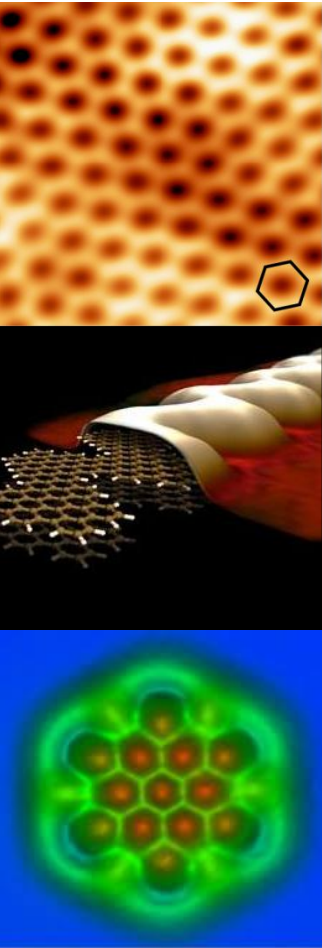




# Graphene, molecules and atoms

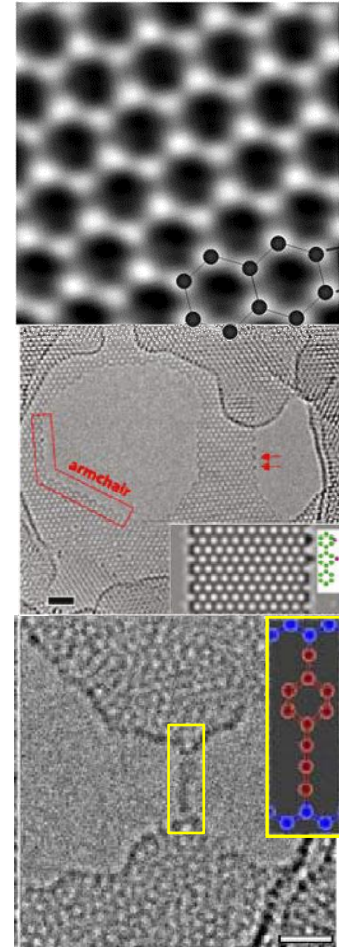


**Erik DUJARDIN**

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<http://www.comosyel.cemes.fr>

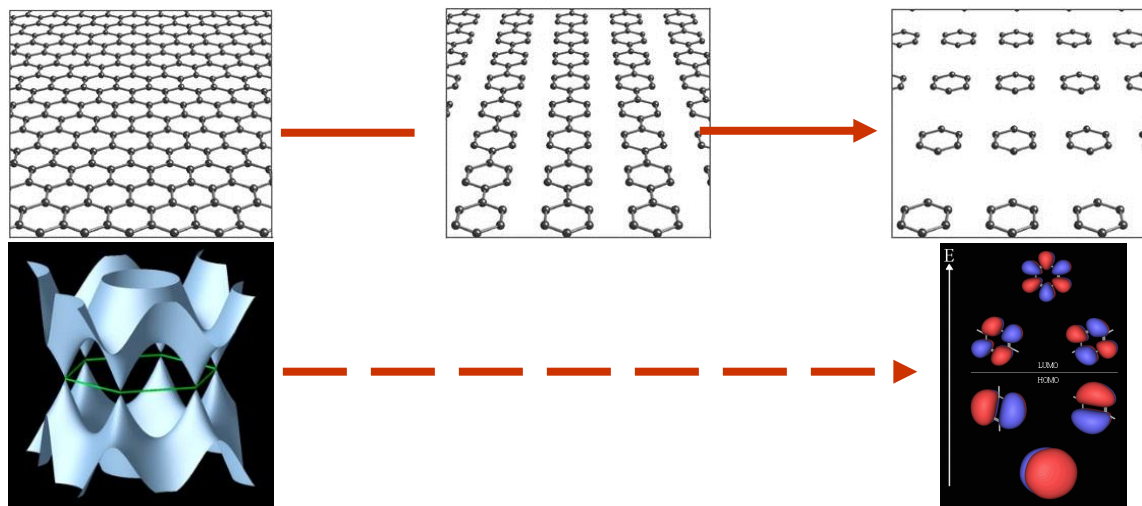
**dujardin@cemes.fr**



Fiches : ISMO (Orsay), CEA IRAMIS (Saclay), IS2M (Mulhouse), LTM (Grenoble), DCM (Grenoble), CEMES (Toulouse)



# Graphene, molecules and atoms



## Integration platform

Micro  
Nano  
Molecule  
Atom

## Gap and electronic states engineering

Physical patterning  
*litho, etching, atomic manipulation*

Chemical functionalization  
*supramolecular assembly, covalent reaction*

## Molecular hybrid graphene

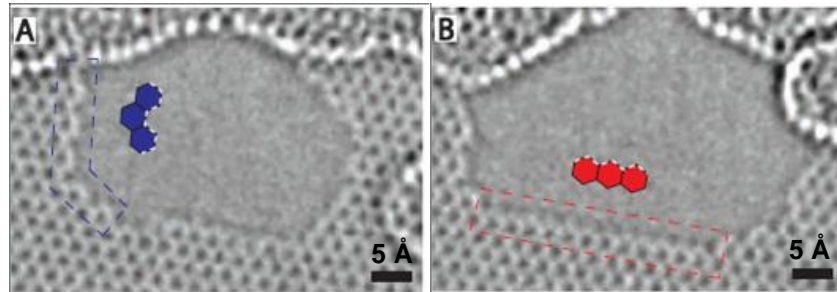
Optoelectronics  
Photovoltaics  
Sensors  
Spintronics



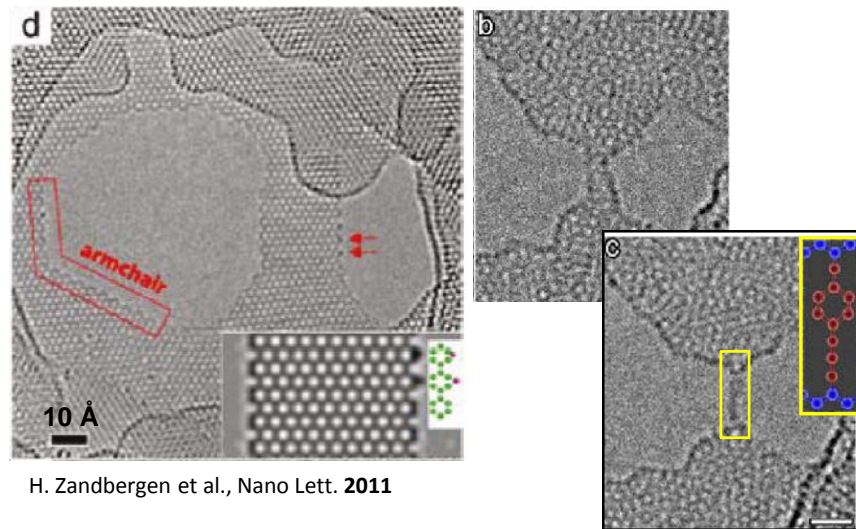
# Atom-scale patterning of graphene

## TEM observations

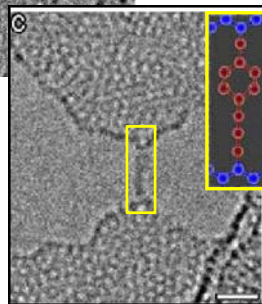
## Perfect nanoribbons



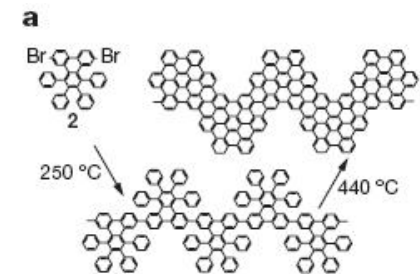
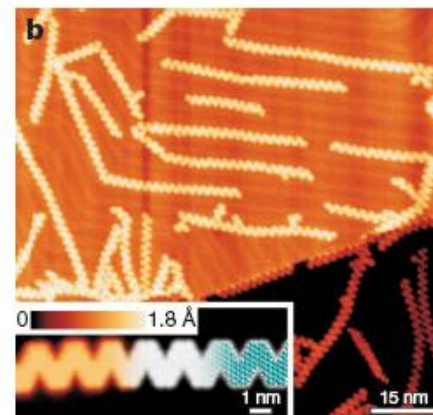
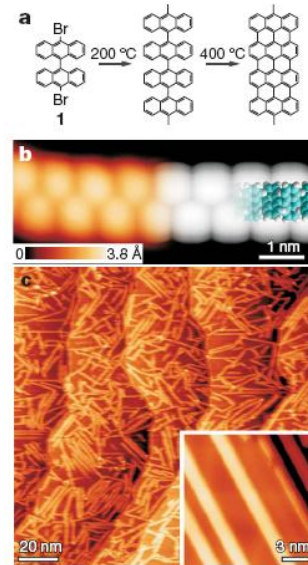
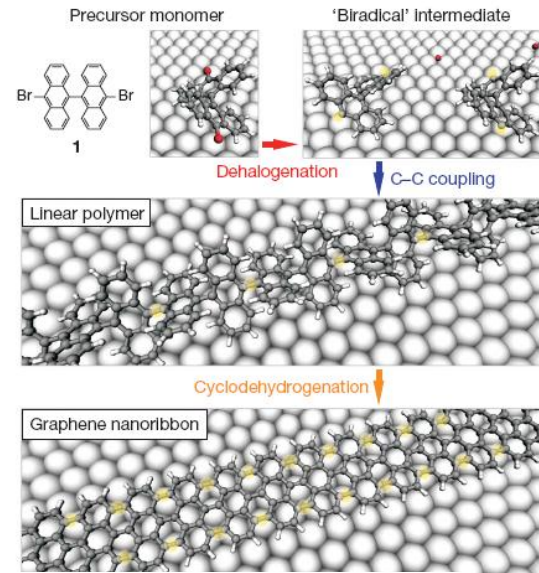
A. Zettl et al., *Science*, 2009:



H. Zandbergen et al., *Nano Lett.* 2011



S. Iijima et al., *PRL* 2009

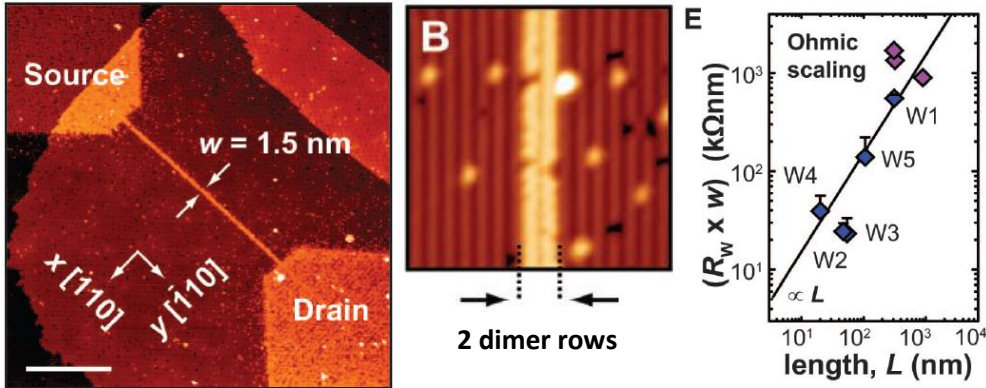


K. Mullen, R. Fasel, et al. *Nature*, 2010, **466**, 470



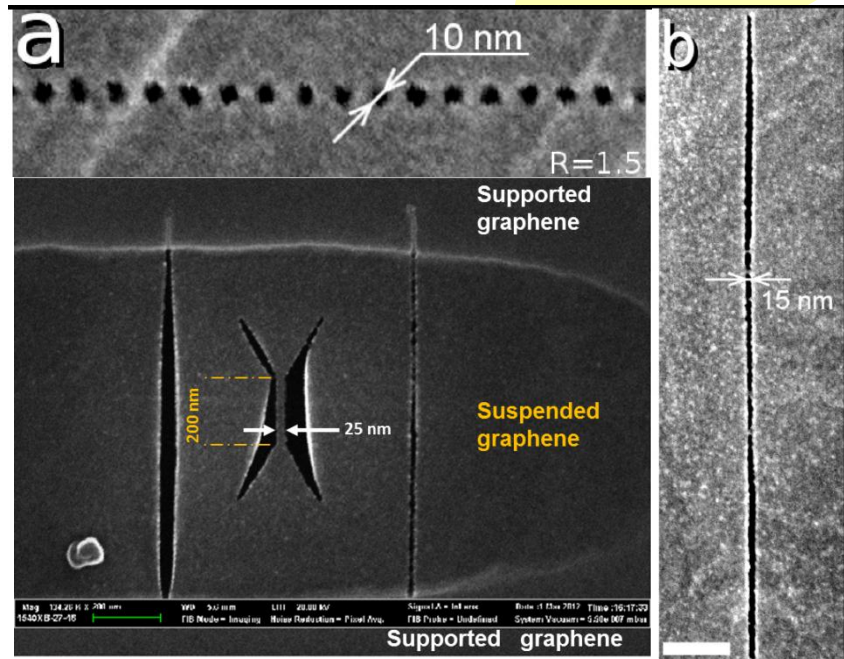
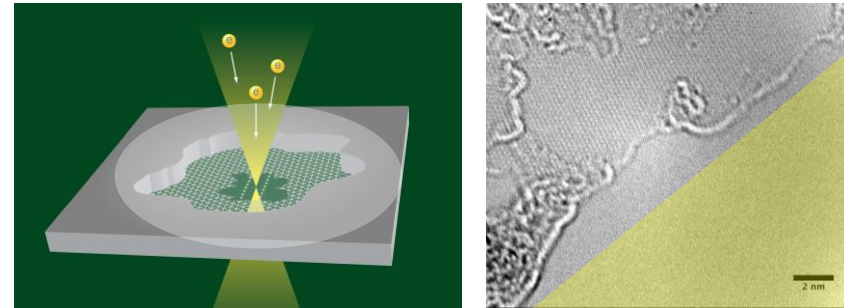
# Integrated platforms for atom technologies

## Si(100)-H & Ge(100)-H

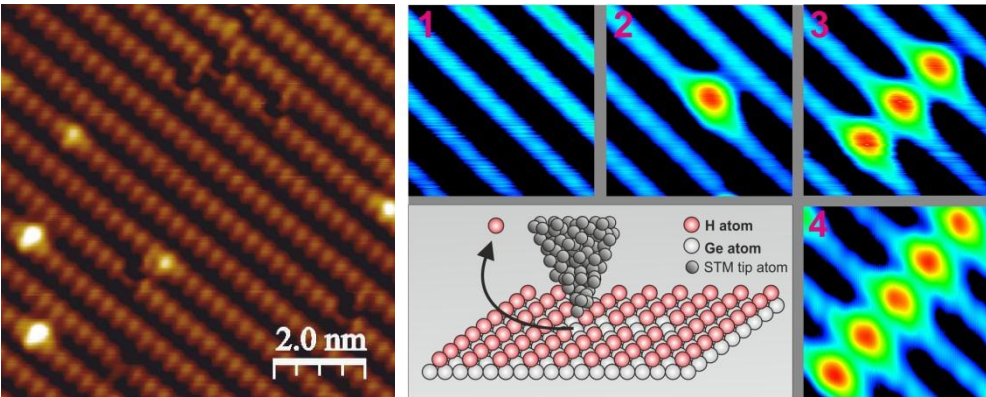


M. Simmons et al., *Science* **335**, 64 (2012)

## EBIE on graphene



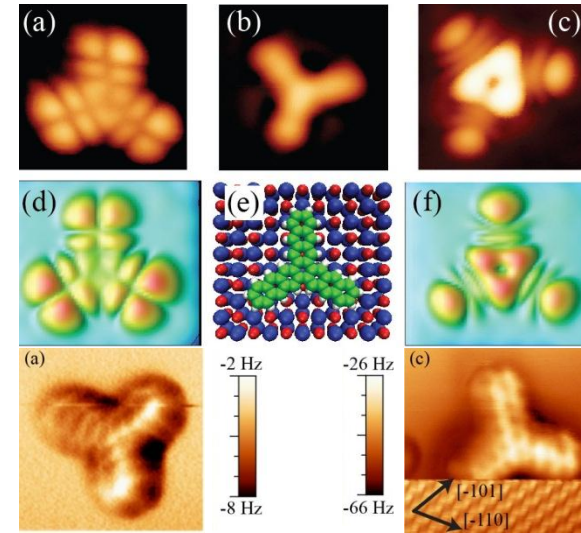
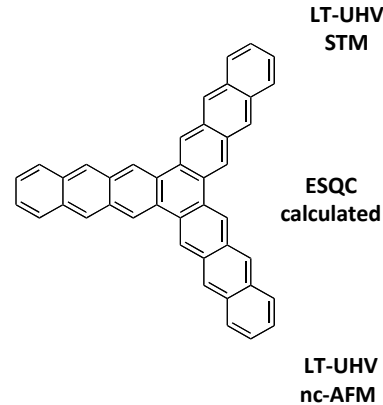
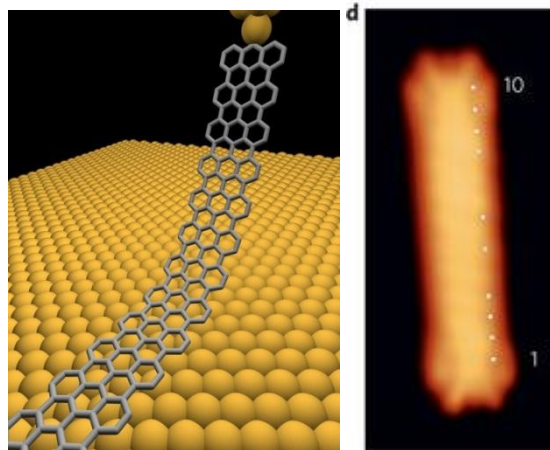
E. Dujardin et al., submitted (2013)



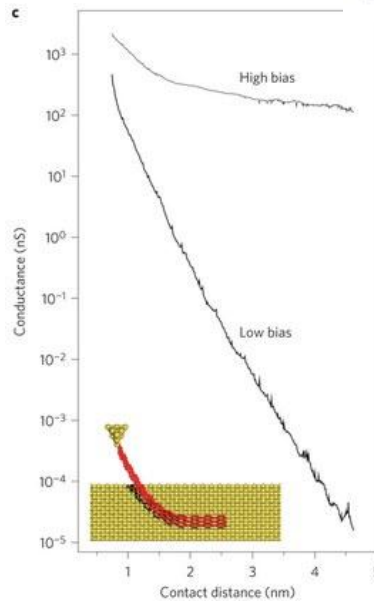
M. Szymonski et al., *Phys. Rev. B* **86**, 125307 (2012)



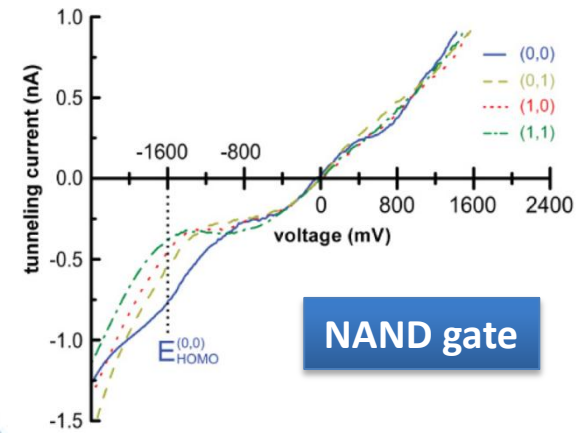
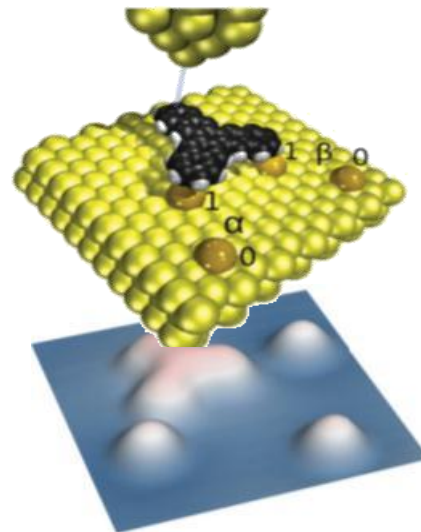
# Integrated platforms for atom technologies



O. Guillermet, et al.,  
*Chem. Phys. Lett.*, **2011**, 511, 482



Koch, M., et al.  
*Nature Nanotech.*  
**2012**, 7, 713.

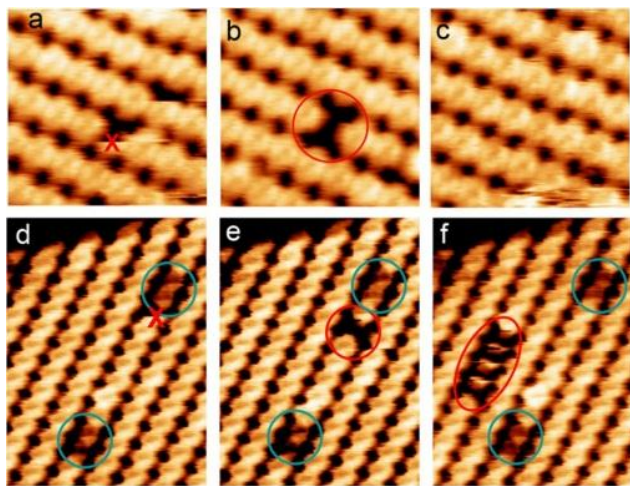
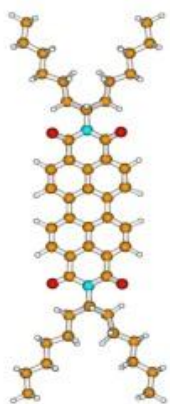
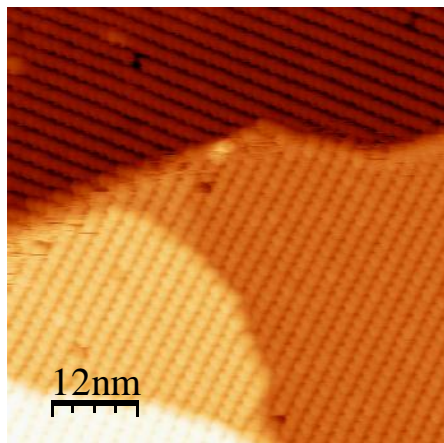


W. Soe, et al., *PRB*, **2011**, 83, 155443



# Gap and electronic states engineering

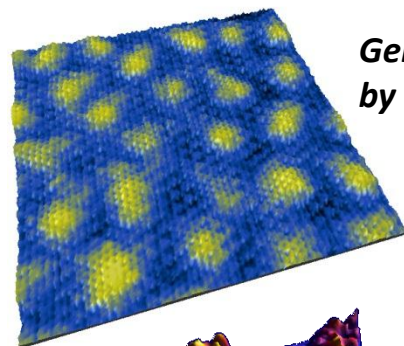
## ✧ Molecule-graphene interface



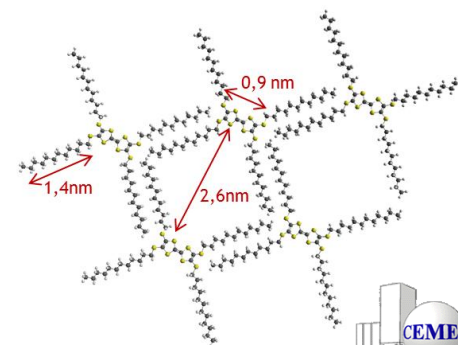
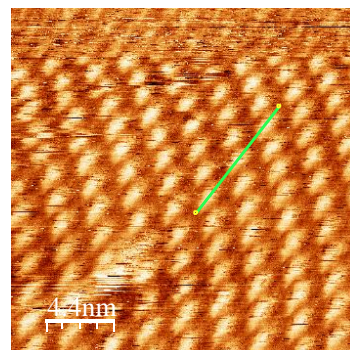
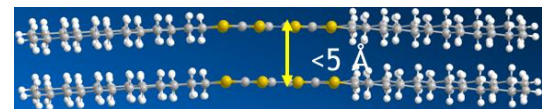
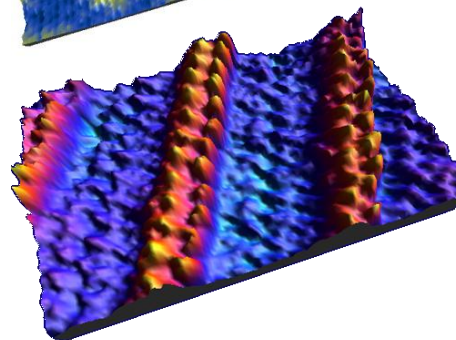
Voltage pulse: +2.2V, 1nA, 200ms



## ✧ Molecule-graphene-metal interface

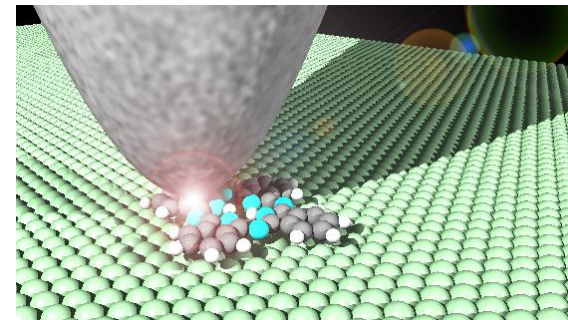
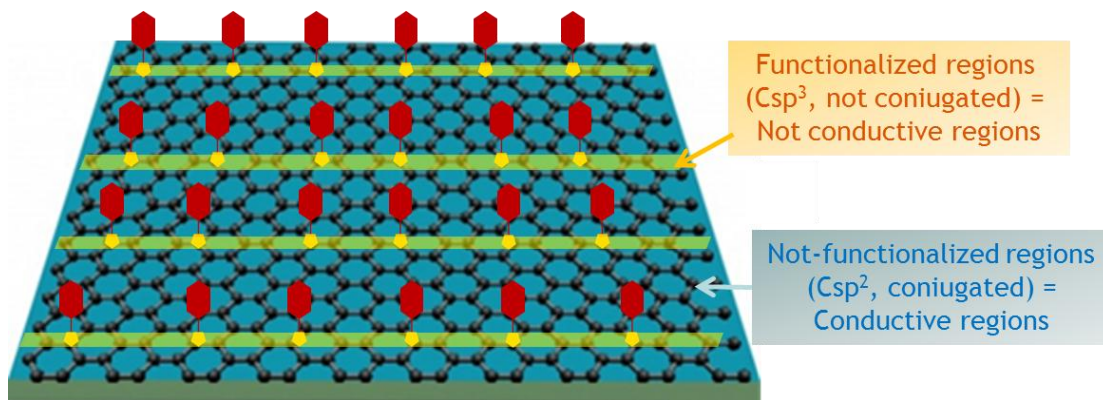


*Generation of standing waves patterns by intercalation of gold nanoclusters.*

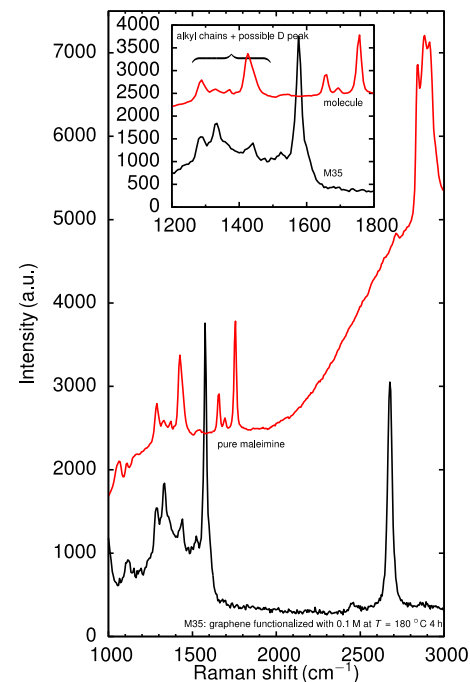
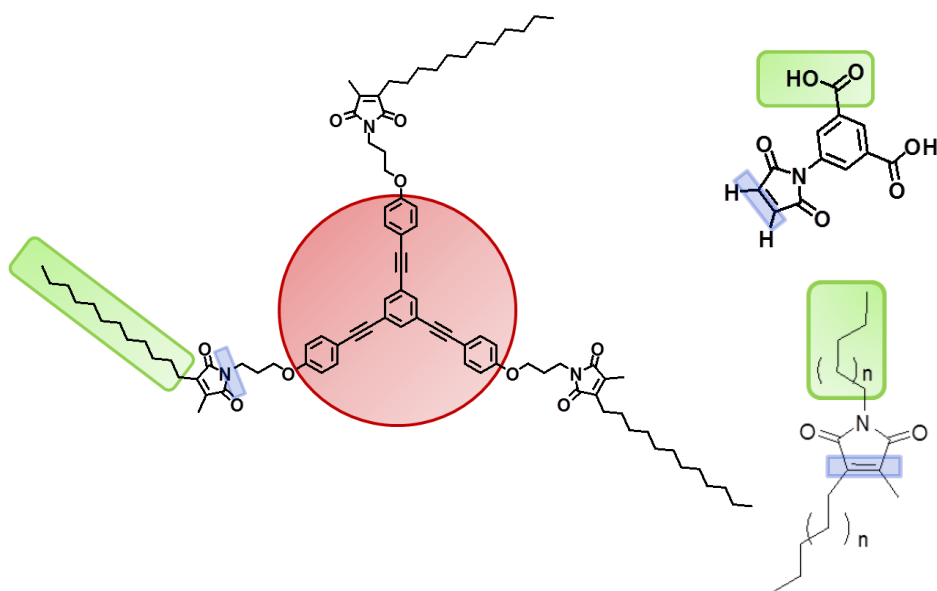




# Functionalization on demand



ISMO IS2M

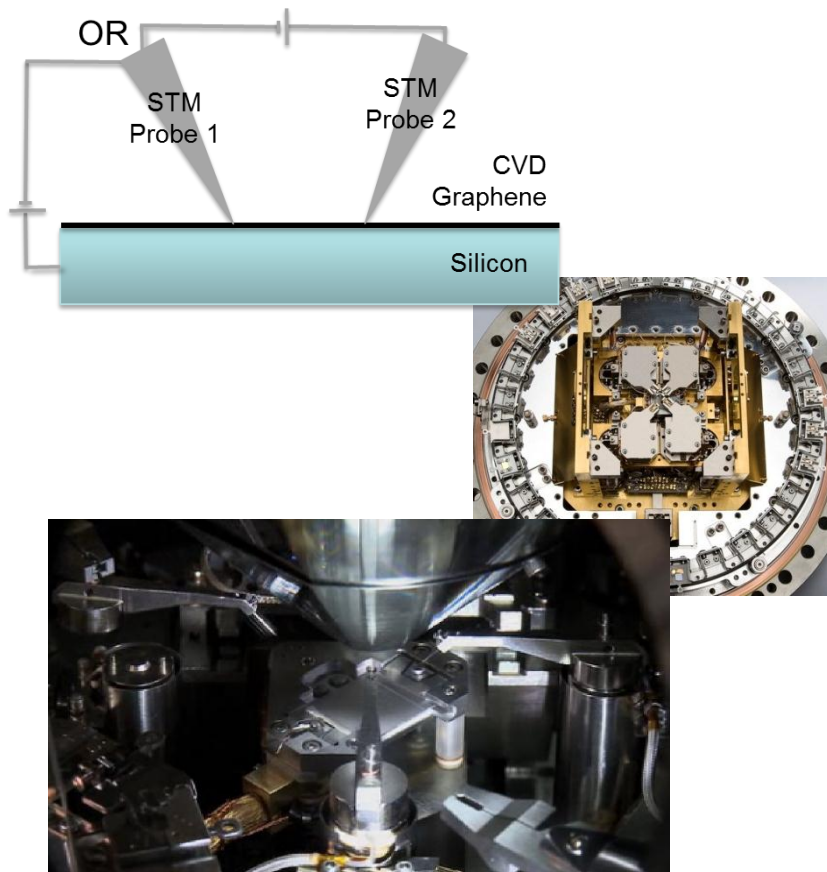




# Strength in the French community (examples)

## Instrumentation & expertise

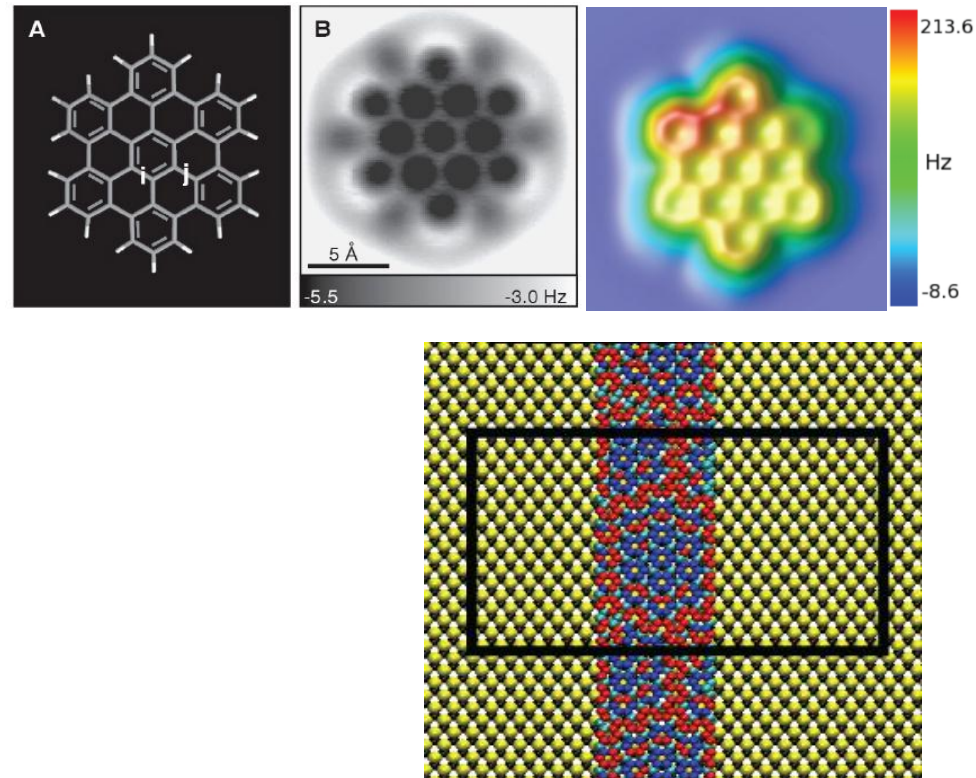
Example: 4 probe LT-STM + SEM with UHV preparation chamber developed by Omicron / CNRS



## Multiscale theoretical modeling & simulations

Broad network

incl. CEA IRAMIS, ENS Lyon, CEMES, Neel, ...

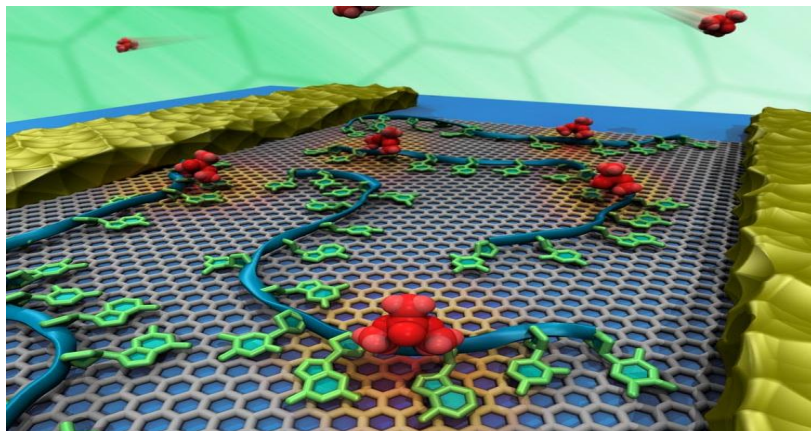






# Technological outsourcing

## Graphene decontamination and Sensors



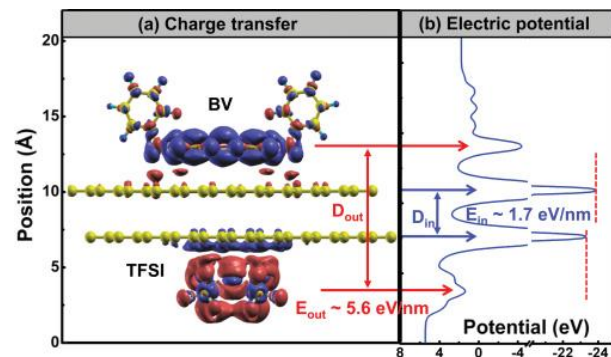
*Graphene processing for UHV-comp and clean interface*

(Ex; LTM Grenoble, IM2NP )

*Graphene sensitization for specific sensors*

(Ex: DCM-BEA UJF)

## Molecular optoelectronics



*Coupling optically active molecules to modulate the properties of graphene*

(Ex: ISMO, ICMMO Orsay)

(Ex: DCM-BEA UJF)



# Molecular and atom-scale technology in Graphene Flagship



## Materials

### WP1

The “Material” group focuses on two key challenges for the development of a new graphene technology for large-scale manufacturing of graphene-based products: access to high quality uniform graphene and other layered materials. Prior to large scale production, developing laboratory scale protocols for graphene synthesis with targeted properties is essential for this group. This scientific group is in charge of studies of how to combine graphene with other materials in heterostructures - all this will play a key role in validating graphene as a disruptive nanotechnology platform for real-world devices.

- ✓ Graphene production.
- ✓ General characterization.
- ✓ Defect analysis
- ✓ Electronic properties of graphene and 2D materials
- ✓ Application oriented optoelectronics
- ✓ Nanofabrication and metrology
- ✓ Macroscopic nanocomposites and devices



## Fundamental science of graphene and 2D materials beyond graphene

### WP3

Fundamental and blue-sky studies of graphene and complementary 2D materials have a twofold aim for the group “Fundamental science of graphene and 2D materials beyond graphene”. The group studies the fundamental mechanisms that determine and may limit the potential of graphene in already foreseen electronic and optoelectronics applications, and develop a second generation of graphene-based nanostructures for the development of electronic devices beyond the complementary metal oxide semiconductor field effect transistor (CMOS). The study of 2D materials beyond graphene is key to enhance graphene’s properties by combining this material with monolayers of 2D crystals in superstructures, which will allow broadening of the range of functional applications of graphene and hybrid superstructure in post-complementary metal oxide semiconductor (CMOS) electronics.

- ☉ Mastering the atomic scale patterning of graphene
- ☉ Multi-scale integration
- ☉ Non-CMOS information processing
- ☉ Molecular and metal cluster architectures in Gr
- ☉ Gap engineering and multifunctional graphene



## Optoelectronics

### WP5

The “Optoelectronics” group aims to establish a new field of graphene photonics and optoelectronics, sustained by the convergence and co-integration of graphene-based electronic and photonic components such as lasers, switches, optical waveguides, optical frequency converters, amplifiers, cavities, modulators, photodetectors, nano-photonics components, metamaterials and solar cells.

