konstantinidis G. Deligeorgis, A. Dinescu, A. Stavrinidis, A. Cismaru, M. Dragoman, A. Stefanescu, **IEEE Electron Devices Lett.**, vol 31, no. 12, 2010, pp 1398-1400)*



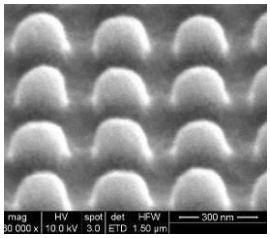
*GaN membrane supported UV photodetector (A Muller, G. Konstantinidis, A. Dinescu et all, **Thin Solid Films** in press doi:10.1016/j.tsf.2011.09.045)*



*SEM photos of the WLAN 5200 filter bottom view (Andrei A. Muller, D. Neculoiu, A. Cismaru, P. Pons, R. Plana, D. Dascalu **Int. J. Electron Commun. AEU (Elsevier)** 65, 2011, 1050-1053)*



Add–drop filters realized with a single microring resonator (left) and three parallel coupled microrings resonator (right) (D. Alexandropoulos, H. Simos, M. Kusko, D. Cristea, D. Syvridis, N. A Vainos, J. Opt. A: Pure Appl. Opt. 11, 2009, 125401)



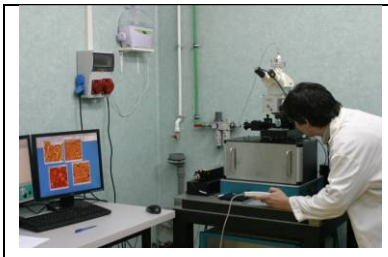
Structured obtained PMMA double- Lenses-with ϕ <150 nm (P. Obreja, D. Cristea, A.Dinescu and R. Gavrila, Symposium on Design, Test, Integration & Packaging MEMS/MOEMS, Rome, Italy, 2009, p.349

(ii) Three experienced scientists (post-docs) have been employed using the project budget. Six applications have been received. Following the interviews with the applicants three of them were hired. The researchers were initially hired for 18 months. At the end of the period, the researchers became full time IMT employees.

		
Dr. Mihai Pavelescu (38), Univ. Kassel	*Dr. Alexandra Stefanescu, (28) "Politehnica" Univ. Bucharest*	*Dr. Mihaela Carp (42), Nanyang Technical Univ. Singapore*

(iii) MIMOMEMS has contributed to increasing the competitiveness of IMT-BUCHAREST as a reliable European partner in micro and nanotechnologies. One of the important tasks was to upgrade the research equipment.

- Near field scanning optical microscope (SNOM) (Co-financed by a national project)
- Upgrade to 110GHz the 1-65 GHz set-up for on wafer characterization - upgrade of the VNA up to 110 GHz, (Co-financed by a national project) and upgrade the on wafer measurements set-up up to 110 GHz,
- Frequency synthesiser up to 110 GHz
- Au plating facility for semiconductor wafers
- Digital Serial Analyzer Sampling Oscilloscope with the Time Domain Reflectometry function, up to 50 GHz and the dedicated software and measuring accessories
- Experimental set-up for UV photodetector responsivity characterization (lock-in amplifier, optical chopper, monochromator, optical source, accessories)

		
The Scanning Near Field Optical Microscope	*The millimetre wave characterization equipment up to 110 GHz*	*The Au plating facility for semiconductor wafers*

(iv) The MIMOMEMS project has funded the organization of two scientific and one strategic workshop in RF and optical MEMS. Reaching key players in the field, these took place alongside the IEEE organized International Semiconductor Conference (CAS) in Sinaia (2008 and 2010), Romania. The **scientific workshops** have evidenced the main technical results obtained by IMT-BUCHAREST and its partners supported by the MIMOMEMS project, together with results obtained by other teams in RF and Optical MEMS. The **strategic workshop** had many invited lecturers from industry and could give some important directions in the topics. The papers presented at the strategic and scientific workshops are available on the project webpage (www.imt.ro/mimomems). The strategic workshop was organized to define a road-map and to contribute to the improving of national co-operation to facilitate knowledge transfer in the field of RF MEMS/NEMS and Optical-MEMS, for promoting a better response of the research activities to the socio-economic need, for improving the centre research strategy and for contributing to national research strategy in the field of MEMS/NEMS/MOEMS/NOEMS

(v) The objective is to maximize the transfer and promotion of project results and activities of the MIMOMEMS project in Romania and across the EU. The MIMOMEMS group has achieved the publication of research results in peer reviewed journal and presentation at international conferences; organization of workshops to make research proposal submissions to relevant calls from the FP7 ICT program.

Publication and participation at scientific conferences with papers having the topics in the scientific objectives supported by the MIMOMEMS project:

- 11 ISI ranked papers published in cooperation with twining partners in prestigious journals like IEEE Electron Device Lett., Electronic Letters, Appl. Optics, Microelectronics Journal, J. Opt. A: Pure Appl. Opt, Thin Solid Films, etc.
- 25 papers submitted and accepted to prestigious conferences (European Microwave Conference, Asia Pacific Microwave Conference, EMRS, NATO

Workshop, MEMSWAVE, CAS, Micromechanics Europe Workshop, EOS Topical Meeting on Optical Microsystems, etc.)

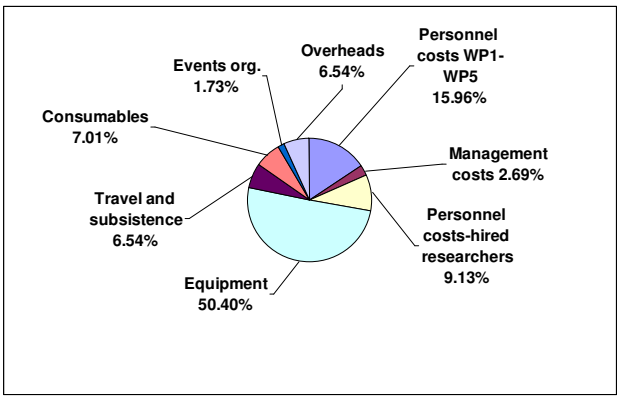
- One chapter in a book (Springer)
- 20 projects in FP7 and FP7 related calls have been proposed during the MIMOMEMS project. Six *of these proposals have been successful:*

➢ ***Four* projects in related to FP7 calls (ENIAC JU and MNT ERANET) were financed and are in progress**

➢ ***Two IP proposals* in the *FP7-ICT-2011-7* call *were wining projects: "SMARTPOWER" and "NANOTEC", both coordinated by Thales TRT France, and started in September 2011.***

The project costs

The project claimed for 1,042,757 EUR and the breakdown of the costs is presented below. Six months after the end of the project costs have been already approved by the EC. It is clear that the most important amount of funds was devoted to equipment acquisition which was a major target of the project.



Cost breakdown for the MIMOMEMS project (post-calculation)

An important contribution was devoted to hire the three Post Doc scientists (two of them from abroad) for 1.5 years during project running. All of them are now included in the permanent staff of the Institute. Research mobilities (18 stages coming to Romania from abroad for common work in the labs, training stages and participation at the two workshops and 41 stages abroad of Romanian scientists (to work in twining partners labs, to disseminate at Conferences the scientific results of the work) have been granted by the MIMOMEMS project. Personnel costs have been partially used to participate at the preparation of 20 project proposals.

Impact of the project after its end

Even though some of them are already widely used in communications systems, radio frequency micro-electro-mechanical systems (RF MEMS) and Optical-MEMS are still considered emerging technologies. Developments in such systems and their application are continually evolving, and constitute a significant field in both research and industry. Under FP7 REGPOT funding, a research facility in Bucharest, Romania, has been established as a Centre of Excellence in MEMS research. The success of the MIMOMEMS team in European cooperation is almost unique in Romania. It is not just pure chance that MIMOMEMS was the first Centre of Excellence to be financed from European Programs after Romania acceded to EU.

As an illustration of the extensive funding from which the Centre has benefited, the new infrastructures of IMT- Bucharest (including the new nanolithographic equipment, the new Low-pressure chemical vapor deposition (LPCVD) and Plasma-enhanced chemical vapor deposition (PECVD) equipment, the nano-identer, the new MA6 mask aligner, the mask fabrication equipment

from Heidelberg, equipment, the new scanning electron microscope (SEM,) the new clean room, etc.) represent investments of around 3 million Euros. The about 0.5 million Euros for investment coming form the MIMOMEMS were now devoted to the microwave, millimeter wave and optical MEMS devices.

Whilst IMT-Bucharest is the lead organisation in the MIMOMEMS Centre of Excellence, the role played by twinning partners LAAS-CNRS and FORTH-IESL-MRG cannot be underplayed: collaborative scientific work and state-of-the-art devices and technologies have been developed in collaboration with these partners, and co-authored papers in high-ranked journals have been published. The published results represent the state of the art in the scientific targets of the project. In addition, a common European laboratory including IMT-BUCHAREST, LAAS and FORTH has been created (LEA SMART MEMS). Strong cooperation has also been harnessed with other important European research centers in the field, including VTT Helsinki, Finland, as well as with a number of European industrial partners (Thales TRT-Fr, NXP-Nl)

MIMOMEMS has brought the level of RF and MEMS research at IMT-BUCHAREST on a par with its partners and collaborators.

Bringing together a number of research bodies at the forefront of this field, MIMOMEMS has demonstrated the importance of working with innovative and influential partners. Benefits of this have included:

- *The creation of a strong multidisciplinary research team with complementary competences and facilities*
- *The creation of opportunities to participate collaboratively in FP7 proposals*
- *The sharing with partners of contacts with industry*
- *The facilitation of knowledge transfer*
- *Opportunities for sharing access to facilities*
- *The collaborative development of research work*

MIMOMEMS has contributed to increasing the competitiveness of IMT-BUCHAREST as a reliable European partner in the entire topics of micro and nanotechnologies. The presence of the MIMOMEMS Centre of Excellence will have a major impact on creating cooperation activities with the new high-tech industry that is now emerging in Romania. In the last years IMT-BUCHAREST has developed also relations with high-tech companies established in Romania, like Honeywell Ro, Infineon Ro, Renault TRT.

The MIMOMEMS Centre has already been made a permanent Department of IMT-BUCHAREST, proof not only of the strength of the MIMOMEMS project, but of its sustainability in the future. It also symbolises the importance of MEMS research for the institute. The new structure of the institute also marks a clear shift in strategy: *from microtechnologies to micro- nano – biotechnologies* (or convergent technologies)

Although in the past, the absence of industrial partners in Romania prohibited productive cooperation, European projects like MIMOMEMS have provided valuable opportunities for IMT-Buxharest to connect with European industrial partners. Today, IMT-Bucharest is involved in four **ENIAC JU projects**, working together with industrial partners (NXP, the Netherlands; Thales, France; and Volvo, Sweden) to research emerging solutions for true ground speed measurements at 77 GHz, and sensors for poisonous gases based on GHz GaN/Si acoustic devices.

The MIMOMEMS IMT team is one of the partners in the **SMARTPOWER and NANOTEC wining Integrated Projects (call FP7 ICT 2011-7)**. Both projects are coordinated by Thales TRT France. The result became public in the last month of the MIMOMEMS project (April 2011). The two integrated projects have started in September 2011. This is a certain sign that the **MIMOMEMS project** was a real success.