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

chop-contact@iemn.fr

CHOP iemn
Caractérisation Hyperfréquence Optique Photonique

IEMN / PCMP

CHOP

NANO-CHARACTERIZATION

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.

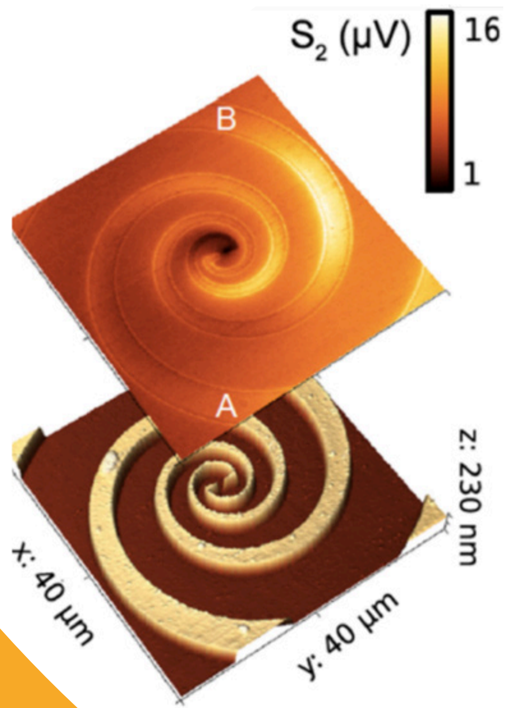
→ EXAMPLE

• 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

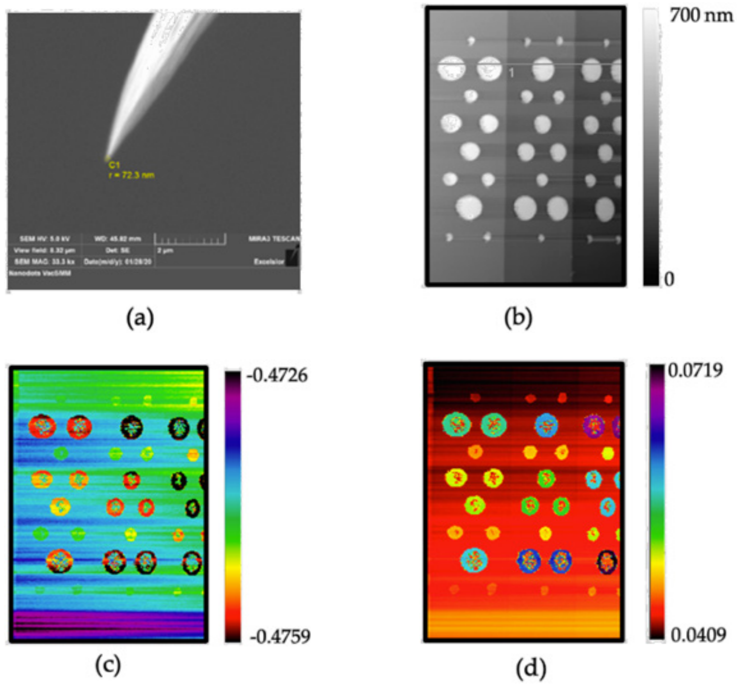
• Under vacuum, a home-made system integrated in a Tescan SEM, up to 67 GHz

→ 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

Vanessa Avramovic Etienne Okada

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

Vanessa Avramovic

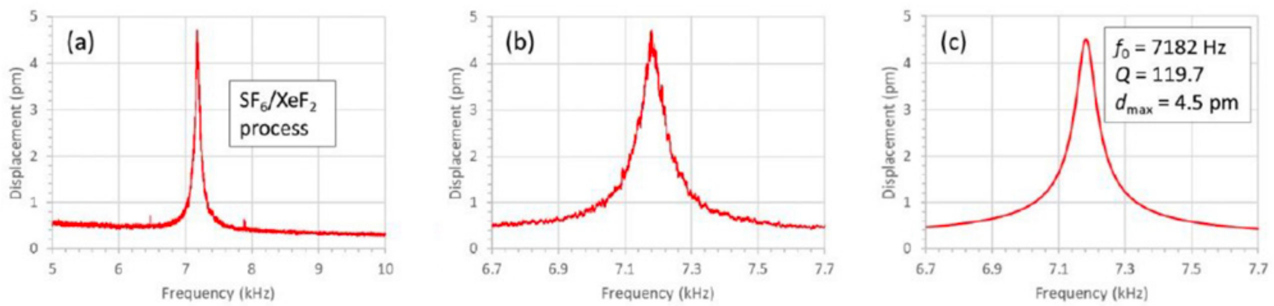
Visualizing surface deformations, knowing the speed, frequency and distance of displacement of a vibrating element, are essential information for MicroElectroMechanical Systems (MEMS).

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.

→ 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

Vanessa Avramovic Sylvie Lepilliet

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

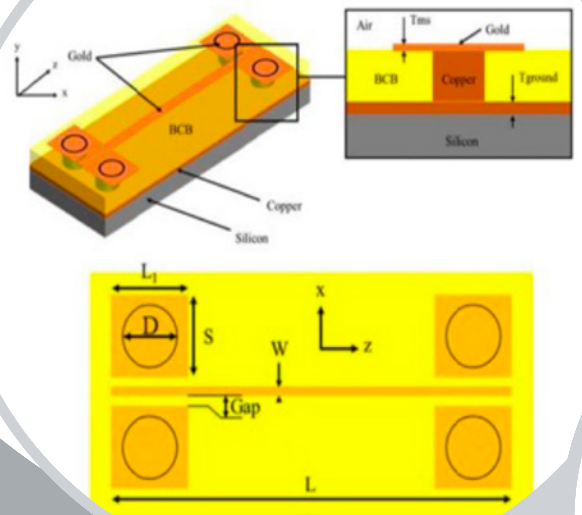
If microwave measurements are required (up to 67 GHz) in cryogenic mode, this is also possible in CHOP

→ ADVANTAGES & LIMITATIONS

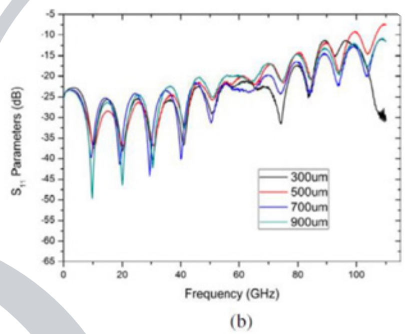
+ Designed of electrical access must be taken into account, come in CHOP for more details!

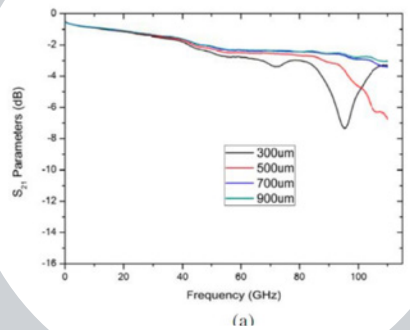
+ Coaxial availlable up to 67GHz versus 110GHz under probing method.

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

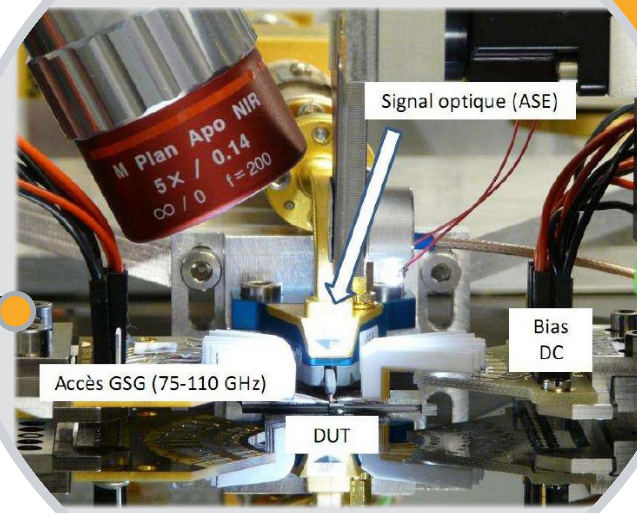


Example of measurements up to 110GHz





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



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

OPTO-HYPER MEASUREMENTS

Vanessa Avramovic

Objectif: establissement 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)

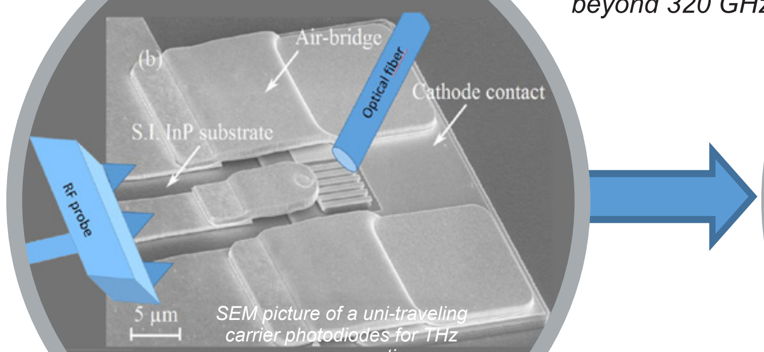
Expertise:

- 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

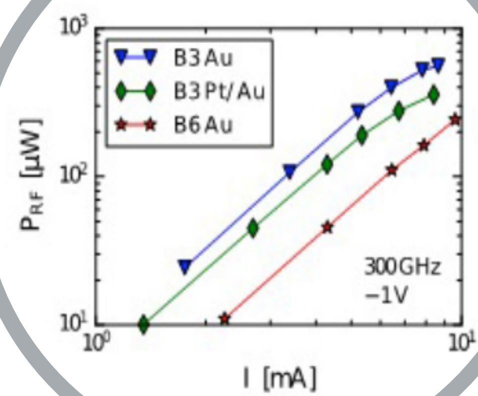
→ ADVANTAGES & LIMITATIONS

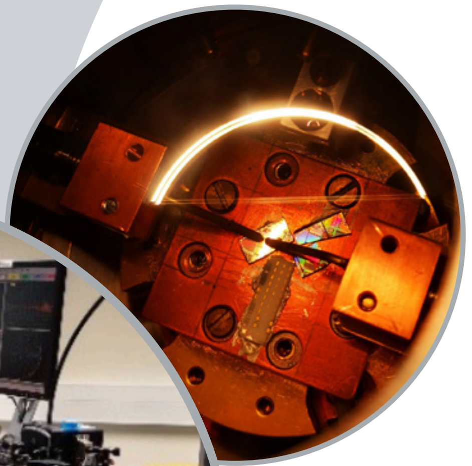
+ Probing on wafer with several type of wavelenght, come in CHOP for more details!

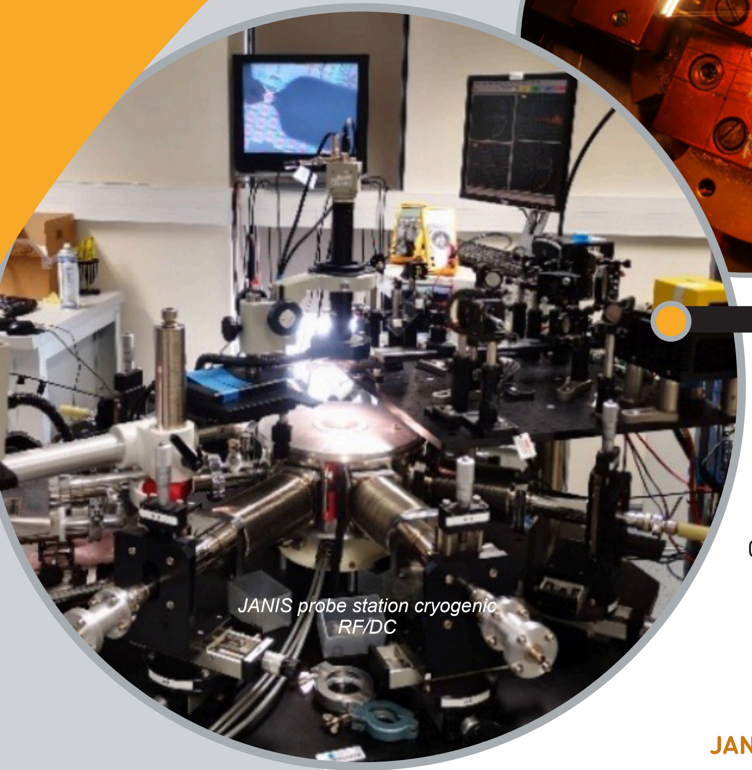
On wafer characterization of ultrafast photodetectors beyond 320 GHz



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







CRYOGENIC DC AND RF MEASUREMENT

Sylvie Lepilliet

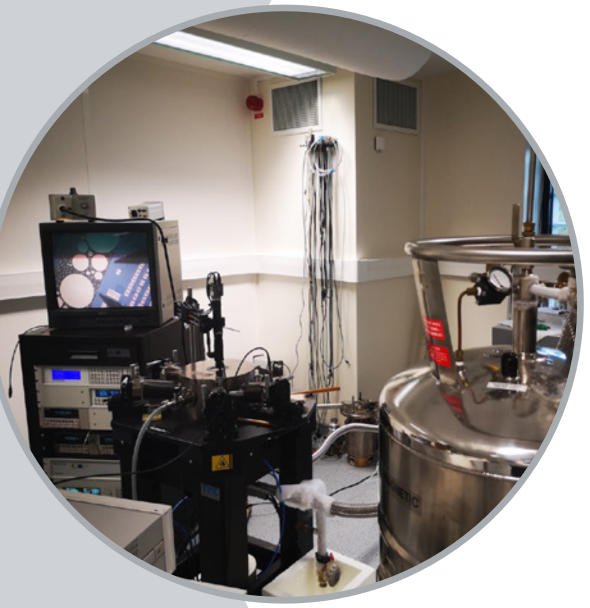
Cryogenic & Vacuum Micro-manipulated Probe Systems

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

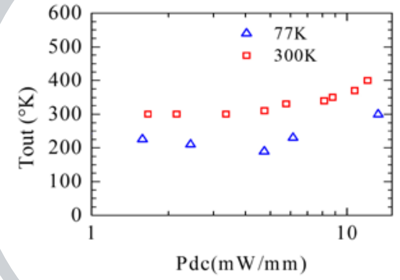


LAKESHORE probe station cryogenic DC/field magnetic

Features :

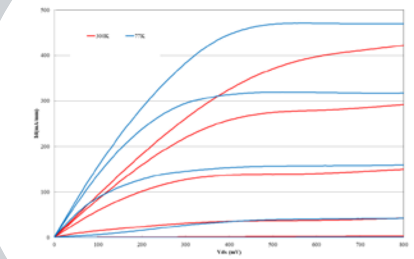
- Low Temperature : 5.5K
- High Temperature : 380K
- Liquid helium or liquid nitrogen
- Without vibrations to sample
- Verticaly Field supraconducting magnetic : to +/- 2.5T
- 4 probes DC

Noise Measurement
(InAs/AlSb high-electron mobility transistors study)



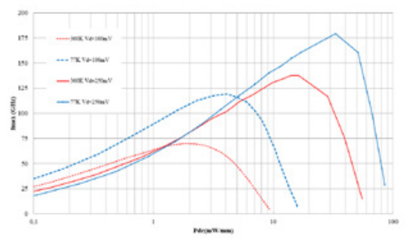
IEEE Trans. Electron Devices 57, 1903

DC measurements
(InAs/AlSb high-electron mobility transistors study)



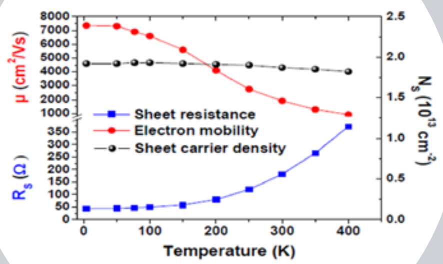
IEEE Trans. Electron Devices 57, 1903

RF measurements
(InAs/AlSb high-electron mobility transistors study)



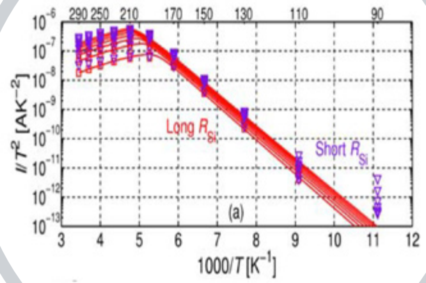
IEEE Trans. Electron Devices 57, 1903

Hall Measurement
(GaN epilayer study)



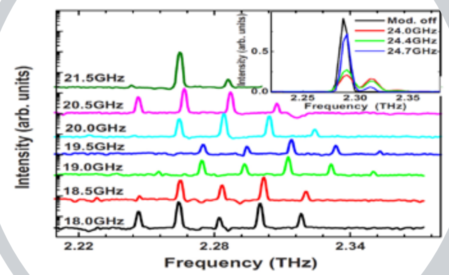
Electronics **2016**, 5, 31

Law discrimination
(Schottky barrier study)



Appl. Phys. Lett. 94, 191913

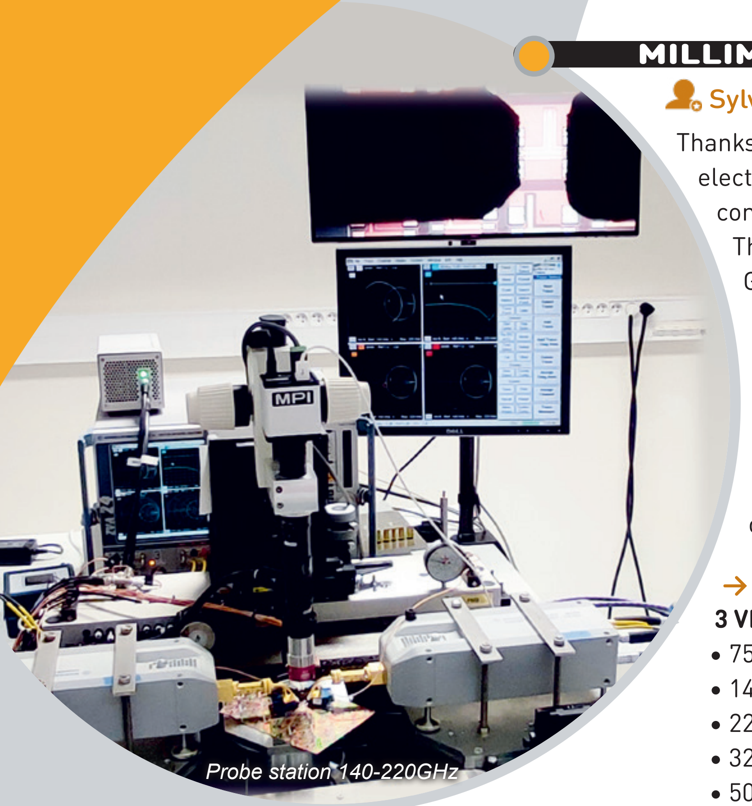
QCL Laser modulation (4K)
(Quantum Cascade Laser study)



APL 96, 021108, 2010

CHOP

MILLIMETRIC & THz



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

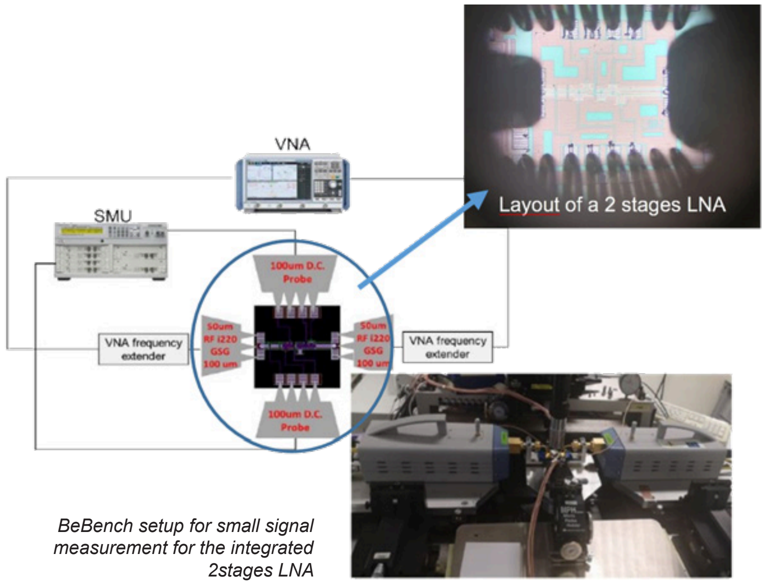
- On wafer
- In waveguide
- In free space

→ 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

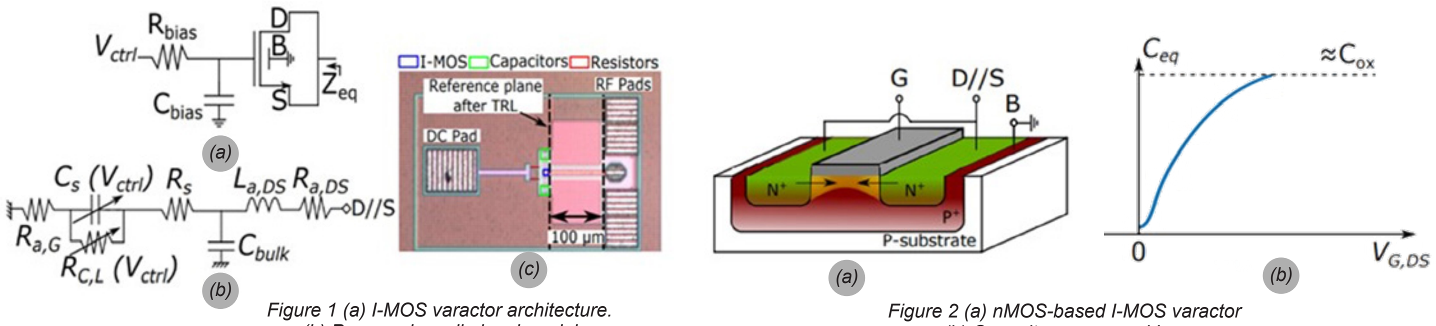


Figure 1 (a) I-MOS varactor architecture. (b) Proposed small-signal model (c) Micrograph of the fabricated circuit

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

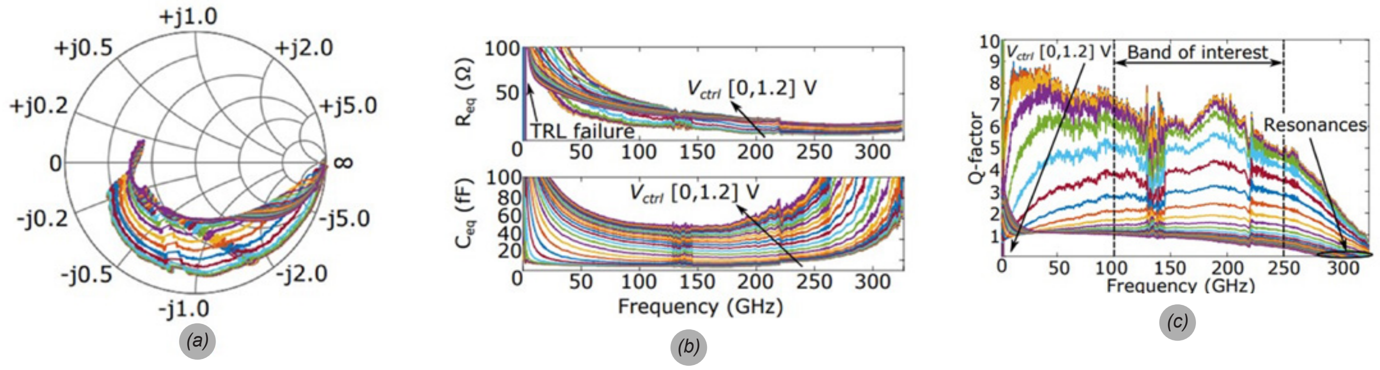
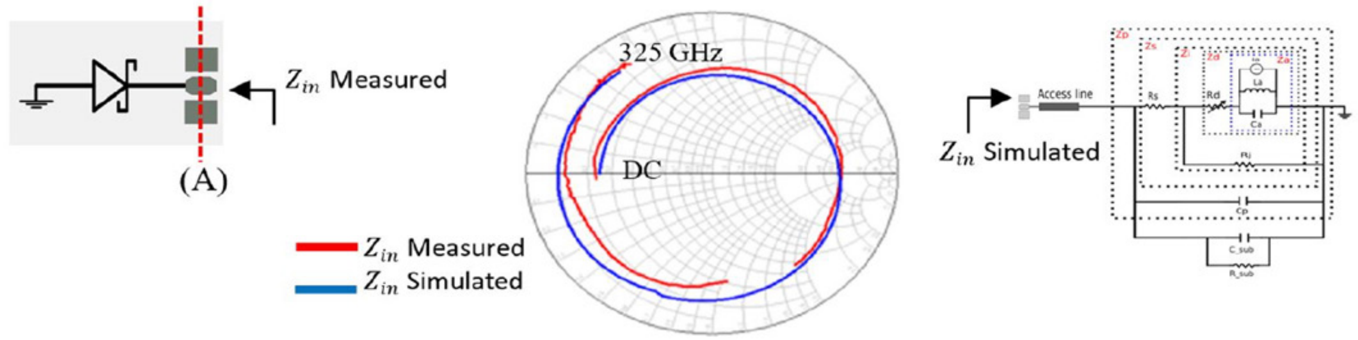


Figure 3 Measurement results in the 1 GHz to 235 GHz band as a function of V_{ctrl} (a) S_{11}, (b) R_{eq} and C_{eq}, and (c) Q-factor

«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.

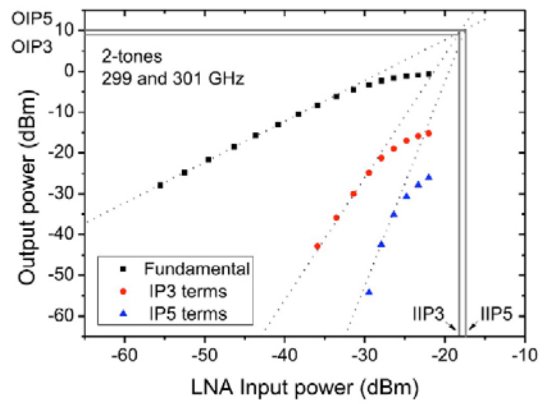
Example 2

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

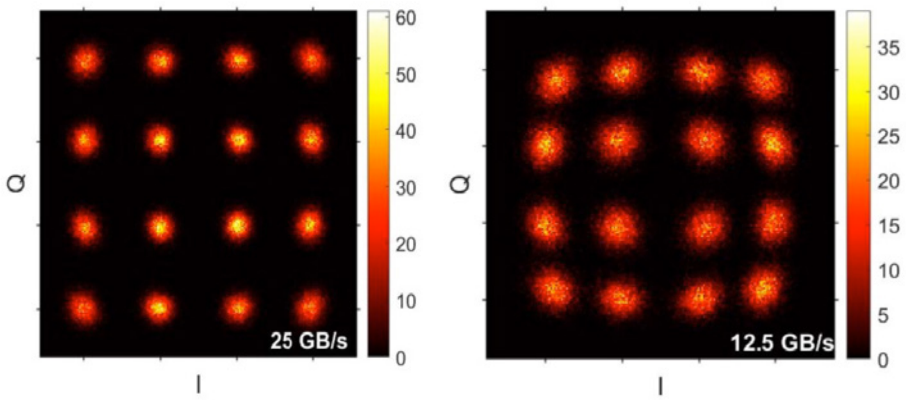


Example datacom

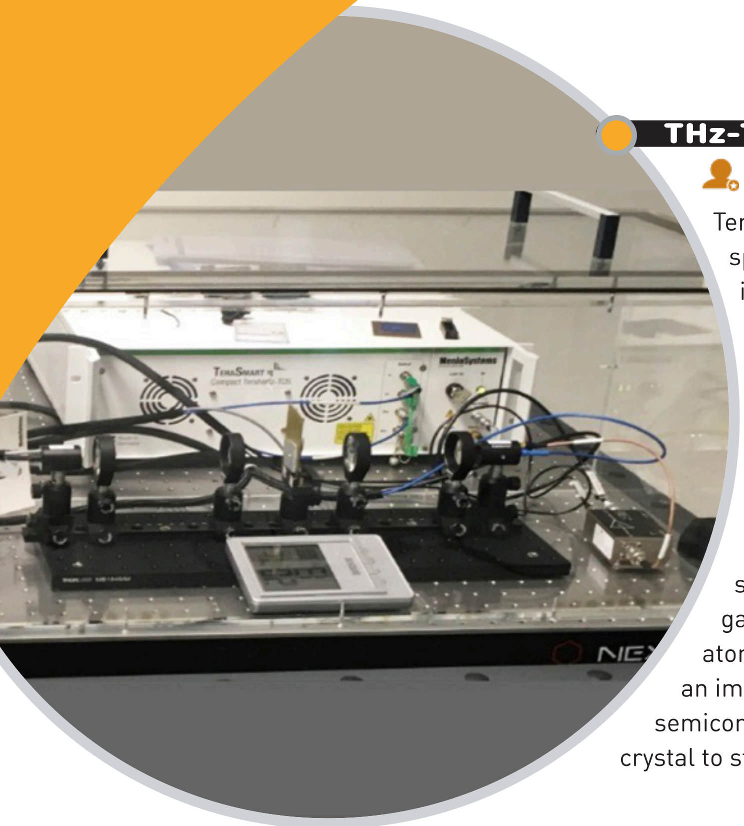
IP3 and I/Q analysis of the compression curve of LNA: IP3 measurement of 300 GHz LNA



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



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



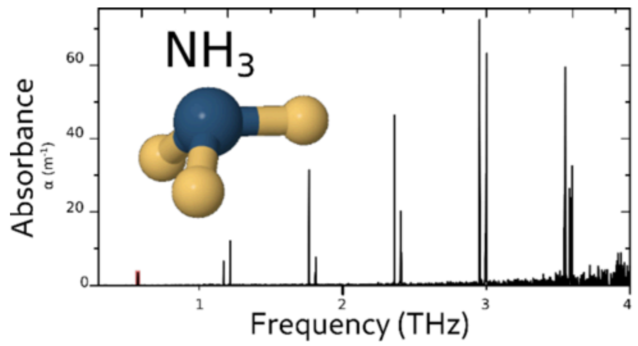
THz-TDS: TERAHERTZ TIME DOMAIN SPECTROSCOPY

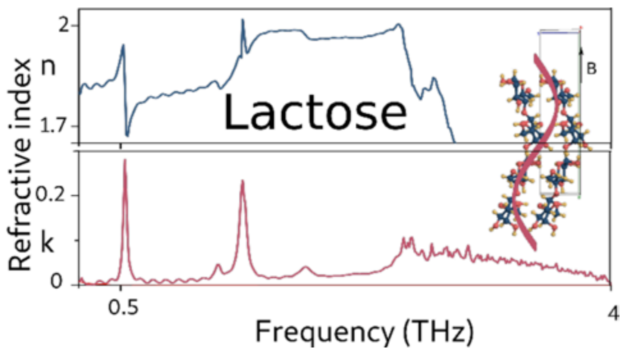
Sophie Eliet

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

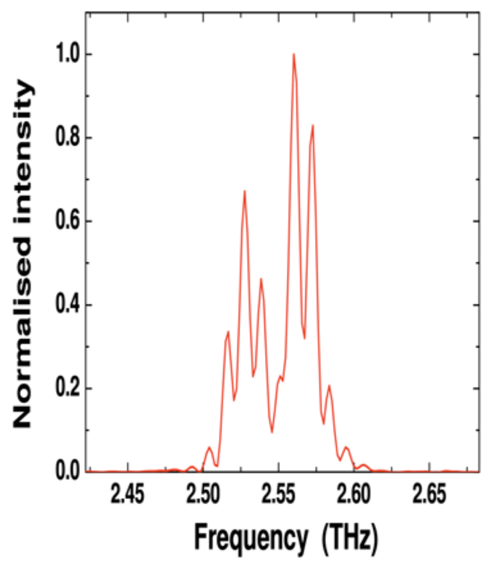
Coupled to a MIR microscope and internal MCT detector (cooled 77K): 12000-600cm^{-1}

Microscope mapping:

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

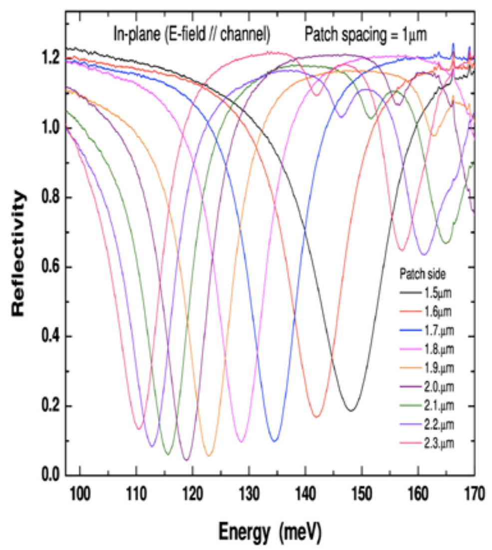
Example 1

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



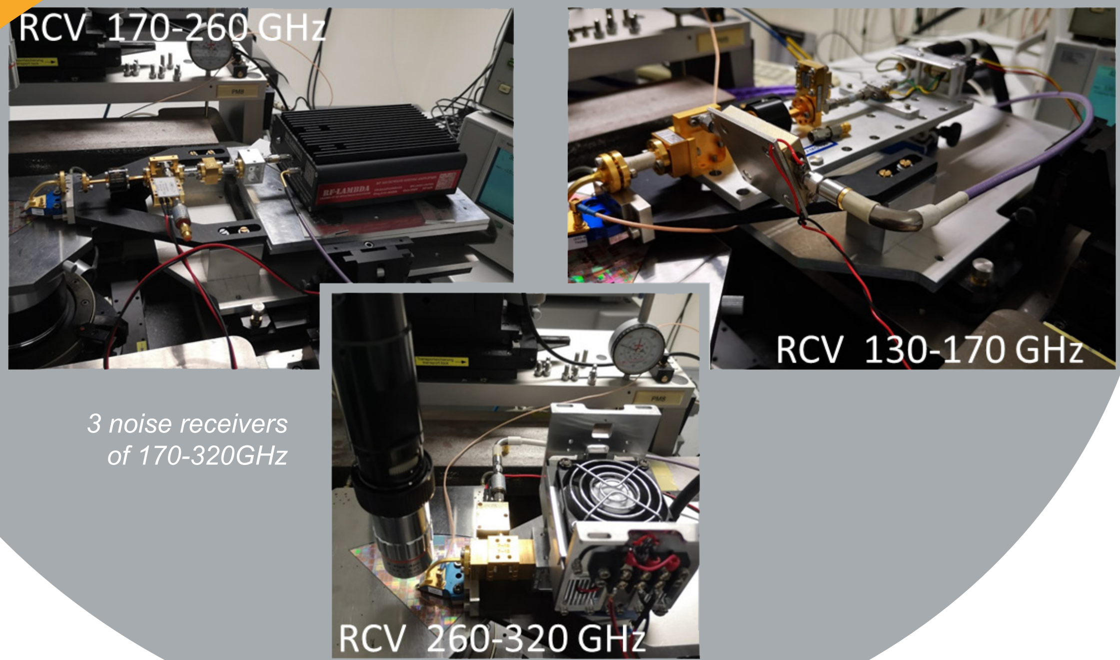
The cavities consist of a GaAs/AlGAs heterostructure sandwiched between metallic top contact and ground plane. Spectra are measured in reflection geometry with the mid-infrared microscope.

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

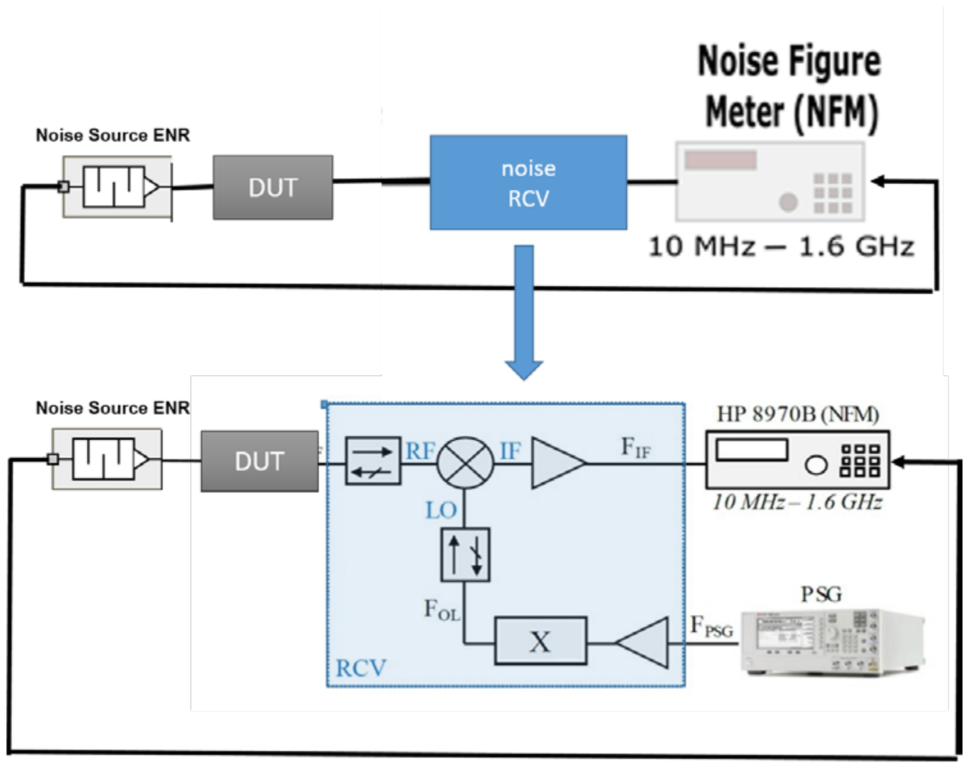


3 noise receivers of 170-320GHz

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

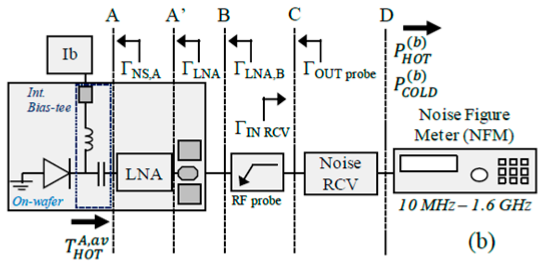
For the extraction of the four noise parameters [gamma opt, Nfmin and Rn] of semiconductor devices studied, several automated measurement benches make it possible to measure the available gain and the noise figure (Noise Figure) of microwave components. according to the following frequency ranges:

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

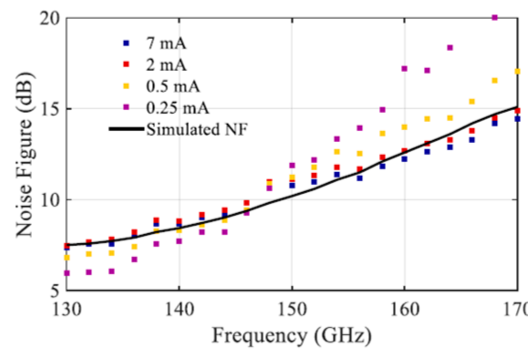
- *On wafer*
- *In waveguide*

Example 1

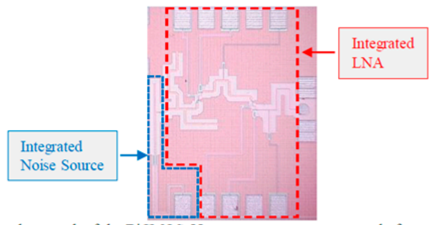
Noise Measurements (LNA integrated 130-170GHz)



lock diagrams of on- and off-wafer setup configurations used to perform on-wafer noise figure extraction of an LNA by the use of an integrated noise source. (a) standalone noise source for ENR extraction on plane A. (b) noise source and LNA for noise characterization of the LNA.



Noise figure of the integrated low noise amplifier, extracted for variable diode noise source bias currents and simulated on noise source impedance.

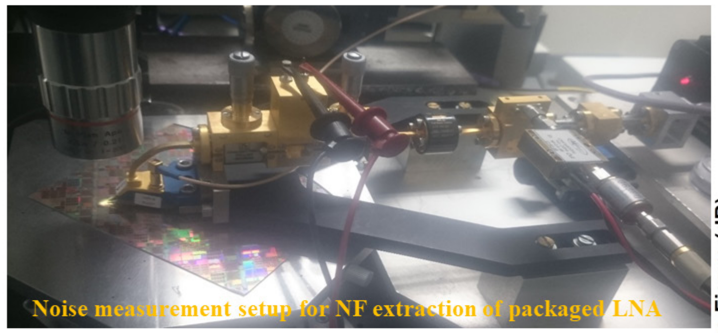


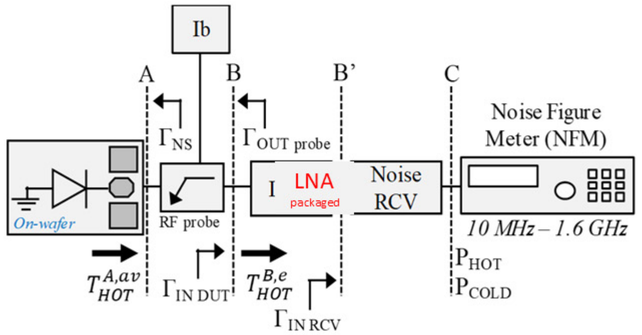
Chip photograph of the BiCMOS 55 nm test structure, composed of the integrated noise source and the LNA.

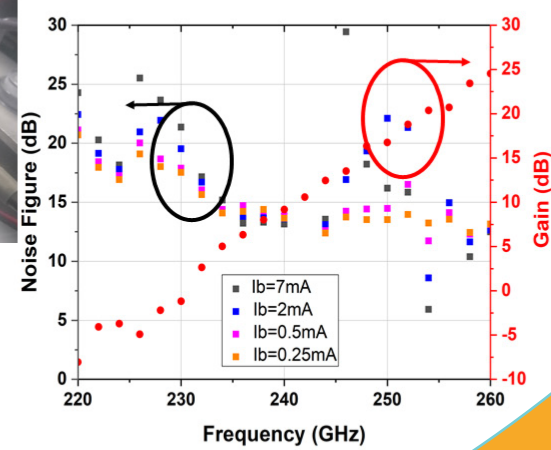
IEEE Transactions on Microwave Theory and Techniques (MTT), vol.67, Issue 9.

Example 2

Noise Measurements (LNA packaged 220-260GHz)

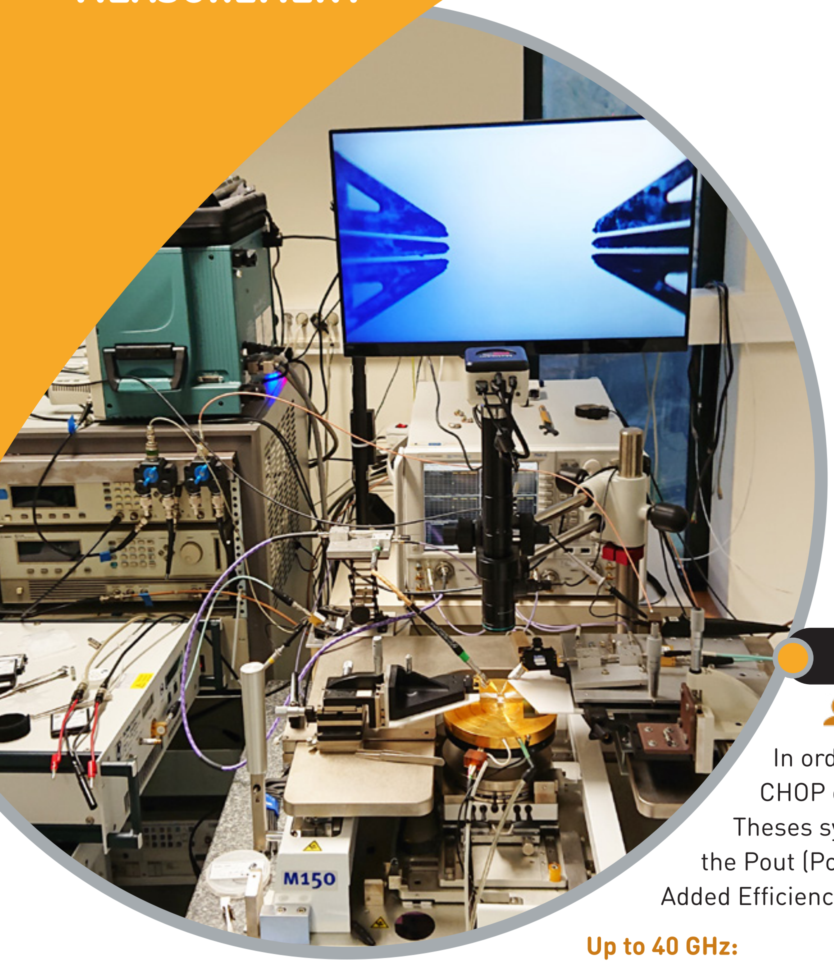






CHOP

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.

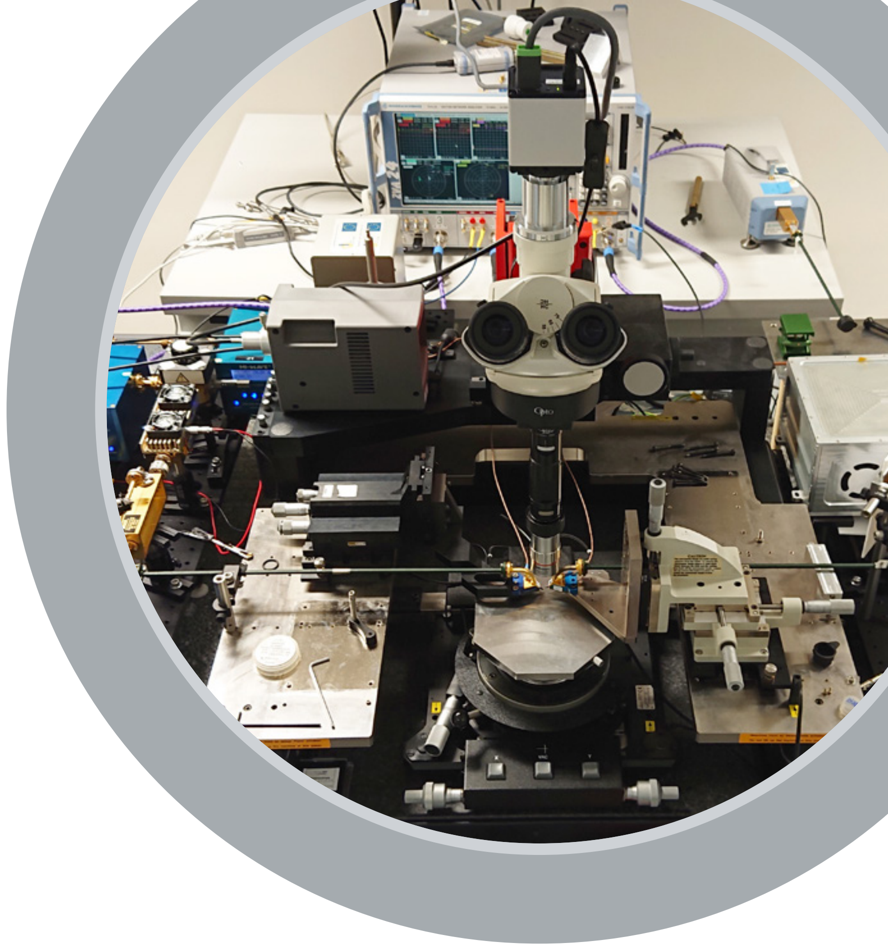
These measurements can be made in «load-pull» mode to modify the impedance presented at the output of the device under test. For this, we developed an active Load-Pull setup to reach high magnitude reflection coefficients. This helps determine the optimal impedance to maximize Gp, Pout or Pae.

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.

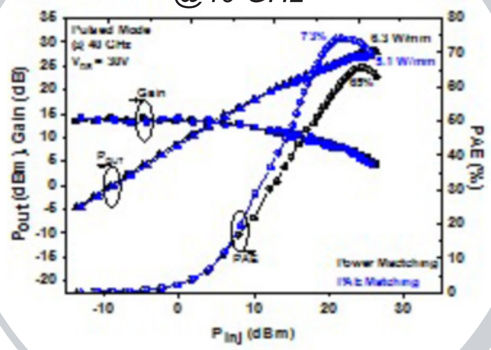
Large signal reliability test can also be made with this bench. We apply a large signal to the DUT and we measure its performance versus time for hours.

@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.

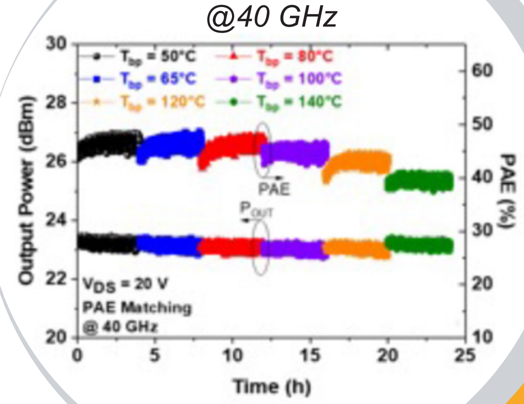


Large signal measurements @40 GHz



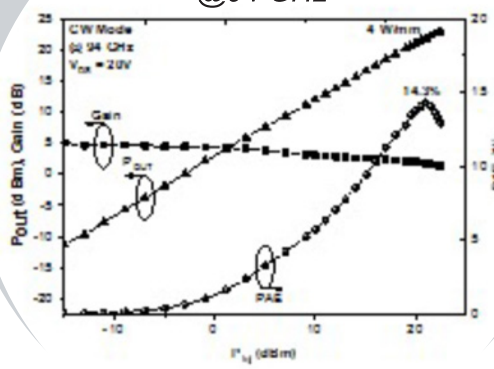
IEEE J. Electron Devices Soc., vol. 7, 2019

Large signal reliability @40 GHz



2020 IEEE IRPS

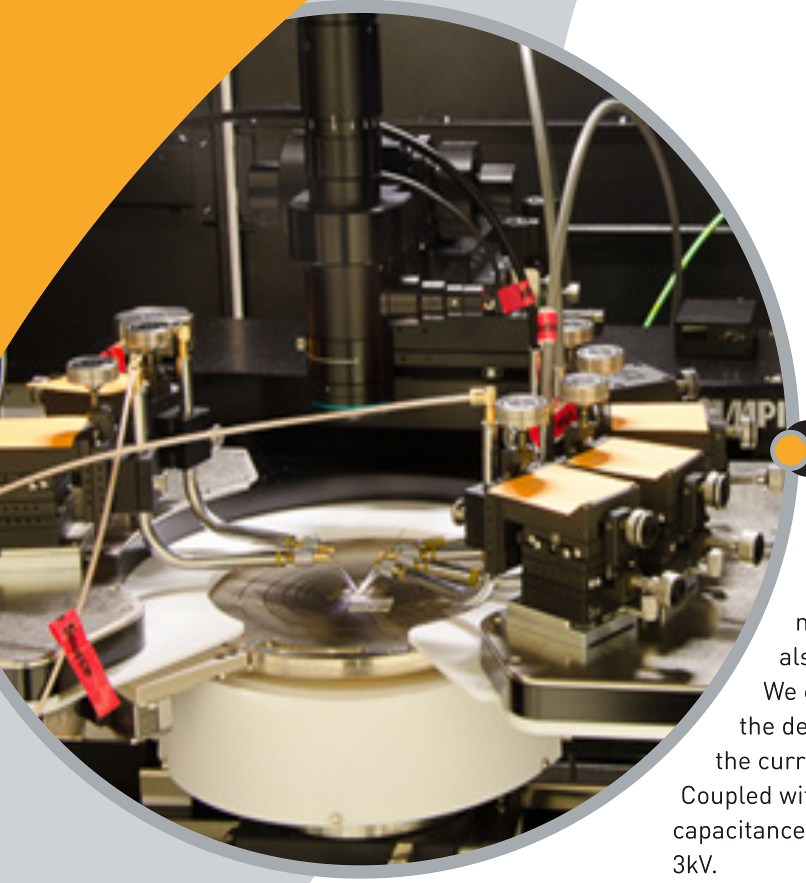
Large signal measurements @94 GHz



2020 IEEE IMS

CHOP

POWER MEASUREMENT



I/V MEASUREMENTS HIGH VOLTAGE OR HIGH CURRENT

Etienne Okada

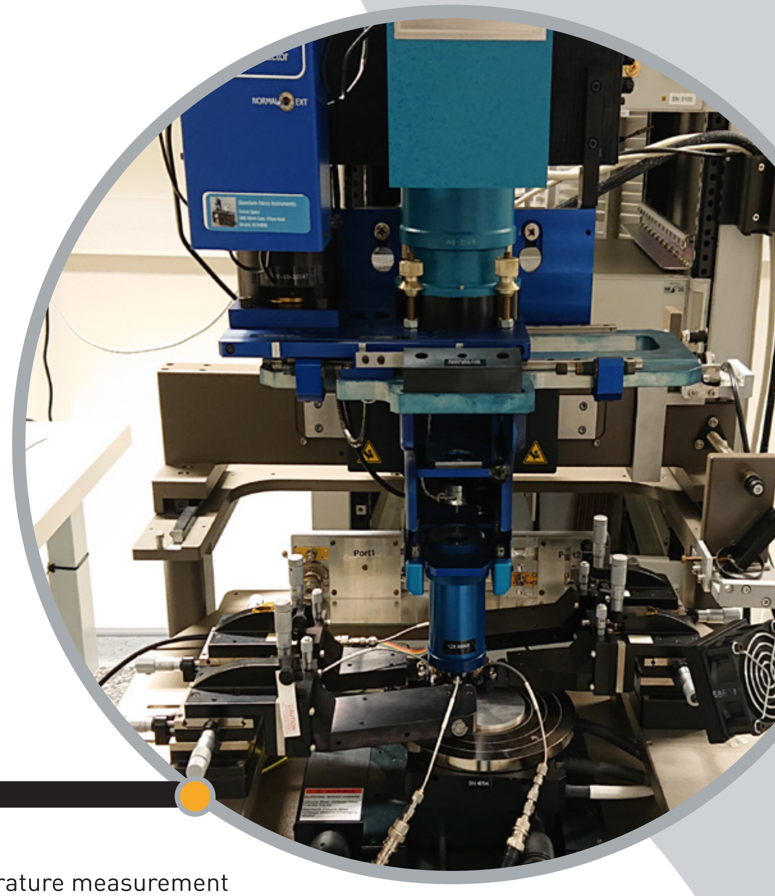
Based on a Keysight B1505A device analyzer coupled with a MPI TS150-HP probe station, this system allows on-wafer measurement up to 10kV DC for breakdown characterization. It also permit high current measurements: 20A @ 20V (Pulsed). We can also extract Dynamic RDS-ON of transistors by switching the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



INFRARED MICROSCOPY

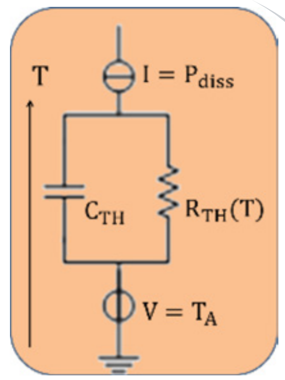
Etienne Okada

• MW InfraRed Camera (InSb / 3-5µm) for microscopic temperature measurement
• Measurement range: from room temperature up to 500°C with 0.1°C resolution
• Thermal mapping or transient IR measurement with 3-microseconds rise time resolution
• 3 magnifications:

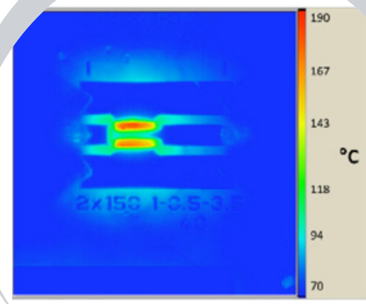
Objectif	Résolution spatiale minimum	Champ de vision (mm^2)
*1	36 µm	12.3
*4	10 µm	3.07
*12	3 µm	1.02

• On-wafer measurement available under DC bias and/or RF power

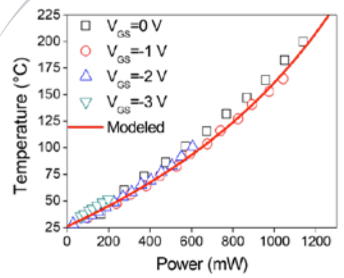
Example



Modeling



Measurement



Validation

EuMIC 2015 The 10th European Microwave Integrated Circuits Conference

Large-Signal Modeling up to W-band of AlGaN/GaN based High-Electron-Mobility Transistors

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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

Vanessa AVRAMOVIC
vanessa.avramovic@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

SIGMACOM

IRCICA
sigma-contact@iemn.fr

Rédha Kassi
redha.kassi@univ-lille.fr ✆ 03 62 53 16 04

David Delcroix
david.delcroix@univ-lille.fr ✆ 03 62 53 16 04

C2EM

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

Lamine Kone
lamine.kone@univ-lille.fr ✆ 03 20 43 48 41 / Office 114

Pierre Laly
pierre.laly@univ-lille.fr ✆ 03 20 33 59 59 / Office 002

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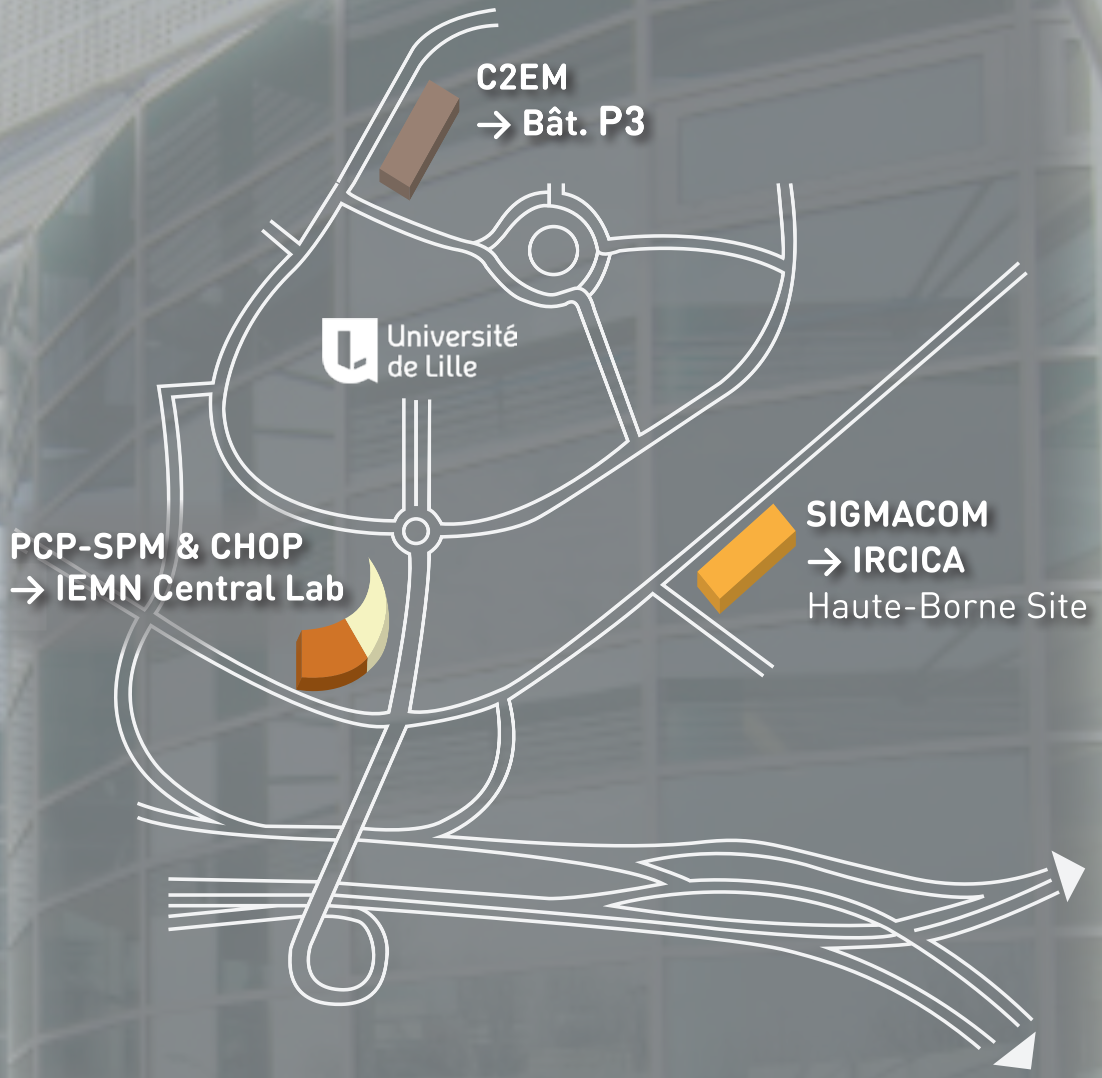

pcmp-contact@iemn.fr

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