# LOOX

# LABORATORY OF OPTICS AND OPTOELECTRONIX

## *RESEARCH ACTIVITIES*


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**DEIM - Department of Energy, Information engineering and Mathematical models**
**University of Palermo - ITALY**

# RESEARCH ACTIVITIES

- ***Silicon Photomultipliers: characterization and applications***
- ***Electro-optical characterization of new classes of Silicon Carbide UV photodetectors***
- ***Photovoltaics***
- ***Wideband THz Time Domain Spectroscopy based on pulsed laser***
- ***Graphene Field Effect Transistors (GFETs) with photoelectrical response***

# *SILICON PHOTOMULTIPLIERS: CHARACTERIZATION AND APPLICATIONS*

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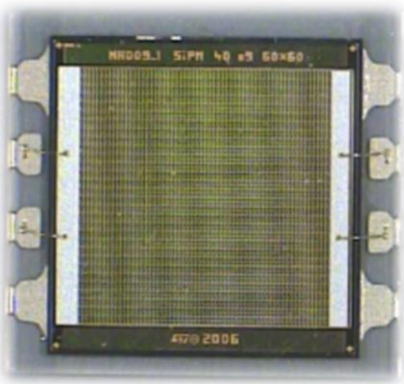
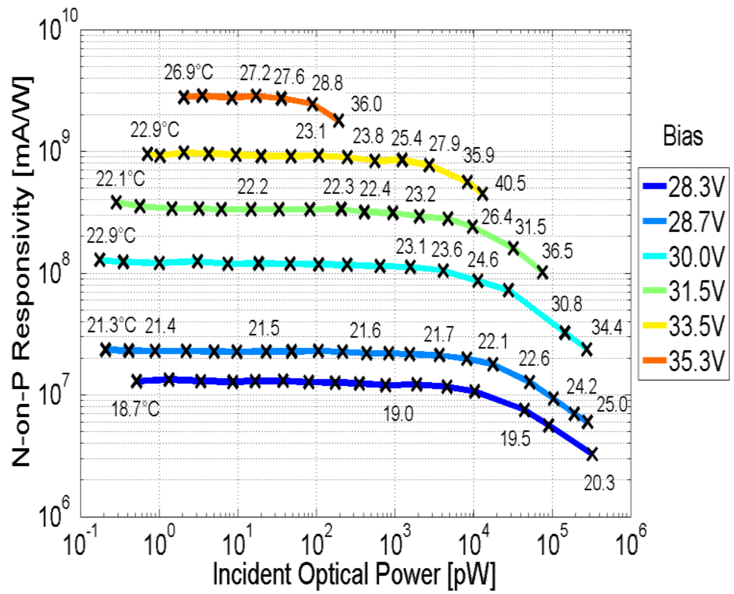
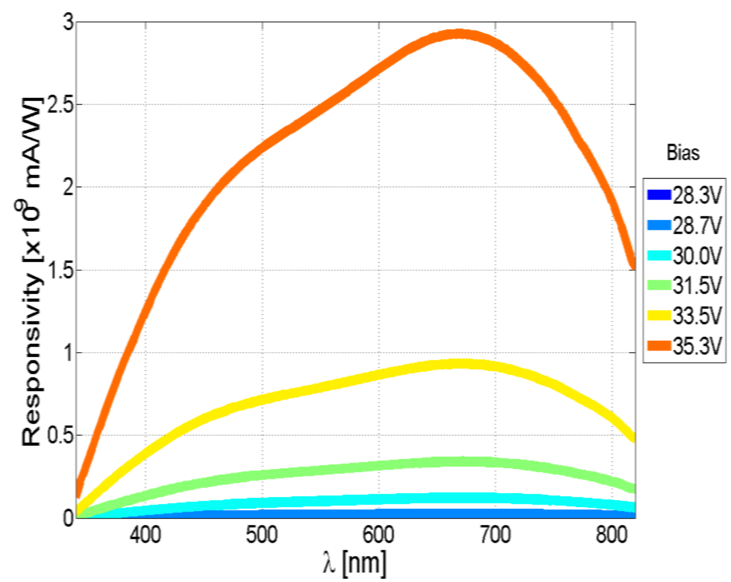
LOOX performs a **complete electrical and optical characterization**, in continuous wave regime, of N-on-P and P-on-N classes of silicon photomultipliers (SiPMs).

Responsivity measurements, performed with an incident optical power down to tenths of pW, at different reverse bias voltages, on a broad (340-820 nm) spectrum and monitoring the device temperature, were carried out. The obtained results demonstrate that such novel silicon photomultipliers are suitable as sensitive power meters for low photon fluxes.






*For this activity, LOOX cooperates with the R&D IMS, STMicroelectronics, Catania, Italy.*

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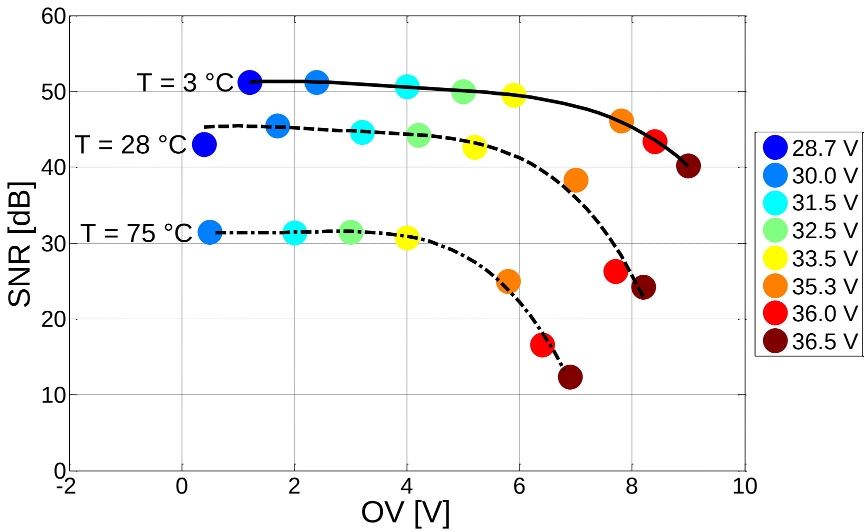
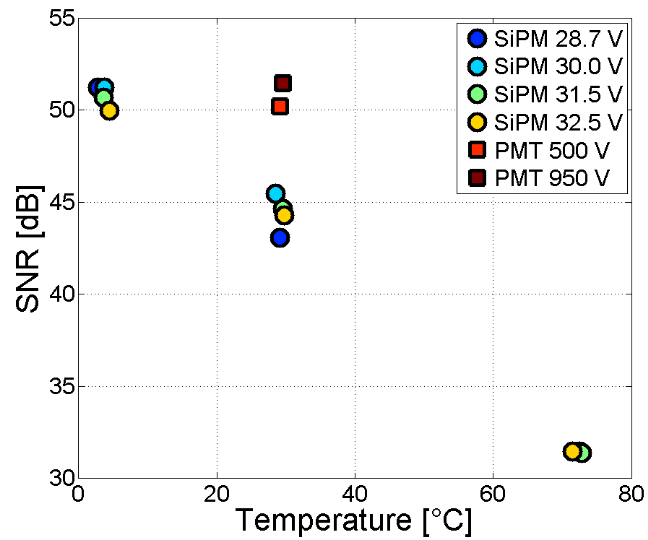
# SILICON PHOTOMULTIPLIERS: CHARACTERIZATION AND APPLICATIONS

LOOX also performs **Signal-to-Noise Ratio (SNR)** measurements, in the continuous wave regime, at different bias voltages, frequencies and temperatures and Excess Noise Factor measurements on SiPMs.

A comparison between the SiPM and the photomultiplier tube in terms of SNR, as a function of the temperature of the SiPM package and at different bias voltages has been carried out. Our results show the outstanding performance of this novel class of SiPMs even without the need of any cooling system.



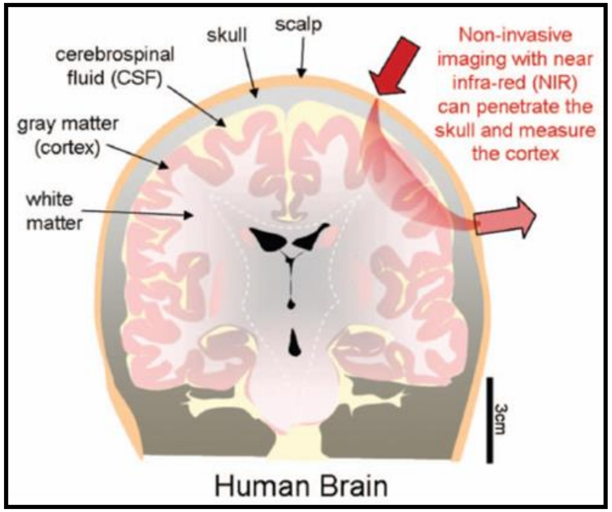




## *SELECTED PUBLICATIONS*


- G. Adamo, et al., "Measurements of Silicon Photomultipliers Responsivity in Continuous Wave Regime," IEEE Trans. Electron. Dev., vol. 60, no. 11, pp. 3718-3725, Nov. 2013
- G. Adamo, et al., "Silicon Photomultipliers Signal-to-Noise Ratio in the Continuous Wave Regime", J. Sel. Top. Quantum Electron. Vol. 20, pp. 3804907, Nov/Dec 2014

# SILICON PHOTOMULTIPLIERS: CHARACTERIZATION AND APPLICATIONS

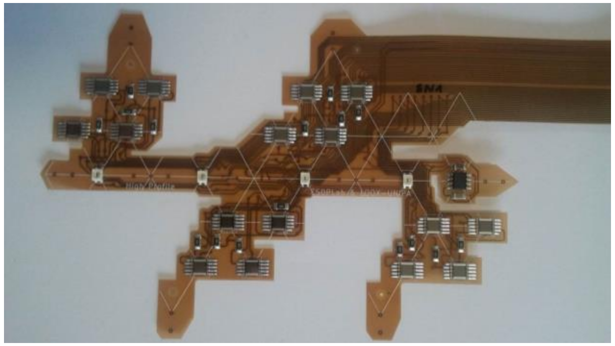
## Embedded Systems for Brain Monitoring




Functional Near InfraRed Spectroscopy (**fNIRS**) is an imaging technique mainly devoted to human brain monitoring.

It is used as a non-invasive technique in medical field in order to measure the **oxygen concentration** of blood and map the in-vivo imaging of the brain.

A portable, low cost, battery-operated, multi-channel, continuous wave fNIRS embedded system has been realized. It is capable to host up to **64 LED** sources and **128 SiPM** detectors.

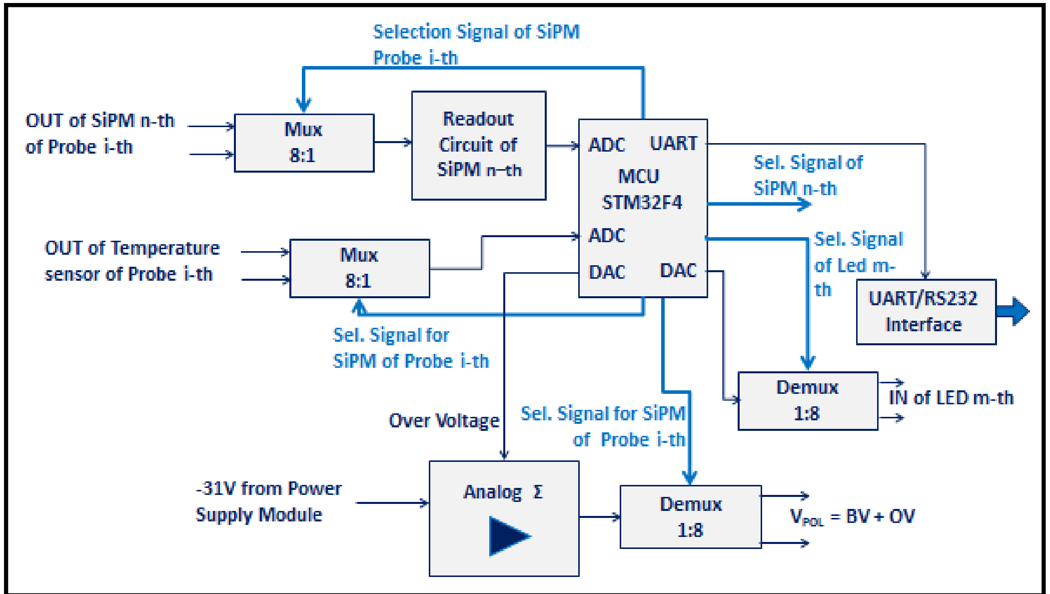


***This experimental work has been realized in the framework of the ARTEMIS "High Profile" European Funded Project (grant agreement 269356).***

High Profile

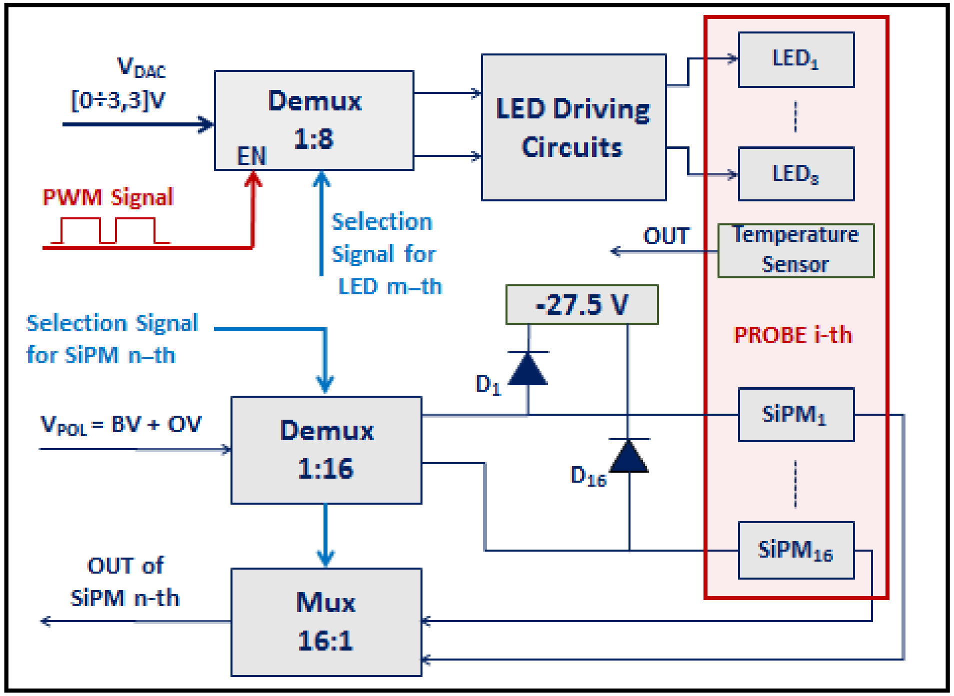
## Embedded Systems for Brain Monitoring

The hardware structure allows to easily set up several relevant parameters: the timing of the LEDs, the optical power emitted by the LEDs; the acquisition of the photodetectors, the bias voltage of each SiPM; the portion of cerebral cortex that has to be analyzed by programming the suitable source photodetector couples that will be involved in the measurement. It is capable to host up to 64 LED sources and 128 SiPM detectors.




**Microcontroller**

STM32F407vg from STMicroelectronics




**Block diagrams of the embedded system**

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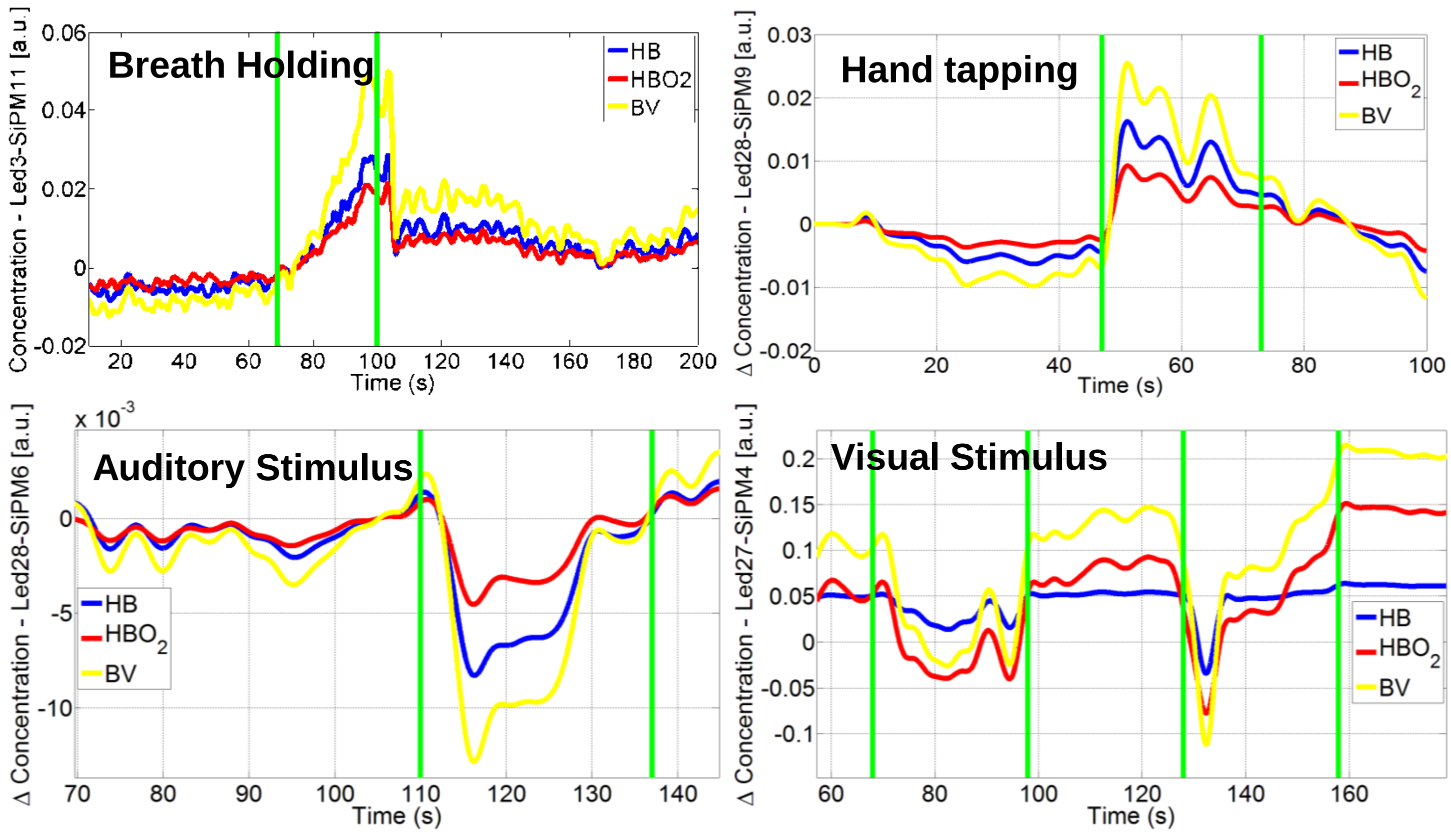
# *SILICON PHOTOMULTIPLIERS: CHARACTERIZATION AND APPLICATIONS*

## *Embedded Systems for Brain Monitoring*

Several preliminary **functional tests** were successfully carried out, thus achieving very encouraging results. In fact, during the stimulus, it is possible to see the activation of the area of the brain dedicated to the functional activity.

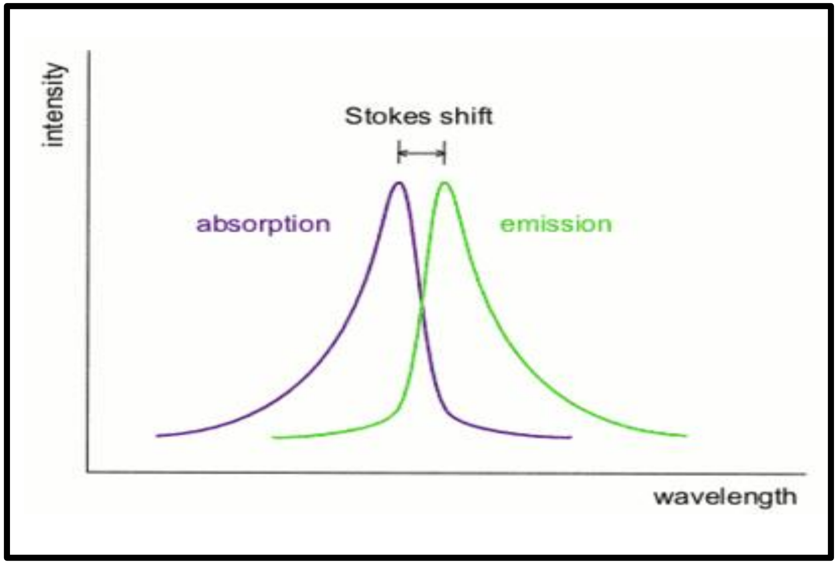



**HB: deoxygenated hemoglobin;**
**$HBO_2$: oxygenated hemoglobin;**
**BV: blood volume**

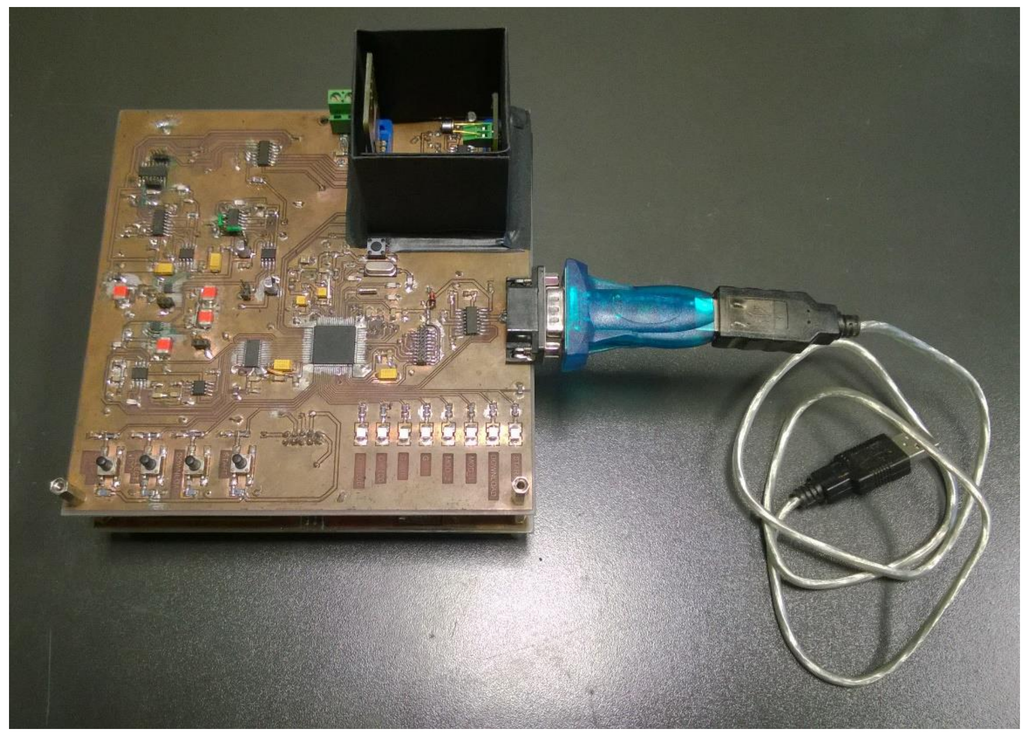
## *Selected publications*


- D. Sanfilippo, et al., Paper no. 8990-40, Photonics West 2014 - Silicon Photonics IX, Feb. 2014, San Francisco, USA
- D. Agrò, et al., ApplePies 2014, Roma, 5-6 Maggio 2014
- D. Agrò, et al., SIMAI 2014, Jul 2014, Taormina, Italy

# Immunoassay tests




- This technique is based on the interaction between antigen-antibody, where the antibody is marked with a fluorophore.
- The antibody is used to distinguish a specific macromolecule in a complex mixture of macromolecules.



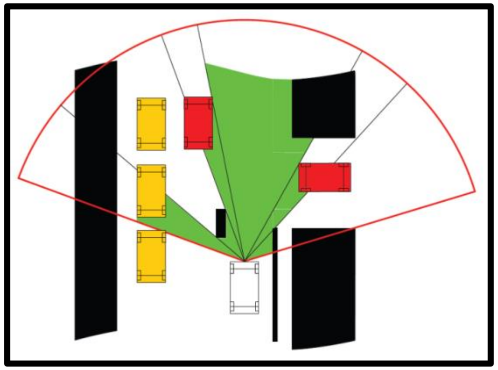
Advantages of **SiPM** for Immunoassay applications

- High Gain
- Output response is picoseconds
- Uniformity of output response
- Wide dynamic range

A portable, low cost and battery-operated embedded system has been realized

# LIDAR

LIght Detection And Ranging: Analogous to RADAR, but using a different part of the electromagnetic spectrum. It uses the laser to illuminate a target and then analyzes the reflection, in terms of time of flight.



LIDAR Applications

- Automotive
- Mapping and Ranging Applications
- Surveying and Civil Engineering
- Terrestrial or aerial scanning

LIDAR requirements

- Wide detection range
- High accuracy
- Temperature stability
- Miniaturized
- Low cost and low power

Advantages of **SiPM** for LIDAR applications

- High Gain
- Output response is picoseconds (~100 ps)
- Uniformity of output response
- Temperature stability
- Wide dynamic range

# SILICON PHOTOMULTIPLIERS: CHARACTERIZATION AND APPLICATIONS

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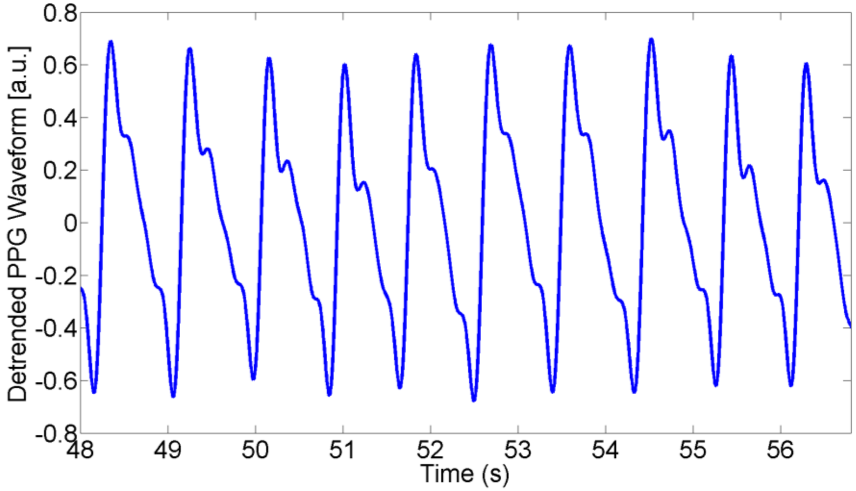
## PhotoPlethysmoGrafy (PPG) for Blood Pressure Monitoring




PPG technique requirements

- Strength
- High Gain
- Temperature stability

Potentially widely applicable
(e.g., for fitness wearable devices)

Advantages of **SiPM** for PPG applications

- High Gain
- Low LED optical power
- Uniformity of output response
- Temperature stability
- Wide dynamic range

## *Selected publications*


- D. Agrò, et al., “PPG Embedded System for Blood Pressure Monitoring,” Convegno Annuale AEIT 2014, Sep. 2014, Trieste, Italy
- D. Agrò, et al., “Blood Pressure Monitoring with a PPG Embedded System”, GE 2014, Jun. 2014, Cagliari, Italy

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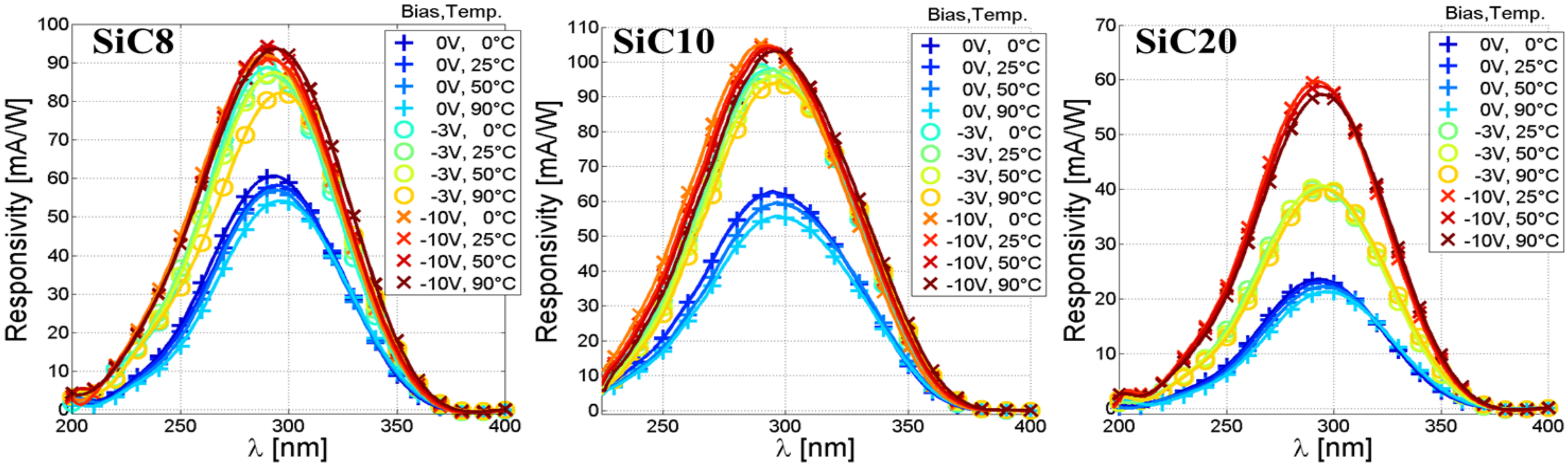
# ELECTRO-OPTICAL CHARACTERIZATION OF NEW CLASSES OF SILICON CARBIDE UV PHOTODETECTORS

LOOX carried out the characterization of **4H-SiC vertical Schottky UV detectors**.

**I-V and C-V characteristics**, as functions of temperature, were measured in dark conditions.

In addition, **responsivity measurements**, for wavelengths ranging from 200 to 400 nm, at varying package temperature and applied reverse bias were performed.

A comparison among devices having different strip pitch sizes (SiC8, SiC10, SiC20) has been realized, thus finding the class that exhibits the top performances.





- G. Adamo, et al., "Responsivity measurements of 4H-SiC Schottky photodiodes for UV light monitoring," Proc. SPIE, vol. 8990, p. 8990-17, Mar. 2014.

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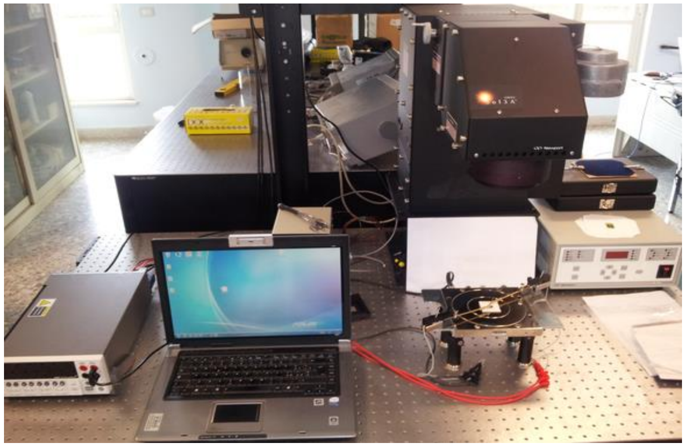
# PHOTOVOLTAICS

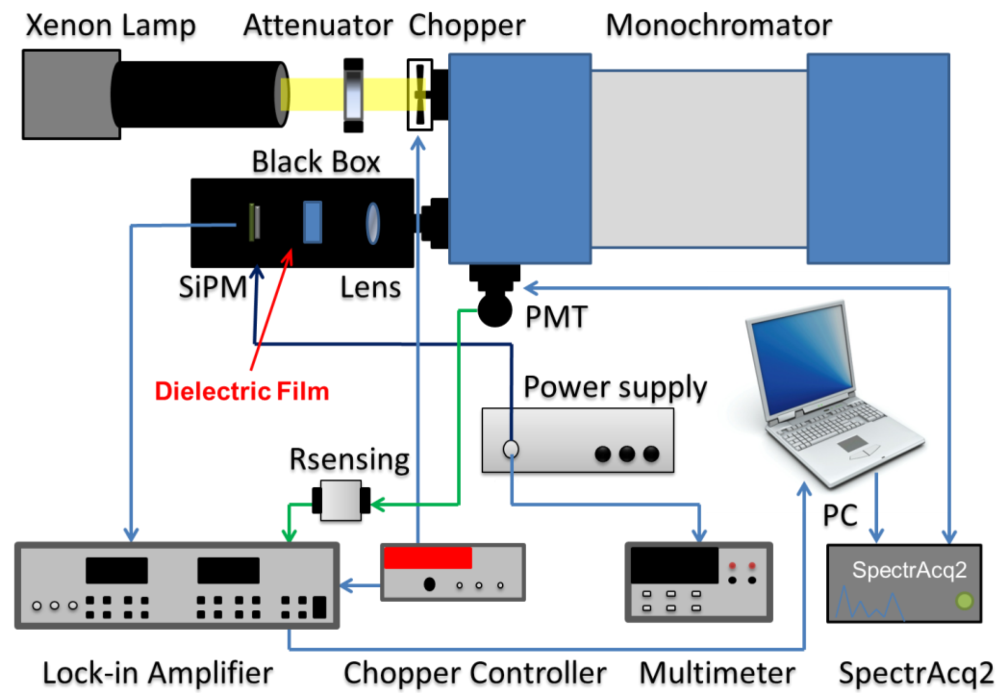
## Electrical characterization of photovoltaic cells

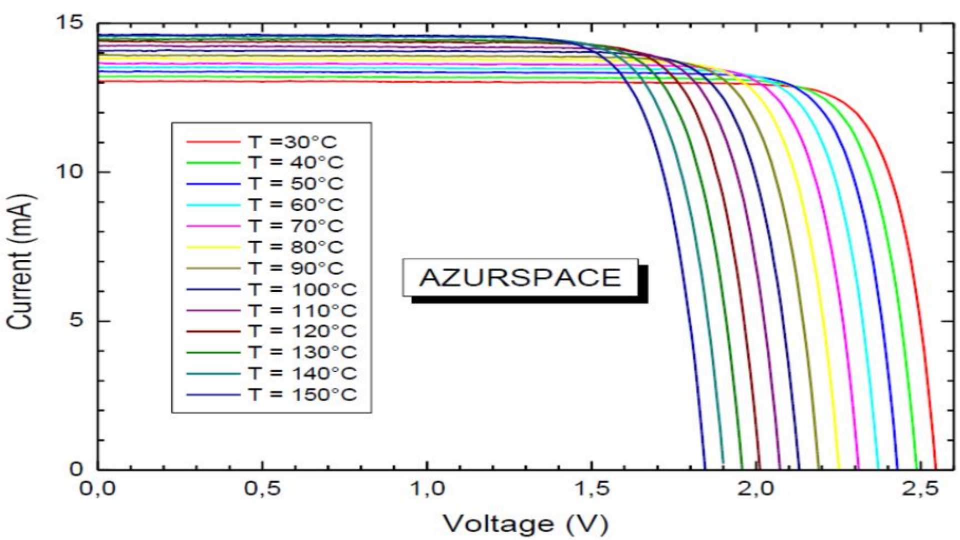
International standard ASTM E948-09: *Standard Test Method for Electrical Performance of Photovoltaic cells using reference cells under simulated sunlight*



Photograph of the experimental setup at LOOX

## Optical characterization of photovoltaic materials

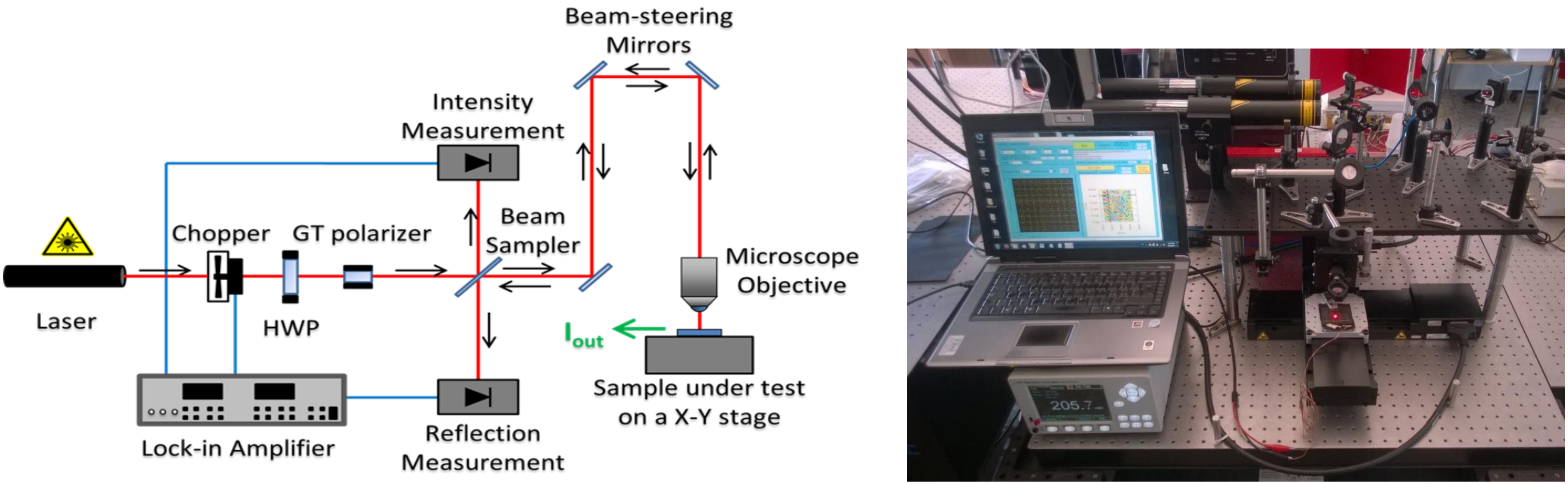


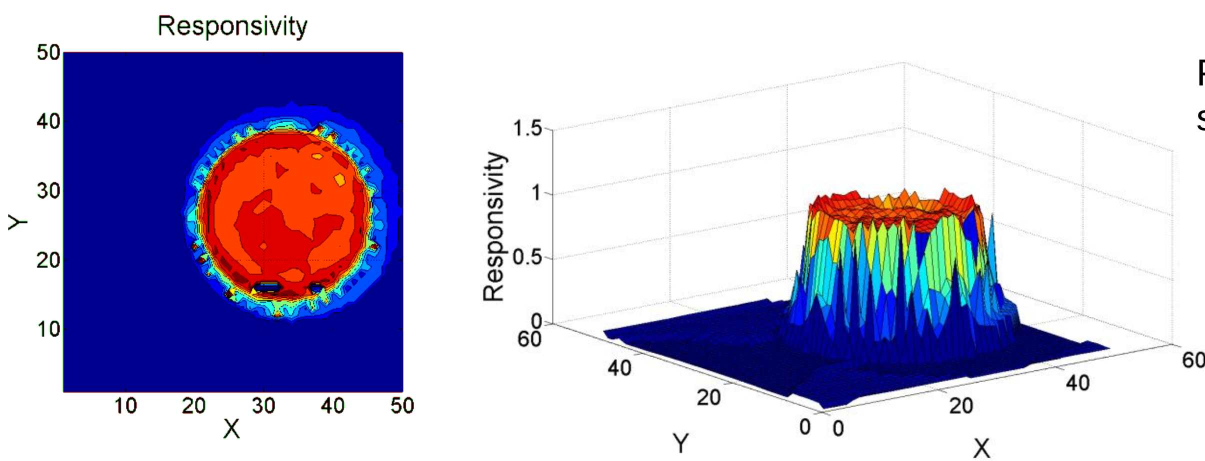

IV measurements of a multi-junction solar cell carried out by using a Oriel® Class AAA solar simulator at 1 sun concentration and at varying temperatures.

# PHOTOVOLTAICS

## Laser Beam Induced Current (LBIC) measurements of solar cells




Sketch and photograph of the experimental setup for LBIC measurements at LOOX




Photoresponse scan of an experimental dye sensitized solar cell via LBIC measurements

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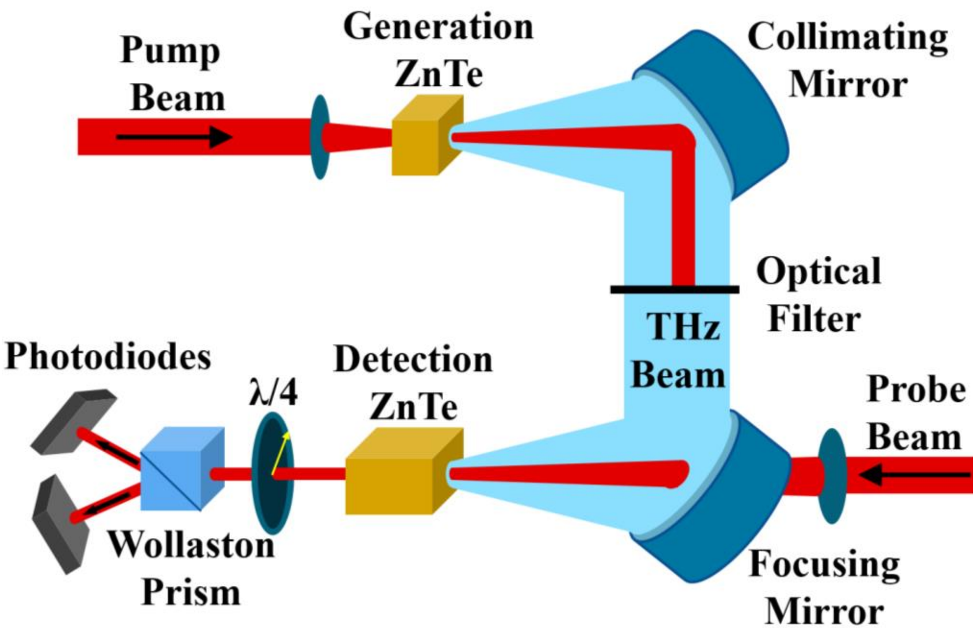
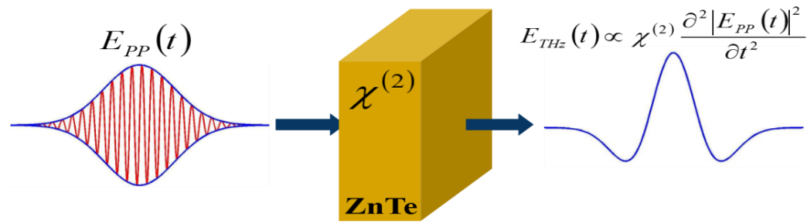
# WIDEBAND THZ TIME DOMAIN SPECTROSCOPY BASED ON PULSED LASER

## Experimental setup

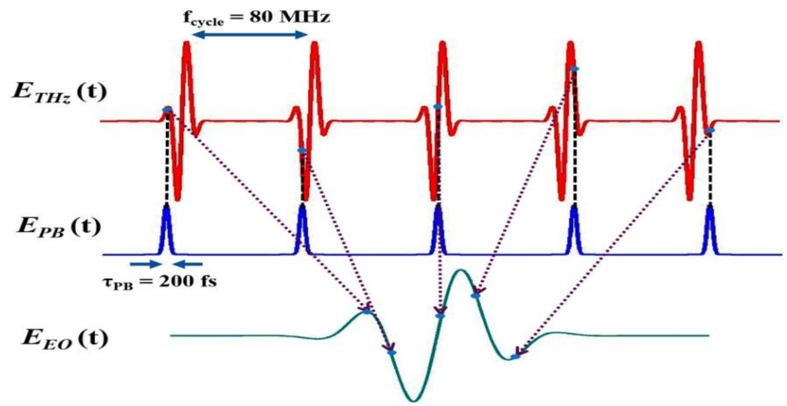



**LASER SOURCE:** Ti:Sapphire ultrafast amplifier
λ=800nm, τ < 50 fs; E > 0.7 mJ (Solstice - Spectra Physics)

## Optical Rectification (OR)




## Electro-Optic Sampling (EOS)



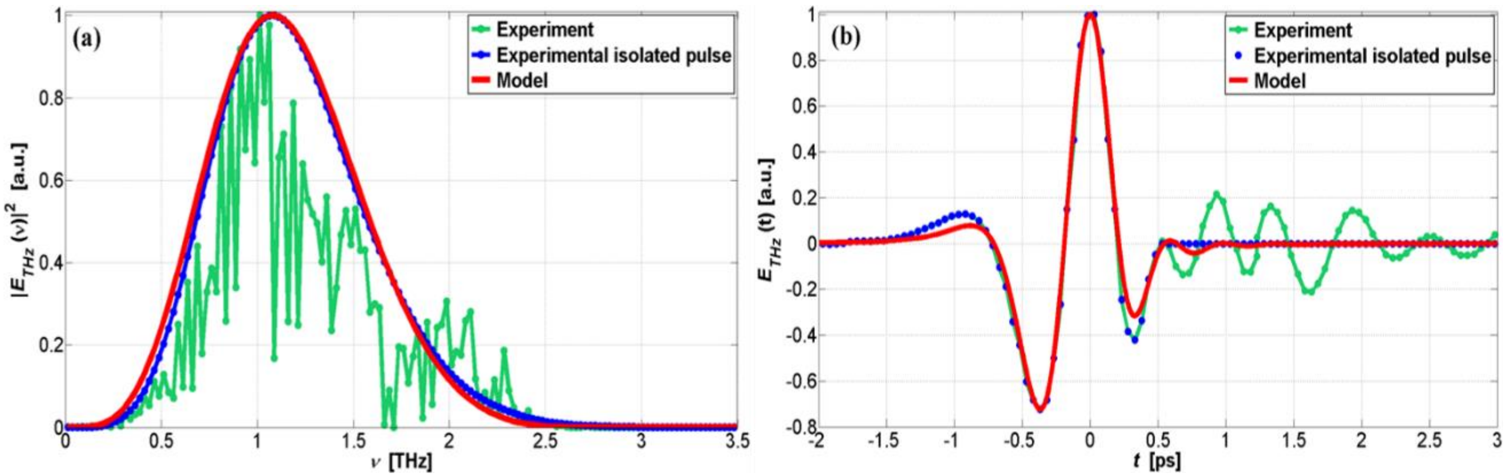

THz waves generation occurs via OR: a train of ultrashort laser pulses at 800 nm, emitted by the laser, is focused through a lens into a ⟨110⟩ ZnTe sample.

For the detection, the THz beam is focused into another ZnTe crystal together with the optical probe pulse: the EOS technique permits to detect the train of THz pulses

*This research activity is carried out in cooperation with the INRS (Institut National de la Recherche Scientifique), located in Varennes (Québec) Canada.*

INRS Université d'avant-garde

# WIDEBAND THZ TIME DOMAIN SPECTROSCOPY BASED ON PULSED LASER

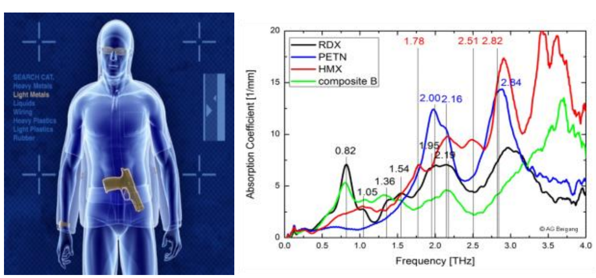



A. Tomasino et al, Sci. Rep. **3**, Article number: 3116 (2013)

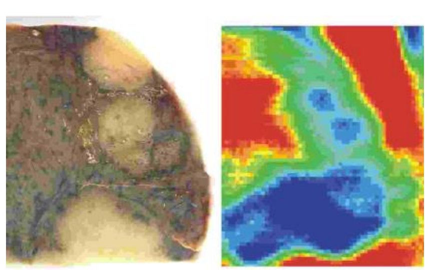
**Comparison between the experimental results (circles) and the simulations (red solid-line), for both the spectra (a) and the waveforms (b).**

The agreement between our model (red line) and the experimental curves is very good, meaning that we are able to describe quite well all the phenomena taken into account and, in particular, the sub-wavelength regime, which is a crucial aspect of the THz propagation modelling in many TDS systems.

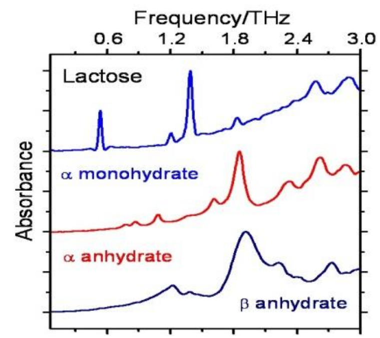
## Applications of THz waves



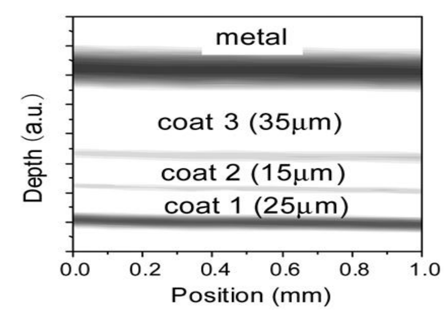

Homeland security



Tissue imaging




Pharmaceutical control




Non-invasive inspection

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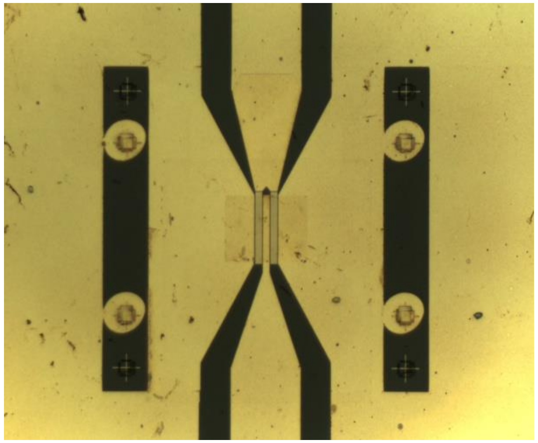
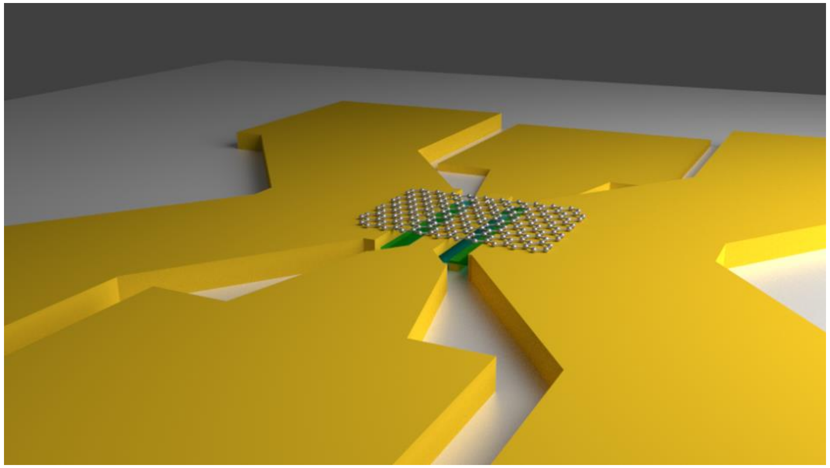
# GRAPHENE FIELD EFFECT TRANSISTORS (GFETS) WITH PHOTOELECTRICAL RESPONSE

Graphene field effect transistors (GFET) for high frequency applications have recently received much attention and significant progress has been achieved in this area.

In this research activity we focus on the fabrication and characterization of a novel generation of GFET in which a graphene sheet, grown via **chemical vapor deposition** (CVD), is used as channel material.





## *Fabrication steps*

- **GFETs on insulating substrate (Sapphire);**
- **Ti/Au back dual gate with gate length 1 to 2 um patterned by e-beam lithography;**
- **10 nm $Al_2O_3$ dielectric layer via atomic layer deposition (ALD);**
- **Ti/Au metal source and drain contacts;**
- **CVD graphene transfer;**
- **Graphene etching;**

*The technological activity is carried out at the Karlsruher Institut für Technologie (KIT) in Germany*

Karlsruhe Institute of Technology

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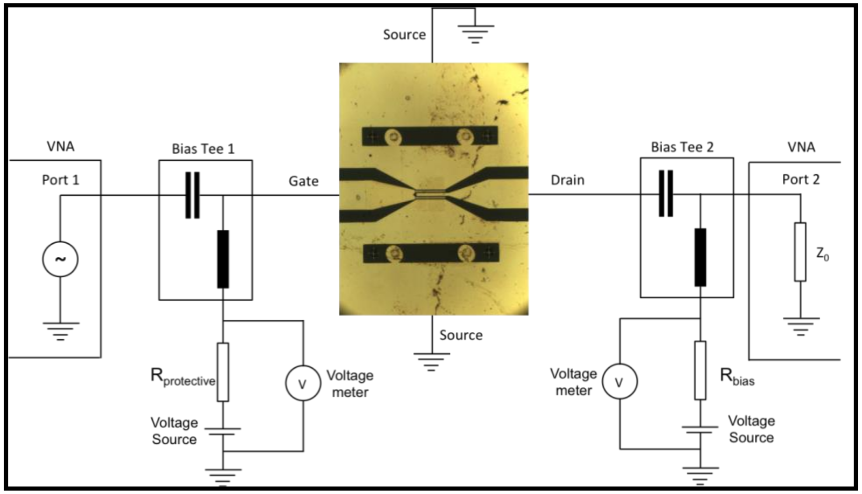
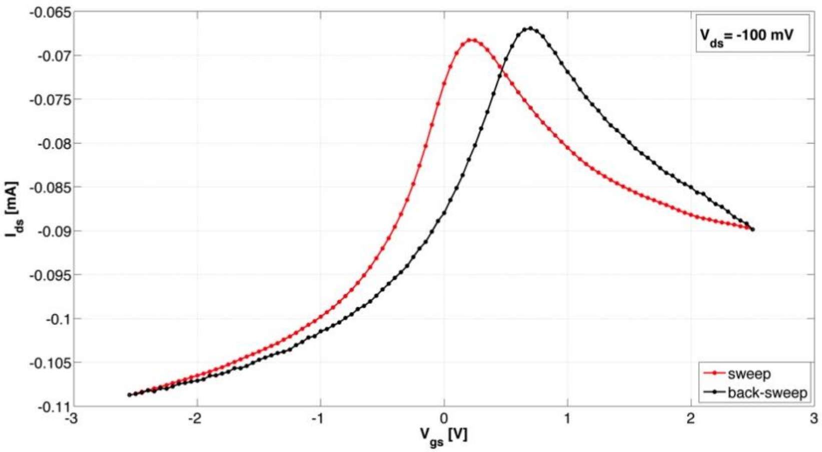
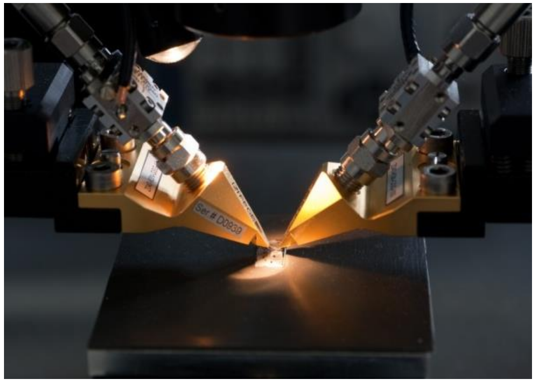
# *GRAPHENE FIELD EFFECT TRANSISTORS (GFETS) WITH PHOTOELECTRICAL RESPONSE*

## *Characterization*

- **Gatesweep $I_{ds}(V_{gs})$**
- Dirac point shifted: Hole/electron asymmetry
- Dirac point at positive gate voltages which means p-doping
- Back sweep showed the hysteresis of the devices
- Hysteresis is caused by charge carriers trapped/detrapped at the impurities introduced by the gate dielectric or by interactions with water molecules attached to the substrate surface



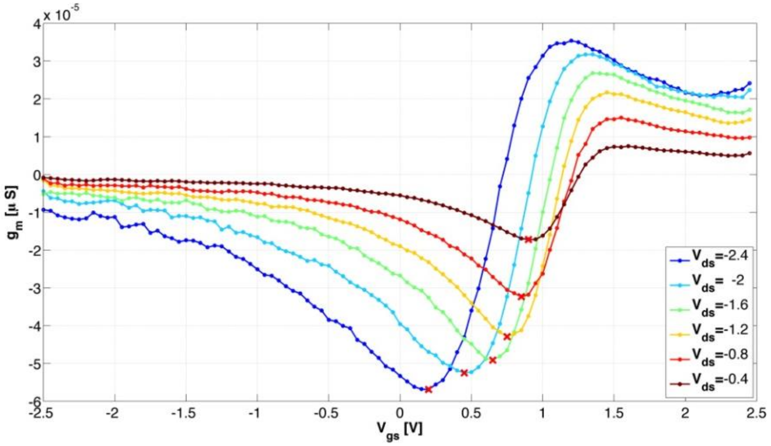



LABORATORY OF OPTICS AND OPTOELECTRONIX

# GRAPHENE FIELD EFFECT TRANSISTORS (GFETS) WITH PHOTOELECTRICAL RESPONSE

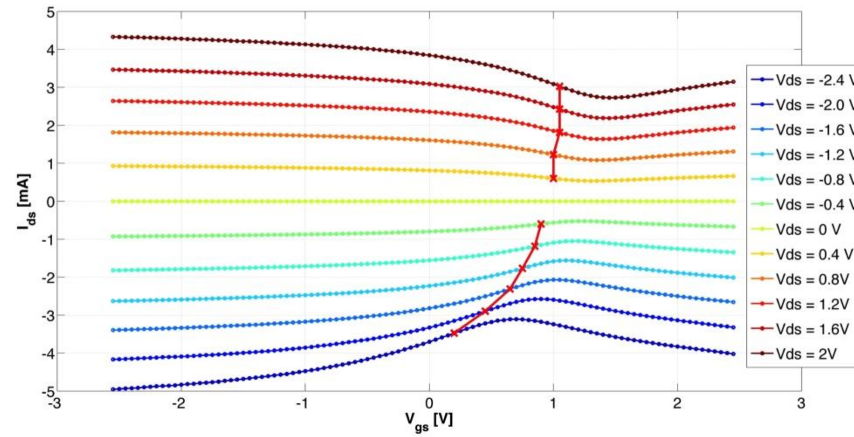
## Characterization

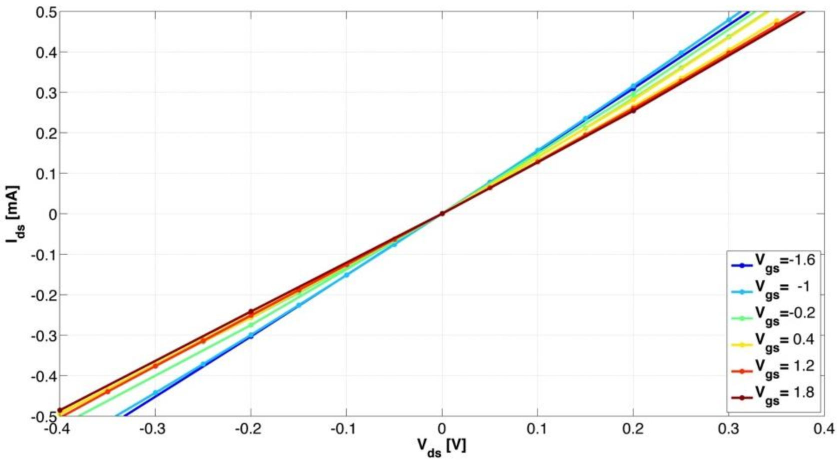
**Transconductance:** $g_m = \frac{dI_{ds}}{dV_{ds}}$




**Drain Characteristics:**

- Ambipolar field effect in graphene devices
- No saturation
- The $I_{ds}(V_{ds})$ dependence of drain-source voltages is linear




## Optical measurements