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Instrumente Structurale 2014-2020

Infrastructura de Cercetare a IMT Bucureşti

Dr. Miron Adrian DINESCU, Manager tehnic TGE-PLAT

Proiect cofinanţat din Fondul European de Dezvoltare Regională
prin Programul Operaţional Competitivitate 2014-2020

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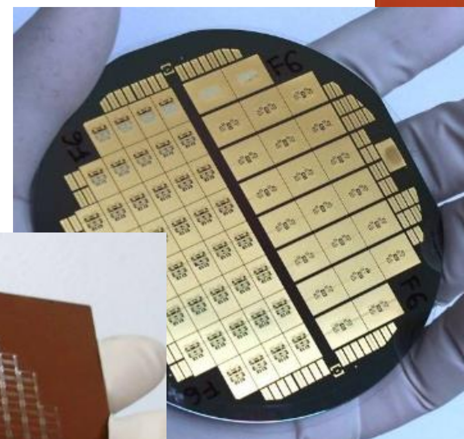
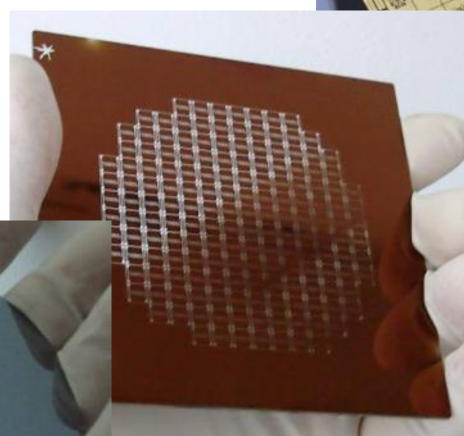
Processing chain

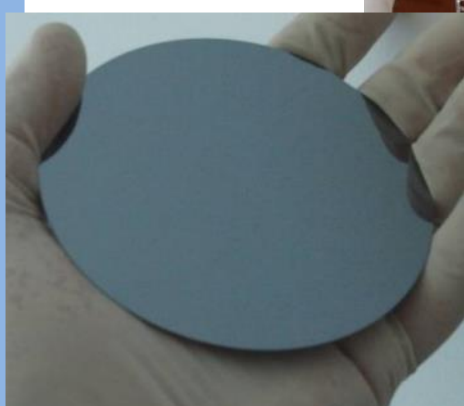
Wire bonding (part of packaging process)



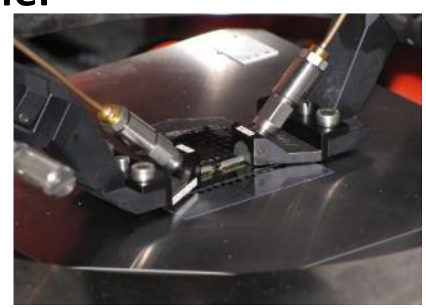
Processed wafer



Photolitographic mask



Silicon Wafer



Testing

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Micro and nano fabrication services:

-Oxidation and diffusion

-Thin film deposition: CVD, PVD, MBE, ALD

-Patterning technologies: photo and e-beam lithography, NIL; dry etching: RIE, DRIE,IB

-Wafer bonding, Chip dicing, wire bonding

Characterization services:

-Optical and scanning electron microscopy

-Scanning probe microscopy

-Nanoindentation

-Ellipsometry

-Spectroscopic methods: Raman, FTIR, UV-ViS, XRD

-Electrical measurements – from DC up to 110GHz

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Centrotherm E1200 H (Centrotherm Photovoltaics, Germany)
Horizontal furnace system for R&D and small-scale production

Four independent quartz tubes dedicated to following processes:

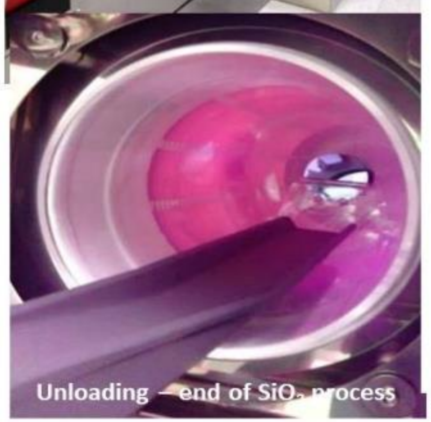
- ❑ Boron diffusion
- ❑ Phosphorous diffusion
- ❑ Annealing
- ❑ Wet and dry oxidation for thermal silicon dioxide (SiO_2)

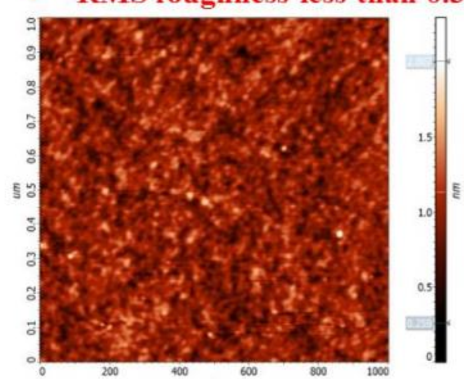
Features

- ❑ Running independent process or in parallel at temperatures up to 1200 °C
- ❑ High temperature accuracy on 3 heating zones with maximum deviation of 0.1°C
- ❑ Full registration & monitoring data for all processes & parameters
- ❑ Integrated lift for automated boat handling
- ❑ Loading up to 35 silicon wafers/process on boat - 4 inch size

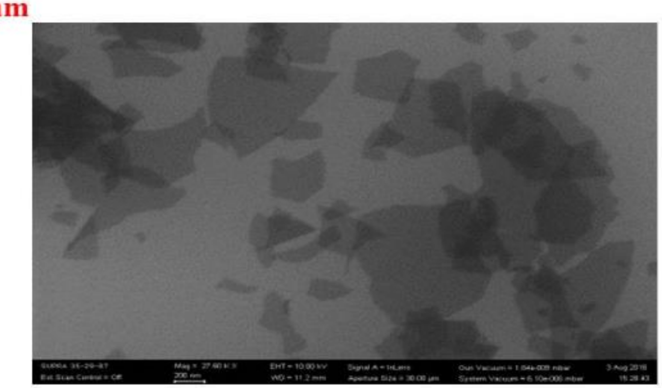
Experimental results for thermal SiO_2

- ✓ Variation of thickness uniformity less than 0.5% on silicon wafer
- ✓ High reproducibility on batch to batch and wafer to wafer processes
- ✓ Processes ready 90 & 300 nm SiO2 substrate for graphene transfer
- ✓ RMS roughness less than 0.3 nm





AFM topography of 90 nm SiO_2 (dry process)



SEM image of GO deposited on 300 nm SiO_2 (wet process)

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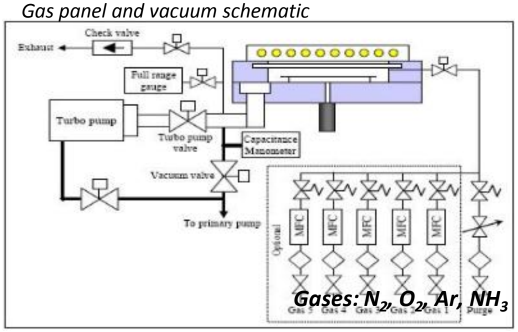
RTP- Rapid Thermal Processing system for Silicon, Compound Semiconductors, Photonics and MEMS processes

Gas panel and vacuum schematic



APPLICATIONS

- Rapid Thermal Oxidation (RTO)
- Rapid Thermal Nitridation (RTN)
- Crystallization and Densification
- Compound semiconductor annealing
- Diffusion
- Silicidation
- Glass reflow
- Sintering (contact alloying)

SUBSTRATES

- Silicon wafers
- Compound semiconductor wafers
- Glass substrates
- SiC and graphite wafers

SPECIFICATIONS

- 3-inch and 4-inch wafer capability
- High reliability assures low cost of ownership.
- Stainless steel cold wall chamber technology
- High process reproducibility
- Ultra clean and contamination-free environment.
- High cooling rates and low memory effect
- High vacuum version (10^{-6} mbar) is available for cleanest process conditions
- Pyrometer and thermocouple temperature measurement are standard features
- Fast digital PID temperature controller provides high and stable temperature accuracy (± 1°C) over the temperature range
- Edge pyrometer viewport insures enhanced temperature control of the susceptor for compound semiconductors and small samples.

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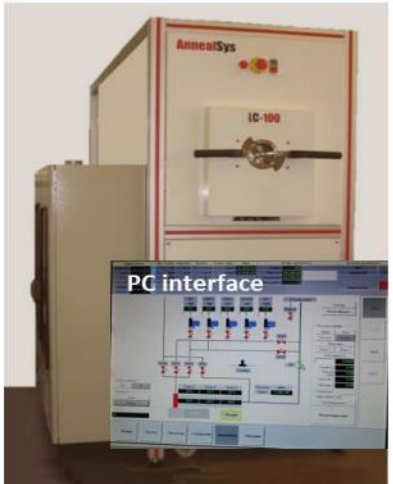
ANNEALSYS LC100 (Annealsys, France)
Low pressure chemical vapor deposition tubular furnace (LPCVD)



Dedicated to following processes:

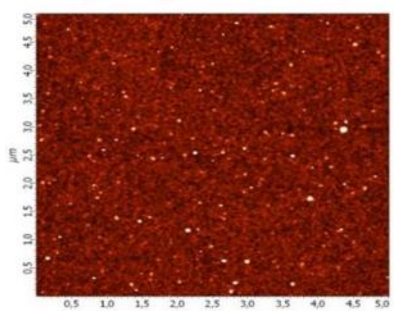
- Low stress silicon nitride (Si_3N_4)
- Polysilicon (poly-Si)
- Annealing
- Low thermal oxide (LTO)

Features

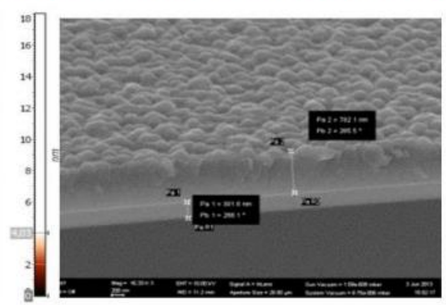
- ❑ Up to 50 wafers per process (3 or 4 inch)
- ❑ Up to 6 process gas lines with mass flow controllers
- ❑ High degree of reproducibility and relatively short deposition time
- ❑ Auto-tuning capability controller and continuous parameter adaptation

Results

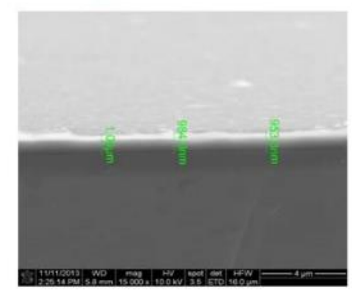
- ✓ Variation of thickness uniformity less than 2%
- ✓ High reproducibility on batch to batch and wafer to wafer processes



***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*



*1 µm **LTO** on Si substrate Deposited at 380°C, silane and oxygen precursors*

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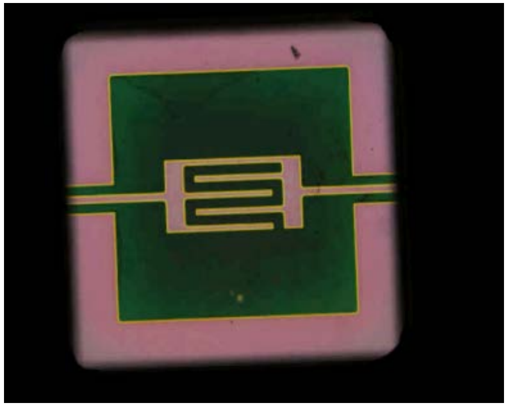
PECVD
Producer: Surface Plasma Technology Systems

Process gases: NH_3, SiH_4, N_2O, O_2, C_4F_8, Ar

Substrate temperature: 100^{o}C – 400^{o}C

HF/ LF processes.



SAW on a SiOx/SiNx membrane

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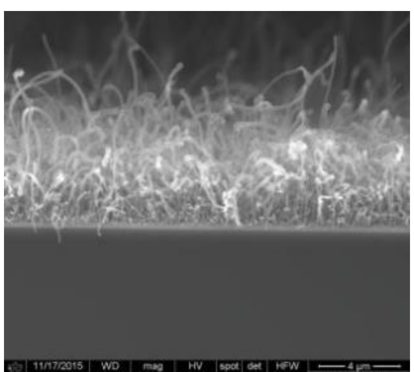
Plasma Enhanced Chemical Vapour Deposition (PECVD)

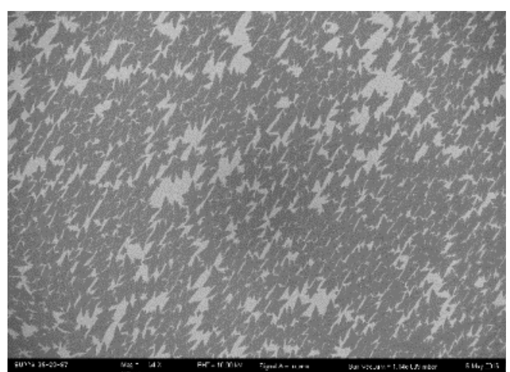
Oxford Instruments

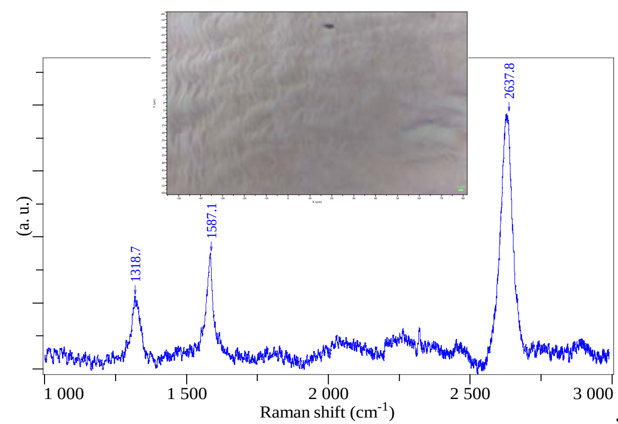
Plasmalab System 100

Nanofab700

- Controllable growth of nanotubes and nanowires with flexible temperature up to 700°C
- Compatible with a wide range of process gases including oxygen
- Plasma pre-treatment of the catalyst and chamber cleaning capability
- PECVD – Standard and high temperature deposition







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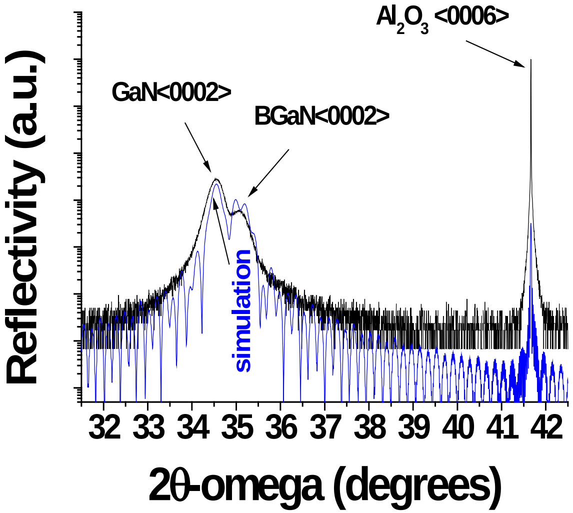
MBE – Molecular Beam Epitaxy

GROWTH CHAMBER (2)

- **3'' wafer growth chamber**
- **12 sources ports**
- **High speed electrically driven cell shutters**
- **High temperature, high uniformity substrate heater – up to 1800°C**
- **Remote control of equipment**
- **All modern in-situ monitoring capabilities**
- **Customized bottom flange**



X-ray diffraction curve (black line) of the BGaN/GaN/sapphire heterostructure together with a simulation of the grown structure assuming 7.7% of B into BGaN, 21 nm BGaN and 28 nm GaN-on-sapphire.

IDEAL FOR III-V / II-VI / GaN / GRAPHENE / OXIDES…APPLICATIONS

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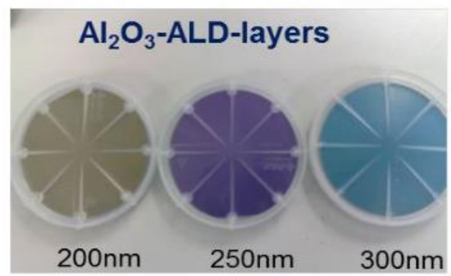
OpAL ™
Systems for thermal and remote plasma ALD
Oxford Instruments

Applications

- **High-k gate oxides**
- **Storage capacitor dielectrics**
- **High aspect ratio diffusion barriers for Cu interconnects**
- **Pinhole-free passivation layers for OLEDs and polymers**
- **Highly conformal coatings for microfluidic and MEMS applications**
- **Coating of nanoporous structures**
- **Fuel cells**

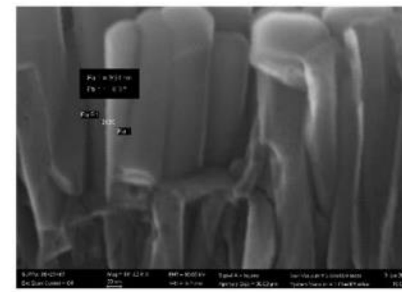
Al_2O_3

- Precursors:
  - TMA, H_2O
- Applications
  - Medium k (~9) dielectric
  - Wear resistant coating of MEMS structures
  - Passivation layer
  - good moisture barrier – e.g. OLED passivation



HfO_2

- Precursors:
  - TEMAH, H_2O
- Applications
  - High k (~20) dielectric
  - Gate dielectric



SEM cross section images for 10 nm Al_2O_3 deposition by ALD on ZnO nanowires

Process Library

	Al	Hf	Ta	Ti	Zn
Oxides	Al_2O_3	HfO_2	Ta_2O_5	TiO_2	ZnO
Multi-component oxides	Al_2O_3: Zn	HfAlO	$TiTaO_x$		ZnO:Al

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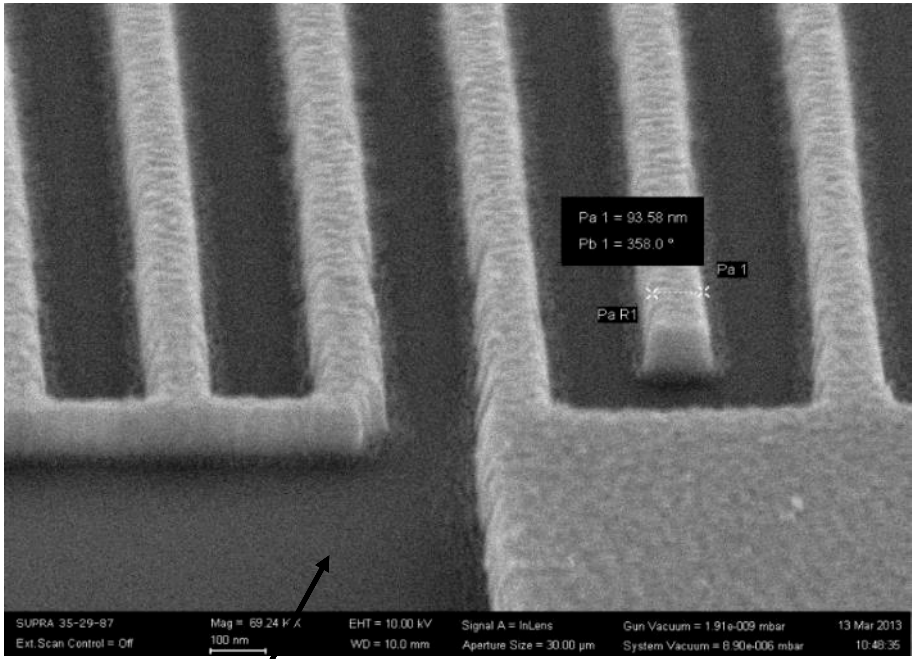


Temescal FC 2000 is a clean-room compatible, bell-jar shaped, load locked PVD system equipped with both e-beam ant thermal evaporation sources

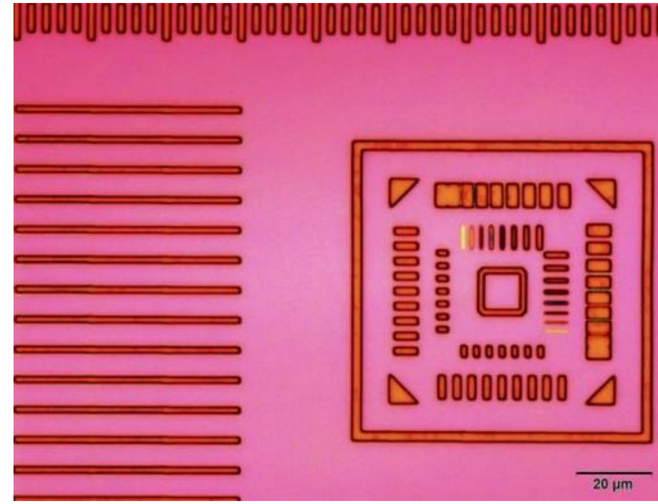
Interdigitated electrodes with <100nm width, fabricated by e-beam lithography and highly directional metal evaporation of 10nm Cr and 100nm Au.

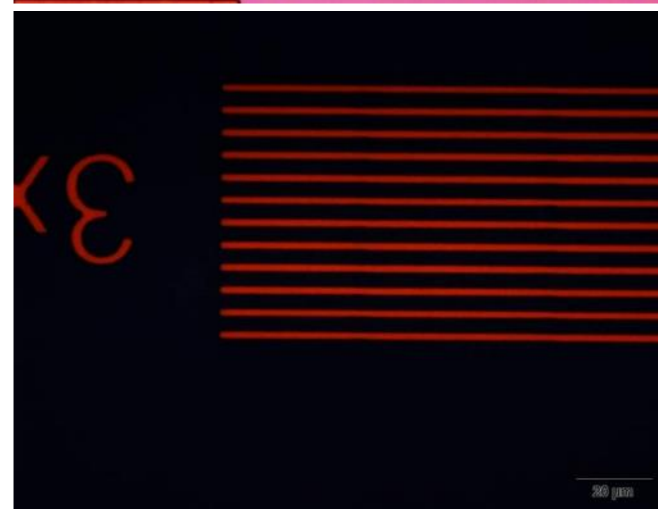
Magnetron Sputtering Deposition – Plasmalab System400

- Single chamber with up to 4 × 200 mm targets
- Deposit from 2 nm to 20 µm films
- Pulsed DC, DC or RF deposition
- Oscillation capability for thin, uniform films
- High vacuum for quality deposition
- Rotating shutter for target & wafer preparation
- RF bias for substrate cleaning
- Up to 4 gas channels for reactive sputtering

Masks Shop

-IMT Bucharest-





DWL 66fs can be used for laser inscription mask, using a DIODE laser with wavelength 405-nm, or directly to the wafers up to 6” realizing a minimal window of 0.6 microns, with the 2 mm writehead. The equipment works in 3D (32 layers).

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GUVERNUL ROMÂNIEI

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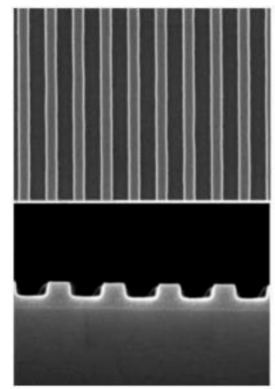
MA6 Mask Aligner with UV-NIL upgrade

Mask and Wafer/Substrate
Substrate Size: 3” and 4”
Mask Size: 4” and 5”

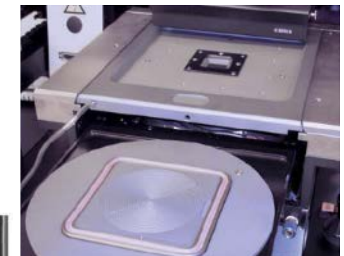
Exposure Modes
Contact: soft, hard, low vacuum, vacuum
Flood Exposures

Exposure Optics
Resolution down to 0.8 um
Wavelenght range
UV400 350 – 450 nm
UV250 240 – 260 nm
Intensity Uniformity +_5%

Alignment Methods
Top Side Alignment (TSA);
Bottom Side Alignment (BSA)
Image Storage Alignment System
Accuracy:
TSA down to 0.5 um
BSA down to 1 um



Line width: 114 nm
Residual: 58 nm



Template holder and chuck for NIL allow printing resolutions in the nanometer range

Quartz stamp

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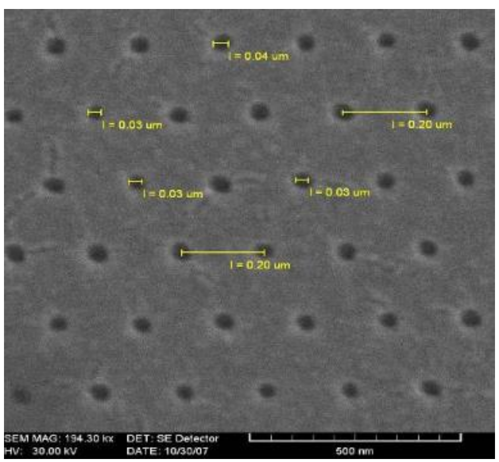
Electron Beam Lithography equipment at IMT Bucharest

First EBL equipment in IMT - Tescan Vega LMU II and Raith Elphy Plus – installation 2006

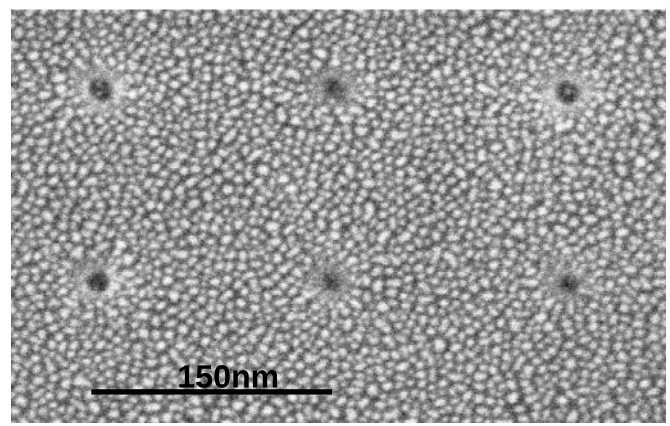
Smallest beam diameter : 5nm @ 3pA beam current and 30kV



30nm diameter holes in PMMA 950k

Raith e-Line – installation 2008

Smallest beam diameter: 1.5nm @ 200pA



~ 10nm diameter holes in PMMA 950k

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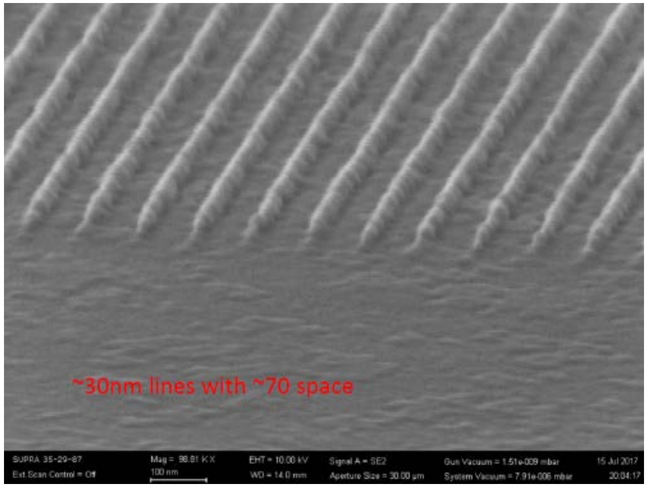

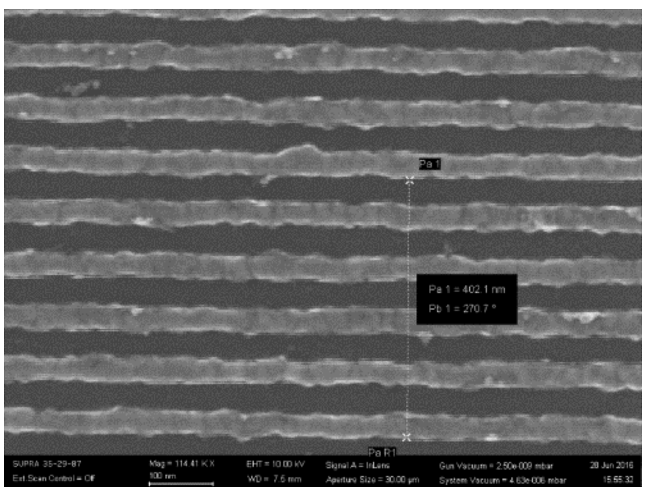

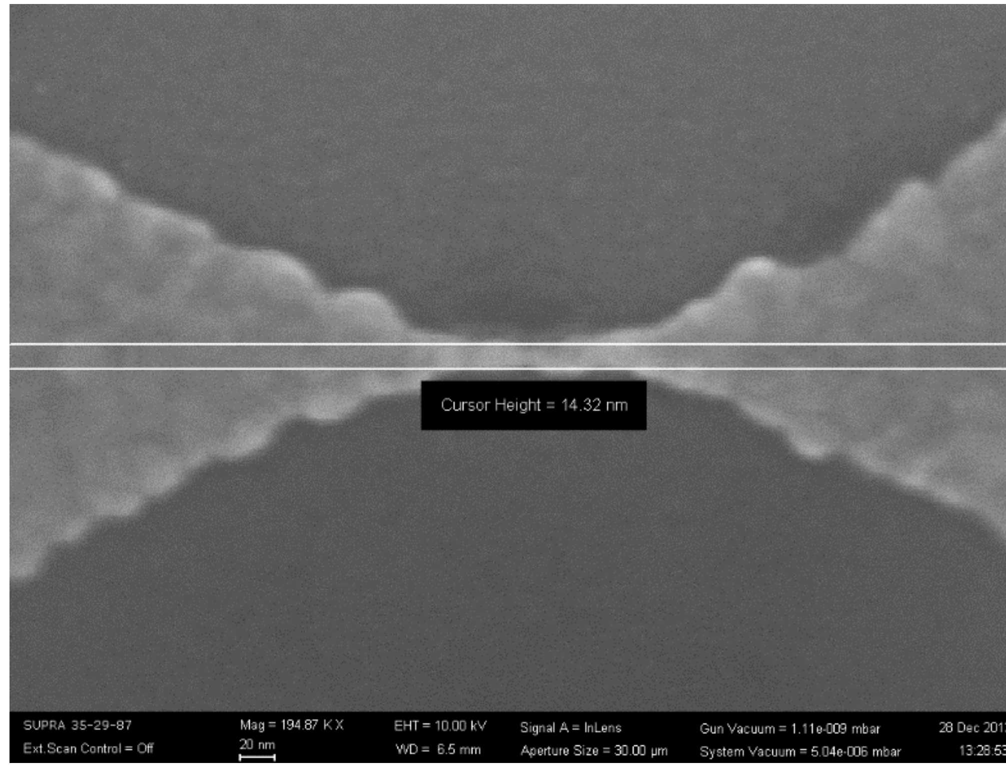

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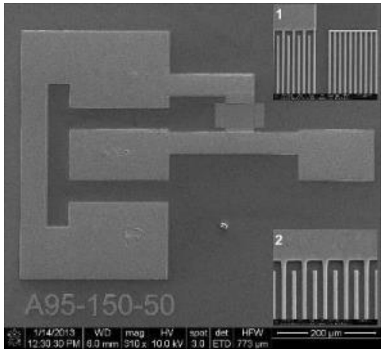
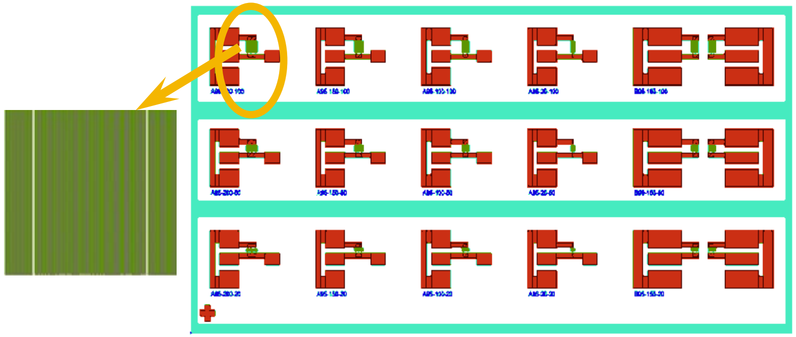
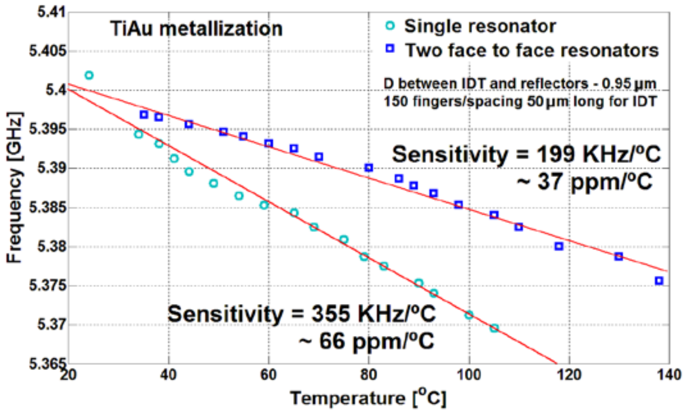
Temperature sensors based on SAW devices

- ❑SAW resonators fabricated, based on new mask design in order to minimize the return loss at resonance and maximize Q
- ❑Both one-port and diport connection pads are provided
- ❑SAW structures having the IDT with 200 nm wide finger and interdigit spacing;
- ❑Finger heights: 100 μm; 50 μm; 20 μm;
- ❑200 fingers; 150 fingers; 100 fingers; 20 fingers and 50 reflectors;
- ❑Distance between IDT and reflectors: 0.95 μm







The temperature dependence of the resonance frequency obtained for the SAW single and face to face resonators (RUN 3 "on wafer" hot plate measurements)

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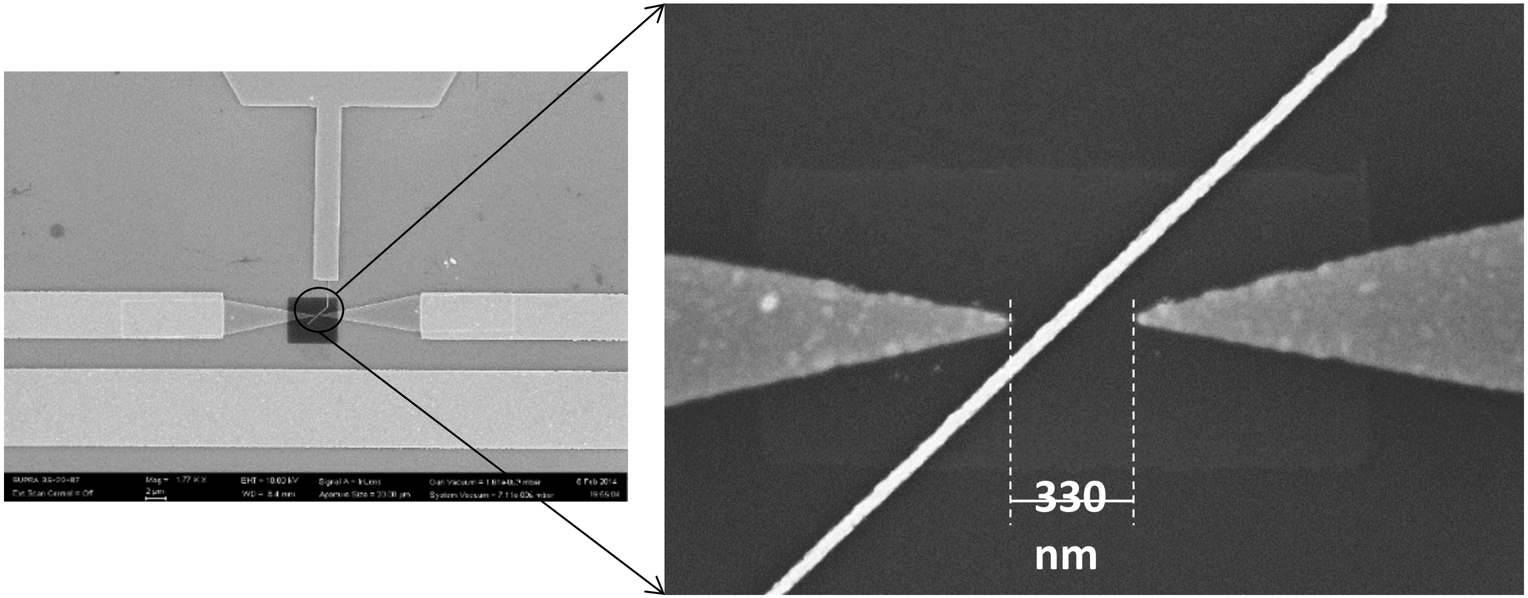
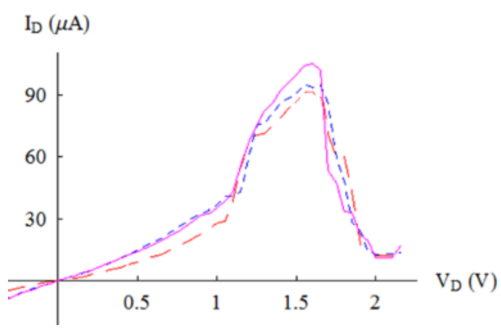
Ballistic FET on graphene featuring strong NDR





NDR behavior of the graphene FET with oblique gate at VTG = 0.5 V (dashed red line), 1 V (dotted blue line), and 1.5 V (solid red line).

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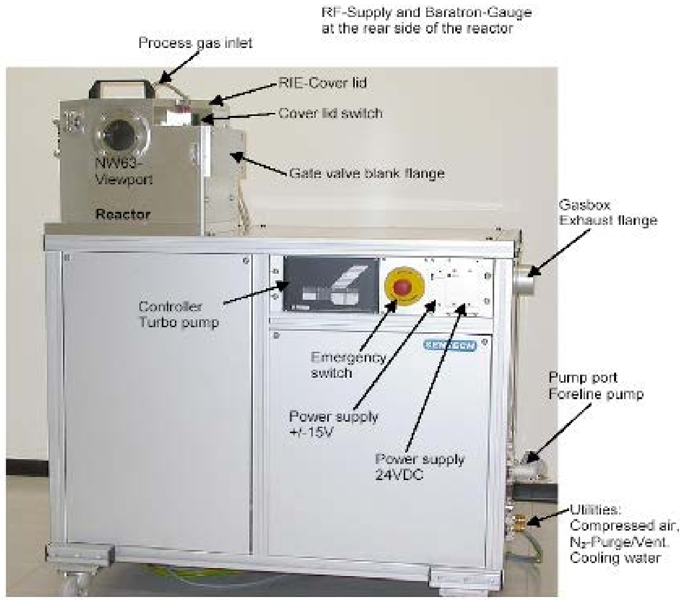
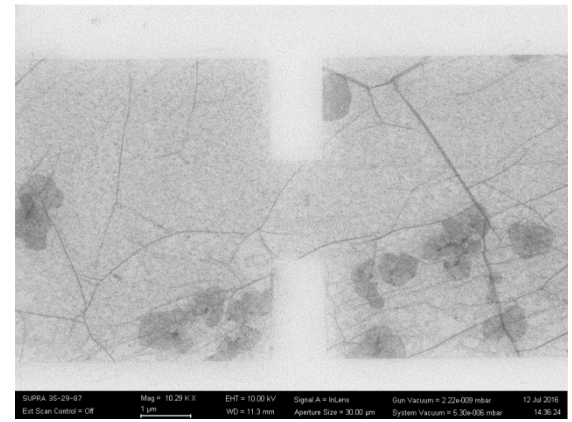
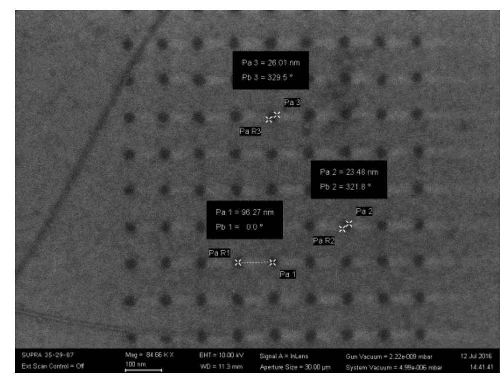
Reactive Ion Etching (RIE) Plasma Etcher- Etchlab 200







Applications:

- the etching of dielectrics (SiO_2, Si_3N_4),

- semiconductors (Si),

- polymers and metals (Au, Pt, Ti, Ni).

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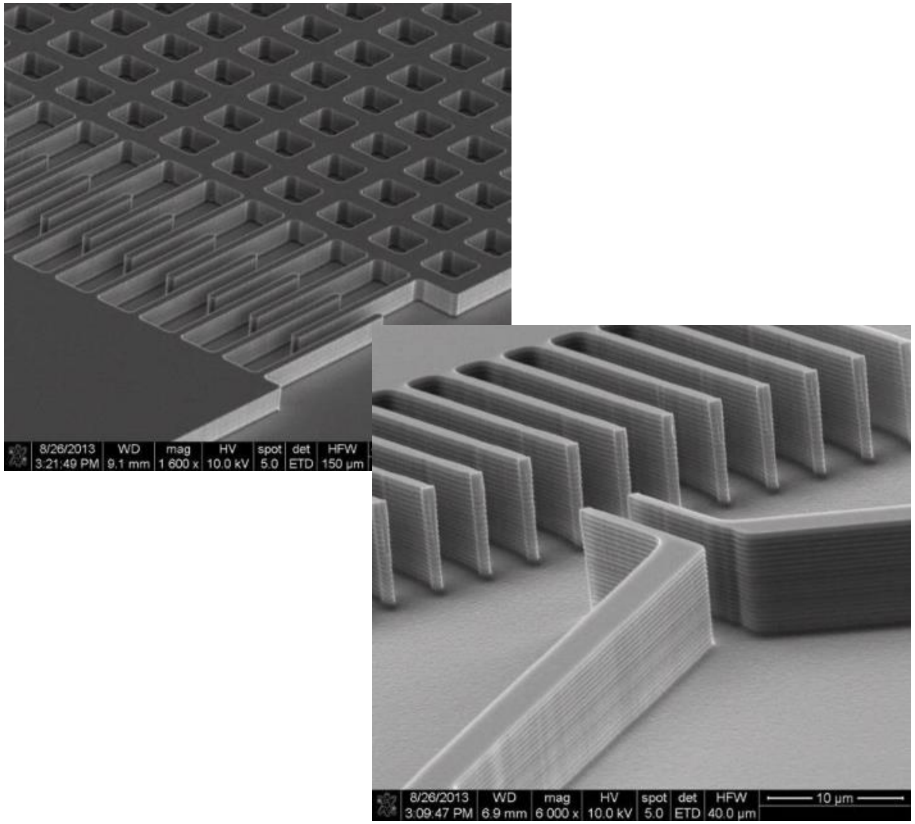
ICP-RIE – PlasmaPro 100 (Oxford Instruments, UK)



Anisotropic etching of Si with perfectly vertical walls

Applications:

Etching:

- **Bosch process for silicon**
- **Cryogenic process for silicon**
- **Bosch Process for SiC**

Single wafer processing.

Can process 4” or smaller wafers, even small pieces.

Process gases: SF_6, C_4F_8, O_2, Ar.

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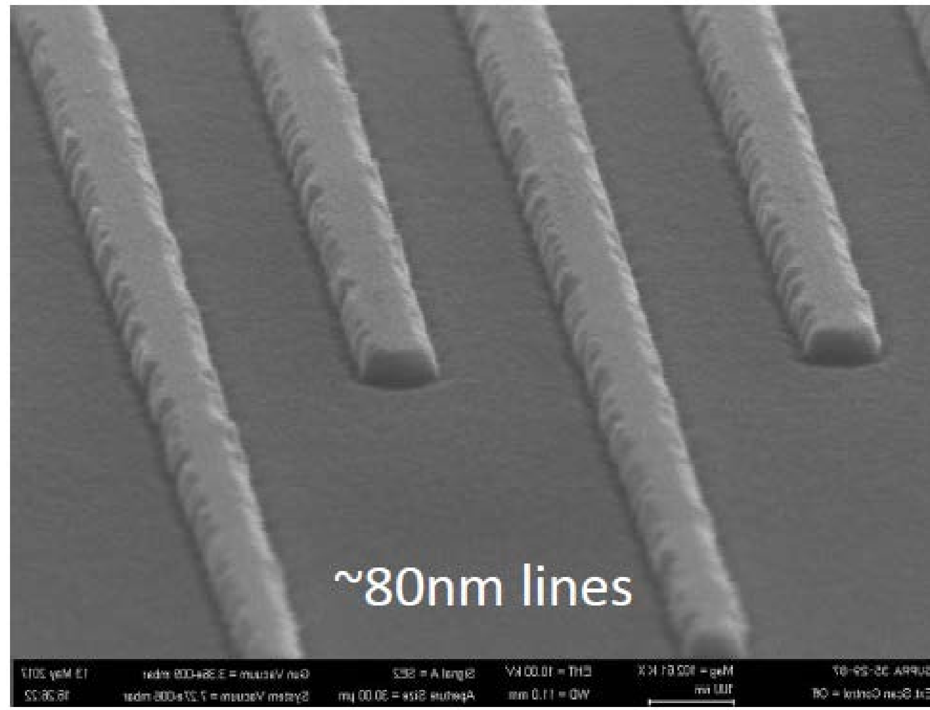
Ion Beam Milling



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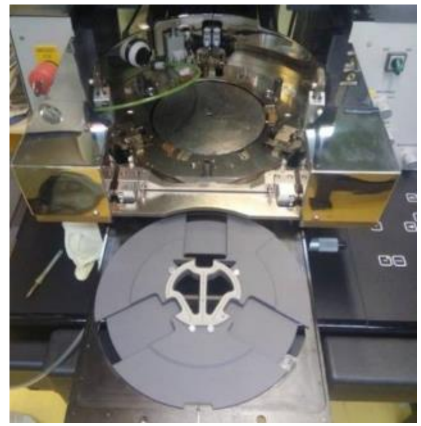
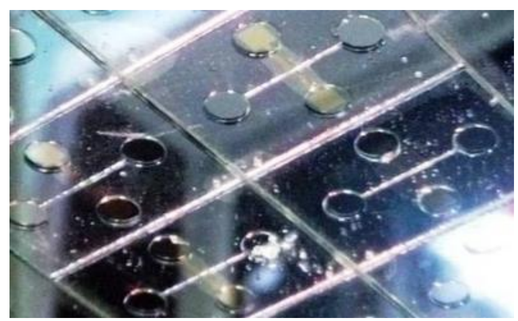
Wafer Bonder System- SB6L- Wafer - Substrate Bonder System (Suss MicroTec)

Equipment is used to provides a semi-automated platform for multiple bonding processes that handles wafers up to 100 mm and supports various substrate types and sizes.
The SB6L is suitable for packaging as well structuring meeting the requirements for MEMS, LED, advanced packaging, 2,5D integration and 3D integration.

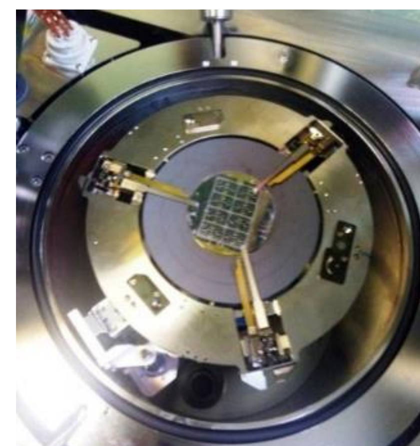
GENERAL CHARACTERISTICS:
- Lower hot bond chuck with temperature control from ambient to 500^{0}C
- Negative High Voltage DC power supply for Anodic bonding (up to -2000V)
- Flexible process: can accommodate polymer and adhesive bonding of different substrates
Bonding processes:
- Silicon to glass
- Pressure/heat assisted polymer bonding
- Adhesive/pressure/heat assisted bonding
PERFORMANCE:
- temperature repeatability ± 3^{0}C
- temperature uniformity ± 1.5%
- up to 8kN applied bond force
- process vacuum pressure down to 5*10-4 mbar



Alignment substrates on MA6



Microfluidics device encapsulated with borosilicate glass



Alignment substrates on SB6L

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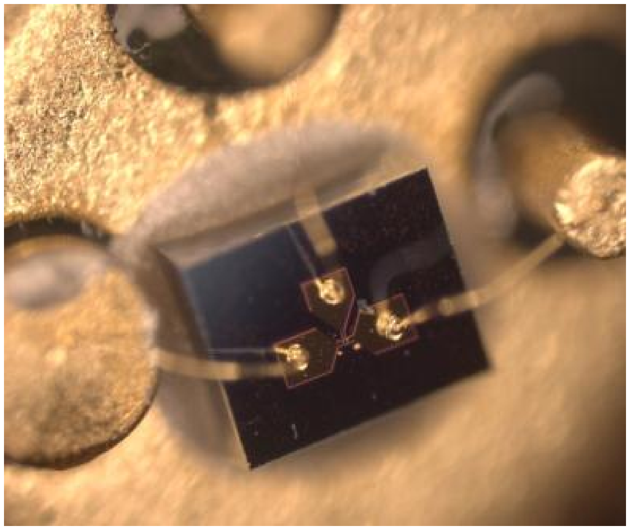
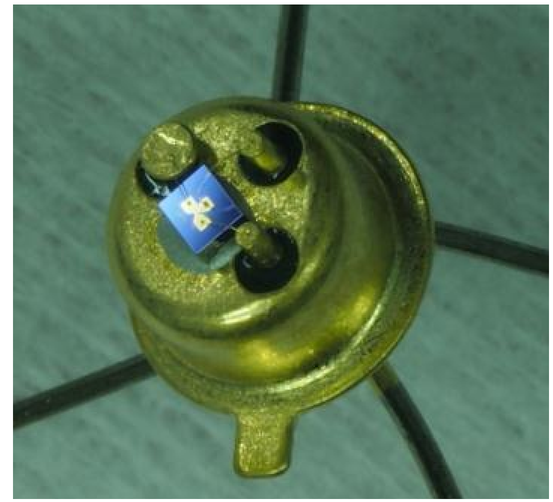
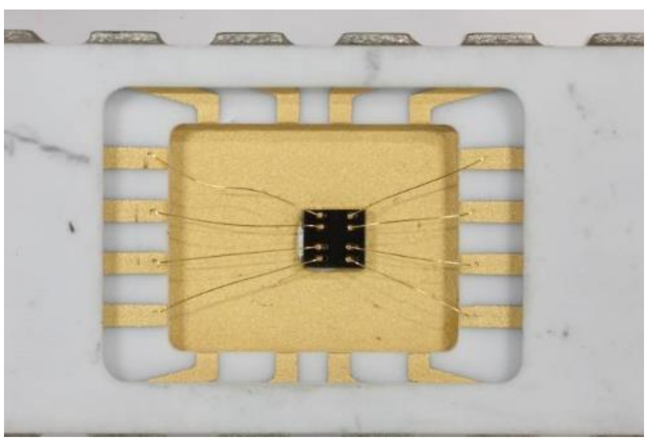
Wire Bonding







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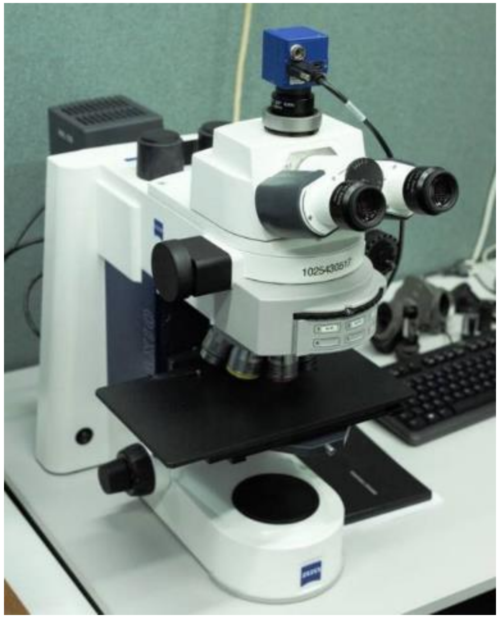
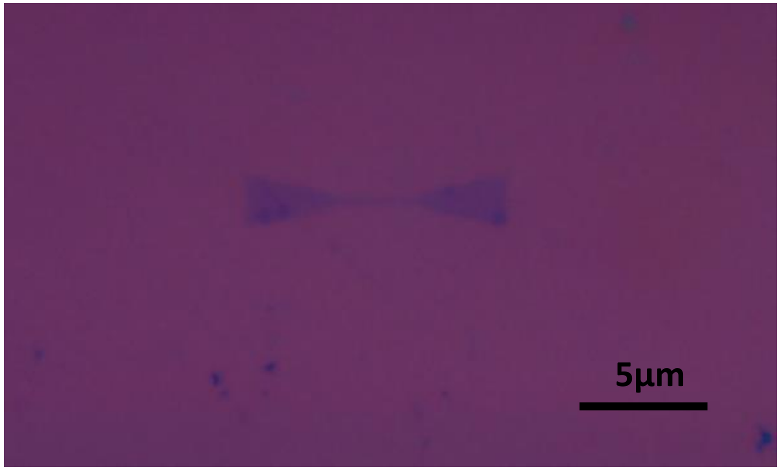
Optical Microscopy :

- **Leica, Zeiss, Olympus**
- **Reflected and transmitted light**
- **BF, DF, PL, Fluorescence**
- **Better than 0.5µm resolution**





Optical micrograph of the channel of a graphene based FET, featuring 0.5µm width

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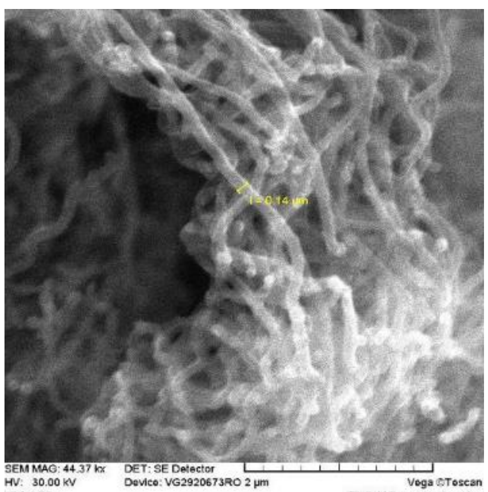
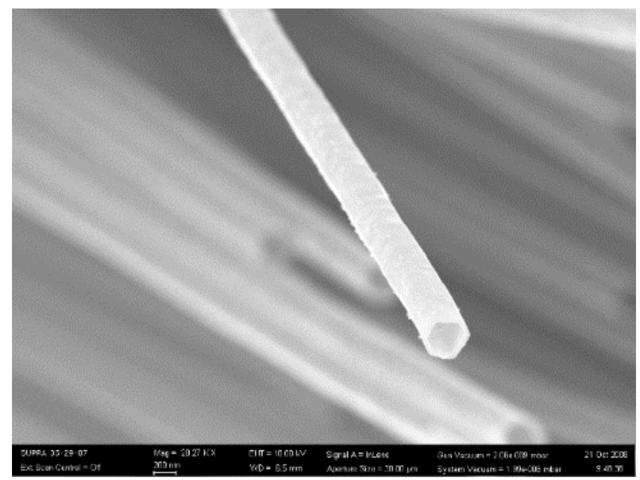
Scanning Electron Microscopy

Tescan Vega LMU II - SEM

FEI Nova NanoSEM630 - FEG-SEM





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➢ Scanning Probe Microscopy

Encompasses several related techniques for high resolution imaging and measuring of surface properties

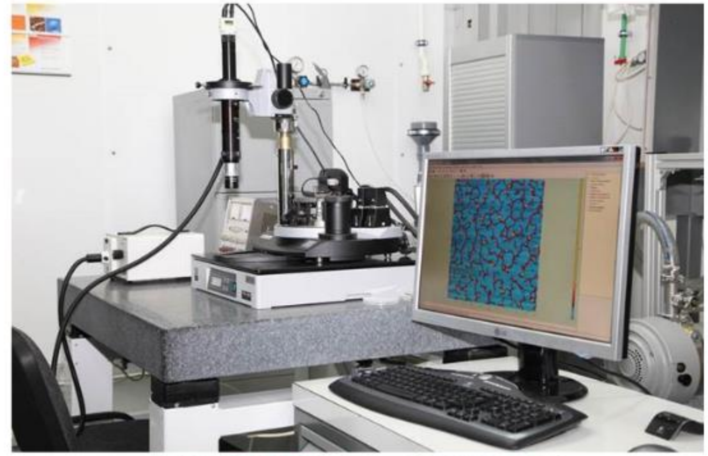
Main applications: High resolution 3D surface metrology

Application examples:

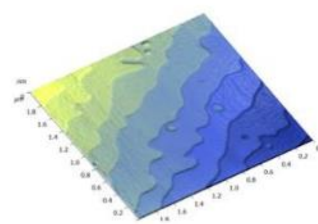
- High-resolution surface profilometry - from from surface roughness to nanometer-sized features
- Evaluation and optimization of thin films and coatings (optical, packaging, paintings, wear-resistant etc)
- Grain and particle size analysis
- Surface treatments, cleaning and polishing studies (optical surfaces roughness, electro-polished metal surface evaluation, plasma treatments)
- Microstructural studies (Pharmaceutical, Polymers)
- Morphological studies of biological and biocompatible materials

Key advantages:

- *any kind of sample, no matter the conductivity* (metallic, ceramic, polymeric, semiconducting)
- *no sample preparation required*
- *various measurement environments* (ambient, controlled gaseous, liquid, low vacuum)

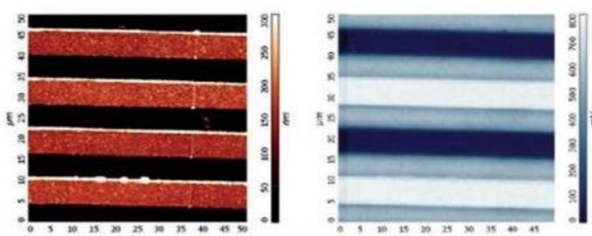


SPM *NTEGRA Aura (NT-MDT Co)*

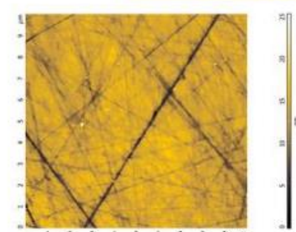


3D rendered AFM image of $NdGaO_3$ (001) single crystal, revealing 0.4 nm height individual atomic terraces

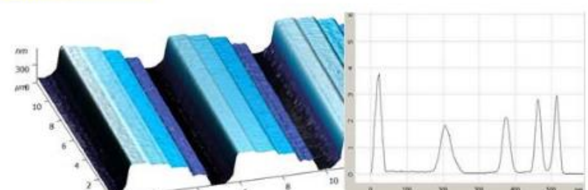
PTB certified 8 nm height calibration structure



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



Mechanical polishing marks on a Ge crystal surface. Scan area: 10 μm x 10 μm



Multi-level stripes obtained by grey tone Electron Beam Lithography in PMMA
left: AFM image of the topography; right: Height histogram for electron dose calibration

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➢ Nanomechanical Characterization

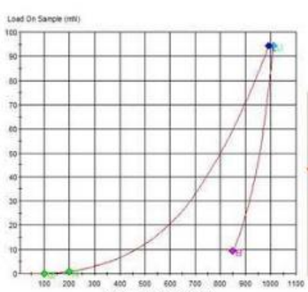
G200 is a nanomechanical characterization equipment operating by ***instrumented indentation*** and ***scratch testing***.
It provides access to various mechanical properties of *small-volume samples*, such as *thin films*, but could be equally applied to investigate bulk samples.

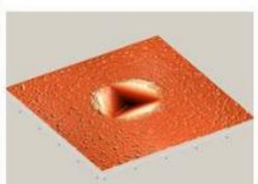
Applications:

High resolution mechanical characterization of various materials (metals, semiconductors, ceramics, biocompatible materials) especially in the form of thin films, coatings and generally small volumes of material.

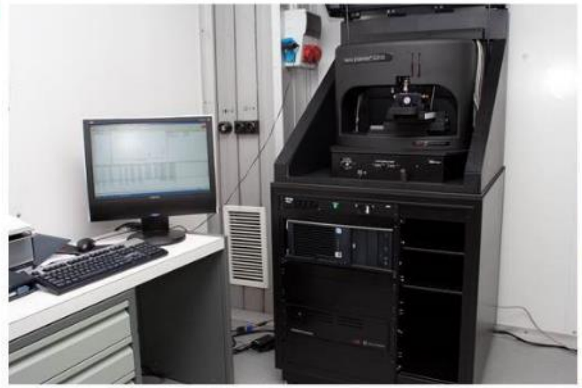
Properties which could be characterized:

- Hardness
- Elastic modulus
- Film adherence (nano-scratch critical loads)
- Wear behaviour
- Stress-strain data.



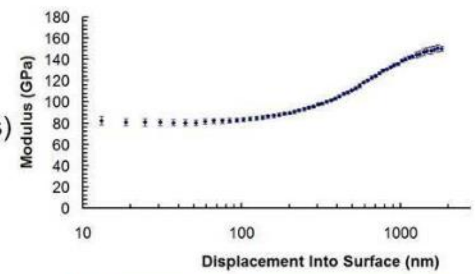


Load vs. displacement curve and image of the indentation site on an Al thin film, showing pile-up behaviour



maximum load : 500 mN
load noise floor : 100 nN
displacement noise floor: 1 nm
position accuracy: 1 µm

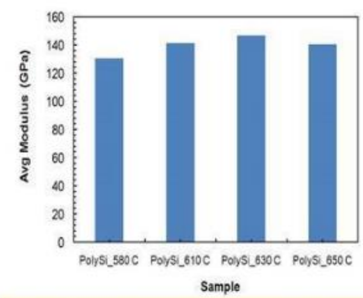
Nano Indenter G200 - Nanomechanical Characterization Equipment *(Agilent Technologies)*



Depth profiling of Young's modulus for a thin SiO2 film grown on Si

*The patented **continuous stiffness technique (CSM)** yields the elastic modulus and hardness values as a function of depth in a single measurement (especially useful for the case of **thin films**) and allows characterization of the time dependent mechanical behavior of samples (e.g. **polymers**).*

Methods are provided for measuring Young's modulus and hardness in compliance with ISO 14577 and ASTM 2546 standards.



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

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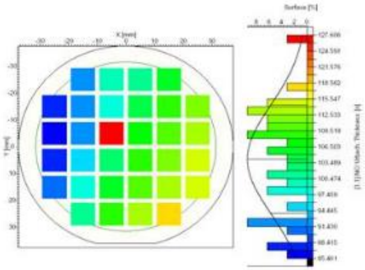
Spectroscopic Ellipsometry

Characterization of single and multi-layers (oxides (SiO_2, TiO_2), (nitrides Si_3N_4, AlN), doped polymers, AlQ_3, polymers (pmma, SU8, LOR)), wide bandgap semiconductors (NiO, ZnO) regading index of refraction (n,k) and thickness (d).

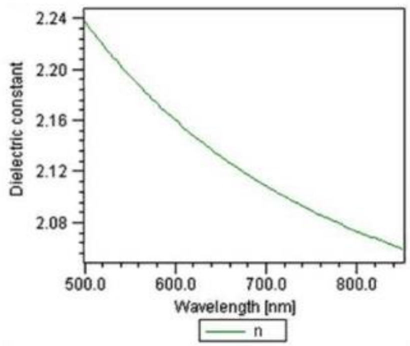
Model ▶

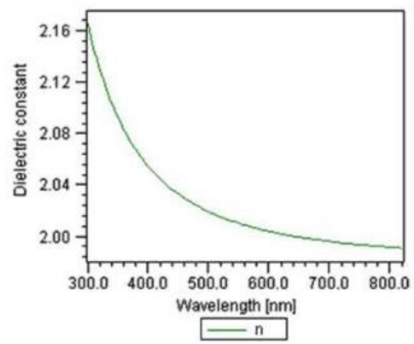
	Air	n=1.0000	NK Layer
103.72 nm	NiO Urbach	n=2.0595 k=0.0305	formula layer
	Silicon (111) (Jellison)	n=3.6544 k=0.0059	File Layer

NiO thickness distribution ▶



◀ NiO refractive index

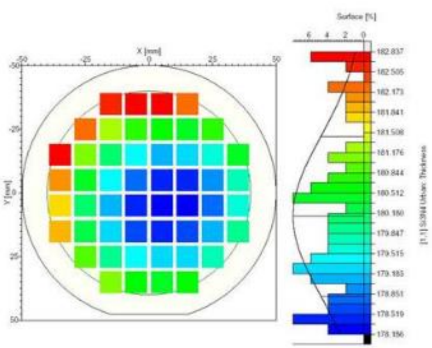




◀ Si_3N_4 refractive index

◀Model

	Air	n=1.0000	NK Layer
180.53 nm	Si3N4 Urban	n=2.0008	formula layer
51.81 nm	Cau-SiO2	n=1.4710	Cauchy Layer
	Silicon (100) (Jellison)	n=3.8717 k=0.0158	File Layer



◀ Si_3N_4 thickness distribution Deposited by LPCVD at IMT

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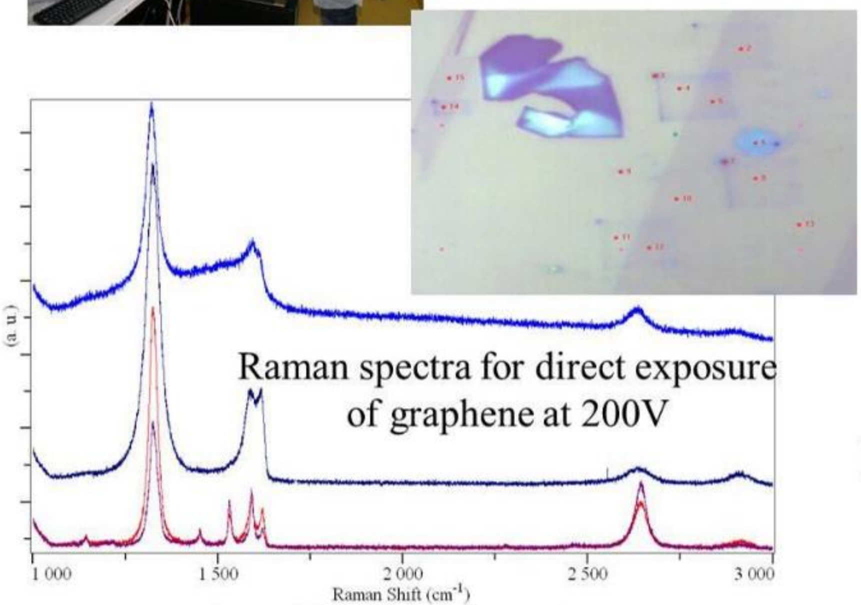
Micro-Raman Spectroscopy

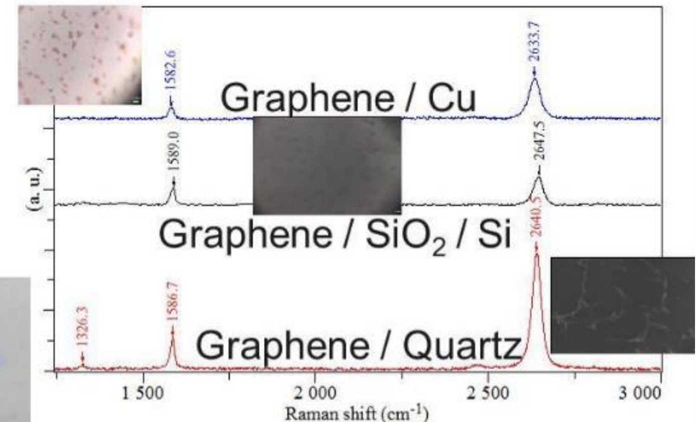
- **Raman spectrometer LabRAM HR800**

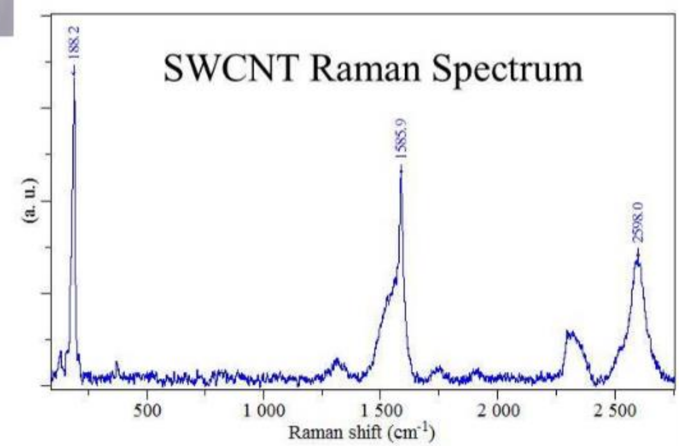


Raman spectra for direct exposure of graphene at 200V

Structural modification of graphene after electron beam irradiation

Investigating SLG graphene transfer by electrical delamination





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FTIR spectrometry

Applications:

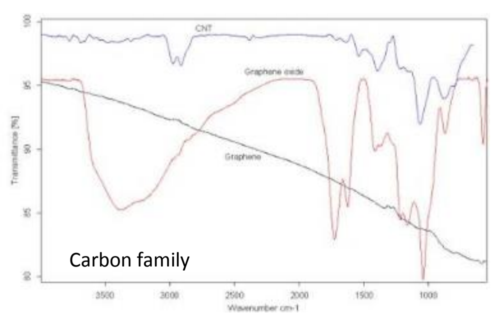
The FTIR spectrometry can be use for study of chemical process and a chemical structure of the compounds liquid and solide.

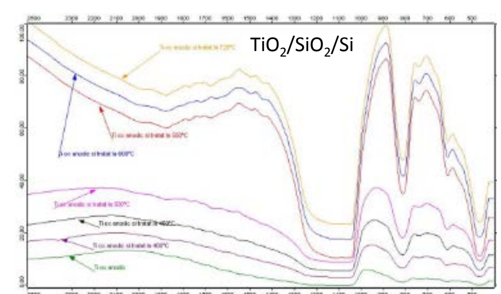
Technical details:

Tensor 27: 4000-400 cm^{-1} (MIR)
Vertex 80/80v: FT-IR spectometer (25.000-50 cm^{-1} (FIR, MIR and NIR-Vis-UV), under vaccum condition) with FT-Raman (RAMII) (4000-50 cm^{-1}) module.
Accessories: transmission units, ATR mono and 25 reflection –ZnSe crystal, ATR multiple reflection (25) at 3 angle reflection (30°, 45° and 60°) – KRS 5 crystal, liquid cell for transmission and ATR multiple unites (windows: KRS, ZnSe, quartz), specular reflection unit at 11° fixed angle, holdere for polarizers (360° rotation) for transmission and specular reflection units, Grazing angle specular reflectance, manual hydraulic press

Some practical application:

a. **Raw materials: liquid or solide.**
b. **Carbon family study: CNT, Graphene**
c. **Film deposition: i.e: TiO_2, InP, Si_3N_4, thiols on silicon substrates**
d. **Silicon process**
e. **Sol-gel, co(precipitation), solide-state process: i.e ZnO, TiO_2, YAG:Ce,Gd**
f. **Nanocomposite study: CNT-PDMS, YAG:Ce,Gd-PMMA, ZnO-OA**
g. **Nanomedical applications – influence of nanoparticle on tumour cells, porous silicon as a biomaterial, dacarbazine (drug for cancer)**
h. **Quantum dot functionalized – Carbon-QD with BSA/HSA, ZnO-QD with SiO_2**





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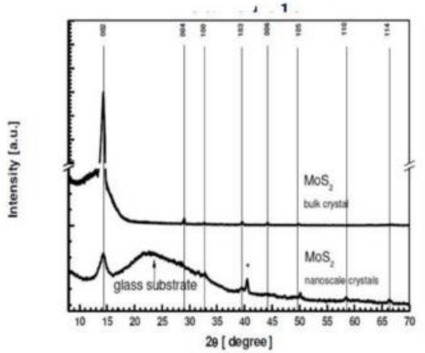
Ultra high resolution triple axis multiple reflection *SmartLab X-ray Thin film Difraction System* (Rigaku Corporation, Japan)

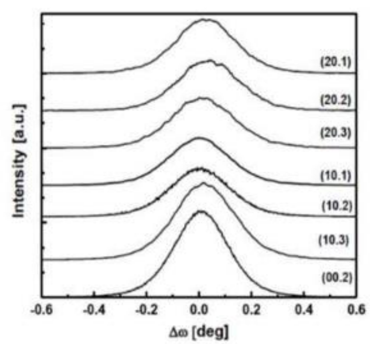
Advanced X-ray diffraction methods (last results):

Diffraction patterns of MoS_2 bulk crystal and MoS_2 nanoscale

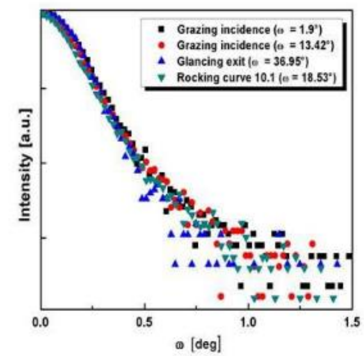


Interlayer distance in the MoS_2 nanoscale crystals higher ($\Delta c/c_o$= + 2.82%) than that in 2H-MoS_2 (6.15 Å).

Determination of the threading dislocations in GaN epitaxial layers

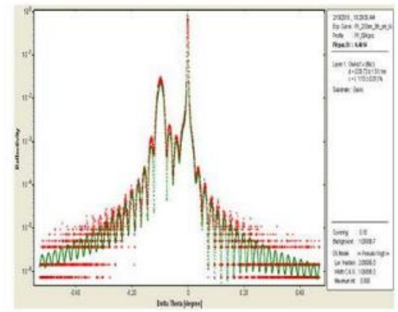


Double-axis rocking curves in symmetric and skew geometry
(ω scan with open detector)



X-ray measurements using both grazing incidence and grazing exit configurations of the asymmetric skew geometry.

GaAsN/InGaAsN/GaAs quantum well for solar cells



X-ray reflectivity analysis - calculation of thin layer thickness

Biosensors and Bioelectronics 75 (2016) 232–237

Cosmin Romanitan, Raluca Gavrila, Mihai Danila, *Comparative study of threading dislocations in GaN epitaxial layers by nondestructive methods*, **Materials Science in Semiconductor Processing** 57 (2017) 32–38

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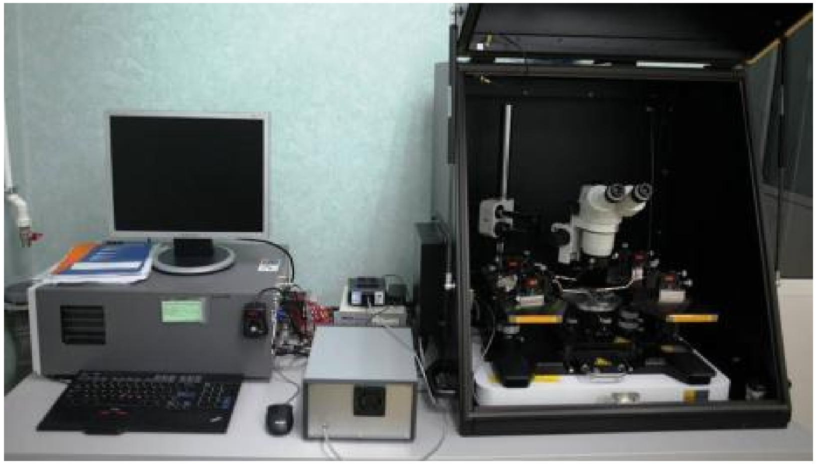
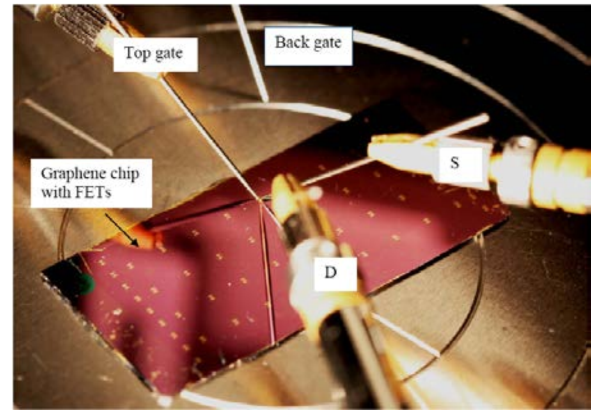
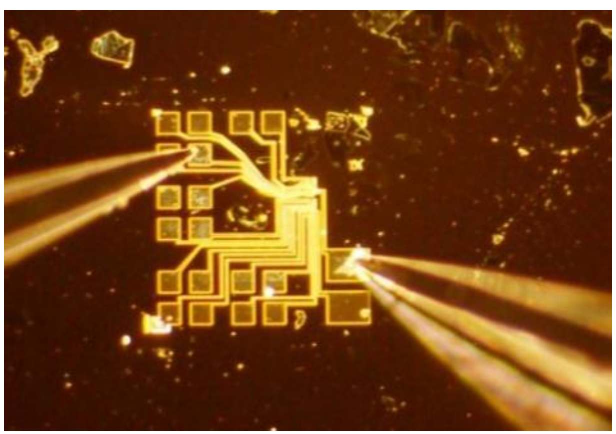
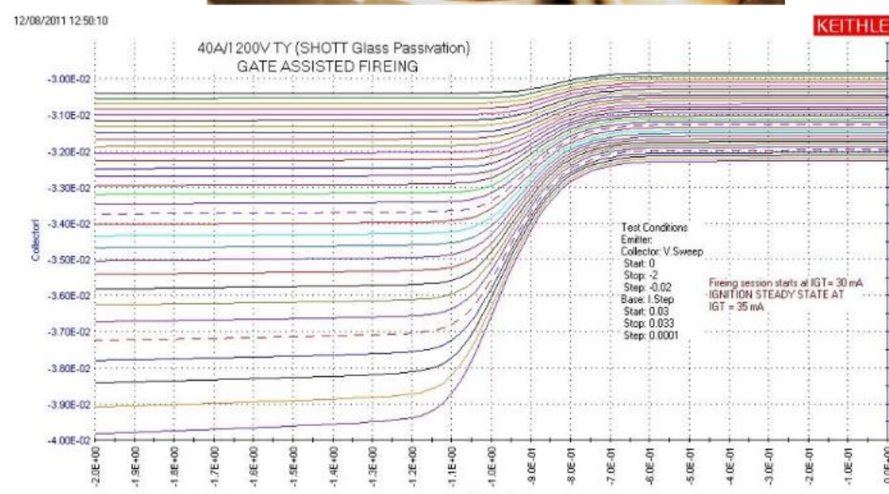
Electrical Measurements – DC and Low Frequencies





Semiconductor Characterization System - 4200-SCS/C/Keithley with Wafer Probing Station –Easyprobe EP6/ Suss MicroTec





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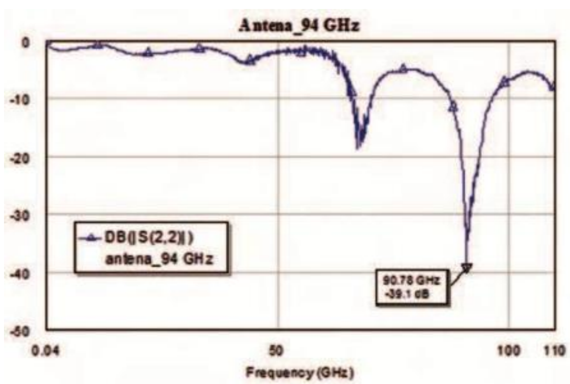
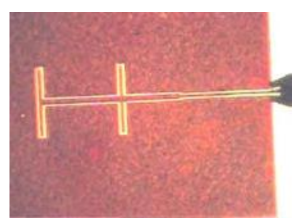
Electrical Measurements – High Frequencies

The VNA is the main equipment of MICROLAB. MICROLAB is a laboratory dedicated to on-wafer characterization of devices and circuits in the frequency range 0.5 GHz -65 GHz. This frequency range encompasses the entire area of the devices and circuits used in the most advanced communications systems such as WLAN, GPS, mobile phones, radar.

Vector Network analyzer
Anritsu, 37397D





S22 parameter for the 94 GHz antenna suspended on a micromachined $SiO_2/Si_3N_4/SiO_2$ membrane

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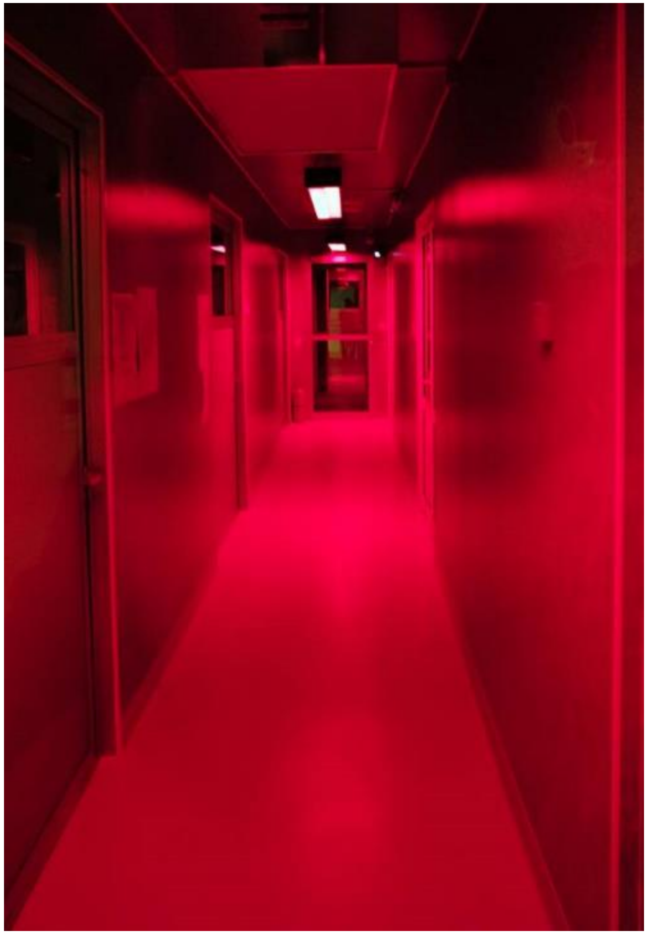

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