iemn

Institute of Electronics, Microelectronics and Nanotechnology

UMR CNRS 8520

Institute of Electronics, Microelectronics and Nanotechnology

April 2023 edition

EDITO

IEMN stands for Institute of Electronics, Microelectronics and Nanotechnology. The laboratory, located in the Hauts-de-France region, was created in 1992 to gather, in a unique research structure, disciplines contributing to the progress of electronics, physics, acoustics and their applications. Hence, such an organization was likely to facilitate interdisciplinary research on a wide spectrum of activities ranging from theoretical physics to telecommunication.

Thirty years later after its creation, with the institutional and financial support of five institutions (Lille University, CNRS, JUNIA/ISEN, Centrale Lille Institute and Polytechnic University Hauts-de-France), IEMN has become a major research centre in Micro and Nanotechnology in France, gathering 450 people, including 170 permanent (teacher)-researchers, 90 engineers and technicians, and 140 PhD students.

Today, the core of the institute's activities is centered on micro and nanotechnologies and their applications in the fields of ultra-high data rate communications, technologies for health, energy, transport, internet of things (IoT) and neuromorphic hardware technologies. In order to work on these topics, IEMN researchers have at their disposal exceptional experimental and technical facilities. A large part of the IEMN's research activities are carried out on two platforms, first, the Micro Nanofabrication platform (CMNF) dedicated to the technological fabrication of the next generation of micro-nano-electronic devices and, second, the Multiphysics Characterization platform (PCMP) dedicated to the characterization of materials, devices and systems. As a member of the RENATECH+ network, IEMN has cutting-edge equipment at the highest European level operated by a highly qualified technical staff within the CMNF and PCMP platforms. This facility has been recently supported by the NANOFUTUR Equipex+ program. IEMN is also a member of the GANEXT and STOREX Labex programs, and is a partner of the RS2E network and Graphene European flagships.

IEMN is organized into five scientific departments gathering the 23 research groups of the lab. Since 2020, the governance of the laboratory is assured by a director (Thierry Mélin, CNRS) and two deputy directors (Christophe Delerue, CNRS, and Christophe Lethien, Lille University) assisted by the administration and three councils (namely the Laboratory Council, the Scientific Council and the Technology Council.)

IEMN has numerous national and international collaborations with academic and industrial partners. Middle term joint programs have been established with industrial partners (common laboratories with STMicroelectronics, HCS Pharma and Horiba, Industrial Chair with MC2 Technologies, common IEMN/LEOST cluster). Since 2015, seven start-ups have been created with the support of IEMN by researchers who aim at transferring technological skills capitalized in the framework of research projects to the society in order to improve the daily life by addressing societal challenges.

IEMN is located in several places in Villeneuve d'Ascq, Lille and Valenciennes. The so-called central laboratory in Villeneuve d'Ascq is the largest building gathering the main technological facilities and the institute administration. The other units located on campuses in Lille and Valenciennes are also devoted to research and host numerous equipments allowing a link between the education and research.

Thierry MÉLIN
Director

Christophe DELERUE
Scientific Director

Christophe LETHIEN
Director of Technology

The laboratory

Facilities

Micro and NanoFabrication Center (CMNF)

- Deposition and epitaxy unit
- Lithography unit
- Etching unit
- Characterisation unit
- Bio/microfluidic unit
- Integration & Prototyping unit

Multi-Physics Characterization Platform (PCMP)

- PCP Scanning Probe Microscopes
- CHOP Optical and photonic microwave characterization
- SIGMACOM Communication Systems
- C2EM ElectroMagnetic Characterization and Compatibility

Scientific collaborations

The laboratory

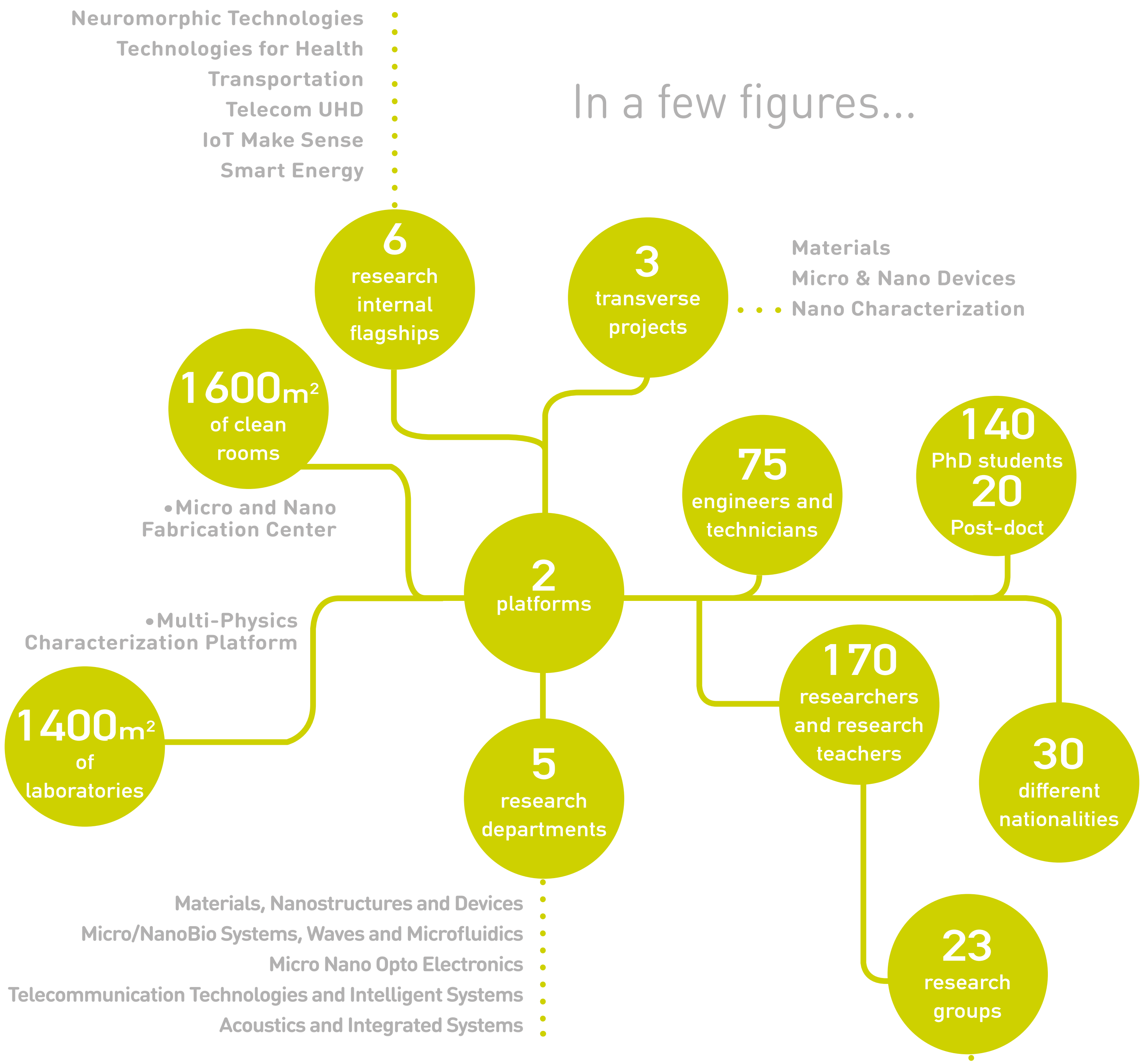
The Institute for Electronics, Microelectronics and Nanotechnology has been created in 1992 with the support of three regional partners: The University of Lille (ULille); the University of Valenciennes and Hainaut Cambrésis (UVHC); YNCRÉA ISEN and CNRS (National Center for Scientific Research), a government-funded research organization, under the administrative authority of France's Ministry of Research and Higher Education. The main objective was to gather, in a unique research structure, disciplines contributing to the progress of electronics, acoustics and their applications. Hence, such an organization was likely to facilitate interdisciplinary research on a wide spectrum of activities ranging from theoretical physics to telecommunication. Twenty-five years later, IEMN has increased in scope, doubled its staff, its budget is four times higher than at the beginning and we can claim that original objectives are fulfilled.

Today, nearly 450 people work together in a scientific field ranging from information and communication technologies to micro and nano technologies. The scientific policy of the laboratory is determined within research groups and five research departments promote emerging activities. Middle term joint programs with industrial partners or other national institutions and long-term research initiatives stimulate the resourcing of our research projects. Thanks to the constant financial support of the Hauts de France Regional Council combined with those of our trustees, IEMN features exceptional technical facilities. As a member of the Basic Technological Research Network (BTR RENATECH) with four other CNRS laboratories involved in micro and nano fabrication, IEMN offers to the scientific community a technical platform ranking among the best in Europe. IEMN is strongly involved in IRCICA, the Institute for Advanced Communication, where IEMN research groups work together with researchers from software and physics background.

In 2015, IEMN has been asked to work with the Laboratoire d'Electrotechnique et d'Electronique de Puissance (L2EP) on a project of integration. After a few meetings at the board of direction scale and an introduction made by L2EP to IEMN, a task force has been settled in order to identify existing common studies. Scientific committees of both laboratories have been committed to establish a joint scientific project. The outcome was presented and it has been decided to pursue the process during the next period. A joint text has been written and it presented in the project section of this report.

IEMN is located in several buildings in Villeneuve d'Ascq, Lille and Valenciennes. The so-called central laboratory is the largest building and it regroups all the main technological facilities and the institute administration. The other units located on the ULille, UVHC campus and in Lille YNCRÉA ISEN building are also devoted to research and host various equipments allowing us to make a link between the education at master and engineer levels and research.

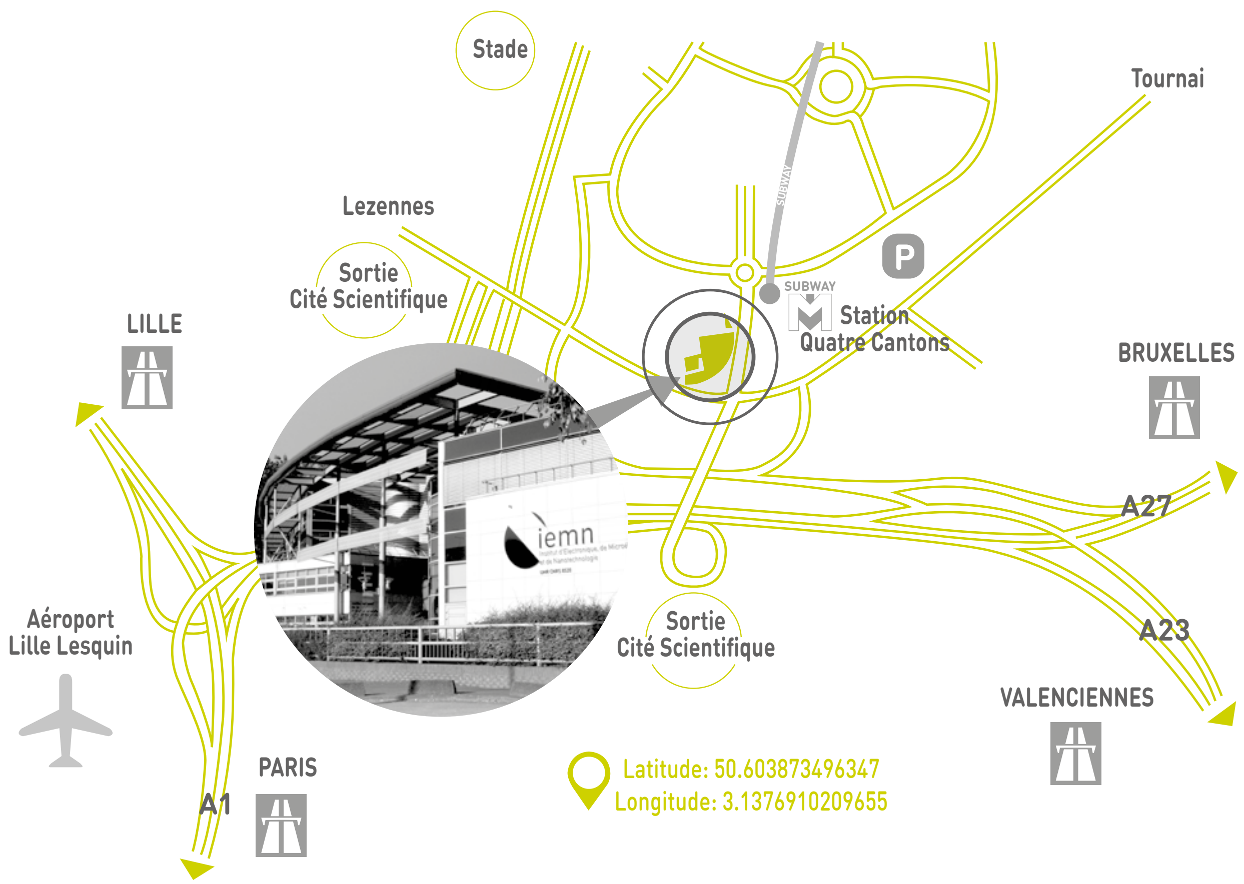
In a few figures...



- EPIPHY: EPItaxy and PHYsics of heterostructures
- NCM: Nanostructures, nanoComponents & Molecules
- PHYSICS: Nano materials physical properties
- SILPHYDE : PHYsical SImuLation of Electronic and optoelectronic Devices
- SUBLAMBDA: Opto and Micro Electronic Devices
- THZ PHOTONICS
- PUISSANCE: Microwave Power Devices
- ANODE: Advanced NanOmeter Devices
- CARBON: Graphene based devices
- OPTO: Optoelectronics
- MITEC: Microtechnology and Instrumentation for Thermal and Electromagnetic Characterization
- ACOUSTICS
- TPIA: Transduction, Propagation and Acoustic Imaging
- MAMINA: Materials and Acoustics for MIcro and NAno integrated systems
- BIOMEMS
- AIMAN-FILMS: Magneto-Nano-Electronics - Active structures, MEMS and flexible structures Ultrasonic thermography - Micro-Fluidics
- NANOBIOINTERFACES
- NAM6: The Micro and Nano Systems
- COMNUM: Digital Communications
- CSAM: Circuits systems and Application of Microwaves
- TELICE: Telecommunication, Interference and Electromagnetic Compatibility
- MICROELEC SI
- WIND group: Wide Bandgap Semiconductor devices

IEMN

Cité Scientifique
Avenue Henri Poincaré - CS 60069
59652 Villeneuve d'Ascq Cedex, France
Tel +33 (0)3 20 19 79 79



By train

- From the "Lille Flandres" SNCF station

Take the metro line 1 → direction 4 Cantons and get off at the station " 4 Cantons ".

- From the "Lille Europe" SNCF station

Take the metro line 2 → direction St Philibert, change at Lille Flandres station.
Then take line 1 → direction 4 Cantons and get off at "4 Cantons" station.

- At the exit of the "4 Cantons" metro station → turn left and walk up Avenue Poincaré for about 150m. You are now at the IEMN.

By plane

Lille-Lesquin airport is linked to the centre of Lille by shuttle bus (indicative journey time: 20 minutes).

- The shuttle bus stop in the airport is located in front of the arrivals hall.
- In Lille, it is located in rue Corbusier, Centre Eurallile.

By car

- Coming from Lille, Paris, Valenciennes or Brussels → take the direction Gent and exit at Cité Scientifique. You are on the Lille1 campus.
- Coming from Gand → take the direction of Paris and exit at Cité Scientifique.

The Laboratory Council
(chaired by the Director)

The laboratory council is consulted on all the major orientations concerning the scientific life, the functioning, the administration, the management of human resources and the internal regulation of the laboratory.

Director
Thierry MÉLIN

The Technology Council
(chaired by the Deputy Director, Head of the Technology)
17 members

It has an advisory role and gives its opinion on the investments to be made, the technological orientations, the functioning and the animation of the platforms in general. Its mission is to define the future technological orientations of the laboratory which will condition the investment policy of the laboratory.

Deputy Director
Technological Direction
Christophe LETHIEN

The Scientific Council
(chaired by the Deputy Scientific Director)
16 members

It is consulted on any question related to the scientific policy of the laboratory. It suggests actions of scientific animation, ensures an active scientific and technological watch, proposes strategic scientific orientations, and contributes to the scientific communication of the laboratory.

Deputy Director
Scientific Direction
Christophe DELERUE

Nanostructures and Components Department
Stéphane LENFANT

Head of Central Micro and Nano - Fabrication Center (CMNF)
Bertrand GRIMBERT

Micro/nano/biosystems, waves and microfluidics department
Vincent THOMY

Management Administrative and Financial
Frédéric LEFEBVRE

Coordinator Multi - Physics Characterization Platform (PCMP)
Sylvie GODEY

Micro, Nano and Optoelectronics Department
Jean-Pierre VILCOT

Director of Education Relations
Sylvain BOLLAERT

Telecommunications technologies and intelligent systems
Virginie DÉGARDIN

Acoustics and integrated systems
Frédéric JENOT

Facilities

CMNF
Micro and NanoFabrication Center

Integration & Prototyping unit

PCMP
Multi-Physics Characterization Platform

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IEMN stands for Institute of Electronics, Microelectronics and Nanotechnology, a laboratory created in 1992 by five institutions: Lille University, Polytechnic University hauts-de-france, JUNIA/ISEN, Ecole Centrale Lille and CNRS. IEMN's research is performed based on a strong connection between its technical (Micro Nanofabrication and Multi Physics PlatForm PCMP) where cutting-edge equipments are operated by a highly qualified technical staff.

The scientific policy of the Institute is declined in five research Departments:

- Materials and nanostructures
- Micro and nanosystems
- Micro, nano and optoelectronics
- Circuits and communication systems
- Acoustics

At the forefront of education and technological research, and owing to numerous dynamic international collaborations, IEMN hosts PhD and graduate students coming from 30 different countries. Nearly 500 people work in IEMN fields of research, mainly Information Communication Technology and Nanotechnology. IEMN's devices can be found in Electronics, Energy, Biotechnologies, Sensors and Instrumentation applications. Moreover, as evidenced by numerous patents plus spin-off's creations, IEMN demonstrates its efficiency in promoting and facilitating technology transfer of innovations emanating from its research groups.

5 RESEARCH DEPARTMENTS AND 23 RESEARCH GROUPS

Materials, Nanostructures and Components

- EPIPHY: EPItaxy and PHYsics of heterostructures
- NCM: Nanostructures, nanoComponents & Molecules
- PHYSICS: Nano materials physical properties
- SUBLAMBDA: Metamaterials and metasurfaces for wave control

Micro, Nano and Optoelectronics

- THZ Photonics
- PUISSANCE: Microwave Power Devices
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- CARBON: Graphene based devices
- OPTOelectronics
- MITEC: Microtechnology and Instrumentation for Thermal and Electromagnetic Characterization
- WIND: Wide Bandgap Semiconductor devices

Micro / Nano / Bio-Systems, Waves and Microfluidics

- BioMEMS
- AIMAN-FILMS: Magneto-Nano-Electronics - Active structures, MEMS and flexible structures Ultrasonic thermography - Micro-Fluidics
- SILPHYDE : PHYsical SImuLation of Electronic and optoelectronic Devices
- NanoBiointerfaces
- NAM6: The Micro and Nano Systems

Acoustics and integrated systems

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Telecommunications Technologies and Intelligent Systems

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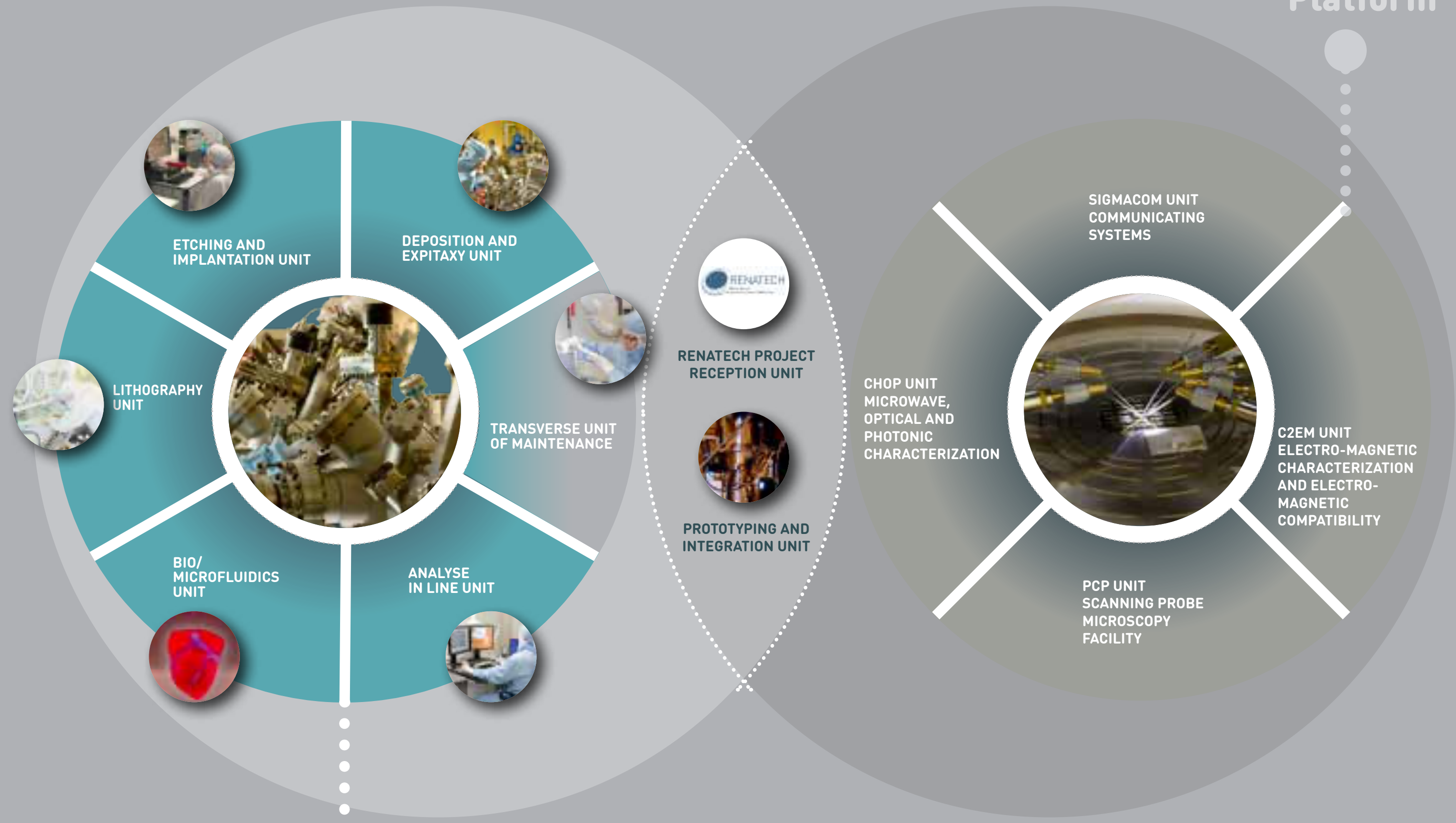
- MICROELEC SI

Central platform of MICRO-NANO-FABRICATION

MULTI-PHYSICS CHARACTERIZATION Platform



Central platform of MICRO-NANO-FABRICATION

IEMN's micro and nanofabrication facility is a 1600 square meter ISO6 certified cleanroom. Organised into six technological units: deposition and epitaxy, lithography, etching, integration, bio-microfluidics, characterisation and one unit of maintenance, the facility is equipped with a full line of cutting edge technological tools supporting device fabrication.

Primarily conceived as an electronics-based research facility, IEMN's clean room is now renowned as a multidisciplinary facility allowing state of the art device and advanced system fabrication in many research fields ranging from photonics to bioMEMS or acoustics. 20 high skilled engineers and technicians work full time to support the research activities and collaborative projects aiming at exploring uses of micro and nanofabrication. The IEMN micro and nanofabrication facility steadily aims to be at the best international research level in micro and nanotechnology to efficiently support academic institutions and companies that require the use of its large clean-room infrastructures. Thus, IEMN is part of RENATECH, the french national network of large technological facilities, that is an integrated partnership of 5 CNRS laboratories in the field of micro nanotechnologies. RENATECH facilities are opened to both academic and industrial partnerships. In this context, IEMN hosts innovative projects in the best possible conditions by sharing and providing the most advanced know-how in the micro and nanotechnology fields through an access to high technology equipment, staff expertise as well as required training support.

Bertrand Grimbert

CONTENTS

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DEPOSITION & EPITAXY

Unit MOLECULAR BEAM EPITAXY

Deposition Manager : Isabelle Roch-Jeune
Epitaxy Manager : Christophe Coinon

Materials engineering process refers to fabrication or modification of materials. The aim is to obtain materials with specific structure, properties and performances depending on the application. 1 Full Time Employee

MOLECULAR BEAM EPITAXY

Christophe Coinon

Molecular beam epitaxy (MBE) is a technique to growth crystalline over-layers and heterostructures on a crystalline substrate using atomic or molecular beams. These beams are produced by heating high purity solid source materials or by cracking very pure gases under ultra high vacuum, that then condensate on the substrate.

- Up to 3 inch wafer
- Around 200 epitaxial growths per year

• Epitaxial growth of III-V semiconductors

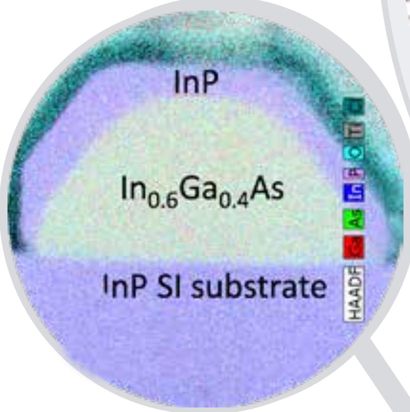
- RIBER COMPACT 21TM
- Effusion cells : Ga, Al, In, Si, GaTe, Be
- Gas injectors : AsH_3, PH_3, CBr_4
- Valved crackers : As, Sb
- Growth on 2 and 3 inch substrates
- RHEED up to 35 KV
- Temperature measurement by band edge thermometry

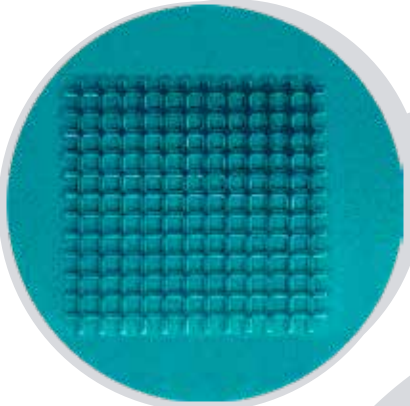
Epitaxial growth of TMDC

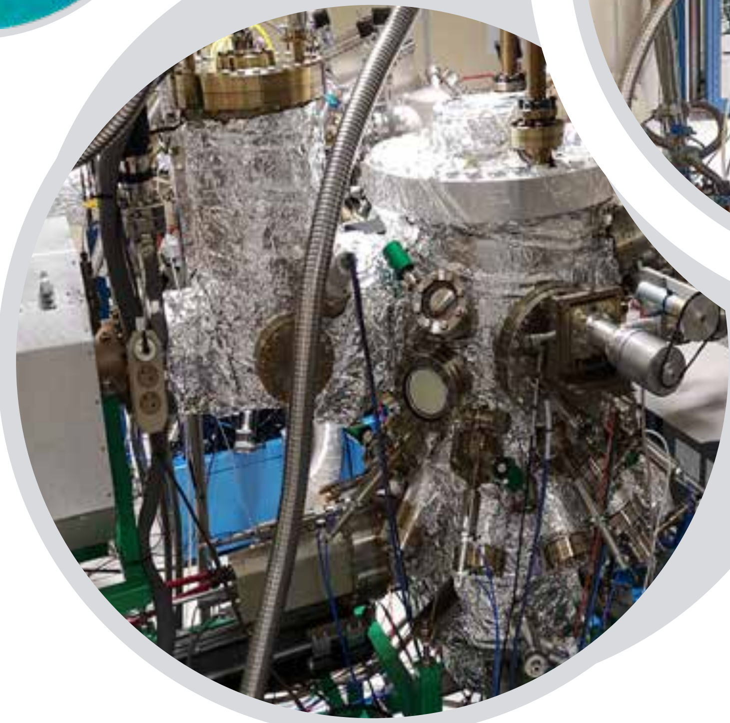
- MBE VINCI Technolgies reactor
- Effusion cells : Ga, In, Se
- Valved cracker : Se
- Linear UHV E-Beam source : Ta, W, Mo, Hf, Nb, Zr
- Up to 3 inch substrates
- RHEED up to 15 KV

Epitaxial growth of Graphene and BN

- MBE RIBER Compact 21
- Carbon, boron & silicon solid sources
- Borazine B3N3H6 gas source
- N2 valved RF plasma source
- Sample holder heating T ≤ 1500°C
- In-situ characterisation by RHEED
- Coupled under UHV with a surface analysis chamber fitted with LEED and Auger spectroscopy







DEPOSITION & EPITAXY

Unit ORGANIC CHEMISTRY

LABORATORY OF ORGANIC SYNTHESIS AND SURFACE FUNCTIONALIZATION

David Guerin

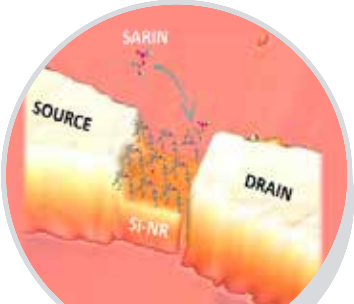
This laboratory is dedicated to chemical synthesis of molecules or materials designed for electronics or nanobiotechnologies. The main activity of the lab concerns the surface functionalization by molecules or by organic thin films. Self Assembled Monolayer technique (SAM) is used to provide specific physico-chemical properties to various surfaces, such as optical or electronical properties, wettability, encapsulation or specific chemical reactivity. Synthesis and grafting of nanomaterials on different substrates are also performed.

Synthesis under inert atmosphere

- Nitrogen glove box
- Schlenkware
- Vacuum / nitrogen manifold

Purification of solvents and organics

- Kugelrohr ovens
- Flash Chromatography
- Distillation
- Rotavapor
- Centrifuge



Sarin gas sensor

ORGANIC PLATFORM

David Guerin

Associated with the laboratory of organic chemistry, the organic platform is dedicated to the preparation of molecular and organic devices. Two connected glove-boxes (M-Braun model, O_2 and H_2O level < 1 ppm) permit to deposit on a substrate various organic materials (self assembled monolayers by surface chemistry or polymers by spin coating) then other organics or metals can be evaporated on-line (by joule effect at 10^{-7} mbar) without any contact with atmosphere.


Vacuum / nitrogen manifold

In addition of usual organic chemistry glassware, the lab is equipped with specific apparatuses for manipulation under inert atmosphere (schlenkware, vacuum/N_2 manifolds, glove box). Solvents, chemicals or nanoparticles can be purified by various equipments (distillation apparatus, Kugelrohr oven, rotavapor, flash chromatography, centrifuge).


Rotavapor


Kugelrohr oven


Flash chromatography

DEPOSITION & EPITAXY

Unit CHEMICAL VAPOR DEPOSITION

Deposition Manager : Isabelle Roch-Jeune
Epitaxy Manager : Christophe Coinon

Chemical vapor deposition process refers to chemical and thermal processes used to deposit or grow high purity conformal thin layers with a good uniformity.
1,85 Full Time Employees

AP-CVD and LP-CVD

Guillaume Cochez

APCVD (Atmospheric Pressure Chemical Vapor Deposition) and LPCVD (Low Pressure Chemical Vapor Deposition) refer to chemical and thermal processes used to deposit high purity thin layers with a good uniformity.

- Up to 4 inch wafer
- 5 process tubes

2 APCVD Tempress Furnaces

- 2 APCVD tubes for thermal oxidations of silicon wafers up to 1100°C with O_2 gas (dry oxidation) or H_2O vapor (wet oxidation) at atmospheric pressure.
- Thickness: from 2 nm up to 2 µm
- Applications: insulation, passivation, smoothing of side effects after plasma etching

3 dedicated LPCVD tubes (dry pumps)

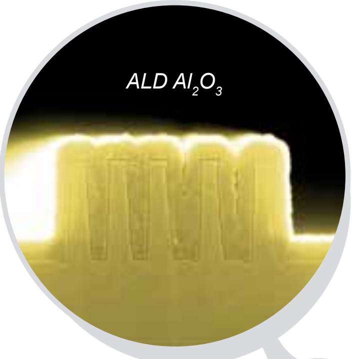
- Polycristalline silicon (≤ 600°C) and in-situ phosphorus doped polysilicon (650 to 750°C)
  - thickness up to 2 µm
- Low Temperature Oxide (SiO_2 deposition at 420°C), boro- (BSGLTO), phospho- (PSGLTO) or BoroPhosphoSilicate Glass (BPSGLTO)
  - thickness up to 5 µm
- Low stress (Si_xN_y) or stoichiometric (Si_3N_4) silicon nitride , 800°C
  - thickness up to 1 µm
- **Applications** → insulation, passivation, p-n junction
- Gas: O_2, H_2, SiH_4, PH_3, BCl_3, SiH_2Cl_2, NH_3, N_2, Ar

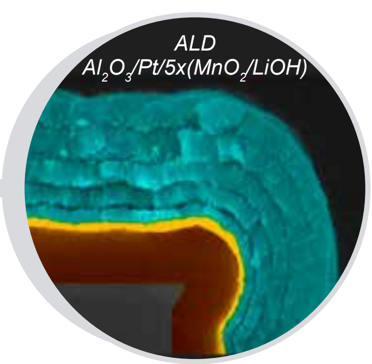
ATOMIC LAYER DEPOSITION

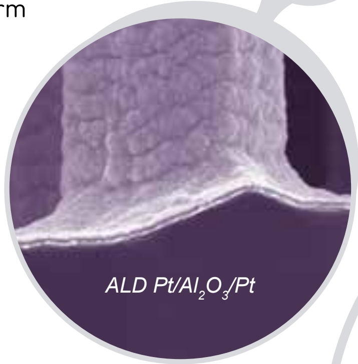
Atomic Layer Deposition (ALD) is an advanced thin film coating method which is used to fabricate ultrathin, highly uniform and conformal material layers.

- 2 process chambers
- 1 mono layer growth control
- 1 glove boxe (N, Ar)
- Up to 8 inch wafer

Al_2O_3, NiO, TiO_2, Ta_2O_5, TiN, TaN, ZrN, HfN, Pt...







Isabelle Roch-Jeune

→ TFS200 Beneq

- Flow through chamber
- Thermal enhanced reaction
- Pulsed or continuous.
- Chamber can be heated up to 500°C

9 precursors available

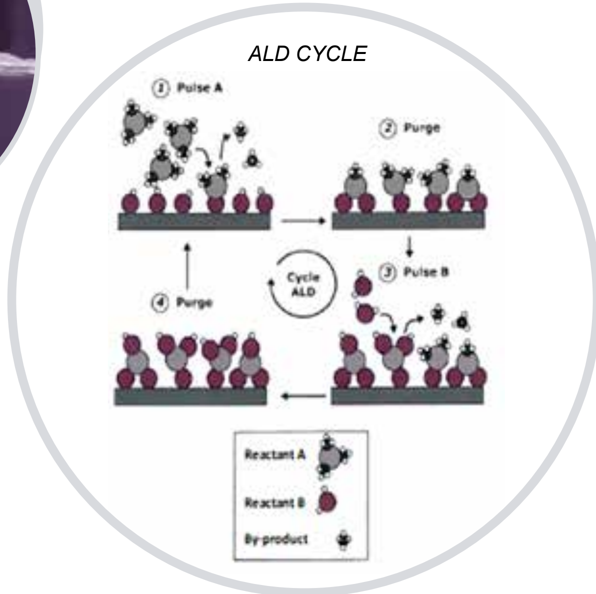
- 3 non-heated canisters :
  H_2O, TMA, $TiCl_4$
- 4 heated canisters up to 300°C :
  $MeCpPtMe_3$
- 4 gas lines: O_2, NH_3, H_2, Ar or N_2

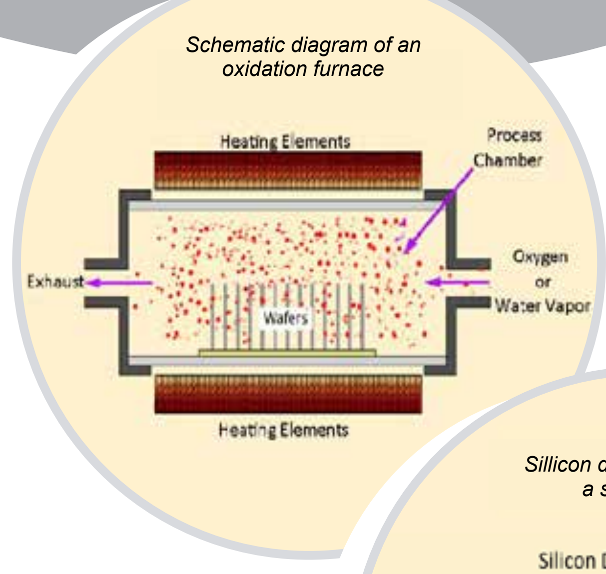
Maxime Hallot

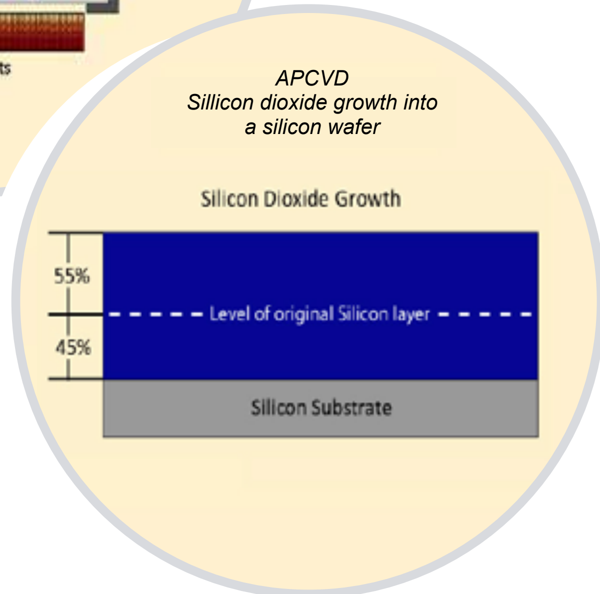
→ ALD PICOSUN - R200 advanced

Through-porous and HAR samples

- Process temperature
  50-500°C
- Substrate loading options
  Pneumatic lift
  Load lock with magnetic manipulator arm
- Precursors
  2 Liquid sources, 3 sources for solid,
  5 gases, Ozone







DEPOSITION & EPITAXY

Unit CHEMICAL VAPOR DEPOSITION

Deposition Manager : Isabelle Roch-Jeune
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GRAPHENE

Dominique Vignaud

Graphene is a two dimensional carbon allotrope with a honeycomb structure. It is known to be a very light and strong material. It has excellent thermal, mechanical, optical and electrical properties. CVD is an inexpensive technique to produce large area graphene. It is done on metal substrates/layers where hydrocarbon precursors decompose and form graphene.

JETFIRST 100F Rapid Thermal Processor

- Materials: Cu, Ni foils or / and thin films
- Graphene growth in Ar / H_2 / CH_4, rapid heating and cooling ramps.
- Typical conditions on Cu : 980°C - 1050°C (10-100 sccm Ar, 1-200 sccm H2, 1-20 sccm CH_4, 10-20 Torr)

Growth of monolayers, multilayers, hexagonal domains
Up to 4cm² homogeneous graphene sheets optimized growth
Transfer technique by removal of the catalytic substrate and sticking on a large set of substrates (components, flexible).

Potential applications and fields of interests :

- Flexible and transparent conductors
- Optical electronics
- Bioengineering
- Energy technology and storage
- Components
- Sensors
- Composite materials

PARYLENE COMELEC C20S

David Guerin

Parylene thin film : COMELEC C20S

Parylene is the trade name for chemical vapor deposited poly(p-xylylene) polymer series.
Parylene C, D, N available.
Room temperature conformal depositions on a wide range of materials and shapes.

Room temperature deposition (3 steps):

- Vaporisation of the solid dimer
- Pyrolysis of the dimer to yield the monomeric diradical
- Simultaneous adsorption and polymerisation of the monomer on the substrate (at room temperature)

Thickness ranging from 30 nm to 50 µm

Characteristics of Parylene / fields of interests:

- Excellent electrical insulator / dielectric layer
- Biostable/biocompatible
- Highly conformal coating, homogeneous surface
- Very low permeability to gases
- Highly resistant to chemicals
- Device encapsulation/ Surface passivation or functionalization
- Shadow masks/ flexible substrates
- Bonding layers

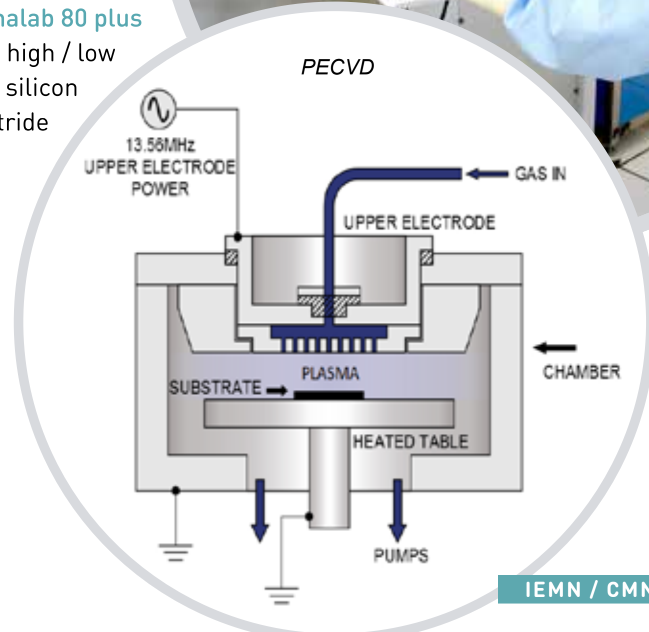
PLASMA-ENHANCED CVD

Plasma-Enhanced Chemical Vapor Deposition is a process used to deposit thin films from a gas state to a solid state on a substrate.

Oxford Plasmalab 80 plus

Film stress can be controlled by high / low frequency mixing techniques to deposit silicon nitride, silicon dioxide and silicon oxinitride

- HF 13.56MHz and BF 50 to 400KHz
- Gas: SiH_4 5% in N_2 - NH_3 - N_2O - N_2 - He and CF_4 / 20% O_2 - O_2
- Deposition temperature: between 100 to 340°C
- Deposition rate: between 100 to 700 Å/mn



DEPOSITION & EPITAXY

Unit PHYSICAL VAPOR DEPOSITION

Deposition Manager : Isabelle Roch-Jeune
Epitaxy Manager : Christophe Coinon

Physical vapor deposition is a vaporisation or condensation coating technique, involving transfer of solid materials onto a substrate.
2,2 Full Time Employees

The heat is provided either by joule heeting via a refractory metal element (resistive evaporation) or directly from a focused beam of high energy electrons (electron beam evaporation). More than 3000 depositions per year (Metal, Dielectric material, Magnetic layer)

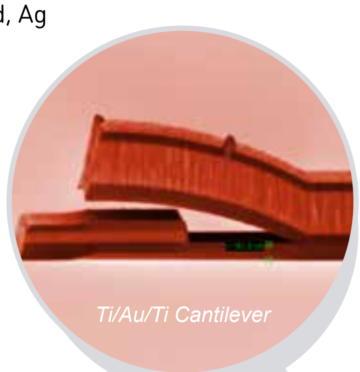
ELECTRON BEAM

Marc Dewitte & Annie Fattorini

- 2 PLASSYS MEB 550S
- Load lock with substrate treatment (ion beam source 3cm)
- Capacity : 4 substrate holders 4 ''
- Materials: Au, Ti, Ge, Al, Pt, Ni, Mo, Cr, Pd, Ag

Marc Dewitte & Isabelle Roch-Jeune

- 1 PLASSYS MEB 550SL
- Load lock with O2 treatment
- Ion beam in chamber
- Capacity : holder 6''
- Materials : Ti, Ni, Cr, Al, Au, Pt, Pd, Ge


Ti/Au/Ti Cantilever


Cr/Au Nanoprobe

RESISTIVE (JOULE)

Marc Dewitte

- 1PLASSYS MEB 450S
- Load lock with substrate treatment (ion beam source 3cm)
- Capacity : 1 substrate holder 4''
- 3 sources: In, Cr, Au
- Substrate holder with planetary rotation

SPUTTERING SYSTEMS

The sputtering method involves ejecting material from a "target" onto a substrate by sending ions to the target.

- Up to 4'' wafer
- 6 deposition process chambers

Marc Dewitte

- 2 ALLIANCE CONCEPT DP650

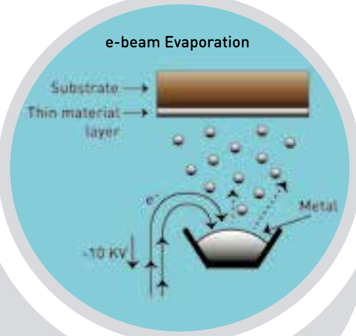
Cold or heated (750°c) substrate holder

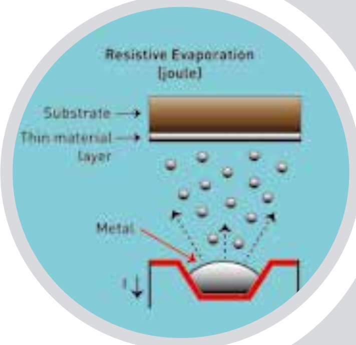
- DP 650n°24
- 4 cathodes 6''
- Powered with 1DC and 1RF source
- Deposited materials : Au, Al, Ti, Cr, Cu

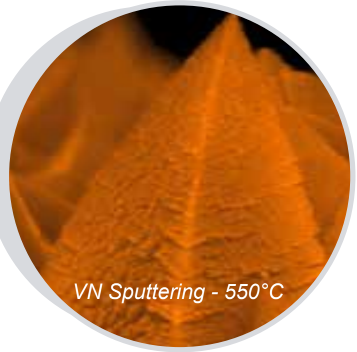
- DP 650n°34
- 6 DC and RF cathodes 4''
- Powered with 1 DC pulse, 1DC and 1RF source
- Deposited materials : Au, Ni, Pt, WTi, TiNi, W, Ta, NiCr, NiCu, TiN, TiC, Fe, Al, Mo, Cu, TaN, Ti, Si, SiO2, ZnO

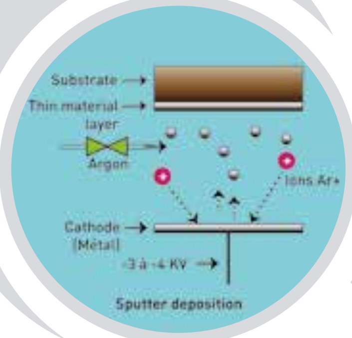
Nicolas Tiercelin

- 1 LEYBOLD Z550
- 1 cathode 6 " and 4 cathodes 4" RF and DC
- Magnetic layer deposition
- TbFe2, TbCo2, TbFeCo, FeCo, Fe, Co, CoPt, FePt, Ta, Cr






VN Sputtering - 550°C



Isabelle Roch-Jeune & Guillaume Cochez

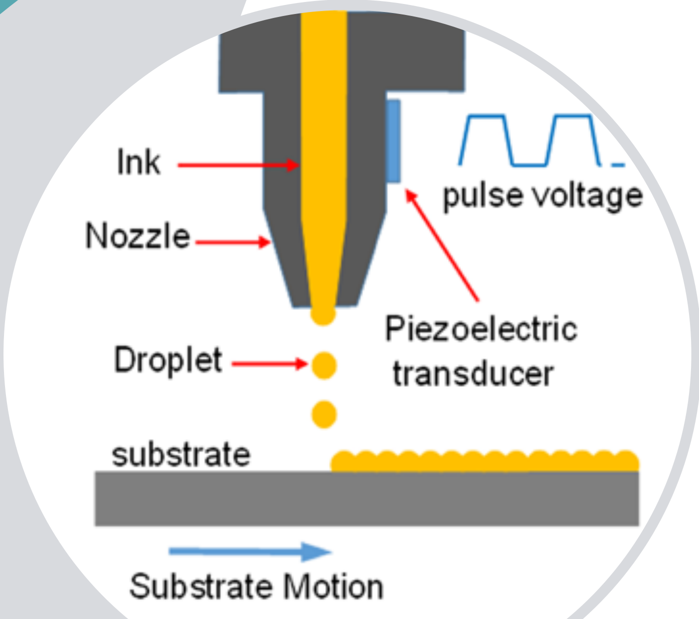
- 1 ALLIANCE CONCEPT CT 200 CLUSTER
- 14 targets, 3 chambers, fully automated sputtering cluster
- **Applications** → single or multi-layers processes, reactive sputtering , co-sputtering
- Realisation of complex structures without vaccum break and cross-contamination of chambers

	Chamber 1 Magnetic Multilayers/Metals (Fe, Co, Pt...)	Chamber 2 - Materials for storage energy (LMNO, WN, VN, LiPON...)	Chamber 3 - Photovoltaic materials AZO, Zn(Sn, Ge, Si)N_2
CHARACTERISTICS	• 6 x 2'' magnetron targets • Confocal sputtering • 2 DC-pulse source and 2-RF sources • Cold or heated (400°C) substrate with rotation for uniformity over 4" • Reactive sputtering of nitrides also allowed • Gas: Ar, N_2	• 4x 4'' (3'' also available) targets in planar mode • 1 DC and 1 RF power source. • Cold or Heated (800°C) substrate holder • Gas: Ar, N_2, O_2	• 3x 2'' magnetron targets in confocal mode + 1x 4'' magnetron target in planar mode. • 1 DC pulse, 1 DC and 1 RF source • Heated (400°C) substrate holder • Rotation for uniformity over 4" • Gas: Ar, N_2, N_2/5%H_2

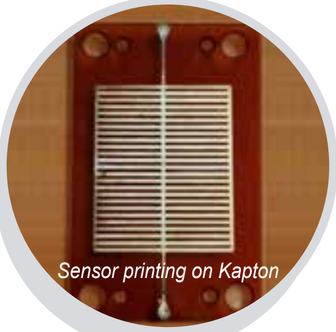
DEPOSITION & EPITAXY

Unit ALTERNATIVE DEPOSITION & HEAT TREATMENT

Deposition Manager : Isabelle Roch-Jeune
Epitaxy Manager : Christophe Coinon

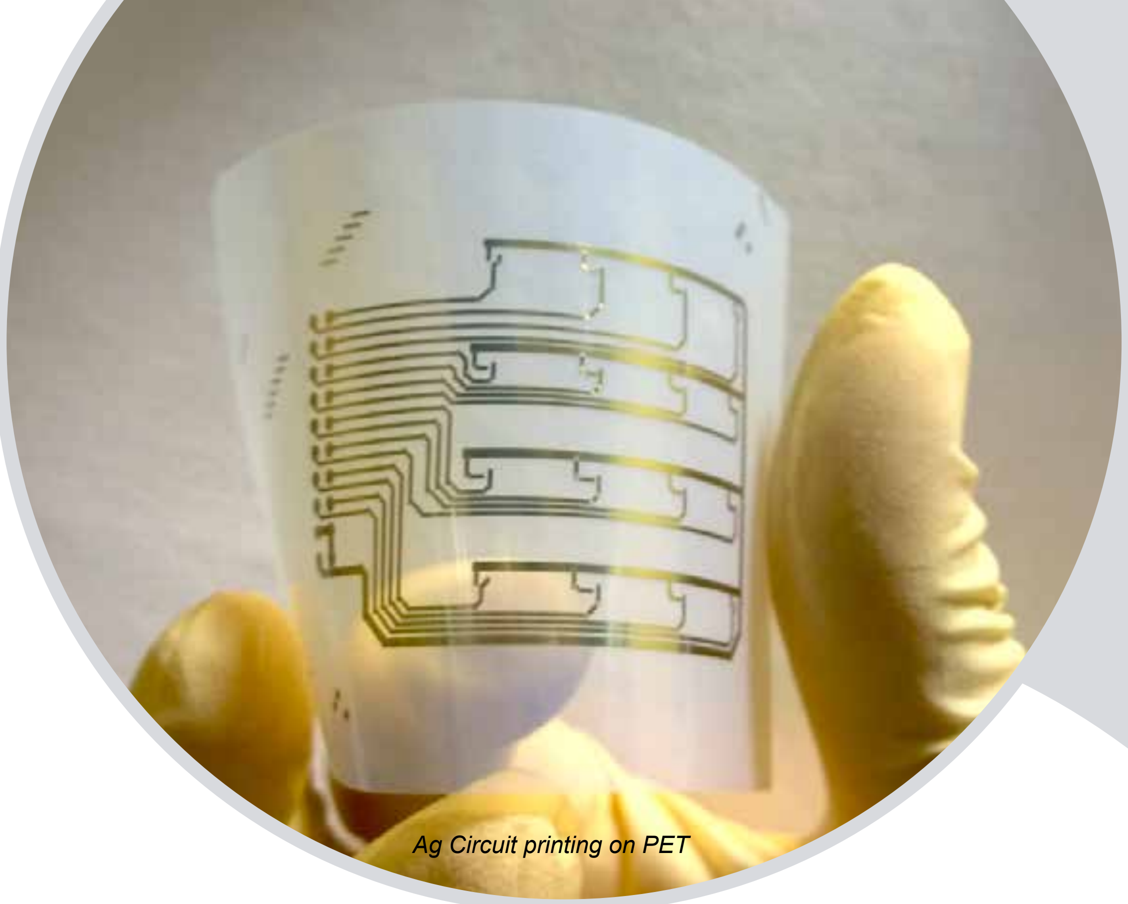


Drop-on-demand inkjet printing



Sensor printing on Kapton

Ag Filter printing on PET



Ag Circuit printing on PET

INKJET PRINTING

Isabelle Roch-Jeune

Powerfull digital materials deposition systems for printing of functional materials: printing onto rigid and flexible substrates

Ceradrop X-Series Inkjet printer

- 2 Dimatix Printhead (128 Nozzles each) Diameter of nozzles 35 µm
- 1 Mono nozzle printhead Diameter of Nozzle 20 µm, 30 µm or 35 µm
- 1 IR Dryer
- Printing with silver nanoparticles ink, biopolymer solutions and carbon ink

FURNACES

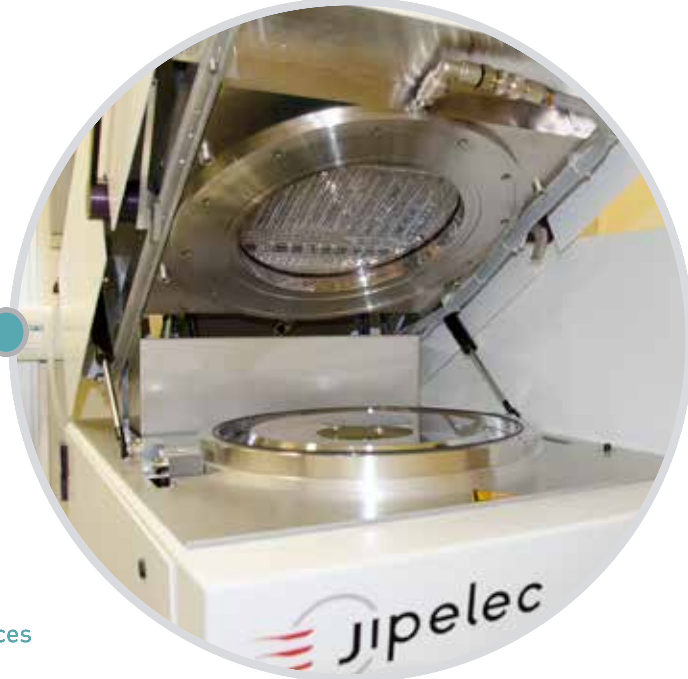
Marc Dewitte

Rapid Wafer Heating System
JIPELEC JETFIRST 200

- Range of temperatures : 100°C - up to 1100°C
- Samples to 8''
- Gas process : N_2 - N_2/5%H_2 - O_2 - Ar

2 Atmospheric Pressure Tubular Annealing Furnaces
CARBOLITE and VASSE

- Range of temperatures : from 100°C to 1000°C
- Samples to 3''
- Gas process : N_2- N_2/5%H_2- Ar



LITHOGRAPHY

Unit

Lithography Manager : Francois Vaurette

- Yves Deblock
- Pascal Tilmant
- Saliha Ouendi
- Christophe Boyaval

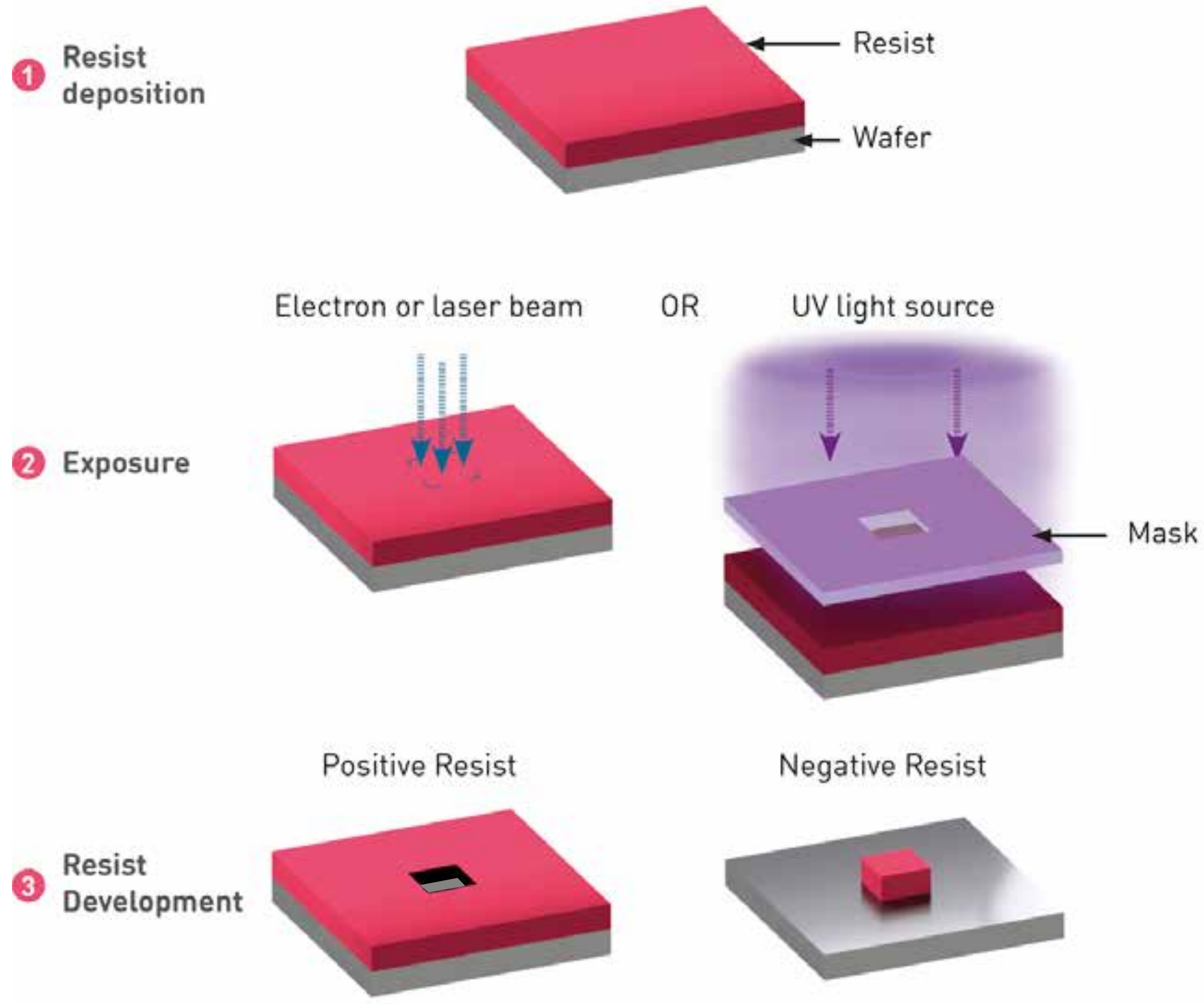
Lithography process gives the capability of patterning materials at micro and nanometer dimensions. It uses radiation (UV light or electrons) to pattern sensitive optical and ebeam resists.
4 Full Time Employees

SPIN-COATING

Pascal Tilmant, Saliha Ouendi, Francois Vaurette

The lithography process uses electron or laser beam to expose in an electron or light-sensitive resist or it uses light to transfer a pattern from a photomask to a light-sensitive chemical photoresist on the substrate.

- From 1/4" to 4 inch wafer
- More than 30 resists available
- Optical resists: SU8 - 2000, AZ series, S1800 series, SPR series, PMGI, LOR, UV210, ARP5320, PDMS, BCB dry etch, BCB photosensible
- E-beam resists: - PMMA, COPO, CSAR62, MaN, UV210, HSQ

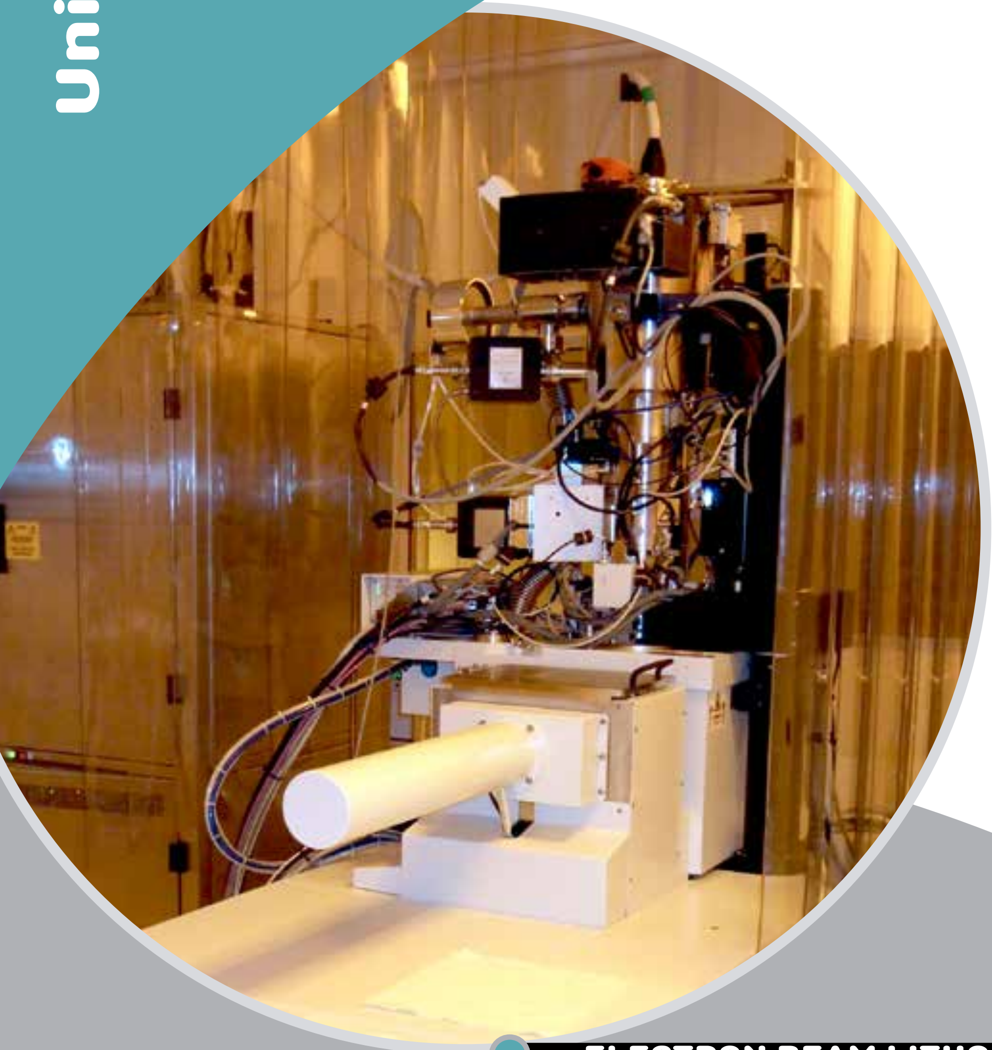


EQUIPMENTS	CHARACTERISTICS
NanoCalc Thin Film Reflectometry System	• NanoCalc UV2000 / UV / NIR • The NanoCalc-2000 can be used to measure the film thickness from 10 nm up to 250 µm
6 Gyrset RC8 and RCD8 spin coaters	• Wafer size from 3x3 mm to 4 inch and optical mask 4*4, 5*5 inch • System (EBR) edge bead remover for wafers and system auto cleaning with specific solvent
5 SSE Hotplates	• Controlled process with nitrogen until 300°C : uniformity 0.1°C • Programmable with lift pins
2 Sawatec Hotplates	• Controlled process with nitrogen and vaccum until 300°C : uniformity 0.1°C • Programmable with lift pins • Controlled ramp up, steps, dwell, and ramp down

Unit

LITHOGRAPHY

Lithography Manager : Francois Vaurette



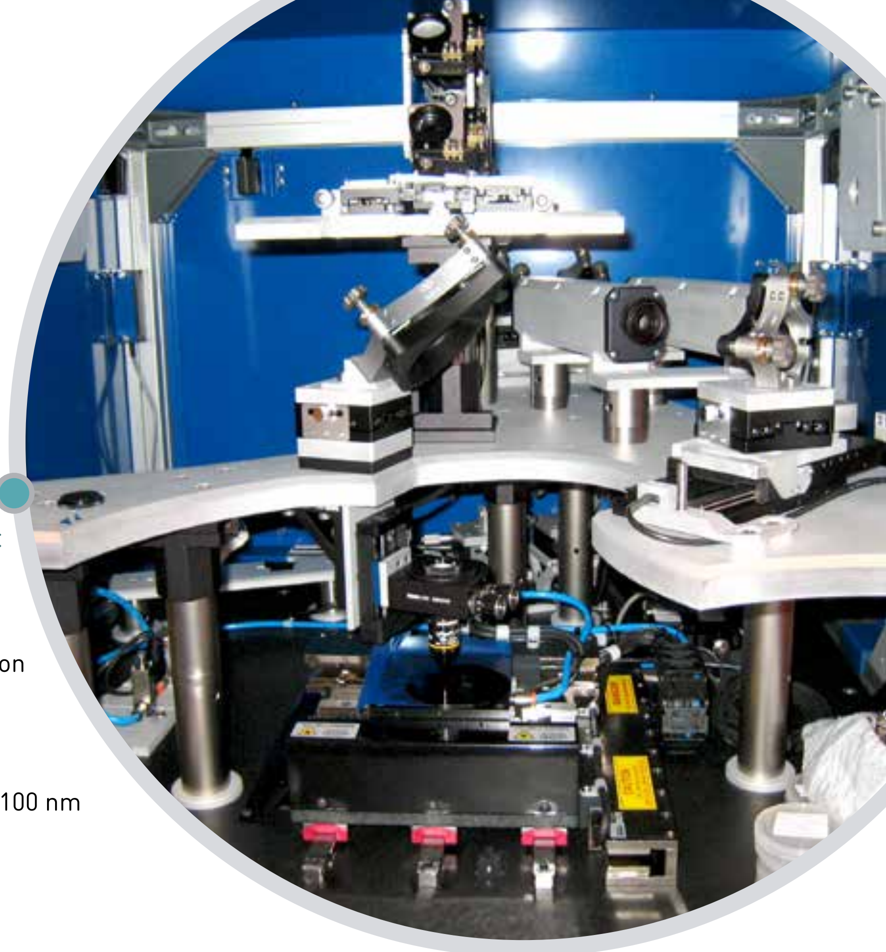
ELECTRON BEAM LITHOGRAPHY

Yves Deblock, Saliha Ouendi, Francois Vaurette

E-beam lithography is a lithographic process that uses a focus beam of electrons to define in an electron-sensitive resist custom patterns. The solubility of this resist is changed by the electron beam. Therefore, there is a selective removal of the resist by immersing it in a solvent (development).

Two beam writers EBPG 5000 plus
- More than 2000 writings per year
- From small sample (4mm x 4mm) up to 4 inch wafer
- E-beam resists: - PMMA,COPO,CSAR62,MaN,UV210,HSQ,...
  - Optical resists used in e-beam: AznLof, AZ15nXT, AZ40XT,...

EBPG 5000 Plus
- High Resolution Gaussian Beam System
- Thermal Field Emission Gun
- 50MHz Pattern Generator
- Minimum address grid 0.08 nm
- Maximum field size : 524 µm (DAC 20 bits)
- Interferometer stage, 0.6 nm positioning accuracy
- Acceleration voltage: 20kV, 50kV or 100kV
- Automatic 10 positions airlock
- Holders for 2" to 4" wafers , 3" to 5"masks and smaller piece parts
- Overlay and stitching better than 30 nm

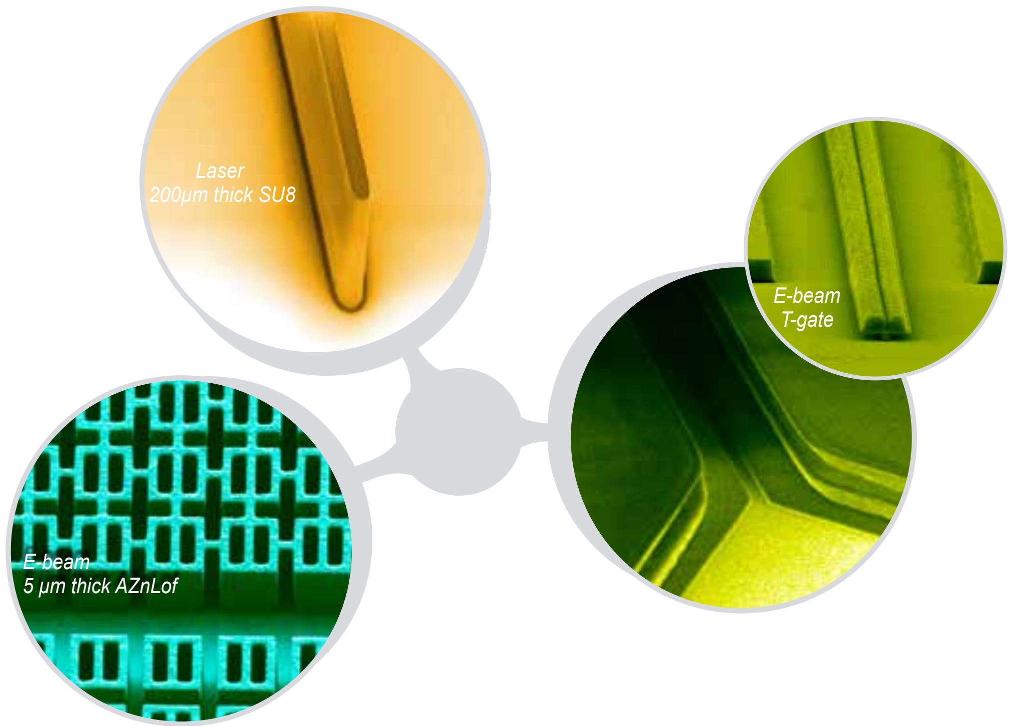


LASER LITHO 2D

Francois Vaurette, Pascal Tilmant

Dilase 650 Kloé

High Resolution Direct Lithography System for fast Prototyping and Maskless Fabrication
- Laser source 375 nm, 73 mW
- Wafer writing area 100 x 100 mm
- Laser spot size: 1µm and 10 µm
- Stage travel resolution and repeatability: 100 nm



Unit LITHOGRAPHY

Lithography Manager : Francois Vaurette

MASK ALIGNERS

Pascal Tilmant, Saliha Ouendi, Francois Vaurette

2 Suss MicroTec MA6/BA6 Mask Aligner and Bond Aligner UV 240-365 nm

- Wafer size from ¼ to 4 inch and mask size: quartz 4*4 and 5*5
- Exposure mode: Proximity, soft, hard and vacuum contact
- Top side alignment (TSA) down to 0.5 µm, bottom side alignment (BSA) down to 1 µm
- Resolution with vacuum contact down to 800 nm with resist Aznlof 2020

WAFER BONDING

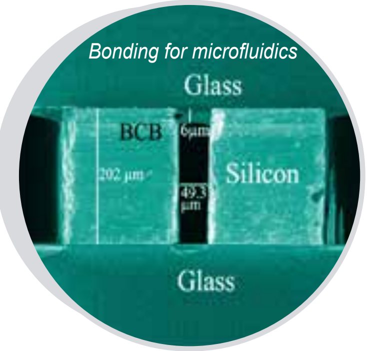
Pascal Tilmant

1 Suss MicroTec SB6e Wafer Bonder in combination with MA/BA6 Mask Aligner

- For aligned and unaligned wafers using thermo-compression, anodic, fusion, adhesive, etc
- Wafer size: pieces smaller than 2 inch, up to 4 inch
- Aligned bonding: down to 3 µm depending on process conditions

	E-beam	Laser	Optical
ADVANTAGES	• High resolution (below 10nm) • No physical mask (computer file only) • High precision for overlay and stitching between 2 layers (better than 30nm) • Possibility to expose very small samples (4mm x 4mm)	• No physical mask (computer file only) • High focus depth (possibility to expose very thick resist)	• Exposure time (a few seconds) • Easy to use
DISADVANTAGES	• Proximity effect • Charging effect • Height measurement • Exposure time (50min for exposing 1mm2 - PMMA on GaAs, 1nA, 100kV)	• Alignment between levels (0,5-1µm) • Exposure time can be long depending on design	• Need a physical mask • Alignment between levels (0,5-1µm)
WHEN USE IT ?	• Design below 1µm • Alignment below 1µm	• Design above 1µm • Prototyping with no physical mask • Very thick resist	• Design above 1µm • Multiple wafers with same design


Air bridge technology



Bonding for microfluidics


Thick resist for deep etching

ETCHING & ION IMPLANTATION

Unit

PLASMA ETCHING

• Etching & Ion Implantation Manager: Dmitri Yarekha
• Timothey Bertrand • Laurent Fugère
• Jean Houpin • David Troadec

Etching is used in microelectronics to chemically or/and physically remove layers from the surface of a wafer during process. For many etching steps, part of the wafer is protected from the etchant by a «masking» material which resists etching.
4,5 Full Time Employees

DEEP SILICON ETCHING

Bosch process

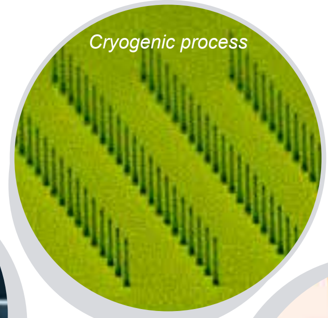
The Bosch process is two steps process. It enables highly anisotropic deep silicon etching. It uses fluorine based plasma chemistry (SF_6), to etch the silicon combined with a fluorocarbon (C_4F_8) plasma process to provide sidewall passivation and improved selectivity to masking materials. A complete etch process cycles between etch and deposition steps many times to achieve deep, vertical etch profiles.

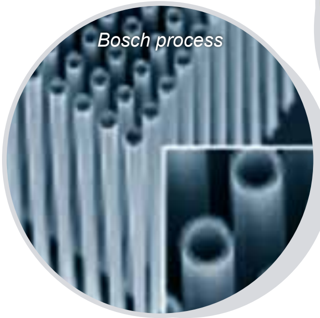
2 Bosch process based reactors:

• **Oxford estrelas plasmapro100 with cryogenic capabilities:**
Dmitri Yarekha

Estrelas is equiped with a **Cryogenic** electrode, that allows to do Si etching at very low temperature (-150°C min. Typically at -120°C / -90°C). No passivation steps or needed at low temperature to obtain anisotropic etching and at the same time it allows to obtain very smooth walls, which is very interesting for optoelectronics applications.
- Etch depth: wafer through
- Selectivity to PR > 250:1
- Selectivity to SiO_2 > 500:1
- Uniformity <± 3%

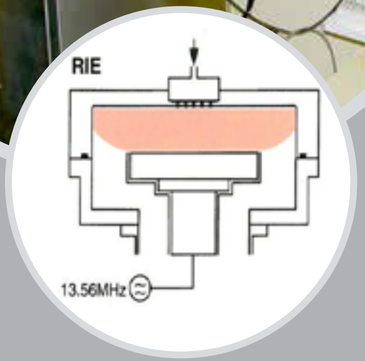
• **SPTS Rapier**
Marc Faucher


Cryogenic process


Bosch process


Cryogenic process

REACTIVE ION ETCHING (RIE)



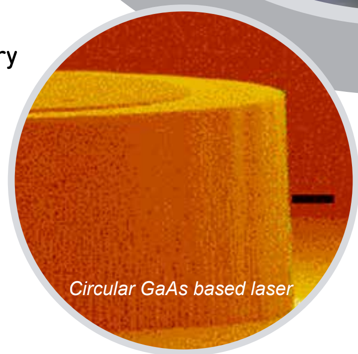
Reactive Ion Etching (RIE) uses chemically reactive plasma and physical sputtering to remove material deposited on wafers.

• 2 systems OXFORD Plasmalab 80plus
- Single 600W RF plasma source determines both ion density and ion energy
- Ion energy dependent on the RF power and process pressure
- Negative self-bias forms at the substrate electrode
- Gas : O_2, CF_4, CHF_3, SF_6, He, Ar, H_2, O_2, N_2
- Laser interferometry endpoint detection systems

INDUCTIVELY COUPLED PLASMA (ICP - RIE)

Timothey Bertrand Dmitri Yarekha

ICP source produces a high density of reactive species. Separate RF generators for ICP and electrode provide separate control over ion energy and ion density often achieving higher etch rate and lower damage. High process flexibility, can also be run in RIE mode for certain low etch rate applications. Materials etched are III-Vs, silicon, silicon oxides, several metals, glass,...
All of our etching chambers are equipped with laser interferometry endpoint detection systems.


Circular GaAs based laser

• OXFORD Plasmalab System 100 dual chamber cluster ICP 180
Two process chambers
- Gas chamber 1 : CH_4, H_2, Cl_2, O_2, SF_6, Ar
- Gas chamber 2 : Cl_2, BCl_3, O_2, SF_6, Ar
- The system includes wafer clamping and helium cooling, providing temperature control (range 5°C to 60°C)

• SENTECH SI 500:
- Gas: CH_4, H_2, Cl_2, O_2, SF_6, Ar, Cl_2, BCl_3, HBr
- Providing temperature control (range -20°C to 250°C)
- For up to 200 mm wafers

SURFACE CLEANING AND TREATMENT

Dmitri Yarekha

• Plasma system PVA Tepla 300 semi-auto
Microwave plasma stripper
Dry process for photoresist stripping and substrate cleaning
Microwave plasma produces a very high concentration of chemically active species with low ion bombardment energy guaranteeing fast ash rate and a damage-free plasma
Tubular quartz chamber with 1000W microwave generator
Option : Faraday cage to reduce electro static discharge (ESD)
Gas : O2, Ar, CF4

• NAVIGATOR 8
Photo-resist stripping
Residues cleaning &
descum Surface activation
High plasma density ICP source
Gases: O2, CF4, N2
Power: 13.56 MHz, 1000 W
Pressure: 50 - 1000 mTorr
Chamber heating: 20 - 250 °C
Chuck heating: 20 - 250 °C

• UV-ozone Cleaner : Surface oxidation and cleaning
by ozone combined with UV(254 nm and 185 nm)

ETCHING & ION IMPLANTATION

Etching & Ion Implantation
Manager: Dmitri Yarekha

Unit
CHEMICAL ETCHING

WET ETCHING

Wet etching is an etching process that uses liquid chemicals to remove materials from a wafer. Chemistry stations:

- Organic, halogeneous, inorganic acids
- Inorganic bases
- Halogeneous and non halogeneous solvents

TREATMENT AFTER WET ETCHING

Jean Houpin

Critical Point Dryer SCFluids (CPD1100)

The Supercritical CO_2 Dryer uses liquid and supercritical carbon dioxide to dry MEMS wafers efficiently and with high yield. Due to zero surface tension in the supercritical state of the CO_2, stiction, a most critical negative yield factor is avoided completely.

The standard used conditions are 76 bar and 40°C

Basic Characteristics:

Wafer max size : 6 inches
Wafer max thickness : 5 mm
Max pressure : 110 bar
Max temperature : 65 °C

WET ETCHING COMPARED TO DRY ETCHING

DRY ETCHING:

- Good Anisotropy
- To achieve small features
- High cost

WET ETCHING:

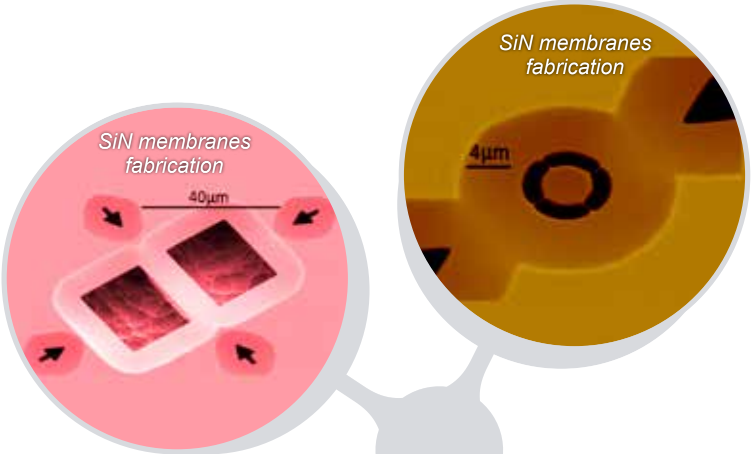
- Low cost, easy to operate
- Good selectivity for most materials
- Isotropic
- sensitive to changes in temperature

XeF2 ETCHING SYSTEM

Jean Houpin Dmitri Yarekha

The Xactix® X4 SeriesTM is the XeF_2 etch system for releasing Silicon based MEMS devices.
It uses cyclic vapor exposition to isotropically dry etch sacrificial silicon:

- high rate silicon etching system with
- high silicon /silicon oxide selectivity



VAPOUR HF ETCHING SYSTEM

Jean Houpin

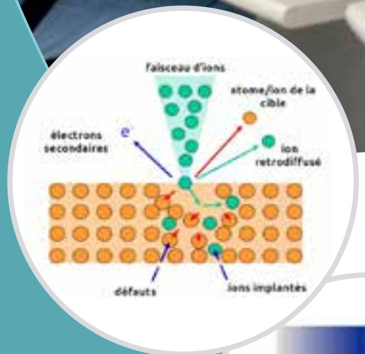
The fabrication process of MEMS devices in silicon microtechnologies involves as final step the releasing of the microstructures by an etching of a silicon dioxide sacrificial layer. The "vapour HF" technique gives access to a releasing process which is an alternative to the one including wet HF etching + CO_2 supercritical drying. Advantages of the "Vapour HF" technique are manifold, and come from the dry and anhydrous conditions the "Vapour HF" machine brings: stiction free releasing, carbon free surfaces, selectivity versus metals and silicon nitride.

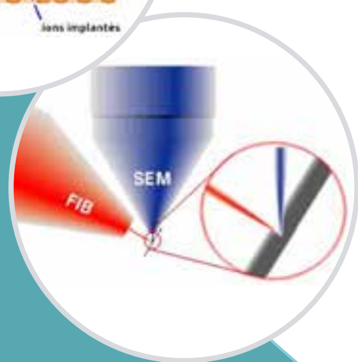
The SPTS "uEtch" is a single-wafer system. Wafers from pieces to 8 inch can be loaded in the chamber. Using 5 different recipes calibrated on the machine, we are able to etch TOX with an etch rate of 100 Å/min to 1650 Å/min and a uniformity around 2% on 3 inch.

ETCHING & ION IMPLANTATION

Unit ION BEAM

Characterisation process refers to in-line inspection for process control and materials study. A wide range of techniques are available from optical, electrical, physical or mechanical.
3,5 Full Time Employees





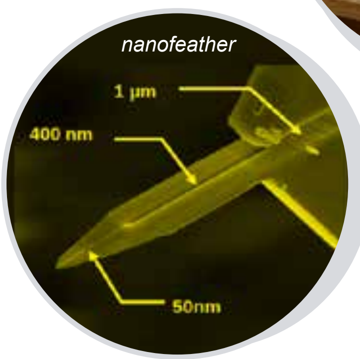
FOCUSED ION BEAM

David Troadec

Dual beam system combines a high resolution secondary electron microscope (SEM) and a focus ion beam with gallium metal ion beam source (FIB) for nanoscale machining, patterning, and nanomaterials characterization.
Materials can be milled or deposited while observing the evolution of the surface topography with secondary electrons (SEM or FIB).

FEI Strata DB235
Stage: 5-axis eucentric, all motorized stage

- **Ionic column**
  - -Emitter (Gallium LMIS)
  - - Acceleration Voltage (5kV - 30kV)
  - - Probe Current (1pA - 20nA)
  - - Image Resolution (7nm)
- **Electronic column**
  - - Emitter (Field effect gun (Schottky))
  - - Acceleration Voltage (200V - 30kV)
  - - Resolutions (SEM: 3nm and STEM: 2nm)
- **Detectors :**
  CDEM, SED, in-lens, STEM
- **Gas Injection System :**
  Platinum, Tungsten and Carbon



ION BEAM ETCHING (IBE)

Dmitri Yarekha

- High resolution (below 10 nm)
- Universal etchant
- No undercut
- monoenergetic beam - varied to suit experiments
- Field and plasma free - relaxes restrictions

IBE - Beam of neutral ions (Ar+)
RIBE - Beam of neutral and reactive ions (Ar+, O+ et O2+)

IonSys 500
Microwave ECR ion beam220 mm source
- ion energies from 100 – 1000 V
- ion current densities up to 1 mA/cm²
Tilting from 0° to 90°, ± 0.1°
Rotation from 2 to 20 rpm
Cooled substrate holder (-20°C to +50°C), helium backside
Six process gas lines: Ar, N2, O2, CH4, SF6, H2
Endpoint detection - SIMS

ION IMPLANTATION

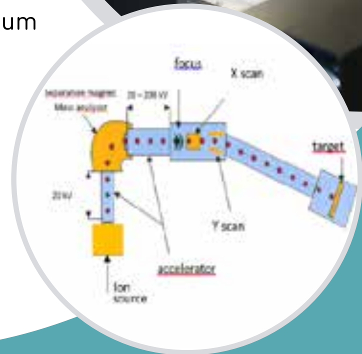
Laurent Fugere Dmitri Yarekha

Ion implantation is a materials engineering process by which ions of a material are accelerated in an electrical field and impacted into a solid. This process is used to change the physical, chemical, or electrical properties of the solid.

- Production and R&D chambers
- More than 250 implantations per year
- Up to 4 inch wafer
- Principal implanted species: As, P, Si, He, Ar, N, C, B, F

Implanter EATON-AXCELIS GA 3204
- Energy : from 5 keV to 200 keV
- Doze : from 1E11 at./cm²
- Sources: Gases, solid
- Tilt : 0° to 45°
- Twist : 0° to 360°
- Target carrier temperature: -10°C to +300°C

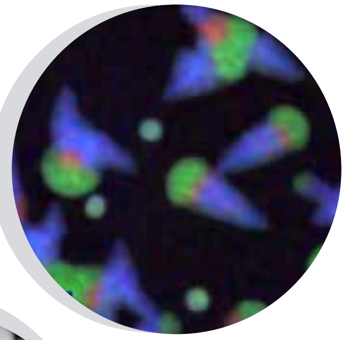
ANNEALSYS Rapid Thermal Annealing
- Temperature range: 100° to 1200°C
- Susceptors : Silicon or Graphite coated with SiC
- Operation : N_2, N_2H_2, High vacuum
- Up to 6 inches



CHARACTERISATION

Unit BEAM

Characterisation process refers to in-line inspection for process control and materials study. A wide range of techniques are available from optical, electrical, physical or mechanical.
3,5 Full Time Employees

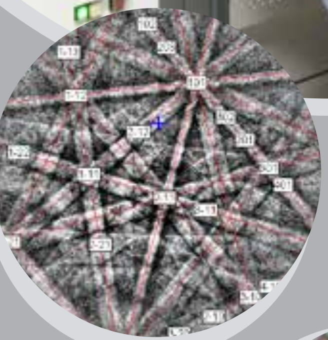


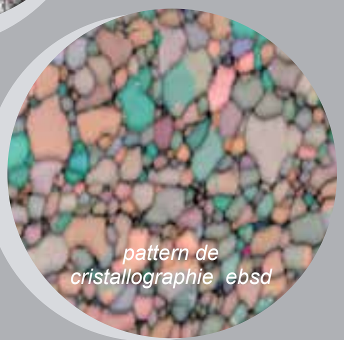
SEM

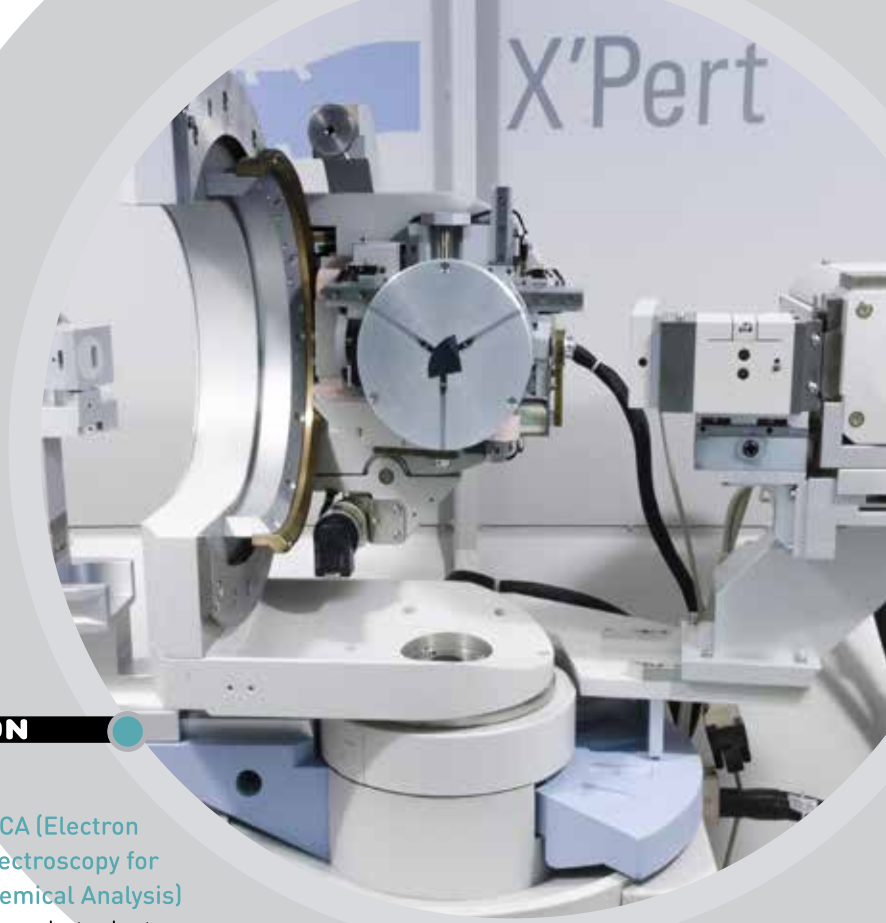
Christophe Boyaval

SEM (Scanning Electron Microscope) is a microscope that uses an electron beam to illuminate a specimen and produce a magnified image with a 1000 times higher resolution than optical light microscope.

Equipments
- ZEISS ULTRA 55 / EDS Bruker
- ZEISS SUPRA 55 VP / EBSD Oxford
- Maximum resolution : Close to 1nm @ 15kv
  Close to 3 nm @ 1kv
- Source type: Field effect gun
- Detector type: Inlens, Secondary and backscattered electrons
- Analysis: Chemical by EDS and Crystallographic by EBSD
- Wafer size: up to 6 inch
- Low Pressure: 1 to 133 mPa







PHYSICAL CHARACTERISATION

Christophe Coinon

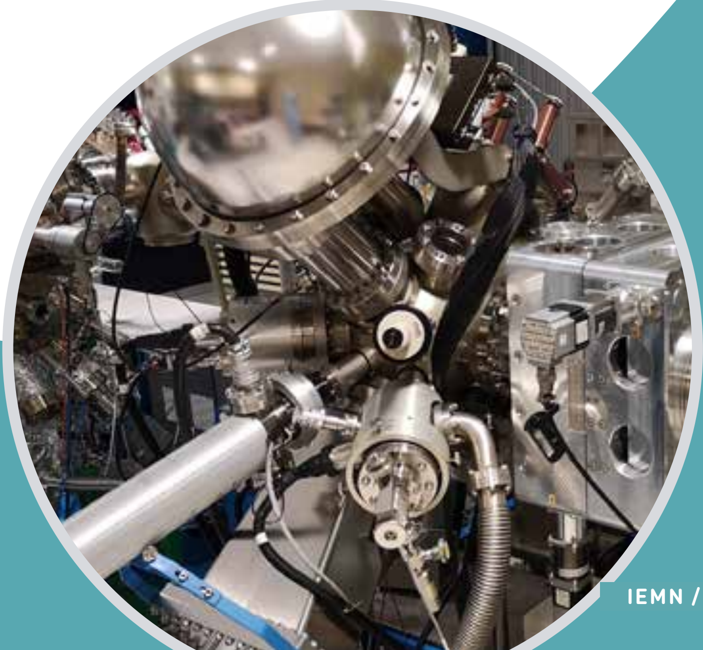
PANalytical X'Pert Pro MRD
TA-DA XRD (Triple and Double-Axis X-Ray Diffraction)
X-ray Diffraction is a tool used for determining the crystalline structure of solids, in which the periodic atomic arrangement causes a beam of X-rays to diffract into many specific directions. The structure is determined by measuring the angle and intensities of these diffraction peaks.

Applications →
- Alloy composition and thickness
- Control of lattice matching of epitaxial layers layers with the substrate
- Interface quality of superlattices
- Thin strained layers
- Relaxation rate, composition and tilt of mismatched layers

ESCA (Electron Spectroscopy for Chemical Analysis)
X-ray photoelectron spectroscopy (XPS) is a surface-sensitive quantitative spectroscopic technique. Based on the photoelectric effect, it allows determining the elemental composition at the parts per thousand range and the chemical state of the elements present within a material.

- Monochromatized XPS with ultimate resolution: 0.45eV
- UPS: HeI and He II excitations
- Low Energy Electron Diffractometer (LEED)

Applications →
- III-V MBE grown surfaces and interfaces
- Graphene
- Organic layers
- Characterization of process steps



CHARACTERISATION Unit

OPTICAL

Christophe Coinon, Yves Deblock, David Guérin

• 2 Horiba Jobin Yvon Spectroscopic Ellipsometers:
Based on optical polarisation for investigating the dielectric properties of thin films (complex refractive index, dielectric function). It can be used to characterise thickness, composition, roughness, crystalline nature, layer inhomogeneity (gradient, anisotropy). Single layers or complex multilayers from a few Å to several µm.
Uvisel: 200 nm - 2000 nm, variable angle, monochromator.
AutoSE: 440 nm - 1000 nm, mapping, spot views.

• Reflectometer
The NanoCalc Thin Film Reflectometry System allows to analyze the thickness of optical layers from 1 nm to 250 µm . Observation of single thickness with a resolution of 0.1 nm and single-layer or multilayer films in less than one second.

• µ-Photoluminescence & Raman Lab RAM HR
PL can be used for band gap measurement, alloys composition and thickness,
Interface studies of heterostrucutres.
Raman can be used for graphene (strain, doping, thickness)

• UV/vis Spectrometer (Perkin Elmer)
Absorption spectrum of liquids or thin films from 200 nm to 900 nm

• Mid/Near Infrared Spectrometer FTIR (Perkin Elmer)
Absorption spectrum by ATR, by specular reflectance or by transmission from 550 to 10000 cm-1 (1-20 µm)

ELECTRICAL

Christophe Coinon, Christophe Boyaval, David Guérin

• Hall Effect: The Accent HL5500PC is a turn-key, high performance Hall System for the measurement of resistivity, carrier concentration and mobility in semiconductors. Modular in concept, allowing easy upgrade paths, the system is suitable for a wide variety of materials, including silicon and compound semiconductors. It has both low and high resistivity measurement capabilities to 300K or 77K.

• Probe station: Two microwave probe stations are available in the IEMN for idv and junction measurement.

• The semilab WT-2000PVN system is a non contact platform for samples inspection (silicon, ...) quality control and process monitoring.
It is equipped with a variety of measuring options, including solar cell characterisations. It enables automatic mappings in the following modes:
- µ-PCD for determination of minority carrier lifetime
- LBIC for diffusion length and internal quantum efficiency evaluation on solar cells
- Eddy current for non-contact resistivity measurement
Thin film's Stress measurements

SURFACE TOPOGRAPHY

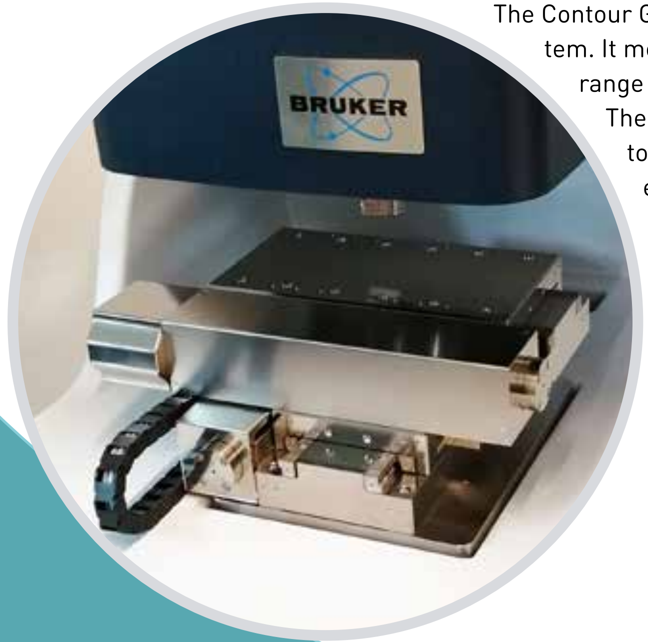
Christophe Boyaval, Flavie Braud

AFM Edge (Bruker).

The AFM Edge is used for measuring very small dimensions such as step heights and roughness on different materials. Roughness around 0.1nm and step heights below 1nm can be measured. Peak Force Tapping™ allows making measurements without damaging surfaces and tips. The motorized table authorizes the positioning of large substrates with a scanning range of 100µm.

Contour GT X Optical profiler (Bruker)

The Contour GT-X is a stand-alone optical surface-profiling system. It measures surface topography with high accuracy in a range from fractions of a nm up to approximately 10mm. The system contains motorized x/y, tip/tilt and z stages to enable automated production monitoring. It is equipped with four interferometric objectives of magnification 2.5x, 10x, 50x and 115x.



3 Mechanical profilometers

They are used for measuring step heights from 10 nm to 1 mm. A stylus on a capacitive cantilever scans the profile of various types of matérials (resists, metallic plots and so on...). Scan range up to 6 inches are available.

MECHANICAL and PHYSICAL

Marc Dewitte

FSM 500TC

The FSM 500TC is a thin film stress measurement system that can test the stress of different films on reflective substrates. The system uses a Non Destructive Optilever™ Laser Scanning technique to measure the change of curvature induced in a wafer due to a deposited film. It can measure stress hysterisis changes in the film during a heat cycle. It has an N2 ambient and a programmable temperature control system, allowing the evaluation of the thermal properties and stability of the films.

- Manual mapping possible
- Film Stress measurements with repeatability of 1.5%.
- Temperature range from room temperature to 500 °C.
- Wafer size from 2inch to 8inch.

Unit SOFT LITHOGRAPHY MACHINATING STATION

Soft Lithography Manager : Aude Sivery

The Soft-lithography resource enables the development and characterization of microfluidic devices.
1 Full time employee

MACHINING STATION

CNC milling machine, DATRON NEO

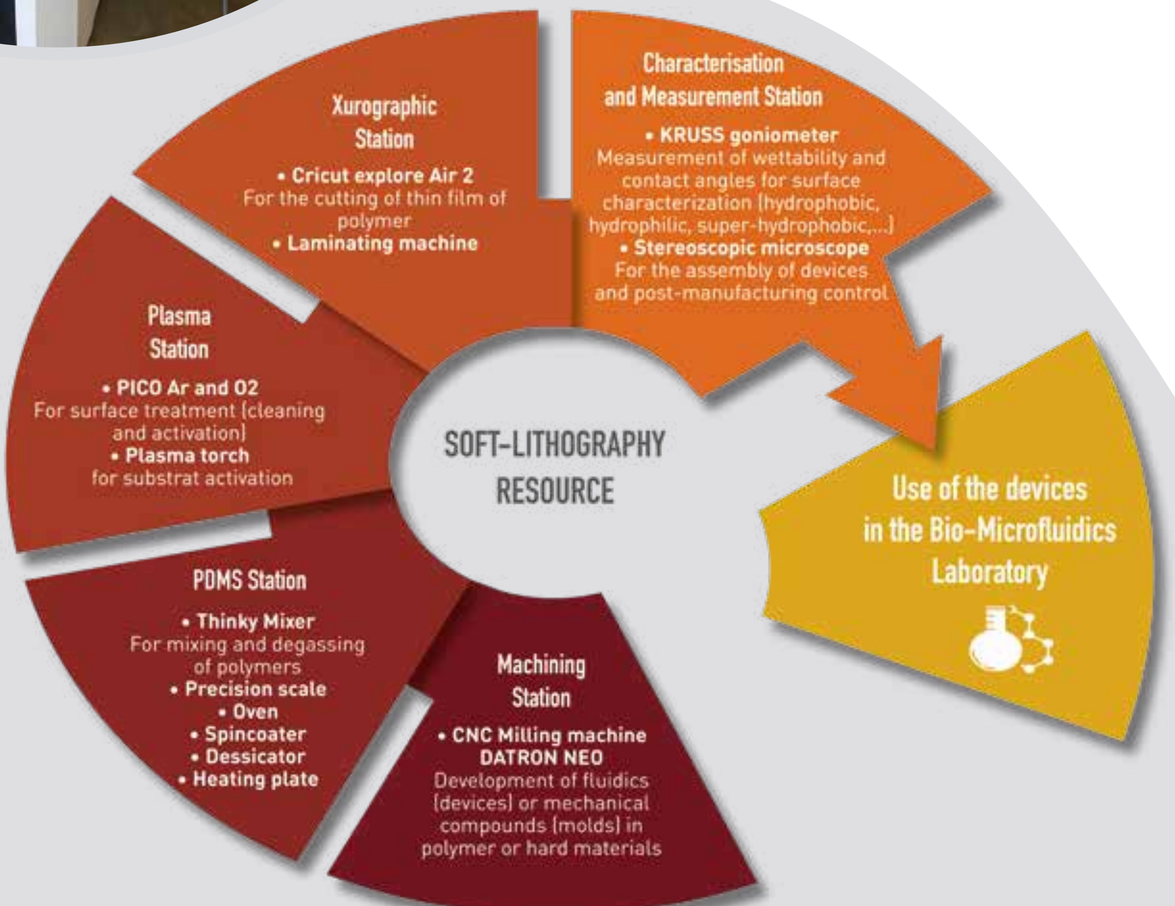
Development of fluidics (devices) or mechanical compounds (molds) in polymer or hard materials

The DATRON neo is a CNC milling machine which enables the ultra-fast and efficient machining of different materials.

Whether for 3, 3 + 2 or 5 simultaneous, high precision or economical machining.

Compatible materials:
- Composites
- Aluminum
- Light alloys
- Wood
- Plastics
- Carbon fiber reinforced plastic
- Stainless steel
- Green ceramics

Machine capabilities:
- Milling
- Drilling
- 3D engraving

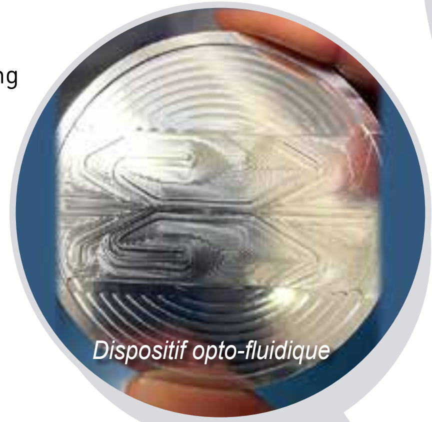


Unit SOFT LITHOGRAPHY PDMS STATION

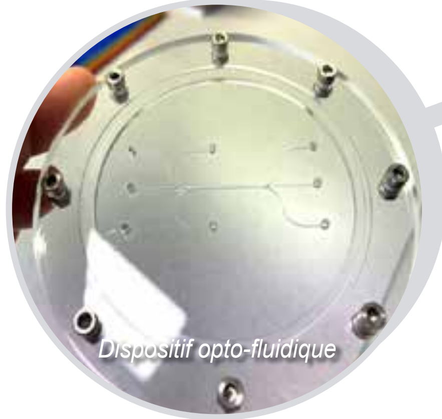
SPIN-PROCESSOR LAURELL WS-650-23 B

The Laurell WS-650-23 B spin coater system will accommodate up to ø150mm wafers and 5» × 5» (127mm × 127mm) substrates, and features a maximum rotational speed of 12,000 RPM (based on a ø100mm silicon wafer).

The WS-650 series is typically employed for Solvent, Base or Acid-based processing:
- Coating
- Etching
- Developing
- Rinsing-Drying
- Cleaning


Dispositif opto-fluidique


Plateforme microfluidique


Dispositif opto-fluidique

THINKY MIXER ARV 310

The association of the vacuum function with the rotary and revolutionary movements allows the complete deaeration of almost all fluids.

The memory mode allows the user to reproduce the optimal conditions of their own mixes for high repeatability

Technical Description:
- Vacuum function: optimal bubble-free dispersion
- Deaerated mixture of highly viscous materials
- Guaranteed without flow, sedimentation or foam during the operation
- Modifiable RPM for mixtures of all types
- Viscosity regulator

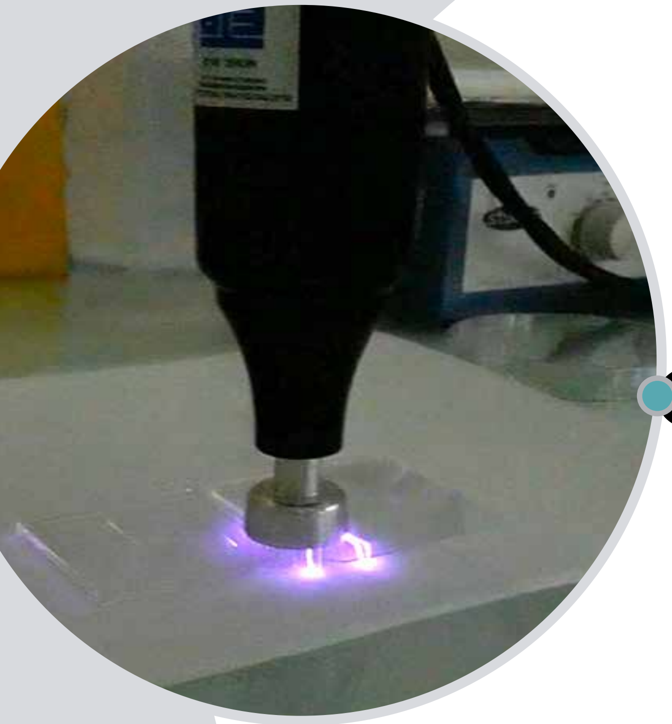
Unit SOFT LITHOGRAPHY

PLASMA STATION

Soft Lithography Manager : Aude Sivery

PLASMA STATION: Ar and O_2 plasma Station

- Cleaning of surfaces
(before bonding, soldering or gluing)
- Activation of surfaces
(before printing, varnishing or gluing)
- Etching of surfaces
(microstructuring of silicon or etching of PTFE)
- Coating of surfaces - plasmapolymerization
(deposition of hydrophobic/hydrophilic layers)



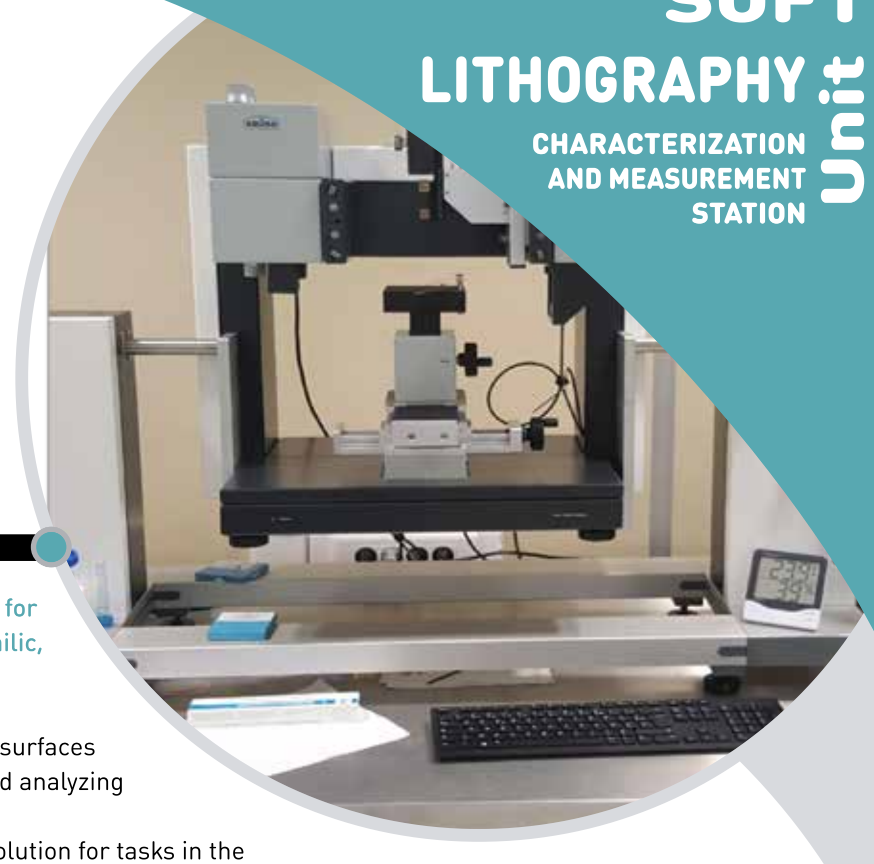
PLASMA TORCH ElectroTechnicProducts MODEL BD 20V

The Corona equipment enables a quick and easy treatment surface, and can be used to bond PDMS with glass or PDMS with PDMS very quickly (a few minutes).
Indeed the Corona tool will change the surface properties in much the same way as a traditional plasma cleaner treatment.
The corona produces a high voltage and high frequencies sparks at the tip of an electrode to ionize the air.

Main Characteristics:
- Device adapted for Soft-lithography applications
- Manual PDMS bonding
- Quick and easy PDMS bonding
- Create quickly strong link between PDMS with glass and PDMS with PDMS

Unit SOFT LITHOGRAPHY

CHARACTERIZATION AND MEASUREMENT STATION



KRUSS GONIOMETER DSA 100

Measurement of wettability and contact angles for surface characterization (hydrophobic, hydrophilic, super-hydrophobic ...)

For wettability and wall angles measurements, surfaces characterization (hydrophilic, hydrophobic...) and analyzing wetting and coating processes
The Drop Shape Analyzer DSA100 is a system solution for tasks in the analysis of **wetting** and **adhesion** on solid surfaces.

Comprehensive analysis of solids and liquids
The DSA100 measures the surface tension of liquids using the **Pendant Drop** method.
The results can be used to analyze the relationship between the wetting of the solid and the liquid properties.

LYNX EVO STEREOMICROSCOPE

For devices assembly and control post-production

- Used for inspection, production, or retouching post-production and gives a 3D depth perception and bright, high-resolution, high-contrast images
- Magnifications from 2.7 X to 240 X
- Very reliable for working in fine detail with magnifications up to 240x, with top and bottom lighting for working on opaque, translucent or perforated subjects.
- The absence of eyepieces removes the adjustment necessary for different users and make it possible to wear safety glasses
- Offering an angular view of the subject, with the microscope head raising and lowering, sliding and rotating, this setup enables the inspection and retouching, with generous space for working with tools

BIO MiCRO FLUIDIC Unit

CELL CULTURE FACILITIES

Bio Micro Fluidic Manager : Aude Sivery

The Biomicrofluidic resource includes all the equipment necessary for cell culture, microscopy and microfluidics experiments.
1 Full time employee

BIOLOGICAL SAFETY CABINET, MSC ADVANTAGE

A Biological Safety Cabinet is a ventilated enclosure offering protection to the user, the product and the environment from aerosols arising from the handling of potentially hazardous micro-organisms. The continuous airflow is discharged to the atmosphere via a HEPA filter. This class 2 cabinet is used when working with **low to moderate risk biological agents.**

The primary purpose of a BSC is to serve as a means to protect the laboratory worker and the surrounding environment from pathogens. All exhaust air is **HEPA**-filtered as it exits the biosafety cabinet, removing harmful **bacteria and viruses.**

The three States of Protection :

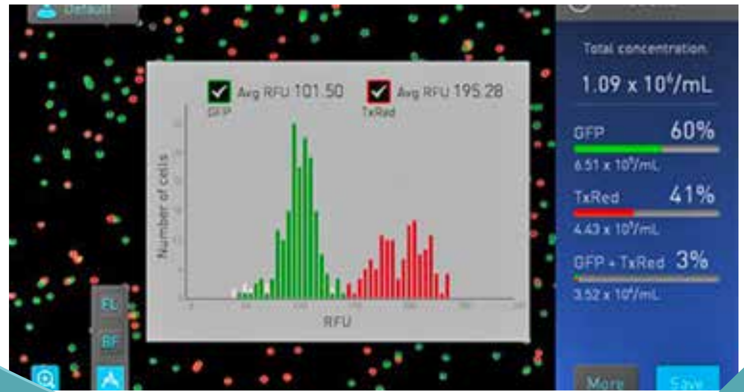
- Personal Protection from harmful agents within the cabinet
- Product Protection to avoid contamination of the samples
- Environmental Protection from contaminants contained within the cabinet

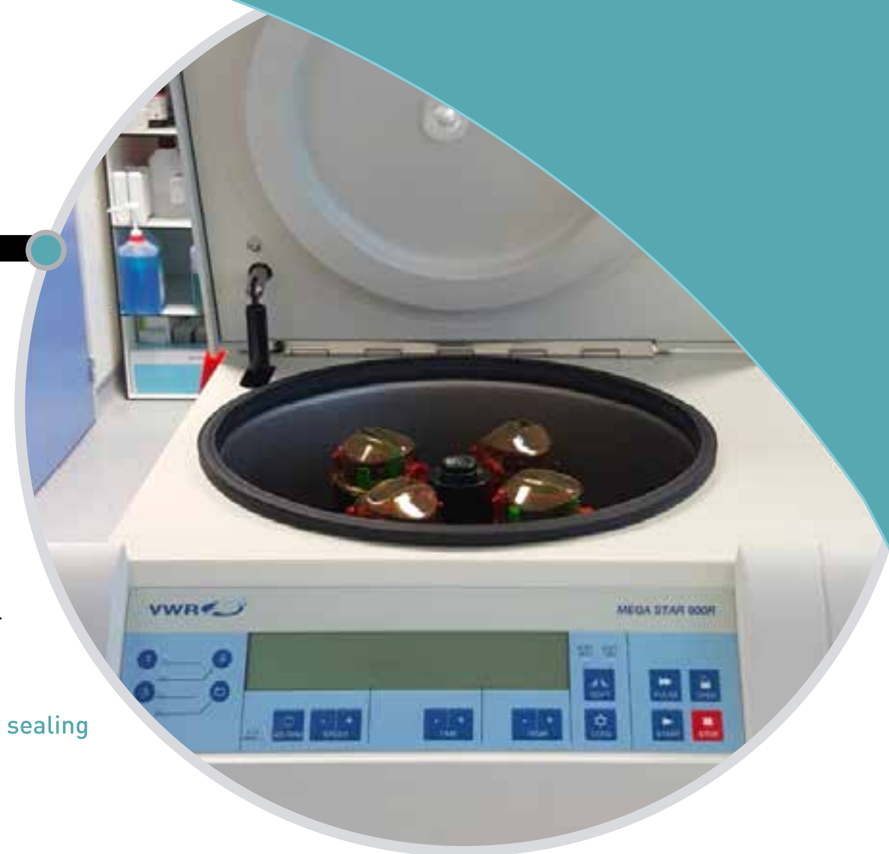
AUTOMATED CELL COUNTER, LIFE TECHNOLOGIES COUNTESS II

The Countess™ II Automated Cell Counter is a fully automated cell counter and assay platform that uses state-of-the-art optics and image analysis algorithms to analyze trypan blue-stained cells in suspension.

• The cells to be counted are loaded into the instrument in disposable Countess™Cell Counting Chamber Slides. Each chamber slide contains two enclosed chambers to hold the sample to allow to measure two different samples or perform replicates of the same sample.

• The Countess™ II Automated Cell Counter takes 10 seconds per sample for atypical cell count and is compatible with a wide variety of eukaryotic cells. In addition to cell count and viability, the instrument also provides information on cell size





CENTRIFUGE VWR MEGA STAR 650

This centrifuge is used as a laboratory apparatus, to separate mixtures of substances of different density. The centrifuge is suitable for temperature-sensitive sample processing with control between −10 and +40 °C.

• Auto-Lock® III rotor system:
Tool-free rotor exchange system enables quick rotor exchange; with just the push of a button users can quickly change rotors and easily access the rotor chamber for cleaning.

• Aerosol-tight ClickSeal® bucket caps and rotor lid sealing system:
Glove friendly one-handed open/close capability.

• Two rotors are available on this centrifuge:
-TX-150 swing out rotor: It offers high speed and high capacity (e.g. 24× 5/7 ml blood tubes or 8x 15 ml conical tubes) combined with the flexibility of a wide range of adapters.

• MicroClick 24 x 2 angle rotor:
This high speed rotor has a max. capacity of 24× 1,5/2,0 ml micro tubes and reaches a max. RCF of 30279 ×g. Ideal for microvolume protocols such as nucleic acid preparation, PCR reaction set up and filtration columns.

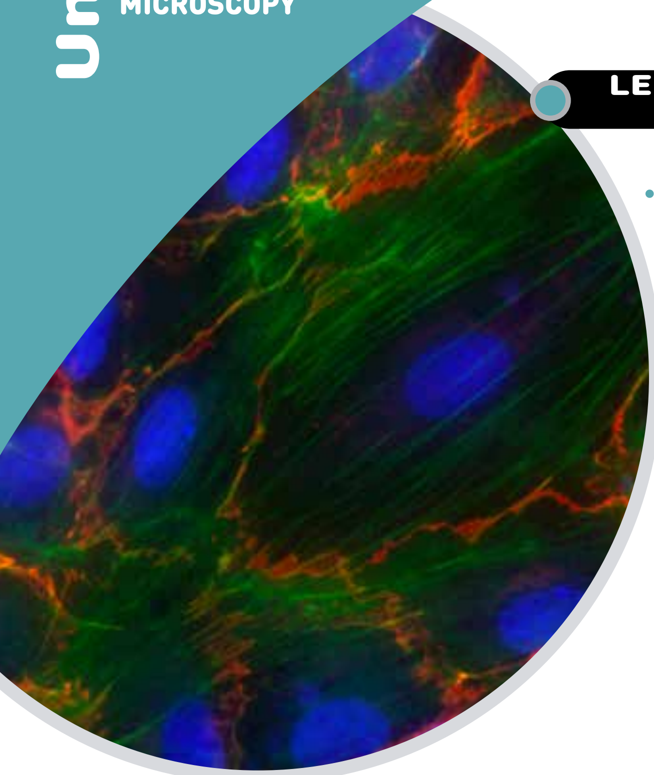
AUTOCLAVE, SYSTEC VX95

Enable to Sterilize solids, liquids and hazardous biological substances. The autoclave is used to sterilize solids and liquids trashs coming from cell culture experiments.
It can also be used to sterilize microdevices before using them in microfluidic experiments.

Standard Features

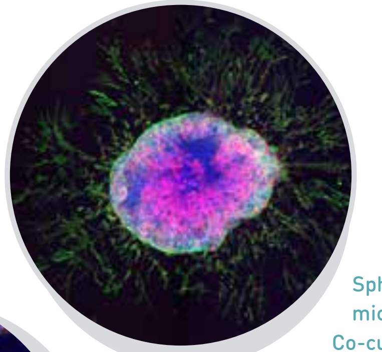
- Integrated, separate steam generator
- Temperature: Up to 140°C
- Pressure: Up to 4 bar
- Number of sterilization programs: Up to 25
- Code-secured access rights for changing parameters and further safety-relevant intervention
- Autofill: automatic demineralized water feed for steam generation

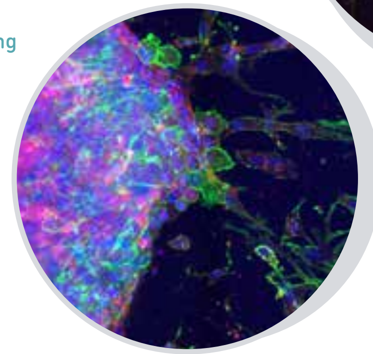
LEICA DMI8 MICROSCOPE ENVIRONMENTAL



HUVEC cells. Hoechst staining for the nucleus (blue). Alexa fluor 546 staining for VE-cadherin (red) and Alexa fluor 488 staining for actin staining (green). 100X immersion oil objective

- This microscope makes it possible to make acquisitions in phase contrast and epi-fluorescence
- It is equipped with a motorized X, Y and Z stage
- The Adaptive Focus Control (AFC) allows long-term acquisitions without focus drift over time
- The temperature and CO2-controlled environmental enclosure allows real-time imaging of devices possibly coupled to microfluidics. The large chamber incubation system is used for the stabilization of temperature and humidity which is designed for pre-heating cell and tissue cultures

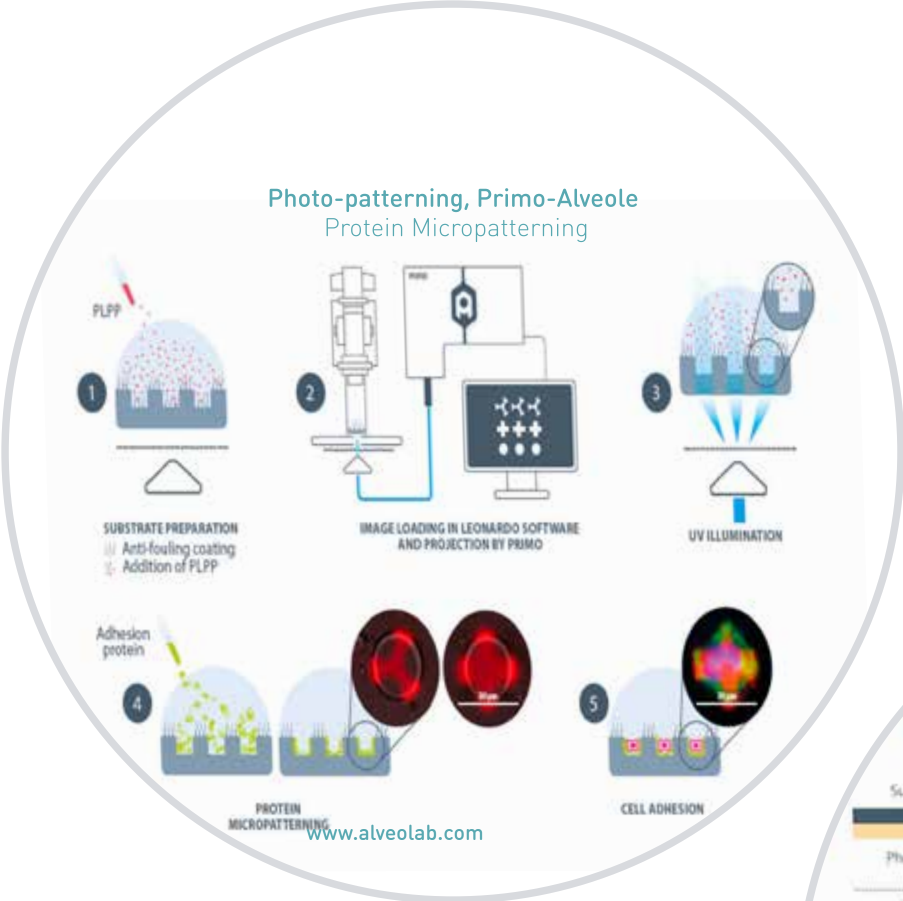




Spheroid inside a 3D perfusion microfluidic device from Ibidi. Co-culture of HUVEC and MCF7 cells. MCF7-mcherry cells appear in red, Actin filament in green and cells nucleus in blue

Filter Cubes	Excitation (nm)	Emission (nm)	Associated LED (nm)
DAPI	325-375	435-485	365
FITC	460-500	512-542	460, 470, 490, 500
Rhodamine	541-551	565-605	550
Y5	590-650	662-738	595, 635

Microscope Lens	Magnification	Numerical Aperture	Immersion	Correction Collar	XY resolution	Z resolution	Working Distance	Serial number
HC PL Fluotar L	63 X	0,7	Dry	0,1-1,3	0,479 µm	1,122 µm	2600	11506216
HC PL APO	100 X	1,44	Oil	0,10-0,22	0,233 µm	0,403 µm	100	11506325
HC PL APO	63 X	1,4	Oil	0,17	0,240 µm	0,426 µm	140	11506379
HC PL Fluotar L	40 X	0,6	Dry	0-2	0,559 µm	1,528 µm	3300	11506203
HC PL Fluotar L	20 X	0,4	Dry	0-2	0,839 µm	3,438 µm	6900	11506243
HC PL Fluotar	2,5 X	0,07	Dry	-	4,793 µm	112,245 µm	9400	11506523



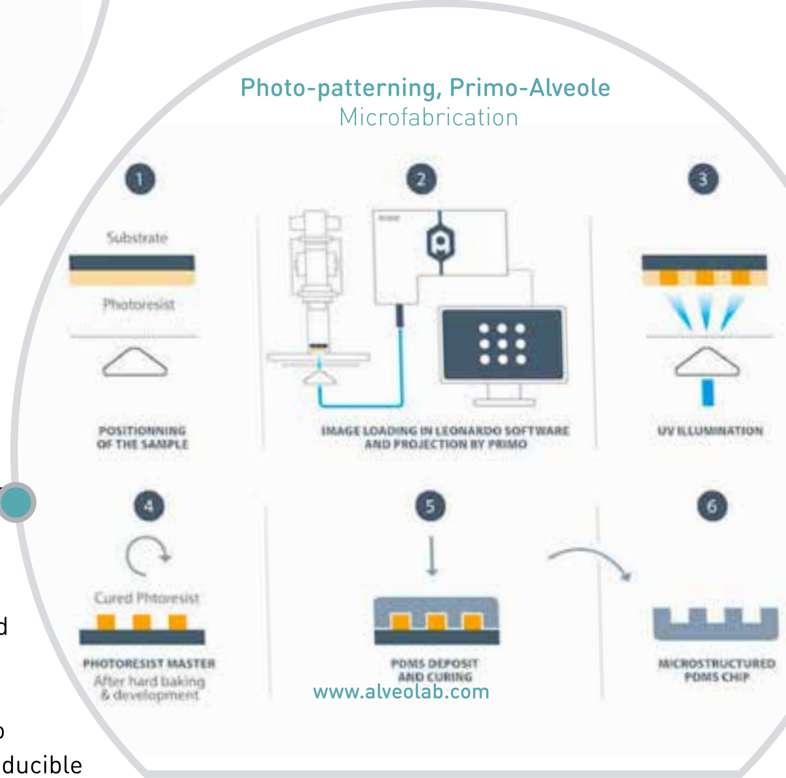


PHOTO-PATTERNING, PRIMO-ALVEOLE

The PRIMO maskless photopatterning system (DMD based) can engineer custom in vitro cell microenvironments through three techniques: micropatterning, hydrogel structuration and microfabrication.

- **Micropatterning:** Allows to precisely control cell adhesion to mimic in vivo phenotypes, isolate them or place them in reproducible conditions for standardized assays.

- **Microfabrication:** PRIMO maskless DMD-based photopatterning system can perform greyscale photolithography on greyscale resists to create complex 3D molds such as ramps, curving wells or microfluidic chips for organ-on-a-chip applications.

- **Hydrogels:** As a photopatterning system, PRIMO can also polymerize and photo-scission most commonly used hydrogels for applications such as 3D cell culture or permeable hydrogel membranes polymerization within microfluidic chips.

- **Fields of application:** The system allows to better study the behavior and development of living cells in a broad range of applications, such as: cytoskeleton dynamics, cell adhesion force measurement, cell confinement, cell migration, tissue engineering, spheroids.

Bio Micro Fluidic Manager : Aude Sivery

SYRINGES PUMPS NEMESYS

Nemesys medium pressure pumps are used for the precise injection of liquids into systems operating at higher pressure levels or with viscous liquids.

The NeMESYS syringe pumps allow emptying and filling syringes by the relative linear movement of a syringe-and a piston holder.

The NeMESYS syringe pump serves for precise and pulsation-free dosing of fluids in the range of nanoliters per second up to milliliters per second.

Benefits:

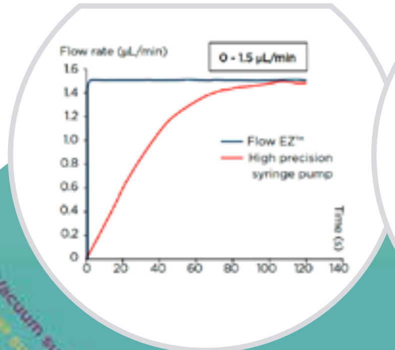
- Support of high-pressure valves for the creation of continuous fluid streams
- Glass syringes or four sizes of stainless steel syringes are available
- Accurate dosing for pressure levels of up to 200 bar
- Modular system: multiple modules can be plugged together

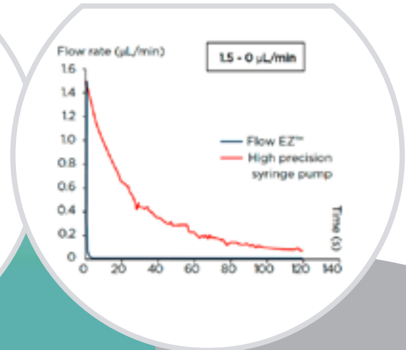
PRESSURE AND VACUUM CONTROLLER : LINEUP PUSH-PULL FLUIGENT

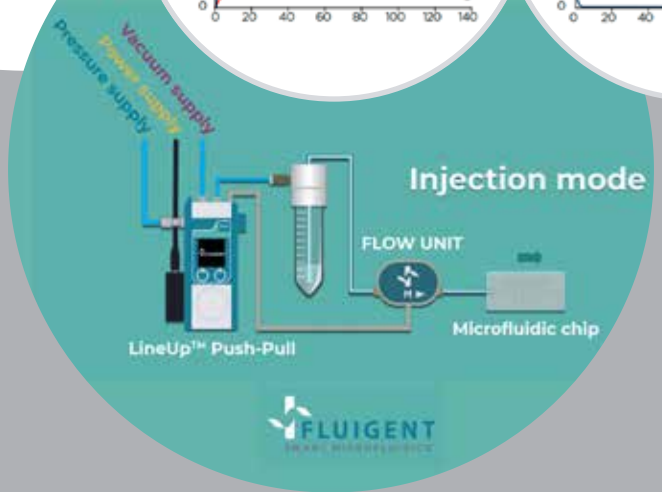
The **LineUp™ Push-Pull** is a standalone controller with the ability to deliver **finely regulated pressure** or a **vacuum** through a single outlet over the range of **-800 to +1000 mbar**. It can be used **without a PC** or controlled with **Fluigent Software Solutions** to benefit from **control in real-time**, protocol **automation**, graphic displays and **custom integration**. Combined with a **FLOW UNIT** it allows for **direct control of flow rate**.

www.Fluigent.com

www.Fluigent.com



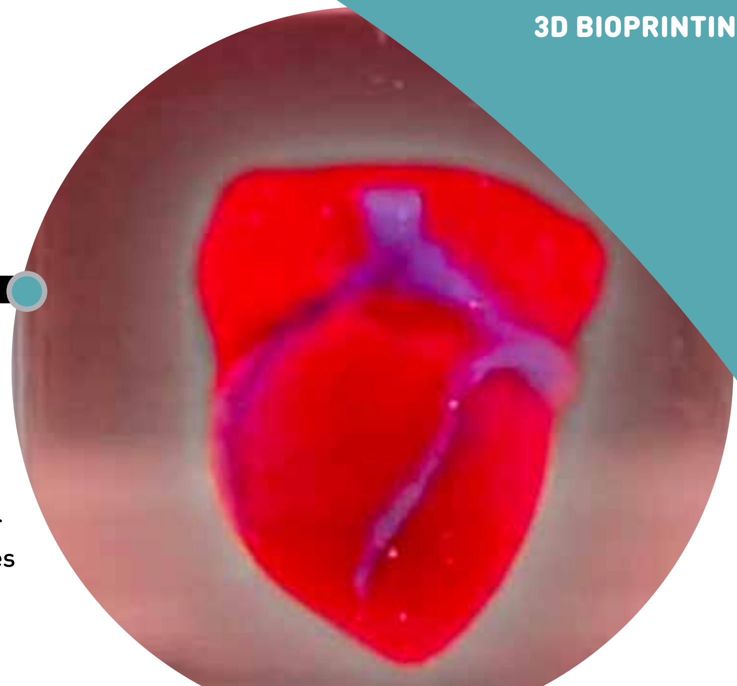




3D BioInk PRINTER

3D bioprinting is the utilization of 3D printing like techniques to combine cells, growth factors, and biomaterials to fabricate biomedical parts that maximally imitate natural tissue characteristics.

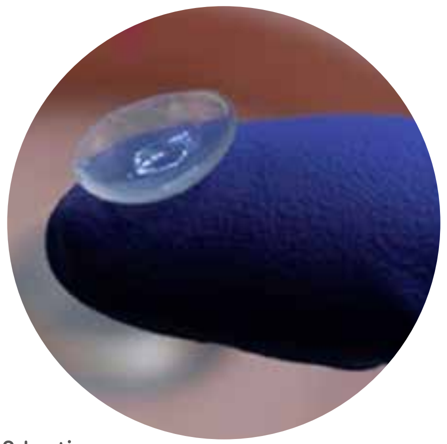
The 3D BioX from CellInk utilizes the layer-by-layer method to deposit bioinks to create tissue-like structures that are later used for biological research.



www.3dnatives.com

Features

- Temperature Controlled Printbed (4 C to 60 C)
- Compatible with standard petri dishes, multi wellplates, and custom inserts
- Compatible with a **wide range of bioinks in CellInk library**
- Clean chamber technology with UV-C germicidal lamps and HEPA H14 dual-filter system
- Exchangeable Photocuring Modules : 365 nm and 405 nm



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- ablation-laser@iemn.fr
- evaporation@iemn.fr
- implant@iemn.fr
- gravure@iemn.fr
- maintenance@iemn.fr
- Accueil-projets@iemn.fr
- analyse-in-line@iemn.fr
- ald@iemn.fr
- pecvd@iemn.fr

Site IEMN : https://www.iemn.fr

Site RENATECH : https://www.renatech.org

Site litho : https://litho.priv.iemn.fr/bddlitho/bdd.php
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IEMN / CMNF

iemn

Institute of Electronics, Microelectronics and Nanotechnology

IEMN - Laboratoire Central
UMR CNRS 8520
Cité Scientifique
Avenue Poincaré BP 60069
59652 Villeneuve d'Ascq Cedex - France
Phone: +33 (0)3 20 19 79 79
Fax: +33 (0)3 20 19 78 78

IEMN - Antenne Université de Lille
Cité Scientifique, Bât. P.3 & P.5
Avenue Poincaré BP 60069
59652 Villeneuve d'Ascq Cedex - France
Phone: +33 (0)3 20 43 67 06
Fax: +33 (0)3 20 43 65 23

IEMN - Antenne OAE
Université Polytechnique Hauts-De-France
59313 Valenciennes Cedex 9 - France
Phone: +33 (0)3 27 51 12 39
Fax: +33 (0)3 27 51 11 89

IEMN - Antenne CCHB
CAMPUS Haute-Borne CNRS IRCICA-IRI-RMN
Parc Scientifique de la Haute Borne
50 Avenue Halley BP 70478
59658 Villeneuve d'Ascq - France
Phone: +33 (0)3 62 53 15 00

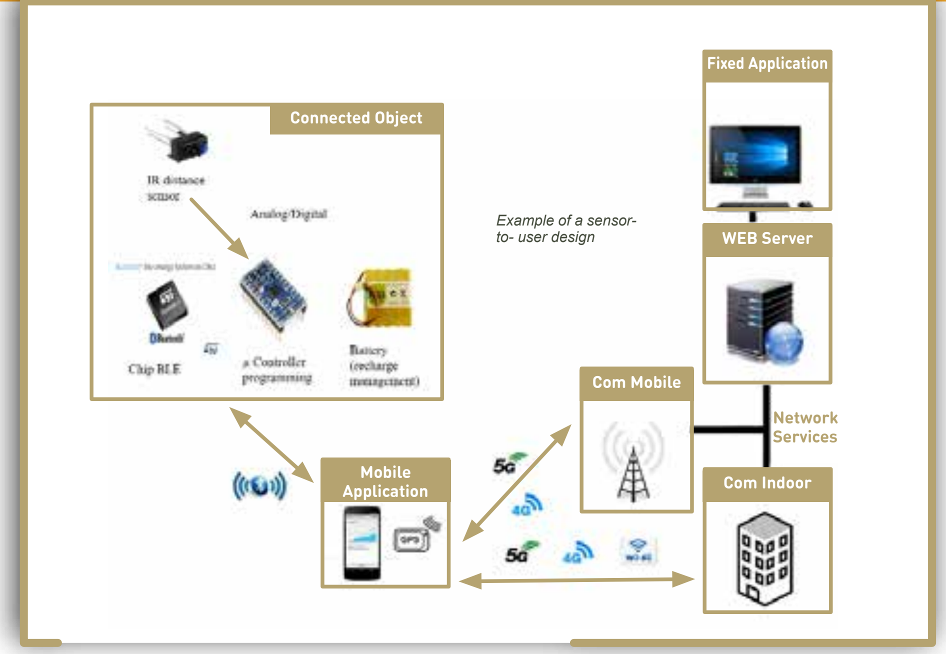
IEMN - Antenne JUNIA
41, Boulevard Vauban
59046 Lille Cedex - France
Phone: +33 (0)3 20 30 40 50
Fax: +33 (0)3 20 30 40 51

https://www.iemn.fr
accueil-projets@iemn.fr
logiciel «MyFab» : lims.iemn.fr

Integration & Prototyping

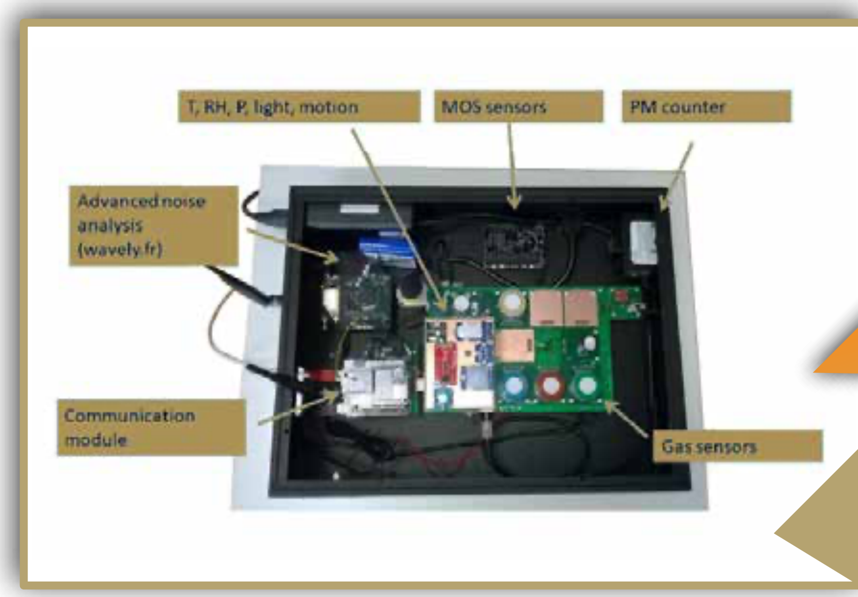
INTEGRATION PROTOTYPING

The integration/prototyping expertise center is a cross-disciplinary center of the IEMN at the service of academic research and partnerships to meet the needs of design, production and testing of innovative complex multi-scale systems from the sensor to the end-user. The pooling of resources guarantees expertise and the sharing of knowledge and know-how to validate and develop new concepts and devices.



Example of a sensor-to- user design


Temporal visualization of data from a sensor node



INTEGRATION

Unit BACK END

Back end process refers to the process done outside cleanroom at chip level from wafer backgrinding to packaging.
2 Full Time Employees

LAPPING, POLISHING

Karine Blary

for a slow lapping and a soft polishing

A plate in rotation carries a cloth impregnated of an abrasive micro suspension. The sample, laid out on a head in rotation and translation, is brought to the contact with a controlled pressure.

PM5 (LOGITECH)

Main Characteristics:

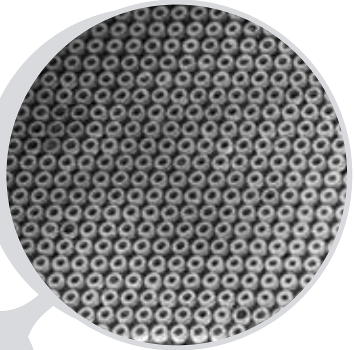
- Materials: III-V Materials (InP, AsGa), Si, Lithium Niobate ...
- Up to 4'' wafers and small pieces
- Sample maximum thickness: 2 mm
- Plate speed: 0-70 rpm
- Applied pressure: 0 to 2 kg
- Removed material mesured by a dial gauge - 1 to 5 µm/min
- Autofeed system
- Automatic lapping plate flatness control
- Thickness resolution : +/- 5 µm
- Roughness of the order of nm

Wafer Substrate Bonding Machine (LOGITECH)

- Up to 4'' wafers and small pieces
- Automated process cycle
- Excellent wafer to support disc parallelism
- Process repeatability

Applications →

- Preparing the surface prior to fabrication,
- Thinning the device after fabrication,
- Providing defect free face polishing on substrate.



Ni pillars thinning and planarization

Silicon components reported on flexible substrate after grinding and chemical etching

MEGASONIC CLEANING SYSTEM

Karine Blary

At the end of the lapping and polishing operations, the surfaces of the samples are contaminated by particles from slurries.
The Polos Spin-Meg Pie is dedicated for the cleaning of substrates, especially for the silicon wafers after CMP process. A spinner with a megasonic transducer composes it. The suitable wafer size is 3 or 4 inches. The standard fluid is desionized water but chemistry can be used also for a better decontamination.

CMP

Karine Blary

E 460 (ALPSITEC)

CMP: for a soft and precise polishing and planarisation process

Chemical mechanical planarization is a process of smoothing and planing surfaces with the combination of chemical and mechanical forces, in order to prepare them for the following steps.
The CMP tool consists of a rotating platen, covered by a pad. The wafer is mounted upside down in carrier. The platen and the carrier are rotating. Pressure is applied by down force on the carrier.
A slurry is supplied from above on the platen.

Main characteristics:

- Authorized substrates: from 2 to 4 inches, possibility to work with small sized-samples
- Substrate rotation speed: 5-130 rpm
- Plate rotation speed: 5-120 rpm
- Applied pressure: 0-950 mdaN/cm2
- 10 steps per recipe
- 4 slurries possible during the process
- Materiels: Si, poly Si, SiO_2, metals (Cu, W...)
- Maximum removed thickness: 20 µm

Applications →

- Interlevels dielectrics ILDs
- Shallow trench isolation STI technology
- Damascene process

GRINDER

Karine Blary

MPS 2 R300 (G&N)

For a fast and agressive mechanical thinning of substrates

A rotation abrasive wheel removes the material on a sample itself in rotation.

Main characteristics:

- Substrate: from 2 to 8 inches
- Five 4 inches substrates max
- Substrate rotation speed: 0-30 rpm
- Head max rotation speed: 2600 rpm
- Height precision: 3 µm
- Grinding speed: 1-30 µm
- Materials: Silicon SiC glass

Ultra pure deionized water allows cooling during the process.

POLISHING

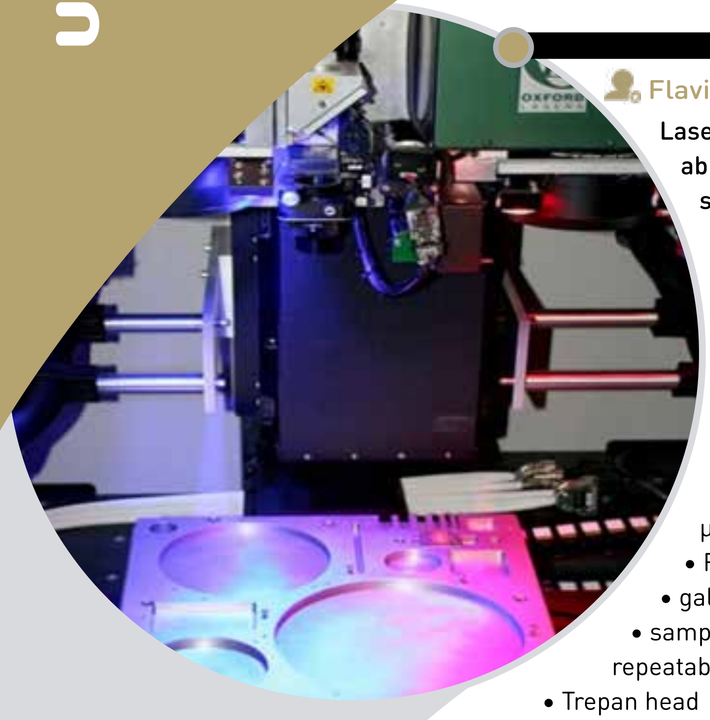
Karine Blary Flavie BRAUD

MINITECH 233 (PRESI)

The MINITECH Polishing machine is robust, powerful and reliable, it allows an easy use and simple maintenance. The machine provides a constant rotation of the plate, whatever the force applied, giving the possibility to polish large sized samples.
MINITECH range can be equipped with plates Ø 200mm or Ø 250mm.

INTEGRATION

Unit BACK END



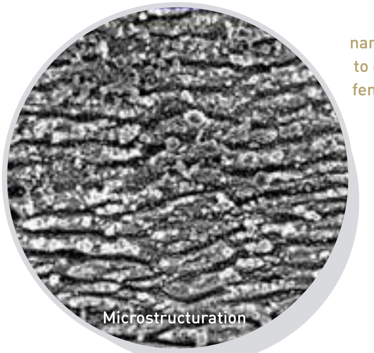
LASER ABLATION

Flavie BRAUD

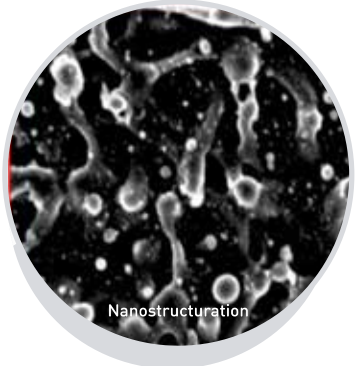
Laser micromachining is emerging as a key technology for structuring, ablating, scribing, cutting, drilling a wide range of materials as diverse as semiconductor crystals, metals and plastics. Ablation selectivity betwen materials can be achieved with a proper selection of wavelength, laser shot repetition rate and beam velocity. Two laser micromachining equipments are available, operating in the nanosecond and femtosecond pulse regimes, respectively.

Oxford Laser Equipment #1, Photonics Industries DS UV Series

- Multi-wavelength femtosecond (300fs) diode-pumped (DPSS) lasers source (UV 343,GR 515,IR 1030 nm)
- Average power up to 20 W @ 200 kHz and pulse energy up to 100 µJoule in IR
- Repetition rate up to 2 MHz
- galvanometer deflection with extended field of 50×50mm2
- sample stage up to 300×300 mm2 with linear accuracy +/- 0.5 µm, repeatability +/- 0.2µm
- Trepan head
- Position synchronized output (PSO)



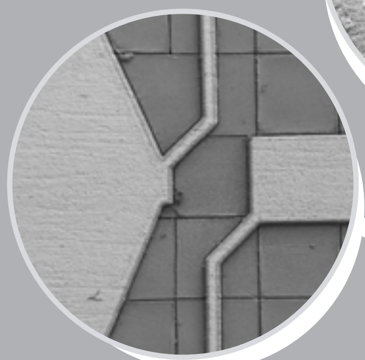
Micro and nanostructuration of metal to create black metal with femtosecond laser system



Oxford Laser Equipment #2, Amplitude Tangerine laser

- UV nanosecond (35 ns) diode-pumped (DPSS) lasers source (351 nm)
- Average power up to 8 W @ 4 kHz and pulse energy up to 5 mJoule
- galvanometer deflection with extended field of 50×50 mm2
- sample stage up to 300×300 mm2 mm2 with linear accuracy +/- 0.5 µm, repeatability +/- 0.2µm

AlN micromachining : Blind and pass-through via (nanosecond laser system)



µ-PCB for mmW applications (laser femto system)

DICING SAW DAD 3240

Flavie BRAUD Karine Blary

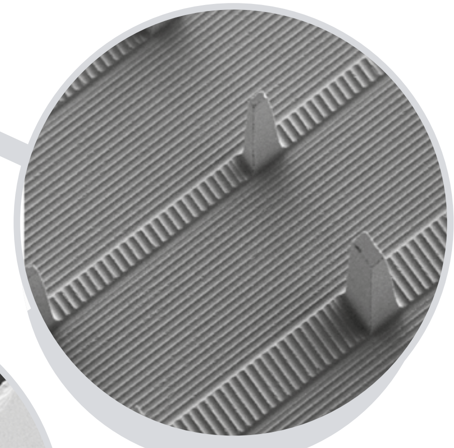
Diamond saw for substrates dicing, components individualisation

The substrate to be diced is positionned on a flexible adhesive film and fixed on the chuck. After alignment between the cutting ways on the substrate and the blade, the substrate moves at a selected speed under the blade. The blade is cooled by water jet and its rotation speed is controlled. Dicing can be made in manual or automatic ways.

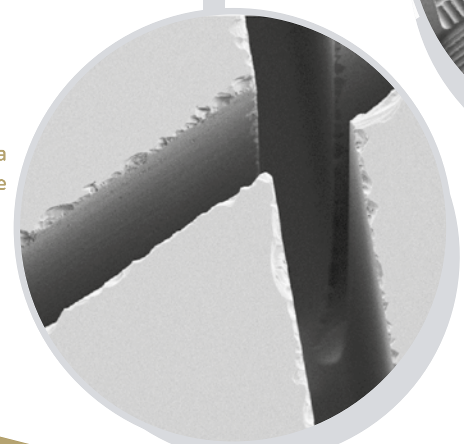
Main characteristics:

- Rotation speed of the blade: 6,000 - 60,000 rpm
- Chuck displacement speed: 0.1 - 600 mm/s
- Substrates size: up to 8 inches max
- Materials: III-V materials, silicon, glass, ceramics, SiC saphir
- Optical alignnment of the blade

Dicing & Patterning



Pillars carried out by DISCO dicing saw



SEM picture of a cutting line

INTEGRATION

Unit BACK END

WIRE BONDING

Karine Blary

JFP WB-100 wire bonder

Wire Bonding: Realisation of electric connections between the component and its support

Wire bonding is a method to make interconnections between a semiconductor device and its packaging during semiconductor device fabrication. A conductor wire is positionned using a specific tool (ball or wedge) to the top of the metal pad of the component contact. A welding is created by the application of force and ultrasounds. An heating effect can be added according to the nature of wire.

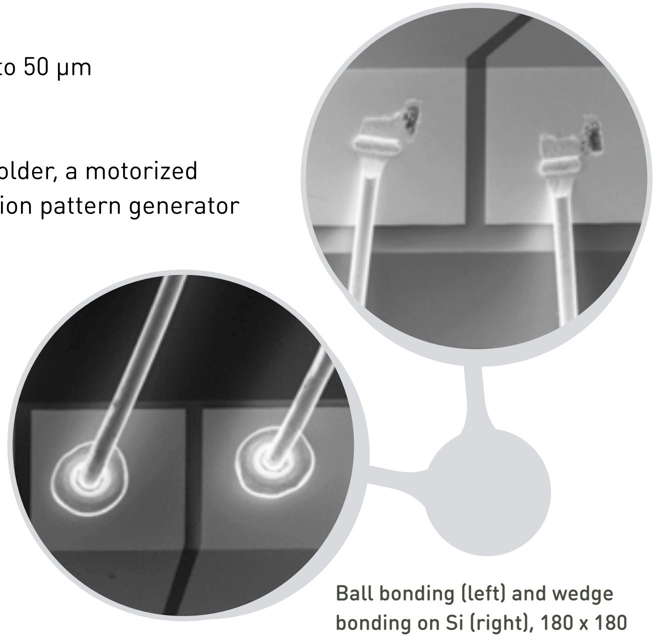
Main characteristics:

- Wire types: Au, Al
- Wire diameters: 12 to 76 microns
- Principle: ultrasonic and thermosonic

Technical characteristics of the WB100:

- Wedge, ball, bump bonder
- Bond force: 15 - 100 cNm
- Bond time: 15 - 5000 ms
- Gold wire diameter: 17 µm to 50 µm
- Motorized Z travel: 20 mm
- Throat depth: 165 mm.
- Fitted with a heated work holder, a motorized wire spool, and a digital position pattern generator coupled with a video cam

Micro-solder in ball mode on a crossbar device 100nm



Ball bonding (left) and wedge bonding on Si (right), 180 x 180 µm pads

WAFER SCRIBER/BREAKER

Wafer Scriber/Breaker: Realisation of a seed in a preferred crystallographic direction to force the cleavage

The scriber is a machine designed scribing & breaking of delicate die, such III-V materials & silicon chip. It keeps the finished die clean and damage-free.

After positioning the substrate on the Mylar film, it aligns the diamond tip on the cutting or along the desired axis lines. Then, it strongly supports the diamond peak on the surface by dragging the substrate to create a fracture line.

Main characteristics:

- Diamond peak
- Substrate up to 4 inches
- Materials type: Si, AsGa, InP
- Resolution of position: 1 µm
- Vision system allowing a programmable or manual alignment
- Break mode: operator control or automatic
- Scribing length programmable and scribing repeatable
- Robust, vibration free, requiring minimal training to operate

JFP Model 100

PICK AND PLACE

Karine Blary Flavie BRAUD

JFP Model PP6-6:

The Flip Chip Die Bonder model PP6 is designed for accurate placement of delicate devices on substrate. It achieves high accuracy placement using high magnification optical device.

The machine provides for single collet vacuum pick and place of die from waffle pack, wafer, Gel-Pak or bulk die media and features adjustable and repeatable subsonic scrub. The placement accuracy is < 3µm, upon configuration.

Small and large devices can placed with flipped vision.

A robust, and reliable mechanical concept, designed to be external vibration free.

JFP Model 100

High precision positioning and connecting by pick-and-place

Flipe-Chip mounting for precision bonding of small componants

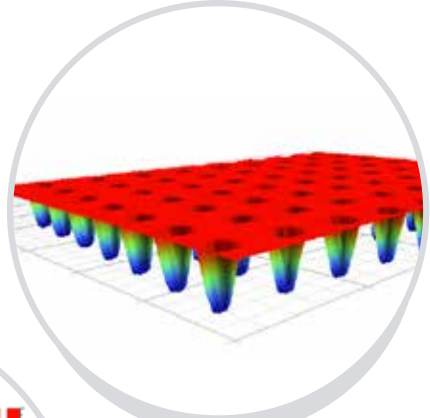
INTEGRATION Unit

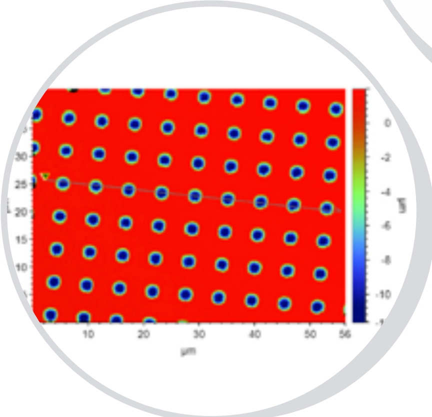
OPTICAL PROFILER

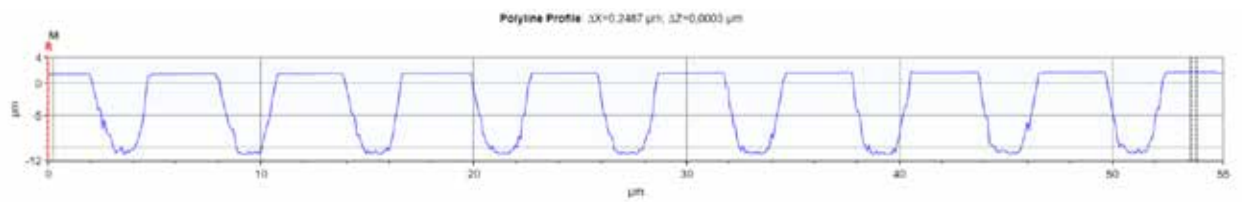
Flavie BRAUD

Contour GT-X, Bruker

The Contour GT-X is a stand-alone optical surface-profiling system. It measures surface topography with high accuracy in a range from fractions of a nm up to approximately 10mm. The system contains motorized x/y, tip/tilt and z stages to enable automated production monitoring. It is equipped with four interferometric objectives of magnification 2.5x, 10x, 50x and 115x







Topographic analysis of 2 µm holes in a silicon substrate

THROUGH-HOLE COPPER PLATING LINE

Bungard compacta 30 ABC

For laboratory prototyping of through-hole plated PCBs up to 210 x 300 mm size.
Clean system including built-in rinsing compartment.

- 5 treatment tanks, 2 of them with heaters
- 1 galvanic copper bath
- 1 triple-cascade rinse with flow control
- 1 spray rinse tank with magnetic valve, foot switch and flow control
- 1 free tank (i.e. for chemical tinning)

DRY FILM LAMINATOR

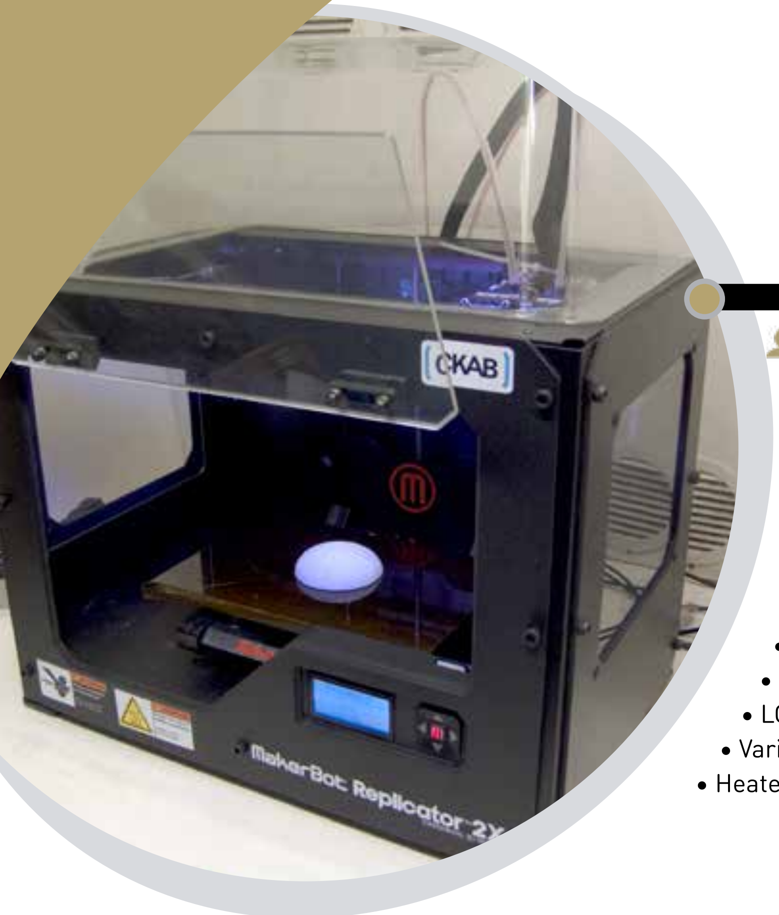
This equipment is suitable for the application of dry film resist containing a very thin temperature and/or pressure sensitive adhesive layer.

Bungard RLM419P

• Sample size: up to 400mm large and up to 8mm thick
• Hot rolls digitally controlled in the 20-200°C temperature range
• Pressure adjustable through the control of the edge gap between rolls

INTEGRATION

Unit BACK END



3D PRINTER

Christophe BOYAVAL

The dual-extruder MakerBot's Replicator 2X 3D printer produces good-quality objects.

MakerBot Replicator 2X

- Two extruders
- ABS, PETT, HIPS (dissolvable) filaments
- 100 µm layer resolution
- SD card / USB
- User-friendly software
- LCD navigation screen
- Various print modes
- Heated platform (110°C – 120°C)

devices by 3D printing

MACHINING STATION

Jean-Michel MALLET

CNC milling machine, DATRON NEO

Development of fluidics (devices) or mechanical compounds (molds) in polymer or hard materials

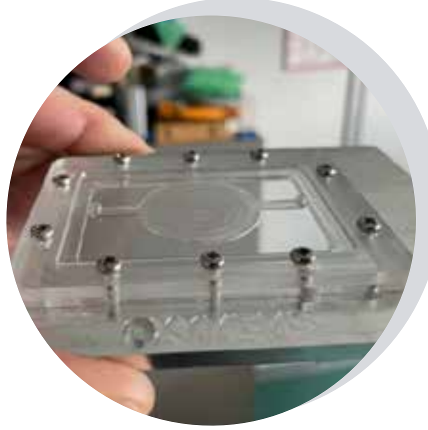
The DATRON neo is a CNC milling machine which enables the ultra-fast and efficient machining of different materials.
Whether for 3, 3 + 2 or 5 simultaneous, high precision or economical machining.

Compatible materials:

- Composites
- Aluminum
- Light alloys
- Wood
- Plastics
- Carbon fiber reinforced plastic
- Stainless steel
- Green ceramics

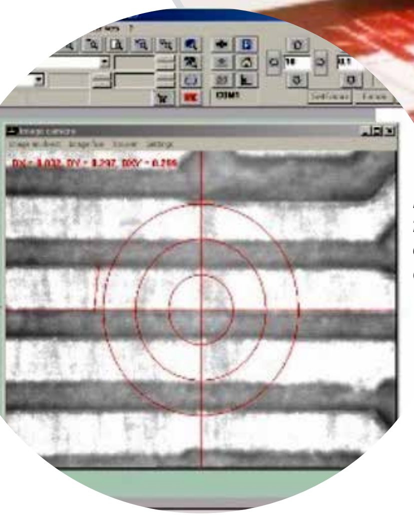
Machine capabilities:

- Milling
- Drilling
- 3D engraving



PROTOTYPING

Unit WORKSHOP



Mechanical engraver for the realization of high frequency circuit boards

PROTOTYPING WORKSHOP

Rédha KASSI David DELCROIX
Pierre LALY

The integration/prototyping expertise center is a cross-disciplinary center of the IEMN at the service of academic research and partnerships to meet the needs of design, production and testing of innovative complex multi-scale systems from the sensor to the end-user. The pooling of resources guarantees expertise and the sharing of knowledge and know-how to validate and develop new concepts and devices.

Our expertise in prototyping is segmented into four resources

- Design (design new advanced systems)
- Realization (quickly realize prototypes)
- Programming (programming digital components and systems)
- Test and measurement (functional validation and commissioning, intra and ex-tramural measurement campaign)

DESIGN:

Designing new advanced systems, up to demonstrator and/or prototype.
Interfacing hardware-software layers and/or instruments for the rapid develop-ment of complex systems (communication, analog and/or digital data acquisition, processing and visualization).

REALIZATION:

We have an electronics workshop with rapid prototyping equipment to produce multilayer test circuits with plated holes to validate new advanced prototypes.

PROGRAMMING:

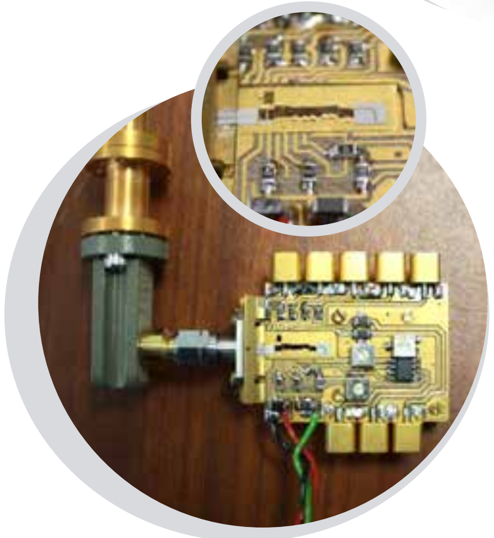
We have several programmable digital development platforms to interface hardware layers and/or instruments for the rapid development of complex systems (communication, data acquisition, processing and visualization).

TEST & MEASUREMENT:

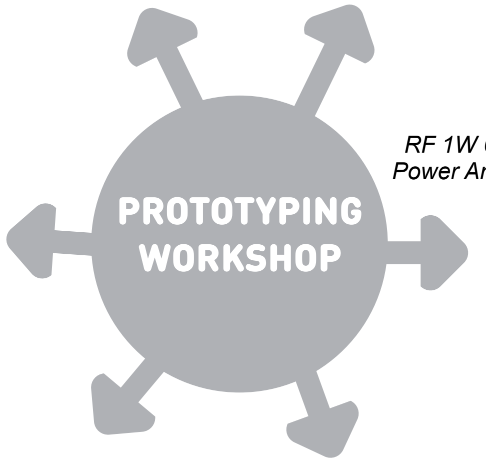
It brings together important means of instrumenting to validate the functional and operational analysis of the systems or subsystems of our prototypes, particularly with regard to the temporal and frequency characterization of innovative analog, digital or mixed devices and systems up to the millimeter range (<50 GHz).
We have the means to carry out measurement campaigns on the ground. We have the ability to adapt to the measurement environment.

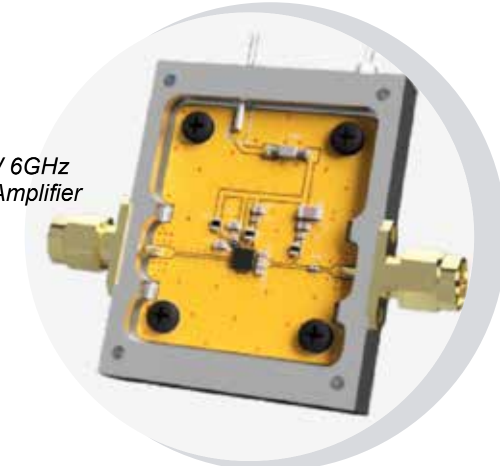
FPGA Card Development for a communication system

60 GHz Patch antenna

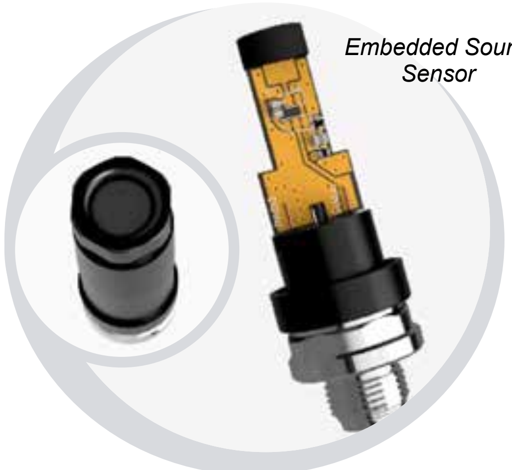


Receiver for an UWB-IR communication system operating at 60 GHz

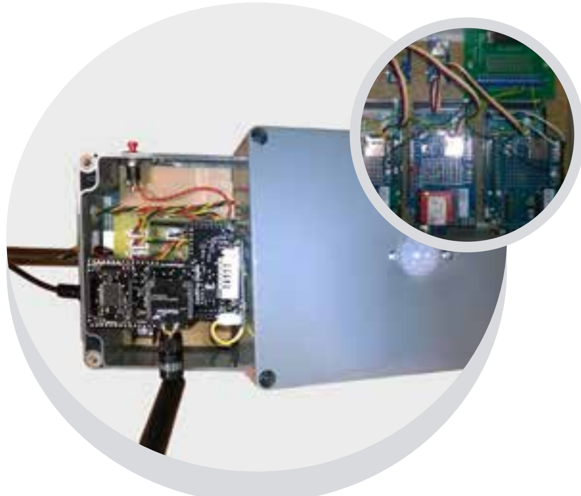




RF 1W 6GHz Power Amplifier

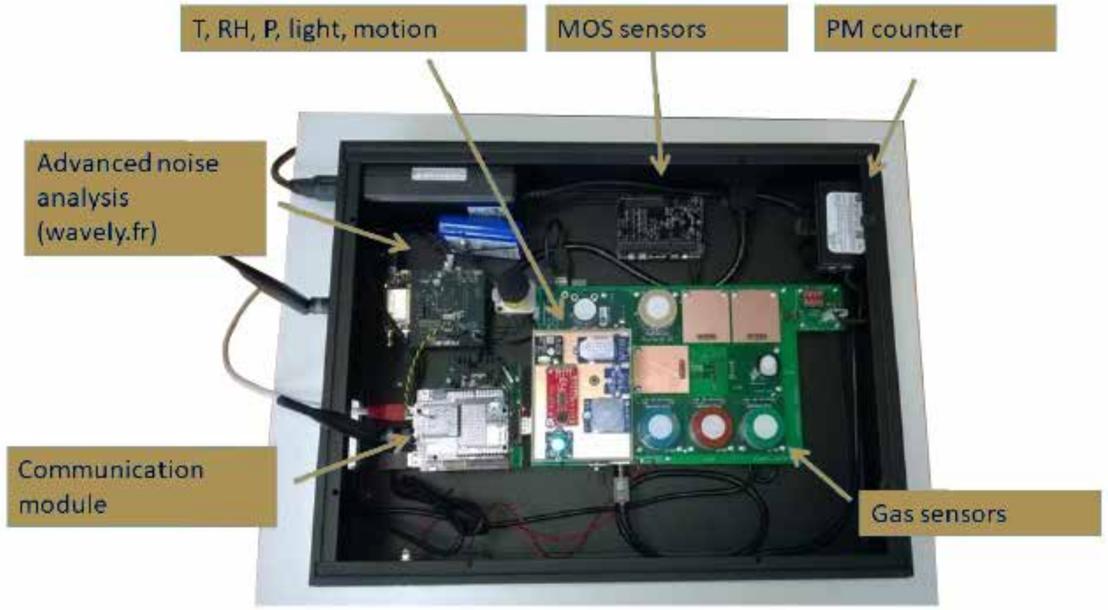


Embedded Sound Sensor

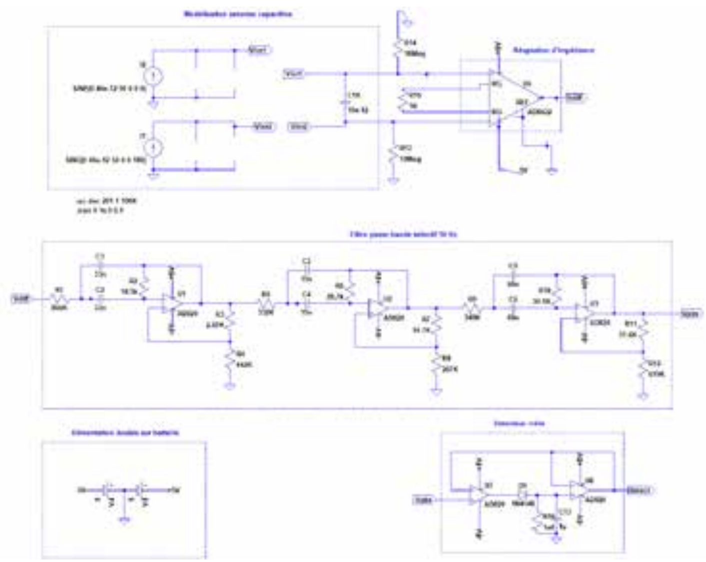


Multi-standard iot gateway

Temporal visualization of data from a sensor node



Embedded instrumentation



Electrical diagram

→ APPLICATIONS

- Connected objects for IOT
- Embedded instrumentation
- Circuit design, electronic systems for instrumentation
- localization people in the engine rooms of a freight freighter in particularly difficult measurement conditions

→ HILIGHTS

DESIGN:

Computer tools to assist in the design and modelling of components, circuits and systems down to the millimeter level.

- **Systems simulations**
  - ADS and CADENCE
  - Matlab-Simulink
  - Spice
  - TINA
  - VHDL
- **3D electromagnetic simulations**
  - -HFSS
  - -CST
- **Data storage and visualization**
  - InfluxDB
  - Grafana

REALIZATION:

For circuit board realization, it is composed of:

- Autodesk Eagle and Fusion 360
- Schematic with Electrical Rule Check
- Board with Design Rule Check
- ECAD-MCAD co-design process
- PCB Design Package TINA
- LPKF PCB ProtoMat H100 fully Automated
  - Mat. Size 400x360 mm
  - Resolution 0.25µm
  - Minimum isolation 0.1mm
  - Minimum width 0.1mm
  - Minimum hole diameter 0.15 mm
  - Automatic 30 position tool changer
  - Optical fiducial recognition
- LPKF Multipress-II (multi-Layer)
  - Up to 6 layers
- LPKF MiniContact RS
  - Holes Metallization
- Semi-automatic station for SMD assembly
- SMD soldering by reflow furnace
- Manual welding station for components
- Microscope
- Packaging
- 3D Printing

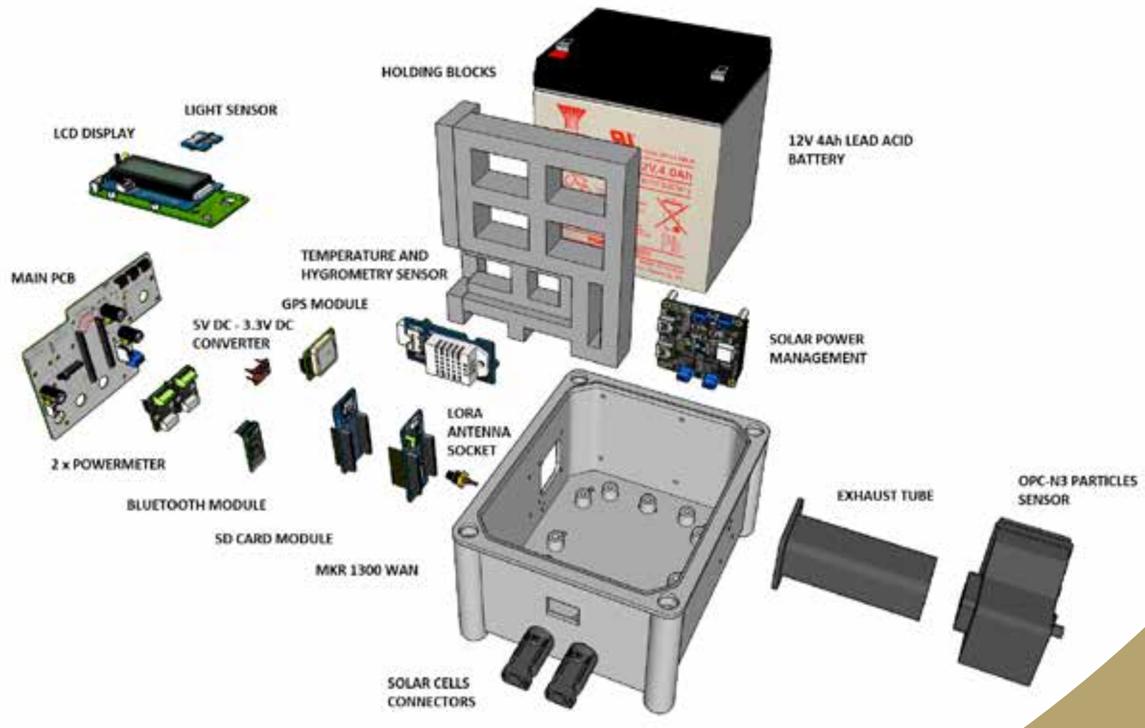
PROGRAMMING:

- FPGA (Altera, Xilinx, Actel)
- Microcontroller (AVR, Arduino, ESP32,...), microprocessor (ARM,...).
- Specific Radio (BT, Lora, Zigbee, Wifi , 802.15.4,...).
- Associated programming and testing tools

TEST & MEASUREMENT:

The main instruments available are:

- portable Oscilloscope, up to 2GHz (Lecroy WaveRunner 204 Xi)
- lab Oscilloscope, up to 13GHz 4 ways (40GS/s) (Lecroy WaveMaster 813Zi)
- Logical analyzer up to 68 ways 600MHz 4Gs/s (Agilent 16950A)
- Network analyzer 4 ports up to 26.5GHz (Agilent PNAx N5242A)
- Signal analyzer up to 50GHz, Bp real time 160 MHz (Agilent PXA N9030A)
- Synthesizer up to 44GHz (Agilent E8257D)
- Vector signal generator, up to 2 GHz, I/Q modulation 1 GHz (Agilent PSG E8267D)
- Data Timing Generator up to 3,35 Gb/s Data rate (Tektronix DTG 5334)
- Arbitrary Waveform Generator up to 20 Gs/s (Tektronix AWG 7102)
- /...



Exploded view of a connected object

iemn

Institute of Electronics, Microelectronics and Nanotechnology

UMR CNRS 8520

Multi-Physics Characterization Platform

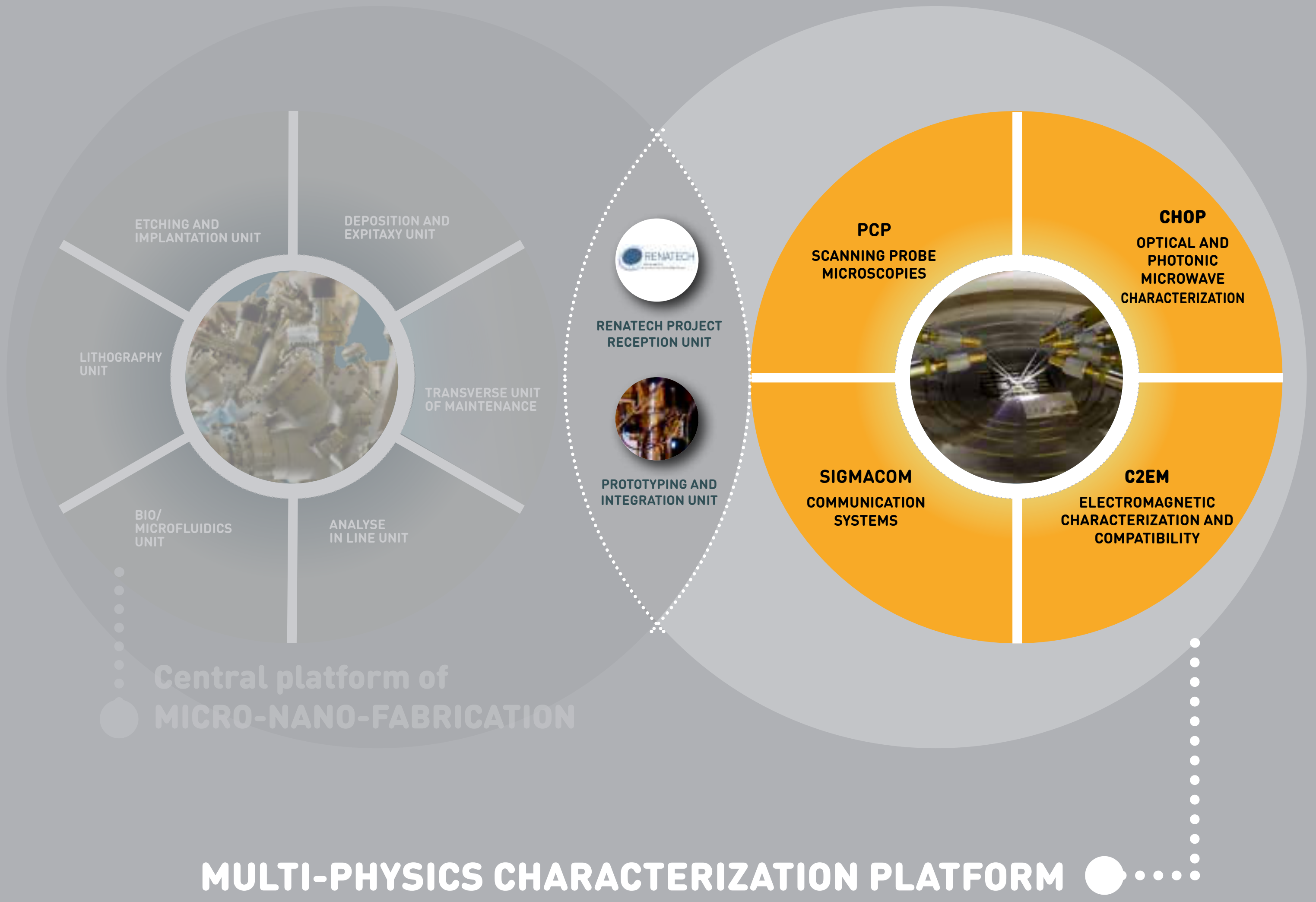
PCMP Plateforme de Caractérisation Multi-Physique

iemn
Institute of Electronics, Microelectronics and Nanotechnology
UMR CNRS 8520

IEMN stands for Institute of Electronics, Microelectronics and Nanotechnology, a laboratory created in 1992 as a joint research unit of five institutions: Lille University, CNRS, Polytechnic University Hauts-de-France, JUNIA/ ISEN, Ecole Centrale Lille. The Institute's scientific policy is based on flagship application projects of societal interest (Transport, Energy, Health, Internet of Objects, Neuromorphic Technologies, UHD Telecommunication) and three transverse scientific and technological axes (Materials, Devices, Nano-Characterization).
IEMN's research is performed based on a strong connection between its 22 research groups and its technlological (Micro Nanofabrication and Multi Physics Characterization) platforms in which cutting-edge equipment is operated by a highly qualified technical staff.

The research groups make up the five research departments of the laboratory:
- Materials, nanostructures and devices
- Micro/nano/bio-systems, waves and microfluidics
- Micro, nano and optoelectronics
- Technologies for telecommunications and intelligent systems
- Acoustics and integrated systems

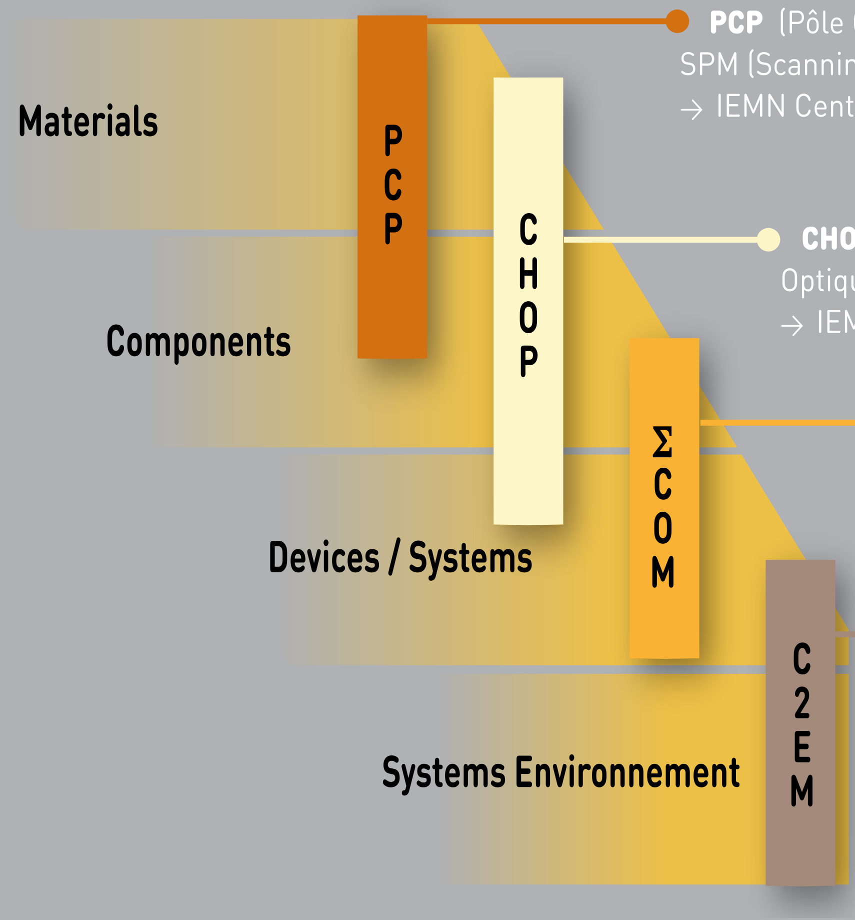
470 people work at IEMN, in research groups, platforms, and administrative services. At the forefront of education and technological research, and owing to numerous dynamic international collaborations, IEMN hosts PhD and graduate students coming from 30 different countries. IEMN designs, manufactures and characterizes devices and systems for Electronics, Photonics, Energy Storage and Harvesting, Bio-micro-technologies, Sensors, Integrated Systems and Instrumentation. Moreover, as evidenced by numerous patents plus spin-off's creations, IEMN demonstrates its effectiveness in promoting and facilitating technology transfer of innovations emanating from its research groups.



The Multi-Physics Characterization Plateform

The Multi-Physics Characterization Plateform is the instrumental facility of IEMN dedicated to characterization of materials, devices and electronic systems, from materials at the nanoscale to electronic systems in their environment. It gathers 4 services localized on Lille University campus «Cité Scientifique», Haute-Borne site and Junia engineering school (Lille center town)

→ **Access to the PCMP Platform is regulated.**
Please contact the head of each PCMP Service to request access.



PCP (Pôle Champ Proche)
SPM (Scanning Probe Microscopy) facility
→ IEMN Central Lab and Junia engineering school

CHOP (Caractérisation Hyperfréquence, Optique et Photonique)
→ IEMN Central Lab

SigmaCom (ΣCOM, Systèmes COMmunicants)
→ IRCICA Haute-Borne site

C2EM (Caractérisation et Compatibilité ElectroMagnétique)
→ P3 building Lille Univ. Campus

CONTENTS

iemn Institute of Electronics, Microelectronics and Nanotechnology UMR CNRS 8520

pcmp-contact@iemn.fr

PCP

The Scanning Probe Microscopy service named **"Pole Champ Proche"** supplies premium tools, to observe and manipulate atoms, molecules or nanoscale objects on the micro to subnanometer scale, making these instruments essentials to Nanoscience and Nanotechnology. The PCP facility is organised into 2 domains depending on the measurement environment:

- AIR domain for microscopes operating in air ambient, liquid or controlled gas atmosphere
- UHV domain for microscopes operating under Ultra High Vacuum

With 8 instruments and 400m² of area in a ISO8-certified environment localized on the ground floor of IEMN, the facility hosts about 30 expert users. Part of the instruments are on free access and can be booked online. One day training for beginners is provided in request. The team is composed of 3 permanent engineers providing internal, external academic and industrial services in the framework of the RENATECH national network. Their mission concern also the development of new instruments and experimental techniques in collaboration with users, Start-up and SPM companies.

Head of PCP
M. Berthe

@

- **Air domain SPM's** I. 1-4

→ Louis Thomas

ICON
DIMENSION
MULTIMODE
BIOSCOPE

- **UHV domain SPM's** I. 5-8

→ Maxime Berthe → Sylvie Godey

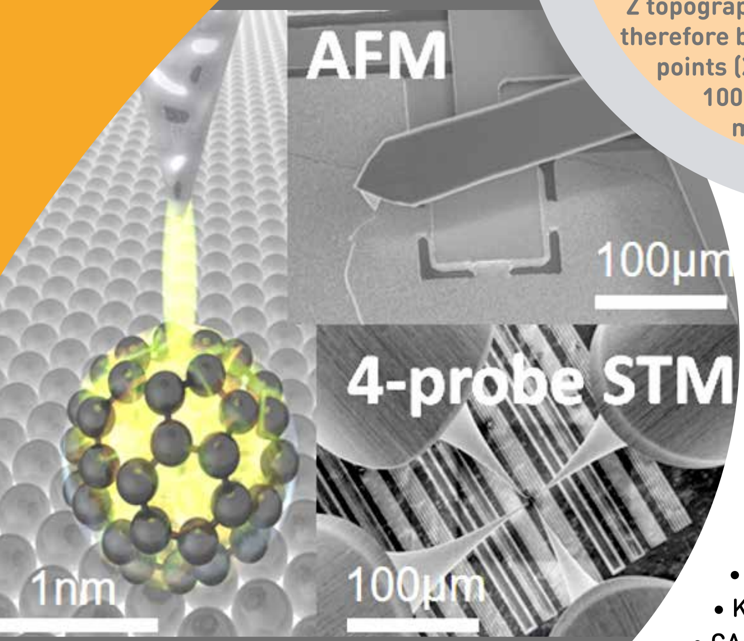
VTAFM
JT-SPM
LT-STM
NANOPROBE

pcp-contact@iemn.fr

PCP

AIR DOMAIN SPM's

The Scanning Probe Microscopes use a recent technique (Nobel prize in Physics 1986) of microscopy where a probe (tip) interacts with the surface of the sample at a very short distance (Angstrom to 100nm). This interaction is based on tunneling current or atomic force that is kept constant thanks to a feedback loop which controls the distance between tip and surface with an actuator. Z topography (Angstrom to 10µm) can therefore be saved for each coordinate points (X,Y) ranging from 5nm to 100µm depending of the microscope model.



The probe interacts in contact (C) or non-contact (NC) mode and can work in static or dynamic mode. Various physical characteristics of the surface can be adressed through differents modes of measurement:

- STM: Scanning Tunneling Microscopy (NC),
- LDOS: Local Density of Electronic States (NC)
- AFM: Atomic Force Microscopy (C, NC), Force Spectroscopy (C)
- EFM: Electrostatic Force Microscopy (NC)
- MFM: Magnetic Force Microscopy (NC)
- KPFM: Kelvin Probe Force Microscopy (NC)
- CAFM: Conductive Atomic Force Microscopy (C)
- PFM: Piezoelectric Force Microscopy (C)
- SCM: Scanning Capacitance Microscopy (C)
- SThM: Scanning Thermal Microscopy (C)

→ APPLICATION EXAMPLES

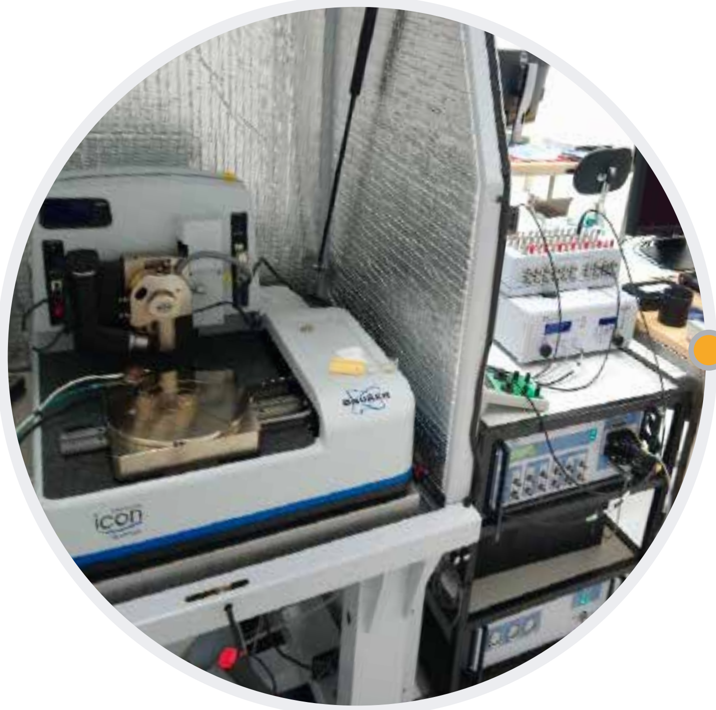
- Topographic monitoring of technological processes and material growth: Molecular beam epitaxy, Etching, Film deposition, lithography
- Local characterization in contact mode of the physical properties of the material: Electrical conductivity by CAFM or thermal by SThM, Piezoelectric response by PFM, Measurement of adhesion force and mechanical property by force spectroscopy
- Local characterization in non-contact mode of the physical properties of the surface: Measurement of electrostatic and magnetic forces (EFM, MFM), measurement of charges , measurement of surface potential (KPFM), Density of states (STM)

→ ADVANTAGES & LIMITATIONS

(+) 3D nanometric topography measurement , sub nanometric roughness measurement

(+) Simultaneous local physical imaging and characterization

(−) Tip Convolution (−) Low scan speed



ICON

Louis Thomas

- **Sample dimension :** 5mm square to 20cm diameter
- **Scan range :** 10nm to 100µm (X and Y linearization feedback: close loop) - Max. Z range: 10µm
- **Resolution :** Lateral: nanometric - Vertical 30pm
- **Working Mode :** AFM Tapping, AFM Peakforce, EFM, KPFM, CAFM, PeakForce TUNA, PFM, SThM, Force spectroscopy
- **Environnement :** Ambient air, Nitrogen gas
- **Temperature :** -25°C to 250°C

→ APPLICATIONS

- PeakForce
- Thermal chuck for small sample

→ ADVANTAGES & LIMITATIONS

(+) Large sample, large coarse displacement of the chuck (2µm resolution)

(−) Acoustic and vibrational Noise sensitive

DIMENSION Bruker

Louis Thomas

- **Sample dimension :** 5mm square to 20cm diameter
- **Scan range :** 10nm to 100µm - Max. Z range: 6µm
- **Resolution :** Lateral: nanometric - Vertical 50pm
- **Working Mode :** AFM Tapping, EFM, KPFM, CAFM, PFM, SThM, Force spectroscopy, SCM
- **Environnement :** Ambient air, Nitrogen gas
- **Temperature :** Ambient

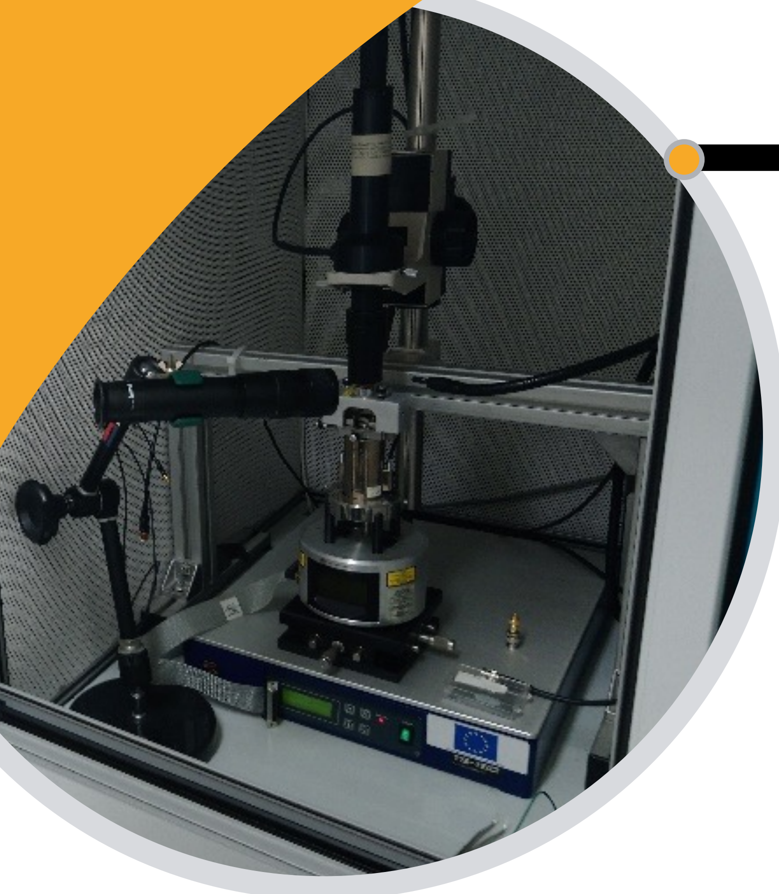
→ ADVANTAGES & LIMITATIONS

(+) Large sample, large coarse displacement of the chuck (2µm resolution)

(−) Acoustic and vibrational Noise sensitive

PCP

AIR DOMAIN SPM's



MULTIMODE Bruker

Louis Thomas

- **Sample dimension :** 5mm square to 15mm diameter
- **Scan range :** 10nm to 10 or 100µm (two scanners available) - Max. Z range: 2 or 5µm
- **Resolution :** Lateral: nanometric - Vertical 30pm
- **Working Mode :** AFM Tapping, EFM, KPFM, CAFM, PFM, Force spectroscopy
- **Environnement :** Ambient air, Nitrogen gas and Liquid
- **Temperature :** Ambient

→ ADVANTAGES & LIMITATIONS

- ⊕ Low noise imaging
- ⊖ Small sample
- ⊖ Limited coarse deplacement

BIOSCOPE Bruker

Louis Thomas

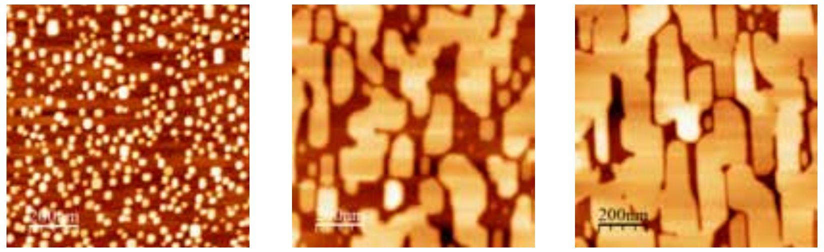
- **Sample dimension :** 5mm square to 5cm diameter
- **Scan range :** 10nm to 100µm - Max. Z range: 6µm
- **Resolution :** Lateral: nanometric - Vertical 80pm
- **Working Mode :** AFM Tapping
- **Environnement :** Ambient air and liquid
- **Temperature :** Ambient

→ APPLICATIONS

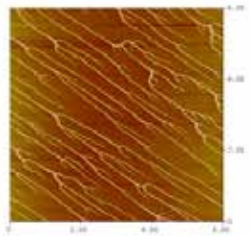
- In situ electrochemical growth monitoring

→ ADVANTAGES & LIMITATIONS

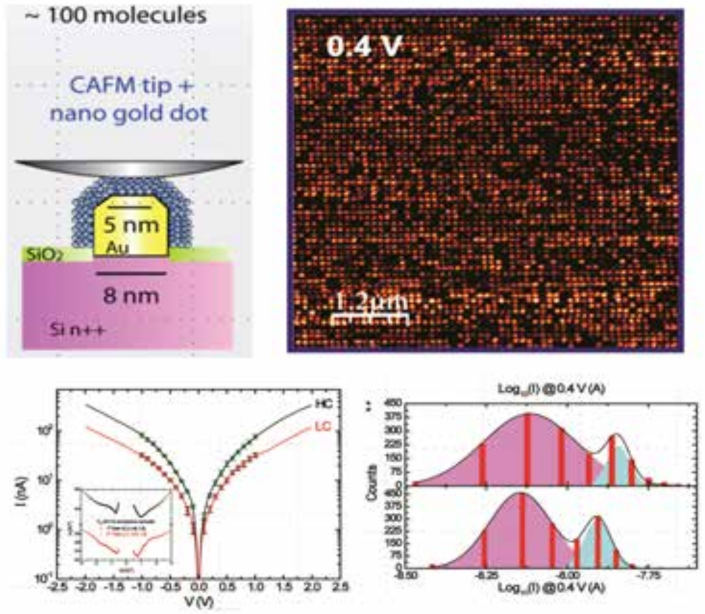
- ⊕ Tip Enhanced Raman Spectroscopy (TERS[1] tip optical bench
- ⊖ Acoustic and vibrational Noise sensitive



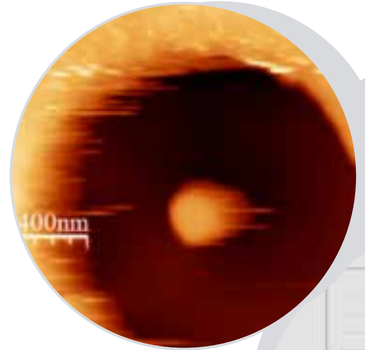
2D-3D growth GaSb/GaAs (AFM)

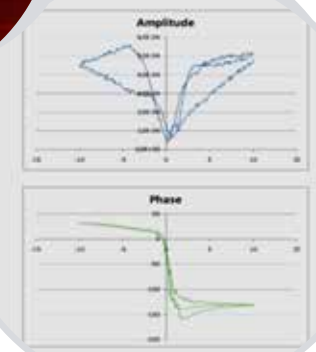


Collagen on silicon surface

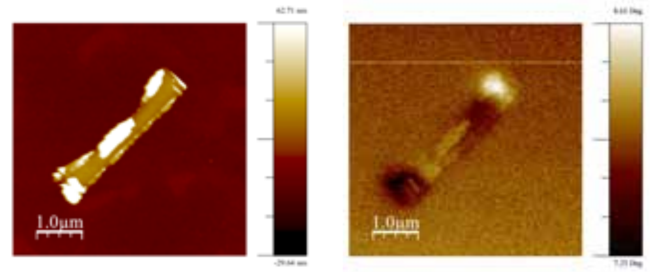


Conducting AFM statistics from a large array of sub-10 nm molecular junstions

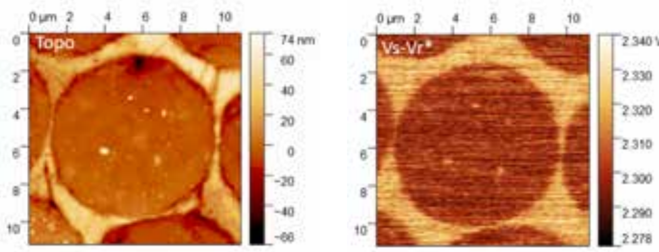




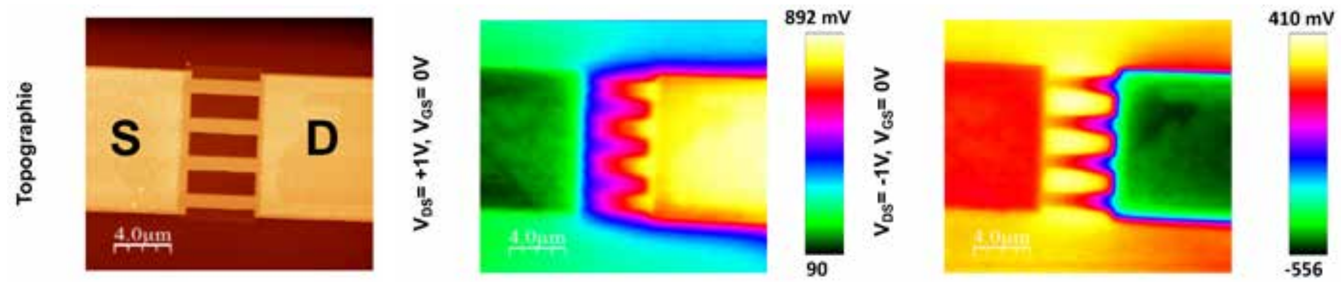
Topo and PFM cycle Of a 60nm PZT dot (1pm displacement sensitivity)



Topo and MFM image of ferromagnetic domain wall position in multiferroic heterostructures



Topography and thermal conductivity of carbon fiber in epoxy matrix (AFM-STHM)



Gas sensing transistor polarization (KPFM)

PCP

UHV DOMAIN SPM's

VTAFM Omicron

Sylvie Godey

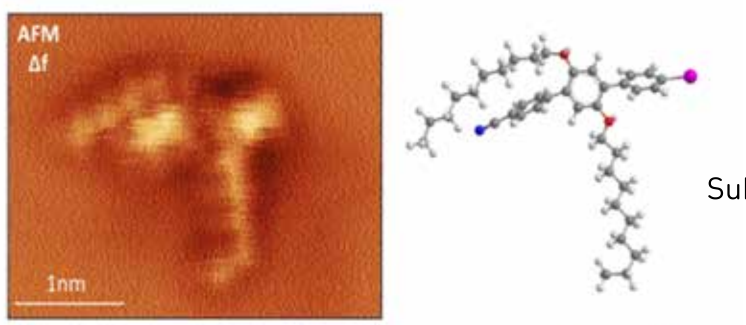
- **Sample dimension :** 4x6mm to 15mm square
- **Scan range :** 10µm - Max. Z range: 2µm
- **Resolution :** Lateral: nanometric - Vertical 30pm
- **Working Mode :** AFM, EFM, KPFM, CAFM, PFM, STM
- **Environnement :** Ultra High Vacuum
- **Temperature :** 50K to 1000K

→ **APPLICATIONS**

- Laser beam deflection (allow contact modes)
- Preparation chamber for sample and Tip
- Sample heater
- Mass spectrometer
- Ion gun
- 3 metal evaporator

→ **ADVANTAGES & LIMITATIONS**

(+) Variable temperature operation
(−) Small sample

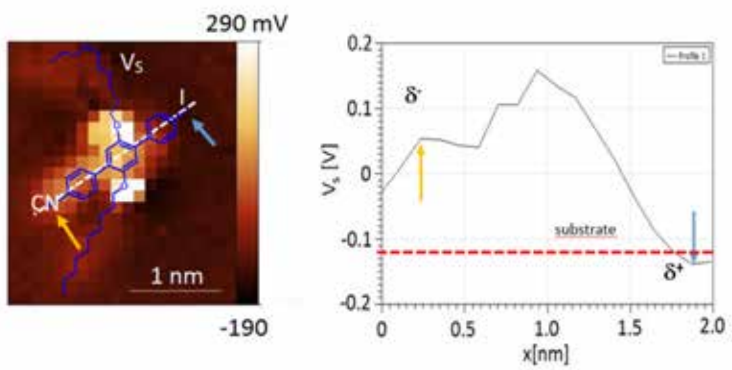


Δf image V_s=0mV

Model corresponding to nc-AFM image

Sub-molecular resolution

KPFM Spectroscopy



→ **Identification of CN et I terminaison groups**

JT-SPM SPECS

Sylvie Godey

- Low temperature Scanning Probe Microscope, 1.2 K minimum (Joule-Thomson stage)
- STM/AFM modes, nc-AFM, KPFM
- Length Extension Resonator (Kolibri sensor): f0= 1MHz K=540 kN/m Q≈100000 at 4K, - Nanonis controller
- XY Scan Range 300K/4K : ~22µm/~4µm, Z Scan Range 300K/4K : ~2.3µm/~0.42µm
- 3T maximum magnetic field perpendicular to sample surface
- Ar sputter gun for surface preparation, LEED-AES
- KENTAX evaporator, CO functionalisation

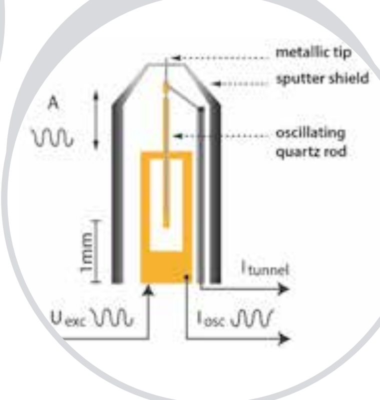
→ **APPLICATIONS**

- Structure and electrostatic properties of surfaces, adatoms, unique molecules or molecular assemblies, nanostructures, nano-objects
- Surface potential determination, single charge transfer detection

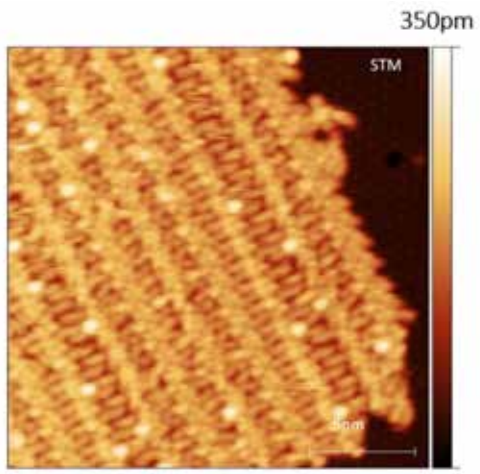
→ **ADVANTAGES & LIMITATIONS**

(+) AFM and STM simultaneous modes
(+) Submolecular resolution, tip functionalization
(+) constant height measurements
(−) need for a minimum density of objects of interest (of the order of one per 0.01 µm2) on about 1mm²

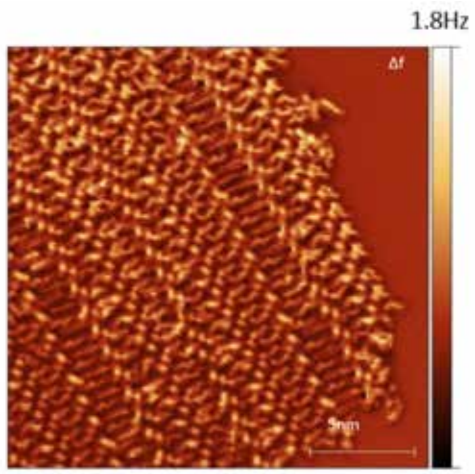
Kolibri Sensor



Self-assembled monolayers on Si:B



STM image
V=-1.8V, I=5pA



AFM constant height image
V = 0 mV

LT-STM Omicron

Maxime Berthe

• Surface imaging of conducting or semiconducting surfaces down to the atomic scale.
• Electrical testing on surfaces or nanostructures with atomic precision and ultra-low drift rate (<10pm/h).
• All modes of operation compatible with low temperature down to 4K.

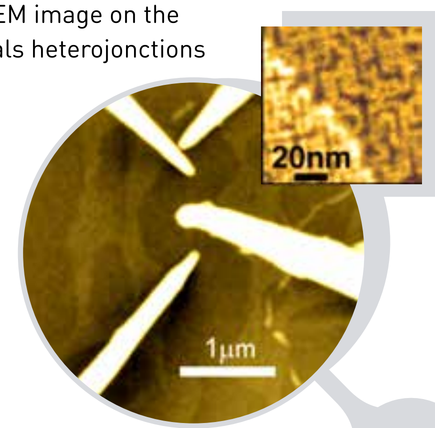
→ APPLICATIONS

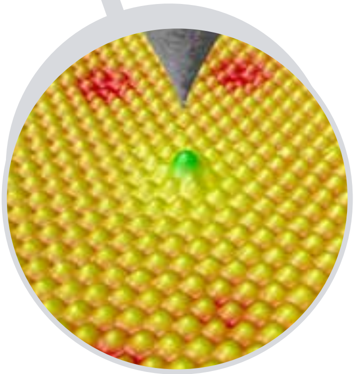
• Investigation of defects at the atomic scale in semiconductors and nanostructures by Scanning Tunneling microscopy (STM). Complementarity with TEM.
• Electronic properties of surfaces and nanostructures at the atomic scale by Scanning Tunneling Spectroscopy (STS). Complementarity with MBE, multiple-probe-STM, tunneling-induced light-emission spectroscopy.

→ ADVANTAGES & LIMITATIONS

+ Extreme resolution (better than 100pm)
+ Electronic measurements (local electronic density of states)
− Limited aspect ratio : only flat surfaces
− Only conducting and semiconducting samples

SEM Image of a four-point-probe measurement on a single domain of colloidal nanocrystals heterojonctions. Inset : zoomed SEM image on the colloidal nanocrystals heterojonctions





3D representation of the reconstructed B-Si(111)-√3×√3 R 30°

NANOPROBE Omicron

Maxime Berthe

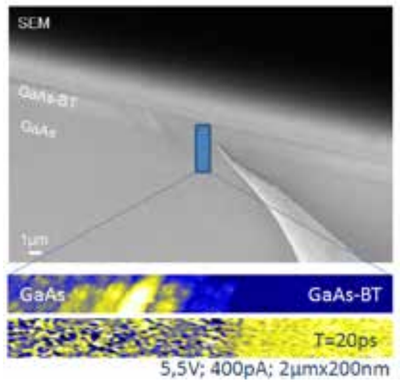
• Scanning Tunneling Microscopy (STM)
• Scanning Electron Microscopy (SEM)
• Nanoscale localization and manipulation
• Multiple-scale (100nm to 1mm) electronic transport measurements
• « fs-Laser-combined-multiple-probe-STM » for time-resolved (<1ps) nanoscale measurements .

→ APPLICATIONS

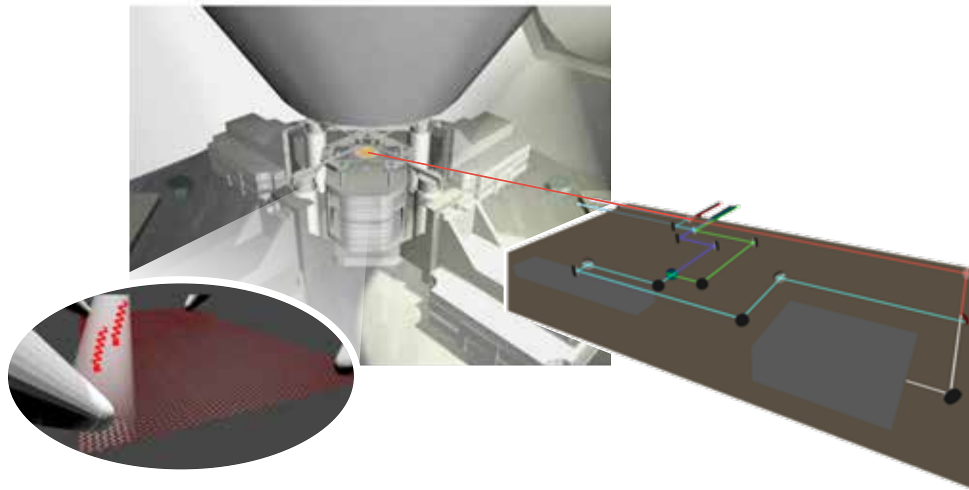
• Transport properties of surfaces and nanostructures. Complementarity with MBE, STM, tunneling-induced light-emission spectroscopy.
• Mapping of transport properties combined with STM. Complimentary with STM and electronics processing.

→ ADVANTAGES & LIMITATIONS

+ Nanoscale imaging and manipulation with SEM monitoring
+ Electronic transport measurements from nanometer to millimeter scale
− Limited STM resolution (nanometer) and stability



Top: SEM image of GaAs/LT-GaAs junction with one STM probe scanning accros the junction. Bottom: Simultaneous acquisition through STM probe of (i)Topographic STM image and (ii) Lock-in-demodulated ultrafast optical signal.



CHOP

The CHOP service covers 900m², in a ISO8-certified environnement, of the IEMN's common resources enabling the characterization of the main electrical parameters of electronic components and subsystems in a wide range of frequencies, from DC to TeraHertz. Most of the measurement benches are modular in order to best meet the needs of research. Engineers develop the test setup in a continuous improvement in order to work in line with technological innovations. Some experiments have been designed to electrically test components under «hard» conditions such as low temperature (5.5 K) or high voltage (10 kV). The expertise in characterizing ultra-fast devices is internationally recognized and allows the CHOP to also play a very important role in the joint laboratory created between the IEMN and French manufacturer ST Microelectronics or foreign research centers. The CHOP hosts 22 research groups, several innovation projects and start-ups (Vmicro, Zymoptiq).

Head of CHOP
S. Eliet Barois

@

- **Nano-characterization** — II. 1-2
  → Sophie Eliet
  SNOM MIR-THz: Scanning Near-Field Optical Microscopy
  Scanning Microwave Microscope (SMM)
- **DC Low Frequency** — II. 3-4
  → Etienne Okada
  DC-CV-PULSE-SOLAR measurements
  Laser Vibrometer
- **Hyper-frequency** — II. 5-8
  → Sylvie Lepilliet
  DC-110 GHz RF-Characterization
  Opto-Hyper measurements
  Cryogenic RF measurements
- **Millimetric & THz** — II. 9-12
  → Sylvie Lepilliet → Sophie Eliet
  Millimeter waves up to 1.1THz
  THz-TDS: TeraHertz Time Domain Spectroscopy
  Fourier Transform Infrared Spectrometer (FTIR) coupled with Microscope
- **Noise measurement** — II. 13-14
  → Sylvie Lepilliet
  Noise measurement
- **Power Measurement** — II. 15-18
  → Etienne Okada
  40 & 94 GHz Load-Pull characterization
  I/V Measurements High Voltage or High Current

chop-contact@iemn.fr

CHOP iemn
Caractérisation Hyperfréquence Optique Photonique

SNOM MIR-THZ: SCANNING NEAR-FIELD OPTICAL MICROSCOPY

Sophie Eliet

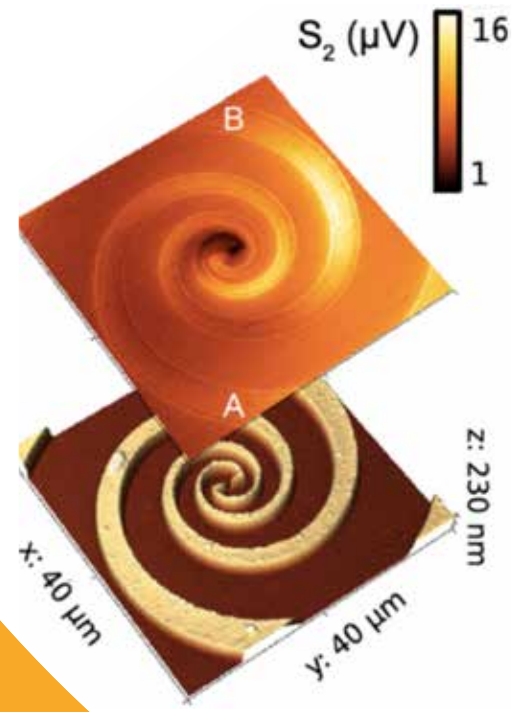
The SNOM MIR-THz is a near-field optical measurement bench allowing the acquisition of images respectively in the mid-infrared and TeraHertz range with a spatial resolution of the order of 30 nm (limitation by the size of the AFM tip). For this, two laser sources are currently available: a 10µm quantum cascade laser and a THz molecular laser pumped by a CO_2 laser.

→ EXAMPLE

- This technique is well suited for the qualitative study of 2D materials such as graphene, molecular electronic nanostructures, doped materials (even weakly) or the study of waveguides induced by laser inscription in glasses.
- It is a complementary with others Scanning Probe techniques (cf PCP service)

→ ADVANTAGES & LIMITATIONS

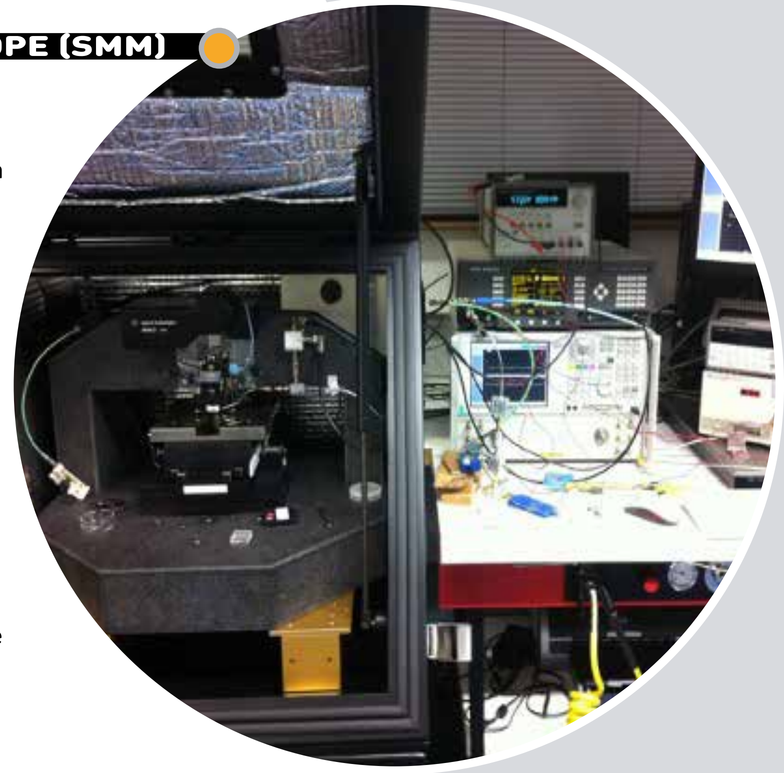
- The spatial resolution is linked to the apex of the probe (almost few tens of nanometers).
- Materials must have a MIR or THz contrast (plasmons resonance ...)
- Sample must be relatively flat few hundreds nanometers of relief maximum



Example of SNOM-THz image of Logarithmic Spiral Antenna @ 2,5 THz (up), simultaneously recorded with AFM topography IRMMW Conference, 2021

SCANNING MICROWAVE MICROSCOPE (SMM)

Sophie Eliet



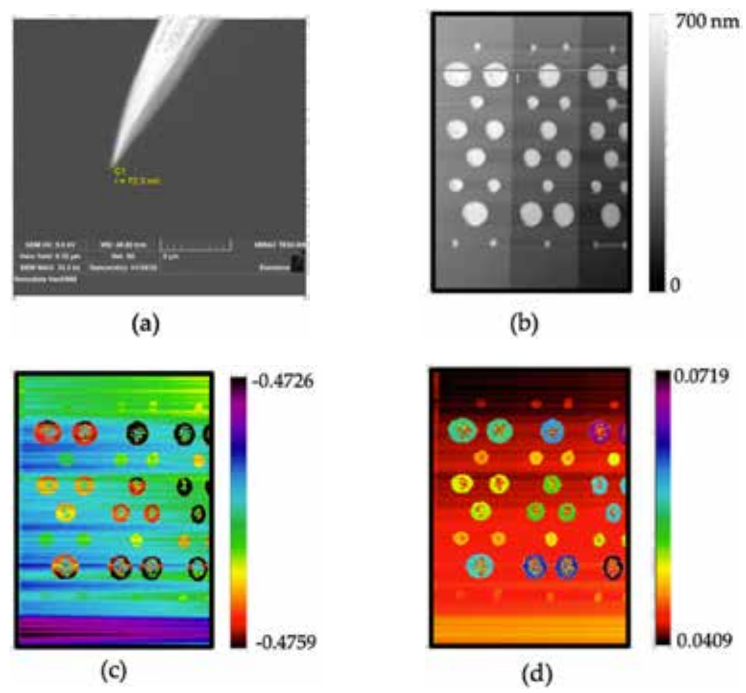
Scanning Microwave Microscopy is Scanning probe technique. It is based on a AFM technique coupled with VNA (Vector Network Analyzer). The probe is specially designed and integrated into a specific support and radio-frequency connectors.
At CHOP, there are 2 types of SMM:
- At air , 3600 LS Keysight, up to 12 GHz
- Under vacuum, a home-made system integrated in a Tescan SEM, up to 67 GHz

→ APPLICATIONS

The technique is based on AFM but develops a specific contact electric mode at microwave frequencies (2-67 GHz) that allows to map material or device surfaces at the nanoscale for topography and microwave reflectivity. The sample must be compatible with AFM topography measurements.

Example

SMM in SEM illustration



Combined AFM, SMM and SEM images obtained in the home-made system (a) SEM image of the apex tip. (b) AFM topography image of a set of metallic dots deposited on a SiO_2/Si substrate to form capacitances, (c) real part and (d) imaginary part images of the complex reflection coefficient ΓM at 30 GHz. The dots diameters range from 1 to 4 µm. From Appl. Sci. 2021, 11, 2788

→ ADVANTAGES & LIMITATIONS

- It combines topography and microwave nanoscale measurement over a large microwave range. The spatial resolution is linked to the apex of the probe (a few tens of nanometers) but also to the microwave frequency. It allows to observe surface contrasts of microwave dielectric properties. The resolution is in the aF range. It can be combined with DC biasing up to 10 V. Traceability to microwave standards is still under study. Calibration based on the probe shape is possible but indicative with several µS uncertainty. The sample must be flat within a few hundreds of nanometers maximum.

CHOP

DC - LOW FREQUENCY


JANIS probe station cryogenic RF/DC

DC-CV-PULSE-SOLAR MEASUREMENTS

Etienne Okada   Ayman Rhellab

Mandatory for any electric component, DC characteristics can be provide by several equipment. To make a technological return as soon as it comes out of production.

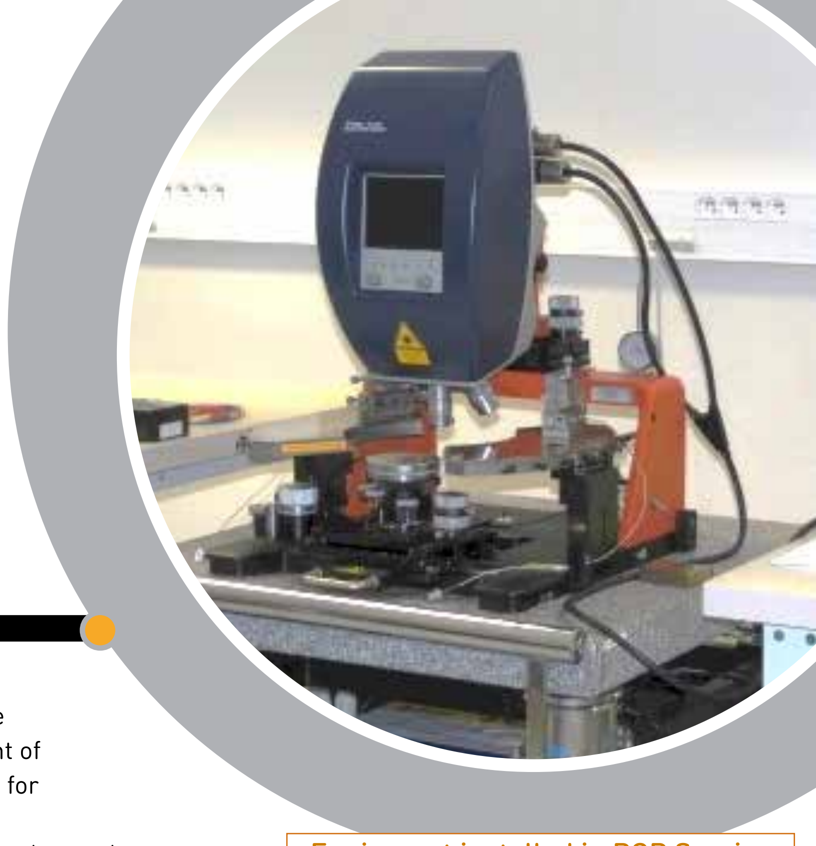
Benches can be adapted to supply several circuits or study one device. With connector or on wafer (from 1 to 16 pins simultaneously) we can measure characteristics to identify performances, homogeneity of manufacturing and also robustness.

Several environments can be use (ask for compatibility), temperature, pressure, lighting/darkness.

- DC are made from 0 to 210 V with current up to 2A.
- Impedance meter is available to highlight capacitance effect. CV from 1 kHz to 100 MHz.
- Pulsed measurements are helpful to mark trapping effect on GaN transistor or to eliminate heating effect. Pulse from 300nsec up to msec.
- Solar Simulator is used to characterize solar cells. Laser beam can be also provided on device

→ ADVANTAGES & LIMITATIONS

- High voltage and current are available but power is limited by the setup.
- Both can be perform on or off wafer.



LASER VIBROMETER MSA 500

Maxime Berthe   Marc Faucher

Visualizing surface deformations, knowing the speed, frequency and distance of displacement of a vibrating element, are essential information for MicroElectroMechanical Systems (MEMS).

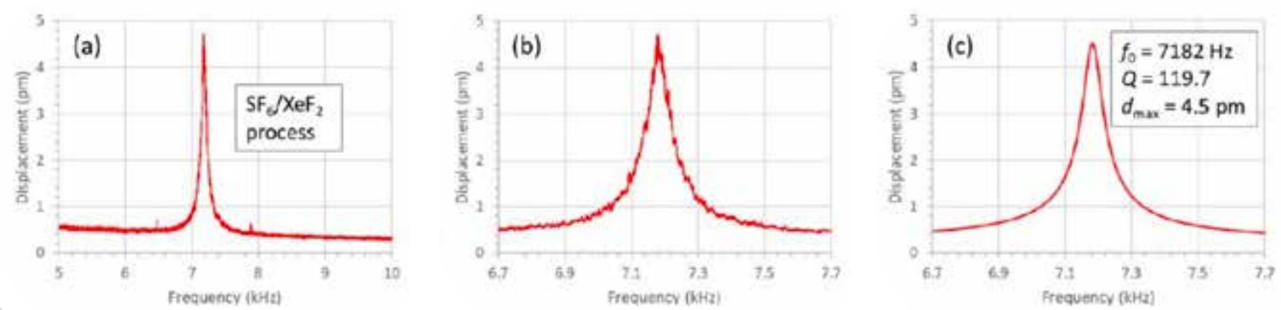
This equipment is based on Doppler effect. Thanks to a laser and an interferometer it is possible to know how an elements vibrates. It is possible to map vibrations modes of a device.

Equipment installed in PCP Service

→ ADVANTAGES & LIMITATIONS

- Max displacement +/- 75nm, frequency 0 up to 24MHz

Example of measured vibration of a cantilever made in IEMN CMNF by NAM6 team



Experimental and modelled resonance curves of a microcantilever fabricated the mixed SF_6/X_EF_2 process. (a) 5-10 kHz frequency sweep, (b) zoom over 1kHz, and (c) modelled resonant frequency curve. The inset to (b) shows a microcantilever fabricated using this process.

DC-110GHz - RF-CHARACTERIZATION

Sylvie Lepilliet Ayman Rhellab

CHOP has acquired and developed several test benches made up of vector network analyzers, power supplies and marble stations fitted with coplanar tips. This equipment and the know-how of CHOP allow in DC regime the establishment of current-voltage characteristics and in RF-regime, the measurement of S parameters.

It is possible to characterize components on wafer or in package (coax) according to different frequency bands. The design of the electrical accesses for placing the probes or the connectors must correspond to the available materials and physical possibilities (see "limits of the technique"). Meet the CHOP team!

To make a technological return as soon as it comes out of production or for the design of complex circuits (frequency converter, amplifier, micro processor, etc.), small signal measurements up to 110GHz are at the core of the CHOP expertise.

→ **This can be a first step before other types of measures:**

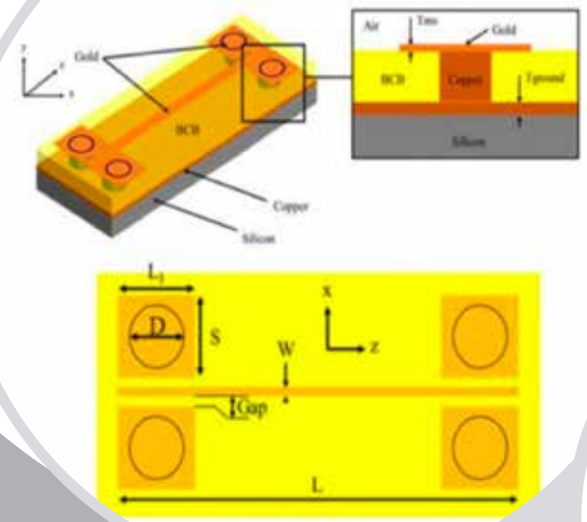
- Millimeter-waves measurements
- Noise measurements
- In power regime
- At High Voltage or High Current measurements

If microwave measurements are required (up to 67 GHz) in cryogenic mode, this is also possible in CHOP

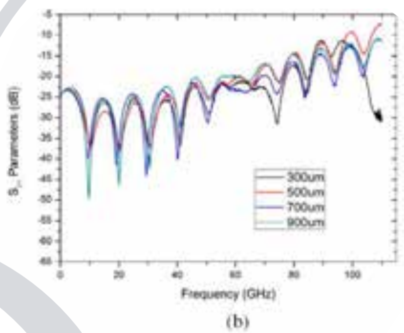
→ ADVANTAGES & LIMITATIONS

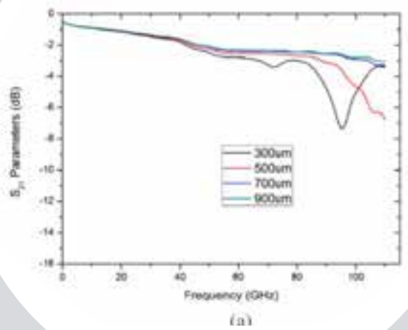
- Designed of electrical access must be taken into account, come in CHOP for more details!
- Coaxial availlable up to 67GHz versus 110GHz under probing method.

Modelled GCPW-MS-GCPW transition including input and output coplanar-microstrip transitions with grounding via-holes and a microstrip transmission line in between



Example of measurements up to 110GHz

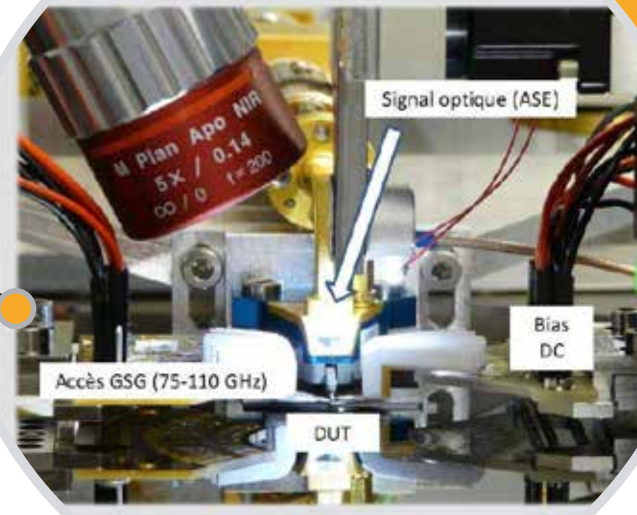




Measurred S-parameter as function of the via-hole diameter: (a) S_{21} and S_{11}

OPTO-HYPER MEASUREMENTS

Sophie Eliet Emilien Peytavit



Characterization (S parameter/ Frequency response) of ultrafast photoconductors up to 320 GHz

Objectif: estabissement of electrical model for material and knwoledge of performances

Technical Specifications:

- Lasers: 780 nm/1064 nm/1300nm/1550 nm. Output power :<10 mW
- Optical Amplifier: 780 nm/1550 nm. Output power: <500 mW
- Near diffraction limit optical focusing capabilities (free space and fiber coupled)
- Optical beam characterization (powermeter / optical spectra analyzer)

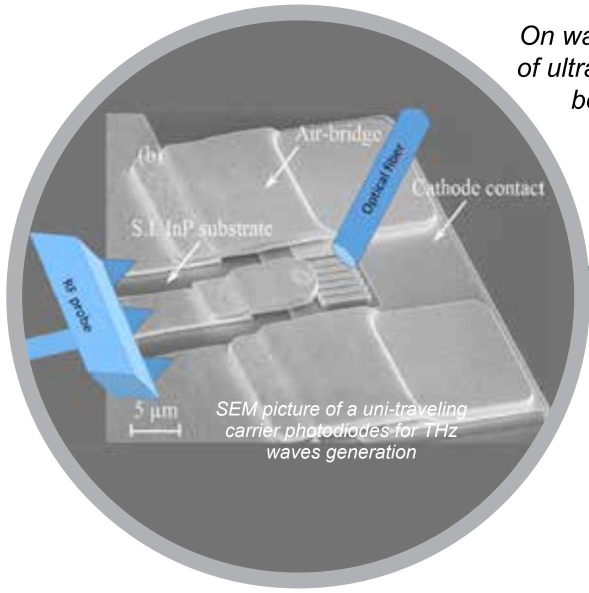
Expertise:

- On-wafer S parameter characterization of device under CW illumination up to 320 GHz (limited by RF probes)
- Frequency response (up to 320 GHz) and noise characterisation (up to 50 GHz) of photodetectors
- Optical waveguide and grating coupler characterization

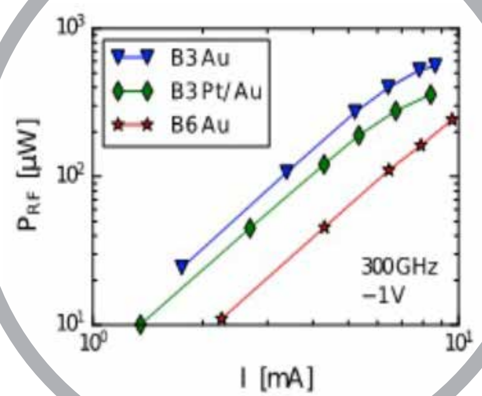
→ ADVANTAGES & LIMITATIONS

- Probing on wafer with several type of wavelenght, come in CHOP for more details!

On wafer characterization of ultrafast photodetectors beyond 320 GHz

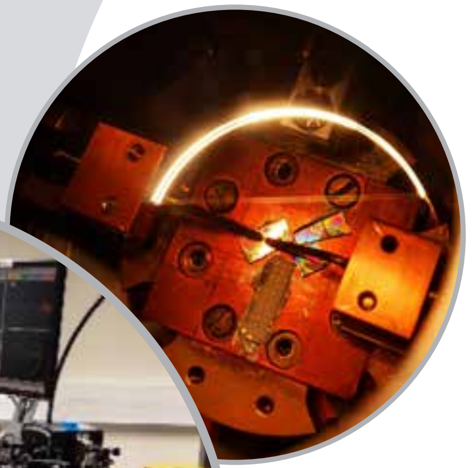


SEM picture of a uni-traveling carrier photodiodes for THz waves generation



CHOP

HYPER-FREQUENCY



JANIS probe station cryogenic RF/DC

CRYOGENIC DC AND RF MEASUREMENT

Sylvie Lepilliet

Cryogenic & Vacuum Micro-manipulated Probe Systems

Characterizing components or devices in cryogenics presents an interest in the analysis of specific changes in the physical parameters of components, such as transistor, diode, amplifier. Cryogenic characterization extends to optoelectronic components.

JANIS probe station cryogenic RF/DC

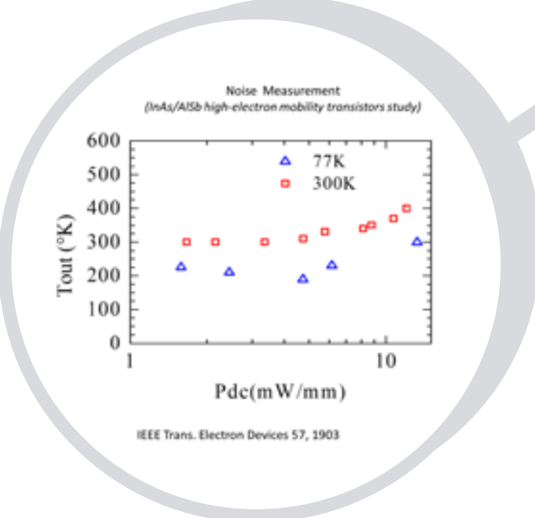
Features :

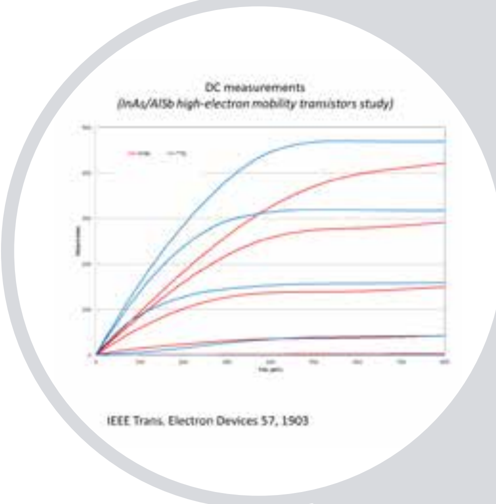
- Low Temperature : 5.5K
- High Temperature : 380K
- Liquid helium or liquid nitrogen
- Without vibrations to sample
- 2 probes RF 0 to 67GHz
- 4 probes DC

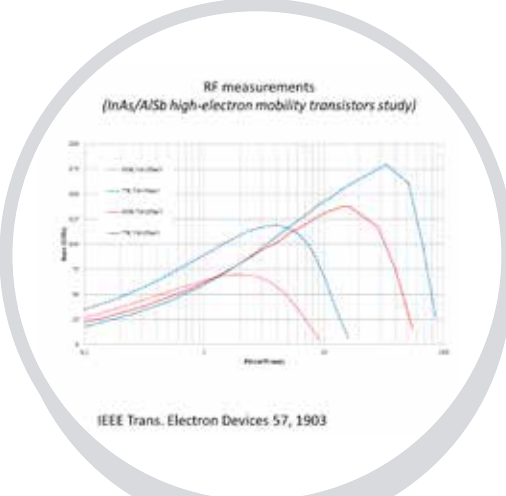
LAKESHORE probe station cryogenic DC/field magnetic

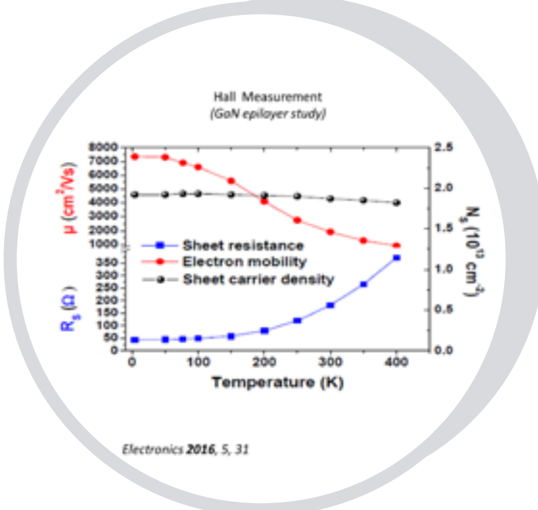
Features :

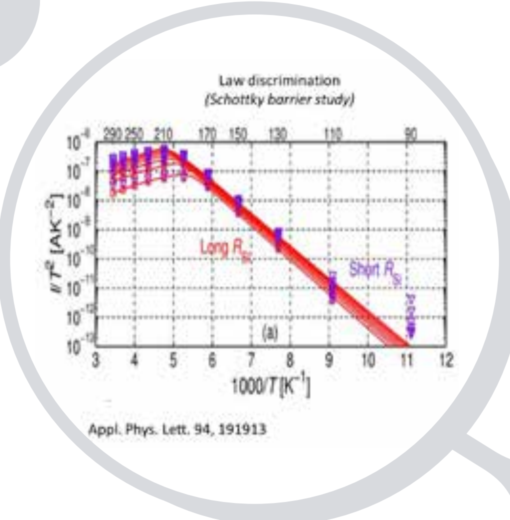
- Low Temperature : 5.5K
- High Temperature : 380K
- Liquid helium or liquid nitrogen
- Without vibrations to sample
- Verticaly Field supraconducting magnetic : to +/- 2.5T
- 4 probes DC

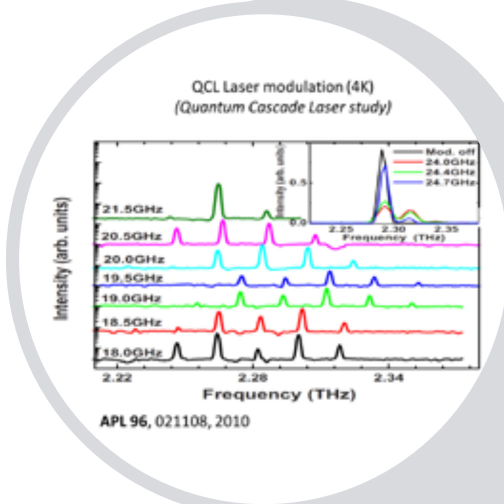


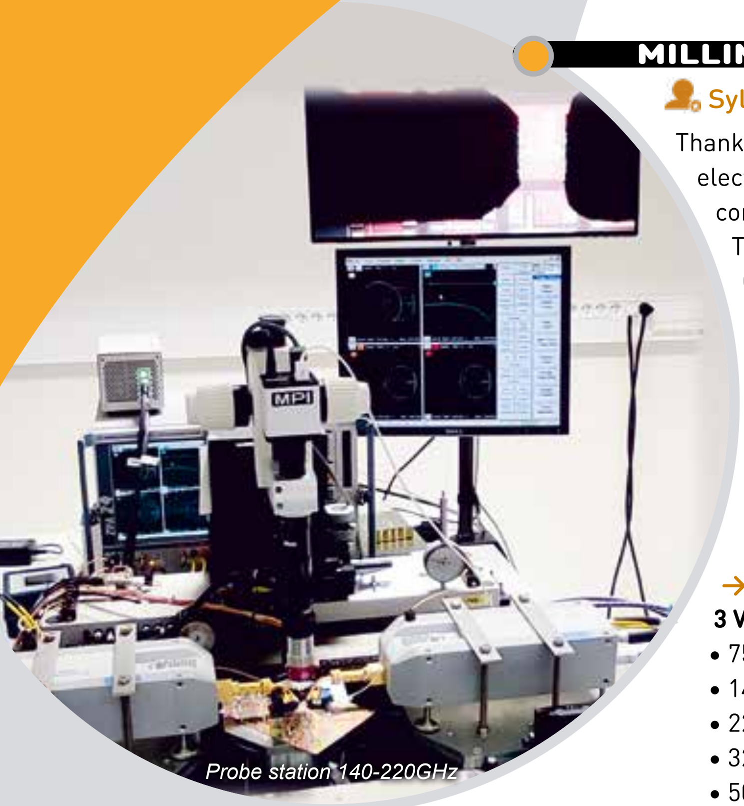












Probe station 140-220GHz

MILLIMETER WAVES UP TO 1.1THz

Sylvie Lepilliet

Thanks to technological advances in the field of micro and nano electronics, more and more applications are emerging and are being considered in the millimeter frequency band (mmW) above 100 GHz. The millimeter frequency band is defined between 30 GHz and 300 GHz, corresponding to wavelengths between 10 mm and 1 mm respectively. Beyond 100 GHz, the millimeter frequency band intersects with the Terahertz (THz) spectrum up to 300 GHz. This frequency band (100 GHz - 300 GHz) commonly known as Sub-THz offers an important lever for increasing the performance of existing systems and opens up prospects for new applications. This part of the millimeter band is of interest mainly in the fields of spectroscopy, imaging and telecommunications.

→ Vectorial measurement capabilities

3 VNAs with 6 converters :

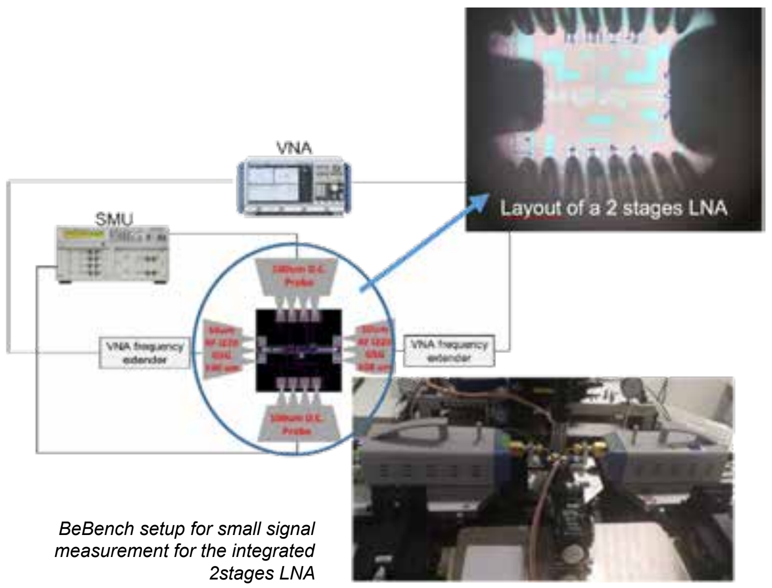
- 75-110GHz – WR10
- 140-220GHz – WR05
- 220-325GHz – WR03
- 325-500GHz – WR2.2
- 500-750GHz – WR1.5
- 750-1100GHz – WR1.0

→ Scalar measurements capabilities:

- Spectrum analyzer mixers up to 1 THz
- Absolute power (PM5 Erickson) 60GHz – 2THz, 1µW – 200mW
- Multiplication chains (80-360, 580-720 GHz)
- Pyroelectric detector: 100GHz – 30THz, 100nW – 100mW free space
- Waveguide integrated zero-bias detectors (Schottky): WR 3.4 (220-325 GHz), WR 1.5 (500-750 GHz) 100GHz, 140-220GHz, 750-1100GHz

→ Photonics-based sources/receivers for THz communications & instrumentation, 200-340 GHz:

- Sources for amplitude modulation and I/Q measurements, in THz range (yp to 340 GHz)
- Receivers for wideband signal reception (60-340 GHz)
- Bit error testers (realtime, 2 channels 25 GBit/s)
- Generation & Analysis of I/Q signals (developed with PhLAM, Lille)
- IP3 bench of scalar evaluation of active devices intermodulations based on photonics techniques (up to 330 GHz)



BeBench setup for small signal measurement for the integrated 2stages LNA

Example 1

Highly Tunable High-Q Inversion-Mode MOS Varactor in the 1–325-GHz Band

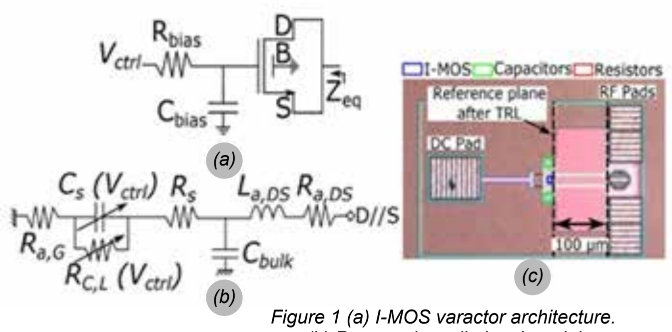


Figure 1 (a) I-MOS varactor architecture.
(b) Proposed small-signal model
(c) Micrograph of the fabricated circuit

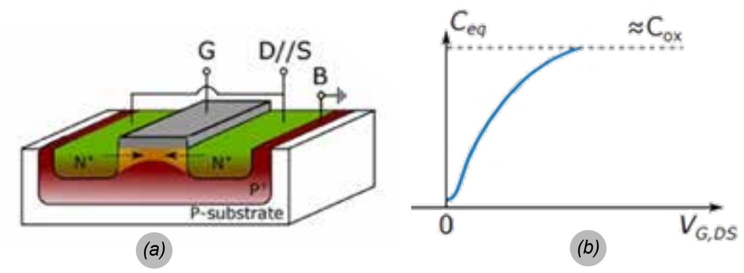


Figure 2 (a) nMOS-based I-MOS varactor
(b) Capacitance versus $V_{G,DS}$

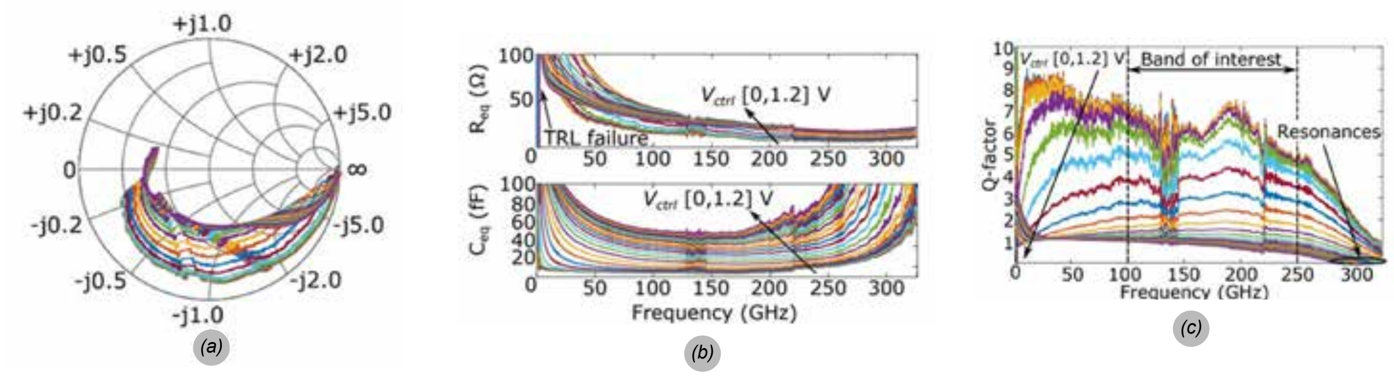
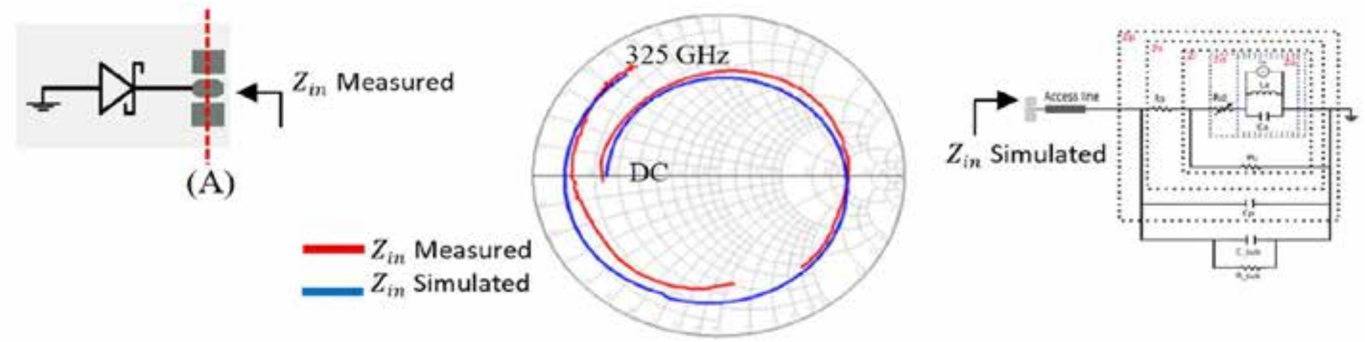


Figure 3 Measurement results in the 1 GHz to 235 GHz band as a function of V_{ctrl} (a) S_{11}, (b) R_{eq} and C_{eq}, and (c) Q-factor

«Highly Tunable High-Q Inversion-Mode MOS Varactor in the 1–325-GHz Band,» in IEEE Transactions on Electron Devices, vol. 67, no. 6, pp. 2263-2269, June 2020, doi: 10.1109/TED.2020.2989726.

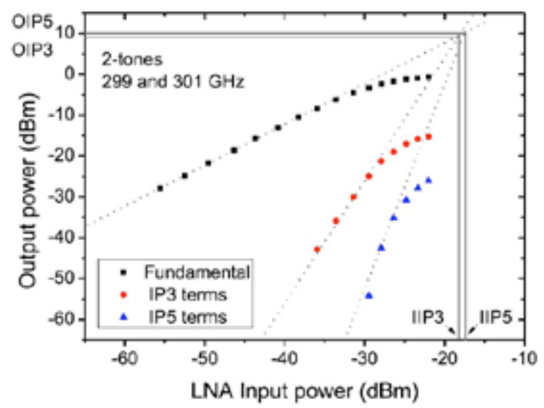
Example 2

To validate the extraction methodology, the unput impedance of this simulated electrical model id compared to the impedance extracted from the S-parameters , in the range DC-325GHz

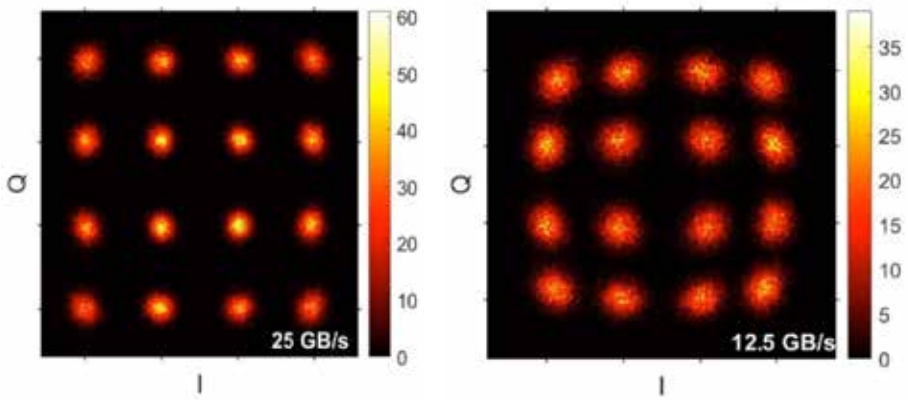


Example datacom

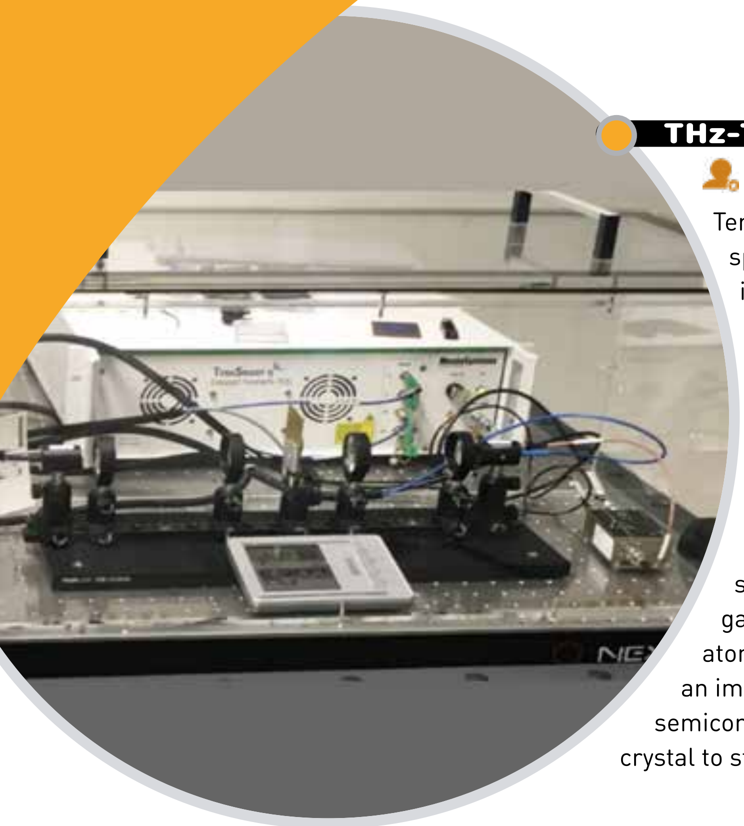
IP3 and I/Q analysis of the compression curve of LNA:
IP3 measurement of 300 GHz LNA



(1) Is an example of 100 GBit/s IEEE 802.15.3d (300 GHz)



(2) LNA output with QAM16 compression (300 GHz)



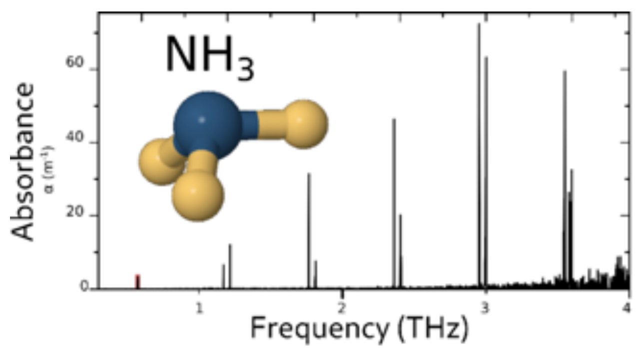
THz-TDS: TERAHERTZ TIME DOMAIN SPECTROSCOPY

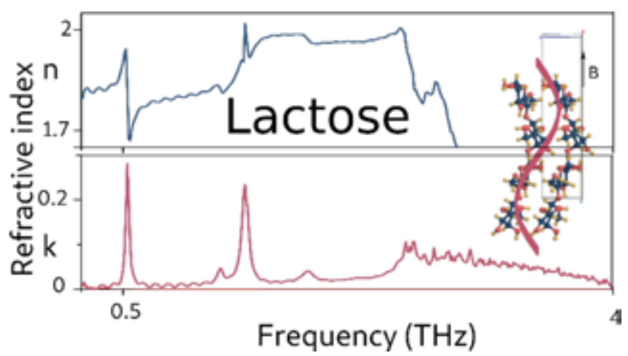
Sophie Eliet

Terahertz Time-domain-spectroscopy is the most spread THz spectroscopy setup for broadband THz spectral measurements. It is based on a femtosecond laser of which pulse is transferred in the THz spectral range thanks to a photoconductive antenna (in our case). The resulting THz pulse is, then, time sampled using another photoconductive antenna trigged by the femtosecond laser after a controlled delay. It leads to time traces that a Fourier transform transfers in the spectral domain.

→ APPLICATIONS

TDS spectroscopy is used on all kinds of samples: gaseous, liquid solid and even plasma. It is used to probe the rovibrational lines of gas with a very good specificity when molecules have from ~3 to ~10 atoms. It is very sensitive to polar liquid such as water and thus plays an important role in biology. THz broadband spectroscopy is used on semiconductor sample to probe very low level of doping and on molecular crystal to study their conformation.





→ ADVANTAGES & LIMITATIONS

- Spectral range: 0,2 - 5 THz
- Total scan range: 850 ps
- Spectral resolution limited by the Fast Fourier Transform : <1,2 GHz
- Dynamic range : 100 dB
- Better resolution possible by temporal signal processing
- Type of sample: Solids (wafers, powder, pellets...) , gases or suspended particles

FTIR: FOURIER TRANSFORM INFRARED SPECTROMETER, COUPLED WITH MICROSCOPE

Sophie Eliet

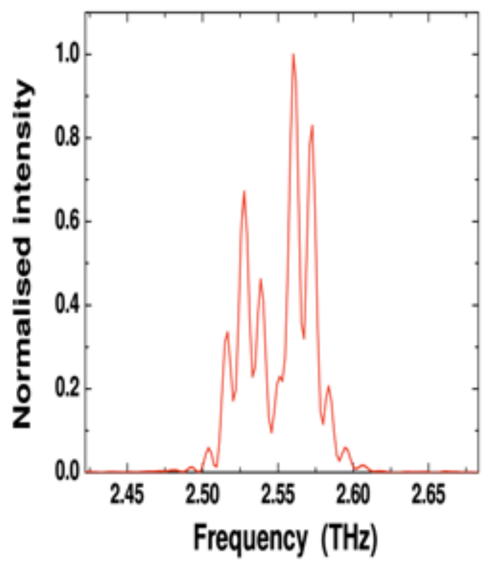
This N_2-purged FTIR allows spectral acquisition from the mid-IR to the THz spectral range
Total Spectral range: 8 000 – 50 cm^{-1} (1,25µm- 200µm) (240 THz- 1,5 THz)
Spectral resolution: = 0,4 cm^{-1}
Detectors: Internal DLATGS 8000-350cm^{-1}; Internal DTGS/PE 680-50cm^{-1}
External MCT (cooled 77K): 12000-600cm^{-1}
Internal source: Blackbody
Coupled to a MIR microscope and internal MCT detector (cooled 77K): 12000-600cm^{-1}

Microscope mapping:

- Precision of step: 0.1µm
- Repeatability: 1µm
- Positioning precision: +/-3µm

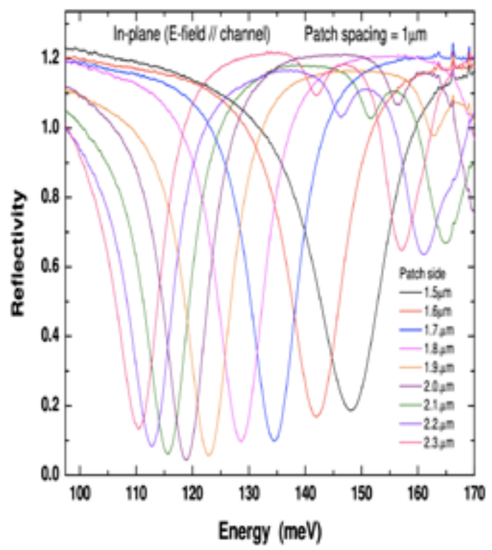
Example 1

Emission spectrum of a THz quantum cascade laser



Example 2

Reflectivity spectra of 2D periodic array (1µm period) of square metallic patch cavities of different side



The cavities consist of a GaAs/AlGAs heterostructure sandwiched between metallic top contact and ground plane. Spectra are measured in reflection geometry with the mid-infrared microscope.

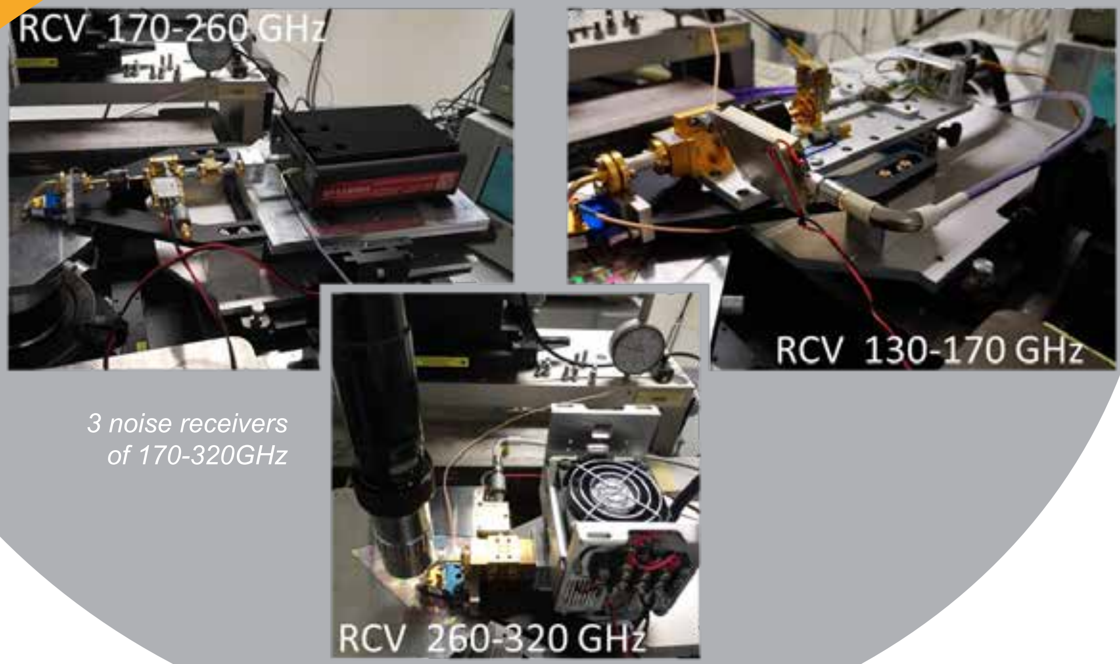
ACS Photonics 8. 464 (2021)

→ ADVANTAGES & LIMITATIONS

- Spectral range depend of the couple beamsplitter / detector
- Type and dimensions of sample for Hyperion module: flat sample of maximum dimensions ~5x7cm

CHOP

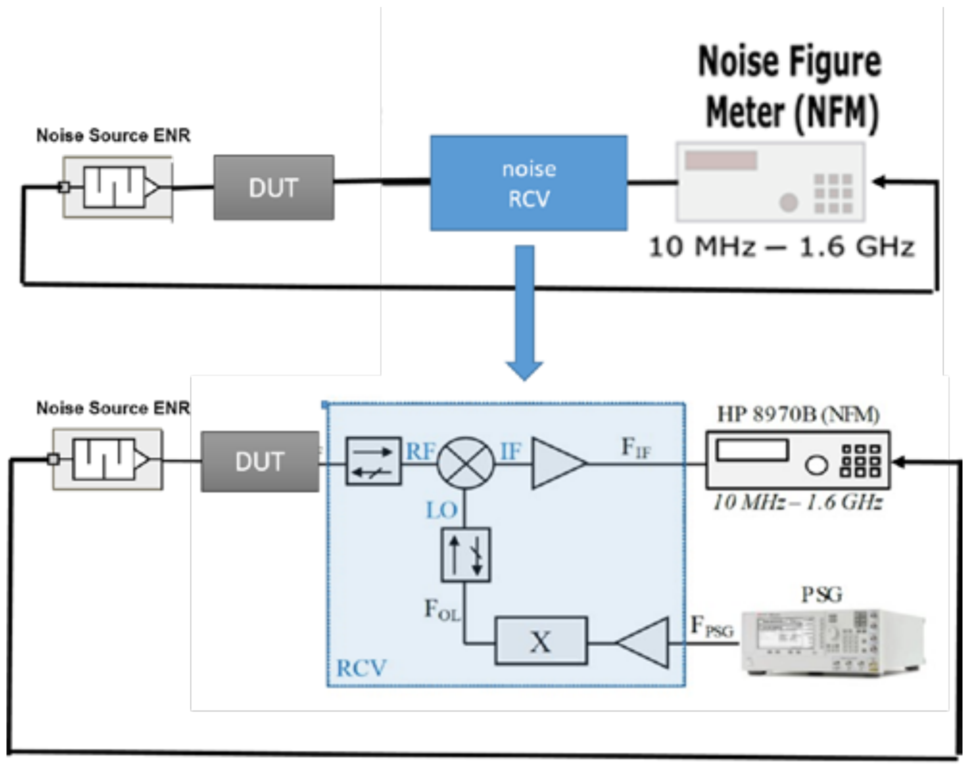
NOISE MEASUREMENT



NOISE MEASUREMENTS

Sylvie Lepilliet

The term "Noise" is normally used to express the unwanted fluctuations that may disturb the information propagation within the signal, or reduce the quality of its contents.
Noise figure (NF) is measures of degradation of the signal-to-noise ratio (SNR), caused by components in a signal chain. It is a number by which the performance of an amplifier or a radio receiver can be specified, with lower values indicating better performance.



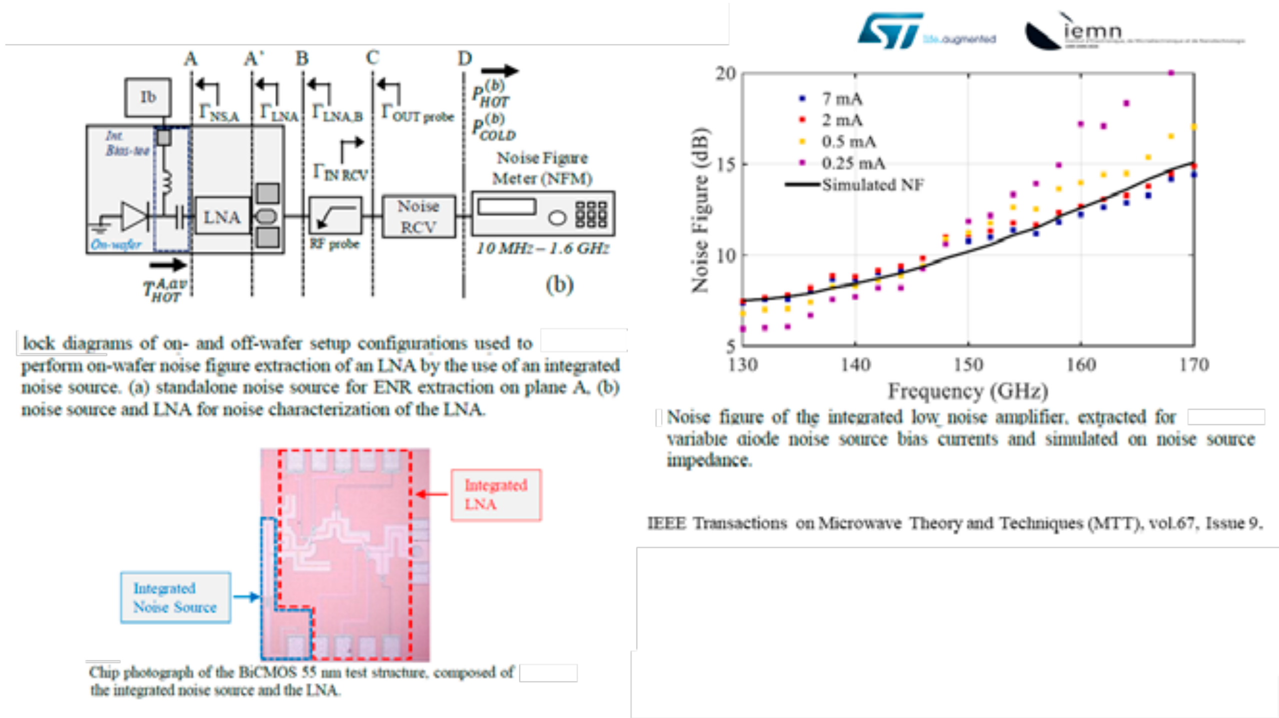
Block diagram of noise measurement

For the extraction of the four noise parameters [gamma opt, Nfmin and Rn] of semiconductor devices studied, several automated measurement benches make it possible to measure the available gain and the noise figure (Noise Figure) of microwave components. according to the following frequency ranges:

6 noise receivers:
- 6-20GHz
- 20-40GHz
- 75-110GHz
- 110-170GHz
- 170-260GHz
- 260-325GHz

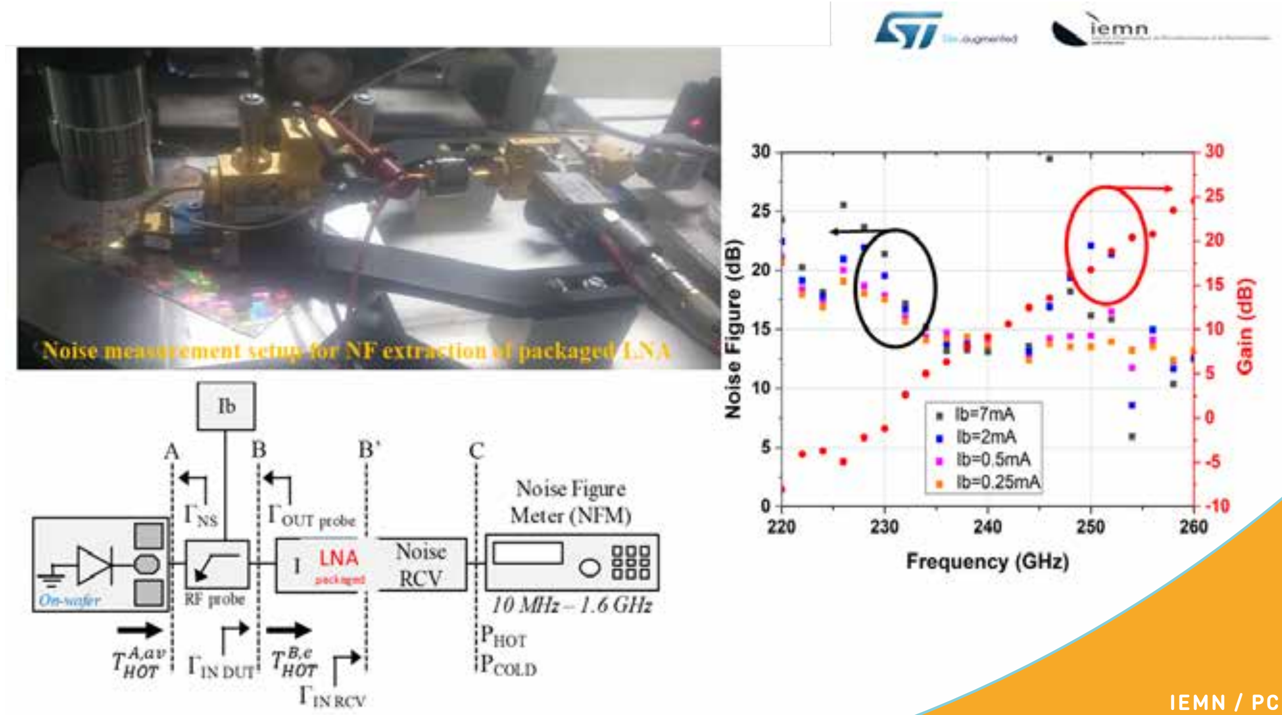
Example 1

Noise Measurements (LNA integrated 130-170GHz)



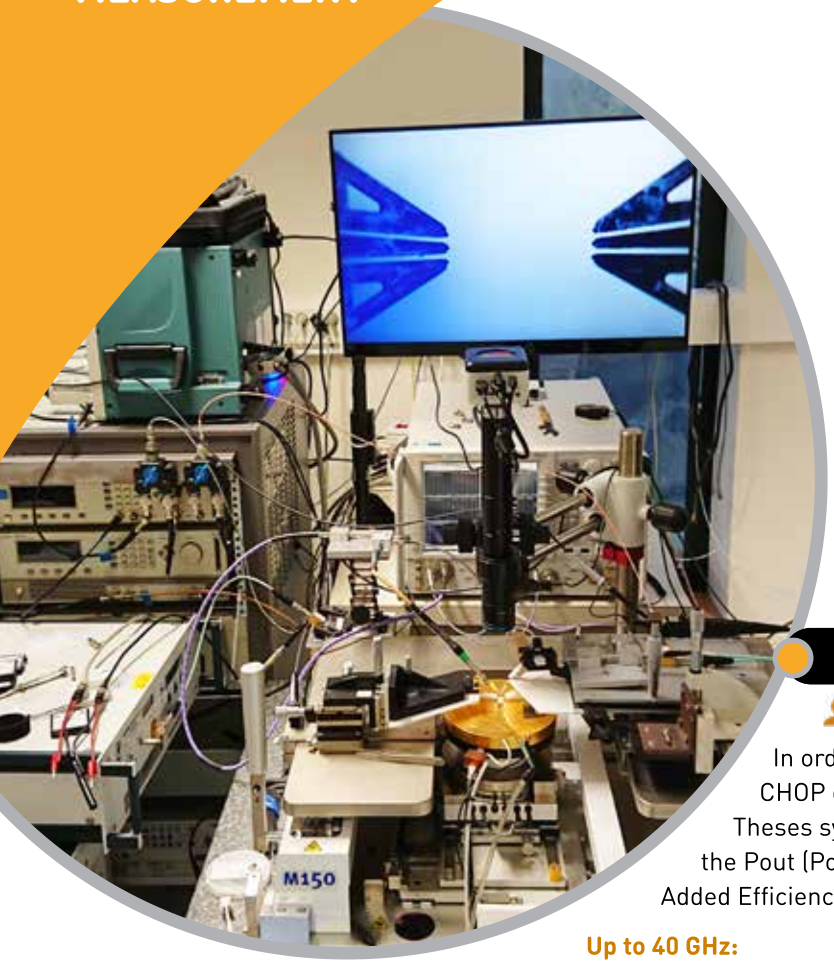
Example 2

Noise Measurements (LNA packaged 220-260GHz)



CHOP

POWER MEASUREMENT



40 & 94 GHz LOAD-PULL CHARACTERIZATION

Etienne Okada

In order to measure the power performance of transistors, the CHOP developed specific "Load-Pull" measurement benches. Theses system make it possible to determine the Gp (Power Gain), the Pout (Power available at the Output) as well as the Pae (Power Added Efficiency) of transistors and amplifiers.

Up to 40 GHz:

Since these parameters can only be determined under saturated conditions, a high power level is required to energize the device under test. For this, several power amplifiers are available and the bench have been optimized to carry the measurement up to the saturation of the DUT at 6, 10, 18 and 40GHz. At these frequencies, we can apply up to +30dBm at wafer level. Devices under test can be bias up to 50V.

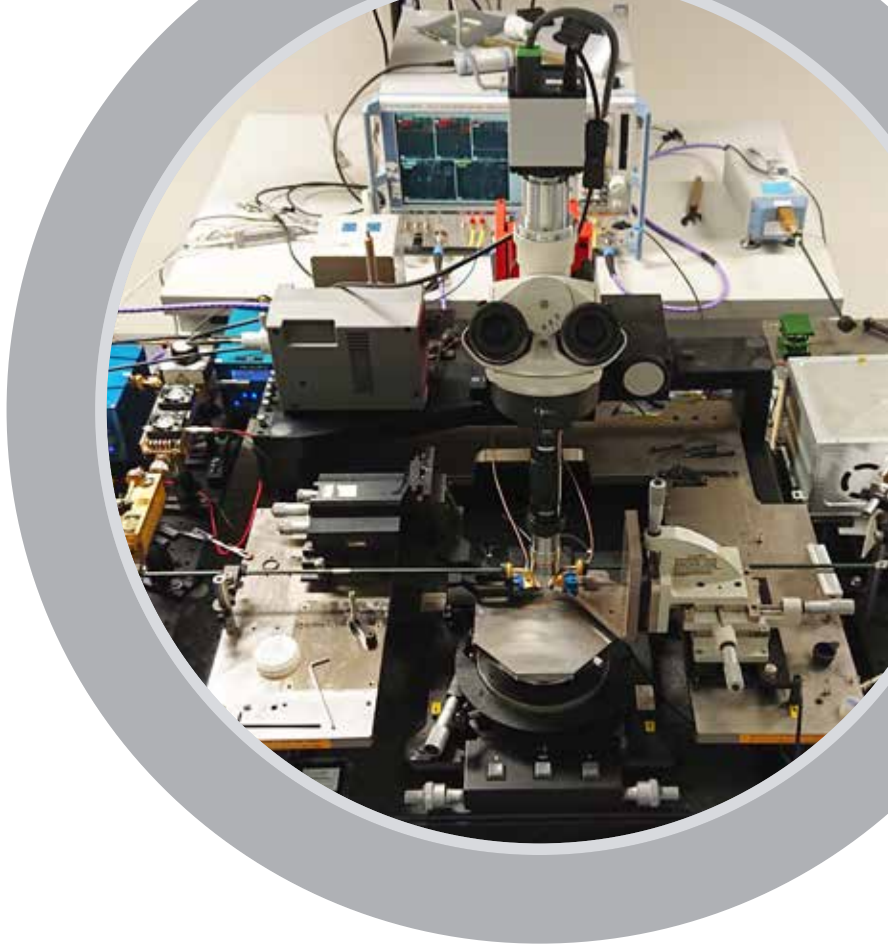
These measurements can be made in «load-pull» mode to modify the impedance presented at the output of the device under test. For this, we developed an active Load-Pull setup to reach high magnitude reflection coefficients. This helps determine the optimal impedance to maximize Gp, Pout or Pae.

All these measurements are possible in CW condition (continuous) or pulsed condition (pulsed bias + pulse RF) with a pulse width of 1µs and a duty cycle of 1%. Pulse measurements make it possible to overcome trap and thermal phenomena, thus maximizing the performance of the components under test.

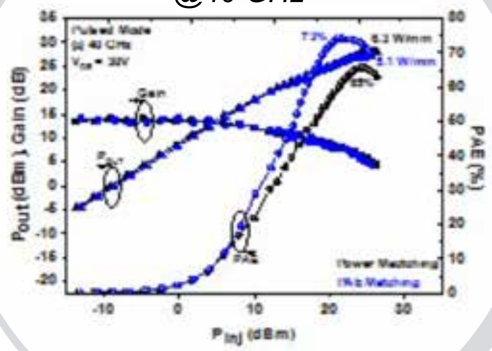
Large signal reliability test can also be made with this bench. We apply a large signal to the DUT and we measure its performance versus time for hours.

@94 GHz:

The 94GHz Load-Pull measurement bench is based on an active Load-Pull technique also. It is quite similar to the 40GHz bench with specific modification due to the high frequency. Big improvements are underway on this bench to reach higher power. Only CW measurement are available for now, pulsed measurements are in development.

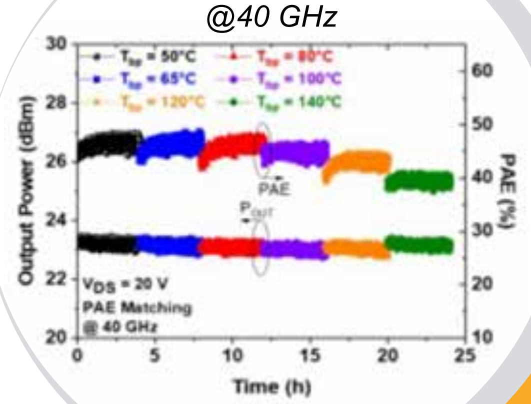


Large signal measurements @40 GHz



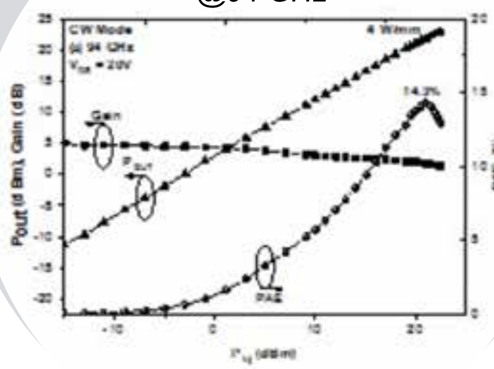
IEEE J. Electron Devices Soc., vol. 7, 2019

Large signal reliability @40 GHz



2020 IEEE IRPS

Large signal measurements @94 GHz



2020 IEEE IMS

I/V MEASUREMENTS HIGH VOLTAGE OR HIGH CURRENT

Etienne Okada

Based on a Keysight B1505A device analyzer coupled with a MPI TS150-HP probe station, this system allows on-wafer measurement up to 10kV DC for breakdown characterization. It also permit high current measurements: 20A @ 20V (Pulsed). We can also extract Dynamic RDS-ON of transistors by switching the device OFF to ON in just 50µs and monitoring the evolution of the current versus time.

Coupled with our HP-4294A Impedance Analyzer we are able to carry capacitance measurement from 1kHz up to 1MHz under bias voltage up to 3kV.

• This equipment can test components or materials up to voltages of 10 kV for breakdown measurements or 20 A @ 20 V.

ADVANTAGES & LIMITATIONS

+ High voltage and current are available but power is limited by the setup.

ΣCOM

The SIGMACOM service offers a large set of advanced scientific equipment's for the conception and test of new radio modules communication systems, (up to the millimeter wave range) and sensors. We can address wide area single hop or multi-hop networks as well as mixed radio-fiber connectivity for smart devices, implementing edge and near sensor computing to optimize rate, power consumption, reliability and/or latency. This service offers both software and hardware facilities to design, program and test both the analog and digital parts of smart and connected devices, up to 110 GHz. We can for example address the challenges related to IOT, 5G and beyond.

Head of SigmaCom
R. Kassi

- **Analog and digital communication systems** — III. 1-8
  → Redha Kassi → David Delcroix
  Telecom test bench
  Software-defined radio
  Multifunctional analog and digital I/O devices
  Energy efficiency test bench

- **Optical communication systems** — III. 9-12
  → Redha Kassi
  Optical telecom testbed
  Optical measurement bench

sigmacom-contact@iemn.fr

IEMN / PCMP

SIGMACOM

ANALOG AND DIGITAL COMMUNICATION SYSTEMS

Real-Time Open Multi user RF communication Test-Bench with Controlled Channel

TELECOM TEST BENCH

Rédha Kassi

This telecom test bench offers a wide range of state-of-the-art scientific equipment for the characterization of new radio modules and communication systems, covering frequencies up to the millimeter wave range. It is particularly well suited for wireless ad hoc networks for smart objects and sensors. In addition, the telecom platform aims at the generation and analysis of complex telecom signals to demonstrate new concepts for wireless communication links.

→ APPLICATIONS

• The bench includes a wide range of test systems and software that can provide a flexible and powerful environment to perform key telecom up to 60 GHz tests such as:

• Real-time characterization of a complex transmission and/or reception system, from baseband generation to RF transmission.

• Real-time characterization of a transmission/reception system from demodulation to data recovery with options to analyze RF signal integrity at each channel stage (EVM, channel power measurements, Occupied bandwidth, Modulation accuracy...), digital signal (BERT, PER, eye diagrams, jitter measurements), and mixed signals.

• Characterization of link robustness against real-time RF channel emulation, interference analysis.

• Physical testing of interoperability in heterogeneous sensor networks

• Testing the non-linearity of an amplifier on the communication channel and hard/soft correction.

• Testing frequency and phase synchronization.

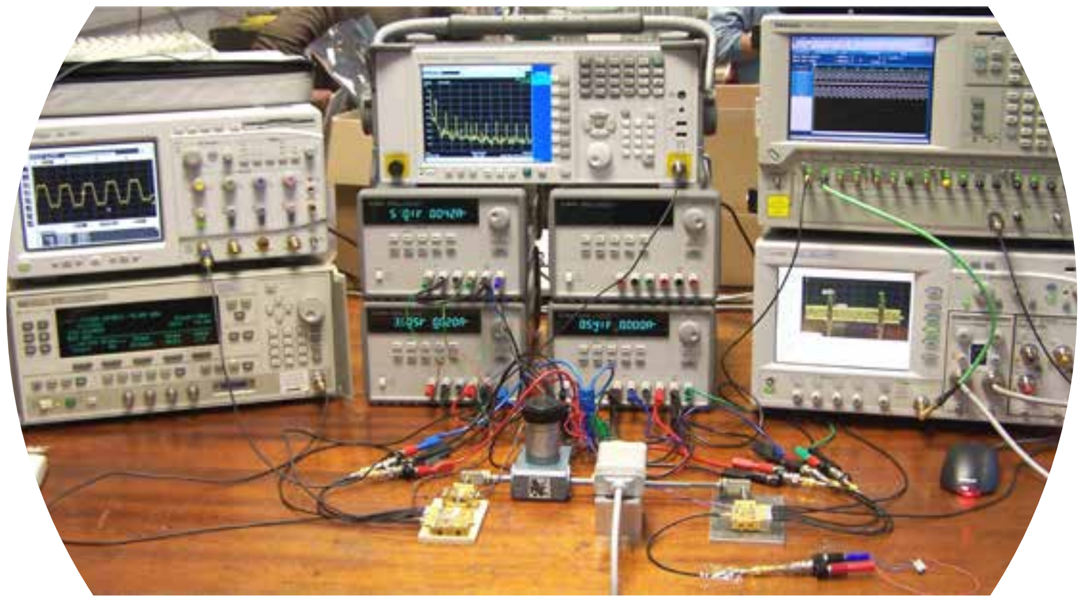
• Testing clock accuracy and stability.

• Optimizing transmission packet size.

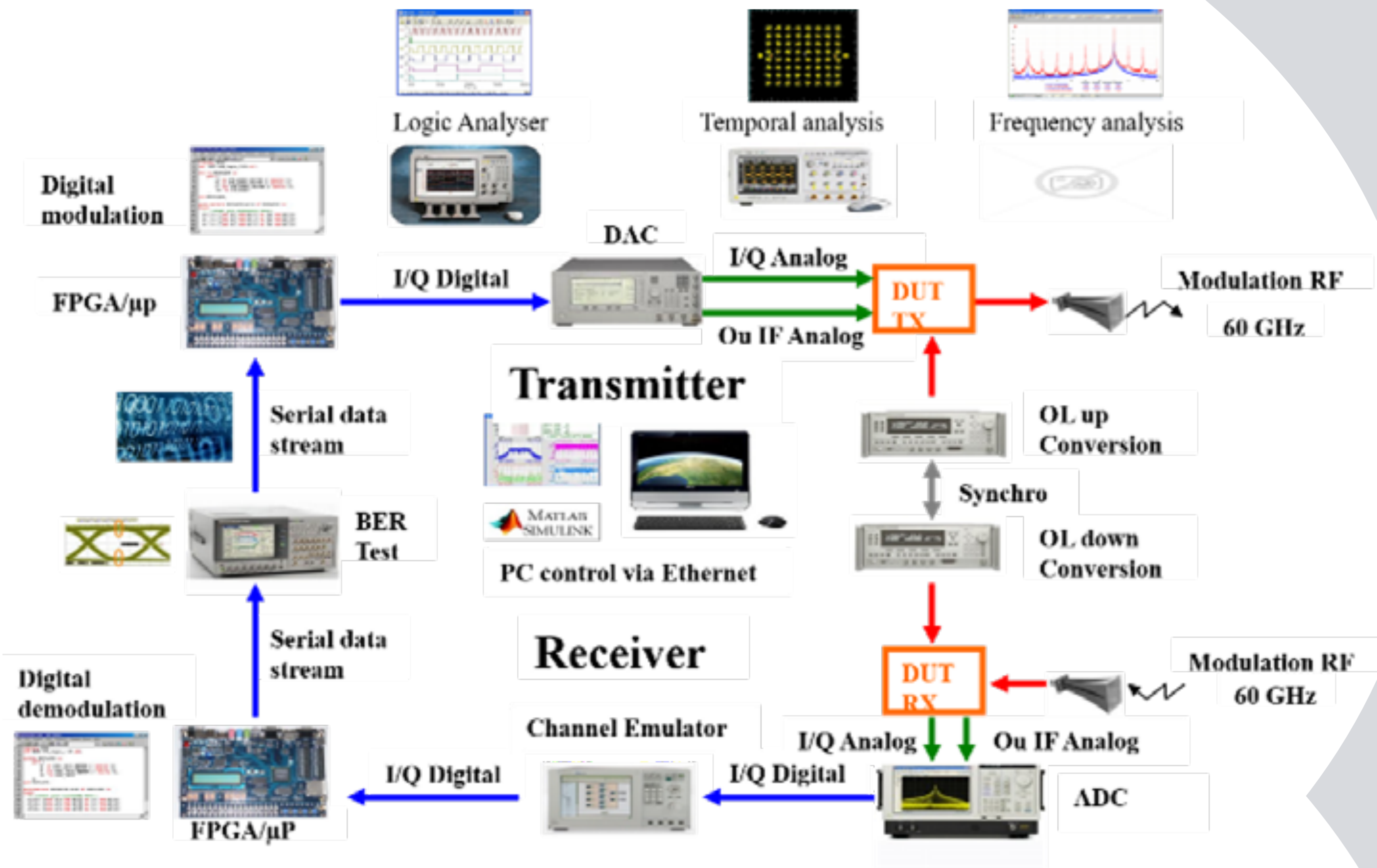
• Optimize the size of the synchronization preamble.

• Measure component temperature drift and impact on transmission.

Some measurement techniques can be used by the CHOP cluster for THz communications.



Mixed signal test bench for an UWB-IR communication system operating at 60 GHz



Characterization of a real-time communication

→ HIGHLIGHTS

Generation of complex analog, digital or mixed signals:

• Generation of vectorial signals up to 20 GHz with a 1 GHz analog bandwidth

• Generation of arbitrary wave form signals up to 1.25 Gs/s with a 15 bits resolution.

• Generation of arbitrary wave form signals up to 20 Gs/s with a 10 bits resolution.

• Pulse and data generation up to 3.35 Gb/s

• Frequency synthesizers up to 75 GHz

Time and frequency domain analysis of analog, digital or mixed signals:

• Automatic phase noise test set up (10 KHz - 110 GHZ), baseband noise, AM, FM measurement, variance, frequency meter.

• Vectorial signal analyzers up to 50 GHz with a potential 160 MHz analog bandwidth

• Sampling oscilloscopes up to 75 GHz

• Single shot oscilloscopes up to 12 GHz

• Spectrum analyzers up to 110 GHz

• Real time spectrum analyzer up to 14 GHz and 14 bits resolution

• Power meters up to 110 GHz

• Differential vectorial network analyzer (100 MHz-26.5 GHz) for RF circuits or radio

• Electrical Clock Recovery Module up to 2.5 Gb/s

• Logic analyzers up to 800 Mb/s for each of the 34 channels

• Bit Error Rate Test bench up to 13 Gb/s

Real time modelling for the channel propagation:
Baseband generator and channel emulator (4*2 or 2*4 MIMO Max, 24 multi-paths per channel, Channel BW 120 MHz, Sample rate 150 Msa/s Max)

Real time telecom signal generation and analysis

• modulation and demodulation for cellular (LTE/LTE-Advanced/LTE-A Pro FDD, GSM, GPRS, W-CDMA...) and non-cellular technologies (Wifi, Bluetooth, ZigBee, LoRa, SigFox, RFID...)

Software suite:

• Labview

• signal studio

• 89600 vsa

Multi-standard communication Gateway

USRP-2954

SOFTWARE-DEFINED RADIO

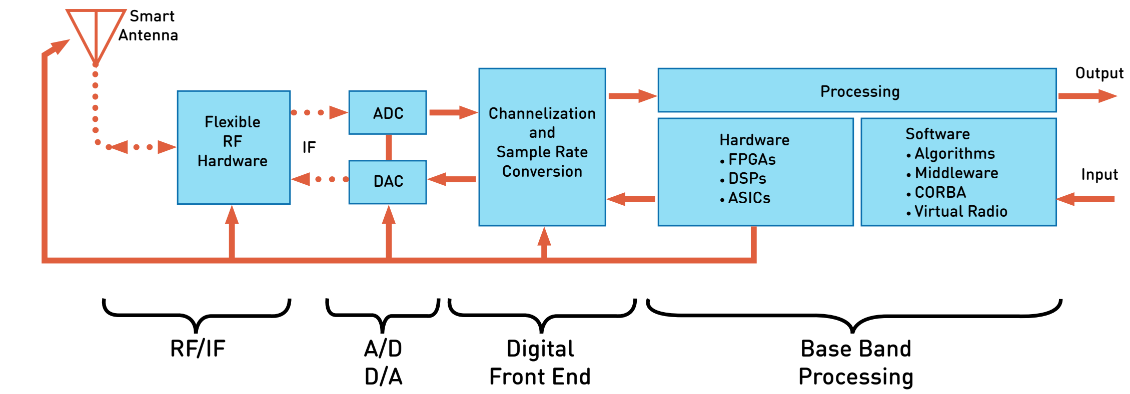
Rédha Kassi

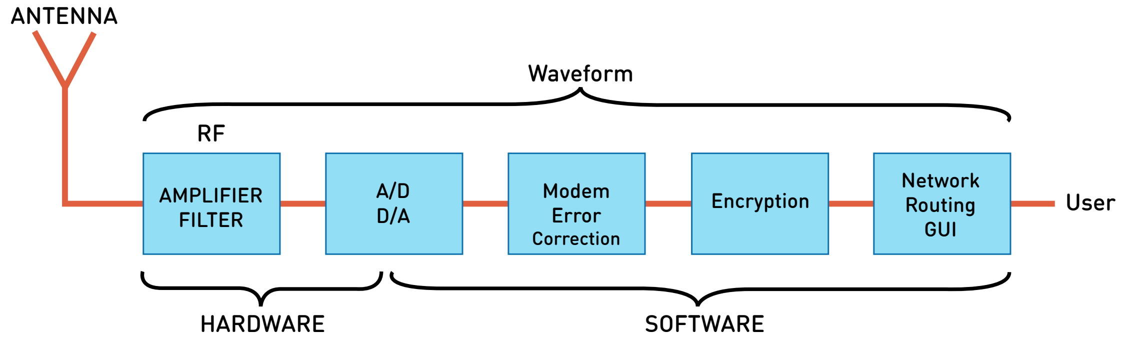
We offer a range of NI Universal Software Radio Peripherals (USRP) to define Software Defined Radios (SDRs) used for RF applications. These integrated hardware and software solutions enable rapid prototyping of wireless communication systems. NI USRP transceivers can transmit and receive RF signals in multiple bands. The USRP hardware architecture integrates RF analog front-ends (high-low conversion, filters, amplifiers), RF I/Q modulation-demodulation stage, ADCs and DACs, a processor or FPGA connected by wire to a host computer (PC or PXI chassis) for sending, and receiving properly formatted baseband I/Q data. The USRPs are programmed using the LabVIEW development environment. This solution offers great flexibility for software radio prototyping and communications research.

→ APPLICATIONS

The USRP hardware allows a wide range of applications.

- Dynamic access to the RF spectrum and real-time recording of signals over a long period of time.
- PHY and MAC layer research for robustness of radio links.
- Build custom transmission or reception protocols.
- Build multi-standard communication gateways
- Integrate USRP into a standard radio communication network to test new wireless algorithms (TDD, FDD) to improve communications.
- Test channel coding or source coding blocks
- Simulate channel degradation and verify the impact on transmissions.
- Implementing of MIMO technology





→ HIGHLIGHTS

Main hardware features of USRP

The USRP are equipped with a GPS-disciplined 10 MHz oven-controlled crystal oscillator (OCXO) reference clock. The GPS disciplining delivers improved frequency accuracy and synchronization capabilities. It is equipped with a reconfigurable FPGA

Transmitter:

- Number of channels 2
- Frequency range 10 MHz to 6 GHz
- Frequency step < 1KHz
- Maximum output power (Pout) 50 mW to 100 mW (17 dBm to 20 dBm)
- Gain range 0 dB to 31.5 dB
- Gain step 0.5 dB
- Maximum instantaneous real-time bandwidth 160 MHz
- Maximum I/Q sample rate 200 MS/s
- Digital-to-analog converter (DAC) Resolution 16 bit
- Spurious-free dynamic range (sFDR) 80 dB

Receiver:

- Number of channels 2
- Frequency range 10 MHz to 6 GHz Frequency step
- Frequency step < 1KHz
- Gain range 0 dB to 37.5 dB
- Gain step 0.5 dB
- Maximum input power (Pin) -15 dBm
- Noise figure 5 dB to 7 dB
- Maximum instantaneous real-time bandwidth 160 MHz
- Maximum I/Q sample rate 200 MS/s
- Analog-to-digital converter (ADC) Resolution 14 bit, sFDR 88 dB

Software suite

- Labview
- Labview FPGA Module
- Labview communications system design suite
- GNU Radio, Python, Matlab, Simulink, C/C++.

Test bench of a neuromorphic system-on-chip

MULTIFUNCTIONAL ANALOG AND DIGITAL I/O DEVICES

Rédha Kassi

We offer several PXI chassis integrating a controller and different multi-channel I/O modules (analog, digital or mixed) allowing to realize several instruments adaptable for multiple test and measurement applications. The originality of this modular, synchronous, standardized solution is to quickly offer several specific instruments to generate, acquire, store and analyze different signals in a single chassis. The National Instrument programming environment is used to create or use software applications to drive the hardware, process, analyze stored data and/or visualize it in continuous time.

→ APPLICATIONS

There are many test and measurement applications, the only limitations of which depend on the technical characteristics of the equipment.

- Generation (DAC) and acquisition (ADC) of data and control
- Instrumentation (function generator, AWG, digital signals, oscilloscope, spectrum analyser, ...)
- Wireless communication test (acquisition and real time generation of baseband or IF)

RF test bench

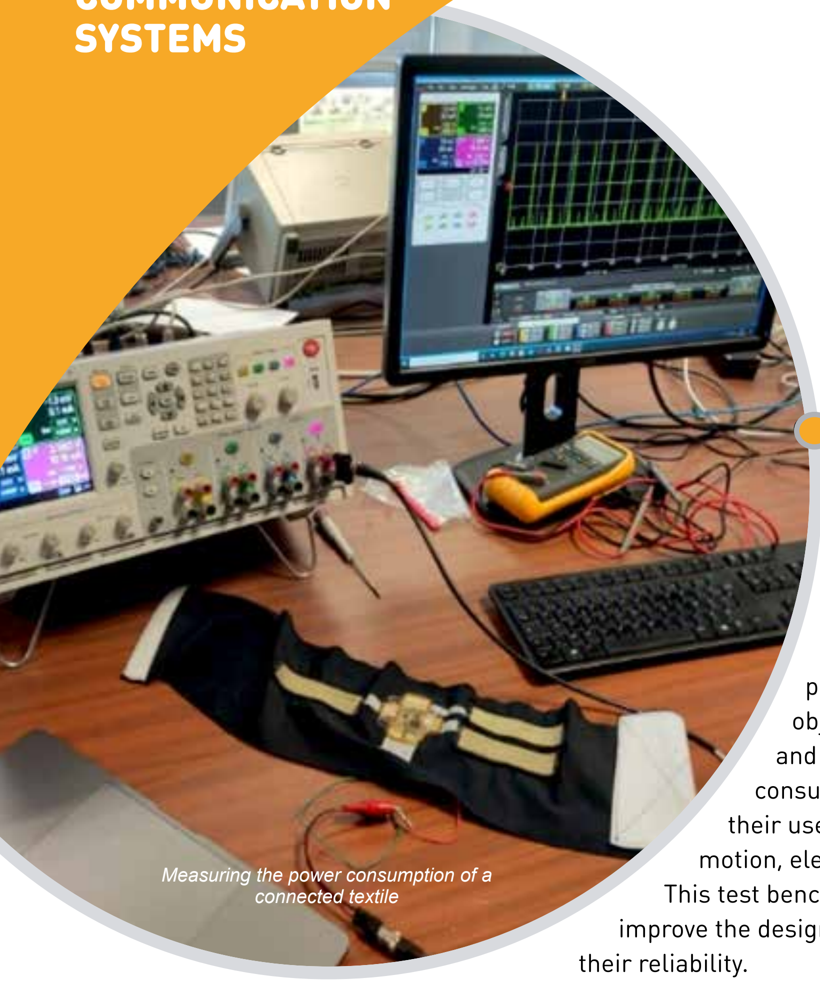
→ HIGHLIGHTS

- **16-bit PXI analog output module, 8 channels, 1 MS/s (8 TTL/CMOS 5V digital I/O lines)**
- **16 simultaneous 24-bit PXI analog inputs module (204.8 kS/s sampling rate, 114 dB, 4 gains, AC/DC coupled)**
- **PXIe, 16 AI (16 bits, 1,25 MS/s/ch), 4 AO, 48 DIO, module I/O multifunction**
- **100 MHz Bandwidth Transceiver Adapter Module (this module must be combined with a PXI FPGA)**
- **200 MHz digital I/O adapter module, 32 LVDS channels (this module must be combined with a PXI FPGA)**
- **Digitizer adapter module 50 MS/s, 14 bit, 16 channels (digitizer must be combined with a PXI FPGA)**

RF Signal Analysis

SIGMACOM

ANALOG AND DIGITAL COMMUNICATION SYSTEMS



Measuring the power consumption of a connected textile

ENERGY EFFICIENCY TEST BENCH

Rédha Kassi

This energy efficiency test bench offers the possibility of optimising the energy consumption of communicating objects for IOT, 5G and beyond, by enabling the energy impact of electronic systems to be measured precisely in a controlled environment through the choice of low-power hardware and software architectures. One of the objectives is to limit the frequent recharging of batteries and to maximise their lifespan. Knowing the AC/DC energy consumption of objects also makes it possible, depending on their use, to size ambient energy recovery technologies (solar cell, motion, electromagnetic, etc.) to create energy autonomous objects. This test bench allows numerous measurement possibilities in order to improve the design of objects to increase their performance and guarantee their reliability.

→ APPLICATIONS

Measure and analyse the power consumed by a system or the sub-systems of a complex object.

• To measure the current and voltage accurately over a wide dynamic range depending on the operating state of the object (on, standby, communication, ...)
• Measure the exact power consumption with sufficient bandwidth not to miss fast digital events.
• Synchronize the power consumption measurement with the software subroutines of the powered object to optimize processor scheduling and maximize the object's battery life.
• Correlate load consumption with RF events and events in the object's sub-circuits.
• Consider the impact of power consumption as a function of RF interference with other wireless devices in a real or controlled environment by combining it with the telecom test bench (influence of channel model, RF disturbance, interferer, electromagnetic pulse, ...).
• Test in difficult electromagnetic environments (C2EM: anechoic chamber, reverberation chamber)

Evaluating the battery characteristics of a device

• Visualize the evolution of the power consumed by an object according to its use and record it over a long period of time in a point file.
• Replay a stored point file to check the performance of a battery and estimate its lifetime.
• Characterize the charge and discharge of a battery over time.
• Analyze statistically (CCDF) the power consumed

Analysis of the energy consumption of a device under test

→ HIGHLIGHTS

Device current waveform analyzers

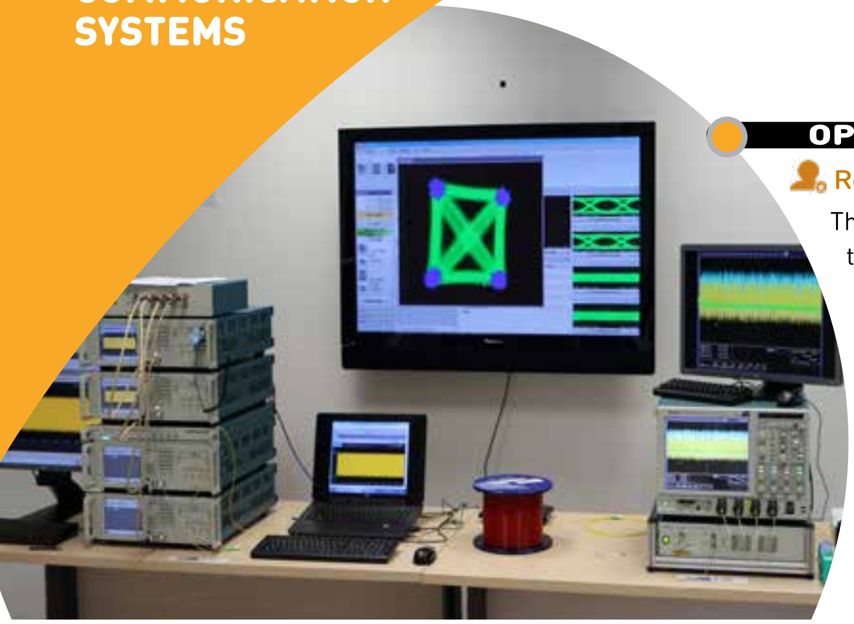
• Widest current measurement range: 100 pA to 10 A
• Capture fast transient effects of spikes with bandwidth up to 200 MHz
• Max sampling rate: 1GSa/s
• Purpose-built low power IoT chip or device characterization

DC power Analyzer and source measure unit

• 20W and 80W power generators
• Measure wide range of current from sub µA to 8 A and voltage in one pass
• Function as current / voltage source and e-load
• Purpose-built for battery drain analysis
• Long term data logging (up to 200 KSa/s, log current drain up to 1000 h, energy consumption measurements (Ah, Wh, Joules, Coulombs)
• Battery emulation mode
• Meter view (output voltage, current and power)
• Scope view (displays output voltage and current as a function of time)
• Data logger view (hours of measurements with a maximum time resolution of 20 µs can be logged internal memory or an external USB)
• CCDF (complementary cumulative distribution function) view (quantify the impact of design changes – hardware, firmware or software- on current flows in your design.
• ARB capability (step, ramp, staircase, sine, pulse, trapezoid, exponential, sequence, user defined; max size of 64000 waveform points, max bandwidth of 100 KHz, two quadrant operation)

SIGMACOM

OPTICAL COMMUNICATION SYSTEMS



Measurements of an optical transmission

OPTICAL TELECOM TESTBED

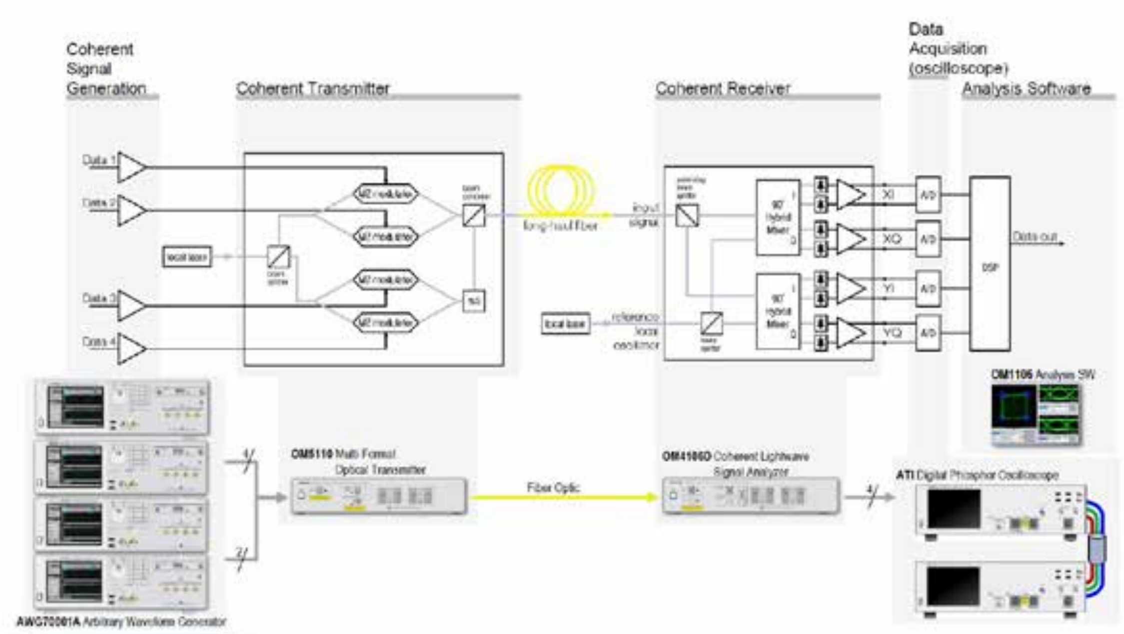
Rédha Kassi

This optical telecom testbed allows the exploration of technologies such as photonic space division multiplexing while combining coherent optical technology with wireless transmissions up to THz to support the insatiable demand for ever increasing data transmission capacity worldwide. This instrumentation test bench is a complex chain of very high speed coherent optical transmission systems that can generate, acquire and analyze the data transmission quality of optical communications systems that allow the combination of THz radio technologies. A software suite allows the instrumentation to be controlled and the transmission quality to be quantified in terms of BER, EVM and eye diagrams for different modulation standards at data rates up to 512 Gb/s. This bench, located at the IRCICA, is managed by the PHLAM and shared with the IEMN.

The instruments constituting the telecom testbed may also be used individually in experiments with high requirements, such as synchronized acquisition of fast electrical or optical signals (group of sampling oscilloscopes with 4 ATI ports at 70 GHz or 8 ports at 33 GHz); or the generation of complex electrical or optical signals (group of arbitrary function generators with 8 ports at 22 GHz).

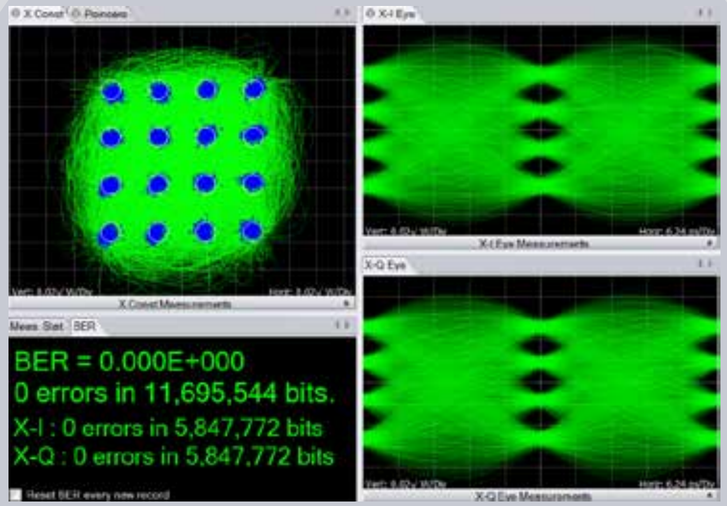
→ APPLICATIONS

- Transmission quality (EVM, Q, BER) in optical fiber on optical carrier ;
- Transmission quality (EVM, Q, BER) in free-space on THz carrier ;
- Coherent modulation formats (N-QAM, 32 Gbaud) ;
- Digital signal processing (DSP, MIMO 4x4) ;
- Shaping and detection of fast optical signals (33 GHz) ;
- Spatial and modal multiplexing.
- Space-time coding
- Implementation of very high speed transmissions on new generation slightly multimode optical fibres using spatial multiplexing such as modal multiplexing to characterise crosstalk.
- Coupling coherent optics technology to wireless transceiver technology in the terahertz range.



Coherent Optical end to end solution

• 32 Gbaud 16-QAM optical signal
• EVM = 6.5%



→ HIGHLIGHTS

This transceiver test bench has several instruments:

- Arbitrary Wave Generator (BW up to 15 GHz, 10 bit vertical resolution, DAC 50 Gs/s)
- Instruments for AWG synchronisation (random jitter 315 fs)
- Multi-format coherent optical transmitter and receiver (46 GBaud BPSK, PM-16 QAM, C or L band lasers or external, Ix, Qx, Iy and Qy base band signals)
- Real time oscilloscope (70 GHz, <7 ps rise time, 200 GS/s sample rate, 100fs jitter noise floor, single-ended 62,5 mv to 300 mv)
- Software generation of RF communication standards
- Display constellation diagrams, EVM, phase eye diagrams, Q-factor, Q-plot, BER,...
- Measures Polarization Mode Dispersion (PMD)
- Coherent lightwave signal analyzer software

Digital photonic transmission systems (10 Gb/s)

OPTICAL MESUREMENT BENCH

Rédha Kassi

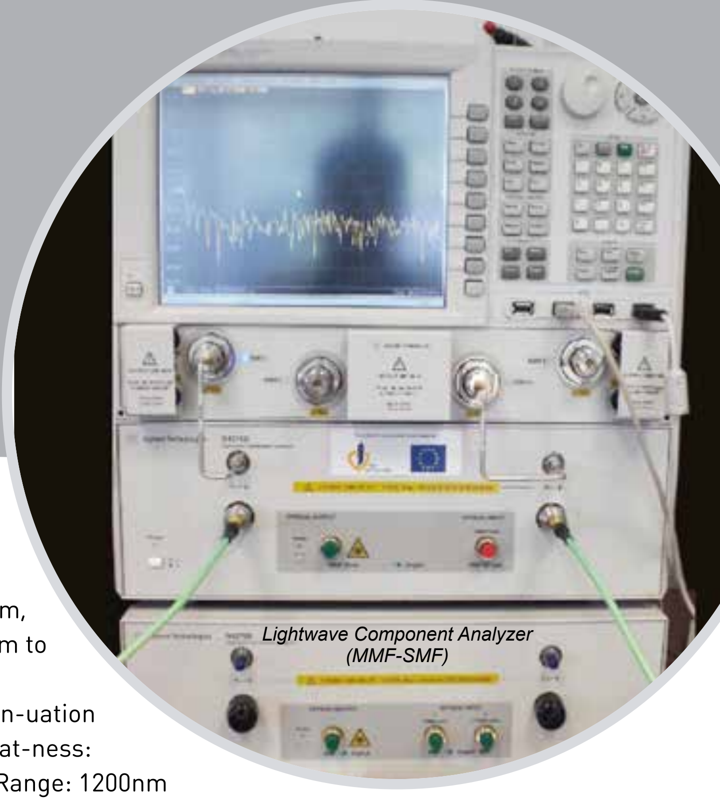
We have specific instruments for the characterization of systems incorporating optical components. We can generate and analyze optical signals to verify the optical performance of fibers, photodiodes and electro-optical components. S-parameter, optical power and reflectometry measurements can be performed. These instruments are complementary to the optical telecom test bench for radio over fiber or the telecom test bench for communications over fiber.

APPLICATIONS

• Fiber radio requires an RF frequency response (from 10 MHz to 26.5 GHz) around an optical wavelength (850 nm, 1550 nm or 1310 nm) in order to accurately characterize an optical transmission chain by measuring the S parameters of electro-optical components (detector diodes, modulators) using a Lightwave Component Analyzer (LCA).
• Basic platform for testing 10 GbE optical and electro-optical components, Fiber Channel FC*8, FC*10, FC*16
• Qualitative analysis of modulated signals with an electrical spectrum analyzer or oscilloscope.

HIGHLIGHTS

Lightwave Measurement System:
• Variable Optical Attenuator Module for Multimode Fiber Applica-tions (50 µm and 62,5 µm, input power level up to 27 dBm, at-tenuation range: 0dB to 60 dB, wide wavelength range: 700 nm to 1400 nm)
• Variable Optical Attenuator Module with Angled Interface (atten-uation Range: 0dB to 60dB, High Input Power Level: 2W, Wavelength Flat-ness: < 0.05dB, High Attenuation Accuracy < 0.1dB, Wide Wavelength Range: 1200nm to 1700nm (SMF))
• Reference transmitter for Optical Receiver Stress Test (10MHz to 33 GHz typical electro-optical bandwidth, Optical wavelength1310 nm & 1550 nm Single Mode Fiber, Operational data rate 622 Mb/s to 14.2 Gb/s, Rise and fall times < 15 ps)
• Reference Receiver is an O/E converter optimized for transceiv-er loop-back test (Opto-electrical modulation bandwidth DC to 9.3 GHz (typical), Wavelength range 750 nm to 1650 nm, MMF 62.5 µm/125 µm, Op-erational data rate 622 Mb/s to 12.5 Gb/s, Rise and fall times < 35 ps)
• General Purpose Optical Power Head (Wavelength range 800 nm to 1700 nm, power range 40 dBm to -90 dBm, Low polarization dependence)



Lightwave Component Analyzer (MMF-SMF)

Lightwave Component Analyzer:
• Operation frequency range 10 MHz to 26.5 GHz
• Transmitter and receiver specifications MMF
• Optical input 62.5 µm
• Optical output 50 µm
• Input wavelength range 750 nm to 1650 nm
• Output wavelength 850 nm
• Transmitter and receiver specifications SMF
• Optical input/output 9 µm single mode angled
• Input wavelength range 1250 nm to 1640 nm
• Output wavelength 1310 nm and 1550 nm

C2EM

The C2EM service is devoted to both Electromagnetic Compatibility (EMC) measurements and, in generic words, to Electromagnetic (EM) characterization in a wide frequency range (few Hz to 20 GHz) with dedicated equipments and instrumentation.
EMC studies / EM interactions between electronic/ electrical equipments and their functioning environment. The aim is to ensure that such equipments will operate correctly both with a sufficient level of EM immunity against external sources and without generating EM emissions susceptible to disturb communication systems.
EM characterization concerns all EM measurements (e.g antennas characterization) requiring a standard 'quite' site and the on-site measurements such as the telecom propagation channels characterization.
The service gathers in a same area of 180 m2 various measurement's chambers and cells, each of them attempting to represent a certain EM environment required for research and EMC testings.

1. Radio Frequency Anechoic Chamber (RF-AC): 6m x 6m x 2.8 m
2. Transverse ElectroMagnetic Cell (TEM-cell) : 2m x 1m x 0.6 m
3. Mode Stirrer Reverberation Chamber (MSRC), 5.6m x .4m x 2.8 m

Head of C2EM
P. Laly

@

- **EMC chambers and cells** — IV. 1-2
  → Pierre Laly
  Radio frequency anechoic chamber (RF-AC)
  Transverse electromagnetic cell (TEM-cell)
- **EM site characterization**, — IV. 3-4
  → Pierre Laly
  Mode stirrer reverberation chamber (MSRC)
  Transfer impedance (ZT) bench test
- **Electronic prototype study and realization** — IV. 5-6
  → Pierre Laly
  Massive multiple input multiple output system acquisition (MAMIMOSA)

c2em-contact@iemn.fr

C2EM

EMC CHAMBERS AND CELLS

RADIO FREQUENCY ANECHOIC CHAMBER (RFAC)

Pierre Laly

The actual RFAC consists in a 137m3 shielded room whose internal walls are covered with radio-frequency (RF) absorbing foams. It is intended to represent a standard free space propagation environment with known properties. The geometrical dimensions and the electromagnetic characteristics of the absorbing materials limit the bandwidth of the chamber, in particular in the lower frequency range. This chamber is devoted to ElectroMagnetic Compatibility (EMC) testing and to all electromagnetic (EM) characterization requiring quiet EM environment (e.g. for antennas radiation pattern and gain assessments). According to the application, the frequency range is from 30 MHz up to 18 GHz. For EMC purpose, the chamber meets the basic EMC requirements in terms of field uniformity and site attenuation for a 3 meters testing. Therefore, it is quite usable for EMC pre-compliance testing according to European and to some military and aeronautic EMC standards, for radiated immunity and emission.

To ensure its functioning, the following instrumentation is available:

- Spectrum Analyzer RS FSV30 (10 Hz -30 GHz)
- VNA RS ZVA 24 (10 MHz -24 GHz)
- Synthesized RF generator (10 MHz -20 GHz, 10 dBm)
- Turntable table
- Broad band antennas (30MHz -18 GHz) : bi-conical, log-periodic, double ridge
- Broad band amplifiers: 30W (1 MHz-1 GHz), 25W (800MHz-4 GHz)
- Broad band Electric field probe (100 kHz-6 GHz), E-field max 200V/m

→ **ADVANTAGES & LIMITATIONS**

- (+) High EM isolation against EM disturbances (90 dB min @1GHz),
- (+) Standard plane waves environment
- (−) Low frequency limitation for antennas characterization (Fmin=200 MHz),
- (−) Size limitation, e.g. 5 m distance max available for RFID tags characterization
- (−) Height scanning limited (1.2m to 1.80m) for EMC testing

→ **MAIN EMC APPLICATIONS**

- Radiated emissions and radiated immunity characterisation of electronic/electric equipments,
- Shielding effectiveness measurement of flat materials,
- Experimental validation of EMC numerical models

→ **OTHER APPLICATIONS**

- Characterisation of RFID (Radio Frequency Identification) tags performance (860 -950 MHz),
- Characterisation of antennas arrays (radiation pattern, gain, antenna factor),
- Experimental validation of antennas numerical models

TRANSVERSE ELECTROMAGNETIC CELL (TEM CELL)

Pierre Laly

The TEM cell is a shielded strip line like a tapered transmission line (TL) of rectangular cross-section with a flat inner conductor (septum). It is intended for establishing standard uniform EM field in the low frequency range (f<30 MHz) where RF-AC and MSRC are not functioning. The cell geometry is designed to give a 50 Ω characteristic impedance for the TL. Within the working volume (under the septum), the fields are those of a plane wave as far as the fundamental TEM mode remains dominant. The cell operates from DC to an upper frequency such that high order modes excited in the cell remain negligible compared to the TEM mode. Therefore, the maximum frequency of measurement depends on the dimensions of the cross-section of the cell and of the size of the device under test (DUT).
The TEM cell constitutes a powerful experimental tool which enables various experiments in EMC domain for the study of EM fields coupling phenomenon to cables and PCB traces.

To ensure its functioning, the following instrumentation is available:

- Spectrum Analyzer RS FSV30 (10 Hz -30 GHz)
- VNA Agilent E8733 (30 kHz-6GHz)
- Synthesized RF generator (10 kHz -1 GHz, 13 dBm)

→ **MAIN EMC APPLICATIONS**

- Measurement of radiated emissions and susceptibility of embedded electronic devices,
- Characterisation of the EMC behaviour of partially shielded cables for aeronautic applications,
- Calibration of electrically small size E and H-field probes,
- Study and validation of numerical models of the EM coupling to cables

→ **Complementary with other techniques present at IEMN :** Pole SigmaCom for HF RFID tags characterization

→ **ADVANTAGES & LIMITATIONS**

- (+) Standard plane wave environment at low frequency
- (−) High frequency limitation (e.g, 100 MHz for our TEM-c)

C2EM

EM SITE CHARACTERIZATION

MODE STIRRER REVERBERATION CHAMBER (MSRC)

Pierre Laly

In contrast with the RFAC (Radio Frequency Anechoic Chamber), the MSRC is a very complex of high Q-factor measurement tool intended to simulate realistic EM environments such as that encountered by electronic devices in large screened boxes, aircrafts, automotive vehicles, etc. The MSRC consists in an electrically large chamber with highly conducting walls . The lowest working frequency (LWF) of a MSRC is such that its wavelength is smaller than the smallest dimension of the chamber. A MSRC is equipped with a metallic paddle (the stirrer) which can be moved by means of a continuous or stepped motor. Physically, a MSRC acts as an oversized cavity in which a high number of resonant modes can be excited around any frequency higher than the LWF. Thus, the rotation of the stirrer allows achieving different boundary conditions, and consequently, it generates a complex EM environment with randomly distributed field in amplitude, phase and polarisation. However, far from the wall > than a quater of wave length, the fields remain in average, statistically uniform and isotropic within the chamber. Consequently, all the physical quantities (e.g. E-field, power, etc) are measured as averaged values of sets of data collected when the stirrer is moving. Uniformity and isotropy properties are checked through a normalized calibration procedure based on the standard deviation (STD) of E field samples acquired at different locations in the chamber. Due to the high Q-factor, high field level can be achieved with low input power

To ensure its functioning, the following instrumentation is available:

- Spectrum Analyzer RS FSV30 (10 Hz -30 GHz)
- VNA RS ZVA 24 (10 MHz -24 GHz)
- Synthesized RF generator (10 MHz -20 GHz, 10 dBm)
- Broad band antennas (30MHz -18 GHz) : log-periodic, double ridge
- Broad band electric field probe (100kHz – 6 GHz)

→ MAIN EMC APPLICATIONS

- Measurement of radiated emissions and susceptibility of electric/electronic equipments
- Characterisation of the shielding effectiveness of flat materials, shielded cables and connectors

→ OTHER APPLICATIONS

- Characterisation of RFID (Radio Frequency Identification) tags radiation efficiency
- Emulation of telecom multipath propagation channel
- Emulation of diffuse environment for assessing human body specific absorption rate

→ Complementary with other techniques present at IEMN : Pole SigmaCom, CHOPE

→ MSRC is an alternative EMC testing site to RFAC

→ ADVANTAGES & LIMITATIONS

- (+) Low cost equipment v.s RFAC
- (+) High Q (quality) factor environment enabling high level of E- field inside the chamber with low power amplifier.
- (+) Low insertion loos v.s free space and RFAC
- (+) Spatial homogeneity of the field over the working volume
- (+) No need of changing antennas polarization and using turntable table when performing EMC testing.
- (+) Capability for measuring the total isotropic power radiated by an equipment
- (−) Loos of antennas directivity,
- (−) Need of rotating the stirrer during any measurement

TRANSFER IMPEDANCE (ZT) BENCH TEST

Pierre Laly

In EMC problems, cables play an important role both in the radiation and in the susceptibility phenomenon of the equipments they interconnect. When the cables are shielded, their EMC performance is generally evaluated, (depending on the field of application), either by a measure of the shielding effectiveness or by measuring a well-known parameter: the transfer impedance denoted Zt.
The IEMN staff TELICE is pioneer in studying Zt measurement's methods. The Zt bench test used in C2EM service as been studied and constructed according to IEC (International Electrotechnic Commission) requirements.

→ APPLICATIONS

- Transfer impedance and shielding effectiveness measurement of shielded cables and connectors

→ ADVANTAGES & LIMITATIONS

- (+) Wide frequency range (few kHz to 2 GHz),
- (+) High sensitivity (e.g. 0.1µΩ/m) in low frequency range (few kHz to 30 MHz)
- (−) Low frequency sampling above 100 MHz

MASSIVE MULTIPLE INPUT MULTIPLE OUTPUT SYSTEM ACQUISITION (MAMIMOSA)

Pierre Laly

Channel sounder MIMOSA (Multiple Input Multiple Output System Acquisition) real-time MIMO (16Tx, 16Rx) and Massive MIMO (64Tx, 16Rx) channel analyzer. The actual model can operate from 1.3 GHz until 10 GHz. Two frequencies are available for now, 1.35GHz and 5.89GHz with 80MHz bandwidth. The sounder is based on numerical processing by FPGA coupled at a computer for data recording.

MaMIMOSA is based on space-frequency division multiplexing, giving a large possibility of tone and antenna allocation. This channel sounder belongs to the new generation of software radio design based systems. The architecture of proposed approach was designed with the highest flexibility thus opening a wide range of applications. In addition, the channel sounder has been built to avoid heavy post-processing: i) the Tx signal is pre-processed to include the non-linearity of the Tx and Rx chain, ii) Thanks to the high sampling frequency of the FPGA, a real digital baseband signal is transmitted to the RF chain avoiding I/Q impairment, iii) the output file gives the 4.Ntx.Nrx transfer function in a versatile binary format. Finally, the power consumption of the sounder is low and can be powered with a 24 V battery with a 8 hours autonomous.

→ MAIN APPLICATIONS

- Real-time propagation channels characterization in indoor,
- Real-time propagation channels characterization in mobility context (such as vehicular, aerial, ship, etc.),

→ OTHER APPLICATIONS

- Cybersecurity,
- Staff fall detection in a confined environment (e.g. ship)
- Localization in a complex environment (e.g. forest)
- Test of new communications techniques (5G, 6G, etc

→ Complementary with other techniques present at IEMN : Pole SigmaCom

→ ADVANTAGES & LIMITATIONS

- ⊕ Real Time
- ⊕ Flexibility
- ⊕ Low post-processing
- ⊕ "Mobile"
- ⊖ New filters for new frequencies,
- ⊖ Mobile but need to adapt to the new environment.

Signal in Baseband		Radio Frequency	
• Multiplex • Used sub carrier • Outputs • N subcarrier / output • Delta frequency • Symbol duration	IFDM 6560 8 820 97.7 kHz 81.92 µs	• Frequencies • Bandwidth • NTx (switched mode) • Power / Tx • NRx • AGC Dynamic	1.35 GHz / 5,89GHz 80 MHz 8 (16 ou 64) 1 to 100 mW 16 63 dB
Sounding characteristics			
• CIR* • Max CIR*	10.24 µs 50 M	- CIR Resolution - Matrix H(16,16,1024) - Matrix H(16,64,1024)	12.5 ns 1 Mo 4 Mo

Manufacturer: IEMN/Telice/Univ. Gent

@

Sylvie GODEY
Coordinator
sylvie.godey@iemn.fr
✆ 03 20 19 78 64 / Office 034

PCP-SPM

IEMN Central Lab
pcp-contact@iemn.fr

Maxime BERTHE
maxime.berthe@iemn.fr ✆ 03 20 19 78 63 / Office 036

Sylvie GODEY
sylvie.godey@iemn.fr ✆ 03 20 19 78 64 / Office 034

Louis THOMAS
louis.thomas@iemn.fr ✆ 03 20 19 78 63 / Office 036

CHOP

IEMN Central Lab
chop-contact@iemn.fr

Sophie ELIET
sophie.eliet@iemn.fr ✆ 03 20 19 79 30 / Office 277

Sylvie LEPILLIET
sylvie.lepilliet@iemn.fr ✆ 03 20 19 78 45 / Office 277

Etienne OKADA
etienne.okada@iemn.fr ✆ 03 20 19 79 30 / Office 277

Ayman RHELLAB
ayman.rhellab@iemn.fr ✆ 03 20 19 79 30 / Office 277

SIGMACOM

IRCICA
sigma-contact@iemn.fr

Rédha KASSI
redha.kassi@iemn.fr ✆ 03 62 53 16 04

David DELCROIX
david.delcroix@iemn.fr ✆ 03 62 53 16 04

C2EM

University of Lille - Building P3
C2em-contact@iemn.fr

Pierre LALY
pierre.laly@iemn.fr ✆ 03 20 33 59 59 / Office 002

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pcmp-contact@iemn.fr

IEMN / PCMP

iemn

Institute of Electronics, Microelectronics and Nanotechnology

IEMN - Laboratoire Central
UMR CNRS 8520
Cité Scientifique
Avenue Poincaré BP 60069
59652 Villeneuve d'Ascq Cedex - France
Phone: +33 (0)3 20 19 79 79
Fax: +33 (0)3 20 19 78 78

IEMN - Antenne Université de Lille
Cité Scientifique, Bât. P.3 & P.5
Avenue Poincaré BP 60069
59652 Villeneuve d'Ascq Cedex - France
Phone: +33 (0)3 20 43 67 06
Fax: +33 (0)3 20 43 65 23

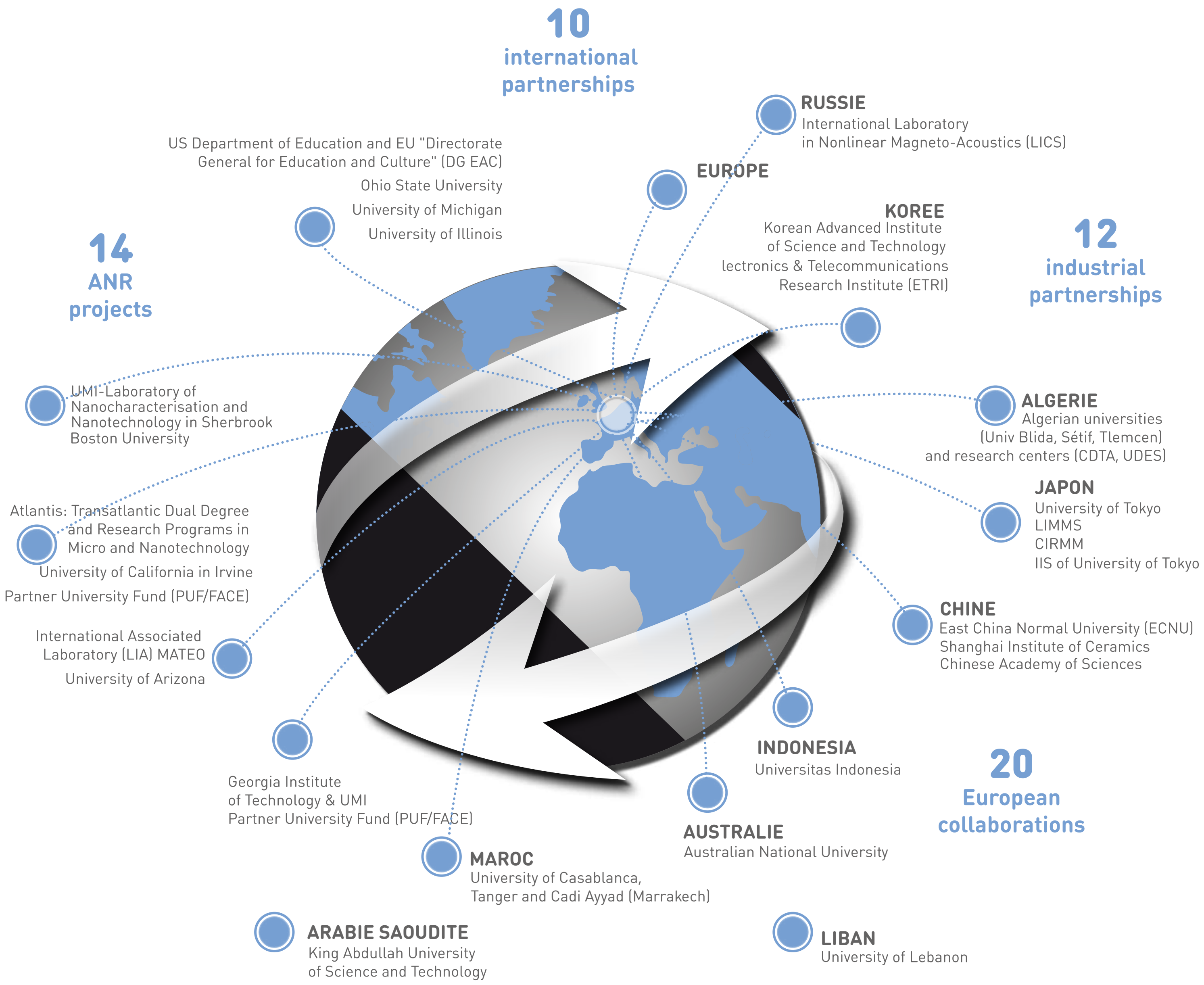
IEMN - Antenne OAE
Université Polytechnique Hauts-De-France
59313 Valenciennes Cedex 9 - France
Phone: +33 (0)3 27 51 12 39
Fax: +33 (0)3 27 51 11 89

IEMN - Antenne CCHB
CAMPUS Haute-Borne CNRS IRCICA-IRI-RMN
Parc Scientifique de la Haute Borne
50 Avenue Halley BP 70478
59658 Villeneuve d'Ascq - France
Phone: +33 (0)3 62 53 15 00

IEMN - Antenne JUNIA
41, Boulevard Vauban
59046 Lille Cedex - France
Phone: +33 (0)3 20 30 40 50
Fax: +33 (0)3 20 30 40 51

https://www.iemn.fr
pcmp-contact@iemn.fr

Scientific collaborations



The collaborations of the IEMN

Research, Innovation and Valorization are the 3 vectors of the IEMN's strategy.

Our objective is to combine fundamental research, field research responding to societal technological developments and cutting-edge research at the heart of our multidisciplinary themes.

To do this, the IEMN maintains cooperation with both academic partners and the industrial sector, for which internal collaboration structures have been set up.

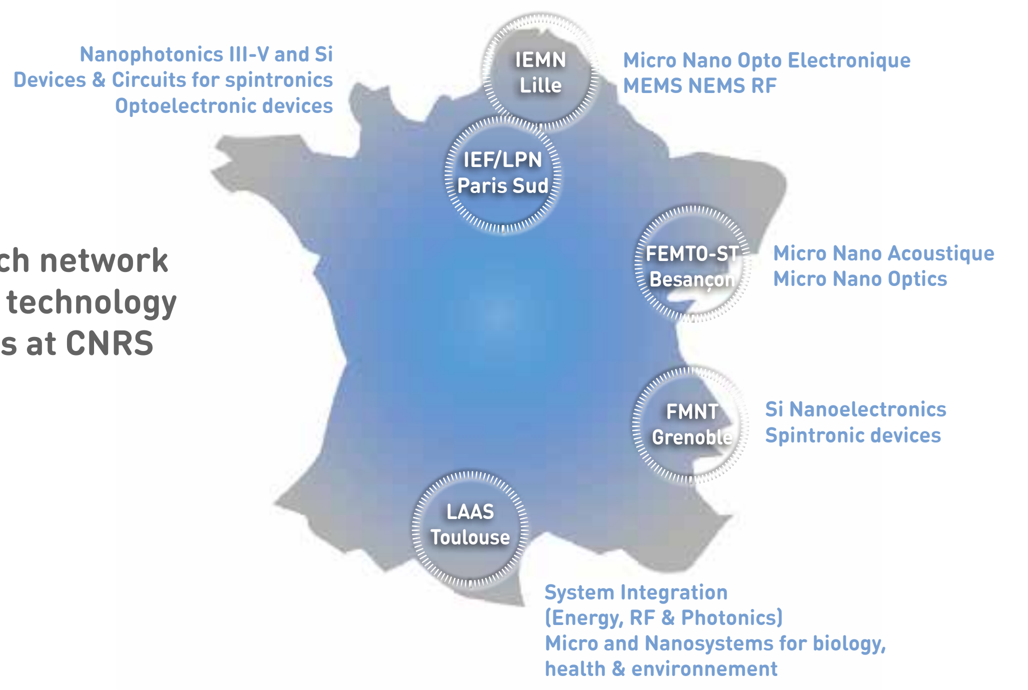
Moreover, this research partnership with companies or other academic circles has proven to be a favorable tool for the integration of our students from the various doctoral programs offered at the IEMN:

- through the financing of their thesis topics in partnership research
- through the possibility of directly joining a company in line with the work they did during their thesis
- by allowing them to join another academic laboratory at the end of their training and perhaps induce a new partnership

Currently, contracts are signed with companies, large groups, SMEs and ETIs in various forms:

- Contract in the form of a collaboration agreement on a scientific program, for a given duration depending on the complexity of the subject
- Framework contract: often multi-year, specifying the scientific field and setting out the various legal aspects of the relationship with the institute (confidentiality, publications, patents and intellectual and industrial property), with an appendix setting out the detailed program and the financial compensation
- Joint laboratory: resulting from recurring contracts between a company and the IEMN, a pooling of equipment and personnel can be set up, thus creating a favourable environment for the success of large-scale research projects.

Renatech network of large technology centres at CNRS



iemn

Institute of Electronics, Microelectronics
and Nanotechnology

IEMN - Laboratoire Central
UMR CNRS 8520
Cité Scientifique
Avenue Poincaré BP 60069
59652 Villeneuve d'Ascq Cedex - France
Phone: +33 (0)3 20 19 79 79
Fax: +33 (0)3 20 19 78 78

IEMN - Antenne Université de Lille
Cité Scientifique, Bât. P.3 & P.5
Avenue Poincaré BP 60069
59652 Villeneuve d'Ascq Cedex - France
Phone: +33 (0)3 20 43 67 06
Fax: +33 (0)3 20 43 65 23

IEMN - Antenne OAE
Université Polytechnique Hauts-De-France
59313 Valenciennes Cedex 9 - France
Phone: +33 (0)3 27 51 12 39
Fax: +33 (0)3 27 51 11 89

IEMN - Antenne CCHB
CAMPUS Haute-Borne CNRS IRCICA-IRI-RMN
Parc Scientifique de la Haute Borne
50 Avenue Halley BP 70478
59658 Villeneuve d'Ascq - France
Phone: +33 (0)3 62 53 15 00

IEMN - Antenne JUNIA
41, Boulevard Vauban
59046 Lille Cedex - France
Phone: +33 (0)3 20 30 40 50
Fax: +33 (0)3 20 30 40 51

https://www.iemn.fr

iemn
Institute of Electronics, Microelectronics
and Nanotechnology
UMR CNRS 8520