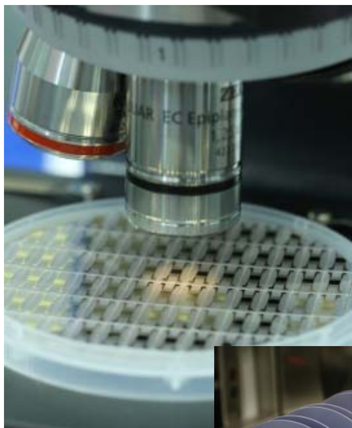
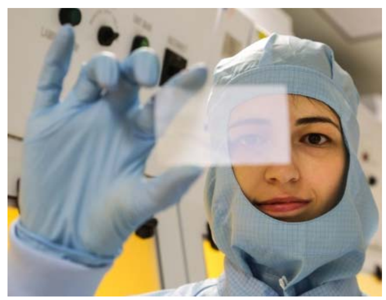
IMT- Bucharest- MINAFAB and CENASIC infrastuctres for micro-nanofabrication/ services/ technological transfer

Raluca Müller- IMT Bucharest





www.imt.ro

IMT Bucharest - general info:

- Non-budgetary public research unit supervised by the Romanian Ministry of Research and Innovation
- Founded: **1993**, National R&D institute: **1996** (fuse with **ICCE**, founded in **1969**)
- **Personnel: around 200, 120** directly involved in research activities
- **11 R&D Laboratories**

- **Fields of activity: in close connection with 4 KETs**

- **micro and nano-fabrication technologies and new materials,**
- **computer-aided design, simulation, microsystems including MOEMS and RF-MEMS, micro/nano photonic structures, sensors and systems,**
- **carbon-based nanomaterials and devices.**

Department for scientific and technological research 4 centers, grouping 11 R&D laboratories

- **MIMOMEMS: Research Centre of Excellence "Micro- and nanosystems for radiofrequency and photonics"**
  - ✓ Micro-Nano Photonics Laboratory (L3) (Dr. Dana Cristea)
  - ✓ Micromachined structures, microwave circuits and devices Laboratory (RF-MEMS) (L4) (Dr. A. Muller)
- **CNT-IMT: Centre for Nanotechnologies**
  - ✓ Laboratory of Nanobiotechnology (L1)(Dr. Mihaela Kusko)
  - ✓ Nano-Scale Structuring and Characterization (L6) (Dr. Adrian Dinescu)
  - ✓ Molecular Nanotechnology Laboratory (L9) (Dr. Radu Popa)
- **CINTECH: Research Centre for Integration of Technologies**
  - ✓ Microsystems in Biomedical and Environmental Applications Laboratory (L2) (Dr. Carmen Moldovan)
  - ✓ Ambiental Technology Laboratory (L8) (Dr. Ileana Cernica)
  - ✓ Laboratory for Micro- and Nano- Fluidics (L10) (Dr. Marioara Avram)
- **CENASIC: Research Centre for Nanotechnologies and Carbon- based Nanomaterials**
  - ✓ Simulation, Modelling and Computer-Aided Design Laboratory (L5) (Dr. Raluca Muller)
  - ✓ Reliability laboratory (L7) (Dr. Octavian Buiu)
  - ✓ Laboratory for nanotechnologies and carbon based nanostructures (L11) (Dr. Andrei Avram)

IMT's infrastructure is organized in two main technological facilities:

IMT-MINAFAB

Facility for Design, Simulation, Micro- nanofabrication of electronic devices and systems

CENASIC

Research Centre for Integrated Systems, Nanotechnologies and Carbon Based Nanomaterials.

IMT MINAFAB

A unique facility in Romania, competitive at EU level, where one can realise micro and nanodevices, sensors and microsystems.

► ***The facility addresses the entire value chain starting with design and simulation to micro-nanofabrication, microphysical characterization, functional testing and reliability investigations.***

► **IMT-MINAFAB** includes:

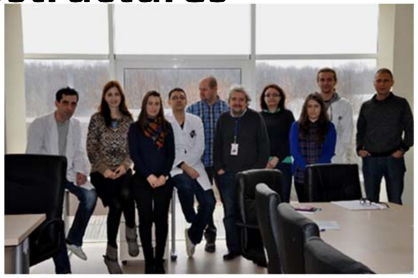
- **clean rooms (class 100, 1000, 10,000, with a surface of 1000 m^2)**
- **state-of-the-art equipment**
- **skilled researchers with high level expertise in the field of micro-nanotechnologies**

CENASIC

►dedicated to technologies and devices based on **carbon** nanomaterials: **graphene**, SiC, nanocrystalline diamond

New Laboratories:

- **Lab for Processing Of Carbon Based Nanomaterials and Nanostructures**
- **Lab for Thermal Processes**
- **Lab for Graphene technology**
- **Lab for Chemistry of Hybrid Interfaces**
- **Lab for Thin Layer Spectrometry**
- **Lab for Electro - mechanical Processes and Sample Preparation**
- **Lab for Electromechanical Testing & Reliability**
- **Laboratory for Simulation and design for carbon-based MEMS/NEMS**



Both infrastructures:

- are introduce in the National Roadmap of infrastructures

- are open to industry and academia
- are intensively used in national and EU projects, including structural funds (ex. TGE-PLAT)
- hosted lab for students, especially for University Politechnica of Bucharest
- help Romanian and foreign students to perform research for PhD Thesis (Italy, UK, South Africa, France, Germany, Moldova)

- Offer services (ERIS and TGE-PLAT)

IMT and European Cooperation

IMT has an active participation in European Technological Platforms:

- Nanomedicine,
- EPoSS (Smart System Integration)

IMT coordinated the MEMSWAVE project (1997-2000), the first European project coordinated by a country outside EU (at that time), which was nominated for the Descartes Prize (the best European R&D project).

- **IMT was involved in 15 FP6 European projects**
- **IMT was involved in 12 FP7 projects**
- **IMT was involved 4 ENIAC (nanaoelectronics) projects**
- **IMT was and is involved in 10 MNT ERA-NET projects and 8 COST projects, 1 EUREKA**
- **IMT was/is involved in 4 ESA projects**
- **IMT was/is involved in 5 Structural Funds projects**

IMT and European Cooperation

HORIZON 2020
The EU Framework Programme for Research and Innovation

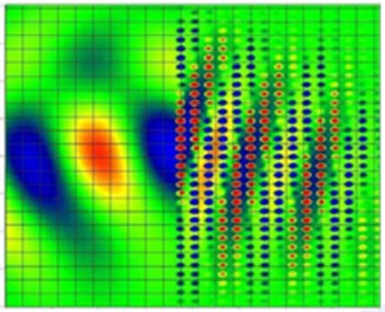
- **7 projects in H2020**
  - Priorities: **FET OPEN→3, ICT →1 , ECSEL→1, CSA →1**
  - **Marie Skłodowska-Curie-** Individual Fellowship→**1**

- **H2020-related projects**
  - **M-ERA.NET→4 ; EUREKA →1**
  - **FLAG-ERA→2**
  - **MANUNET→1**
  - Project supported by the German Federal Ministry of Education and Research (BMBF)→1: **Network of nano research infrastructures in the Danube region (DNMF_net), coordinator KIT, Germany**

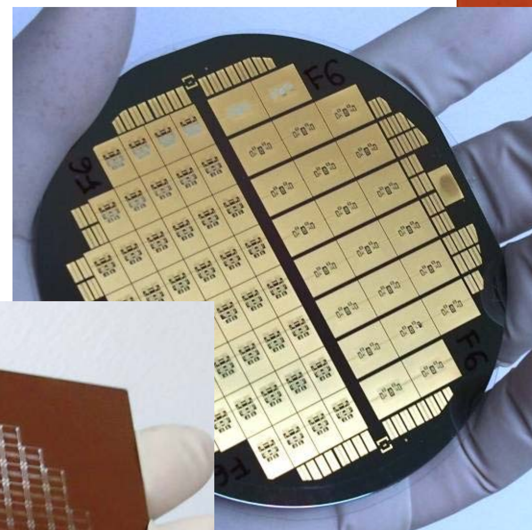
MARIE CURIE ACTIONS ECSEL JU M-era.Net manu net FLAG-ERA

Infrastructure: IMT-MINAFAB views

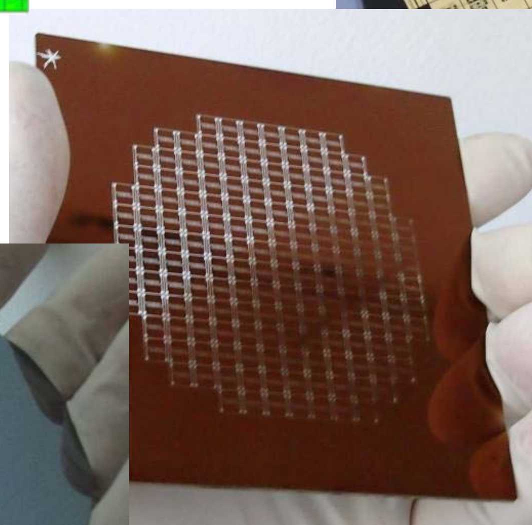
Processing Steps

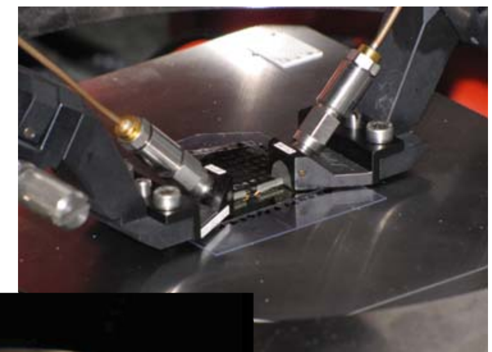


Wire bonding (part of packaging process)

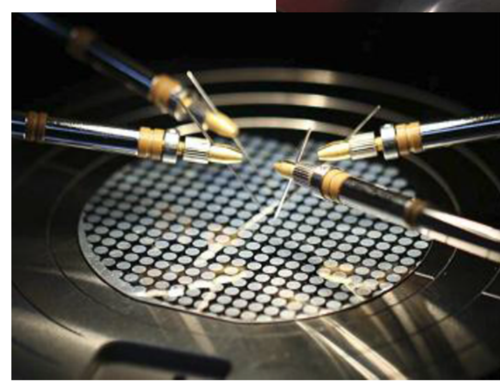


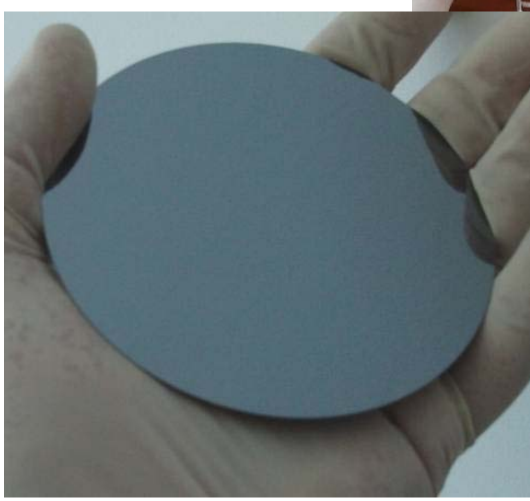
Processed wafer





Photolitographic mask





Tests

Silicon Wafer

Infrastructure: IMT-MINAFAB views

CENASIC clean rooms

CENASIC

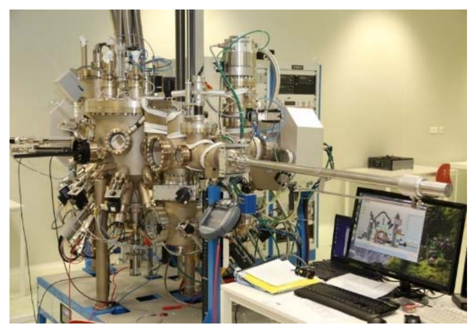
- .

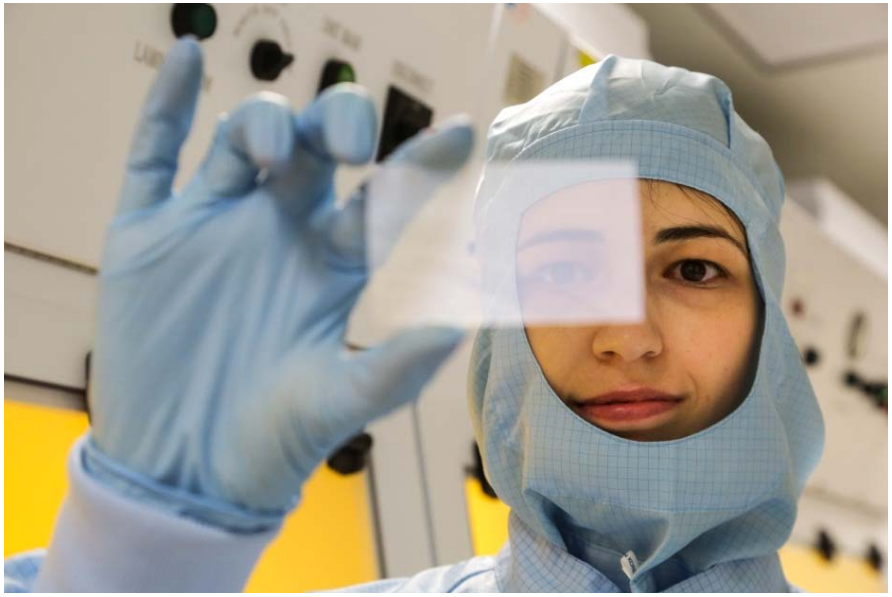
Atomic Layer Deposition (ALD) - OpAl / Oxford Instruments Plasma Technology, Ltd./2015

Clean room class 1000 and 100

T-IR spectrometer, with FT-Raman module - VERTEX 80/80v with RAM II FT-Raman Module / Bruker Optics /2015

Molecular Beam Epitaxy (MBE) - COMPACT 21 DZ/Riber Inc./2015



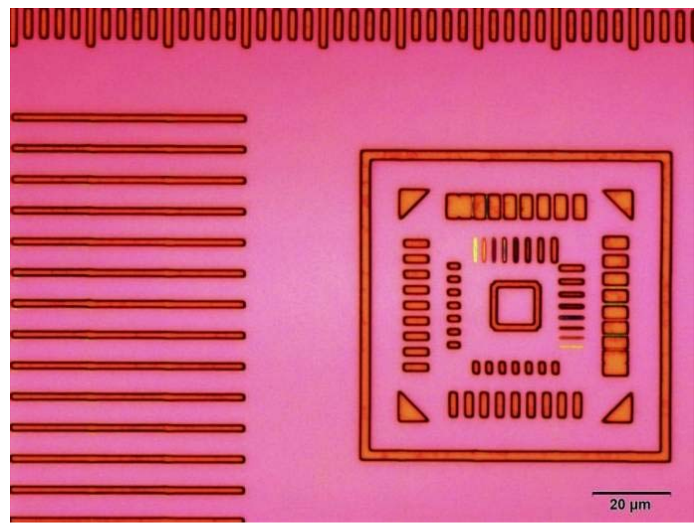


CENASIC clean rooms

Micro- and nanofabrication capabilities exemples

Patterning – Laser lithography
MASK SHOP

- **Heidelberg DWL 66fs - Ideal for MASK WRITING**
- **3 write heads (10mm, 4mm, 2mm) – achievable resolution <1 µm**
- **Possibility of gray scale for 3D lithography (32 layers).**
- **Possible substrates:**
  - **4” and 5” soda lime mask plates**



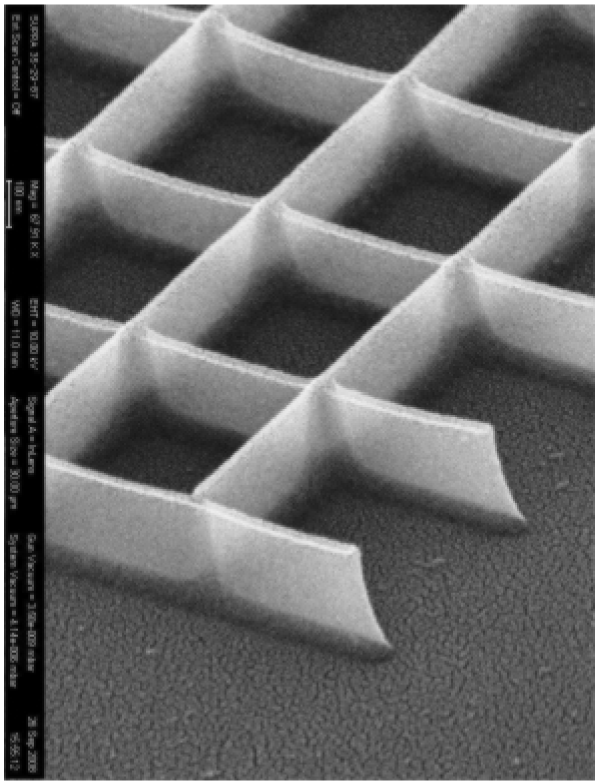
Patterning – E-Beam Lithography #1

- Raith e_Line for ultra high (single digit!) resolution
- Thermal assisted field emission gun
- 1.5nm spot size at 200pA
- Laser interferometer stage with 100 x 100 mm^2 travel range and 2 nm resolution achieved by closed-loop piezo-positioning

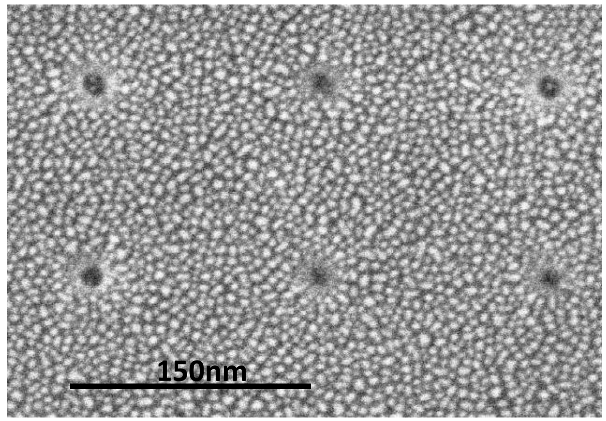
  - Minimum line width < 10 nm
  - Stitching accuracy 40 nm
  - Overlay accuracy 40 nm
  - Excellent for nano-lithography and SEM inspection

Installed in 2008

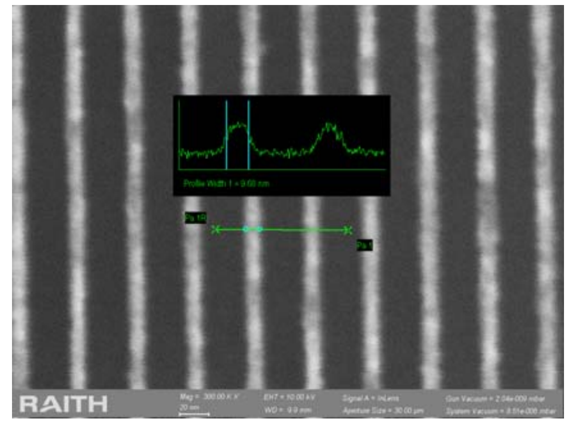
Patterning – E-beam lithography #2



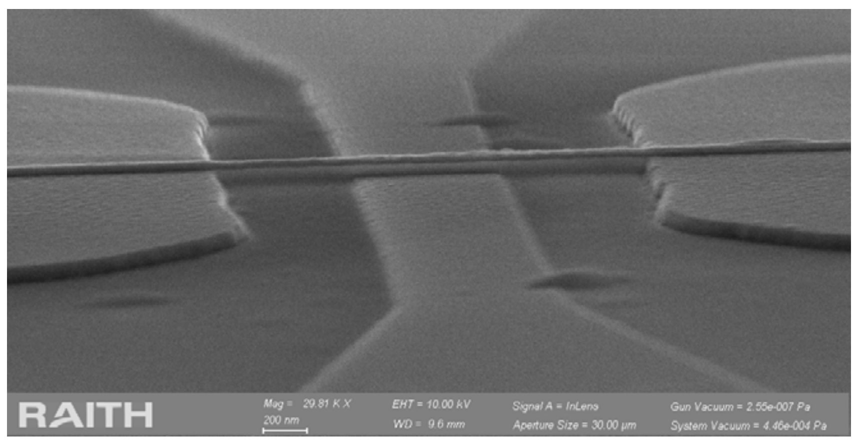
High aspect ratio (12:1) crosslines in PMMA



10nm diameter holes in PMMA 950k



10nm lines in HSQ 2%



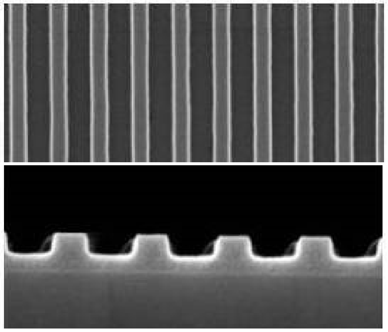
Nanoelectromechanical switch with a suspended 120nm wide beam

Patterning – Photo-lithography + Nanoimprint

- Suss MicroTec MA6/BA6
- **Double side alignment (typical resolution <1µm)**
- **Equipped with UV 365nm laser and Deep UV 249 nm laser**
- **Possibility of Nanoimprint lithography with resolution ~100 nm**

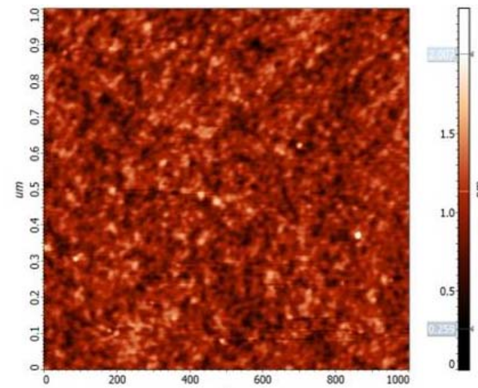
Quartz stamp

Line width: 114 nm
Residual: 58 nm



Oxidation, diffusion and annealing

90nm SiO_2 (dry process)



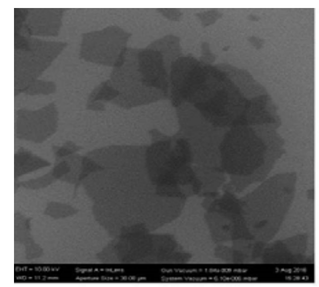
LINDBERG furnace

- **thermal treatment in oxidizing, reduci inert and forming gas atmosphere**
- **Temp range: 350-1250°C**
- **Up to 4 inch wafers**

Thermco 2000 furnace

- **Batch processing up to 50 4" wafers**
- **With load lock**

GO deposited on SiO_2 (wet process)



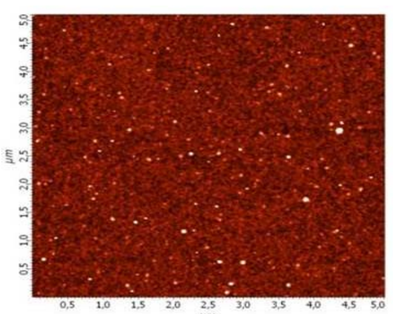
Annealsys rapid thermal annealing

- **Gases: N2, O2, Ar, NH3 for 3 and 4" wafer capability**
- **Temp range: RT to 1250°C (± 1°C accuracy)**
- **Oxidation, nitridation, crystallization and densification**

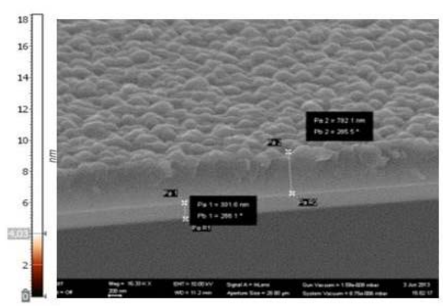
Oxides and nitride deposition - CVD

- Low pressure CVD
- (ANNEALSYS LC100)
- **Low stress Si3N4, poly-Si, etc.**
- **Thickness non-uniformity <2%**
- **Up to 50 wafers/process**

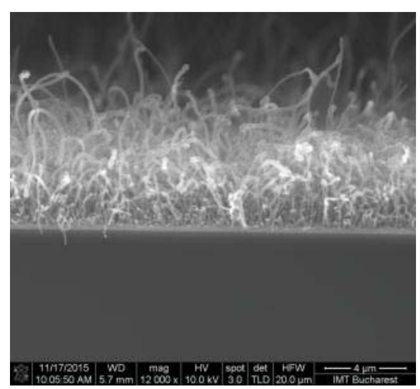
- Plasma enhanced CVD
- (Oxford Sys Plasmalab 100)
- **Oxide and nitride standard and high temp depo (up to 700°C)**
- **Possibility of growing nanotubes and nanowires**



***Silicon nitride**, AFM topography (thickness 200 nm ,RMS=0.4 nm, resistivity 10^{21} ohm.cm)*



***Polysilicon** on SiO2/Si substrate SEM image, deposited at 610oC thickness 780nm*



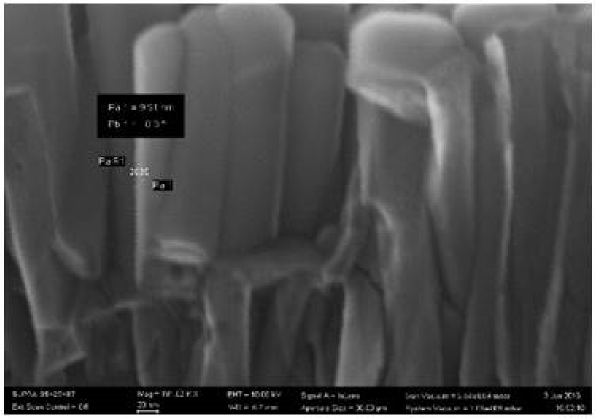
***Nanowires.** SEM image*

Oxides and nitride deposition - ALD

Oxford Instruments – OpAl system

- **Thermal and remote plasma ALD**
- **Highly conformal coatings and pinhole-free passivation layers**

- **Several precursors available, such as:**
  - **Al_2O_3 (TMA): good moisture barrier, wear resistant MEMS coating,…**
  - **HfO_2 (TEMAH): high k (~20) gate dielectric, active layer for RRAM,…**



10nm Al_2O_3 coating on ZnO nanowires.
SEM image

Oxides and nitride deposition - PVD

- **RF sputtering**
- **(Oxford Sys Plasmalab 400)**

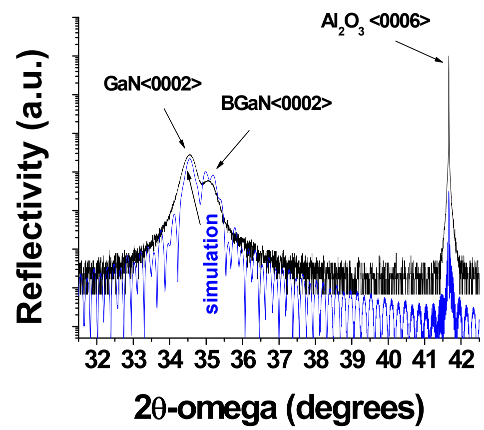
6" targets for high uniformity on large wafers (available: Ti, TiO_2, SiO2, Ni, ZnO:Al, …)

- **Ar, O_2, N_2**
- **Two RF magnetrons**
- **Up to 8 wafers (3 or 4")**
- **Uniformity shields**
- **Loadlock**

- **E-beam deposition**
- (Neva EDV 500A)
- **Used for a wide range of metal depositions, but reduced oxide (Al_2O_{3-x}, TiO_{2-x}) deposition was also successfully performed from crystalline pieces**

Oxides and nitride deposition - MBE

- Ideal for III-V / II-VI / GaN / graphene / oxides…
- **3'' wafer growth chamber with 12 sources ports**
- **High uniformity substrate heater – up to 1800°C**
- **All modern in-situ monitoring capabilities**



Simulation (blue) and x-ray diffraction curve *(black) of a BGaN/GaN/sapphire heterostructure*

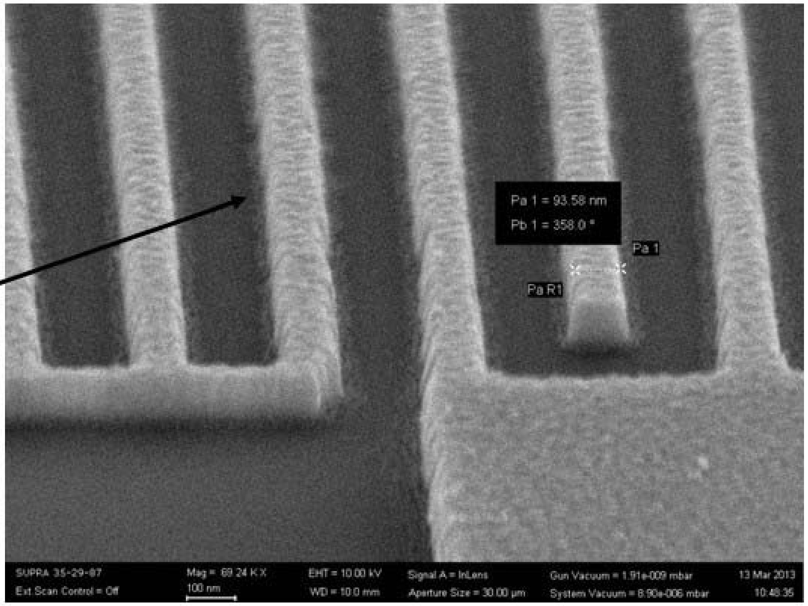
Metal deposition

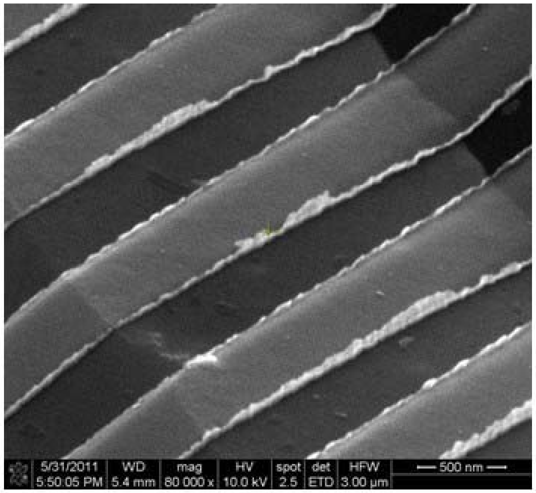
- **E-beam deposition (Temescal FC-2000)**
- **6 metals (Au, Pt, Ag, Ti, Cr and Al)**
- **High uniformity + optimized for lift-off**

- E-beam and DC sputtering (Edwards AUTO 500)
- **Al, Ni, Cr, Au, Pt. Up to 250ºC substrate heating**

Interdigitated electrodes

with 100 nm width, fabricated by E-Beam Lithography and highly directional metal evaporation of 10 nm Cr and 100 nm Au.

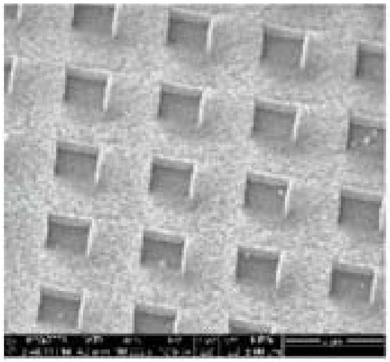


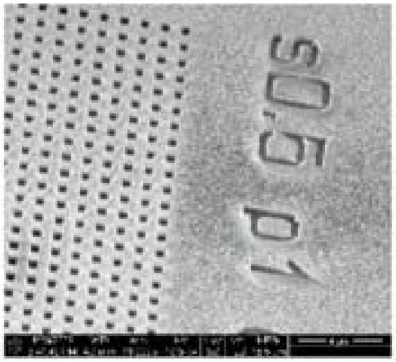


Temescal FC 2000 is a clean-room compatible, bell-jar shaped, load locked PVD system equipped with both e-beam ant thermal evaporation sources

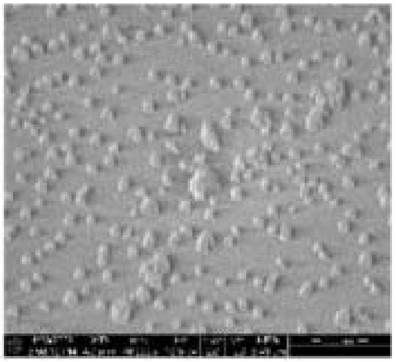
Dry etching – RIE

- **Sentech Etchlab 200**
- **Single wafer & small pieces**
- **High etch rate and low damage**
  - **etching of dielectrics (SiO_2, Si_3N_4)**
  - **semiconductors (Si)**
  - **polymers and metals (Au, Pt, Ti, Ni)**
  - **graphene,…**

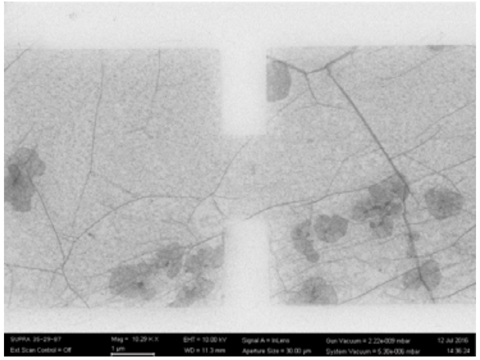




Etched squares and holes



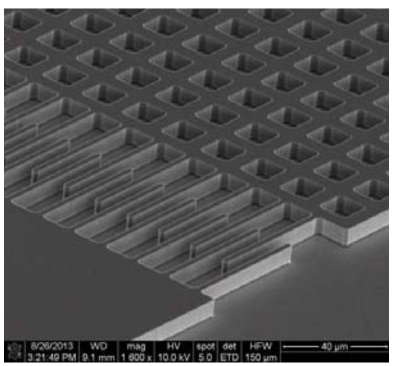
Nanodots

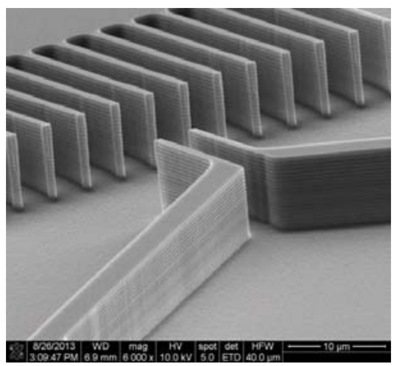


Etched graphene

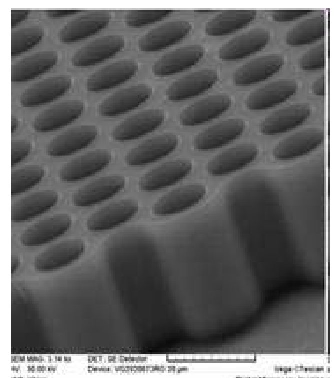
Dry etching – DRIE

- Oxford Instruments Plasmalab 100
- Bosh processes for Si and SiC
- Single wafer processing and small pieces
- Si etch rate: up to 7.5 µm/min
- Process gases: SF_6, C_4F_8, O_2, Ar
- Aspect ratio: 20:1 of vertical sidewalls

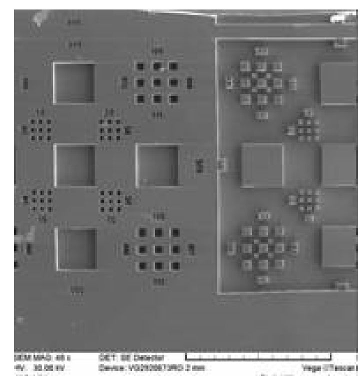




Anisotropic etching of Si with perfectly vertical walls



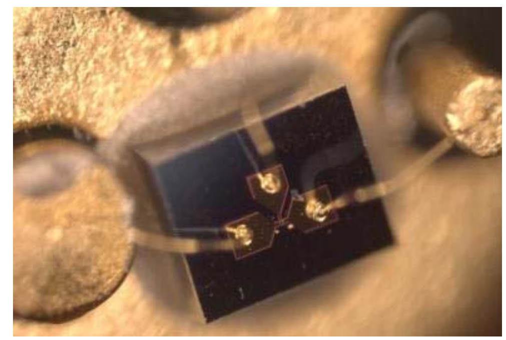
Honeycomb etching



Positive + negative etching

Packaging – wafer bonding

- **Suss MicroTec – wafer bonder SB6L**
  - **Up to 8kN applied force**
  - **Silicon to silicon; silicon to glass; pressure/heat assisted polymer bonding**
- **Wire-bonding**
  - **Gold wires down to 17µm**
  - **y of pad dimensions and materials**



Chip dicing

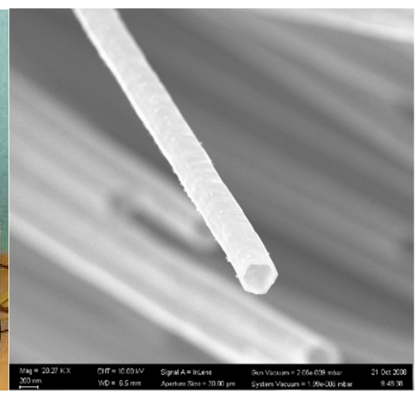
A variety of substrates (Silicon, quartz, glass…)
Low/high water flow and dicing speed to reduce particle contamination

Characterization capabilities

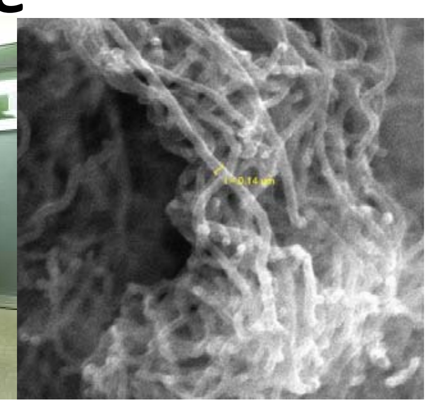
Scanning Electron Microscopy

- **FEI Nova NanoSEM630**
  - **Field-emission SEM**
  - **Ultra high resolution: 1.6nm @ 1kV**
  - **Nanoprototyping possible**

- **Tescan Vega LMU II**
  - **Tungsten heated thermal-emission**
  - **Resolution: 5nm @30kV**
  - **Nanoprototyping possible**



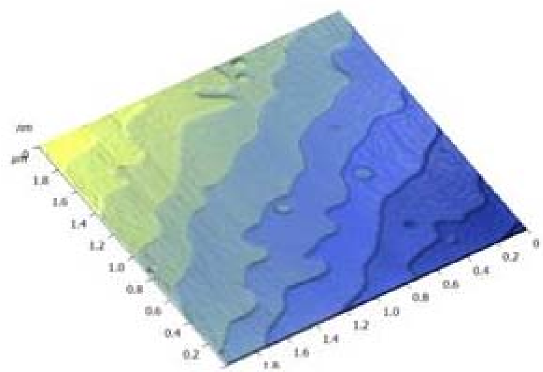
Nanodots



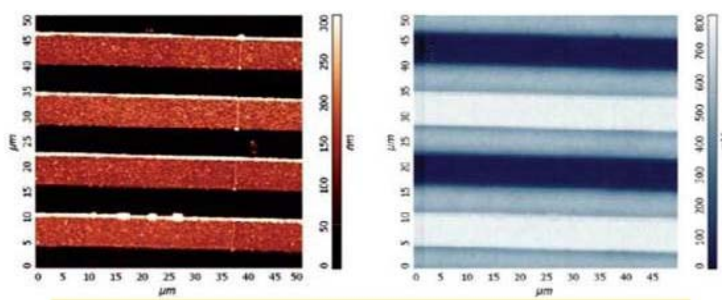
Etched squares and holes

Scanning probe microscopy

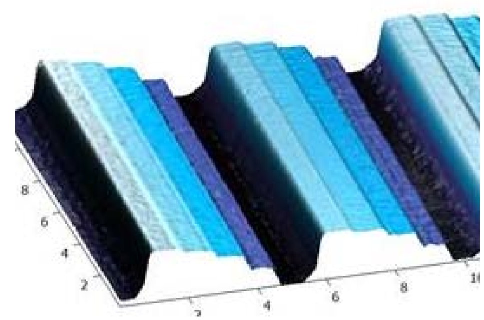
- **NT-MDT Co. SPM NTEGRA Aura**
- **Varied substrates (metallic, ceramic, polymeric…)**
- **Various measurement environments (ambient, controlle low vacuum)**
- **Various signal recording possible (AFM, c-AFM, KPFM, etc.)**



NdGaO3 (001) single crystal, with 0.4nm height individual atomic terraces



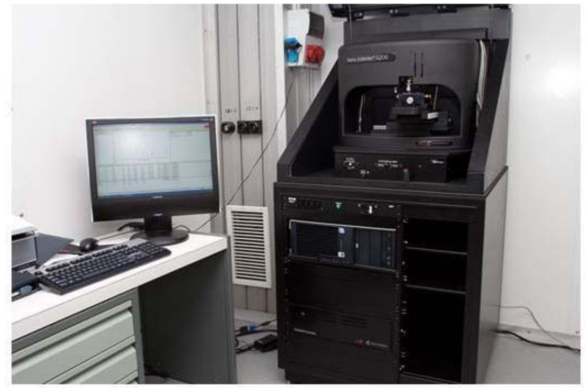
Simultaneously recorded topography (AFM) and potential (KPFM) images of a biased interdigitated structure

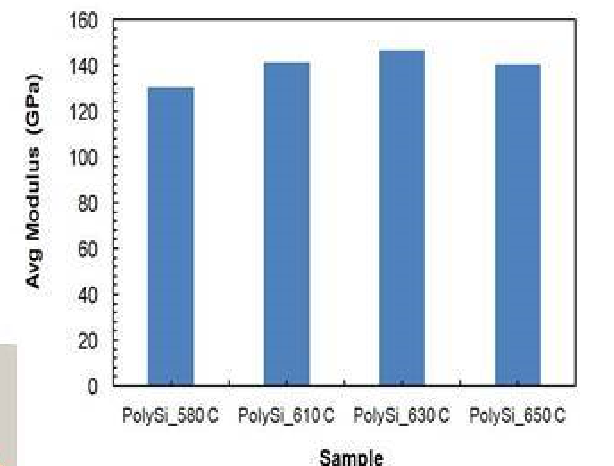


Multi-level stripes obtained by gray tone e-beam lithography in PMMA

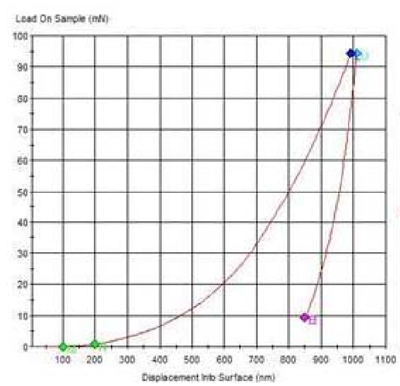
Nanomechanical characterization

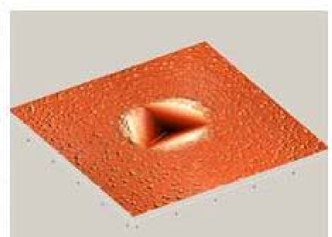
- **Agilent Tech. Nano Indenter G200**
- **Instrumented indentation and scratch testing**
- **Thin films, coatings and small volumes of material**
- **Measured properties:**
  - **Hardness**
  - **Elastic modulus**
  - **Film adherence**
  - **Wear behavior**
  - **Stress-strain data**





Plot of Young's modulus for polysilicon thin films by LPCVD at four temperatures





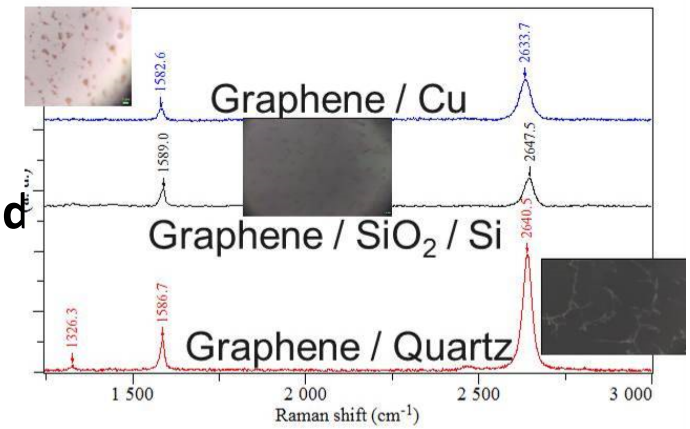
Load vs. displacement curve and AFM image of indentation side (Al thin film)

Spectroscopy

Raman spectrometer LabRAM HR800

- **High resolution (0.3 cm-1/pixelat 633 nm);**
- **Large spectral Raman shift from 30 to 4000 cm^{-1} id inorganic species**

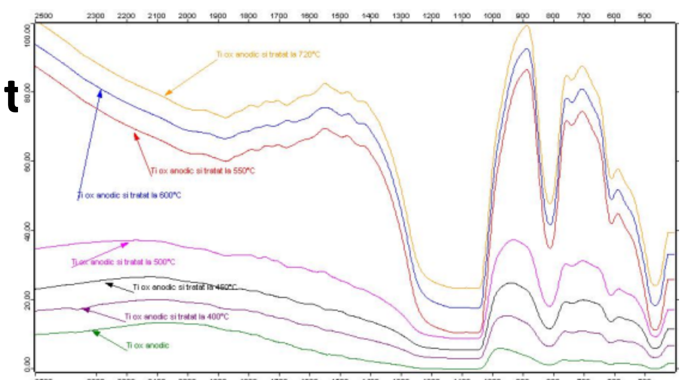
SLG graphene transfer by electrical delamination



FTIR spectrometer Tensor 27 Bruker

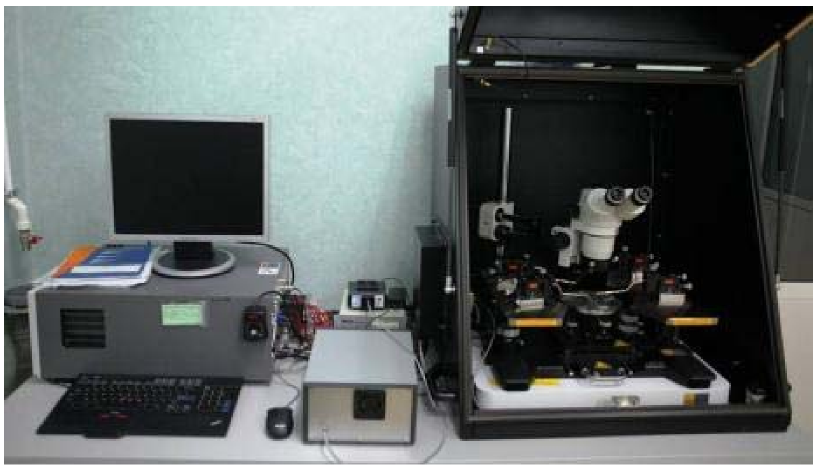
- **High resolution (0.3 cm-1/pixelat 633 nm);**
- **Chemical structure of compounds for liquid, solid t**

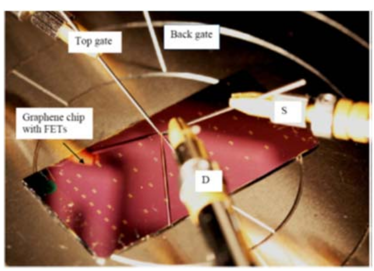
FTIR spectra of $TiO_2/SiO_2/Si$



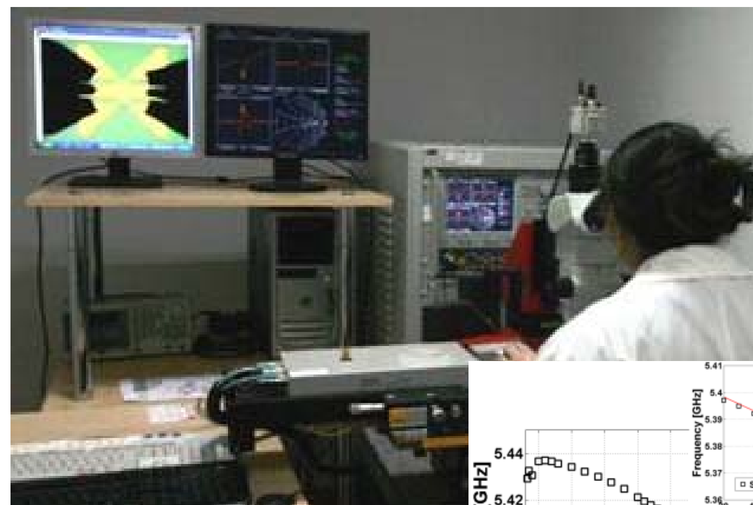
Electrical characterization

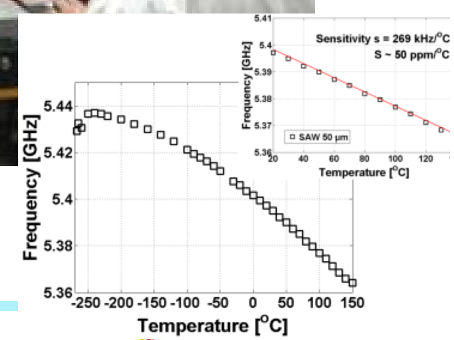
- DC and low frequency (Keithley 4200 SCS)
- 3 SMUs + GNU
- Pulse + C-V capabilities





- **High frequency**
- **(Anritsu VNA 37397D)**
- Frequency range 0.5GHz-110 GHz
- **On wafer**

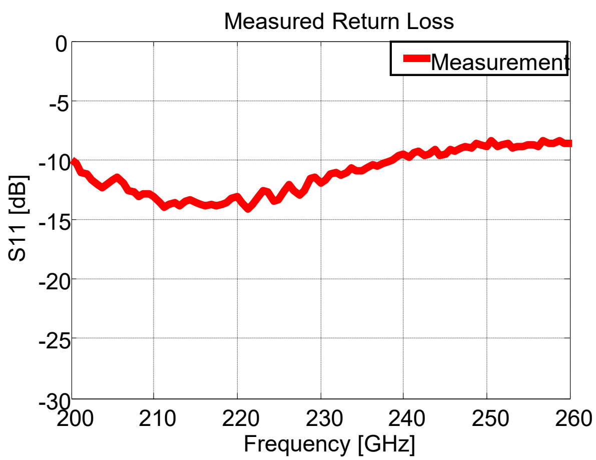


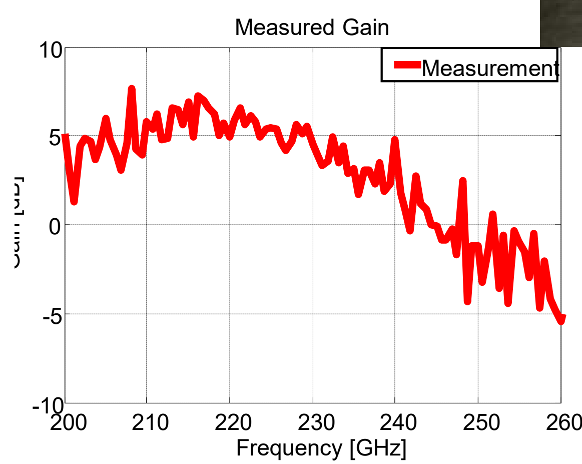


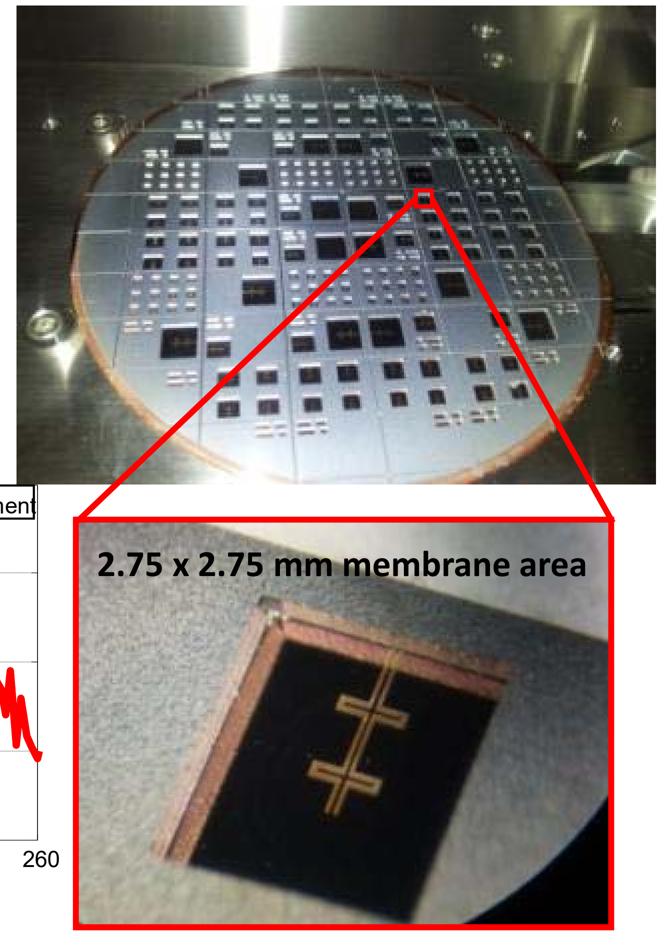
0.2 THz on-chip antennas

Contact: Dr. Dan Neculoiu, e-mail: dan.neculoiu@imt.ro
Dr. Alina Bunea E-mail: alina.bunea@imt.ro

- **2 μm thin dielectric membrane released using DRIE of low-resistivity Si (525 μm)**
- **High performance on-chip antenna**
  - **measured bandwidth (|S11| < – 10 dB) between 200 – 240 GHz**
  - **measured gain of 5.5 dB at 220 GHz (higher than 0 dB between 200 – 220 GHz)**



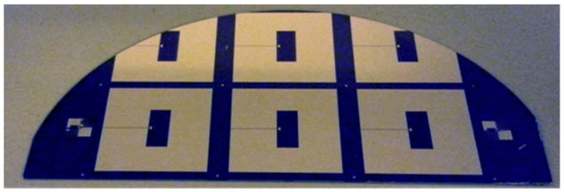




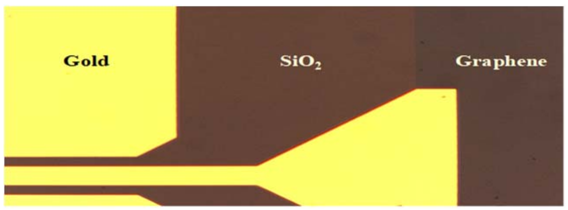
Carbon Based Smart System for Wireless Applications
(FP7 STREP NANORF) (2011 - 2015)

Coordinator Thales Research & Technology, France; IMT-Bucharest Partner

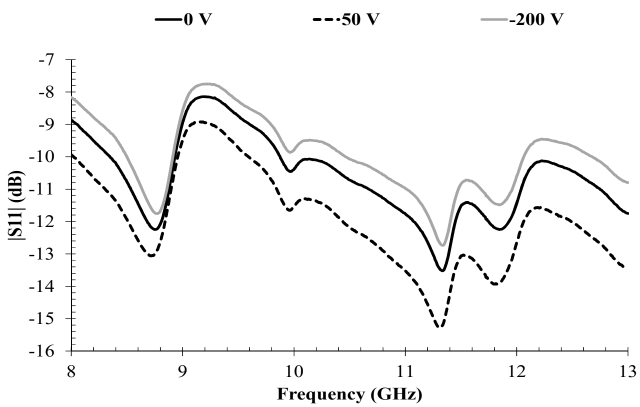
13 partners from 8 countries (9 research institutes and universities, 2 SMEs and 2 subsidiaries of a major industry)



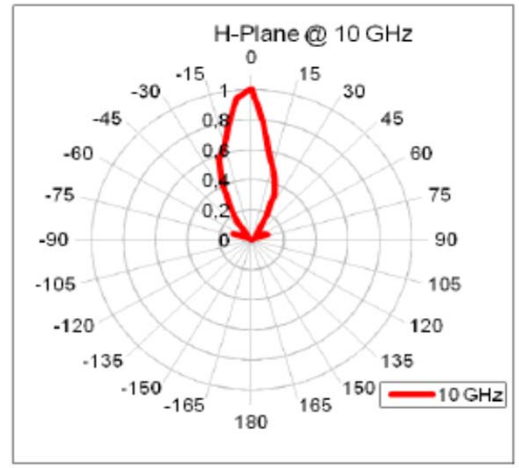
Optical image of the fabricated graphene-based antennas



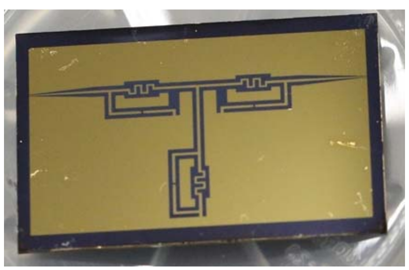
Detailed view of the graphene/gold interface

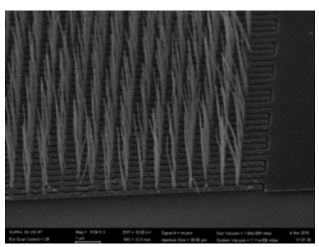


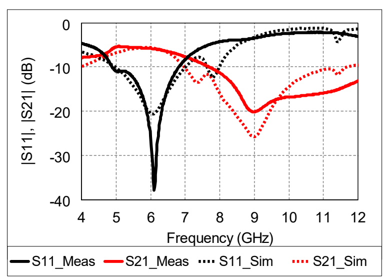
Improvement of antenna matching via the applied bias voltage



2D radiation pattern at 10 GHz







Prototype and RF characterization of the CNT-based RF filter with CNT-based varactors in the C and X bands

Published papers:

- M. Dragoman, D. Neculoiu, A-C Bunea, et. al., ***Applied Physics Letters***, vol. 106, no. 15, p. 153101, 2015 .
- M. Aldrigo, M. Dragoman, et. al, Semiconductor Conference (CAS) 2016, pp. 63-66, 2016.
- M. Aldrigo, M. Dragoman,et. al., 47th European Microwave Conference (EuMC), pp. 308-311, 2017.

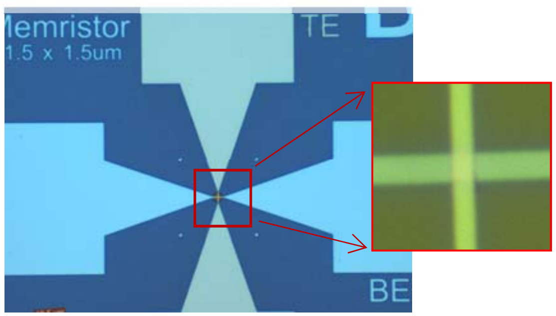
Integrated Crossbar of Microelectromechanical Selectors and Non-Volatile Memory Devices for Neuromorphic Computing

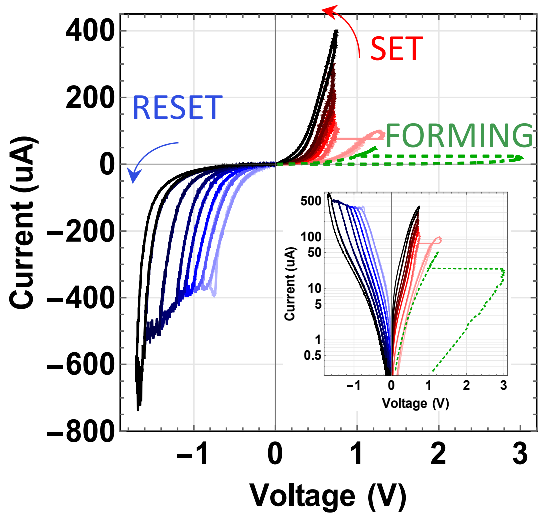
(H2020 Marie Sklodowska Curie IF SelectX) (2016 - 2018)

Coordinator IMT-Bucharest (secondment partner EPFL, Switzerland)

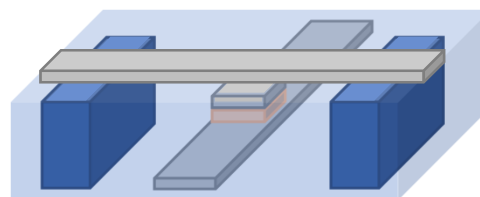
Nanoelectromechanical switches (NEMS) with low actuation voltage (<1V) as selectors in memristive crossbars

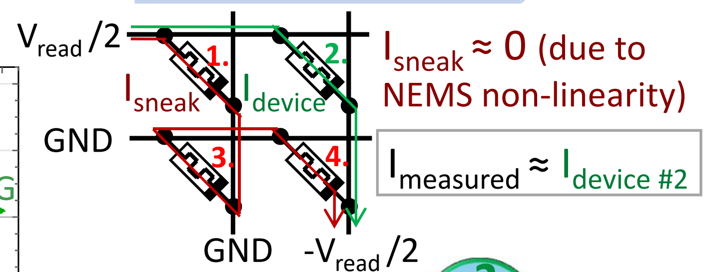
Memristor with analog behavior

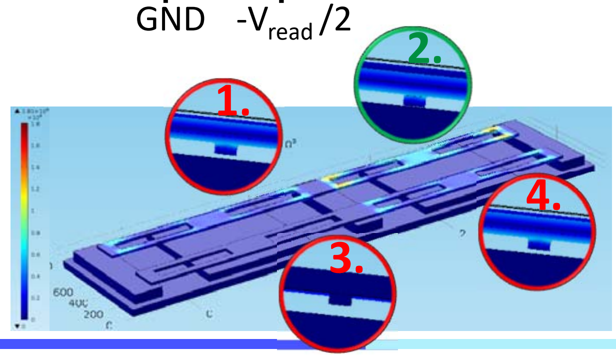




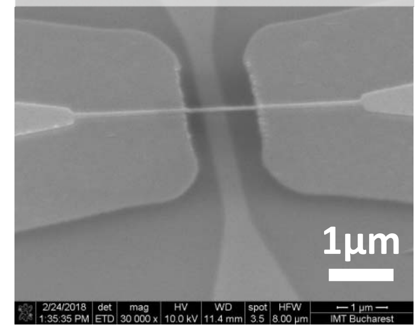
Integrated memristor/NEMS concept

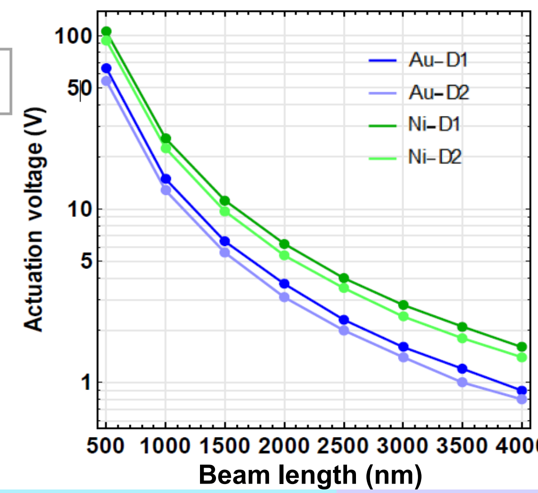






NEMS with 100nm wide beam

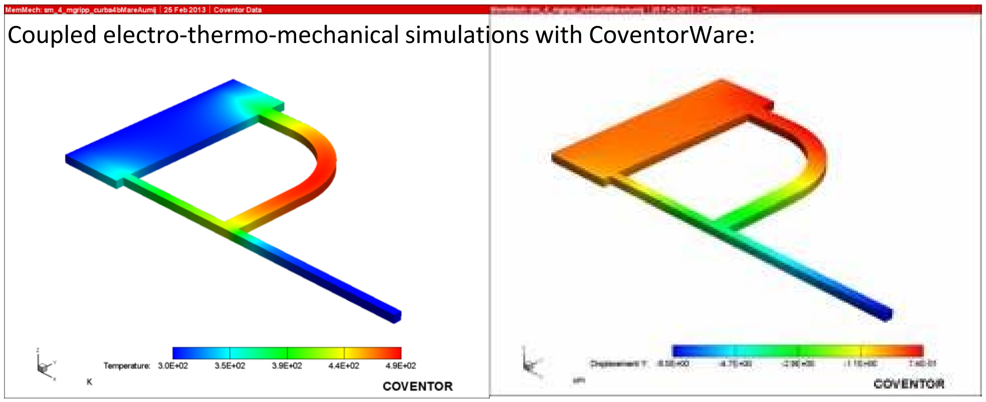


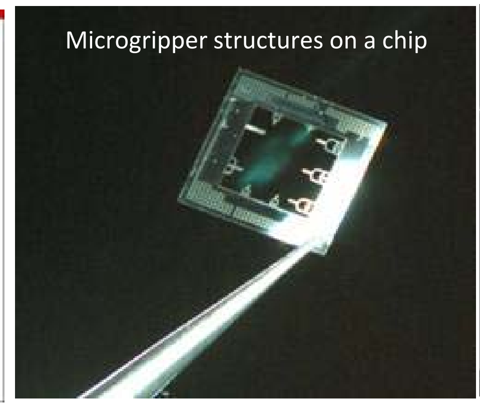


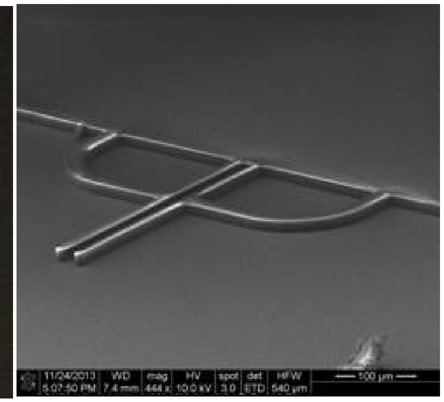
MEMS Electro-thermally actuated Polymeric Microgrippers

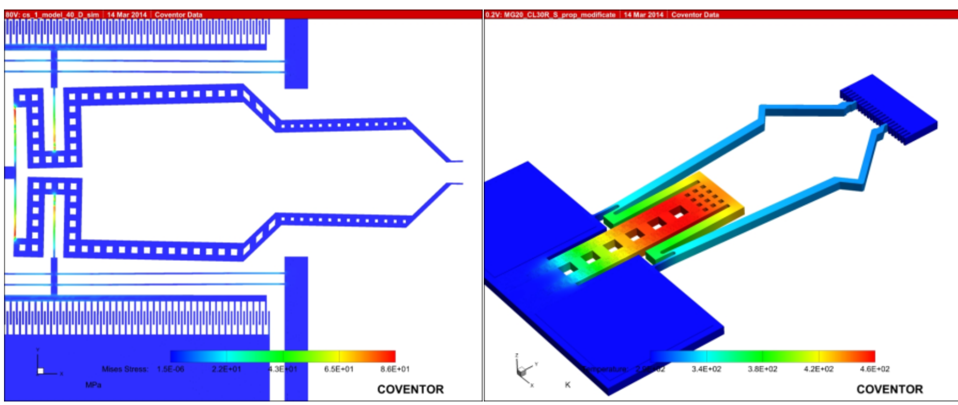
Applications:

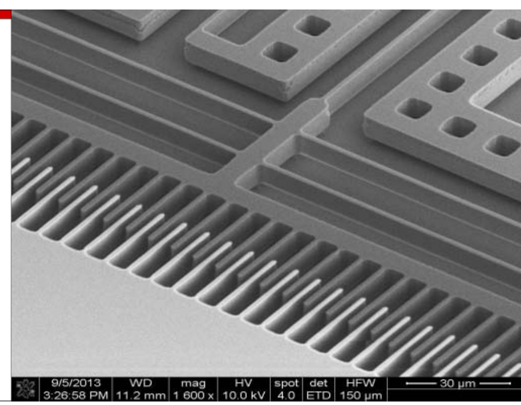
- **manipulation of MEMS and optic components: lens, fibers;**
- **micromanipulation of cells and biological tissues**



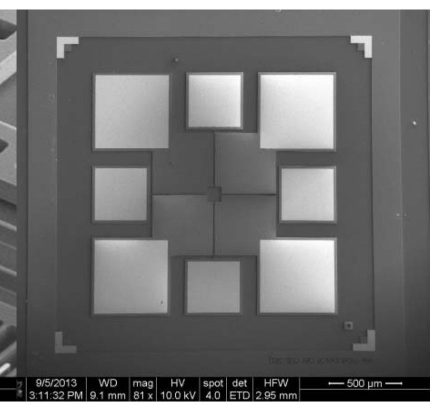








Electrostatically actuated microgrippers



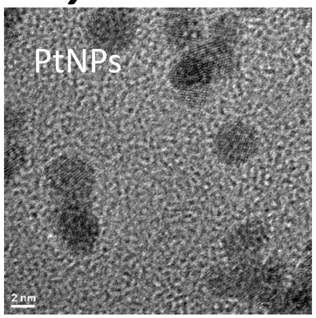
Vibrating structures

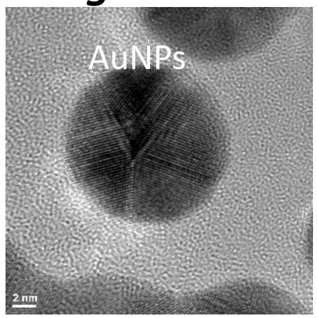
ERA.Net Project "3-Scale modelling for robust-design of vibrating micro sensors" - 3SMVIB
National Project - "*Microsisteme MEMS de manipulare pentru micro-robotica*"

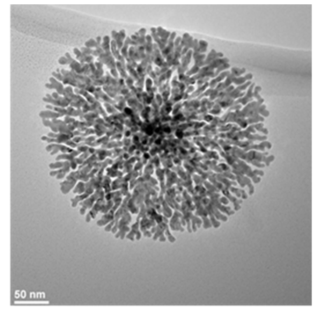
FUNCTIONAL NANOMATERIALS

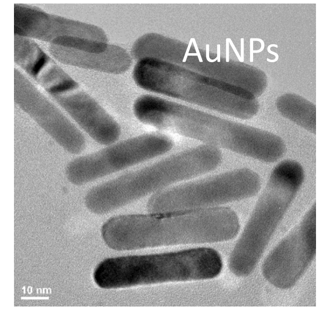
Metallic nanoparticles

Chemical synthesis > towards green chemistry (different sizes/shapes of AuNPs, AgNPs, PtNPs)



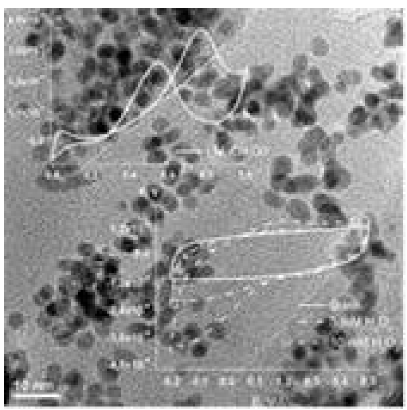






Multilayer nanostructures based on layer by layer technology

for sensing and/or methanol electrocatalysis (fuel cells applications)



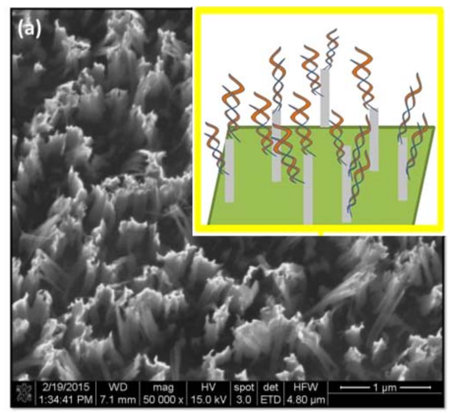
Nanocomposite polyelectrolyte/MeNPs or graphene nano-sheets or CNT multilayers >

good tolerance towards carbonaceous species during methanol oxidation

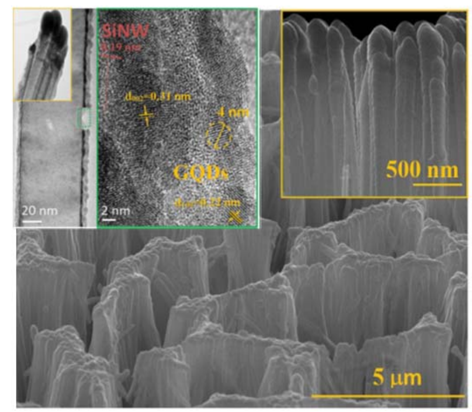
Materials Chemistry and Physics 146 (2014) 538

Colloids Surf. A: Physicochem. Eng. Aspects 461 (2014) 133

Silicon nanowires for optical sensors



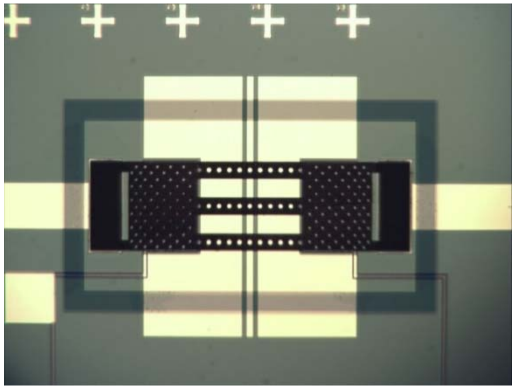
Enhanced nucleotide mismatch detection based on a 3D silicon nanowire microarray

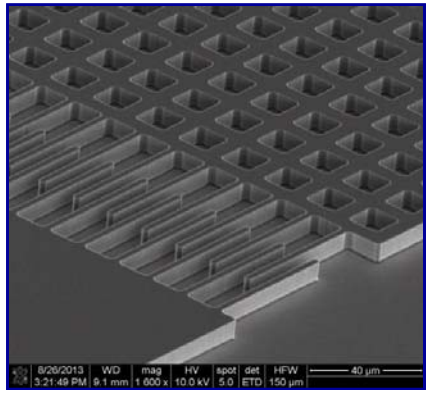


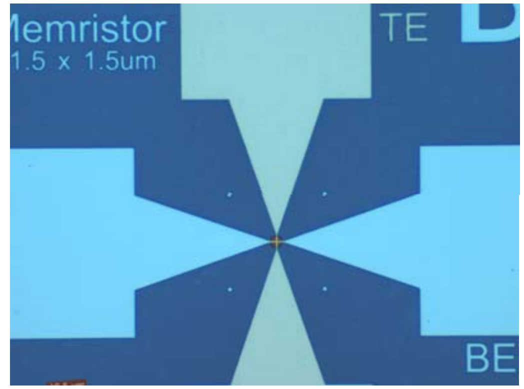
Core-shell Silicon Nanowires / Graphene Quantum Dots for Enhanced Ultraviolet and Visible Light Photodetector

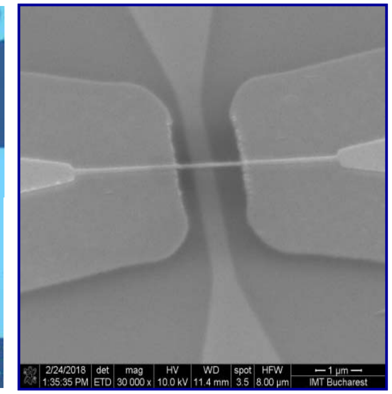
RSC Advances 5 (2015) 74506

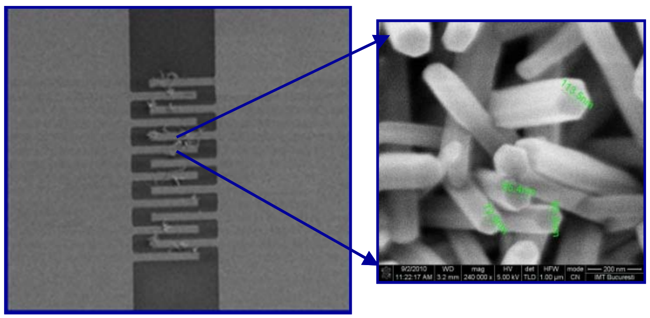
ACS Appl. Mater. Interfaces 9 (2017) 29234

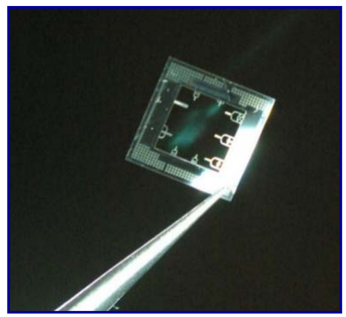


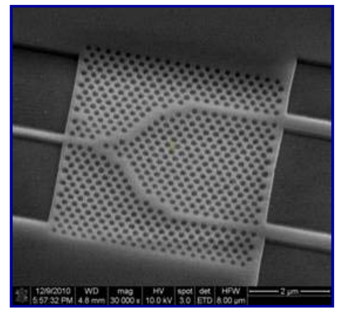


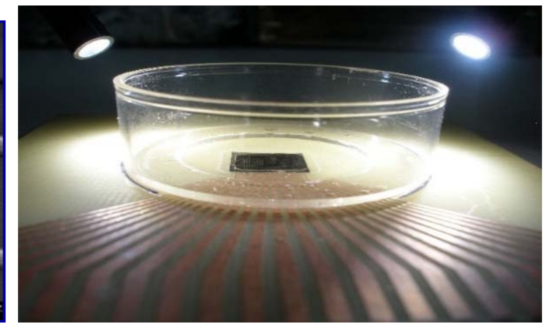

1.5 x 1.5um
TE
BE

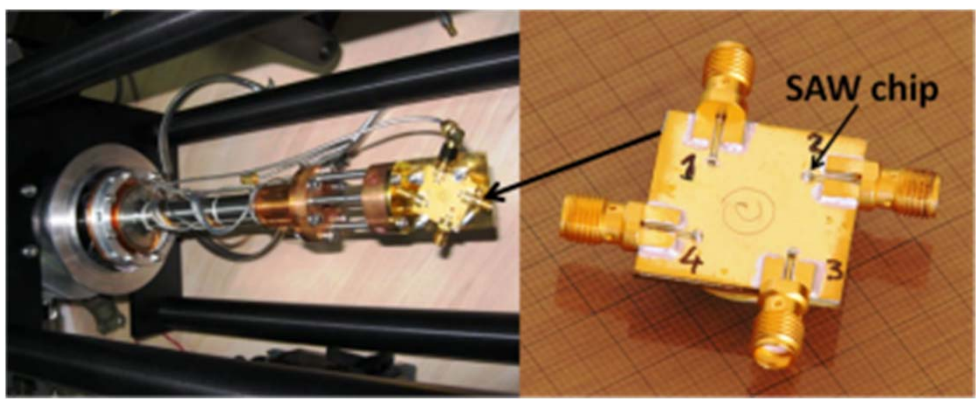


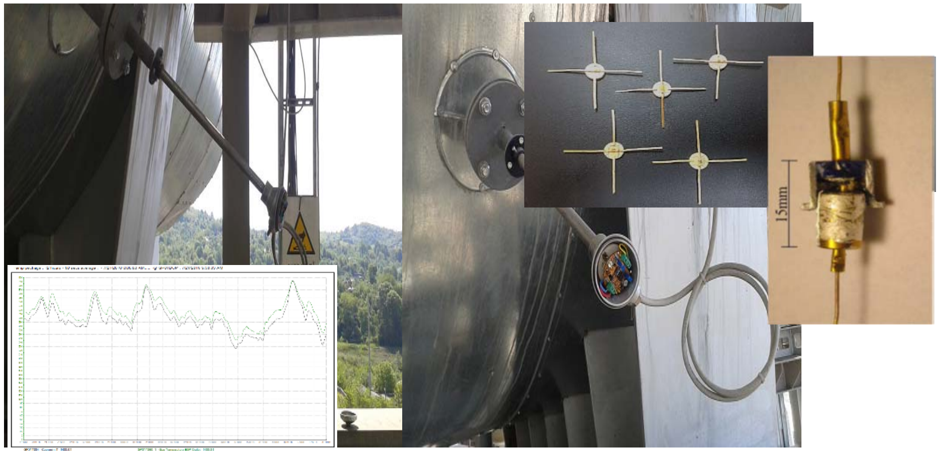






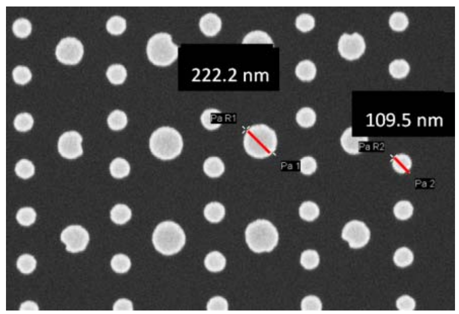


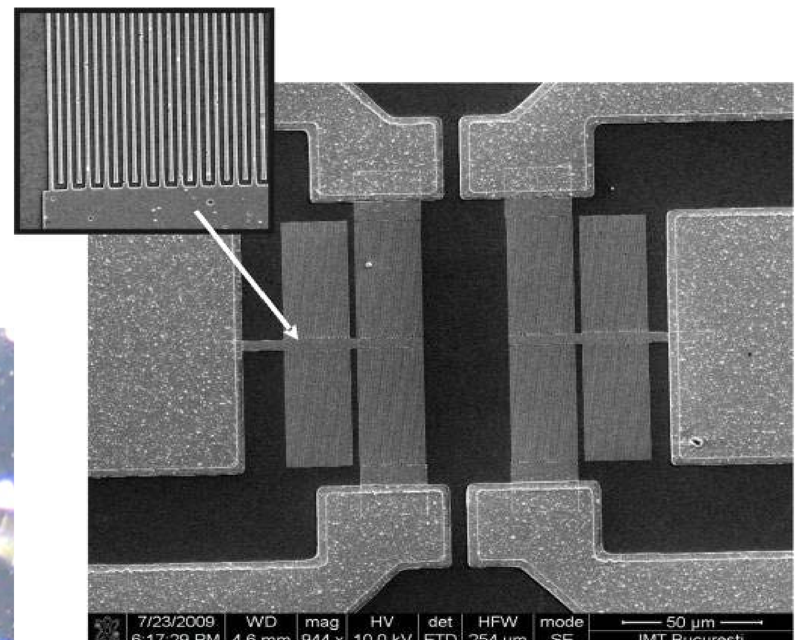

SAW chip
1
2
3
4




MICRONANOFAB L10
50
75
100
125
MICRONANOFAB L10

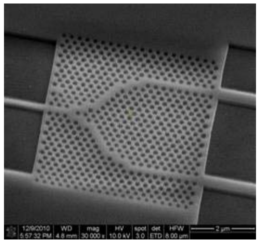

2.75 x 2.75 mm
membrane area
220
GHz


222.2 nm
109.5 nm


7/23/2009 6:17:29 PM
WD 4.6 mm
mag 944 x
HV 10.0 kV
det ETD
HFW 254 µm
mode SE
50 µm
IMT Bucuresti

IMT-MINAFAB
CENASC

- Offer Key support to national and EU R&D projects
- Colaborate with industry partners (Infineon, NXP, Thales, Renault)
- Offer Services to industry
- Help national industrial partners to scale up and innovate their research
- Offer open access to students



Thank you for your attention!