NanoSaclay
Laboratoire d'Excellence
en Nanosciences et Nanotechnologies

cnrs université PARIS-SACLAY CentraleSupélec

*"Nanomatériaux pour l'énergie"*
*"Instrumentation multifonctionnelle à l'échelle nano"*

*Noelle Gogneau*

# NanoVIBES

## Nanomaterials and nano-structured architectures for micro-devices harvesting mechanical energies

*« Imagine a world where the micro-devices could draw the energy they need to operate from their direct environment! »*

*This is today the desire of a large number of companies or start-ups using this type of microsystems and facing the recurring problem of batteries*

C2N Centre de Nanosciences & de Nanotechnologies
MSSMat
Structures Properties Modeling of Solids
GeePS Génie électrique et électronique de Paris
GEMaC Groupe d'Etude de la Matière Condensée
LSI

# NanoVIBES Consortium

## NanoVIBES: 6 major laboratories from NanoSaclay with recognized expertise in Energy Harvesting

MSSMat

- *Triboelectric nanomaterial synthesis*
- *Device design and testing*
- *Micro-Macro-characterizations*
- *Simulation/Numerical generator*

Structures Properties Modeling of Solids

- *Ferroelectric nanomaterial synthesis*
- *Transducer design and fabrication*
- *Macro-characterizations*
- *Simulation*

**NanoVIBES**
**A fundamental project with real applicative aims**

C2N Centre de Nanosciences & de Nanotechnologies

- *III-Nitride NWs synthesis*
- *Clean-room facilities*
- *Device fabrication & testing*
- *Nano- & Macro-characterizations*

GEMaC Groupe d'Etude de la Matière Condensée

- *ZnO NWs synthesis*
- *Macro-characterizations*
- *Micro-Nano-fabrication*

- *Piezo-polymer nanomaterial synthesis*
- *Transducer fabrication & testing*
- *Macro-characterizations*

GeePS Génie électrique et électronique de Paris

- *Instrumental developments*
- *Nano-scale electrical characterizations*
- *Surface characterization*

Involved Industrial Partners
*Support letters & Actions*

SNCF · cnes Centre National d'Études Spatiales · Schlumberger · MOTEN Technologies · TE-OX · Sercel · SAFRAN · CAIRDAC

# Challenge

**The number of smart objects is constantly on a rise both in our daily life and in high-tech applications**


- ✓ To deal with the critical increase of their associated energy consumption
- ✓ To enhance their condition of use, *especially for ones evolving in environment with restricted or without electrical grid infrastructure*

**The question of their energetic autonomy is today a key worldwide challenge**

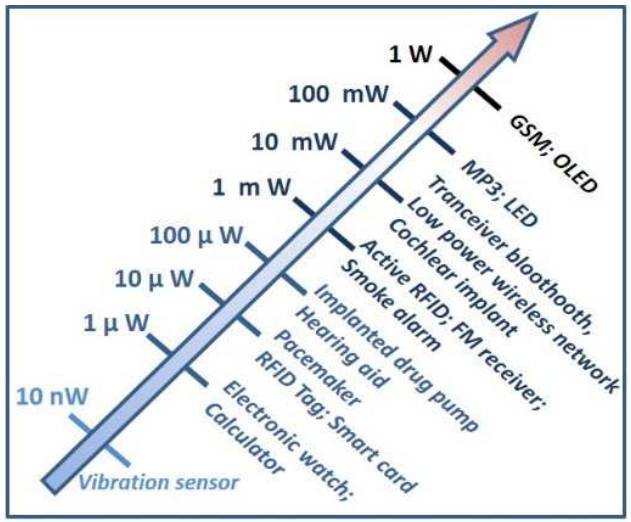
*Today, (micro)**batteries** are the most common solution for self-supplying these microsystems*

- *Complex integration*
- *Limited capacity*
- *High cost*
- *Contamination risks*


***Smart Objects***

- ✓ *with long lifetime (> 2 years)*
- ✓ *Working in non-accessible or hostile environment*

# Challenge



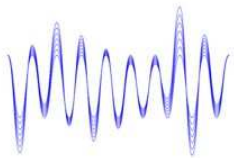

**The recent miniaturization of the electronic micro-devices for sensing, monitoring and nomad electronics**

→ **Results in the reduction of their energy consumption to mW and even µW**

**Autonomous power systems based on renewable energy harvesting**

**Energy Harvesting** *Conversion of the ambient energy found in the vicinity of the device into usable electrical energy*

**Mechanical deformations & Vibrations**



**Piezoelectric**
**Ferroelectric** } **Materials**
**Triboelectric**

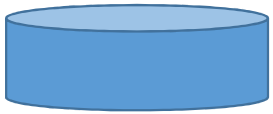
*Ability to convert mechanical deformation directly into electrical energy without any external energy source requirement*

# NanoVIBES objectives

***General convertor concept***

***Environmental solicitation***

*f (Hz)*
*Amplitude (m)*
*Acceleration (G)*



***Active layer***
*Electromechanical coef.*
*Mechanical resistance*

**Criteria to replace batteries in Micro-devices with Energy Harvesting System:**

- **Ultra-compact and integrable, without increasing their size or weight**
- **Generating sufficiently power to supply the µ-systems, under environmental conditions and for an important lifetime**

**Conventional bulk and 2D-layer based Piezo/Ferro/Tribo-transducers**

***For supplying nomad electronics and micro-systems …***

**The size of the conventional and 2D-layer-based generators** often represents **a major limitation**

***Weak commercialization of wireless micro-devices***

# NanoVIBES objectives

***General convertor concept***

***Environmental solicitation***

*f (Hz)*
*Amplitude (m)*
*Acceleration (G)*

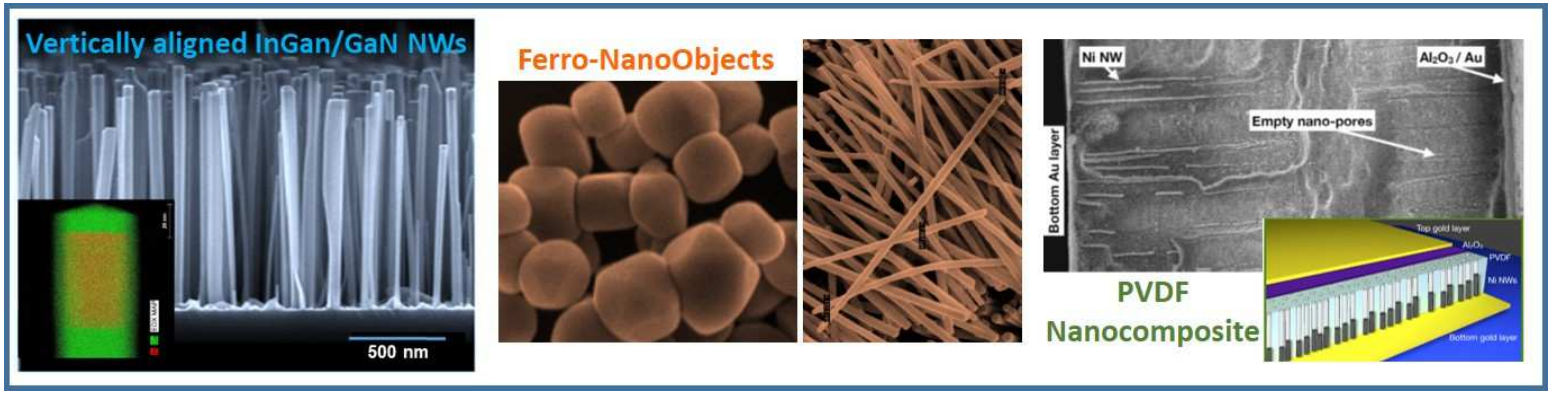
***Nanostructured Active layer***

*Electromechanical coef.*
*Mechanical resistance*

## Criteria to replace batteries in Micro-devices with Energy Harvesting System:

- **Ultra-compact and integrable, without increasing their size or weight**
- **Generating sufficiently power to supply the µ-systems, under environmental conditions and for an important lifetime**

**Materials structured at nanometer scale to enhanced electromechanical coupling of the active layer**



# NanoVIBES objectives - State-of-the-art

**Nanomaterial based transducers: A new class of generators with exalted electromechanical coupling properties**

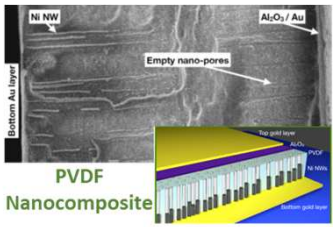
Superior mechanical properties

Exaltation of the Piezo/Ferro-electric properties

Enhanced sensitivity to small deformation

New properties at nanometer scale dimensions

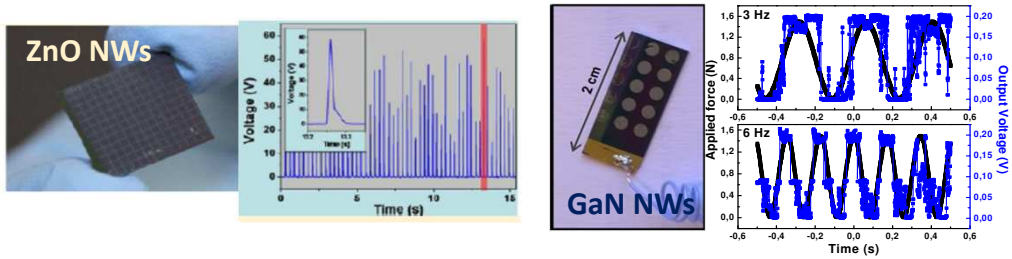
❖ PVDF nanostructures under nanofiber, nanoporous films or NWs
Piezoelectric performance enhancement by 2.5



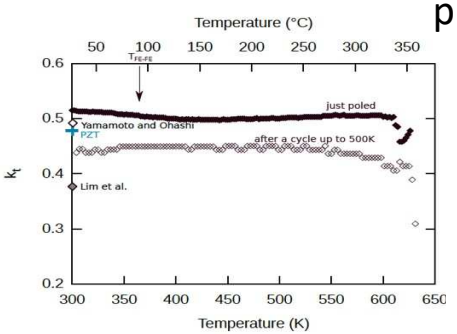

*Science 6, 2631 (2013);*
*Nano Lett. 11, 5142 (2011);*
***J. Material Sci. & Eng. 7, 444 (2018)***

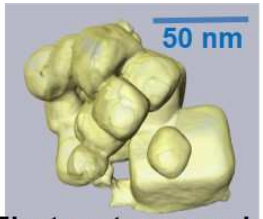
❖ ZnO and GaN NW based piezo-generators
Power density reaching several tens of $mW/cm^3$

*Nano Lett. 12, 3086 (2012);* ***Nanotechnology 27, 325403 (2016)***




❖ Integration of ferro-nano-objects - Enhance their piezoelectric properties (d~2000 pC/N)

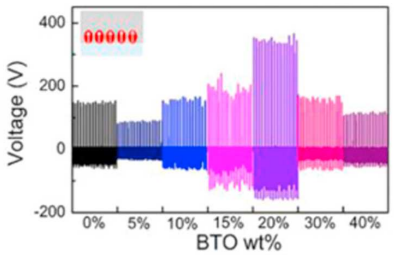


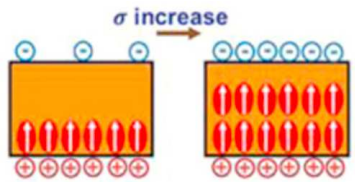




**Electron tomography reconstruction**

***Nature Mater. 17, 427 (2018)***
***Nature Mater. 14, 985 (2015)***

❖ Increase triboelectric materials performances by integrating sub-100 nm BTO nanoparticles
Generation of power density up to $2.5\ mW/cm^2$

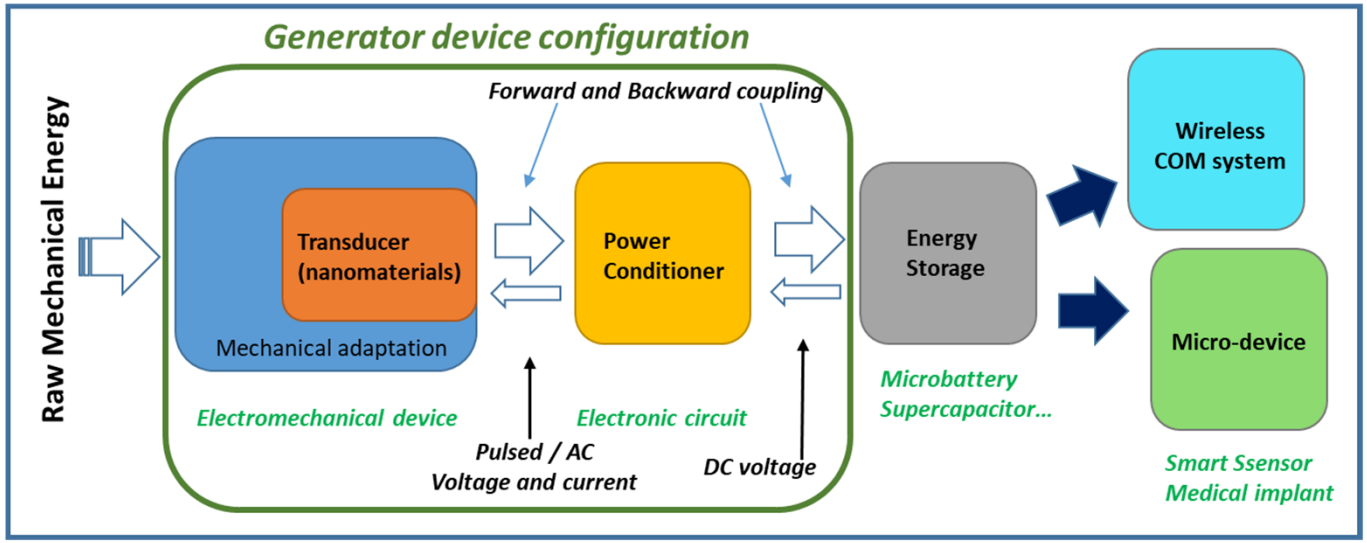


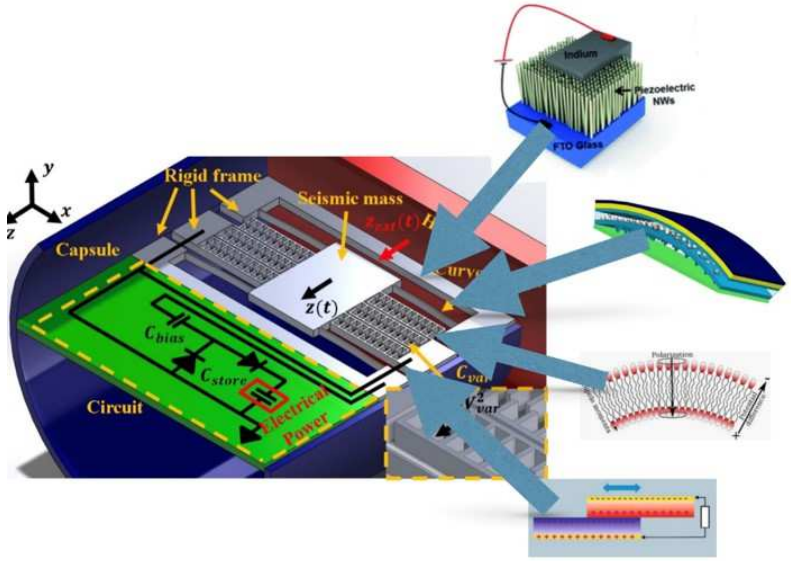




*Nano Ener. 25, 225 (2016)*

# NanoVIBES objectives

Autonomous
Smart micro-device



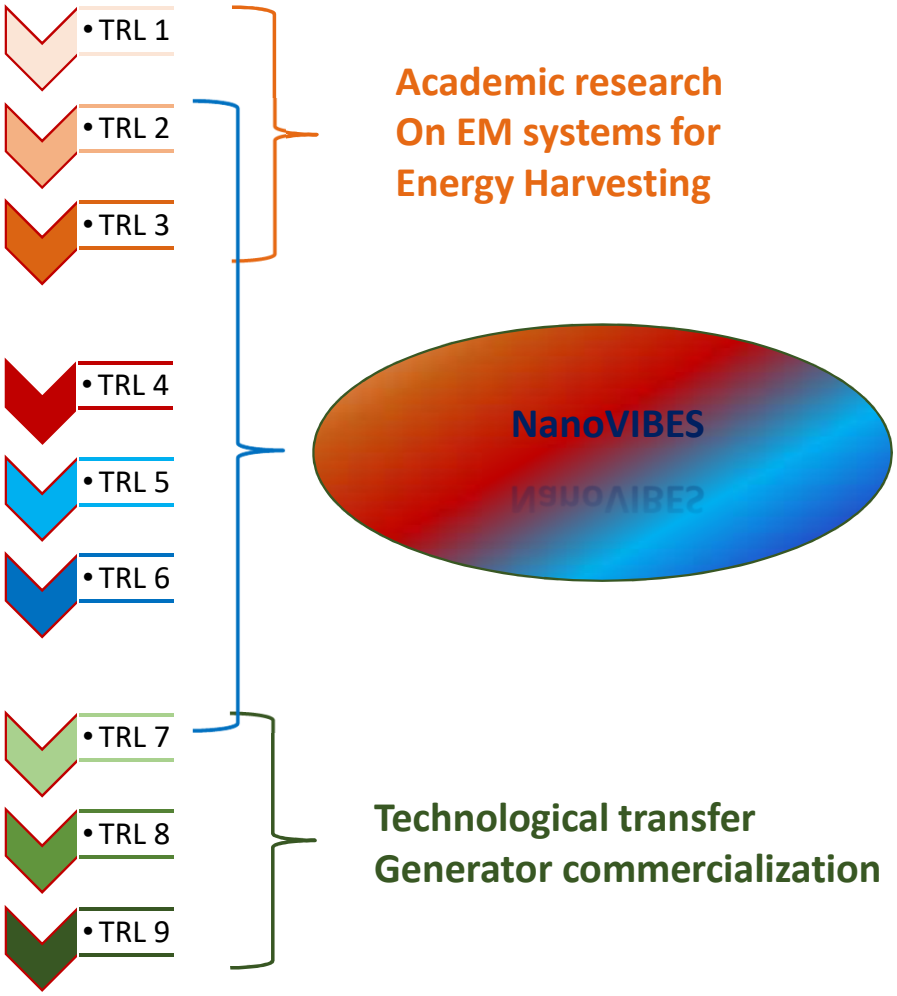

**Integration of the active layer into MEMs …**

**…With optimized architecture**

**Investigation of the generator robustness and durability**

**Maximize of the generator effectiveness**

# NanoVIBES Positioning




***The ambition to bridge the gap between the demonstrators fabricated today in laboratories and the useful energy harvesters ready for technologic transfer***

Disruptive approach

## Address fundamental challenges

1- **The enhancement of the electromechanical coupling efficiency**
2- **The optimization of the device architecture**
3- **The investigation of generator robustness and durability in real condition**

## In agreement with the market demands

SNCF, cnes CENTRE NATIONAL D'ÉTUDES SPATIALES, Schlumberger, MOTEN TECHNOLOGIES, TE-OX, Sercel, SAFRAN, CAIRDAC

# NanoVIBES Positioning

## Investigation of 3 families of generators
## Bringing common objectives

| Family | Low cost generators without strong volume constraints | Ultra-compact generators | Generators for hostile environments |
|---|---|---|---|
| **Objective** | **Structural Health Monitoring of** bridges (SERCEL comp.), aging of railway (SNCF comp.) | Module to supply **medical implant devices**, such as pacemaker (CAIRDAC startup) | **Monitoring sensors** evolving in hostile environments (high T°, large range of T° or radiation (SAFRAN, CNES companies)) |
| **Requirements** | Generators sensitive to the own **vibrations** of the infrastructures/bodies while being cost competitive | **Ultra-compact, integrable, bio-compatible**, robust and durable generators | Materials with properties supporting **hard environment** and supplying electrical energy in a given size |
| **Proposed solution** | **Few cm² large generator integrating BaTiO3 or ZnO/PDMS or PVDF composite** | **Generator size < 1 cm3 integrating GaN or ZnO NWs** | **cm² generator integrating GaN NWs with specific matrix and contacts; or BaTiO3/metal foils** |

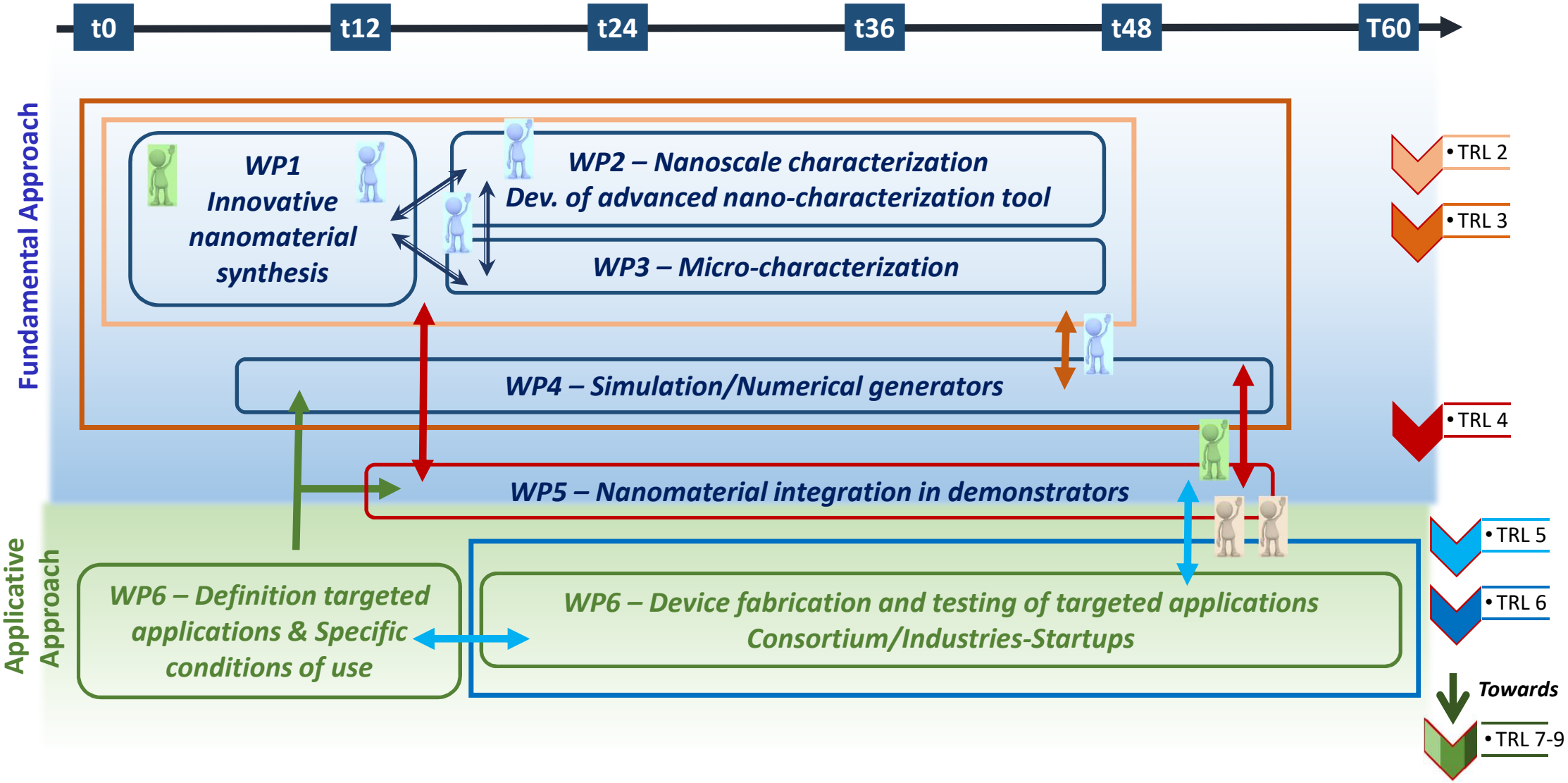
**Fundamental challenges oriented by real application aims defined with industrial partners**

Disruptive approach

**Validation with real applications in close collaboration with active industrial partners**

# Methodology

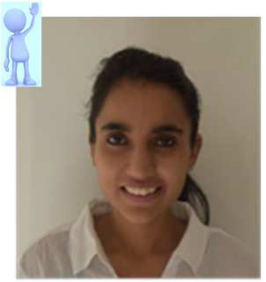
PhD student  Post-doc  CIFRE fellowship



# NanoVIBES project: The NanoVIBES team is growing !

PhD student | Post-doc | CIFRE fellowship

*Already recruited !*



**Monika PARIHAR**
PhD Nano-characterization – GeePs / C2N
*From October 2020*
*Characterization at the nanometer scale of the electro-mechanical conversion properties of piezoelectric nanostructures*

**Dr. Potrzebowska Natalia**
18-month post-doc at CEA/DRF/IRAMISLSI
*From July 2020*
*Fabrication and study of innovative flexible piezoelectric nanostructured generator based on poly(vinyldifluoride) (PVDF) thin films*

**Mathilde Lavanant**
CentraleSupélec student (2nd y)
*Research program on Energy harvesting at the nanoscale*

**Matthieu Fricaudet**
PhD student at SPMS
*From October 2020*
*Multi-energy harvesting*

**Dr. Andraz Bradesko**
Post-doc at SPMS
*From summer 2021*
*Energy harvesting using nanoferroelectrics*

*They will arrive in the first semester of 2021 !*

PhD Student - C2N
*January 2021*
*Development of InGaN/GaN NWs based transductors for piezoelectric applications*

PhD Student – CIFRE CAIRDAC/C2N
*As soon as possible !*
*Robustness and fatigue of Energy Harvester system*

**Dr. Samiran Garain**
Post-doc at MSSMAT
*January 2021*
*Polymer nanocomposites and their Piezo/Triboelectric propreties for Energy Harvesting applications*

# NanoVIBES project: Innovative solutions for supplying Micro-devices under environmental conditions

- **Innovative solutions at nanometer scales with** the development of an **advanced and unique nano-charaterization tool**
- Integration of **real user's needs which highlight fundamental issues that must be addressed upstream of device conception**
- **Nanostructured transducers integrated with enhanced** coupling properties into a complete generator device, packaged with a micro-device and **tested under real conditions in collaboration with industrial partners**

NanoVIBES will provide **essential building blocks and patents for a future technology transfer in the field of renewable energy harvesting**

# NanoVIBES project