National Institute for R&D in Microtechnologies - IMT Bucharest (www.imt.ro)

Brief history

IMT was set up in **1993**, being *the first institute with the profile of micro-system technologies in Eastern Europe.* In **1996**, IMT merged with ICCE (the former institute for research in electronic components), becoming a *national institute*. The European Commissioner for Research, Philippe Busquin, visiting IMT in February **2004**, called it "*a pioneer of integrating Eastern Europe in ERA*". During the **2005-2008** time period, IMT was coordinating the support action MINOS-EURONET (http://www.minos-euro.net), pursuing *the integration of Eastern Europe in the micro-nanosystems community* from Western Europe. *The first Research Centre of Excellence financed by the European Commission* (**2008-2011**) in Romania, after the admission in EU, belongs to IMT and it is devoted to research in radio-frequency and photonic micro-nanosystems. In May **2009**, IMT launched through a special event in Brussels *the first "open centre" for micro- and nanotechnologies in Eastern Europe*, the so-called IMT-MINAFAB (IMT centre for Micro- and NAnoFABrication). IMT coordinated (**2010-2011**) a prospective study (www.imt.ro/NANOPROSPECT) devoted to nanotechnologies in Romania, illustrating *the potential of this country for a few "Key Enabling Technologies"* (KET), considered to be the key of the industrial competitiveness, according to "Horizon 2020". According to EC Report about Innovation in Europe (June **2011**), IMT is *the first among the national institutes as far as participation to European Programs is concerned*.

Mission

IMT should act as a **technological pole in the domain of micro-nanotechnologies and convergent technologies**. Its competences and infrastructure are devoted to interaction in multidisciplinary research, education and training, interaction with industry and innovation. During the last years, its collaboration with foreign companies, as well as with SME's and multi-nationals acting in Romania has increased. The joint educational activities are much better developed, in cooperation with the University "Politehnica" in Bucharest. IMT is visible at the national level, but it also intends to play a role *at the regional scale* and interacts with other European partners in an attempt to cooperate in providing access to experimental facilities for research. IMT is active in a few "Key Enabling Technologies" (KET), considered to be essential for the industrial competitiveness, according to "Horizon 2020".

Research objectives

The strategic objectives of the institute on medium term is to extend its visibility and international cooperation as a **centre of excellence** in research and development related to the **integration/convergence of technologies** (micro-nano-biotechnologies) and their applications in various domains. Emphasis will be put on the study and implementation of technologies for modeling, obtaining, processing and integrating in advanced systems of nanomaterials and nanostructures with special properties (with a particular emphasis on carbon-based nanomaterials). In view of implementation of KETs, efforts will be made in providing higher Levels of Technological Readiness (TRLs)

The institute will enhance the technical offer based on its clean room facilities, equipments and computational techniques, by consolidating a **platform for interaction of the Romanian research in micro-nanotechnologies with the industry and the academic environment**. Through the activities carried out so far, IMT has a unique position at national level; these activities will be developed and strengthened. ***The main instrument is the "open" Centre for Micro- and Nanofabrication IMT-MINAFAB*** (inaugurated in 2009, the first of this kind in new member states from Central and Eastern Europe), which offers a wide range of scientific, technological, computing and testing facilities. This centre is *ISO certified* and it is extended continuously with new scientific and technological services. Efforts will be made to integrate this facility in a network of experimental facilities at the European level, along with the European priority of "*integrating and opening of national experimental facilities"*.

In order to increase the degree of application of research results, *the institute will form a "cluster" of organisations oriented towards technological development and commercialization of activities.* The main instrument will be the existing infrastructure for technology transfer and innovation, as well as the project for cross-border cooperation, implementing a Romanian-Bulgarian Centre for Microsystems and Nanotechnology. In doing this, IMT will cooperate with other research centres at the national and regional level. IMT is already participating to the cluster initiated on the "Magurele Physics Platform", close to Bucharest, in connection with the development of the big infrastructure ELI (Extreme Light Infrastructure), located in Romania, Hungary and Czech Republic.

Directions of research (according to the medium-term strategy of IMT)

A. Development of nanoelectronics, photonic and microwave components

- Developing new techniques for micro/nanofabrication of components and microsystems using silicon technology and wide band gap semiconductors (GaN, AlN), as well as dielectric materials, polymers, carbon-based materials, ceramics and piezoelectric materials.
- Development of new techniques for design/simulation and characterization of materials, micro/nano-structures and systems.
- New concepts and structures of devices (nano-electronics, photonics, microwave) and Microsystems (Optical MEMS, RF-MEMS)

B. Advanced materials

- Advanced materials and biomaterials for the improvement of the quality of life: nanomaterials, biomaterials and hybrid materials.
- Synthesis and processing of materials with special electronic, mechanical and thermal properties, used as substrates for advanced micro-nanosystems. Focus on graphene, silicon carbide, nanocrystalline diamond. Note: With the completion (in 2015) of the *Research Centre for Integrated Systems Nanotechnologies and Carbon Based Nanomaterials (CENASIC)* the research directions for IMT will be consolidated with the following assumed priorities: (1) Processes for *silicon carbide* based micro- and nanostructures; (2) Technologies for *graphene* and hybrid micro- and nano-electromechanical systems; (3) Technologies for *nanocrystalline diamond* and applications in MEMS/NEMS and precision mechanics.

C. Development of new technologies

- Development of new conventional and unconventional technologies for fabrication (including "soft lithography", replication technologies) to obtain cheap products in large quantities.
- Technologies for structuring and integration of carbon-based materials.
- Micro-and nanomechanics, unconventional technologies in high precision mechanics.
- Development of technologies for the heterogeneous integration of microstructures and systems and assembly/micro-assembly techniques, quick assembly.

D. Integration and convergence of technologies

- Integration of micro-and nanotechnologies and development of a set of mixed technologies (example: microfluidics/ICT/micro-nano, bio/ICT/micro-nano, chemo-bio/ICT/micro-nano, RF MEMS/NEMS).
- Nano-bio-technologies: computer-based analysis and experimental studies of nano-bio interaction; combining nano-chemistry with nano-biology, microfluidics, with the aim to obtain biosensors and biochips.

Note: Development of applications (for components, micro/nanosystems, materials and technologies) will be crucial for the institute. The strategy selects the following:

- Application of nanostructured materials and nanotechnologies **in traditional industries** and constructions in order to improve product quality and functionality;
- **Energy harvesting and conversion** systems at the nanoscale;
- Integration of smart micro/nano systems (sensors, actuators, control systems, mechanical structures) and development of **industrial applications, as well as applications in transport;**
- Micro/nanostructures and systems for **communications;**
- Micro-nanosystems for **biomedical applications** (prevention, diagnostic and treatment);
- Sensors and micro/nanosystems for environmental and **food quality** monitoring.

The most representative projects of IMT, FIVE EXAMPLES:

(1) MIMOMEMS - "*European Centre of Excellence in Microwave, Millimetre Wave and Optical Devices, based on Micro-Electro-Mechanical Systems for Advanced Communication Systems and Sensors*", FP7- REGPOT call 2007-1, Contract no. 202897, 2008-2011, Coordinator: IMT-Bucharest, http://www.imt.ro/mimomems

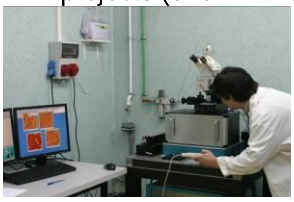
The RF MEMS Laboratory and the Microphotonics Laboratory have joint their efforts to create this European Center of Excellence in the frame of the FP7 REGPOT call.

This initiative came from previous successes of our teams: (i) the coordination of the FP4 EU project "Micromachined Circuits for Microwave and Millimetre Wave Applications "(***MEMSWAVE***, 1998-2001, FP4-INCO). This project was one of the first European projects in RF-MEMS and the first ICT project coordinated by an Eastern European Country team (IMT-Bucharest). For its state of the art results MEMSWAVE was nominated in 2002 among the top ten European projects for the Descartes Prize; (ii) successful participation in the FP6 NoE in RF-MEMS "AMICOM" (2004-2007) with many new and SOTA results in the topics

MIMOMES represented 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.

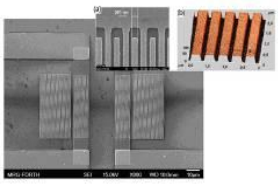
Main results:

- ***Collaborative scientific work and state-of-the-art devices and technologies*** have been developed in collaboration with the twining partners (LAAS Toulouse and FORTH Heraklion). **A *common European laboratory*** including IMT-Bucharest, LAAS Toulouse and FORTH Heraklion has been created (LEA "SMART MEMS").
- ***Three Post Doc scientists*** (two Romanian with a PhD in Germany and Singapore, one with a PhD at Politehnica Univ. Bucharest) have been hired using the project budget; now they have permanent positions at IMT-Bucharest
- ***Up-grade of the research equipment:*** Upgrade to 110GHz the 1-65 GHz set-up for on wafer characterization - upgrade of the VNA up to 110 GHz, and upgrade the on wafer measurements set-up up to 110 GHz, Frequency synthesiser up to 110 GHz; Near field scanning optical microscope (SNOM); 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
- ***State of the art scientific results in cooperation with the twinning partners in the proposed topics: (RF MEMS, millimetre wave components and circuits, photonics and GHz operating acoustic devices based on WBG semiconductors: 11 ISI ranked papers*** published in prestigious, high ranked journals like IEEE Electron Device Lett., Electronic Letters, Appl. Optics, Microelectronics Journal, J. Opt. A: Pure Appl. Opt, Thin Solid Films, etc. and ***25 papers presented to prestigious conferences***
- ***Successful participation in European projects:*** two winning **IPs in the FP7-ICT-2011-7** call: "SMARTPOWER" and "NANOTEC" (2011-2014) both coordinated by Thales TRT France, and two related to FP7 projects (one ENIAC project-Nanocom and one ERA-NET)



The Scanning Near Field Optical Microscope

The millimetre wave characterization equipment up to 110 GHz



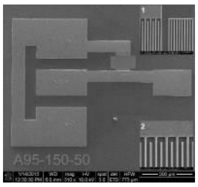
GaN based 5.3 GHz SAW structure (A. Muller; G. Konstantinidis et al. ***IEEE Electron Devices Lett.****,vol 31, no. 12, 2010, pp 1398-1400)*

(2) SMARTPOWER "Smart integration of GaN & SiC high power electronics for industrial and RF applications ", Integrated Project FP7-ICT-2011.3.2, contract no. 288801, 2011 - 2014 Coordinator: Thales SA - Thales Research & Technology, France, 15 European partners

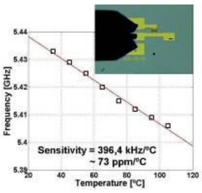
http://project-smartpower.com/

The IMT team is involved in the development of a GHz SAW based temperature sensor, manufacturing together with FORTH Herakion and Thales TRT. The sensing system will be placed close to the GaN MMIC based radar, (developed by Thales Systemes Aeroportuare), to monitor the temperature of the GaN MMIC. Wired and wireless data transmission is required. Monolithic integration of the sensor with the GaN MMIC will be also tested.

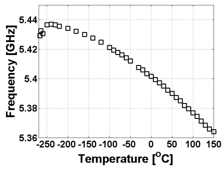
The work is based on the original IMT idea of a single resonator GaN based SAW structure, operating in the GHz frequency range; the temperature is measured using the shift of the resonance frequency vs. temperature. (http://www.imt.ro/smartpower/index_eng.php) .



Single resonator SAW test structure; the two insets present details of the IDTs and reflectors (fingers and interdigit spacing 200 nm) manufactured at IMT using advanced nano-lithographic processes (Run 3)



The temperature dependence of the resonance frequency of SAW single resonator having 50µm length fingers from S_{11} on wafer parameter measurements



The temperature dependence of the resonance frequency obtained for SAW diced chips from run 3 mounted on ceramic substrate obtained from S_{11} measurements in the range -250^o - +150^{o}C

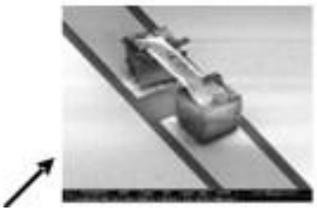
Technical details: Demonstrators of SAW temperature sensor structures working in the GHz frequency range were realised. The new technologies for GaN SAW structures based on advanced nano-lithographic process have been developed at IMT. Microwave characterization and sensitivity measurements vs. temperature were carried out at IMT. Measurements of S_{11} parameters and sensitivity vs. temperature were performed on wafer (using hot plate heating) in the range 23-150 °C; also the sensor structures were mounted in a special ceramic test fixture and characterized in the -268°C - +150°C temperature range, in a cryostat, using the VNA. State of the art results have been obtained at IMT for the sensitivity both for on wafer as well as for encapsulated devices measurements. The building blocks developed for wired data transmission electronics were assembled and the functionality of the temperature measuring system was demonstrated; wireless data transmission experiments are in progress.

(3) CATHERINE - *FP7-* FET Proactive 1: Nano-scale ICT devices and systems

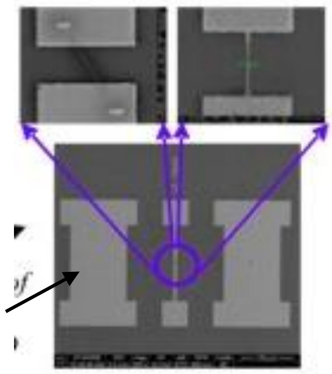
Carbon nAnotube Technology for High-speed nExt-geneRation nano- InterconNEcts – (2008-2010) - http://www.imt.ro/organisation/research%20labs/L6/projects.htm

The *Catherine* consortium consisted of 11 partners from 6 different countries, coordinated by Dr. Stephen Trueman **from** Consorzio Sapienza Innovazione, Rome, Italy.

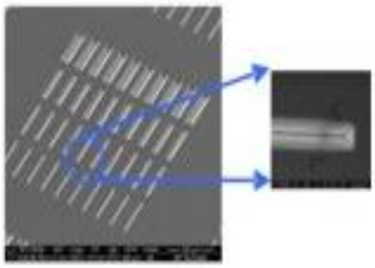
CATHERINE was focused to develop an innovative cost-effective and reliable technological solution for high-performance next-generation nano-interconnects **beyond the limit of current technology.** The new approach, which exploited the carbon nanotube (CNT) technology, permited to realize interconnects with **high-transmission speed, high current density, exceptional mechanical and thermal properties, optimum signal and power integrity.**



SEM micrographs of test vehicle for vertical interconnects



Structure used for electrical characterization of CNTs at high frequencies. EBL was used for patterning the small calibration line and EBID technique for fixing the CNTs.



Platinum deposition was used for fixing the CNTs across V-shaped trenches in order to measure their mechanical properties

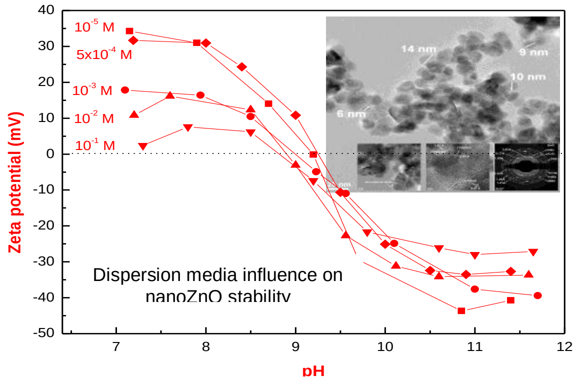
Significant results:

- Development of cost-effective and reliable technological process for realization of high performance next-generation interconnects;
- Development of electromagnetic and multifunctional test procedures and experimental characterization methods;
- Manufacturing and testing of proof-of-concept samples of nano-interconnects at laboratory level.

***(4) NanoSustain - FP7 Collaborative Project** (Small or medium-scale focused research projects) „Development of sustainable solutions for nanotechnology based products based on hazard characterization and LCA" (2010 – 2013) -* http://www.imt.ro/nanosustain/.

The *NanoSustain* consortium consists of 12 partners from 8 different countries, coordinated by Rudolf Reuther - **NordMiljö AB (NOMI)**, Sweden. The project is focused on developing innovative solutions for the sustainable design, use, recycling and final treatment of nanotechnology-based products, namely: ◘ nanocellulose based materials and products (e.g. paper additive); ◘ nanoTiO_2 based products (paint application); ◘ nanoZnO based composites (glass coatings); ◘ MWCNT based products (epoxy plates; solar cells).

Significant results: scientific data generated during the project has provided new evidence and knowledge on how nanomaterials may interact with living systems and how strongly their behaviour depends on the particular physicochemical form and surface properties rather than on composition or concentration. IMT has realized a comprehensive physico-chemical characterization of nanoZnO (commercial name *Zincox*™ - Nanogate AG), relevant for hazard assessment, providing useful information towards better control of biotoxicological tests (A.Bragaru et al, *J. Nanopart. Res. 15:1352*, 2013).

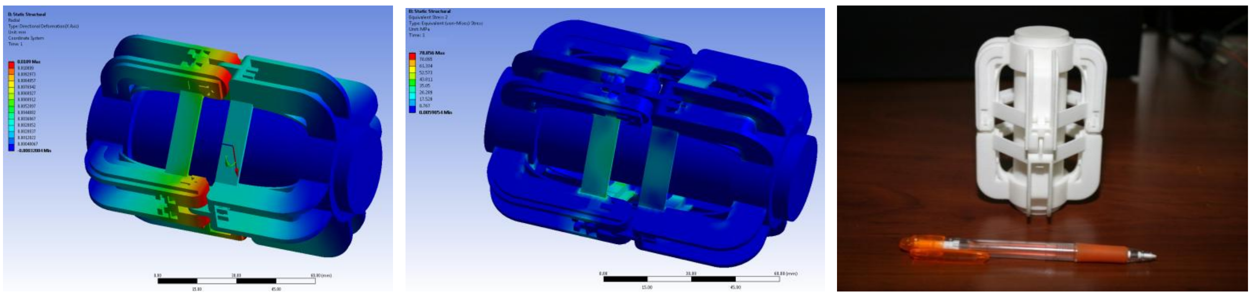


Note: the encouraging preliminary results allowed to see forward and consisted the base for a new ***FP7 Large-scale Integrating Collaborative Project*** - ***"Development of reference methods for hazard identification, risk assessment and LCA of engineered nanomaterials – NanoValid" (2011 – 2015) -*** http://www.imt.ro/nanovalid/, coordinated also by Rudolf Reuther - NordMiljö AB (NOMI), Sweden. ***NanoValid*** has been launched as one of the "flagship" nanosafety projects. The project consists of 24 European partners from 14 different countries and 6 partners from Brazil, Canada, India and the US and will run from 2011 to 2015, with a total budget of more than 13 mio EUR (EC contribution 9.6 mio EUR). It is devoted to validation of the measurements and test methods for testing toxicity.

(5) MotorBrain - ENIAC Project „Development of sustainable solutions for nanotechnology based products based on hazard characterization and LCA" (2011 – 2014) -

The MotorBrain project (http://www.motorbrain.de/) is developing sustainable drive train technologies and control concepts / platforms for inherently safe and highly efficient Electric Vehicle (EV) powertrains of the 3rd Generation. The *MotorBrain* consortium consists of 30 partners coordinated by Reiner Jon – Infineon Technologies AG (Germany).

The role of IMT consists in the design and realization of a demonstrator of a torque sensor, in collaboration with Infineon Technologies Romania (for the magnetic field sensor). *Significant results:* three novel type torque sensors have been devised (magnetic field, optical and nanostructure based The torque sensor using magnetic field has been designed, simulated and realized as a demonstrator on plastic. Metal version is under progress. The sensor responds to the requirements imposed by automotive industry. A novel type of magnetic field sensor has been devised.



ANSYS simulation of the torque sensor behaviour under the action of centrifugal force at 10.000 rpm. Left: radial displacement; Middle: von Mises stress; Right: Beta version of the torque sensor