L4: Laboratory of micromachined structures, microwave circuits and devices

The laboratory has coordinated one of the first European founded projects in **RF MEMS "MEMSWAVE"** (1998-2001). The project was nominated, in 2002 between the first ten European projects for the Descartes Prize (awarded for the best European co-operative research projects). The laboratory is one of the promoters of the RF – MEMS topics in Europe, The laboratory is participating in the FP6 network of excellence **"AMICOM"** (2004 -2007). The laboratory was recognized at national level as RF-MEMS Center of Excellence, financed by the National Programme MATNANTECH (2002-2005).

• **Mission:** scientific research and technological development of micromachined microwave and millimetre wave devices and circuits, contributions to the developing strategy of the domain. The new RF MEMS technologies including the "membrane supported circuits" represents a solution to manufacture high performance microwave and millimeter wave devices and circuits devoted to the emerging communication systems.

• **Main area expertise:**

♦Development of a new generation of circuits devoted to the millimeter wave communications based on the semiconductor (Si, GaAs, GaN) micromachining and nanoprocessing materials;

♦Design and manufacturing of micromachined, passive circuits elements: inductors, capacitors, filters and antennae (endfire and broadband);

♦Design and manufacturing of monolithically and hybrid integrated receiver front-ends based on silicon and GaAs micromachining;

♦Design, modelling and manufacturing of reconfigurable millimeter wave circuits for wireless communication systems;

♦Electromagnetic modelling of RF switches;

♦Studies on magnetostatic wave resonators in microstrip and CPW configurations;

♦Design, modelling and manufacturing F-BAR resonators on GaN membrane;

♦MEMS and NEMS technologies development.

• **International network:** Partner in the international network FP6 Network of Excellence "Advanced MEMS for RF and Millimeter Wave Communications" coordinated LAAS-CNRS Toulouse/ Univ. Perugia

• **International bilateral cooperations:** The laboratory has bilateral governmental cooperation with ITC-irst Trento, Univ Tor Vergata , Rome and CNR Rome. FORTH Heraklion, KERI Chanwong, Koreea,

• **National projects:** The national projects contributes to the development of a new generation of circuits based on MEMS and NEMS technologies, devoted to the millimeter wave communications. The laboratory had 6 projects in the MATNANTECH Programme, one in the MINASIST project, three CEEX projects (INFOSOC and RENAR programme) as coordinator, two CEEX projects as partners and three projects in the MINASIST+. National partners in these projects are: "Polytechnica" Univ Bucharest, Nat. Inst in Mat. Physics, Military Tech. Academy, "P. Poni" institute Iasi, Valahia Univ. Targoviste.

• **Research team:** has multidisciplinary expertise in physics and electronics of microsystems and is composed of 7 senior researchers (5 of them with PhD in physics, electronics, microwave and chemistry), 1 early stage researcher (PhD in electronics), two PhD students in physics and one Master Student.

Team from left to right: Dan Neculoiu; Cristina Buiculescu; Dan Vasilache; Alexandru Muller; Ioana Petrini; Gheorghe Sajin; Alexandru Takacsi; Cornel Anton; Andrei Muller; Alina Cismaru;

• **Specific facilities:** Computers and software for microwave electromagnetic simulations (IE3D and Fidelity from ZELAND software packages); Vector network analyzer Hewlett Packard 0.1-18 GHz; Süss Microtech EP 4 prober; Access (by international cooperation) to millimeter wave on wafer measurements. At the end of 2006 the laboratory has obtained through a successful CEEX project (Module 4) acquisited an and network analyzer with "on wafer" measurement system in the 0.1 -65 GHz range

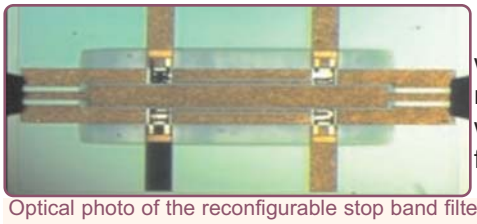
Laboratory Head – Dr. Alexandru Muller (alexm@imt.ro)

He obtained M.Sc. in Physics at Bucharest University (1972) and PhD in physics at Bucharest University in 1990; **Competences:** Silicon, GaAs and GaN micromachining and nanomachining: manufacturing of RF MEMS components and circuits, technological process in GaAs MMICs, design, modelling and manufacturing of microwave passive membrane supported circuits (1997-European priority), micromachined inductors, filters and antennae, monolithically as well as hybrid integrated receiver front end modules.

Dr. Müller has coordinated the European Project FP 4 MEMSWAVE (1998-2001), and is the leader of the Romanian team in the FP6 NoE AMICOM and member of the Board of Directors of this project He is member of Micromechanics Europe Workshop and MEMSWAVE workshop steering committees.

He is an expert in project evaluation in the national program Research for Excellence (started in 2005). He is member of IEEE and EuMA. Dr Muller is member of PhD Jury in Politechnica Univ. Bucharest and Univ. Paul Sabatier/LAAS Toulouse. Co-editor of the Micro and Nanoengineering Series (Romanian Academy). He had invited papers at important European conferences. Dr. Müller is finalist of the Descartes Prize competition 2002 of the European Community with the MEMSWAVE Project, Romanian Academy Prize "Tudor Tanasescu" for "Micromachined circuits for microwave and millimeter wave applications" project); second prize for the MATNANTECH project, SIRMEMS (at CONRO 2003). He has more than 150 contributions in books and international journals/conferences.

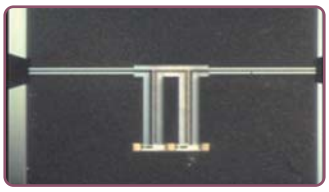
RECONFIGURABLE FILTERS FOR MOBILE COMMUNICATION



Optical photo of the reconfigurable stop band filter

New reconfigurable micromachined filters for millimeter wave applications were designed and manufactured on silicon substrate or on dielectric membrane on silicon. For the second version, two levels of micromachining were processed. Demonstrators of reconfigurable band pass and band stop filters were manufactured and characterized. Original architecture for the two cantilever shunt switch was designed.

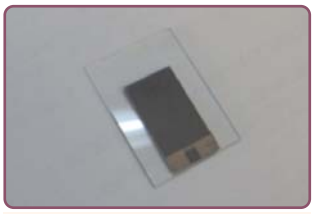
Achievements: Design and manufacturing and characterisation for cantilever type switch; design, modelling and simulation for stop band and band pass reconfigurable filters for 38 GHz.



Optical photo of the reconfigurable band pass filter

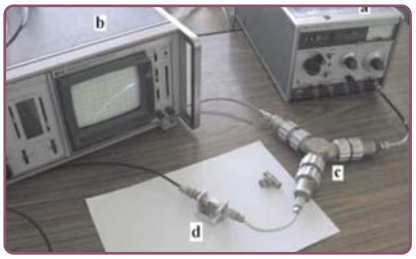
MATNANTECH Project "Silicon based reconfigurable filters for millimeter wave applications"- FIREMEMS, (2004-2006), Co-ordinator, IMT-Bucharest, Project Manager: Dr. A Müller (alexm@imt.ro)
Partners: Institute of the Macromolecular Chemistry "Petru Poni", Iasi, Military Technical Academy Bucharest

ACOUSTIC WAVE DEVICES – SAW-BAW



Micromixing SAW device glued on a microscope glass slide ready to be mounted in functional holder.

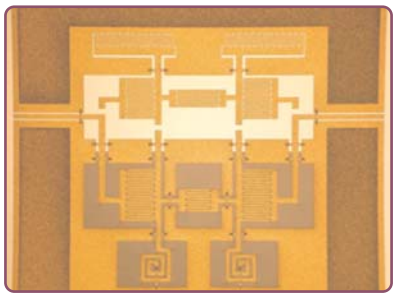
Manufacturing of a micromixer using SAW type resonators as mixing element for use in bio-medical applications, mainly in DNA in situ hybridization is in progress. Also, a BAW resonator as detecting element for environmental pollutants will be manufactured.
Achievements: Manufacturing of SAW and BAW resonators test structures; preliminary electrical characterization of these structures; experiments concerning biological compatibility of the used materials (piezoelectric ceramics used in SAW fabrication); experiments for obtaining the piezoelectric polyimides in collaboration with ICM "Petru Poni" Iasi



MATNANTECH Project: "Surface and bulk acoustic waves devices for biomedical applications and environment pollution monitoring", (2004 – 2006).
Co-ordinator, IMT-Bucharest, Project Manager, Dr. Gheorghe Ioan Sajin (gsajin@imt.ro).
Partners: INCD ICPE CA Bucharest; "Carol Davila" Medical University, Bucharest; Institute of the Macromolecular Chemistry "Petru Poni", ICM, Iasi.

Test setup for functional characterization of SAW device:
a) High frequency sweep generator; b) Network analyzer; c) High frequecy power splitter; d) Device under test in a dedicated test fixture.

MICROMACHINED FILTERS FOR DCS 1800 RANGE



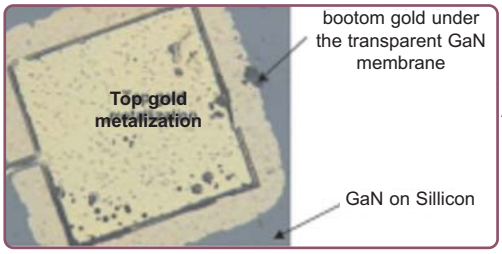
Optical photo of the DCS 1800 filter

New topology for L-C type filters based on membrane suspended inductors and interdigitated capacitors manufactured by silicon micromachining are processed. L-C type filters using MEMS technology, are key elements in microwave and millimeter wave applications such as mobile communication systems.

Achievements: Two level of micromachining for manufacturing membrane suspended inductors; new topology for micromachined L-C type filters

MINASIST + project "High selectivity filters for Rf and millimeter wave communications" (2006-2008)
Contact person Master student: A A Müller (andreim@imt.ro)

EXPERIMENTAL PROCESSES FOR GaN MEMBRANE SUPPORTED FBAR STRUCTURE



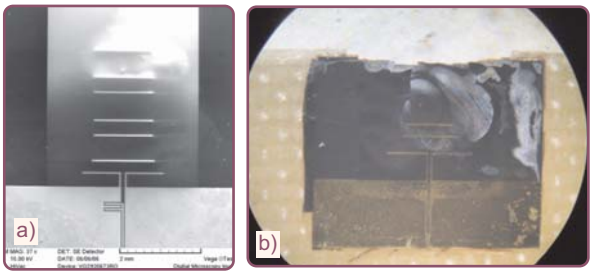
The experiments regarding membrane supported GaN FBAR structures were performed using a 2μm thin GaN layer, grown by a Riber MBE system, on a high resistivity silicon substrate (ρ>10kΩm) was used as active region of the device. The thickness of the silicon wafers was about 500μm. The grown epitaxial layer includes thin AlN layers in order to reduce the stress in the GaN layer and avoid cracking.

CEEX INFOSOC Project "Integrated RF-MEMS circuits based on silicon, gallium arsenide and wide band gap semiconductors for advanced communication systems – ACOMEMS" (2006-2008)
Co-ordinator, IMT-Bucharest, Project Manager: Dr. A Müller (alexm@imt.ro)
Partners: National Institute for Material Physics, "Politehnica " Univ. Bucharest, "Valahia" Univ. Targoviste, "Ovidius" Univ. Constanta, Institute of the Macromolecular Chemistry "Petru Poni", Iasi.

ENDFIRE MICROMACHINED ANTENNAE ON SILICON AND GaAs

Yagi-Uda antennae suspended on GaAs membrane for 60 GHz were manufactured by surface and volume micromachining using reactive ion etching. Micromachined 77GHz Yagi-Uda antennae were manufactured by anisotropic etching of high resistivity <100> silicon. Microwave characterization of the antennae was performed by "on wafer" measurements.

Achievements: Design, modelling and manufacturing of millimeter wave endfire antennae for 60 GHz and 77 GHz

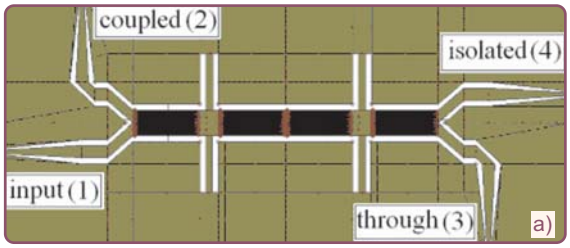


a) SEM photo of 77 GHz Yagi-Uda antenna micromachined on silicon; b) Optical photo of 60 GHz Yagi-Uda antenna suspended on GaAs membrane)

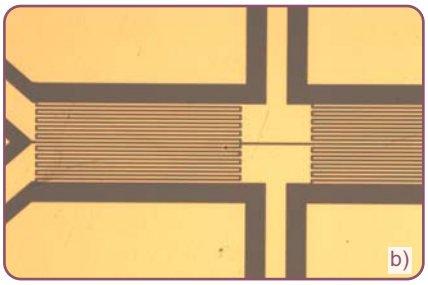
CEEX INFOSOC Project "Integrated RF-MEMS circuits based on silicon, gallium arsenide and wide band gap semiconductors for advanced communication systems – ACOMEMS" (2005-2008)
Co-ordinator, IMT-Bucharest, Project Manager: Dr. A Müller (alexm@imt.ro);
Partners: National Institute for Material Physics, "Politehnica " Univ. Bucharest, "Valahia" Univ. Targoviste, "Ovidius" Univ. Constanta, Institute of the Macromolecular Chemistry "Petru Poni", Iasi.

METAMATERIAL MEDIA AND DEVICES IN MICROWAVE FREQUENCY DOMAIN

Metamaterials are media with special propagation properties and applications in the entire electromagnetic domain. These materials are periodical structures obtained by microprocessing / micro-machining of ceramics, semiconductors or metals up to sub-micronic levels, (depending on substrate, frequency, and the desired application). Applications are non-conventional microwave devices (filters, resonators, miniature antennas, etc.) with different characteristics from those of similar classic devices.



Achievements: Analysis of the correlations between dimensions and geometry of these transmission media and the frequency band gaps; the function modeling of these structures and design of non-conventional microwave devices.



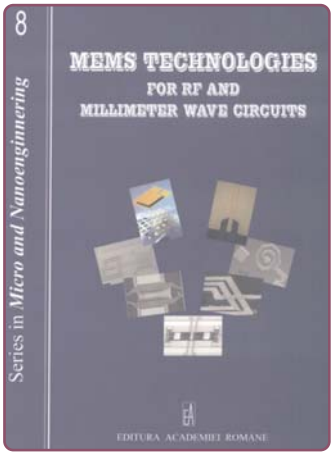
CEEX INFOSOC Project "Microwave structures and devices on microprocessed media with frequency selectivity"-ELMAG_SF (2005-2008),
Co-ordinator, IMT-Bucharest, Project Manager: Dr. George Sajin-(gsajin@imt.ro);
Partners INCDIE ICPE CA Bucharest; Politechnica University Bucharest, INCD-FM Bucharest.

CLRH directional coupler layout (a) and details from the region of the interdigitated capacitors and CPW stubs (b).

THE VOLUME "MEMS TECHNOLOGIES FOR RF AND MILLIMETER WAVE CIRCUITS"

The volume "MEMS technologies for RF and millimeter wave circuits" - editors A. M. Ionescu (EPFL), Anja Skrivervik (EPFL), A. Müller (IMT), D. Dascalu (IMT) - was launched at Orvieto in June 2006, during the **7th edition of the international Workshop on RF MEMS "MEMSWAVE".** The volume was printed in the **Micro and Nanoengineering Series** coordinated by **Prof Dan Dascalu** and was edited by the Romanian Academy Press. The volume contains the extended papers of the 6th MEMSWAVE Workshop, Lausanne, 2005.

The international MEMSWAVE workshop was generated by IMT Bucharest in 1999, in the frame of the MEMSWAVE project.



L4: Participation to NoE in FP6

Results obtained by the Laboratory team in the FP6 Network of Excellence

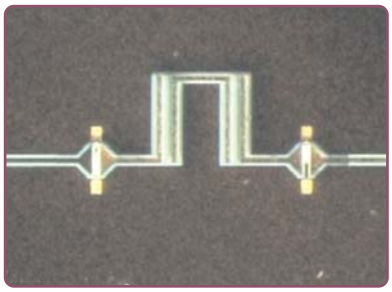
Results obtained by the Laboratory team in the FP6 Network of Excellence "Advanced MEMS for RF and Millimeter Wave Communications" (**AMICOM;** 2004-2007) – ***http:\\www.amicom.info***, coordinator LAAS-CNRS, Toulouse/ Univ Perugia. IMT contact person for **AMICOM**: Dr. Alexandru Müller, member of Board of Directors (**alexm@imt.ro**)

The research work in **AMICOM** in 2005-2006, was performed in the second year via two "North Star" Projects: "MMID – Millimeter Wave Identification" and "ReRaFE – Reconfigurable Radio Front-End". The technological research is developed together with partners from FORTH Heraklion, TU Darmstadt, LAAS Toulouse, VTT Helsinki, IMEC Leuven and ITC-irst Trento.

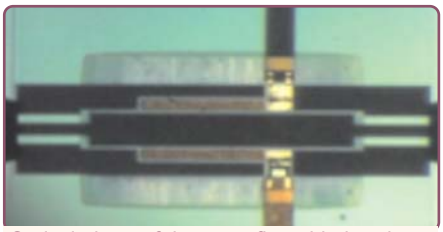
L2 - Results obtained in AMICOM project

Achievements:

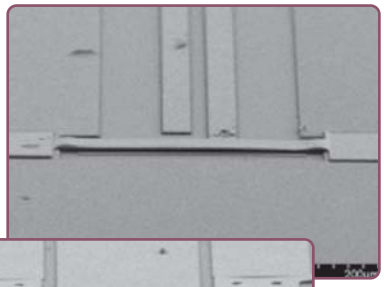
- Design, modelling and manufacturing of a membrane supported Yagi-Uda antenna for 45 and 77 GHz,
- Monolithically integrated receiver front end with a membrane supported Yagi Uda antennae
- Design, modelling and manufacturing of advanced F-BAR test structures;
- Switches for 60 GHz on GaAs substrate;
- Lumped elements filter structure manufactured by bulk and surface of micromachining;
- Architecture for the 60 GHz membrane supported reconfigurable filter;
- Diplexer filters based on FBAR resonators;
- Design of tunable bandpass and bandstop reconfigurable filter for MMID applications;
- Millimeter wave identification (MMID) system
- 60 GHz Band-pass and band-stop tunable filters using surface and bulk micromachining
- 60 GHz radiating elements (Yagi-Uda antenna)
- FBAR resonators
- Tunable band-pass filters for 1-6 GHz frequency range
- 60 GHz receiver for the MMID tag
- Demonstration of the MMID concept

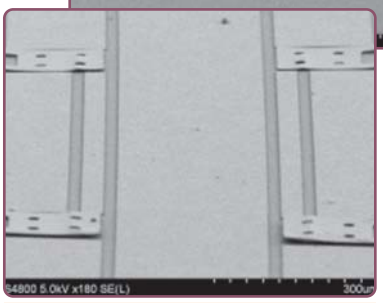


Optical photo of the reconfigurable bandpass filter for 60 GHz (IMT, LAAS)

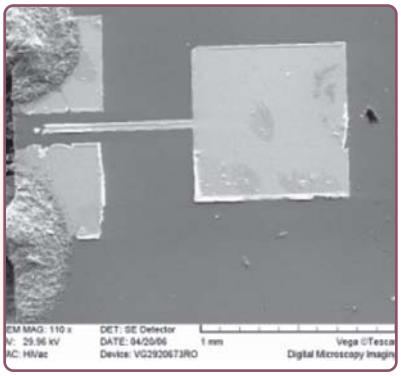


Optical photo of the reconfigurable bandstop filter for 60 GHz (IMT, LAAS)

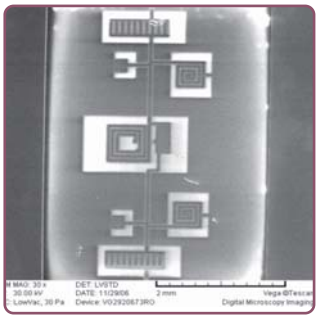


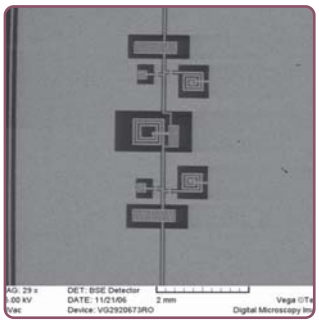


SEM photo with detail of the cantilever type switch

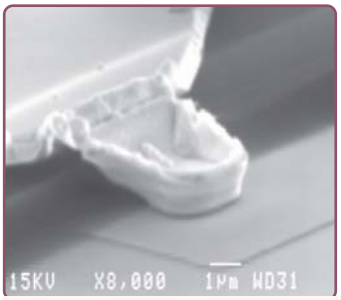


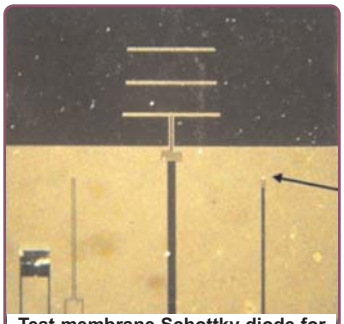
SEM photo (top side) of the GaN membrane supported F-BAR structure. The silver epoxy on the left side is used in order to provide a connection of the ground electrode to the bottom metallization of the FBAR membrane and allow measurements with GSG probes (IMT, FORTH, TUD)- Superlatices&Microstructures, 40, 2006, pp. 426-431





SEM photos of WLAN 5200 band-pass filter (top and bottom view) (IMT, LAAS) - Proc of Micromechanics Europe MME 2006, Southampton, Sept 2006, pp 125-128

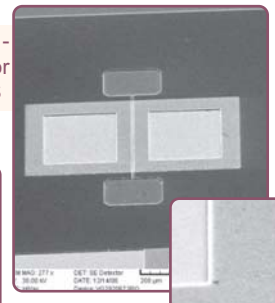


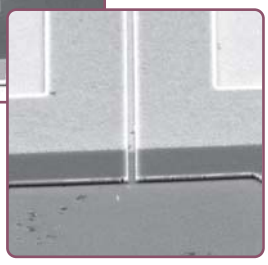


Test membrane Schottky diode for parameter extraction

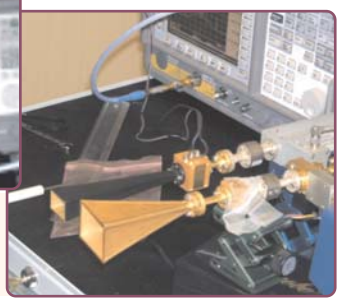
Photo of the manufactured 60 GHz receiver structure for the MMID tag and a SEM detail with of the Scottky diode (IMT, FORTH) - Proc of the SPIE Conf on Smart Materials Nano and Microsystewms 10 -13 December Adelaide 2006

SEM photos nano-oscilator based on carbon nanotube (CNT) - micromachined structure on GaAs metalized on the bottom for CNT support; trench structure 1.5x1.5μm -IMT, FORTH, LAAS





Millimeter wave TAG-experiments performed at VTT Helsinki by the IMT and VTT scientists



Millimeter wave TAG-experiments performed at VTT Helsinki by the IMT and VTT scientists