# NANOBIOSENSORS AS EFFICIENT AND SUSTAINABLE TOOLS FOR DEMOCRATIZING OUR CURRENT ENVIRONMENT MONITORING SYSTEM

**Prof. Arben Merkoçi**
*Nanobioelectronics & Biosensors Group*
ICREA & Institut Català de Nanociéncia i Nanotecnologia (ICN2)
Barcelona, Spain
NanoAlb, Tirana, Albania
e-mail: arben.merkoci@icn2.cat


www.icn2.cat www.icrea.es www.nanobiosensors.org www.nanoalb.al

# What is NanoAlb ?

- Albanian NanoScience and Nanotechnology Unit

- Created in 2019 next to and with the support by the Academy of Sciences of Albania.

- It is a virtual center that coordinates the activities in the area of nanoscience and nanotechnology in Albanian universities in Albania, Kosova, North Macedonia and Montenegro.

- 25 research groups are already part of its network

# Nanotechnology importance for Albanian and Western Balkans economy

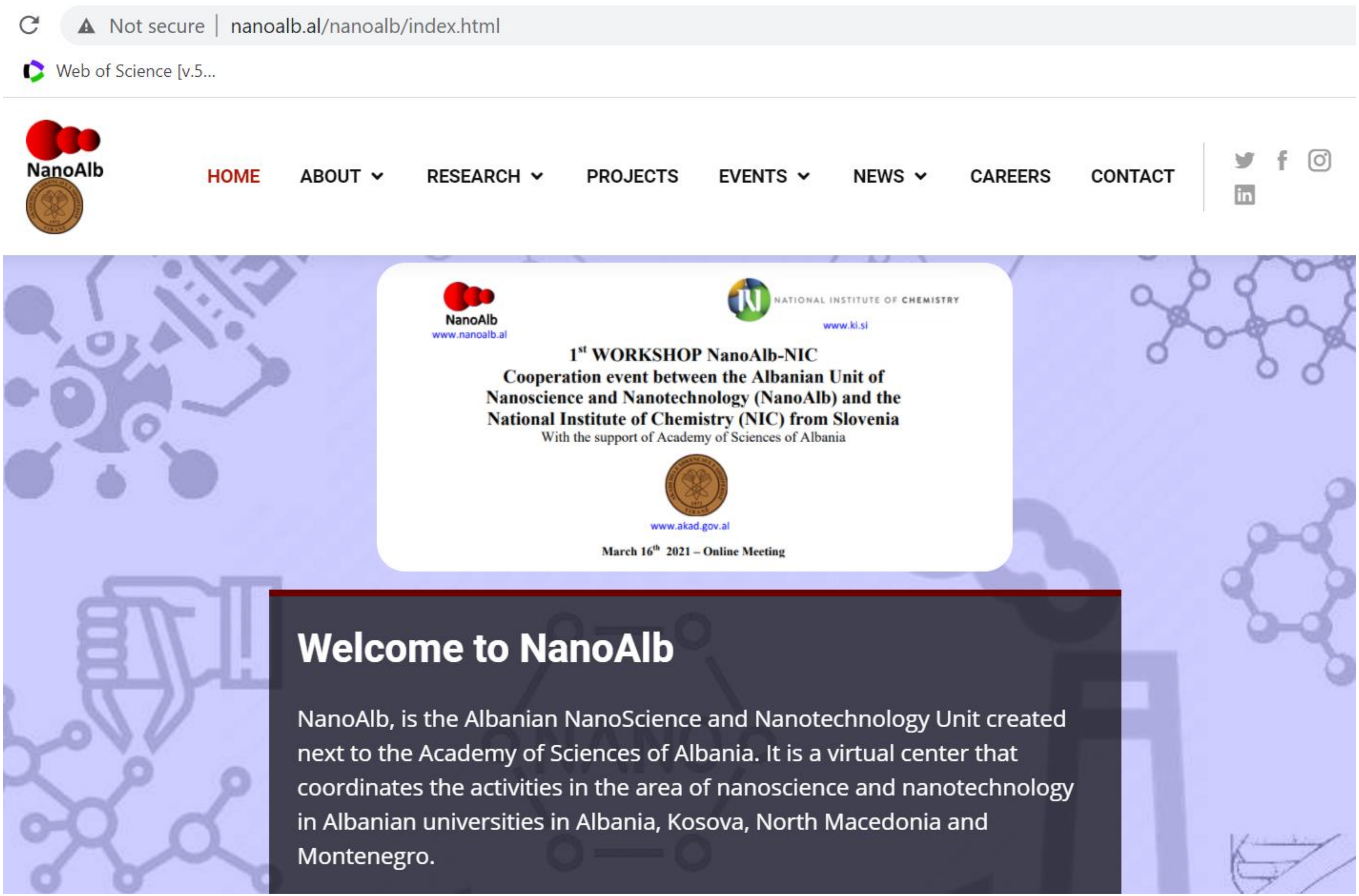
- Applications in HEALTH, AGRICULTURE, ENVIRONMENT, SAFETY AND SECURITY and other industries

- It is a transversal field of research (englobing from physics, chemistry, biochemistry, material science, electronics, medicine, agriculture etc. )

- Societal impact
  - ⇨ Opening a new model of science in Albania and region (highly competitive research centres)
  - ⇨ Attracting & retaining talent
  - ⇨ Attracting investment from international high tech industries
  - ⇨ Building a new vision:
    science /high-tech friendly country & region

- Industrial impact.
  - ⇨ Serving as hub of spinoff companies and other links with various industries in the region.
  - ⇨ Opening of new working places for professionals

# More info on NanoAlb at the website www.nanoalb.al

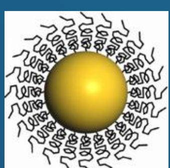


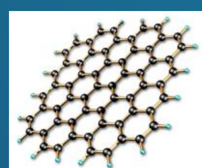
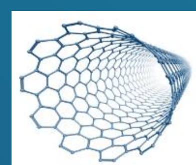
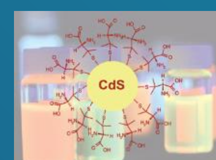
# Catalan Institute of Nanoscience and Nanotechnology (ICN2)

# NANOBIOELECTRONICS AND BIOSENSORS

## The Group

Focuses on **discovering** and on the **technological development** of cutting-edge nanotechnology and nanomaterials towards **simple and cost-effective nanobiosensing platforms.** We do this controlling their architectures at both **nano** and **macro** scales with the objective to link together these two worlds.




## Application areas:

- ✓ Diagnostics
- ✓ Environmental Monitoring
- ✓ Food quality
- ✓ Safety / security
- ✓ Other industrial applications

## Technology transfer:

paperdropdx

GraphenicaLab

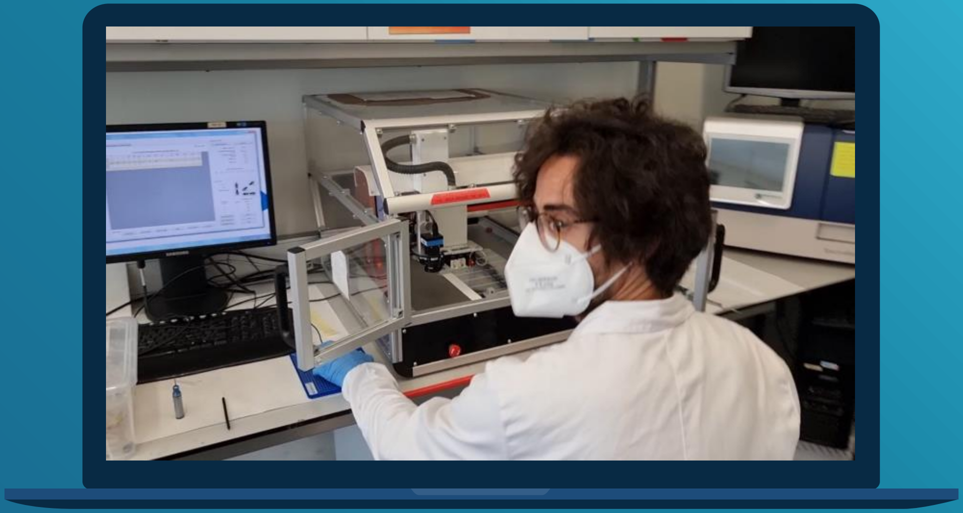
# OUR RESEARCH

## Nanomaterials

Graphene and 2D materials,
Metal nanoparticles,
quantum dots

## Paper-based

Lateral flow assay,
hybrid
electrochemical/LFA,
optical redout



## Printing technologies

Inkjet printing, screen printing, graphene transfer electrodes,
FET-based biosensors,
electrochemical readout

## Fully integrated PoC devices

Smartphone based,
wearables,
wireless readout

# OUR CHALLENGES


❶ Can we make diagnostic devices completely non-invasive?

❷ Can we ensure continuous / real time (bio)monitoring?

❸ Which partners & expertise's we need to develop devices for real applications that generate (bio)data?

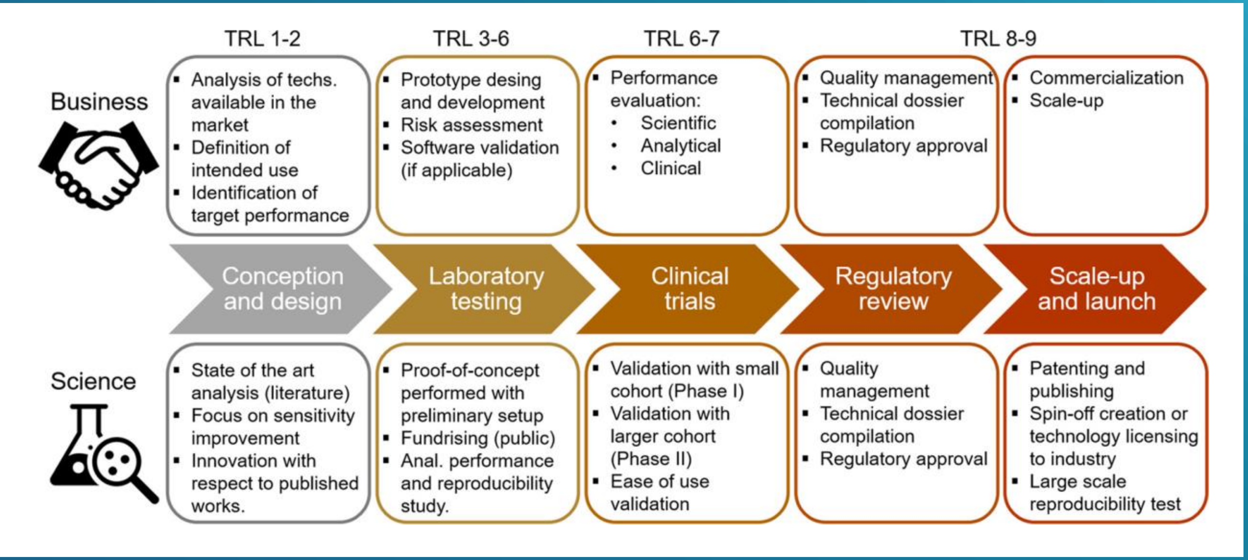
❹ How to make cheap/low cost devices that can be disposable?


❺ How to correlate (sensor)data to get insights about the body?

# How COVID19 changed the scenario

The development of new diagnostic devices is a process characterized by several bottlenecks. Most of them related to sub-optimal interactions between the actors involved, i.e.:

- **The scientists**
- **The clinics**
- **The regulatory bodies**
- **The companies**




**What can we do to change the status quo?**

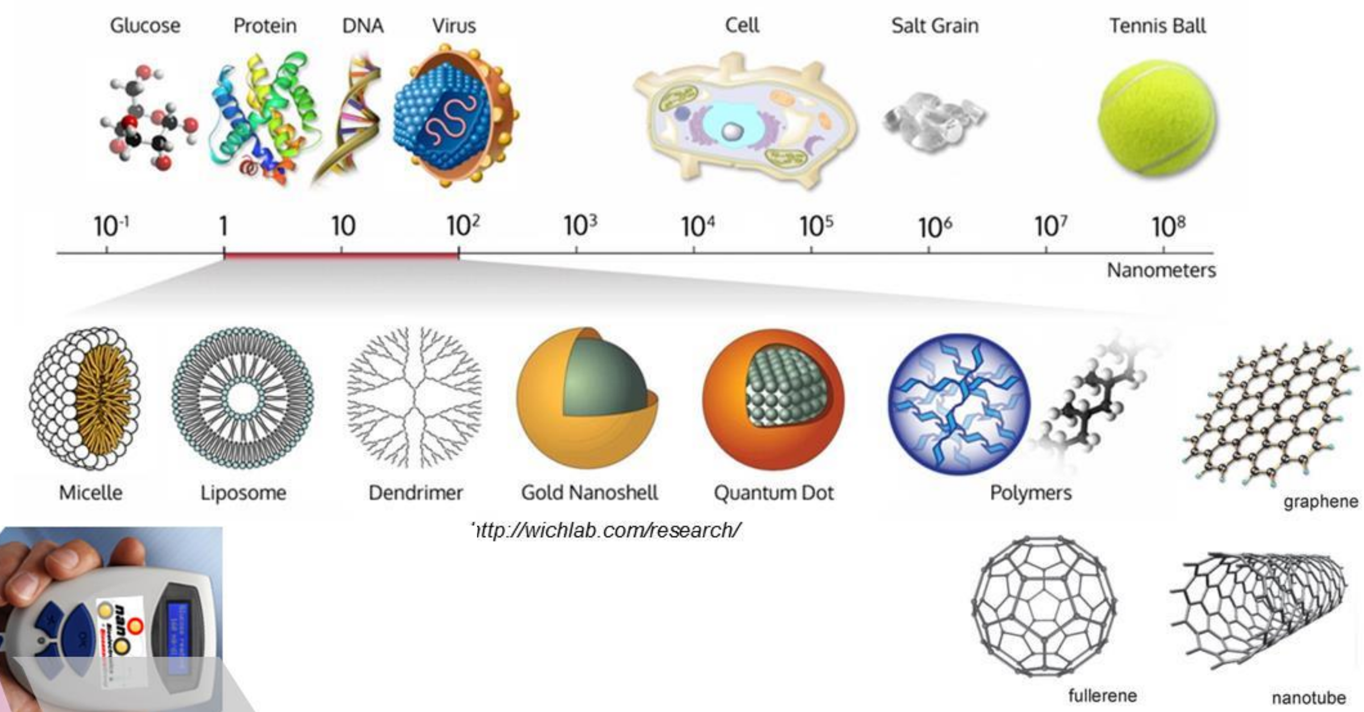
Rosati, Merkoçi et al. 2021 Nanodiagnostics to Face SARS-CoV-2 and Future Pandemics: From an Idea to the Market and Beyond
ACS Nano 2021, 15, 11, 17137–17149

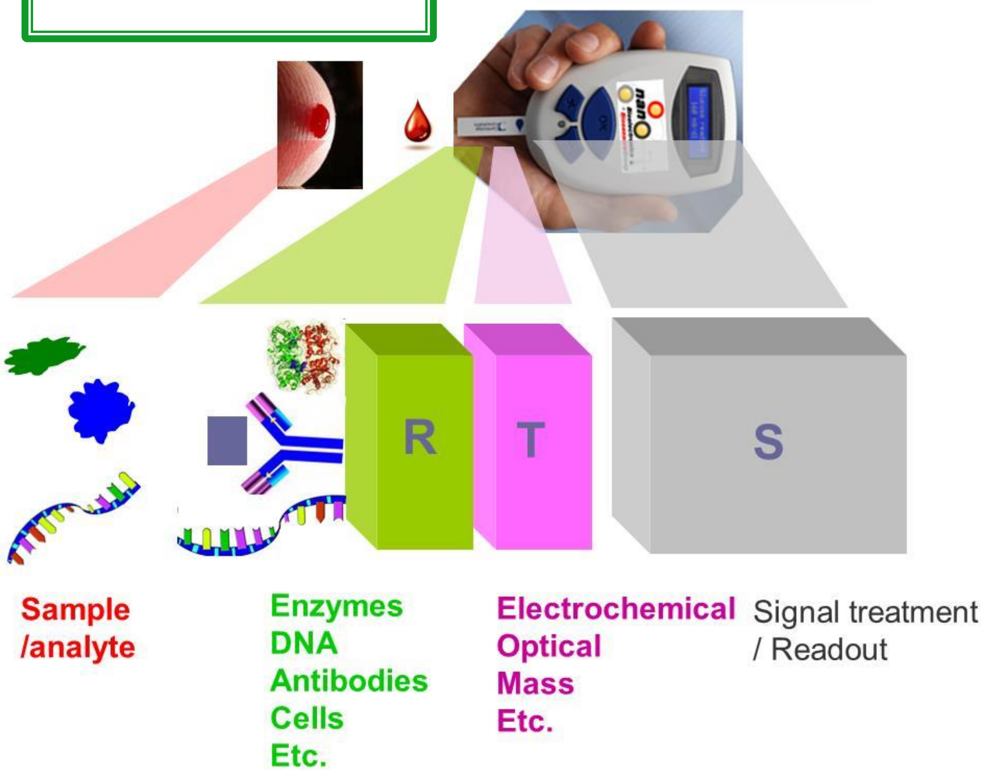
# PLENTY OF POSSIBILITIES FOR NANOBIOSENSORS

## ASSURED (WHO)

Affordable
Sensitive
Specific
User Friendly

Robust
Equipment free
Deliverable




## VARIETY OF CONFIGURATIONS

- Wearable sensors
- Smart/packaging and control of food
- Implanted devices
- In-vivo formats
- etc

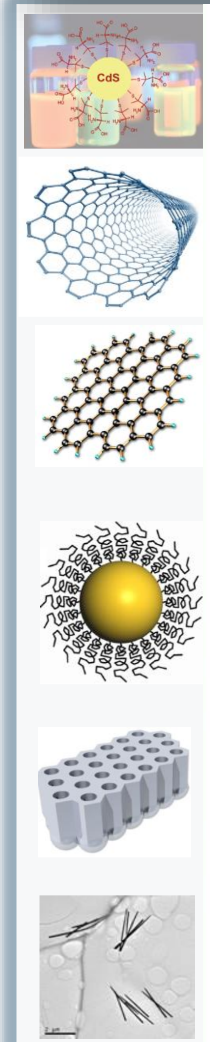
# NANOBIOELECTRONICS AND BIOSENSORS

Bioelectronics & Biosensors Group

Institut Català de Nanociència i Nanotecnologia

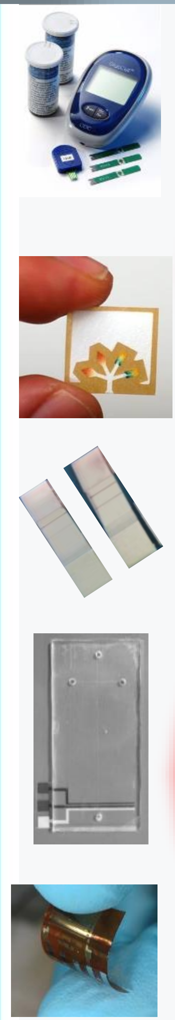
EXCELENCIA SEVERO OCHOA

## Objectives




NANOMATERIALS

DEVICES



Environmental monitoring

Diagnostics

Other industrial applications

Food quality

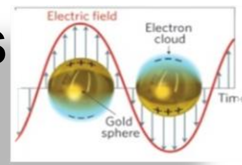
Safety / security

**NANOBIOELECTRONICS & BIOSENSORS**'s research aims to integrate nanotechnology methods, tools and materials into **low cost, user friendly and efficient (bio)sensors** with interest for diagnostics , safety /security and other fields

# OUR MOTIVATION

## To design new simple nanobiosensors and improve existing ones

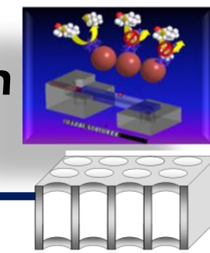
### Nanoparticles




New electro /optical labels

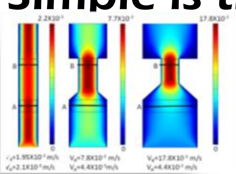
### LOCs / Nanochannels

Preconcentration, filtering, automation

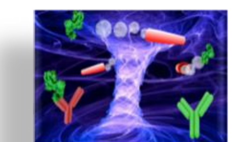



### Paper-based sensors

Simple is the best

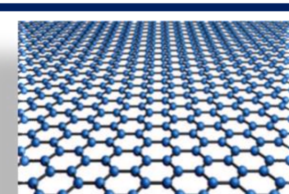


### Nanomotors



Catch even single analyte, bring it to sensing surface

### Graphene

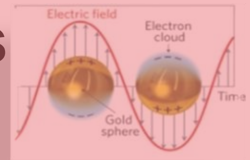


New (bio)sensing opportunities (?)

# OUR MOTIVATION

## To design new simple nanobiosensors and improve existing ones

### Nanoparticles




New electro /optical labels

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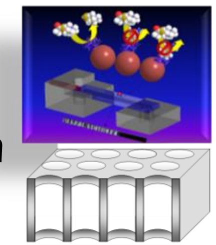

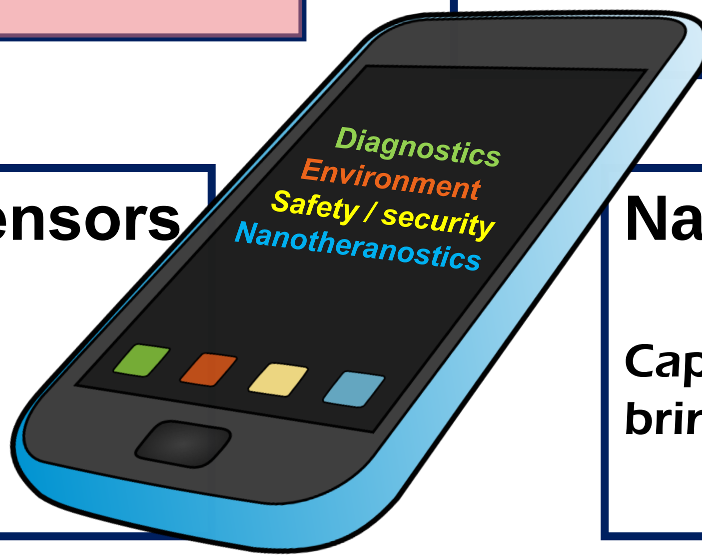


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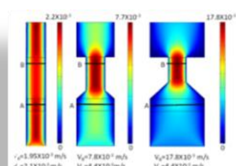
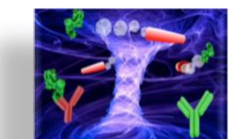
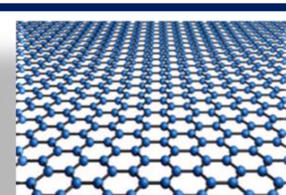


### Nanomotors



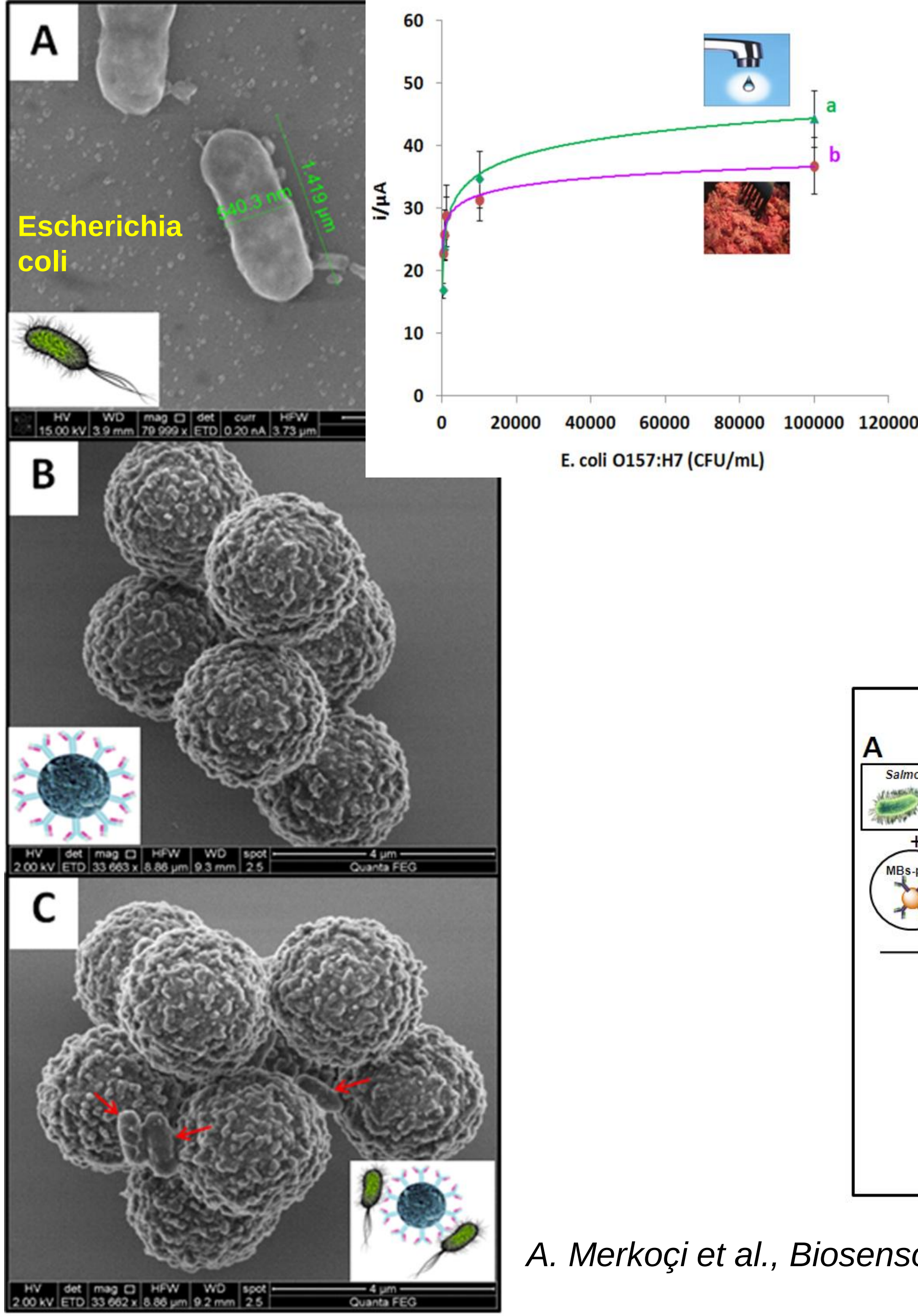
Capture even single analyte, bring it to sensing surface

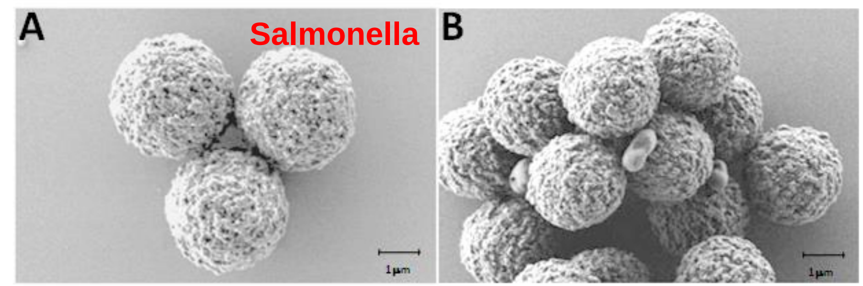
### Graphene

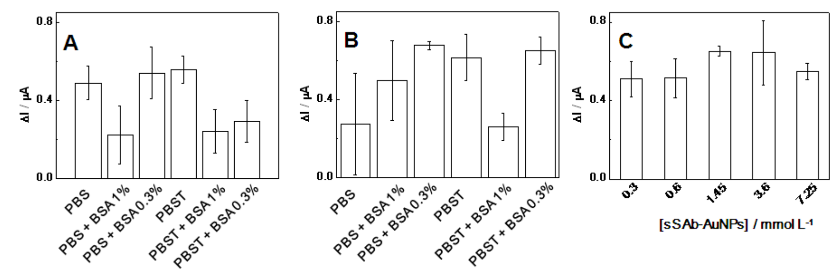


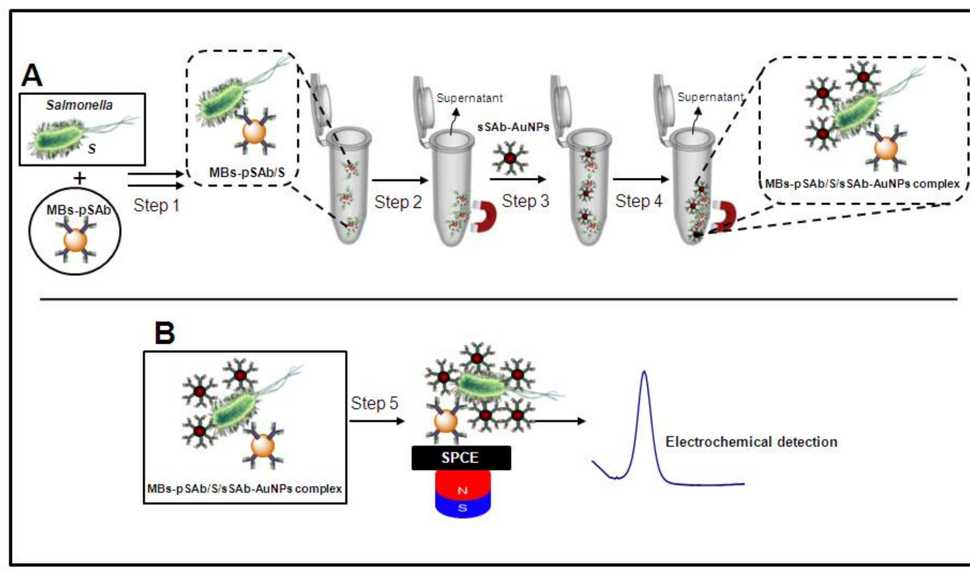
New (bio)sensing opportunities (?)

# Au-NP-based detection of bacteria



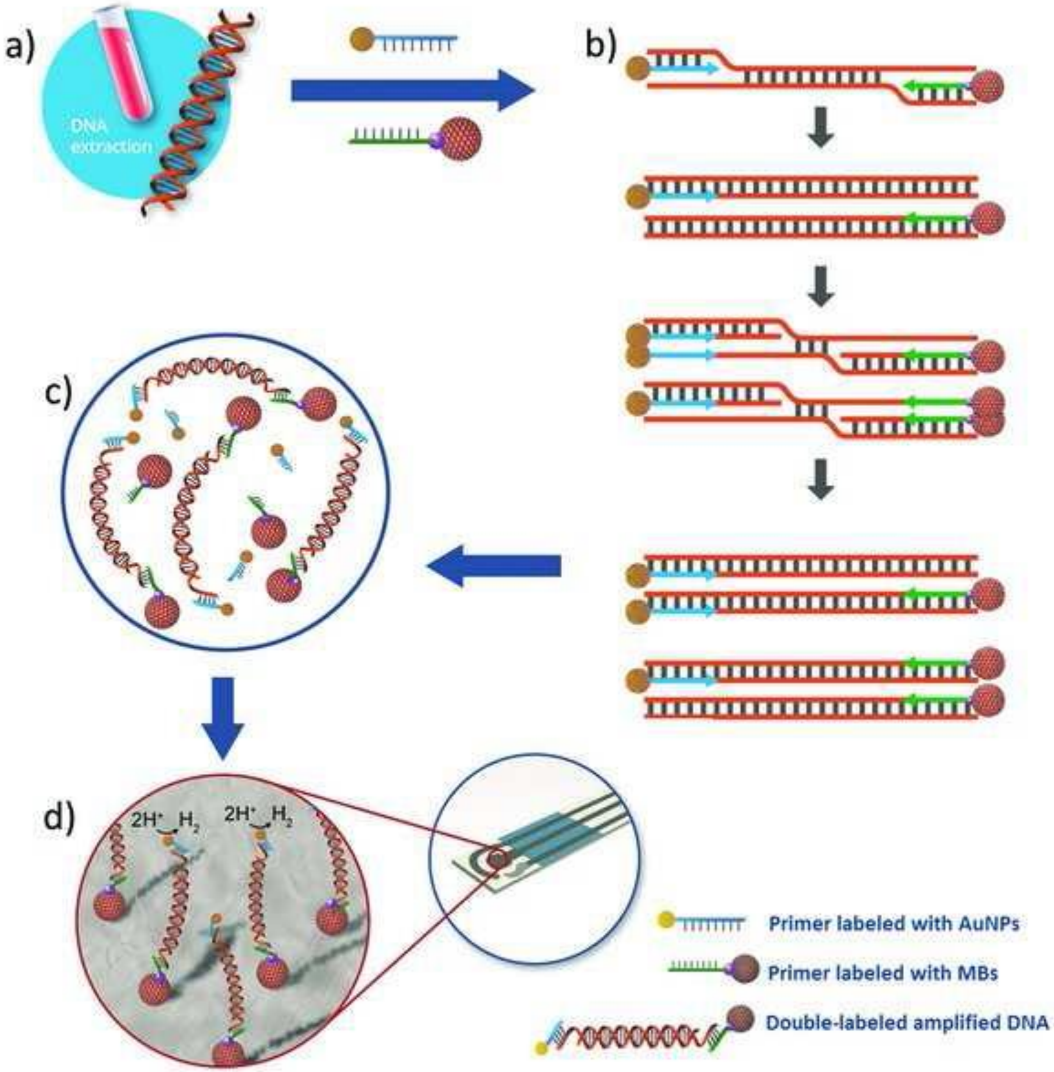



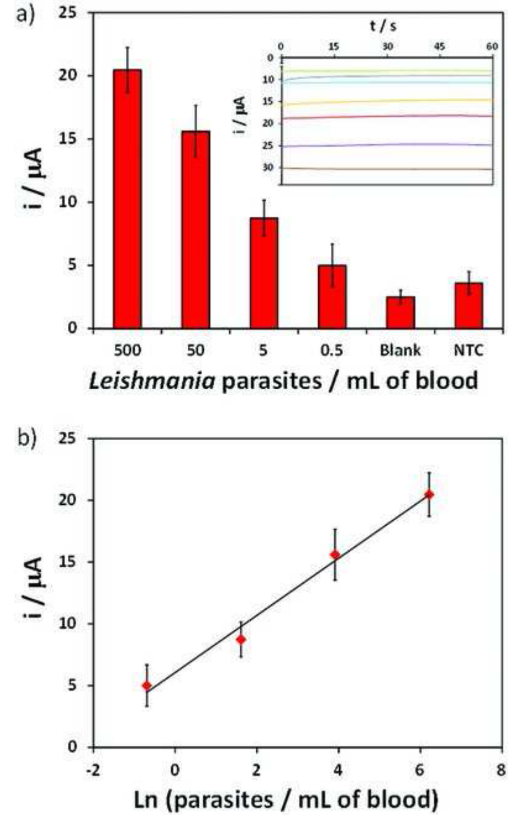



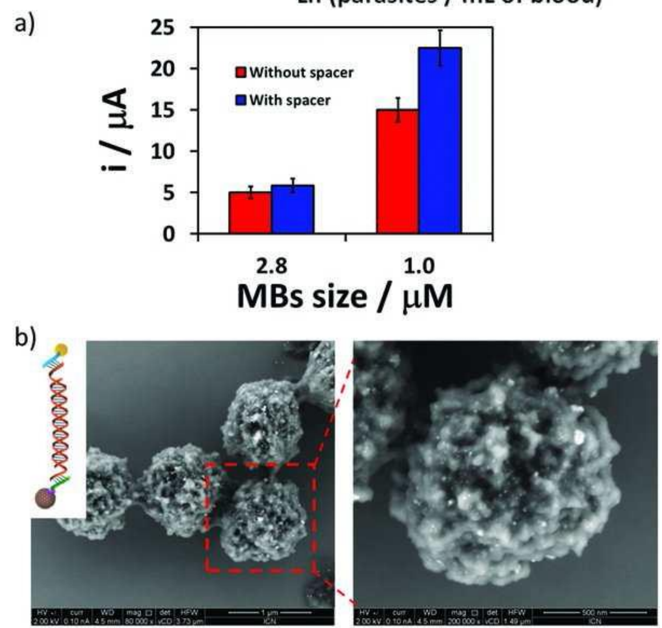




*A. Merkoçi et al., Biosensors and Bioelectronics, 2013, 40, 121–126*

# Magnetic Bead/Gold Nanoparticle Double-Labeled Primers for Electrochemical Detection of Isothermal Amplified *Leishmania* DNA



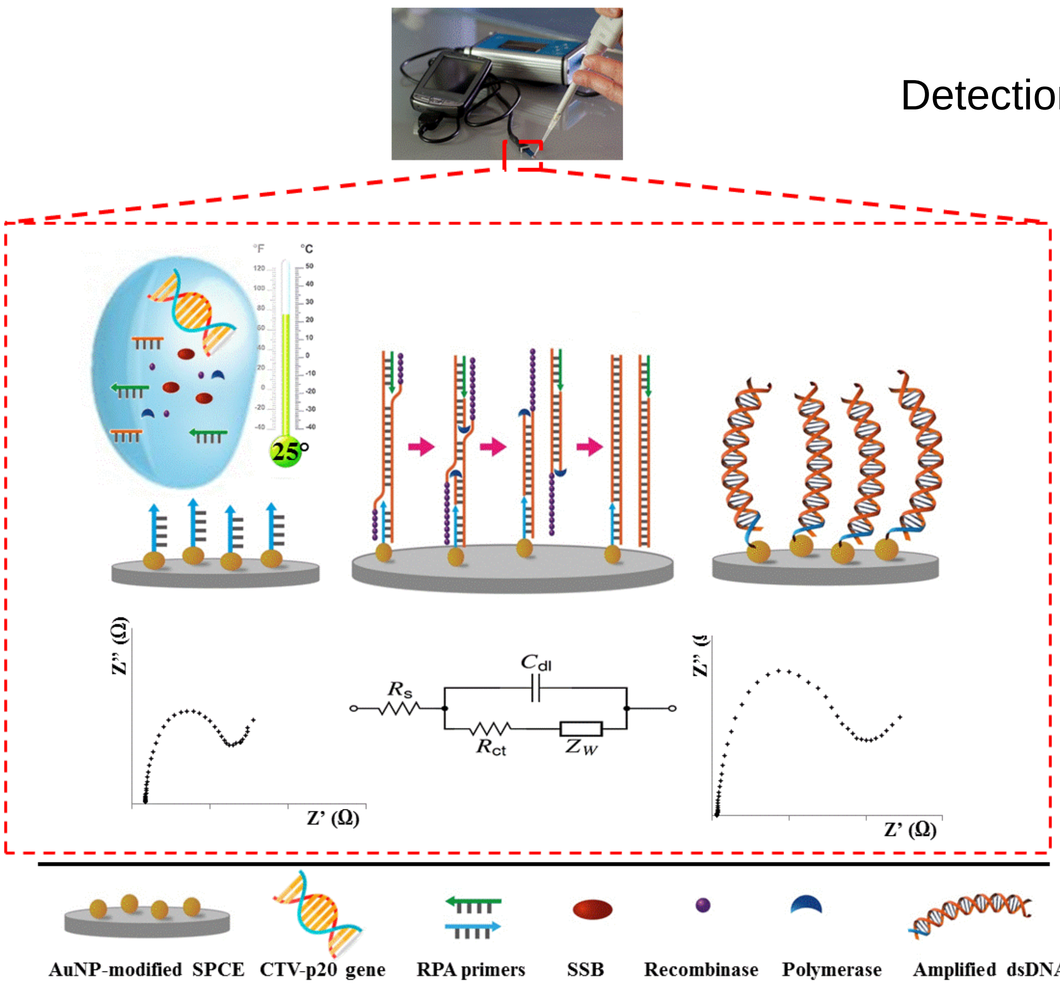

Escosura, Pires, Merkoçi et al., Small 2016, 12, 205–213

analytical chemistry
Article
Cite This: Anal. Chem. 2019, 91, 4790–4796
pubs.acs.org/ac

# In Situ Plant Virus Nucleic Acid Isothermal Amplification Detection on Gold Nanoparticle-Modified Electrodes

Mohga Khater,[†,‡] Alfredo de la Escosura-Muñiz,[†] Laura Altet,[§] and Arben Merkoçi*[,†,∥]

Detection of citrus tristeza virus (CTV)




The in situ-amplified CTV target was investigated by EIS in a $Fe(CN_6)^{4-}$ /$Fe(CN_6)^{3-}$ red–ox system, being able to quantitatively detect 1000 fg $\mu L^{-1}$ of nucleic acid. High selectivity against nonspecific gene sequences characteristic of potential interfering species such as *Citrus psorosis* virus (CPsV) and *Citrus caxicia* viroid (CCaV) was demonstrated. Good reproducibility (RSD of 8%) and long-term stability (up to 3 weeks)

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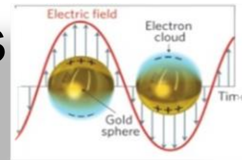


New electro /optical labels

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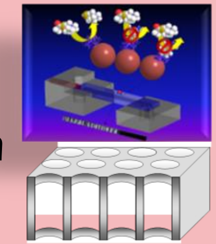
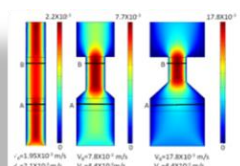



### Paper-based sensors

Simple is the best



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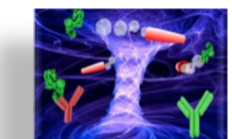
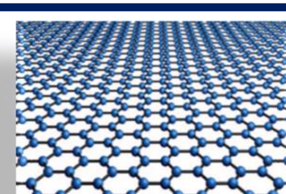


Capture even single analyte, bring it to sensing surface

### Graphene

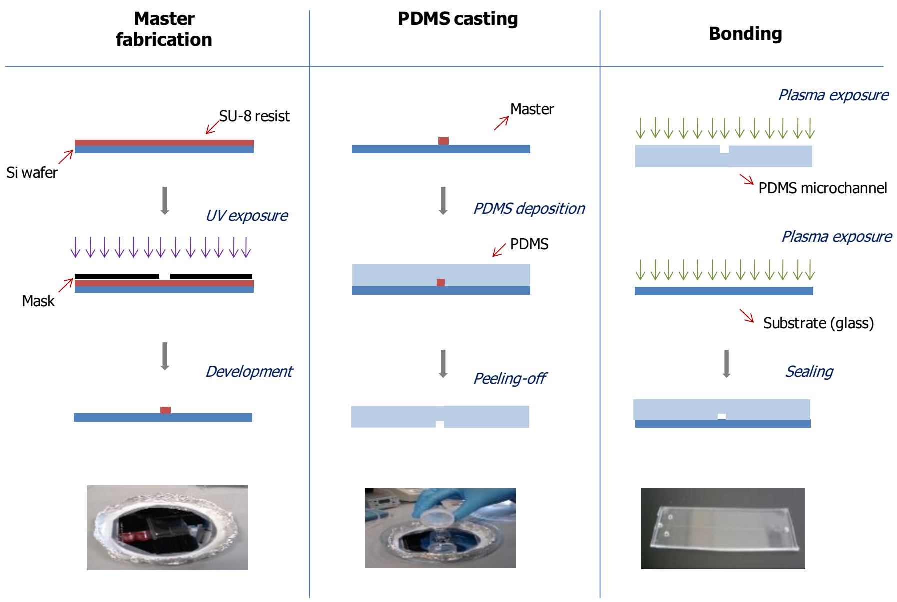


New (bio)sensing opportunities (?)

# Chip fabrication and electrode integration

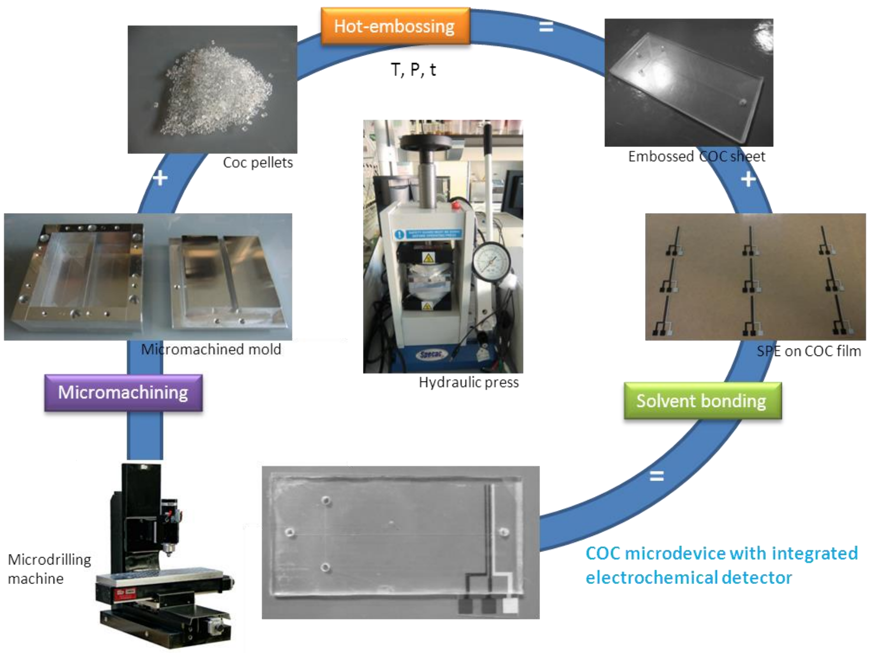
## PDMS Chips

softlithography process

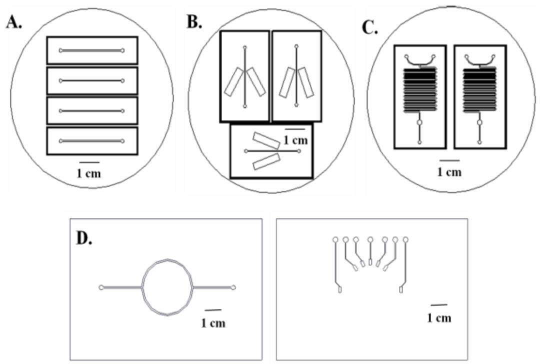



## COC Chips (Collaboration. J.L.Viovy)

Simple and low cost fabrication techniques

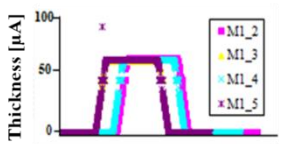


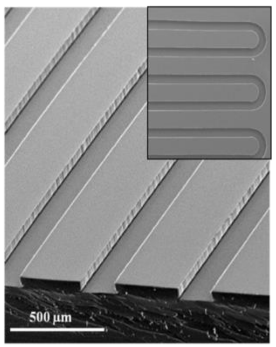
# Chip fabrication and electrode integration



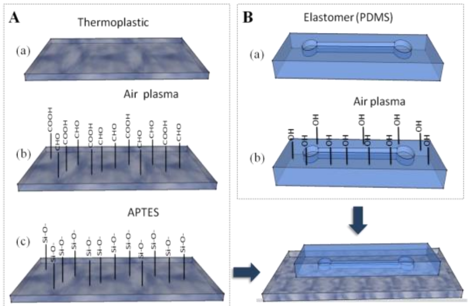

Designs of different microfluidic platforms

| | | | | |
|---|---|---|---|---|
| M1 | 63.12 µm | | | |
| M2 | 71.37 µm | | | |
| M3 | 64.87 µm | | Average | 54.89 µm |
| M4 | 61.47 µm | | Standard Deviation | 3.82 µm |
| M5 | 61.99 µm | | | |
| M6 | 57.49 µm | | | |

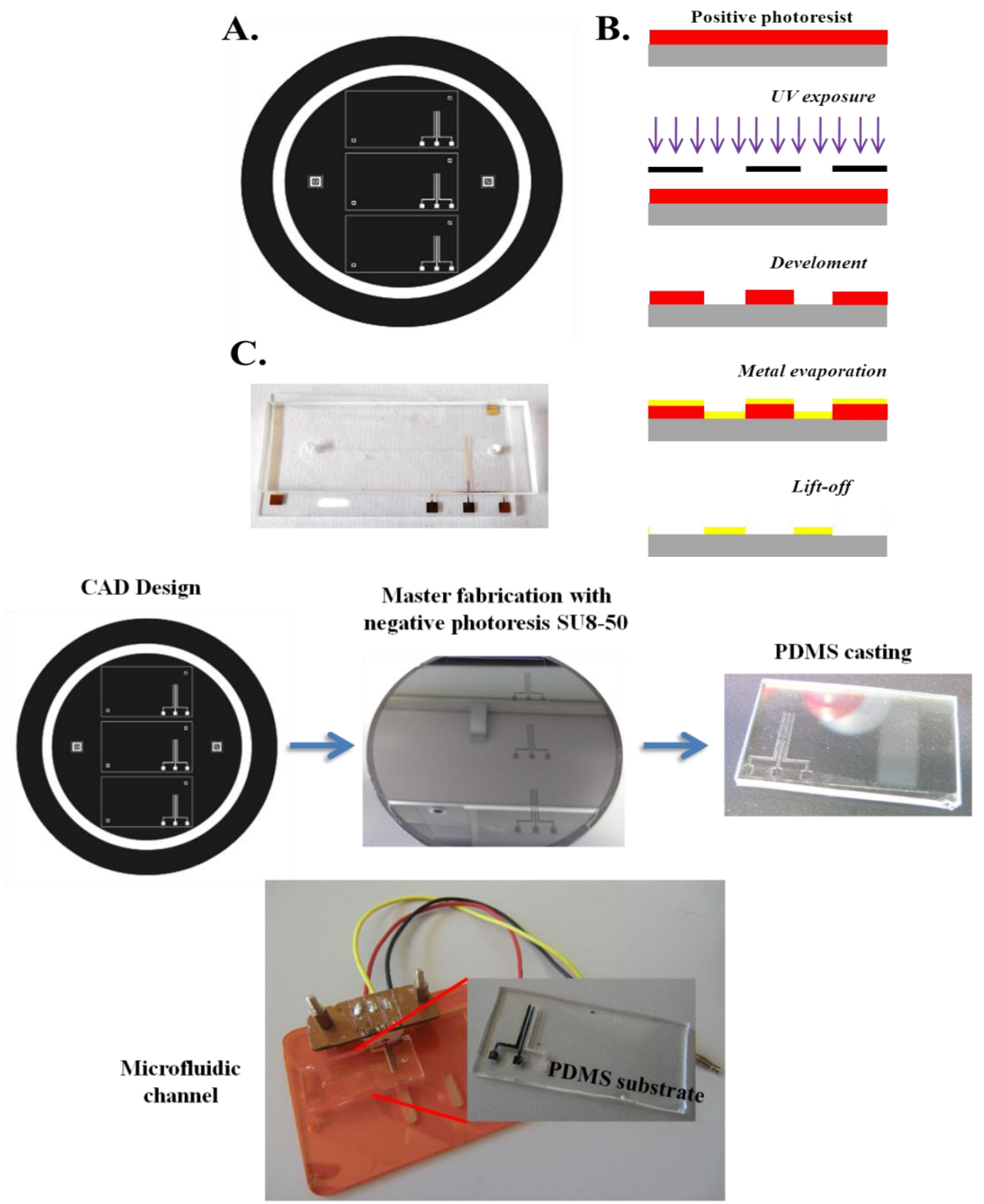



SEM images of the PDMS channel



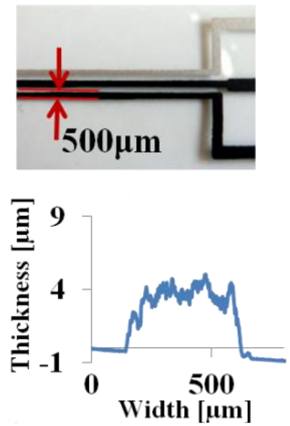

Bonding thermoplastics and PDMS

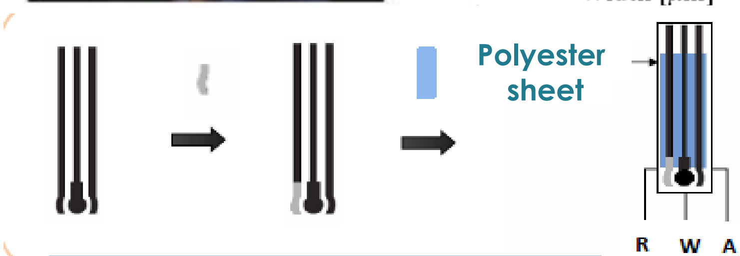



Electrode integration

# Electrode fabrication

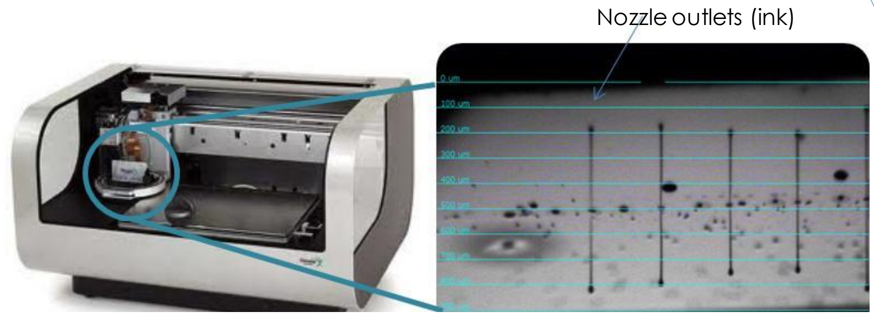
## Screen printing

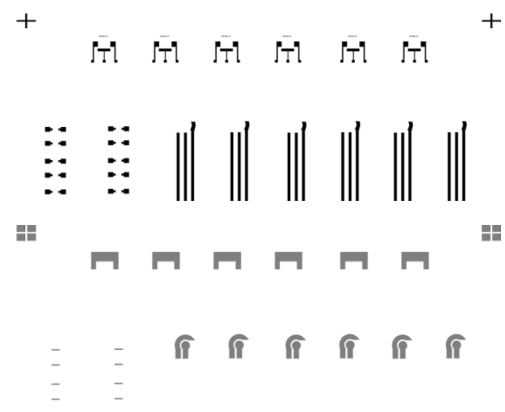


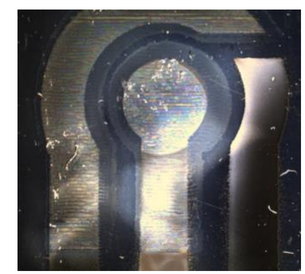



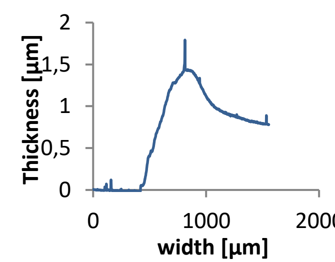

-High viscosity inks
-Electrodes width up to 20 µm (if the surface is pretreated)
-Thickness up to ~ 4 µm

## Inkjet printing








-Low viscosity inks
-Electrode width up to 20 µm without surface treatment
-Thicknesses up to 1µm

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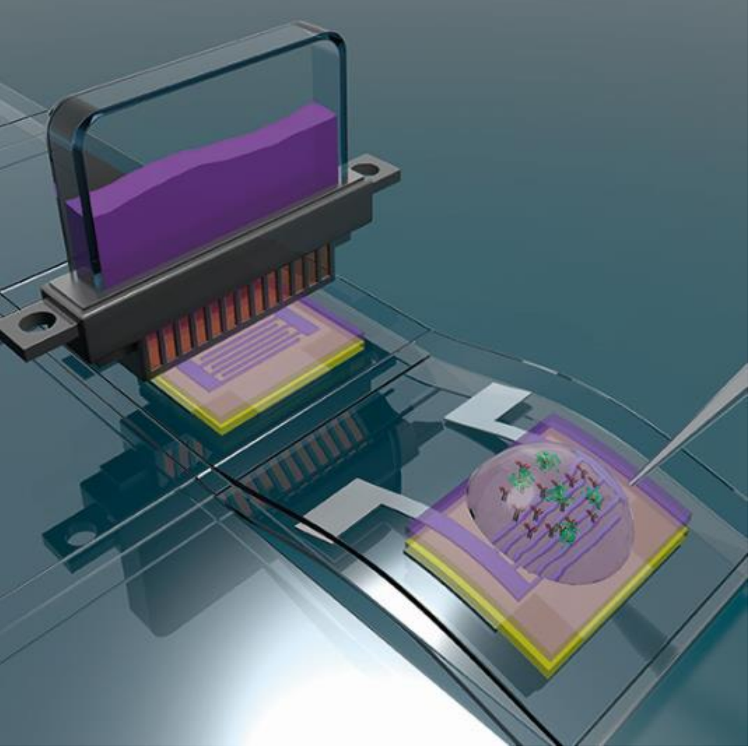
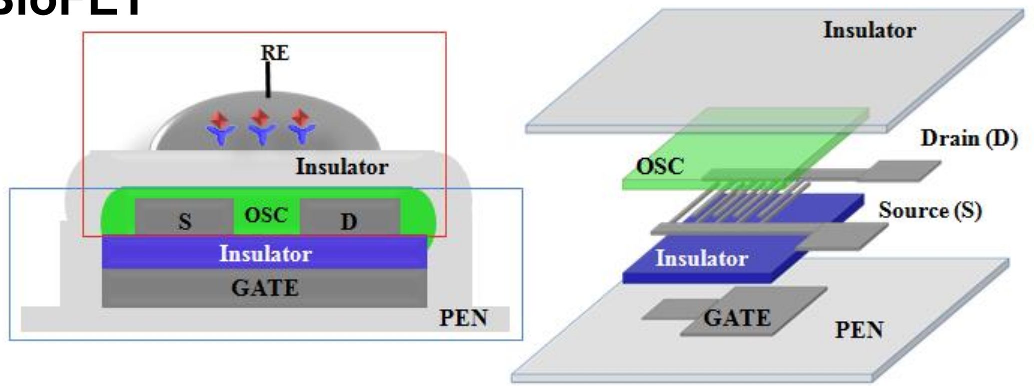
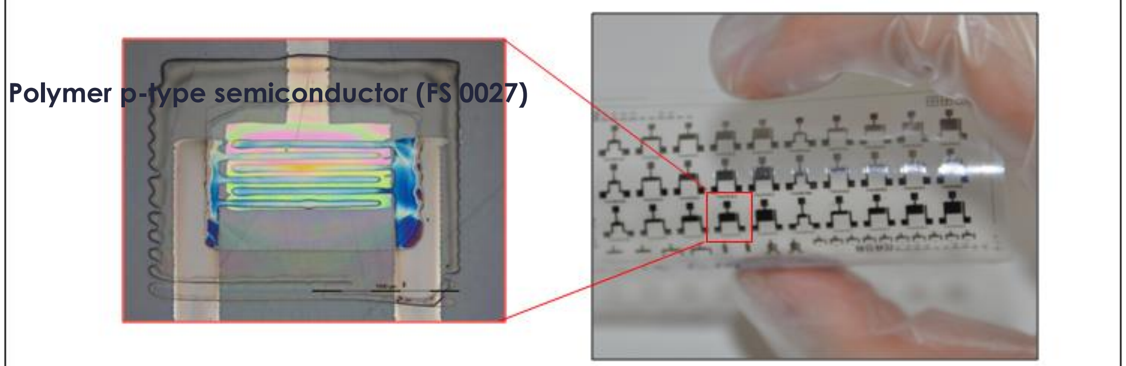


## Inkjet-printed sensing platforms using nanomaterial-based inks and other materials

No need for clean room at all!

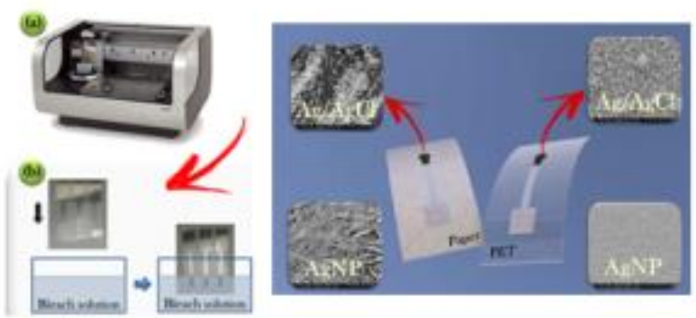
**BioFET**




Merkoçi et al.
Advanced Functional Materials, 20, 6291–6302. 2014

**AgNP-ink jet printed reference electrode in paper or plastic**

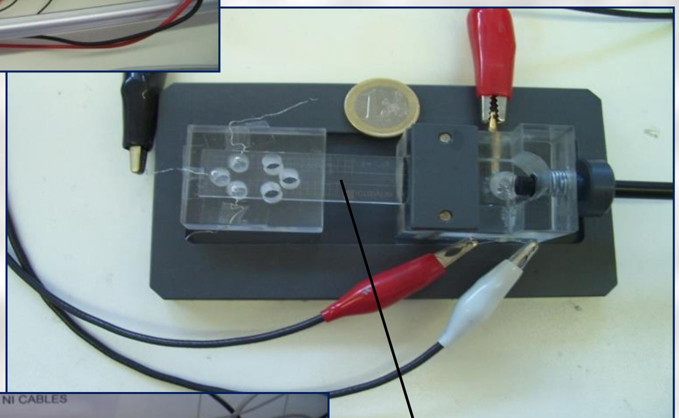



Merkoçi et al. Anal. Chem. 86, 10531–10534. 2014

# CNT / LOC and capillary electrophoresis-based analysis

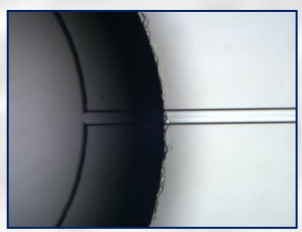
**Carbon based detectors for out-channel LOC detections**
**Rigid Graphite-Epoxy Composite Detector / CNT modified electrodes**
**Detection of nitrocompounds, phenols etc.**

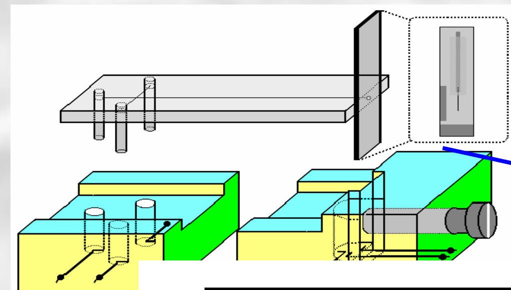
High voltage

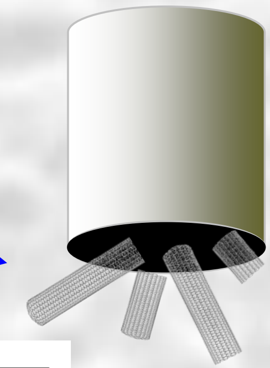


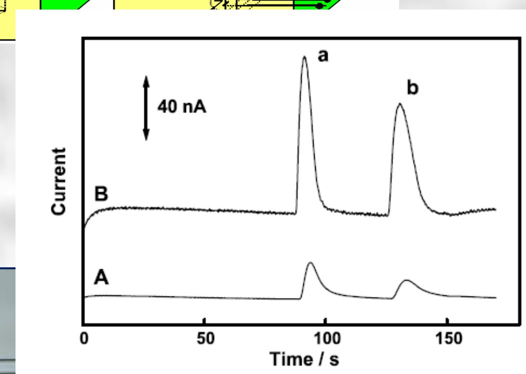

Measuring instrument

Chip (Micralyne; MC-BF4-001)







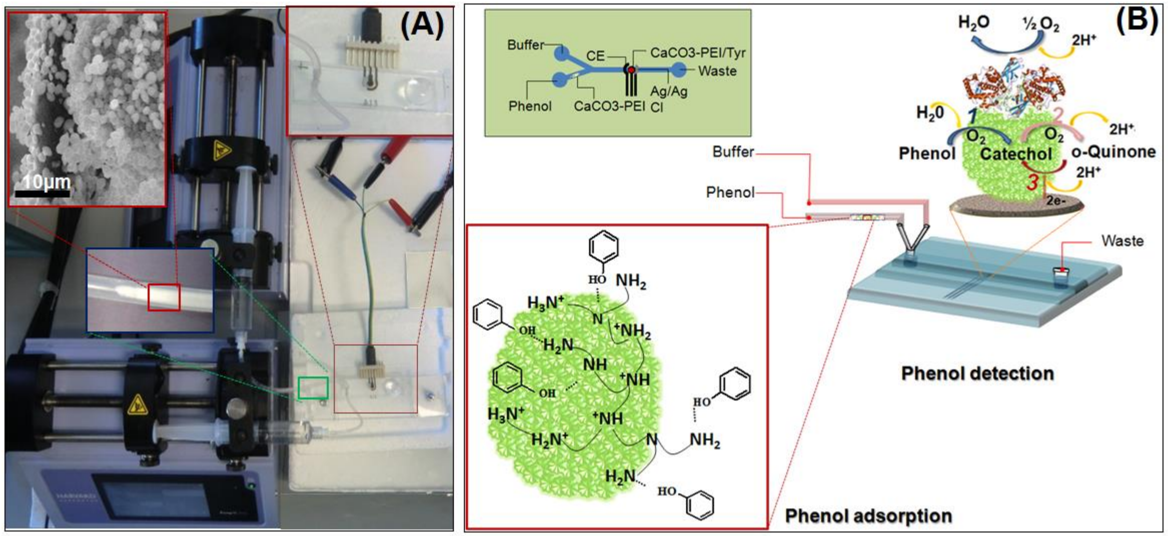



p-aminophenol (a)
o-aminophenol (b)

**Microchimica Acta, 152, 261–265, 2006**
**Electrophoresis 27, 5068–5072 , 2006**
**Electroanalysis 18, 207 – 210, 2006**
**Electrophoresis 28, 1274–1280 , 2007**

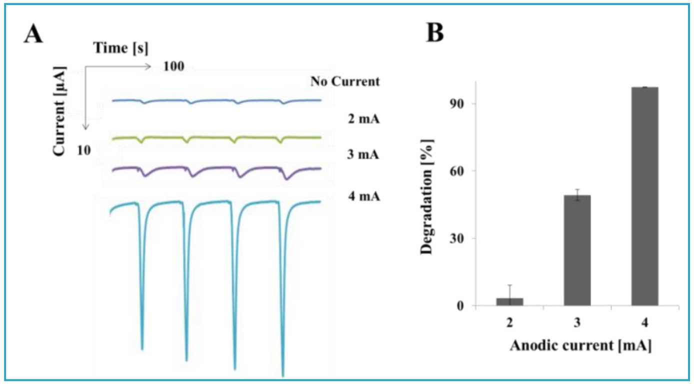
# BIOSENSOREMOVAL NanoTechnologies

## Phenol detection and removal

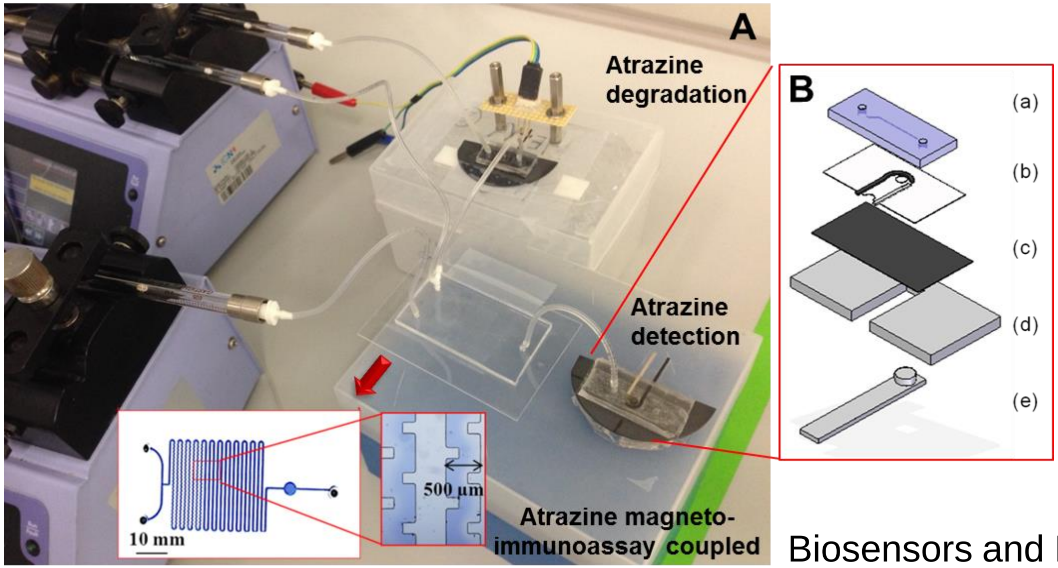


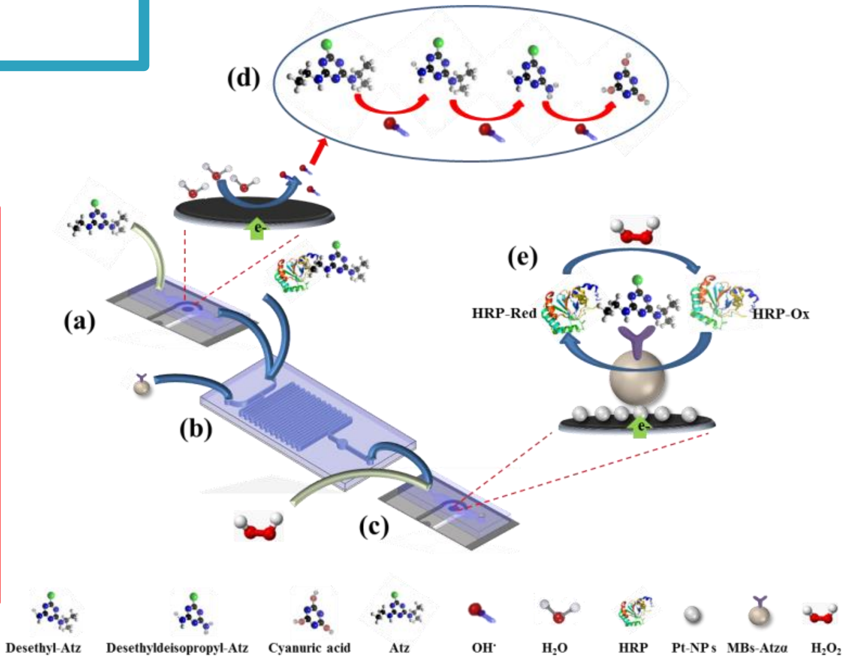

Nanostructured vaterite ($CaCO_3$) / Poly(ethyleneimine) (PEI)

Biosensors and Bioelectronics, 2015, 67, 670–676.



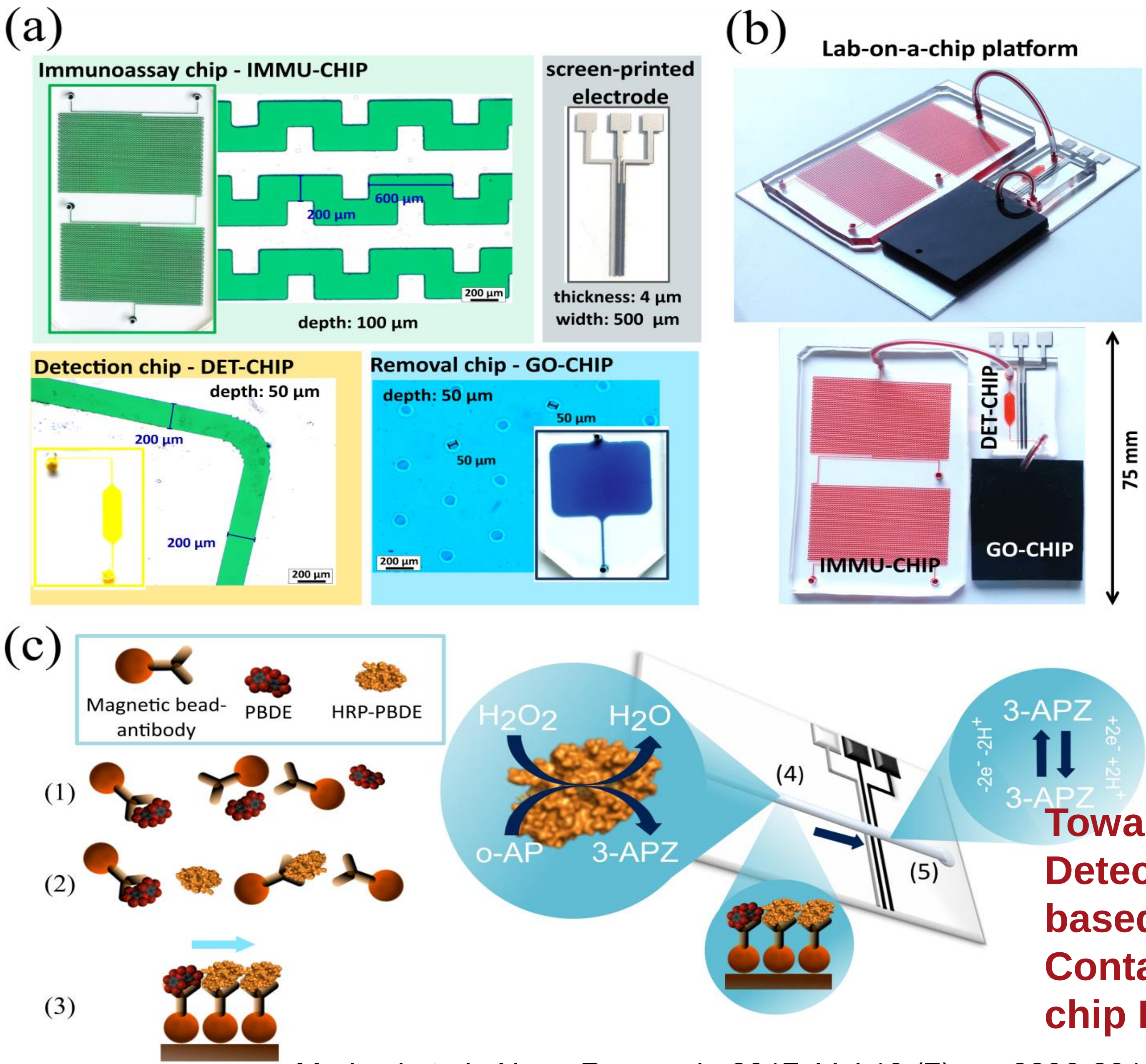

## Pesticide detection and removal




Biosensors and Bioelectronics, 75, 2016, 365-374

# BIOSENSOREMOVAL NanoTechnologies

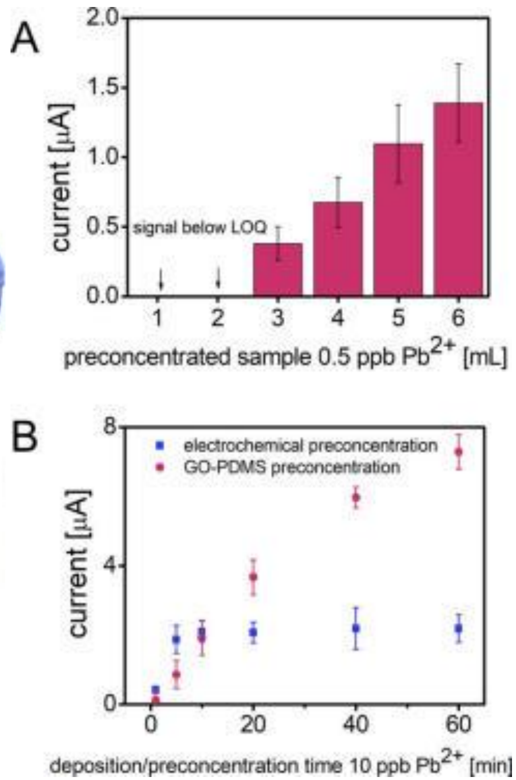


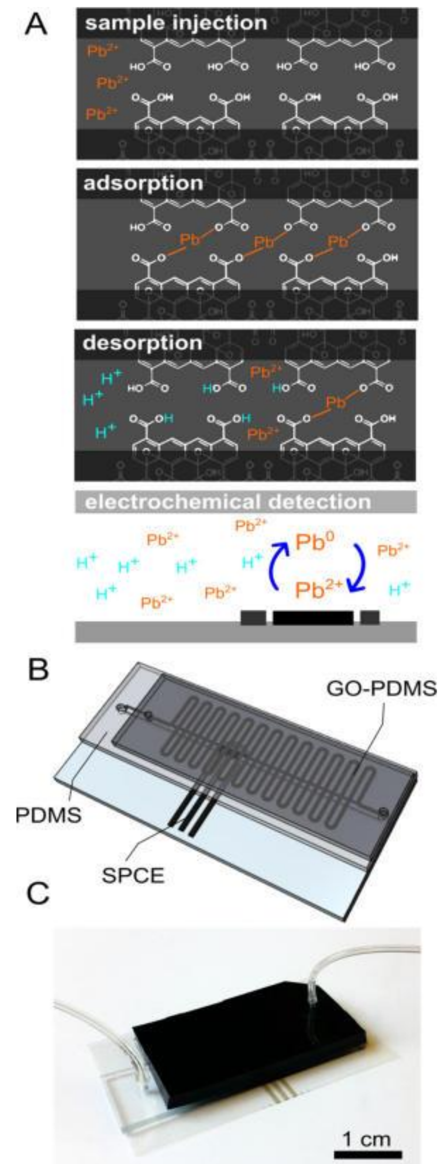

Polybrominated diphenyl ethers (PBDEs), a class of halogenated compounds, similar to polychlorinated diphenyls (PCBs) and commonly used as flame retardants.

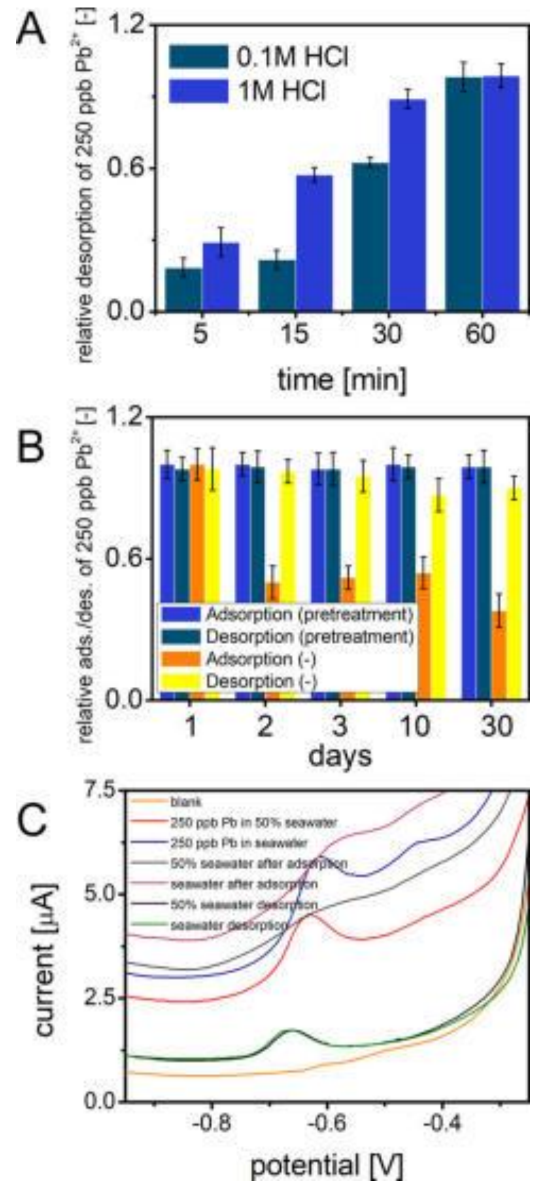
**Towards Integrated Detection and Graphene-based Removal of Contaminants in Lab-on-a-chip Platform**

Merkoçi et al., Nano Research, 2017, Vol 10 (7), pp 2296-2310

# Graphene Oxide−Poly(dimethylsiloxane)-Based Lab-on-a-Chip Platform for Heavy-Metals Preconcentration and Electrochemical Detection



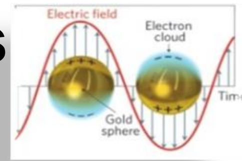




Merkoçi et al., ACS Appl. Mater. Interfaces 2017, 9, 44766−44775

# OUR MOTIVATION

## To design new simple nanobiosensors and improve existing ones

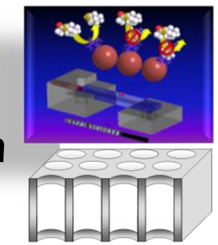
### Nanoparticles




New electro /optical labels

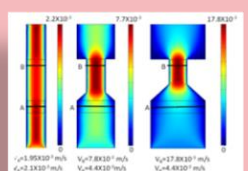
### LOCs / Nanochannels

Preconcentration, filtering, automation

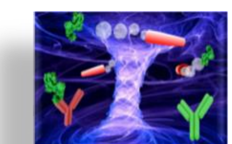



### Paper-based sensors

Simple is the best

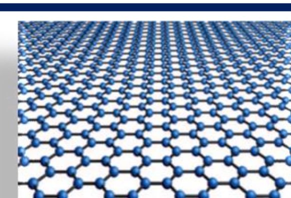


### Nanomotors



Capture even single analyte, bring it to sensing surface

### Graphene



New (bio)sensing opportunities (?)

# Paper-based biosensors

## *Why to move biosensors to paper format?*

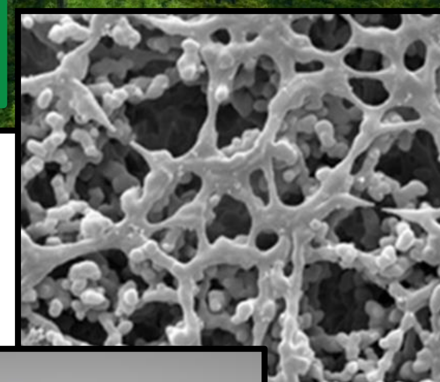
Paper…

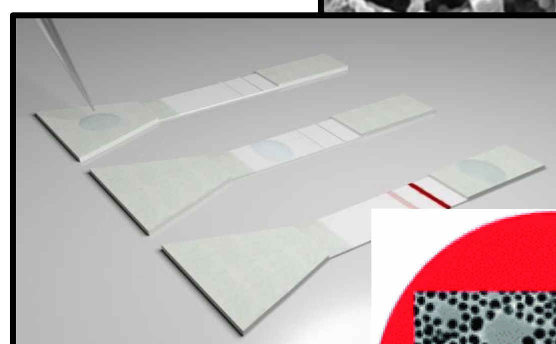
…is formed by cellulose.

- Low-cost and aboundant material.
- Easy to manufacture
- Recyclable & biosustainable.


…has a porous matrix.

- Several reactions can be carried out within it.
- The porosity can be modified.
- Capillary forces creates autonomous microfluidics making “zero energy” device!



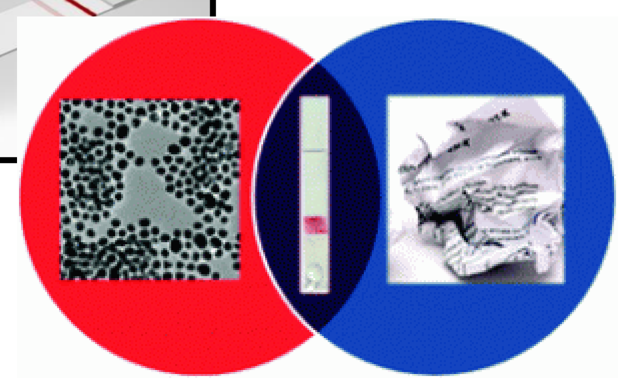


…is easily tunable.

- Its microfluidics by porosity.
- Its architecture.

…is compatible with nanomaterials

- Printing of nanomaterials
- Easy nanoplasmonics



Claudio Parolo, Arben Merkoçi. *Chem. Soc. Rev., 2013, 42, 450 - 457*

# Paper based biosensors

## Simple is the best

- **Dipsticks**

- **Lateral Flow strips**

- **Microfluidic devices**


https://www.microessentiallab.com/

http://www.cliawaived.com


www.dfa.org

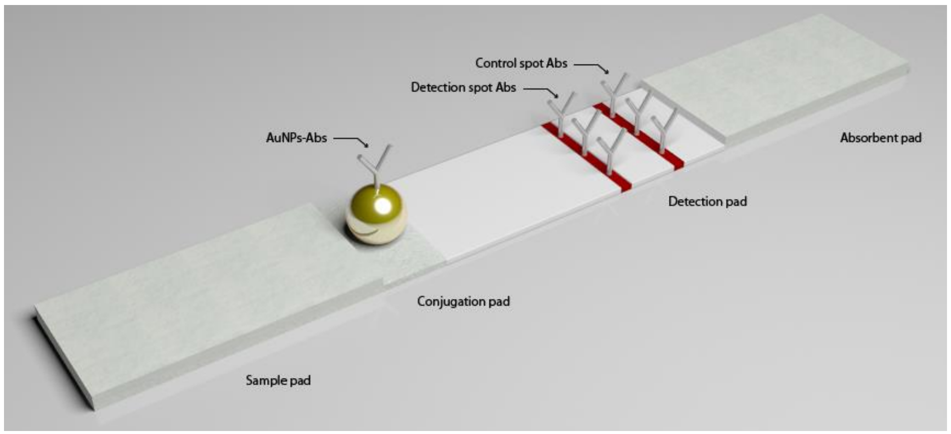
| Type of paper-based biosensor | Possible detection methods | Advantages | Disadvantages |
|---|---|---|---|
| Dipstick | • Optical | • Easy design<br>• Fast optimization | • Just one step<br>• Only optical detection<br>• Mostly no quantification |
| LFA | • Optical<br>• Electrochemical | • Versatile<br>• Flow<br>• Electrochemical detection<br>• Possible quantification | • Long optimization times<br>• Long fabrication<br>• Sample volume (around 100 μL) |
| μPAD | • Optical<br>• Electrochemical<br>• Chemiluminescence<br>• MEMS | • Versatile<br>• Flow<br>• Different detection methods<br>• Quantification<br>• Small sample volume (less than 10 μL)<br>• Massive production | • Long optimization times |

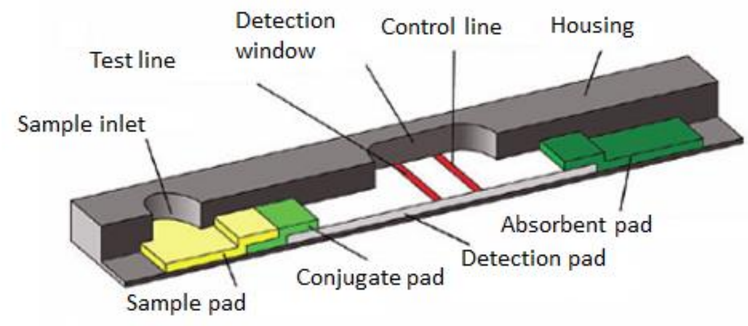
*Parolo, Merkoçi Chem. Soc. Rev., 2013, 42, 450*

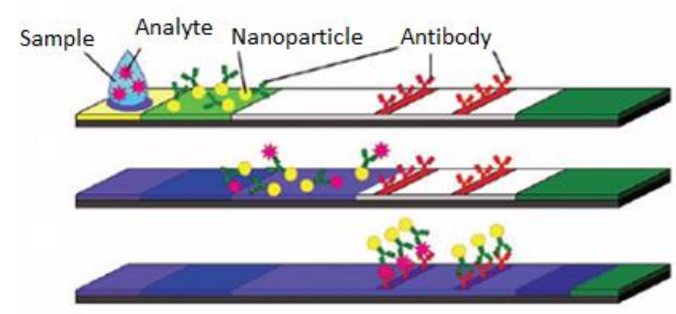
# NP-based lateral flow immunoassay

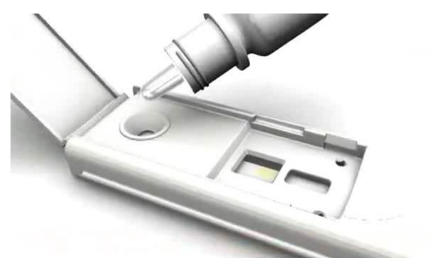
ICN2 Institut Català de Nanociència i Nanotecnologia — EXCELENCIA SEVERO OCHOA

More antigen → More AuNPs → More color intensity



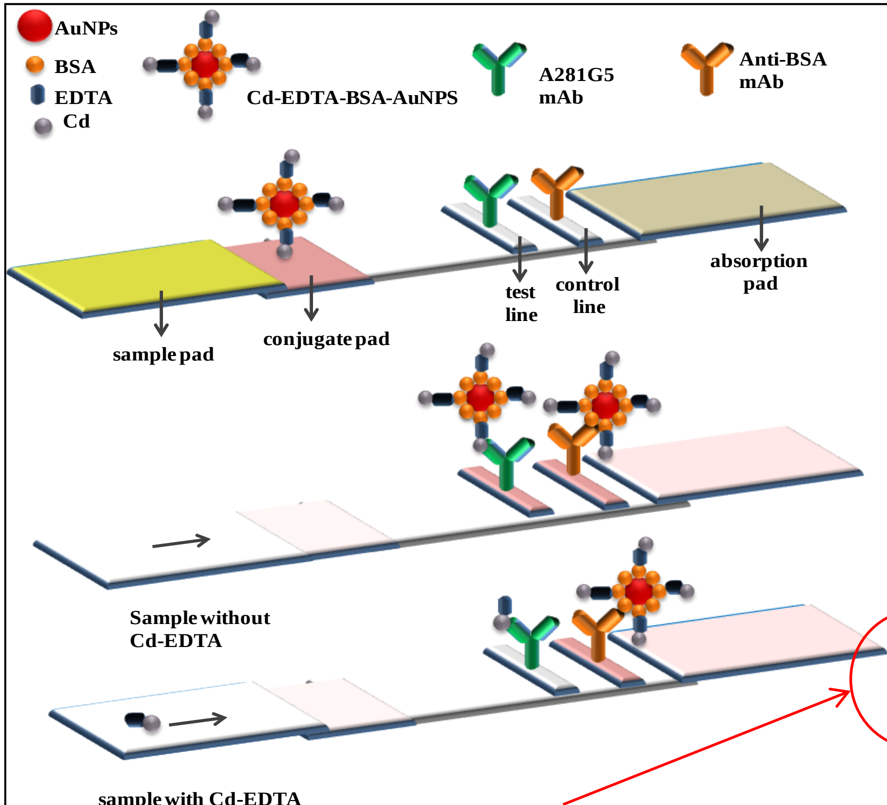



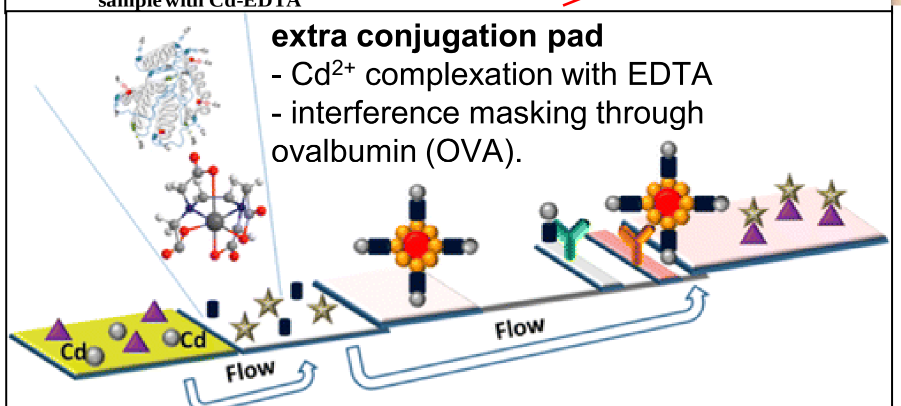
Analyte concentration

http://www.bbiinternational.com/

Chem. Soc. Rev. (2010) 39, 1153

# LFIA (Cadmium determination in drinking water)

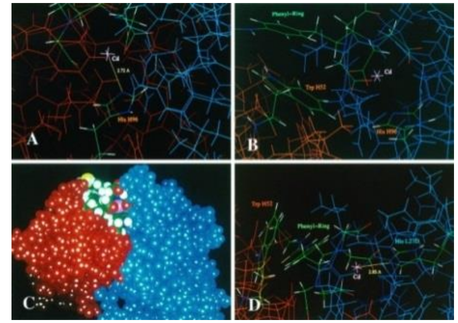


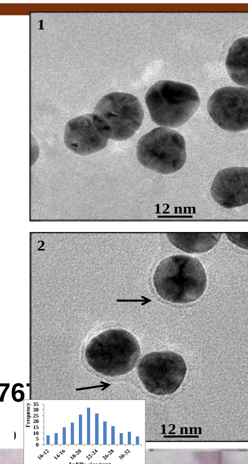

**extra conjugation pad**

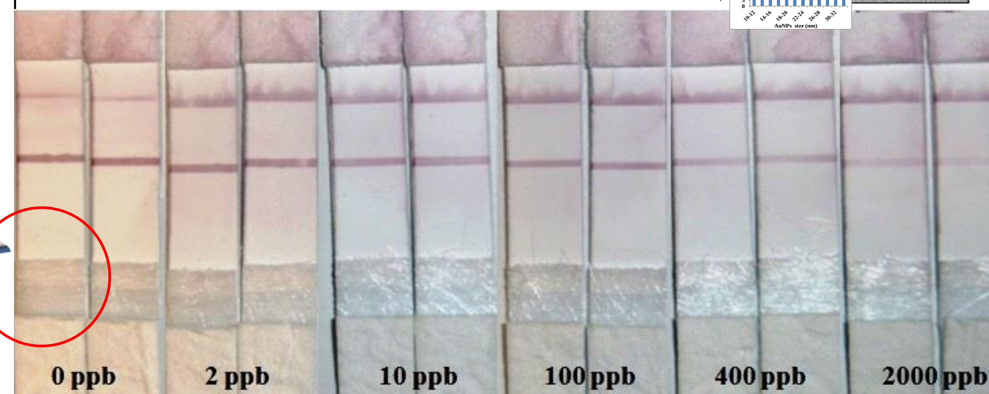
- $Cd^{2+}$ complexation with EDTA
- interference masking through ovalbumin (OVA).

Anal. Chem., 85, 3532–3538 (2013)

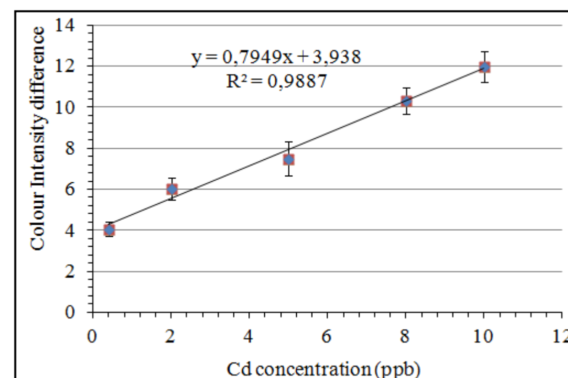



Blake D A et al. J. Biol. Chem. 1996;271:276



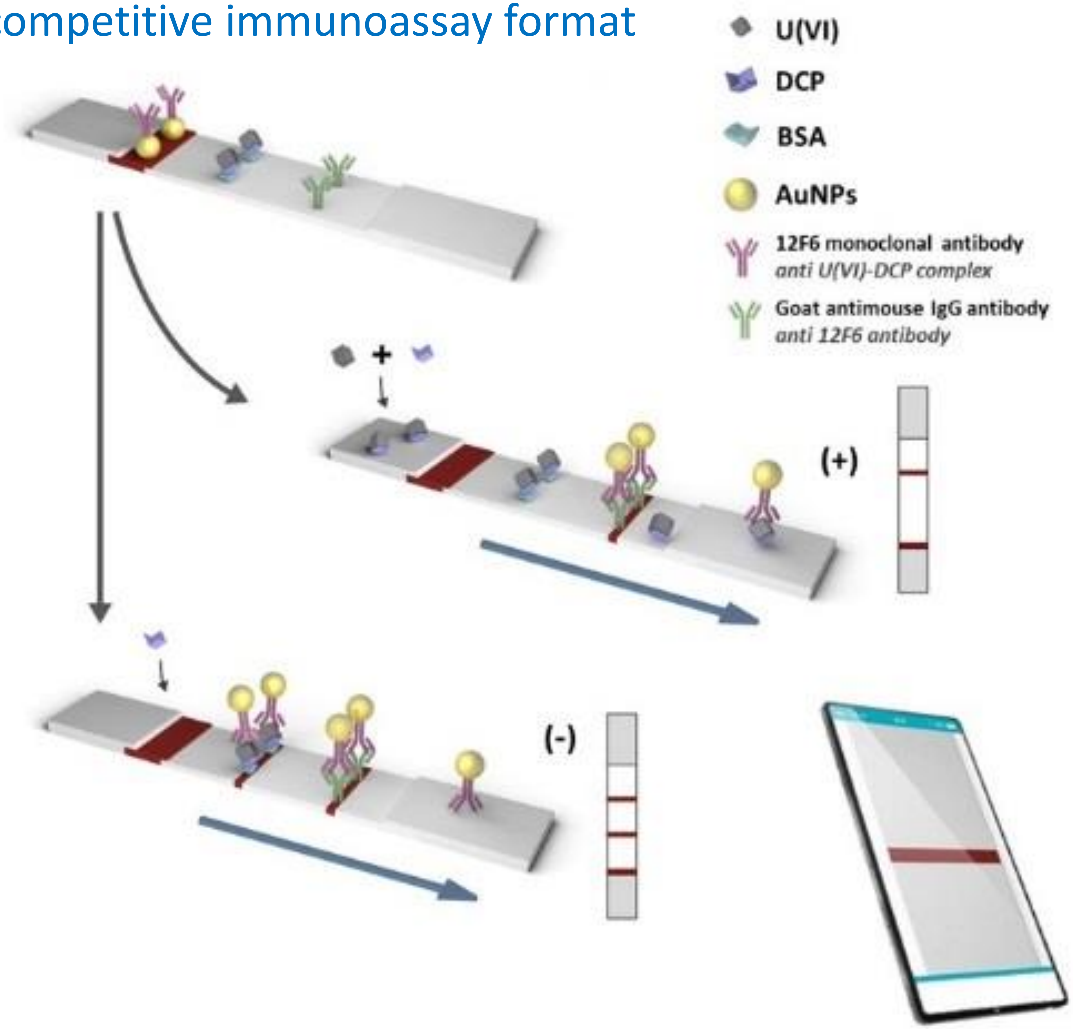



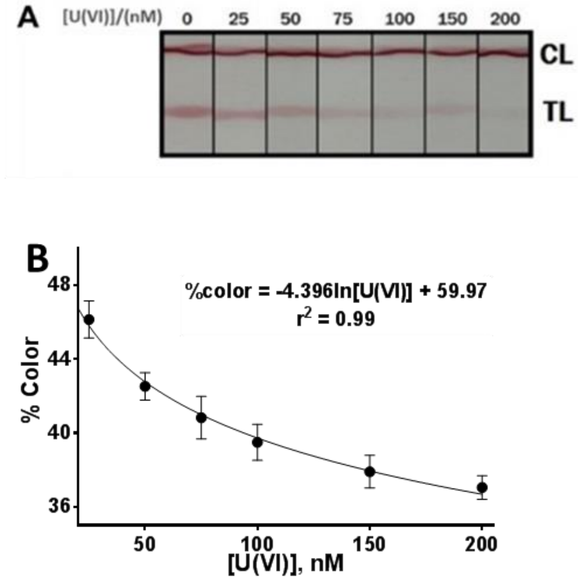

LOD < 1 ppb Cd



# Uranium (VI) detection in groundwater using a gold nanoparticle/paper-based lateral flow device

A competitive immunoassay format



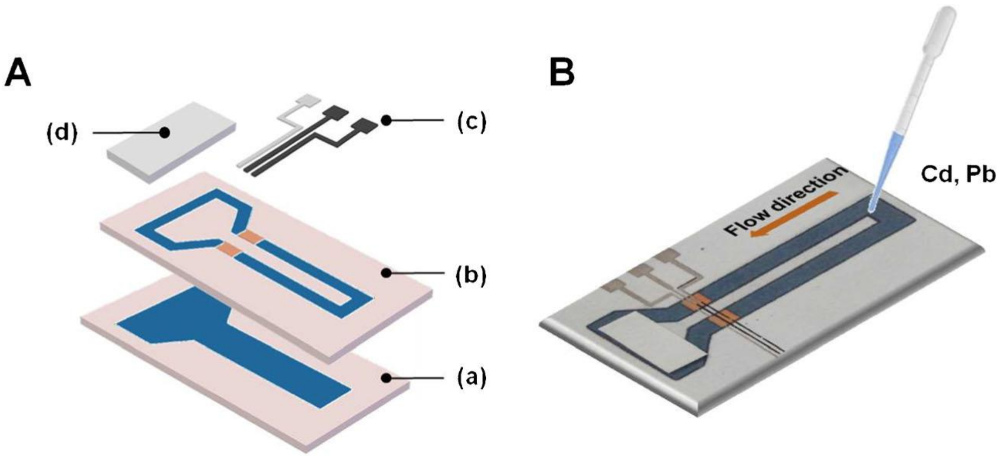



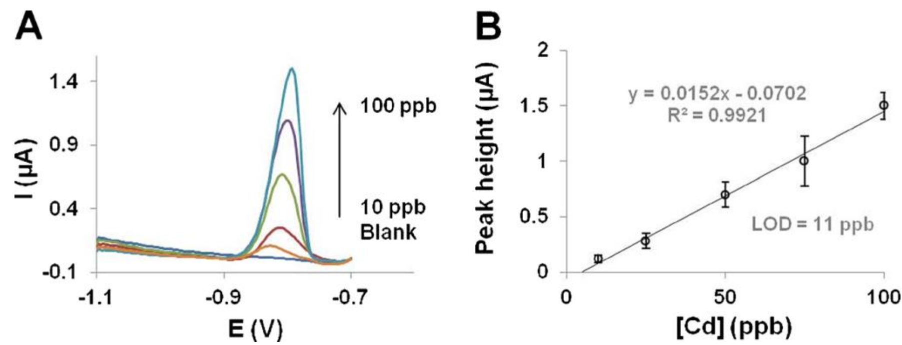

LOD of 6 nM in standards and samples

LOD of 36.38 nM in tyreated samples

Merkoçi et al., Scientific Reports volume 8, Article number: 16157 (2018)

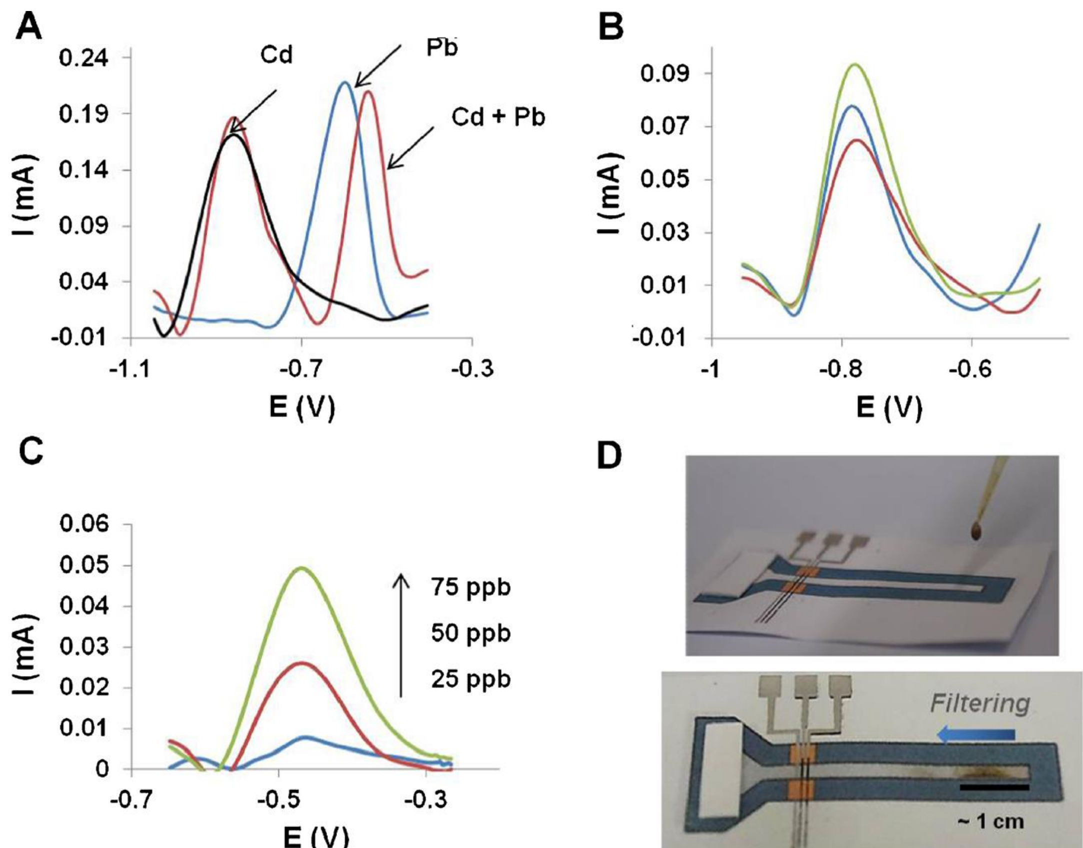
# Electrochemical lab-on-paper for heavy metal detection




The quantification of lead and cadmium in aqueous samples

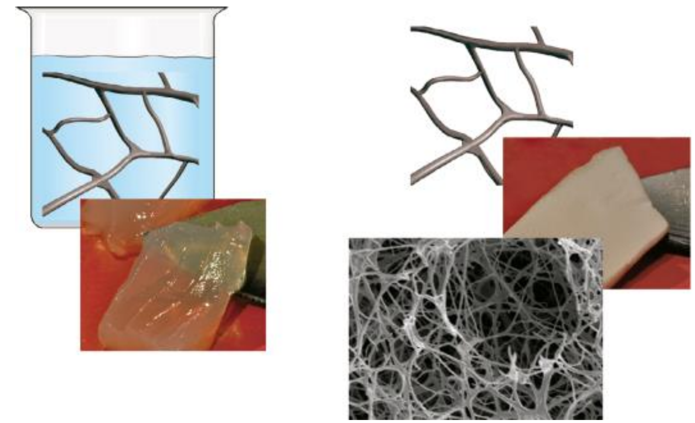
from 10 to 100 ppb with a limit of detection of 7 and 11 ppb respectively.



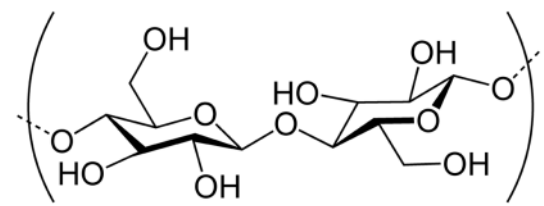

Merkoçi et al., Anal Bioanal Chem (2015) 407:8445–8449

# Bacterial Cellulose Nanopaper

- **Multifunctional Biomaterial**
- Hydrophilicity
- High porosity
- Broad chemical-modification capabilities
- High surface area

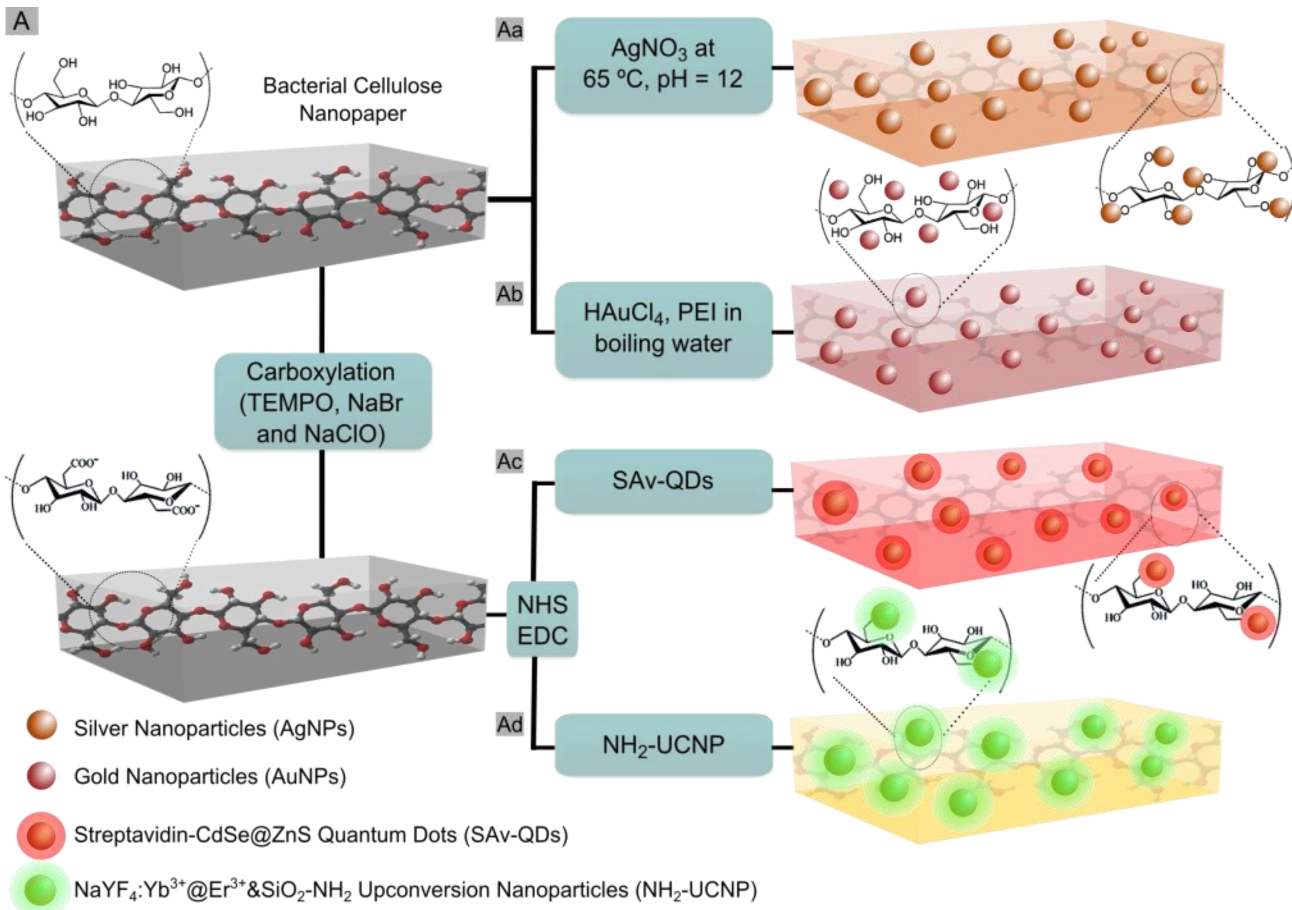


*Nat Nanotech* **2010**, 5:584



# Nanopaper as an Optical Sensing Platform

## Pathways to obtain Plasmonic / Photoluminescent Nanopaper



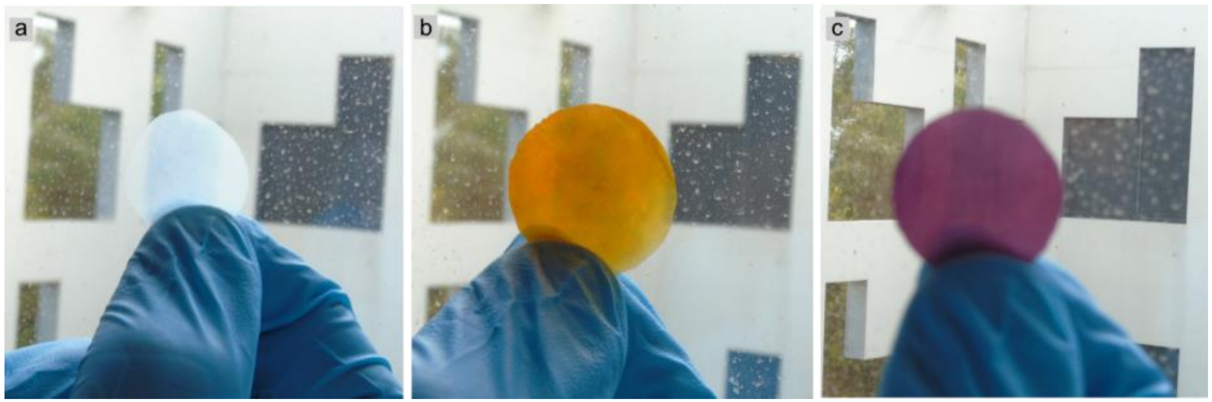

**A)** Reducing agent for chemical reduction of noble metal ions to metal nanoparticles

**B)** Nano-network to embed metallic nanoparticles during their synthesis

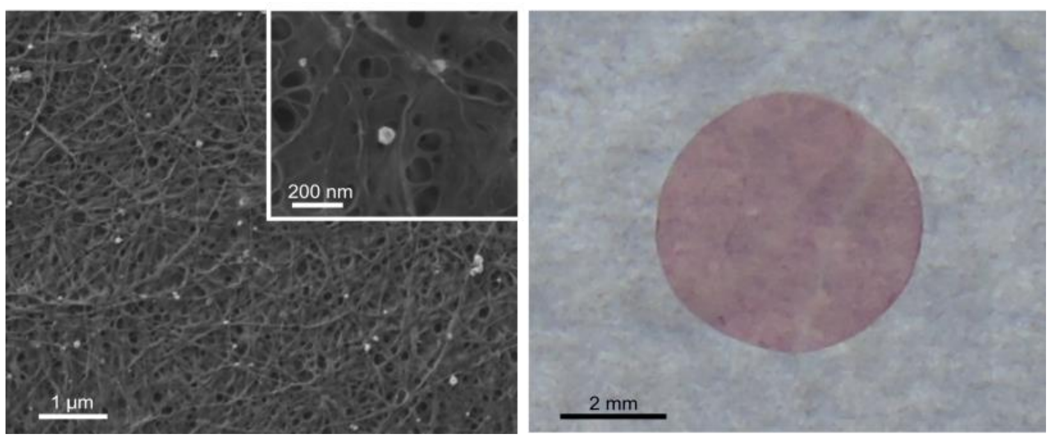
**C)** Producing carboxylic groups on the cellulose, for subsequent coupling with protein/amino-functionalized nanoparticles

<u>E. Morales-Narváez</u>, <u>H. Golmohammadi</u>, T. Naghdi, H. Yousefi, U. Kostiv, D. Horak, N. Pourreza, A. Merkoçi, *ACS Nano* **2015**, 9:7296

# Nanopaper as an Optical Sensing Platform
## Plasmonic Nanopaper (appearance)




**a.** Bare BC. **b.** AgNP-BC. **c.** AuNP-BC.




E. Morales-Narváez, H. Golmohammadi, T. Naghdi, H. Yousefi, U. Kostiv, D. Horak, N. Pourreza, A. Merkoçi, *ACS Nano* **2015**, 9:7296

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E. Morales-Narváez, H. Golmohammadi, T. Naghdi, H. Yousefi, U. Kostiv, D. Horak, N. Pourreza, A. Merkoçi,
*ACS Nano* **2015**, 9:7296

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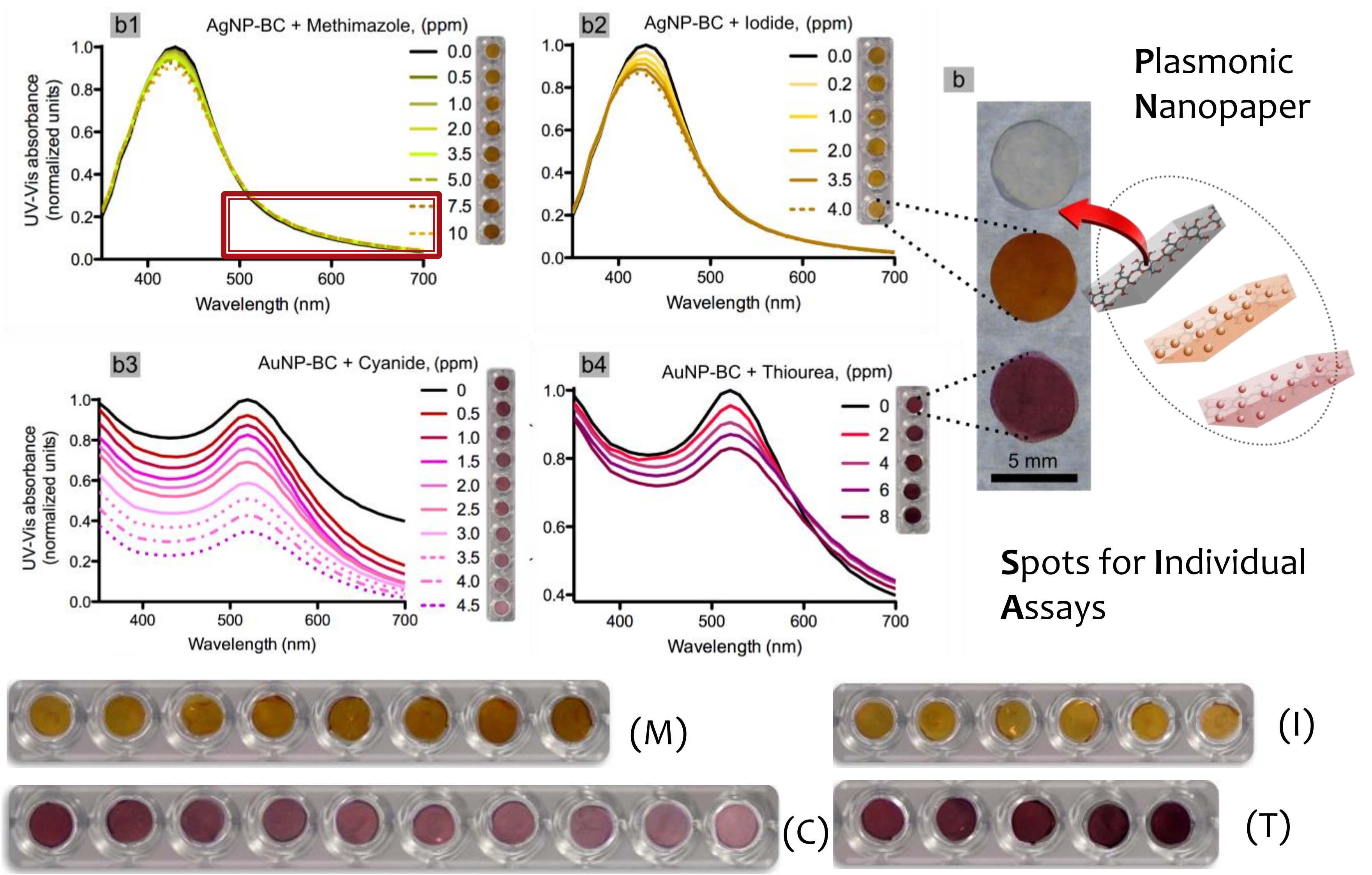
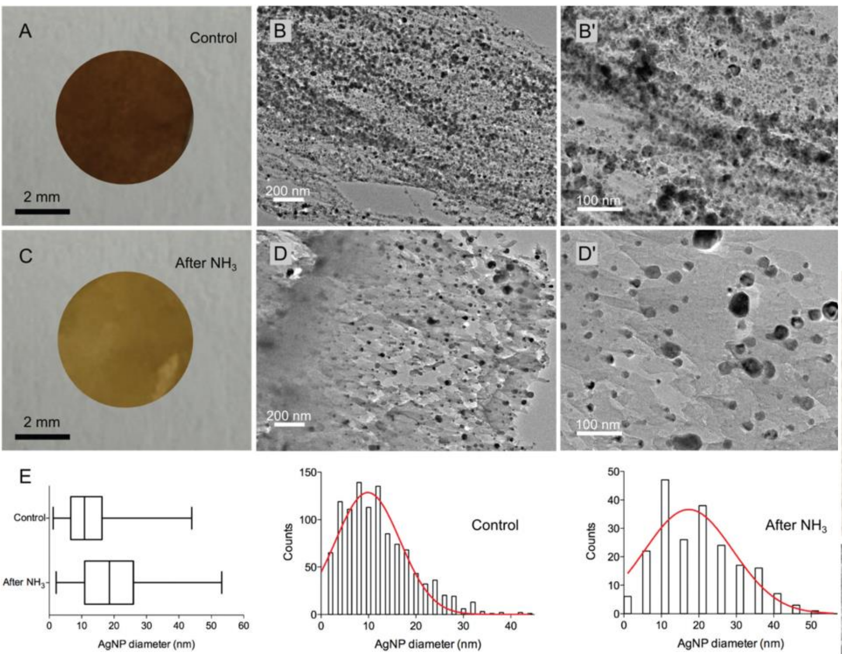
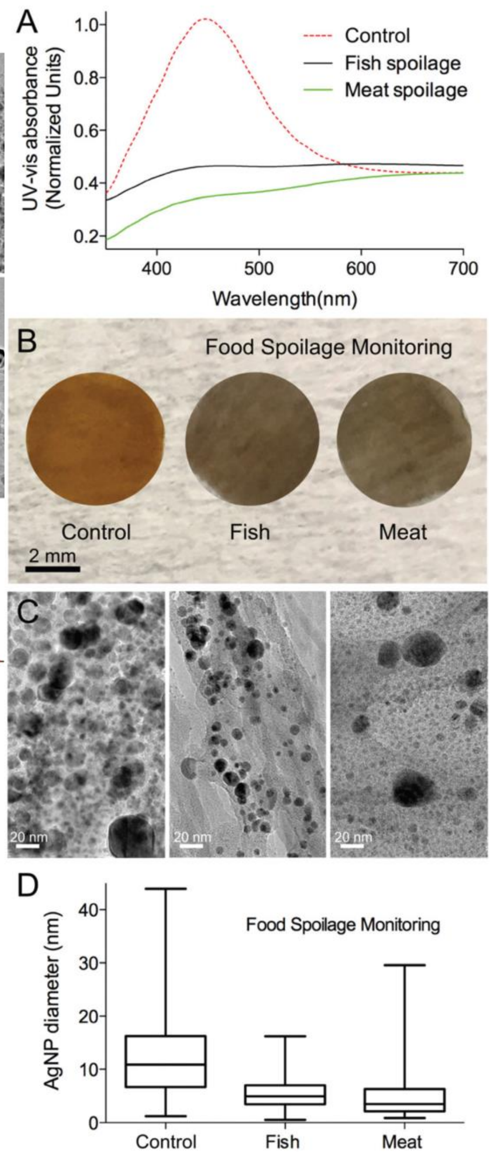
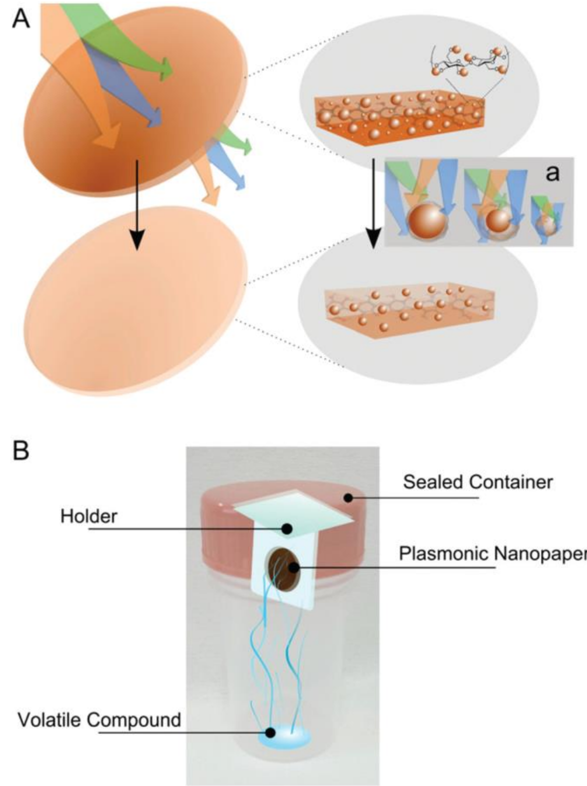



E. Morales-Narváez, H. Golmohammadi, T. Naghdi, H. Yousefi, U. Kostiv, D. Horak, N. Pourreza, A. Merkoçi, *ACS Nano* **2015**, 9:7296

# Visual detection of volatile compounds in a piece of AgNP-based plasmonic nanopaper



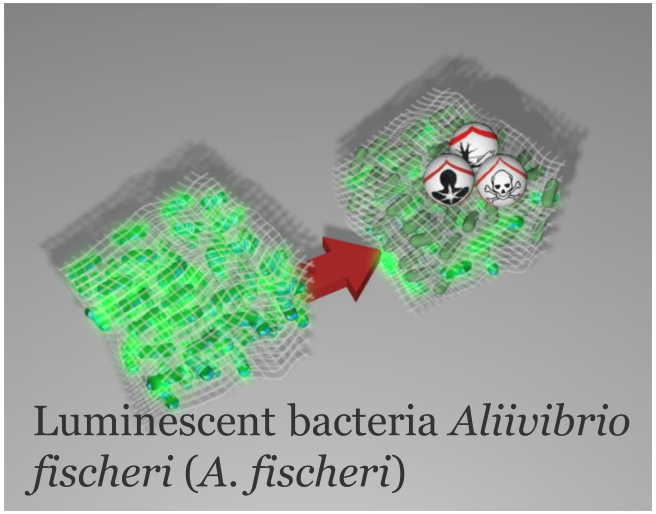



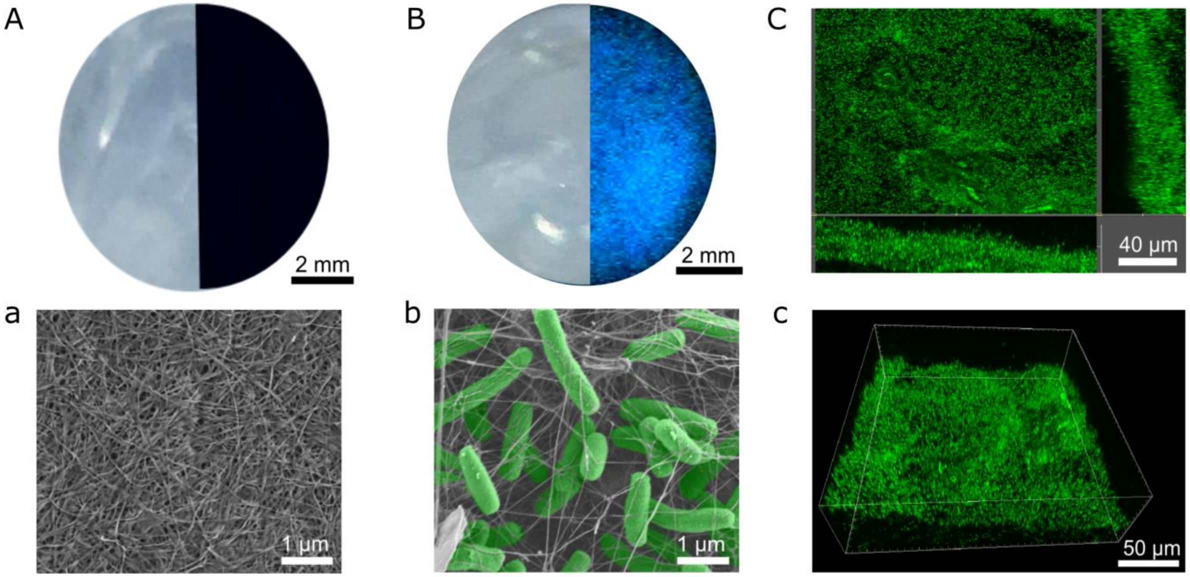

Modulation of population density and size of **silver nanoparticles** embedded in bacterial cellulose via ammonia exposure:

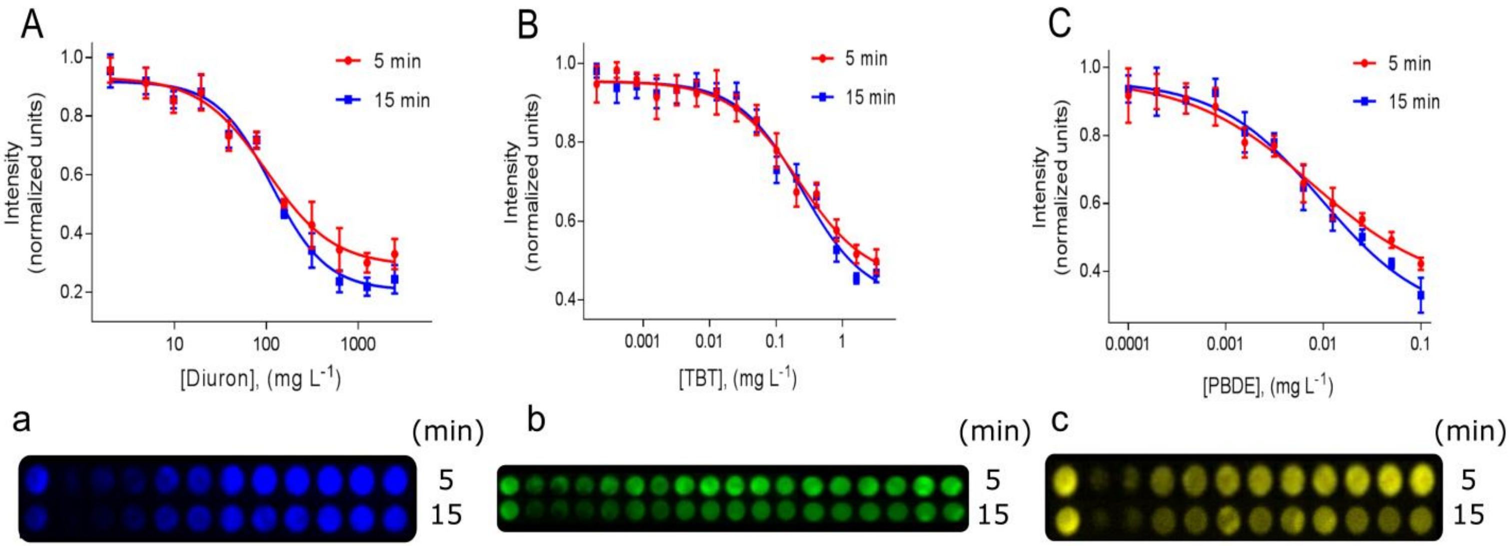
a simple visual detection, which opens the way to innovative approaches and capabilities in gas sensing and smart packaging

Merkoçi et al., Nanoscale, 2016, 8, 7984

# Bioluminescent Nanopaper for the rapid Screening of Toxic Substances




Merkoçi et al., NanoResearch, 2018, Vol 11 (1), pp 114-125

# NP-based lateral flow immunoassay

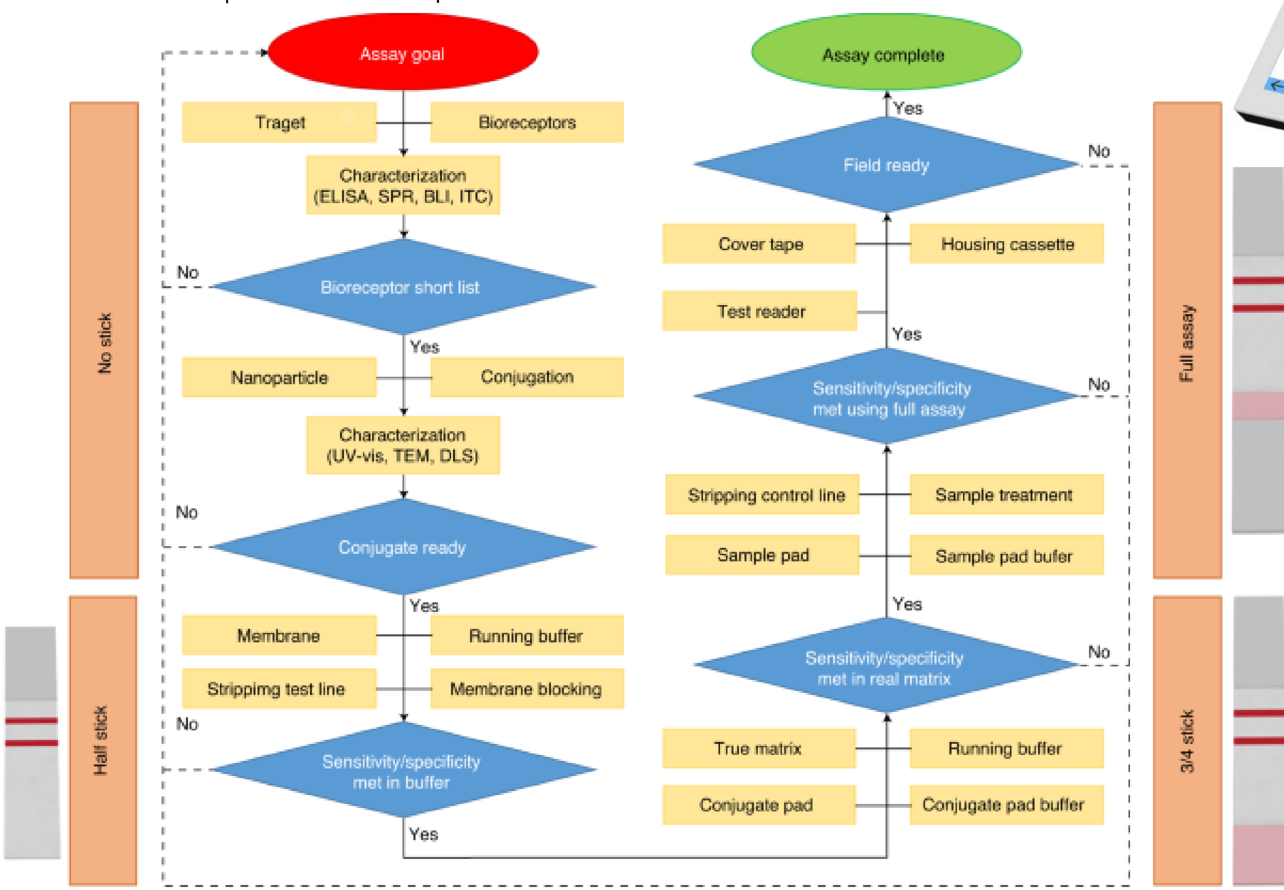
ICN2 Institut Català de Nanociència i Nanotecnologia
EXCELENCIA SEVERO OCHOA

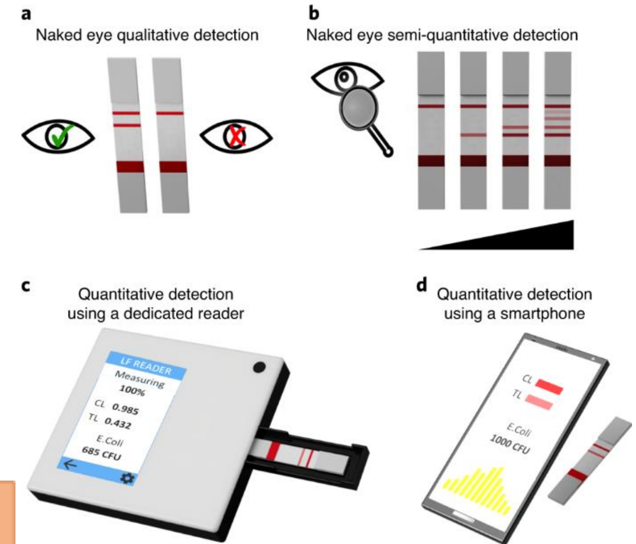
nature protocols
REVIEW ARTICLE
https://doi.org/10.1038/s41596-020-0357-x
Check for updates

## Tutorial: design and fabrication of nanoparticle-based lateral-flow immunoassays

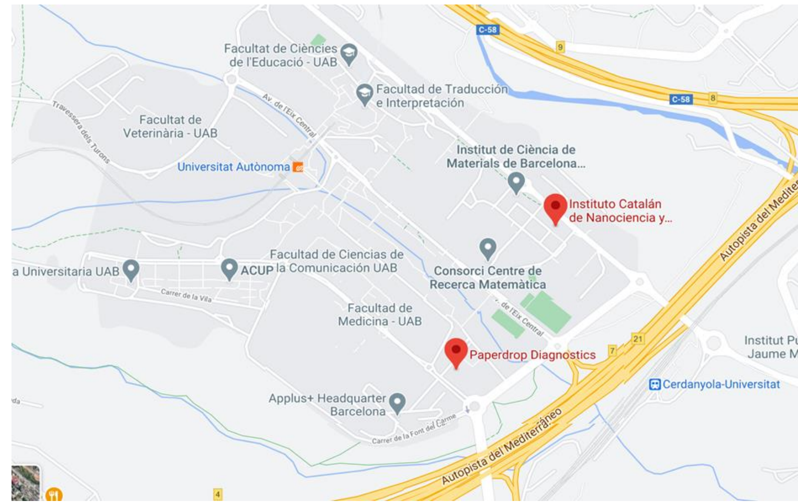
Claudio Parolo[1,5], Amadeo Sena-Torralba[1,5], José Francisco Bergua[1], Enric Calucho[1], Celia Fuentes-Chust[1], Liming Hu[1], Lourdes Rivas[1], Ruslan Álvarez-Diduk[1], Emily P. Nguyen[1], Stefano Cinti[2], Daniel Quesada-González[3] and Arben Merkoçi[1,4]✉

NATURE PROTOCOLS | VOL 15 | DECEMBER 2020 | 3788–3816 | www.nature.com/nprot



# A small-medium enterprise founded in 2016


Spin-off company of:

Part of:

paperdropdx

# Professional & Self-testing In Vitro Diagnostics

Technology awarded with the Seal of Excellence of the European Commission

**Rapid diagnostic tests based on paper-microfluidics** highly flexible that enable the integration of a wide range of bioreceptors in a very short period of time.

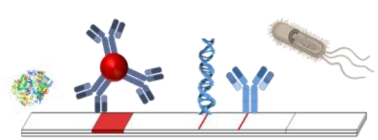
### Equipment-free
No need of any equipment, just a device as simple as a pregnancy test and one drop of sample.

### Ultrasensitivity
Molecular and genetic biomarkers along with new signal detection and visualization strategies.

### Low cost
Paper has unlimited capacities, is easy to be manufactured and is totally reciclable.

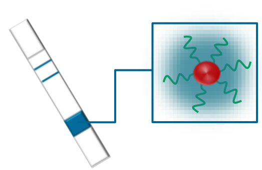
### Fast & Easy
Just one drop on the paper, wait about 5 minutes and that's it: the diagnostic is done.

- **Adaptative platform**



for Abs, Aptamers, Probes, PNAs and different bioreceptors entities

- **Proprietary technology**



with strong plasmonic resonance 10-100 times stronger than commercial NPs

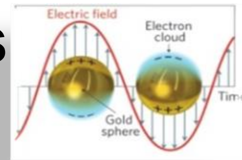
- **Image support and connectivity**

taking advantage of the different imaging tools and the wireless connectivity of smartphones

# OUR MOTIVATION

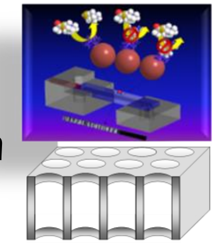
## To design new simple nanobiosensors and improve existing ones

### Nanoparticles

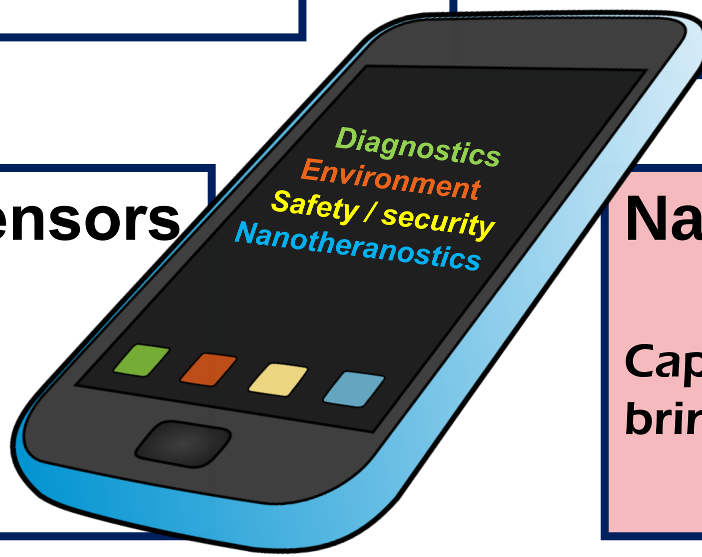



New electro /optical labels

### LOCs / Nanochannels

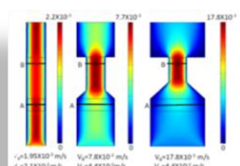


Preconcentration, filtering, automation

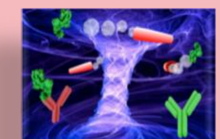



### Paper-based sensors

Simple is the best

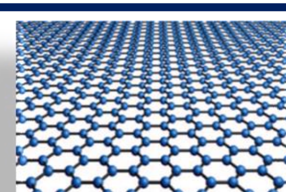


### Nanomotors



Capture even single analyte, bring it to sensing surface

### Graphene



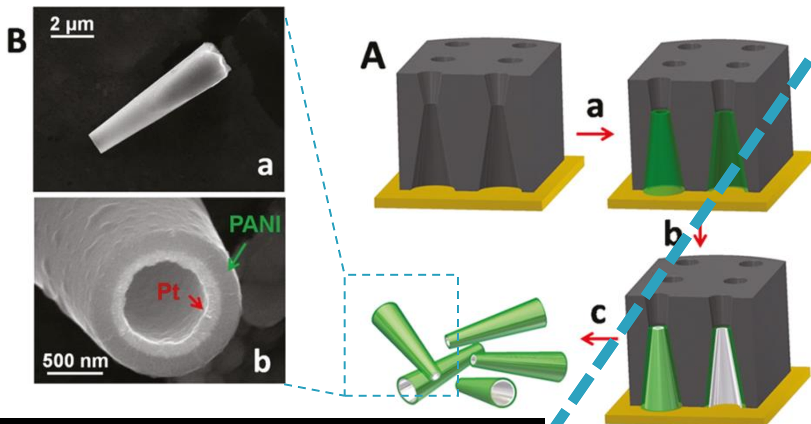
New (bio)sensing opportunities (?)

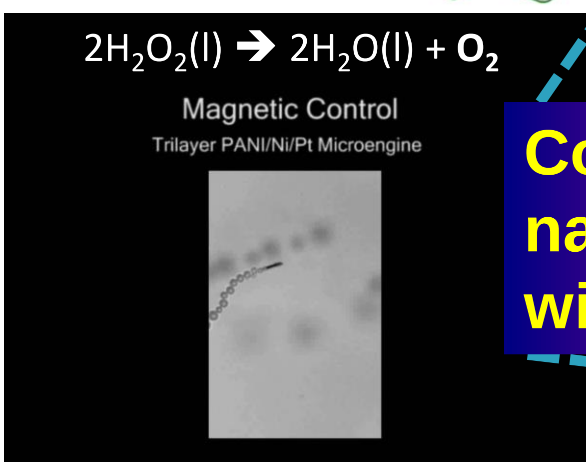
# Nano/micromotors (Collaboration with J.Wang, USA
# Maria Guix

## Enhancing of biosensing

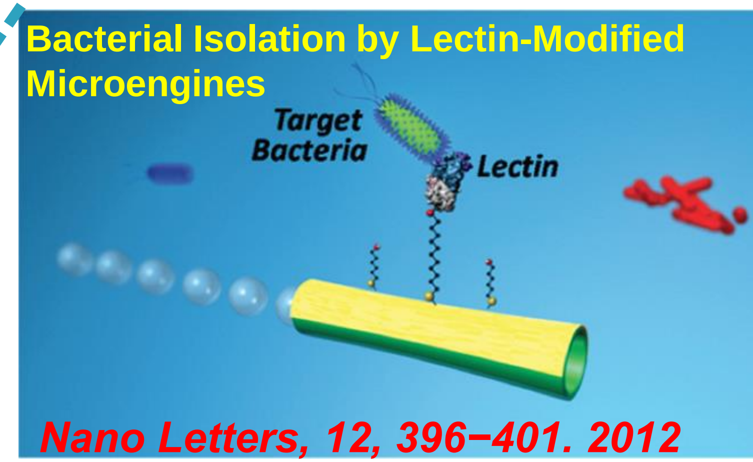
**Template-based catalytic microengines (no need for clean room)**

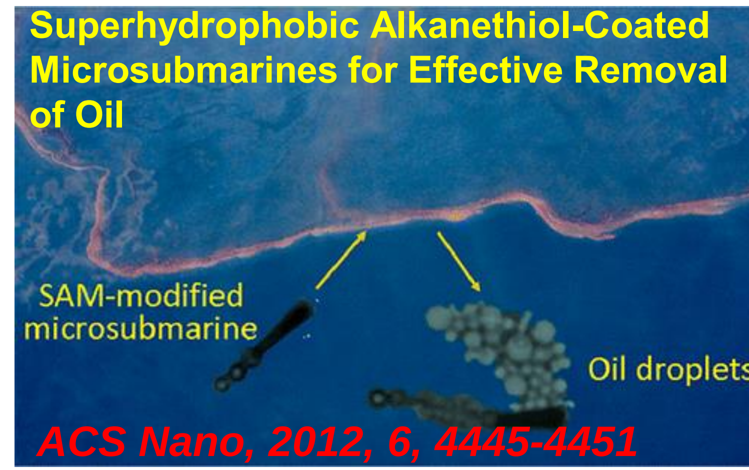
**Au/Ni/PANI** Polyaniline**/Pt**

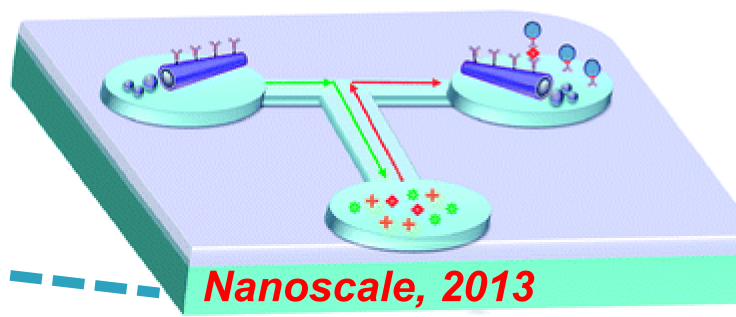



## Coupling nanomotors effect with biosensing

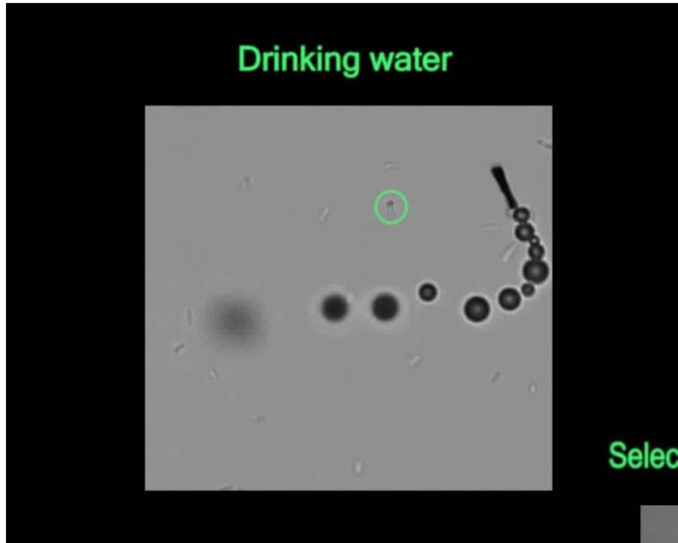


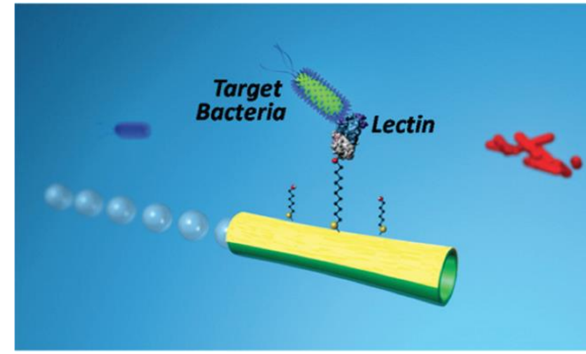



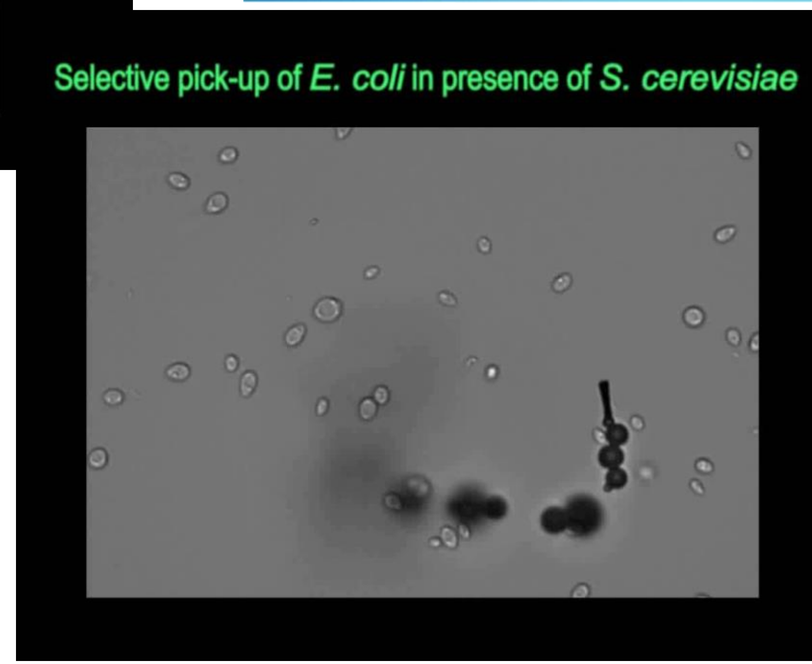



# Bacterial Isolation by lectin-modified microengines

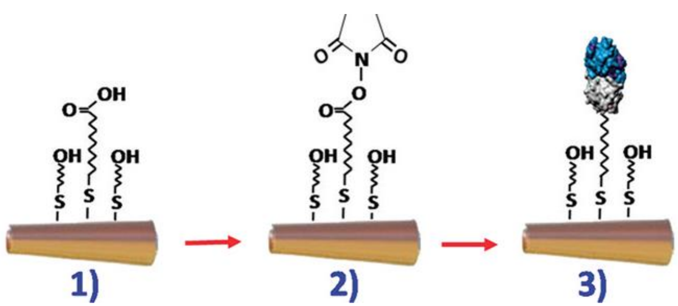
Selective capture of *Escherichia coli* from **food** and **clinical** samples



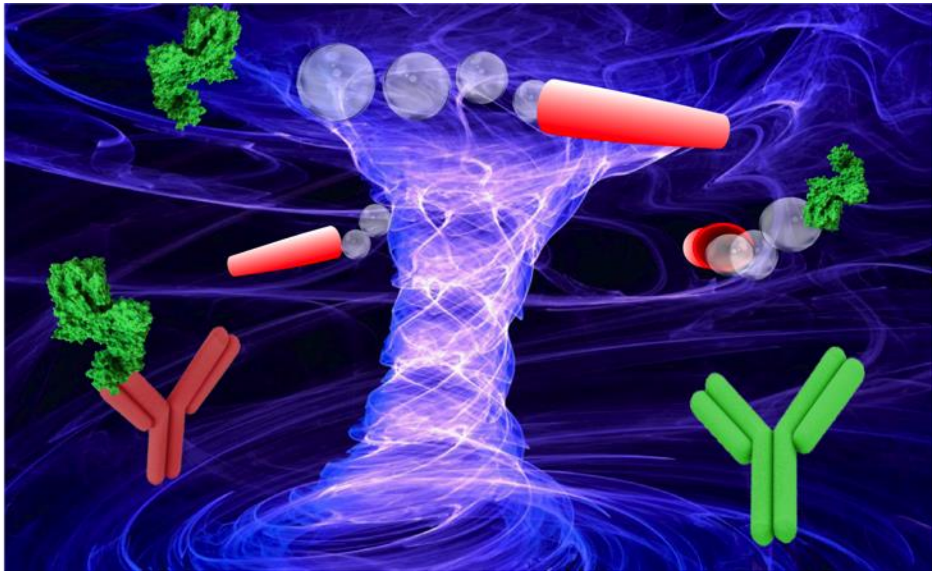

Template-based self-propelled microengine
**Au/Ni/PANI/Pt**
Modified with Concanavalin A (ConA: lectin bioreceptor)

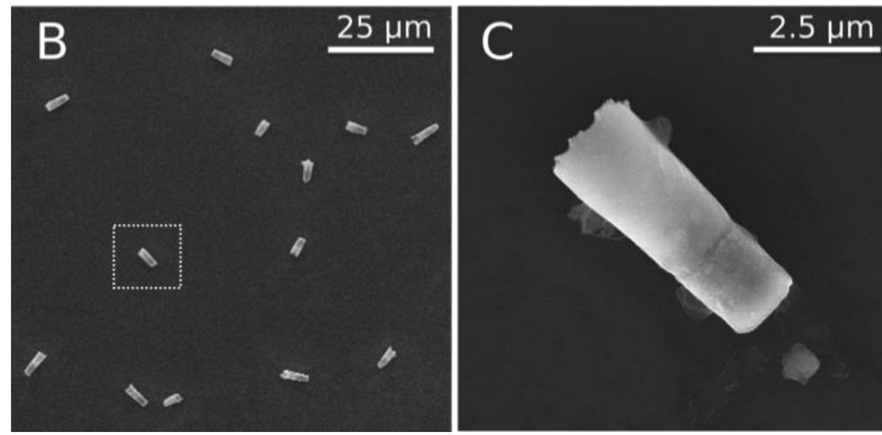



S. Campuzano et al. Nano Lett. 12, **2012**, 396–401.

NANO Bioelectronics & Biosensors Group

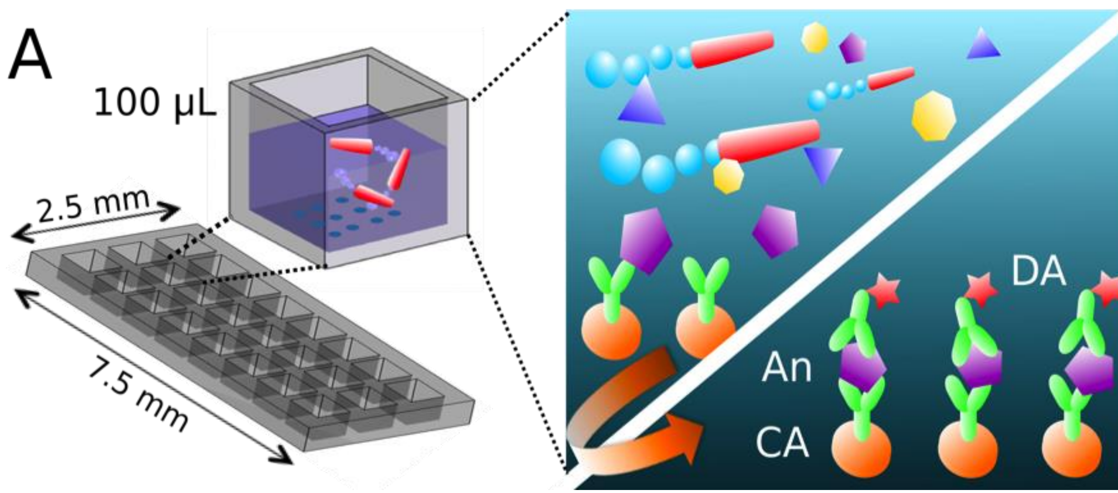
# Microengines meet μA technology





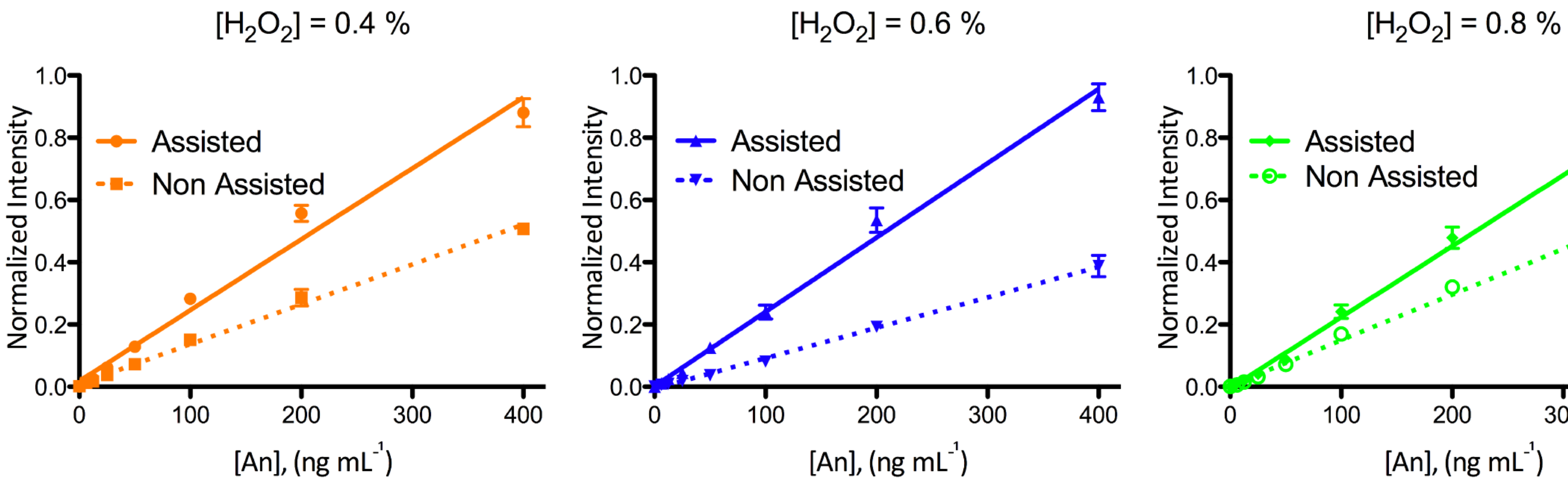

Hydrodynamic motion

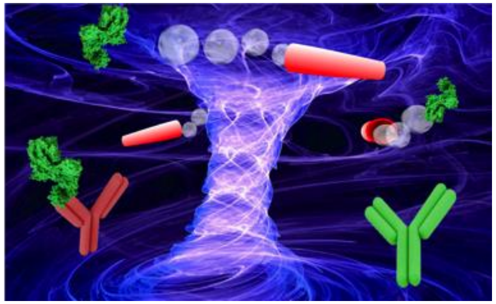
Antigen – Antibody interaction




Morales-Narváez, Guix*, Medina-Sánchez, Mayorga-Martinez, Merkoçi, ***Small***, **2014**

# Microengines meet μA technology

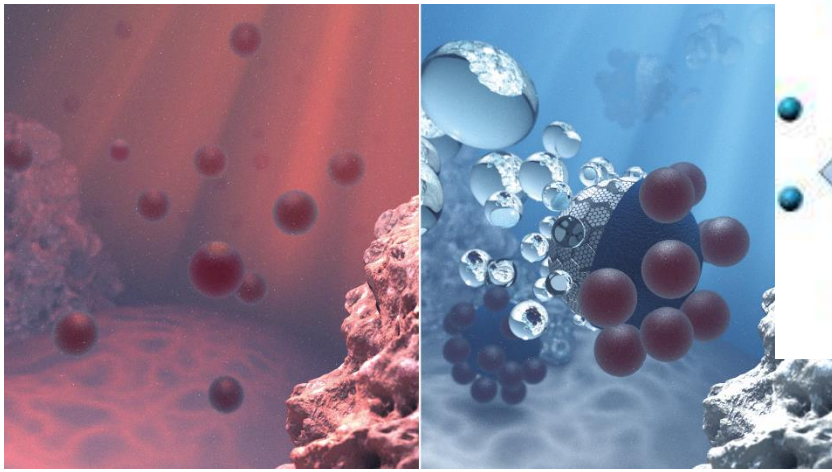


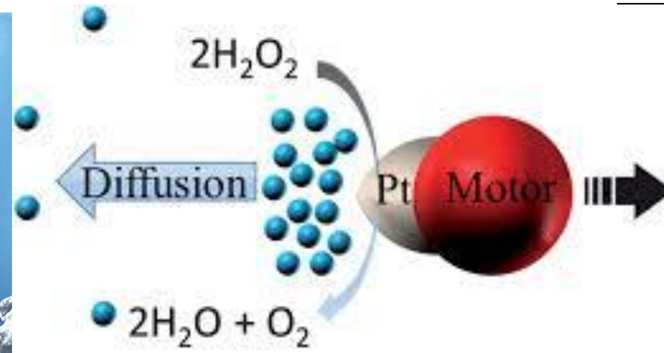



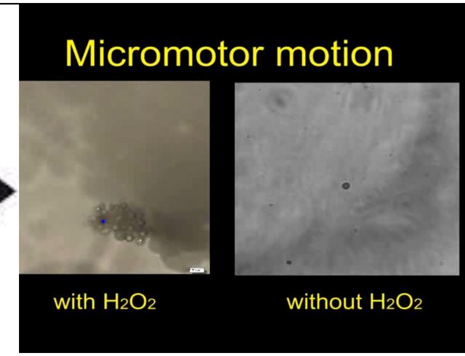
<u>Morales-Narváez*</u>, <u>Guix*</u>, Medina-Sánchez, Mayorga-Martinez, Merkoçi, ***Small***, **2014**

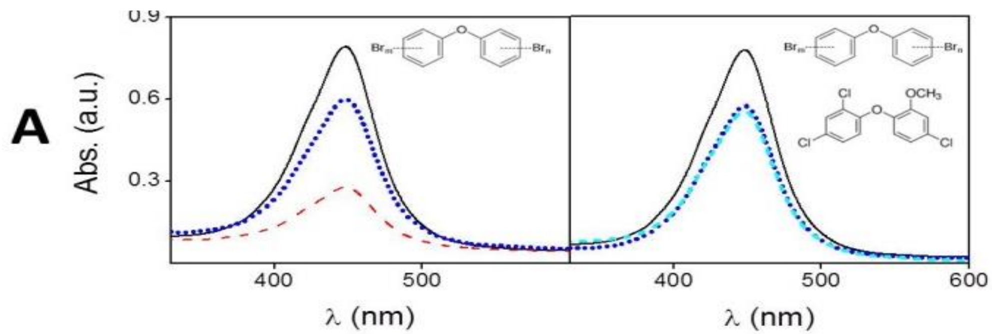
# $SiO_2$@rGO–Pt Janus Micromotors

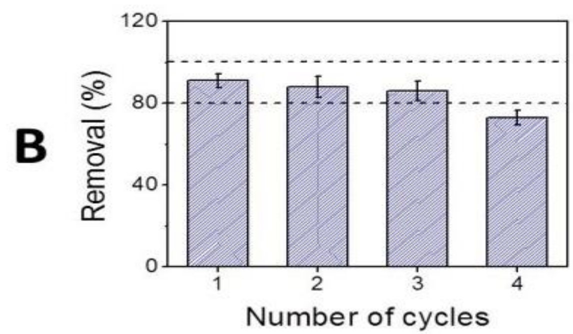
## Enhanced removal of Persistent Organic Pollutants (POPs)

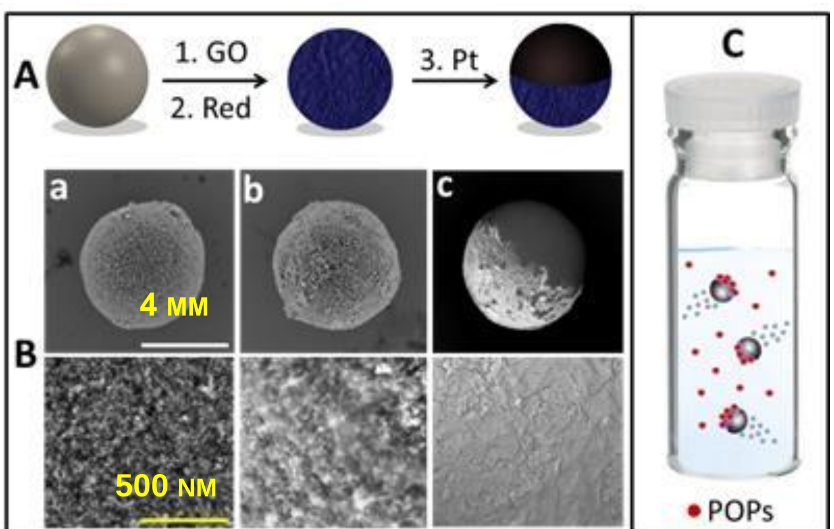




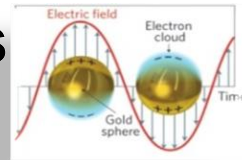

Polybrominated diphenyl ethers (PBDEs)
5-chloro-2-(2,4-dichlorophenoxy) phenol (triclosan))

Jahir Orozco, Luiza A. Mercante, Roberto Pol, Arben Merkoçi, J. Mater. Chem. A, 2016,4, 3371-3378

# OUR MOTIVATION

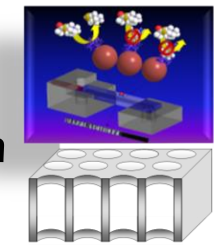
## To design new simple nanobiosensors and improve existing ones

### Nanoparticles




New electro /optical labels

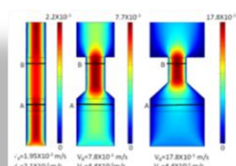
### LOCs / Nanochannels



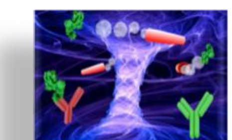
Preconcentration, filtering, automation


### Paper-based sensors

Simple is the best

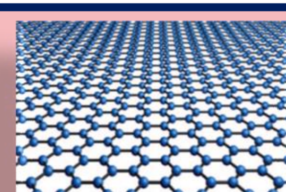


### Nanomotors



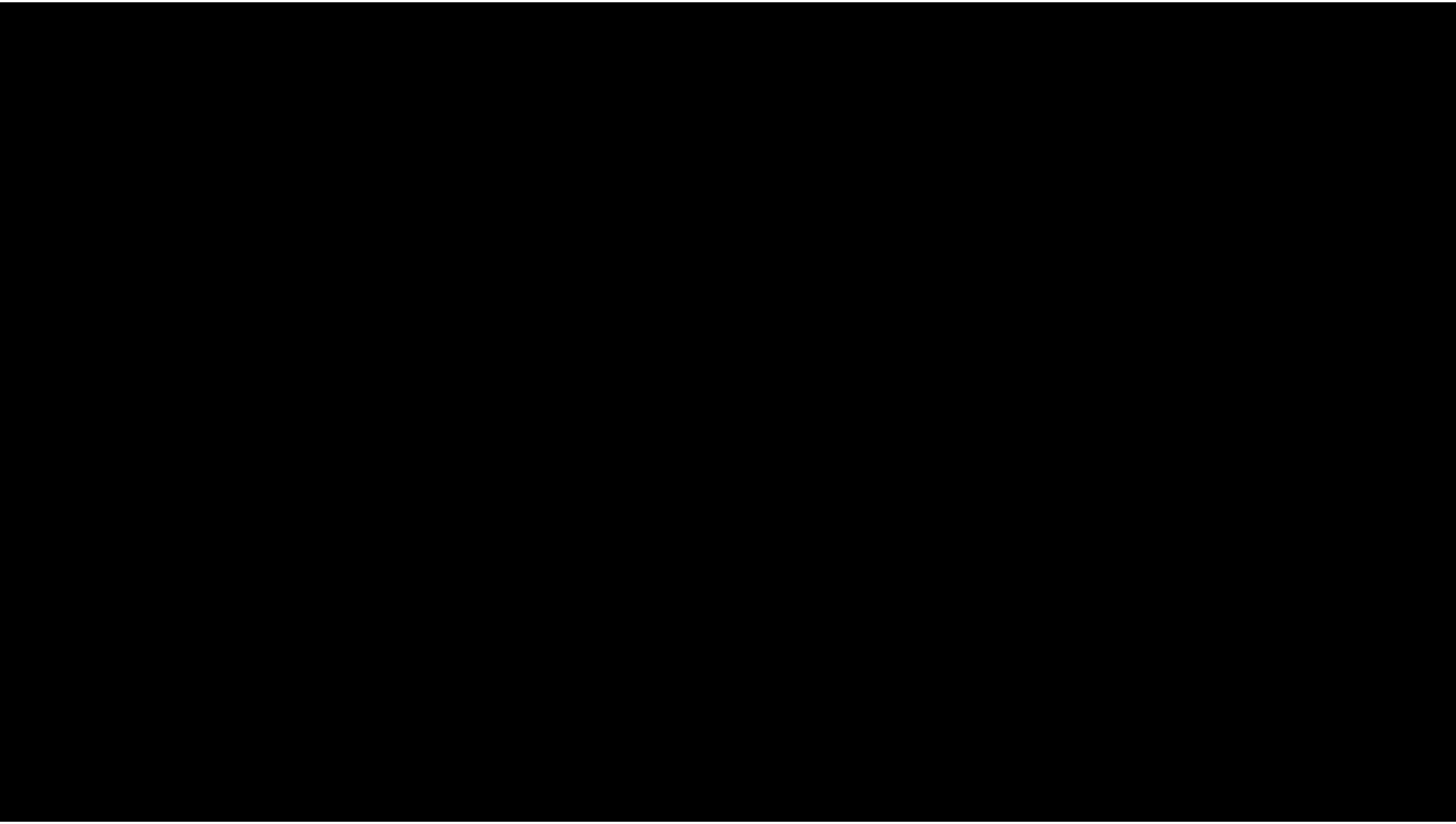
Capture even single analyte, bring it to sensing surface

### Graphene



New (bio)sensing opportunities (?)

GraphenicaLab



ICN2 Institut Català de Nanociència i Nanotecnologia
EXCELENCIA SEVERO OCHOA

ICREA

NANO Bioelectronics & Biosensors Group

# Properties with interest in Biosensing

- Superlative mechanical strength

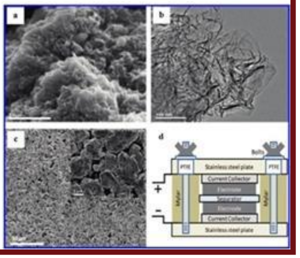
Yung's modulus ca. 1100 GPa

*Science* **2008**, 321:385–388

extremetech.com

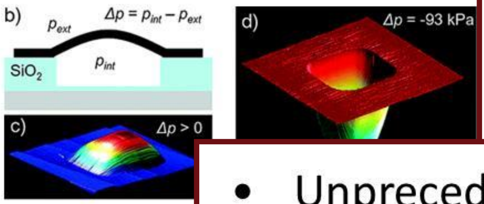
- High planar surface 2630 $m^2\ g^{-1}$

*Nano Lett* **2008**. 8:3498–3502



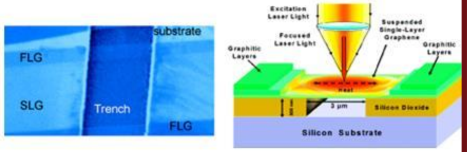
- Impermeable to standard gases including helium

*Nano Lett* **2008**, 8:2458–2462



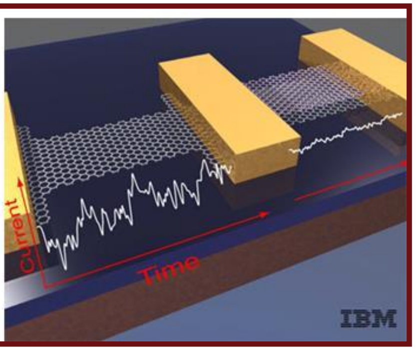

- Unprecedented thermal conductivity 5000 $Wm^{-1}K^{-1}$

*Nano Lett* **2008,** 8:902-907




- High electrical conductivity 1738 $S\ m^{-1}$

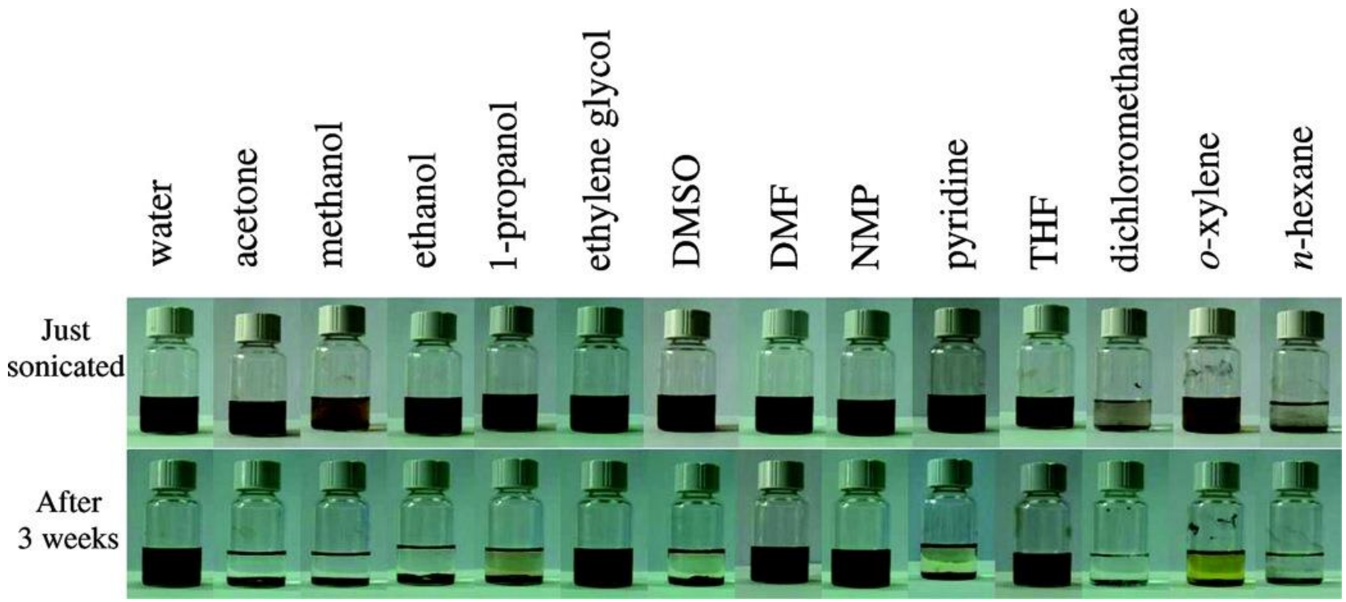
*Science* **2012**, 335:1326-1330



# Properties with interest in Biosensing



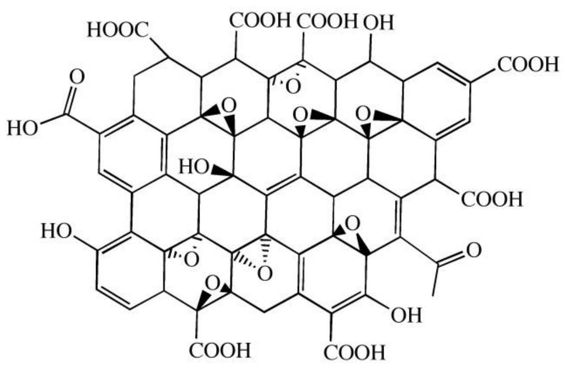
## GO can be processed in suspension form

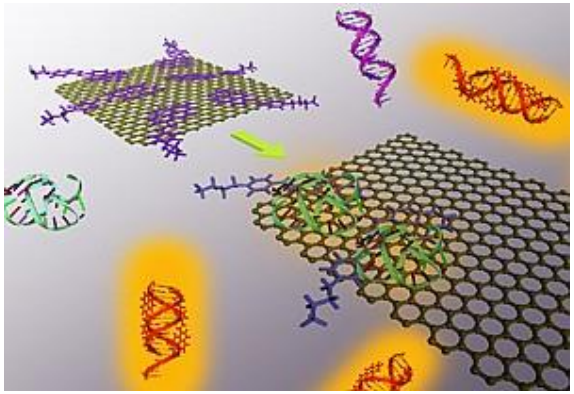


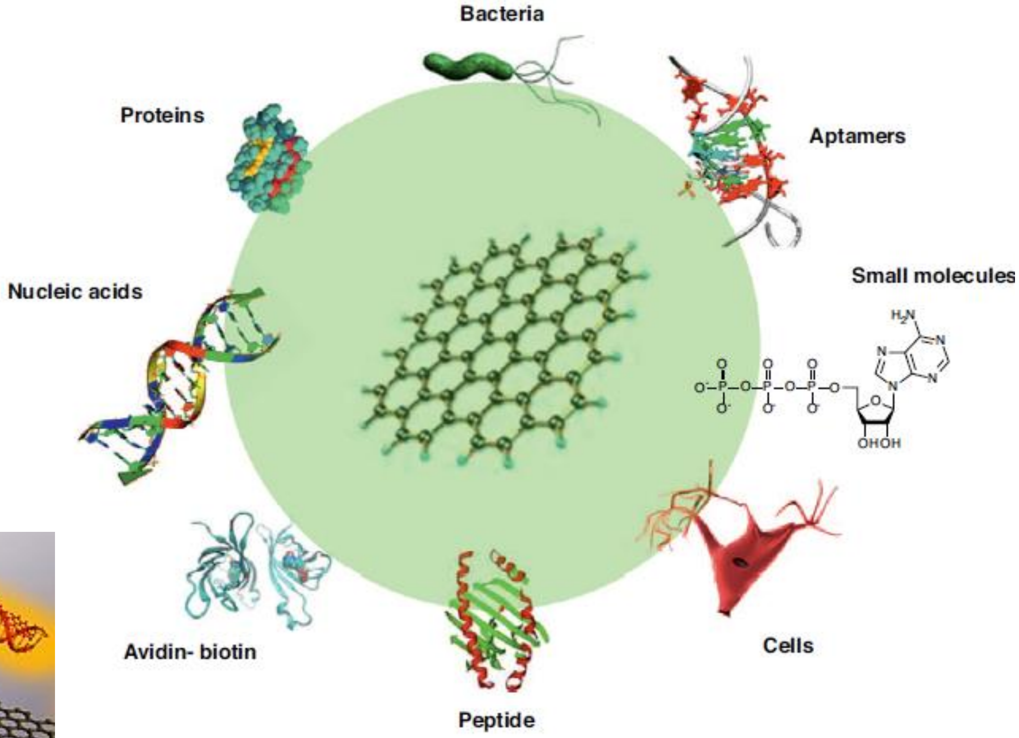

*Langmuir* **2008**, *24:*10560-10564

# Properties with interest in Biosensing

- Direct wiring with biomolecules





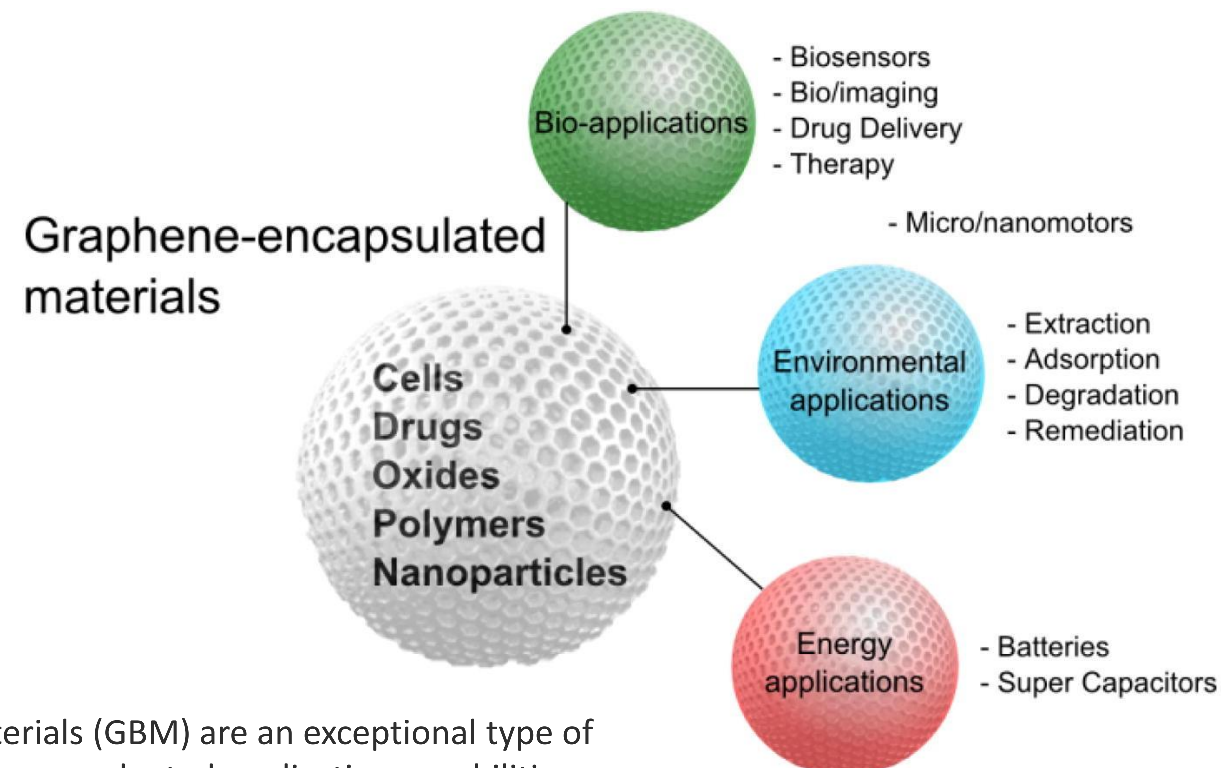

*Chem Soc Rev* **2010**, 39:4146–4157

*Trends Biotechnol* **2011**, 29:205-212

Progress in Materials Science
Volume 86, May 2017, Pages 1-24

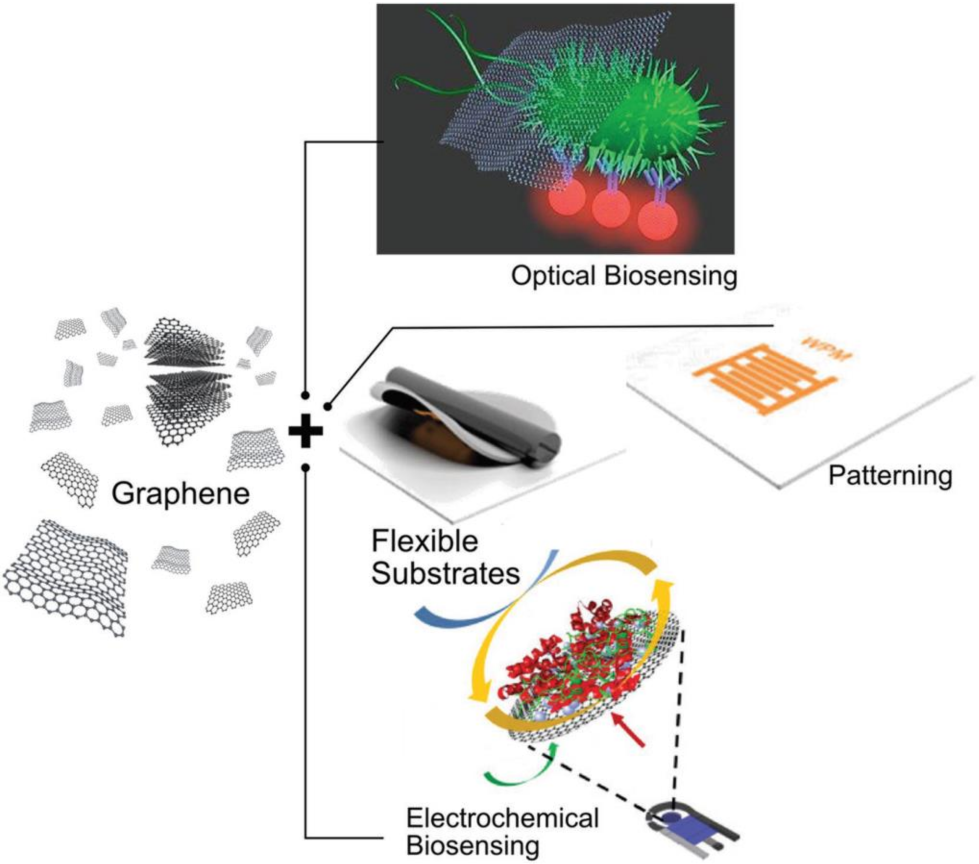
# Graphene-encapsulated materials: Synthesis, applications and trends

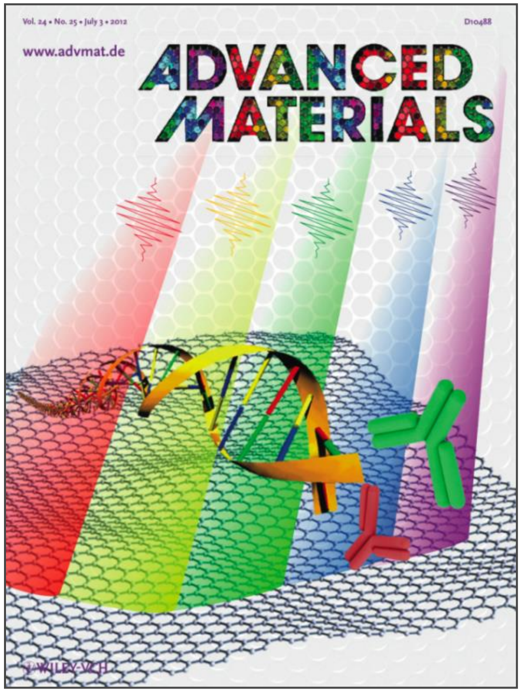
Eden Morales-Narváez [a], Lívia Florio Sgobbi [a, b], Sergio Antonio Spinola Machado [b], Arben Merkoçi [a, c]

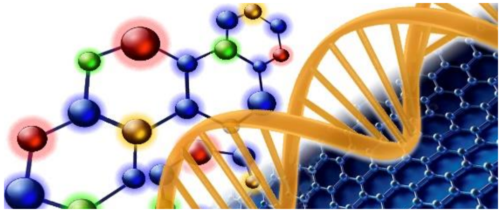



Graphene-based materials (GBM) are an exceptional type of materials that offer unprecedented application capabilities to the scientific and technologic community.

# Graphene-Based Biosensors: Going Simple



ADVANCED MATERIALS
www.advmat.de
ADVANCED SCIENCE NEWS
www.advancedsciencenews.com

## Graphene-Based Biosensors: Going Simple

*Eden Morales-Narváez, Luis Baptista-Pires, Alejandro Zamora-Gálvez, and Arben Merkoçi**

ADVANCED MATERIALS
www.advmat.de
Materials Views
www.MaterialsViews.com

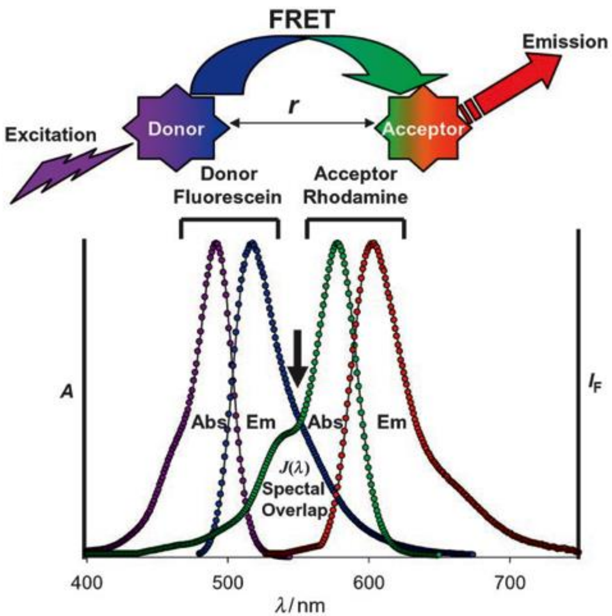
## Graphene Oxide as an Optical Biosensing Platform

*Eden Morales-Narváez and Arben Merkoçi**

# Properties with interest in Biosensing

## Excellent quencher of fluorescence

FRET entails the transfer of energy from a photoexcited donor to an acceptor molecule




*Angew Chem Int Ed* **2006**, 45:4562 – 4588

**Typically**

$$E = 1 / [1 + (R / R_0)^6]$$

**d ~ 10 nm**

**Using Graphene**

$$E = 1 / [1 + (R / R_0)^4]$$

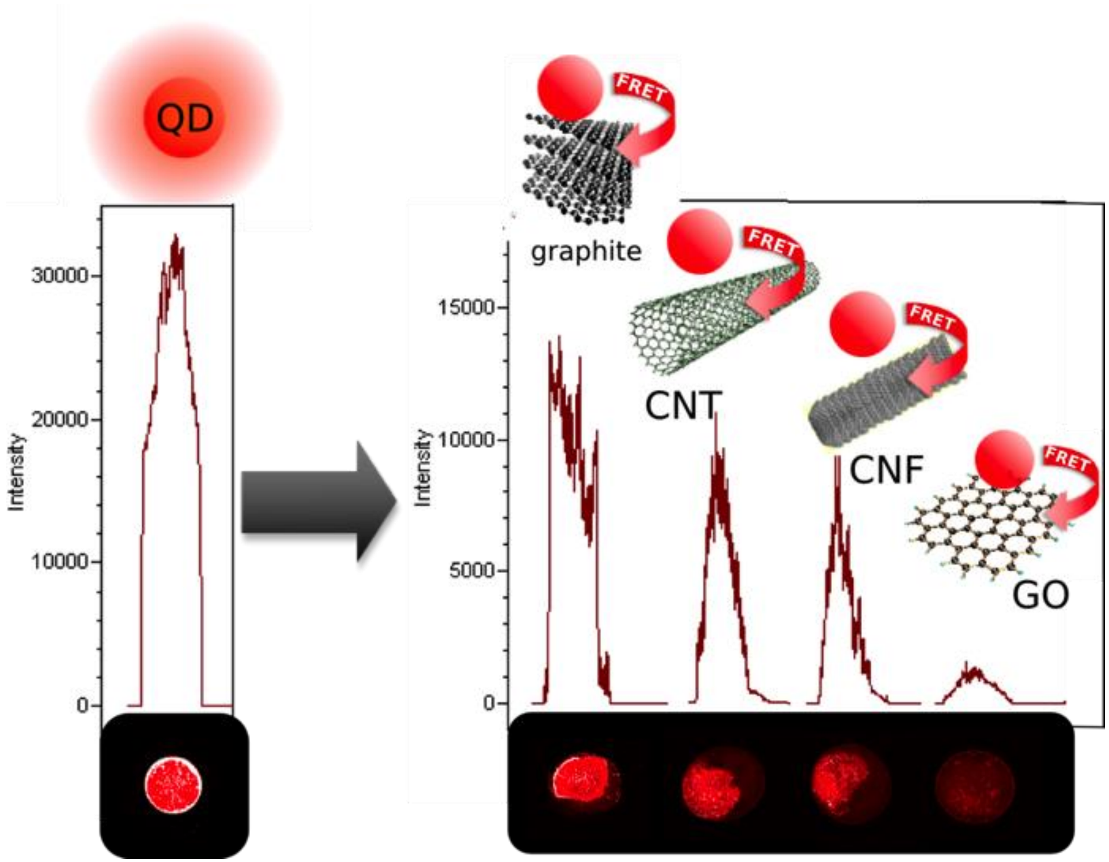
**d ~ 30 nm**

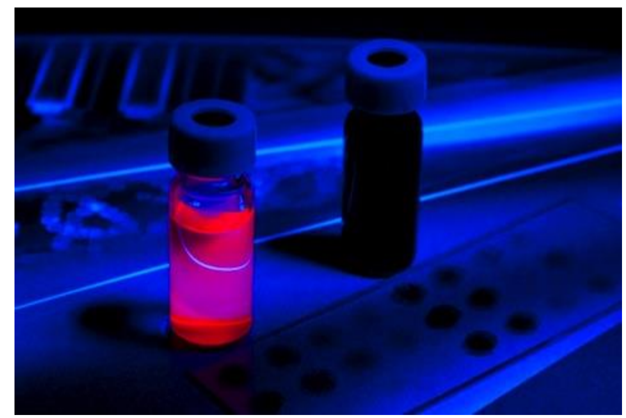
*J Chem Phys* **2009**, *130*:086101

*Adv Mater* **2012**, 24, 3298–3308

# Graphene Oxide in FRET (solid phase)

Simple FRET evidence for the ultrahigh QD quenching efficiency by GO compared to other carbon structures

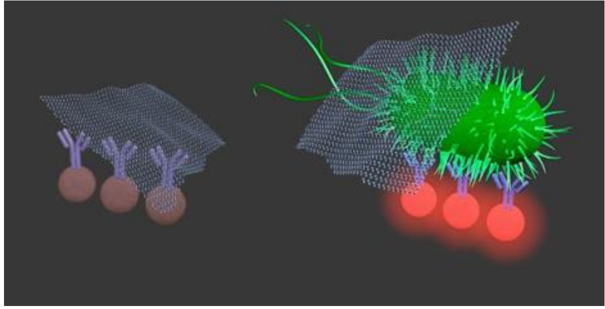


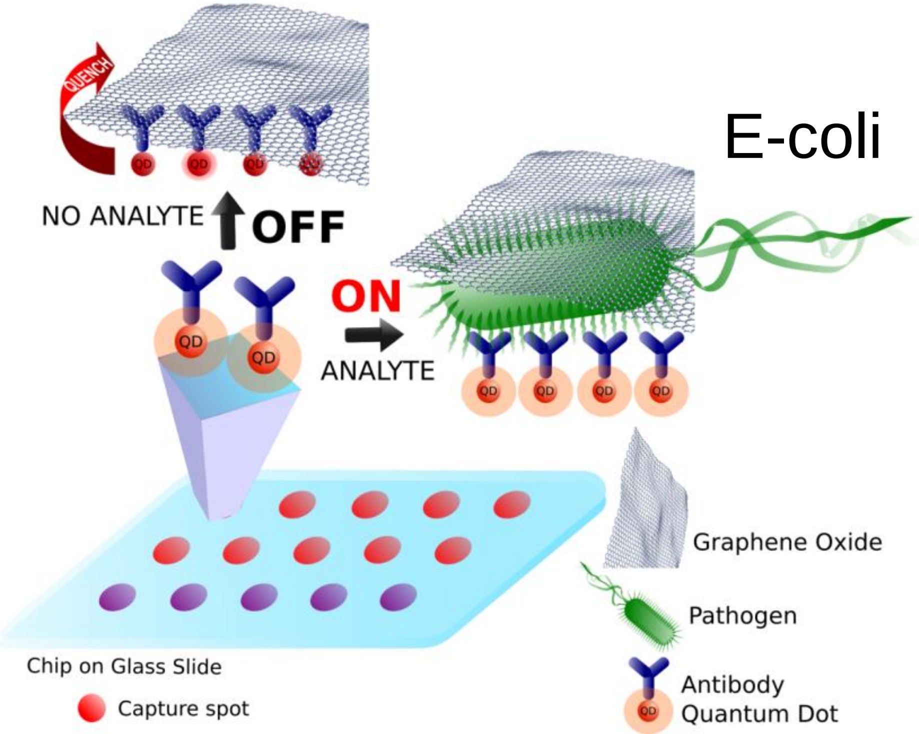



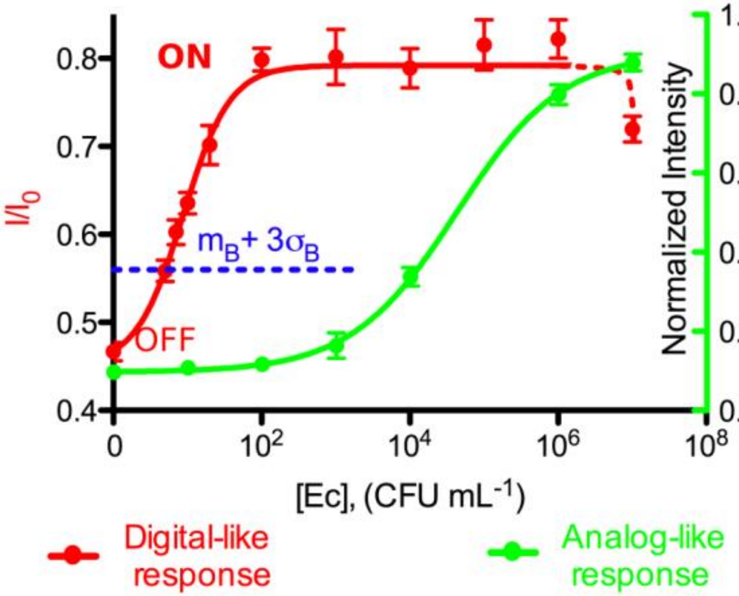
| | QD Quenching Efficiency range (%) |
|---|---|
| g | 17±05 ÷ 66±17 |
| CNT | 63±07 ÷ 71±01 |
| CNF | 52±10 ÷ 74±07 |
| GO | 91±02 ÷ 97±01 |

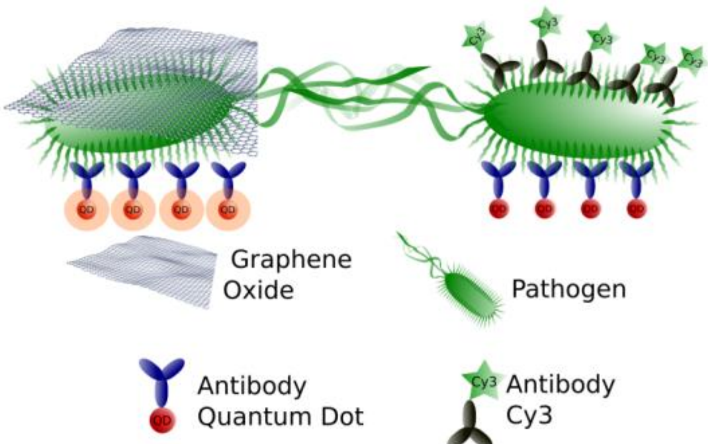
Morales-Narváez, Merkoçi, *et al.Carbon* **2012**, *50:*2987

# GO as a pathogen-revealing agent






## Patent

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

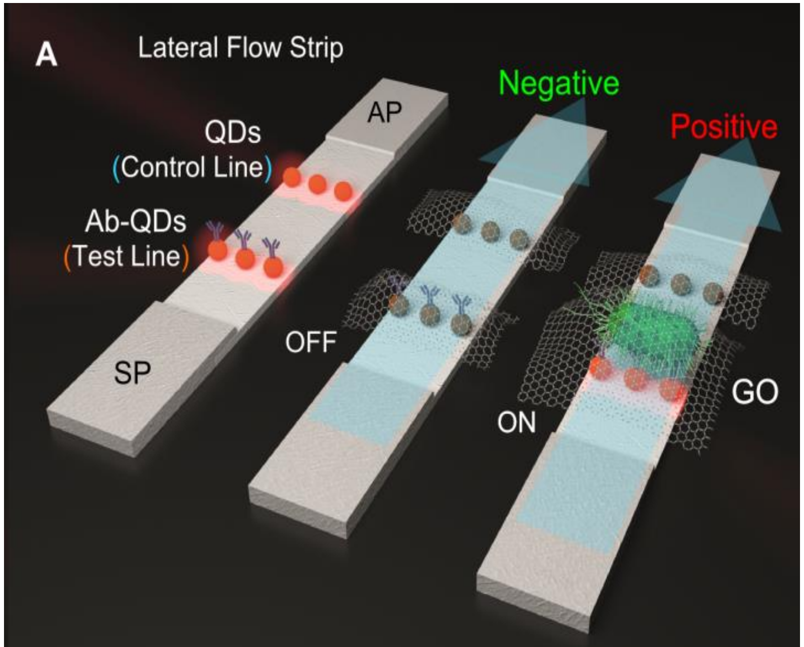
(43) International Publication Date
23 April 2015 (23.04.2015)

WIPO | PCT

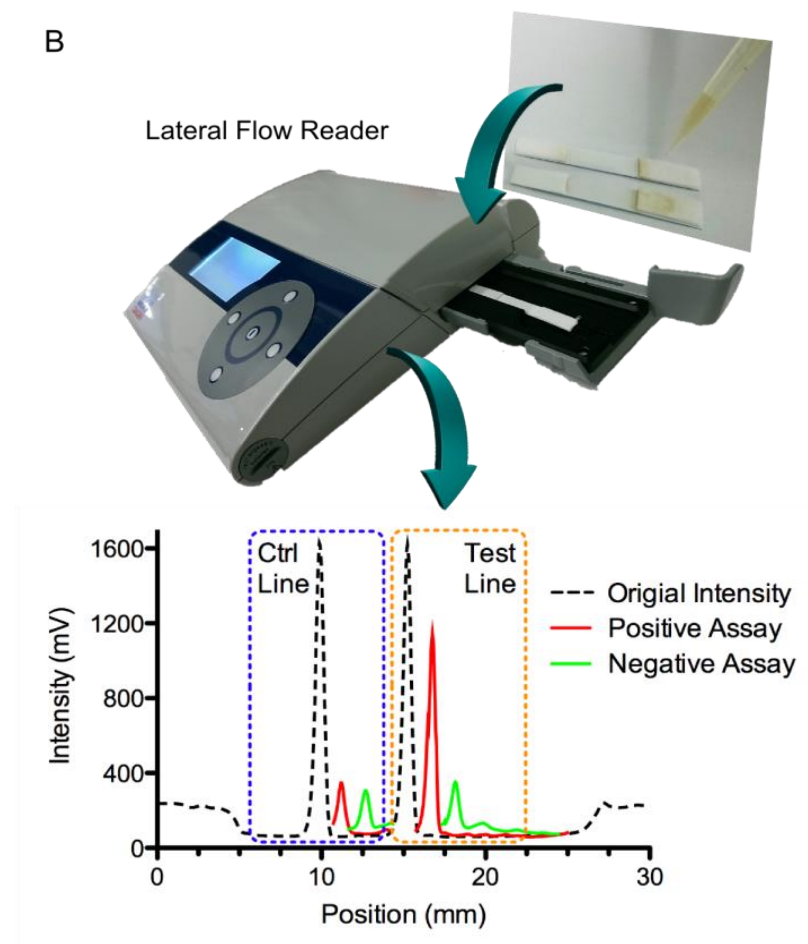
(10) International Publication Number
**WO 2015/055708 A1**

Morales-Narváez, Merkoçi, et al., *Angew. Chem. Int. Ed.* **2013**, 52, 13779

# GO as a pathogen-revealing agent




Video of the process

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WO 2015/055708 A1

ales-Narváez, Naghdi, Zor, Merkoçi, *Anal. Chem.* **2015**, 87:8573

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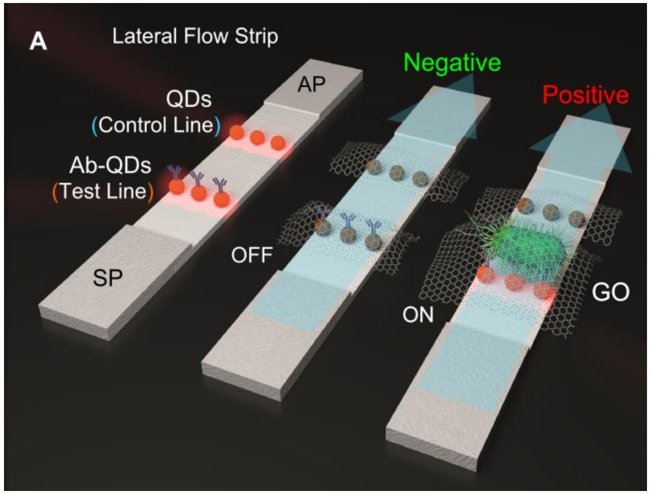
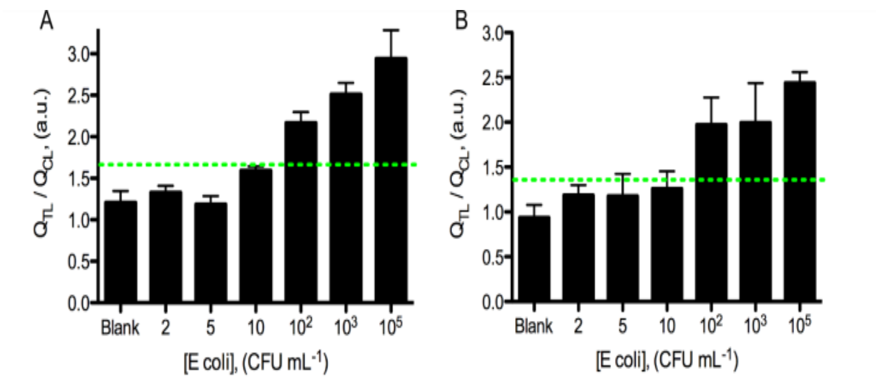
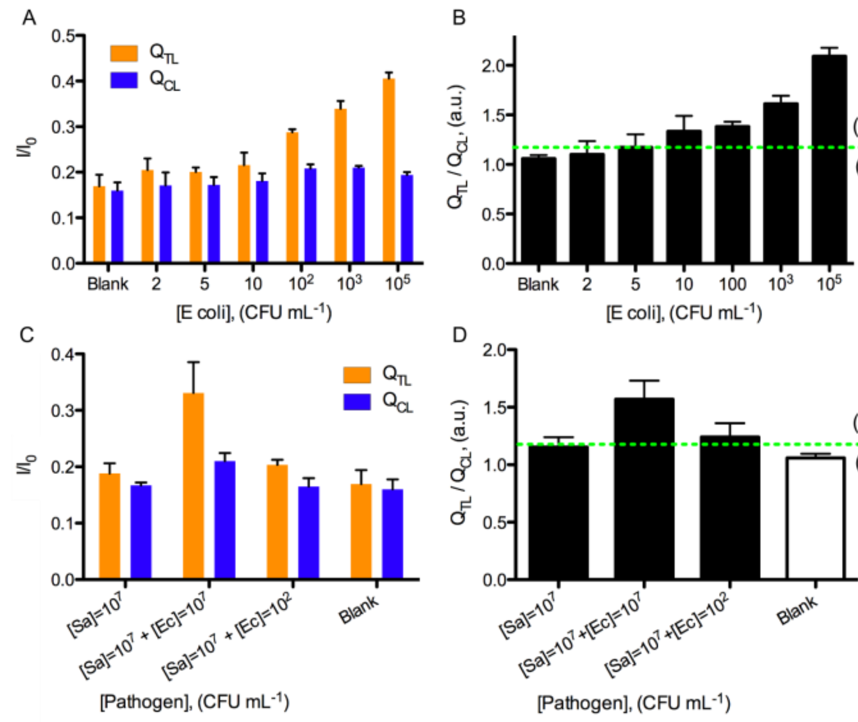


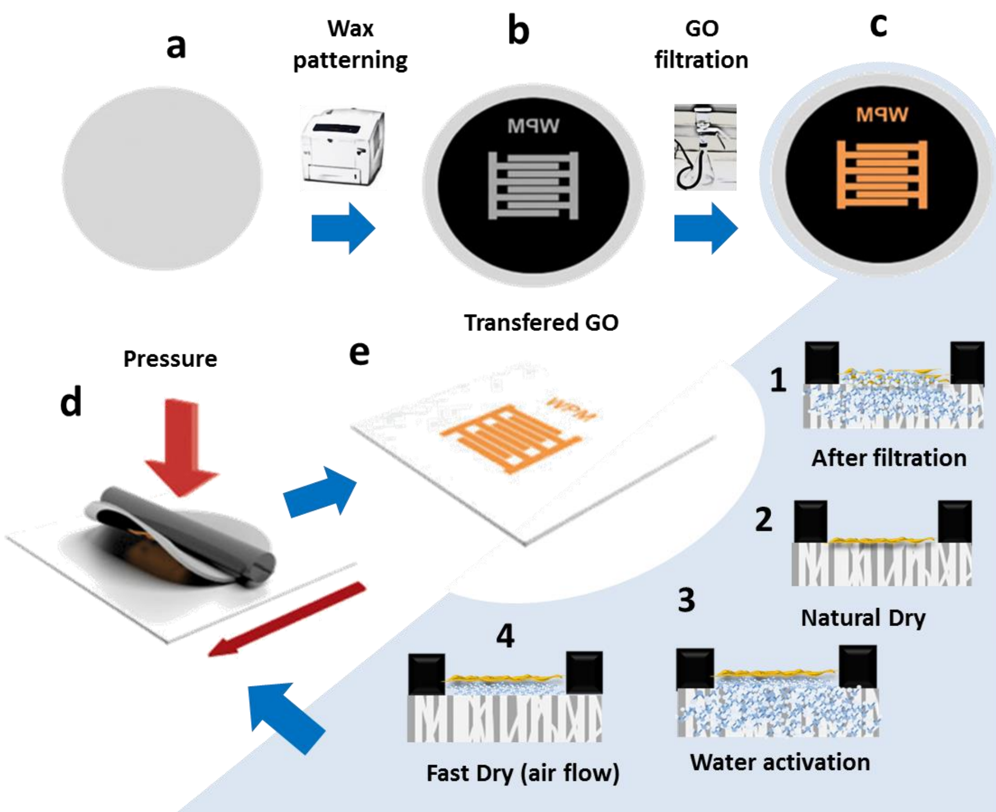




Morales-Narváez, Naghdi, Zor, Merkoçi, *Anal. Chem.* **2015**, 87:8573

ICN2 Institut Català de Nanociència i Nanotecnologia EXCELENCIA SEVERO OCHOA

# Water Activated Graphene Oxide Transfer Using Wax Printed Membranes for Fast Patterning of Electrical Devices




Video of printing


Baptista-Pires,Mayorga-Martínez, Medina-Sánchez, Montón, Merkoçi, **ACS Nano** 2016, 10, 853−860

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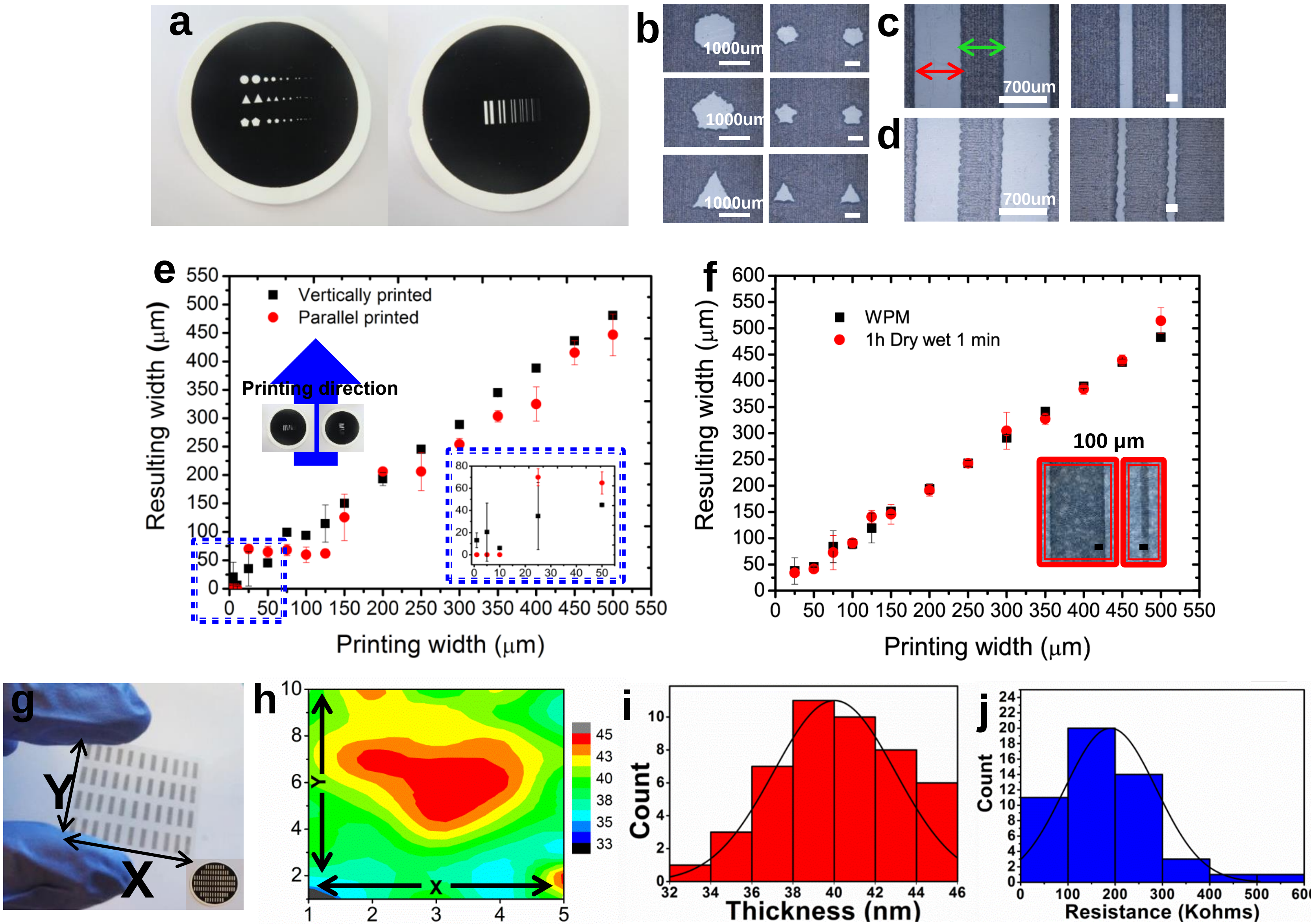


Baptista-Pires,Mayorga-Martínez, Medina-Sánchez, Montón, Merkoçl, **ACS Nano** 2016, 10, 853−860

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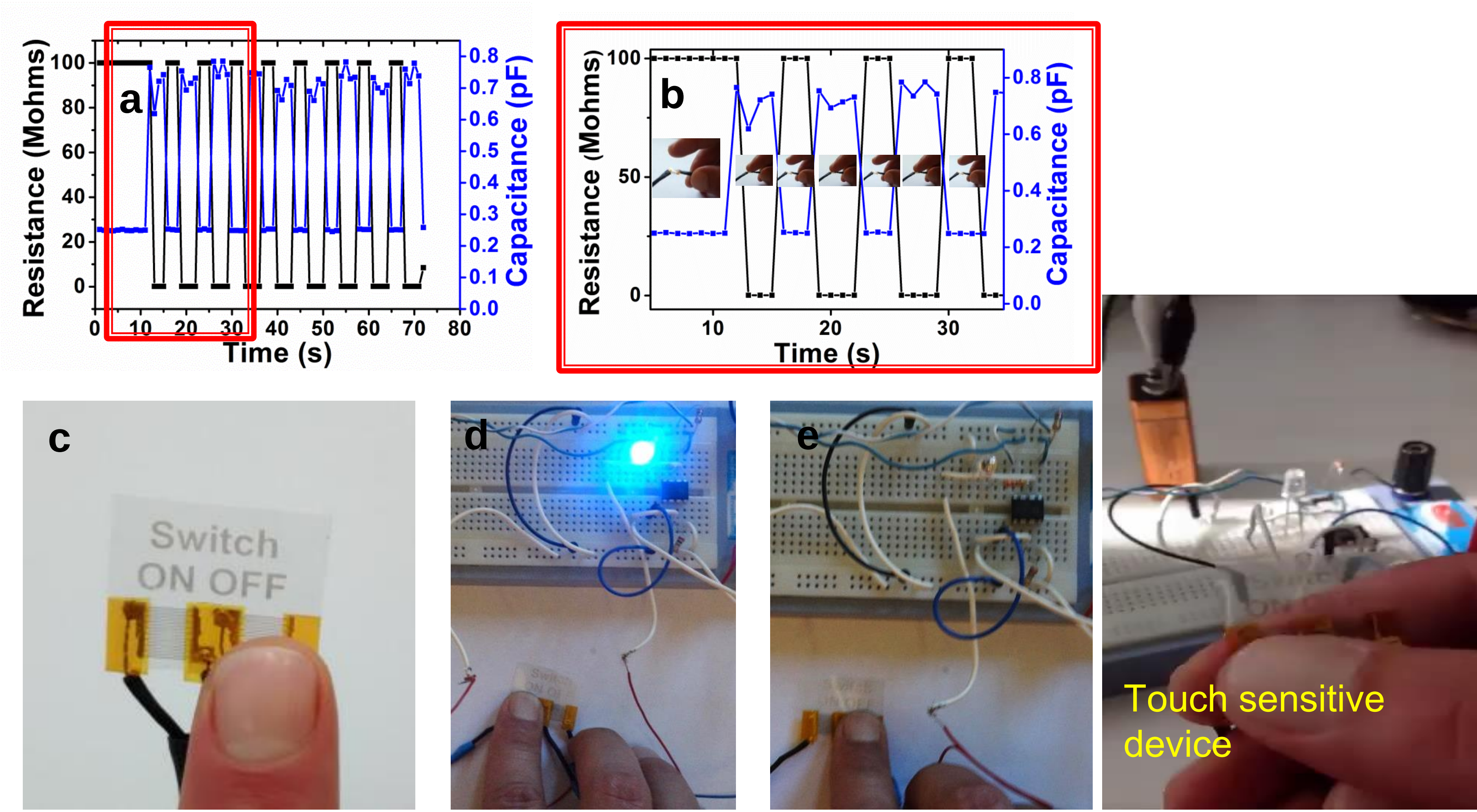
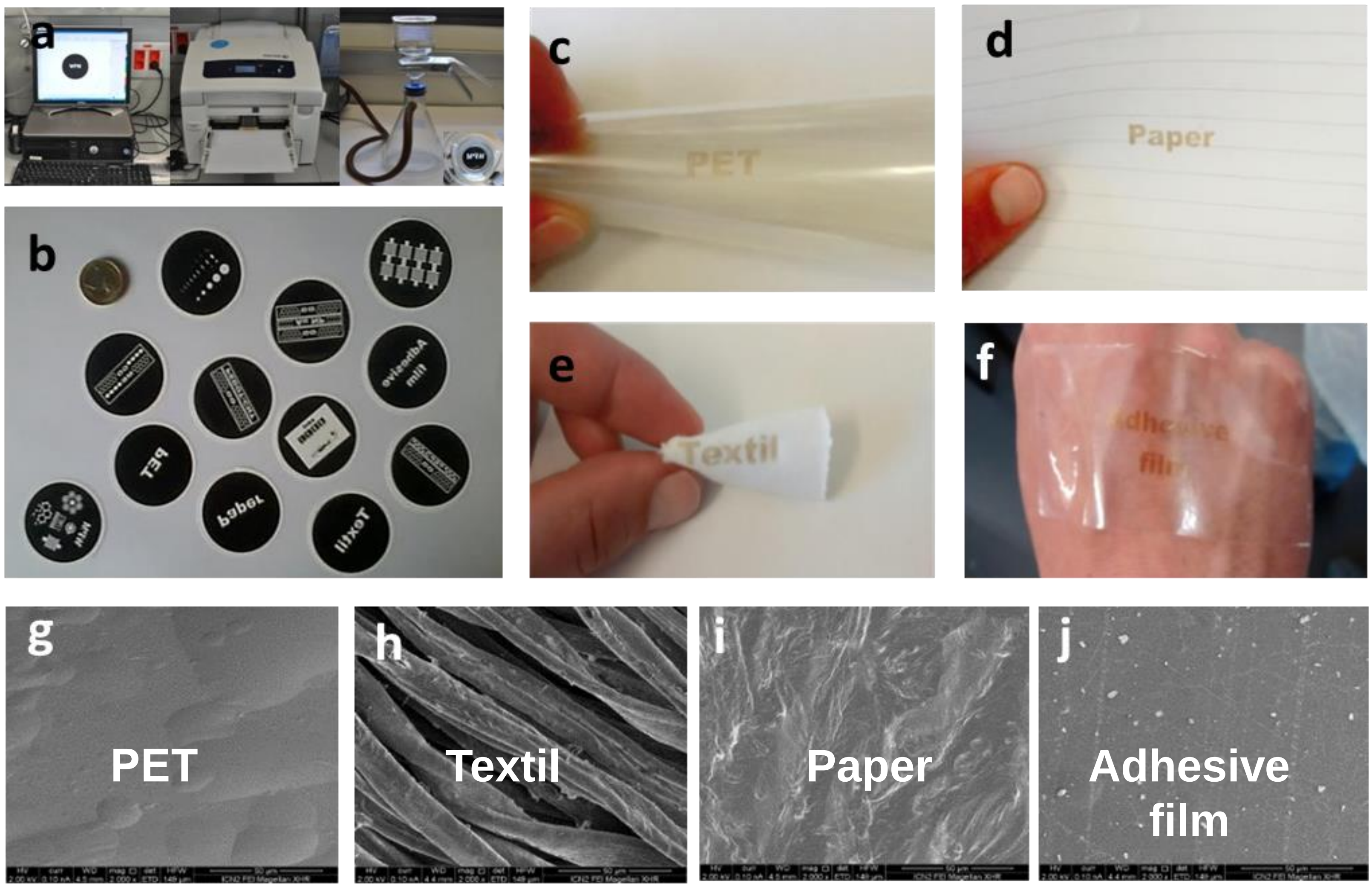


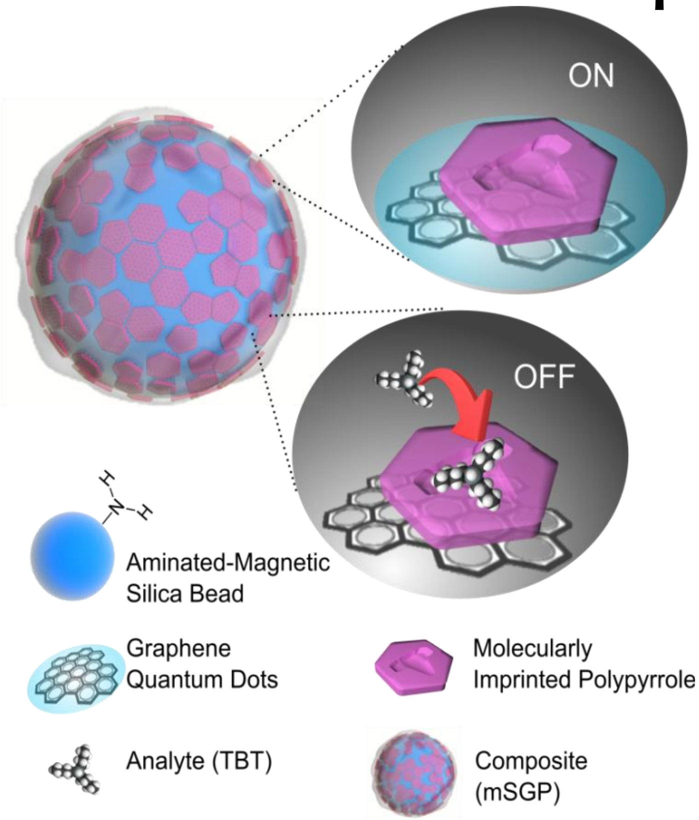

Baptista-Pires,Mayorga-Martínez, Medina-Sánchez, Montón,  Merkoçl, **ACS Nano** 2016, 10, 853−860

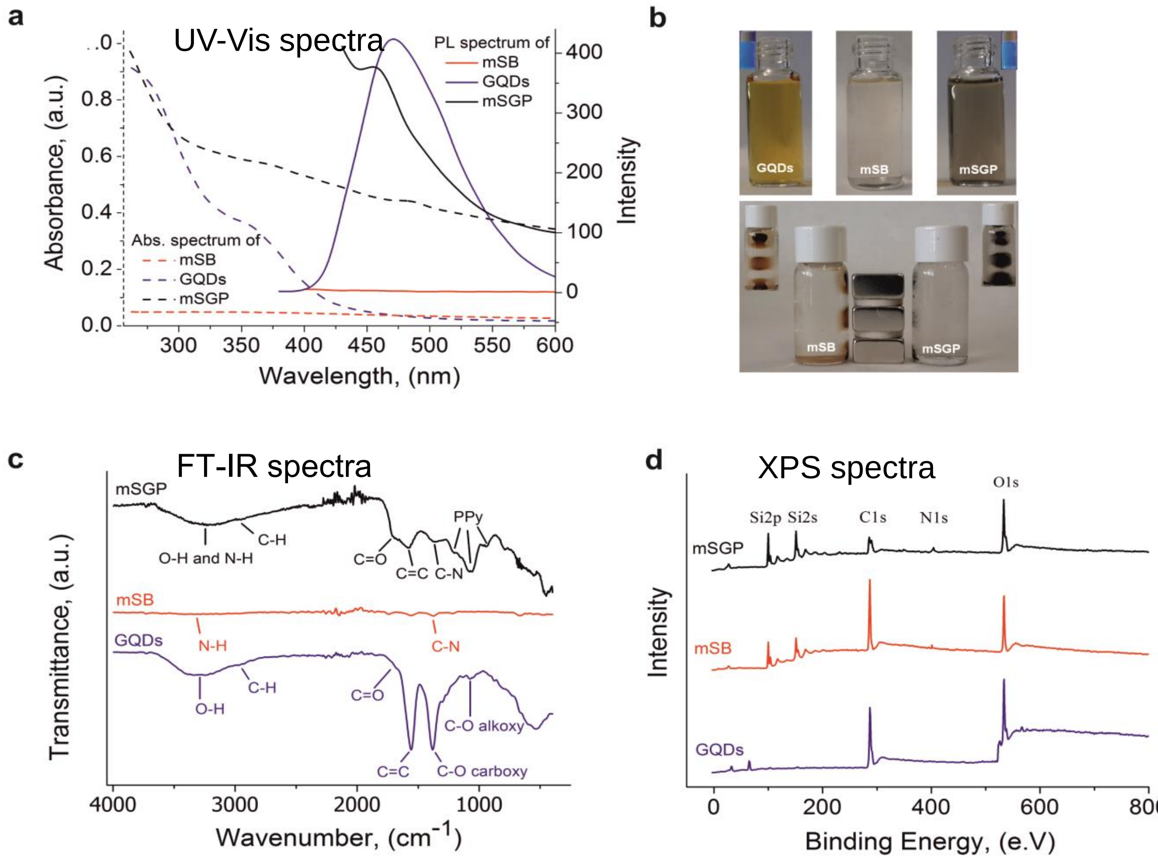
# Transfer onto flexible substrates



# GO as a PL donor

## Graphene Quantum Dots-based Photoluminescent Sensor: A Multifunctional Composite for Pesticide Detection




Zor, Morales-Narváez, Zamora-Gálvez, Bingol, Ersoz, Merkoçi, *ACS Appl Mater Interfaces.* **2015**, 7:20272

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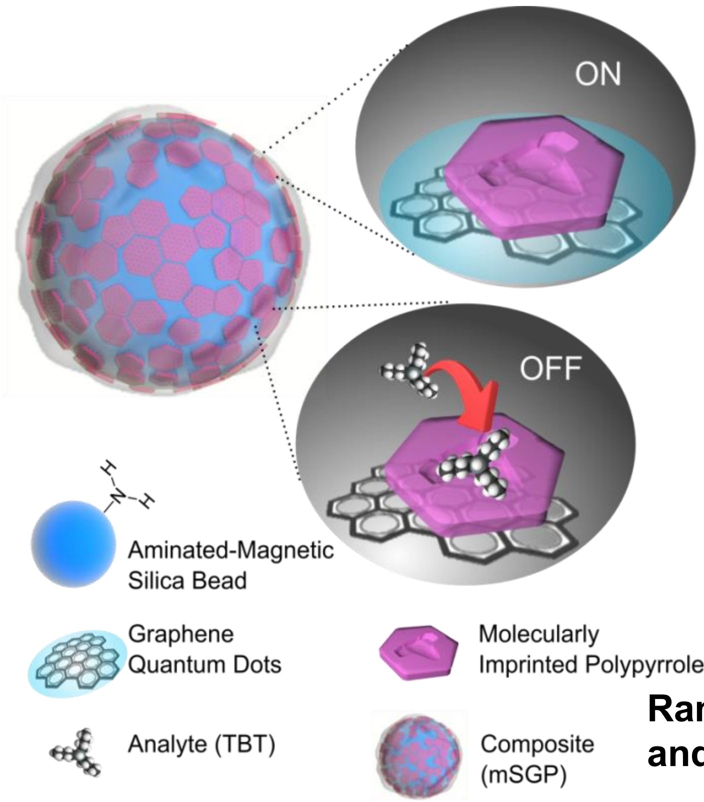
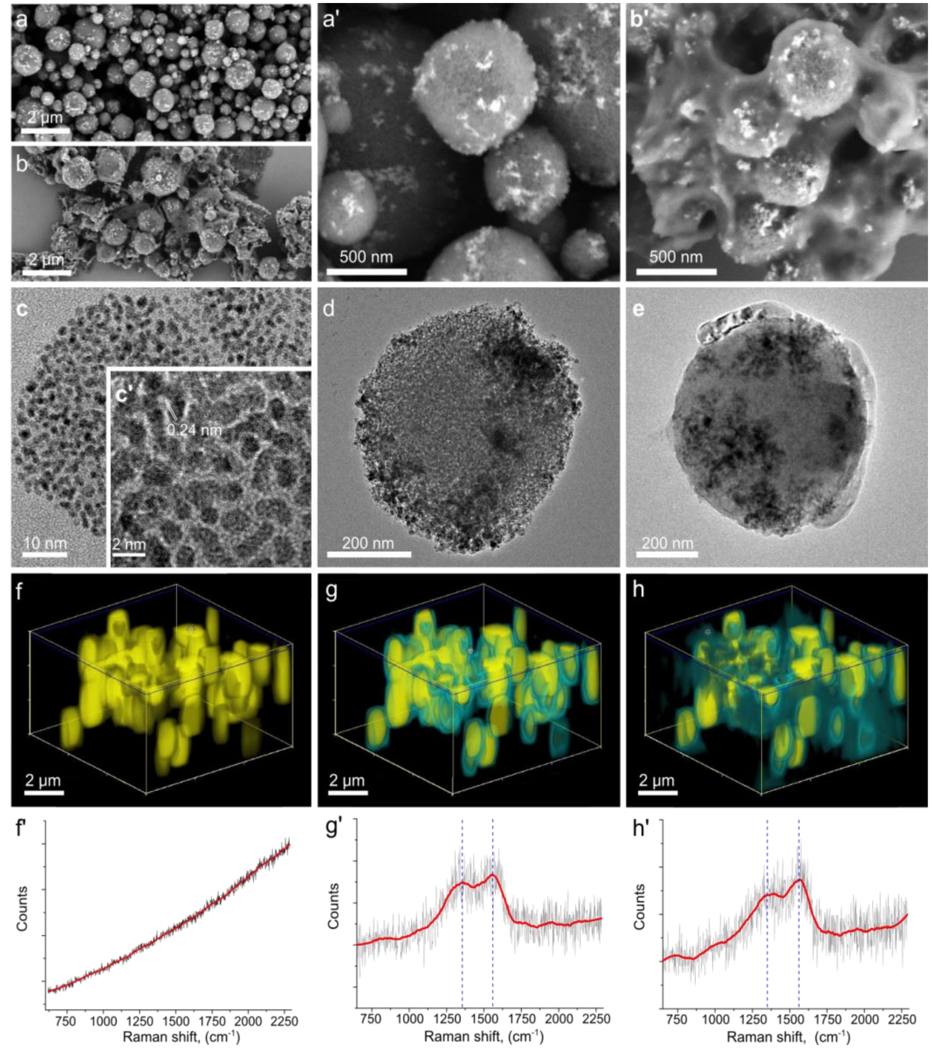



**SEM**

**HRTEM**

**Raman images and spectra**

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EXCELENCIA SEVERO OCHOA

Zor, Morales-Narváez, Zamora-Gálvez, Bingol, Ersoz, Merkoçi, *ACS Appl Mater Interfaces.* **2015**, 7:20272

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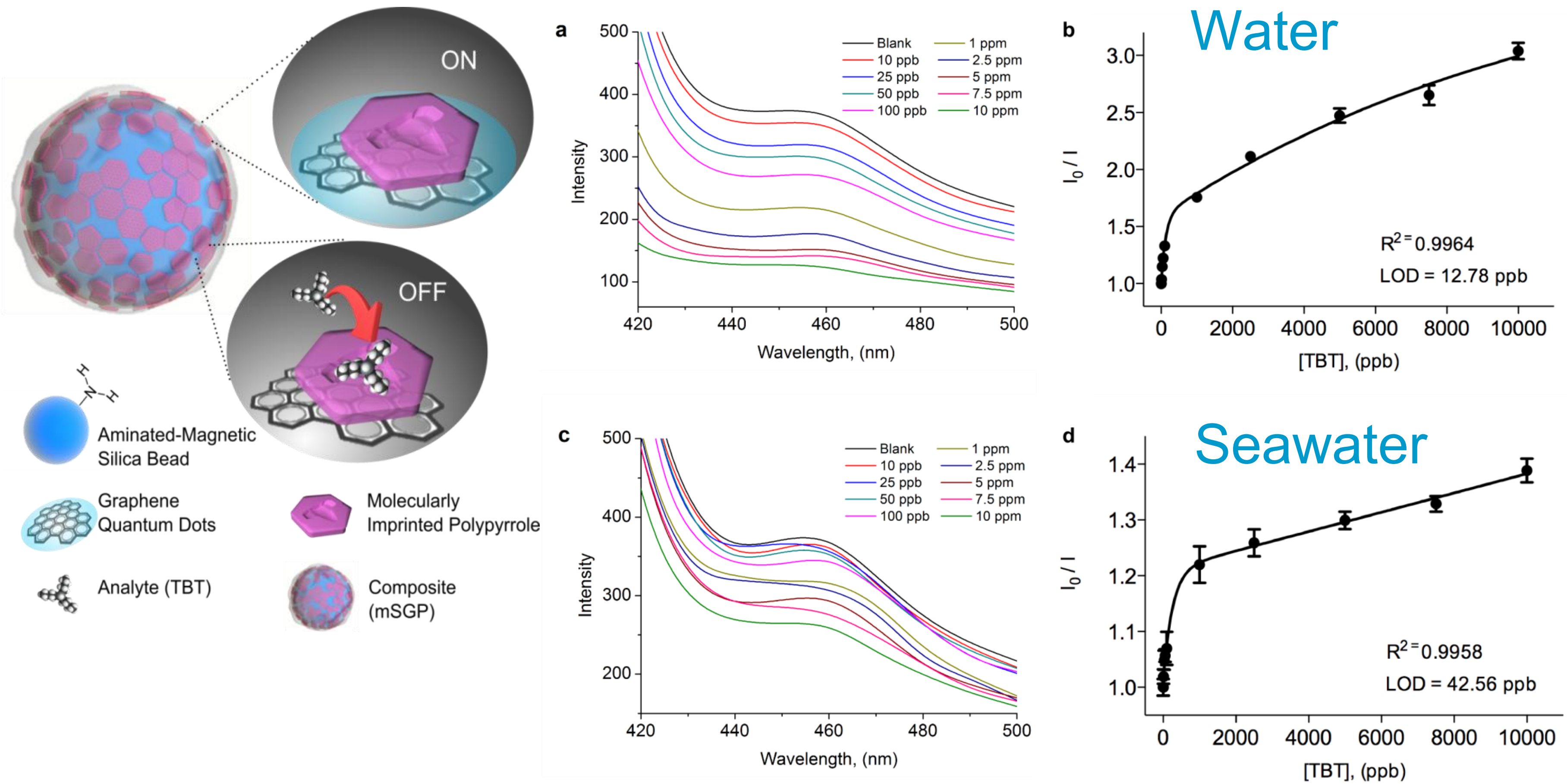
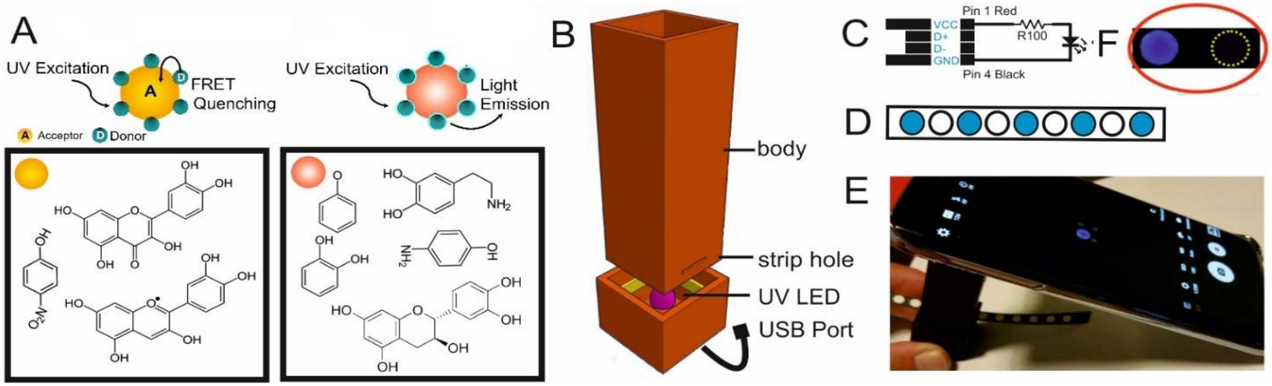
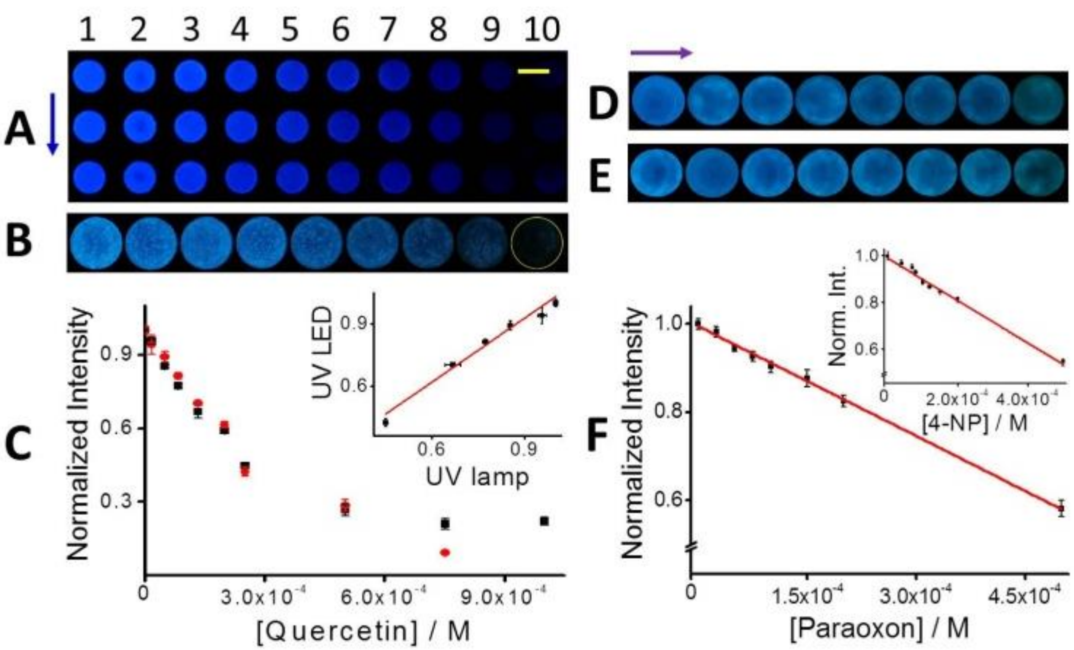
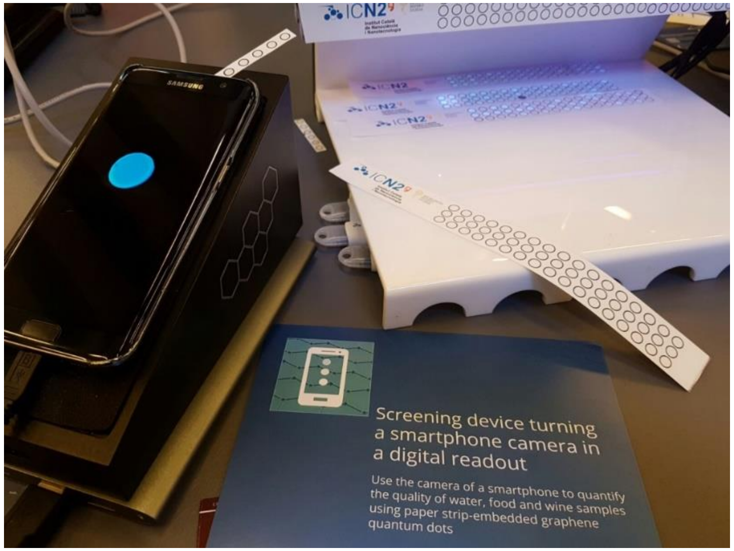



Zor, Morales-Narváez, Zamora-Gálvez, Bingol, Ersoz, Merkoçi, *ACS Appl Mater Interfaces.* **2015**, 7:20272

# Smart-phone /graphene -enabling biosensing




**Smart-phone paper/graphene-based sensor for safety and security applications**

**European Patent Application P30540EP00**

*Arben Merkoçi et al. Scientific Reports, 2017,*

# SMARTPHONE
## Paper/Graphene-Enabling Biosensing

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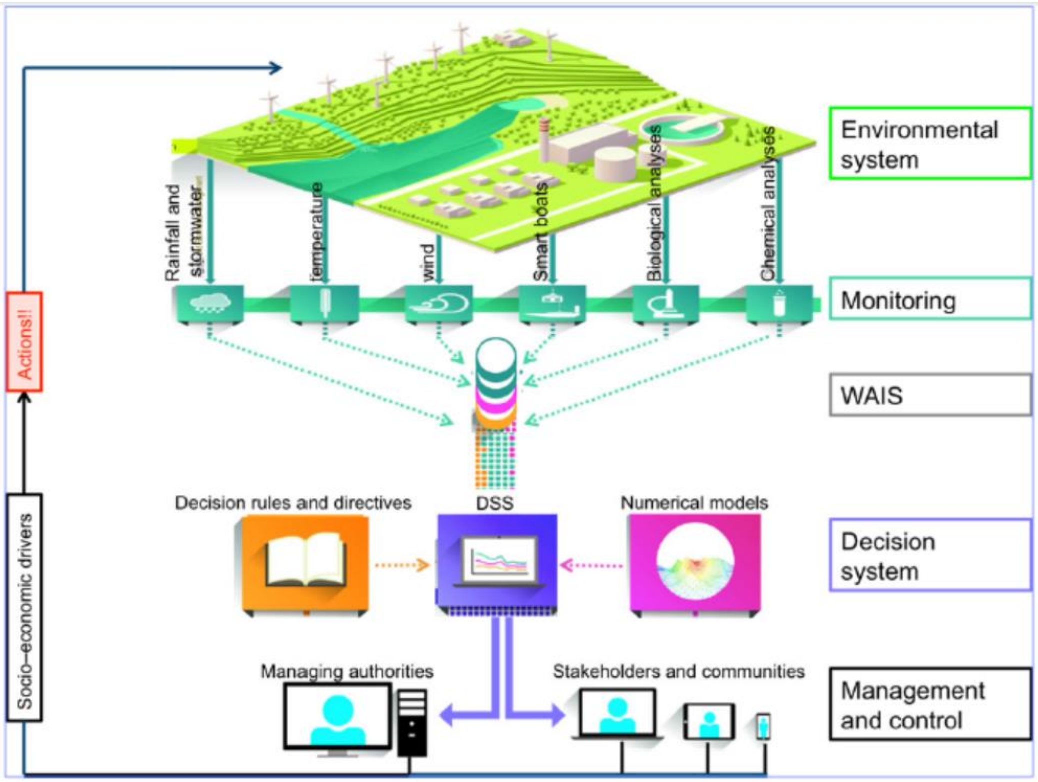
# Innovative monitoring tools for river and lake water quality, and a new business model for 2020 and beyond



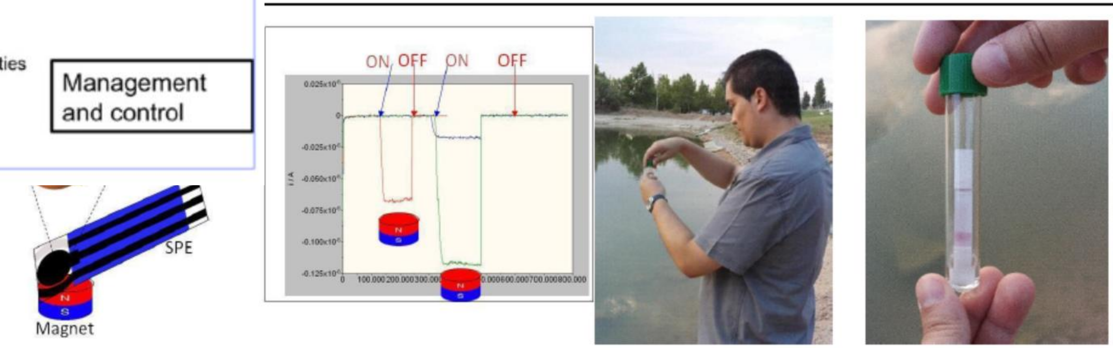
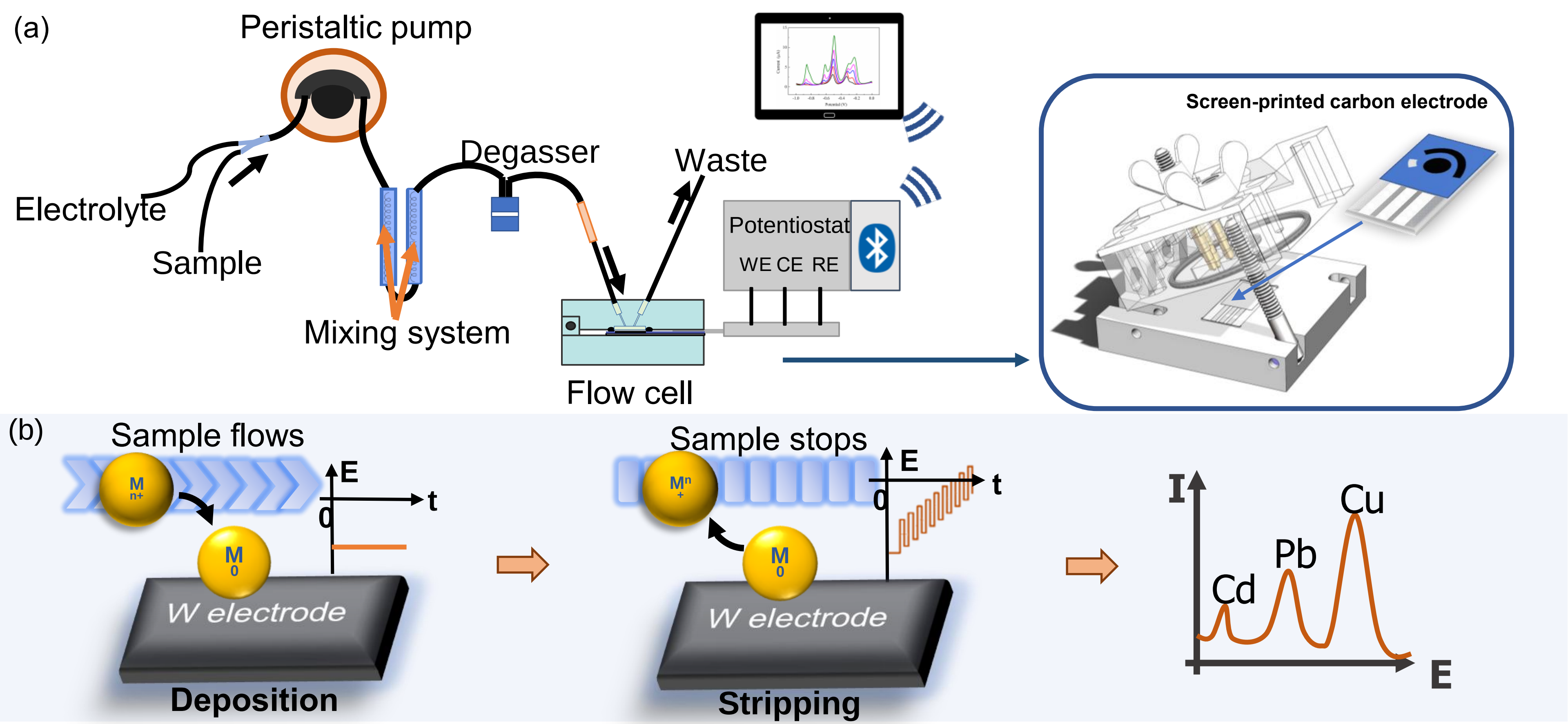



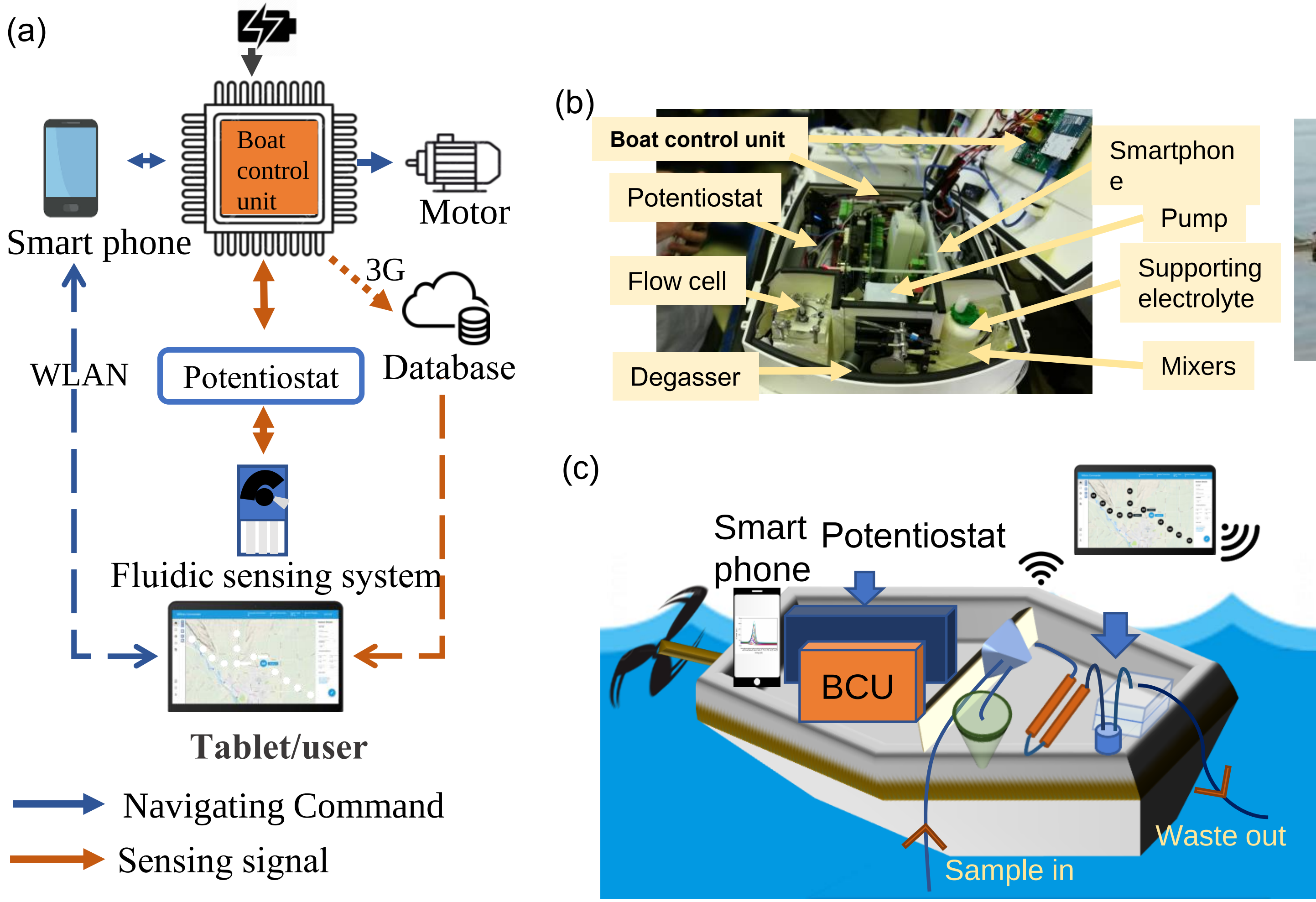

**Figure 1.4** The two approaches to using innovative sensors the nanoparticle based metal system for the boats (left), and the land-based strips (right)

# Laboratory set-up for *in-situ* and automatic heavy metal sensing measurements




*Yang, Qiuyue, Merkoçi et al. "Development of a heavy metal sensing boat for automatic analysis in natural waters utilizing anodic stripping voltammetry." ACS ES&T Water 1.12 (2021): 2470-2476.*

# Autonomous boat for heavy metal sensing measurements




- Automatic driving and measurement
- Real-time route and modification
- Wireless data transmission

*Yang, Qiuyue, Merkoçi et al. "Development of a heavy metal sensing boat for automatic analysis in natural waters utilizing anodic stripping voltammetry." ACS ES&T Water 1.12 (2021): 2470-2476.*

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## Heavy metal sensing performance

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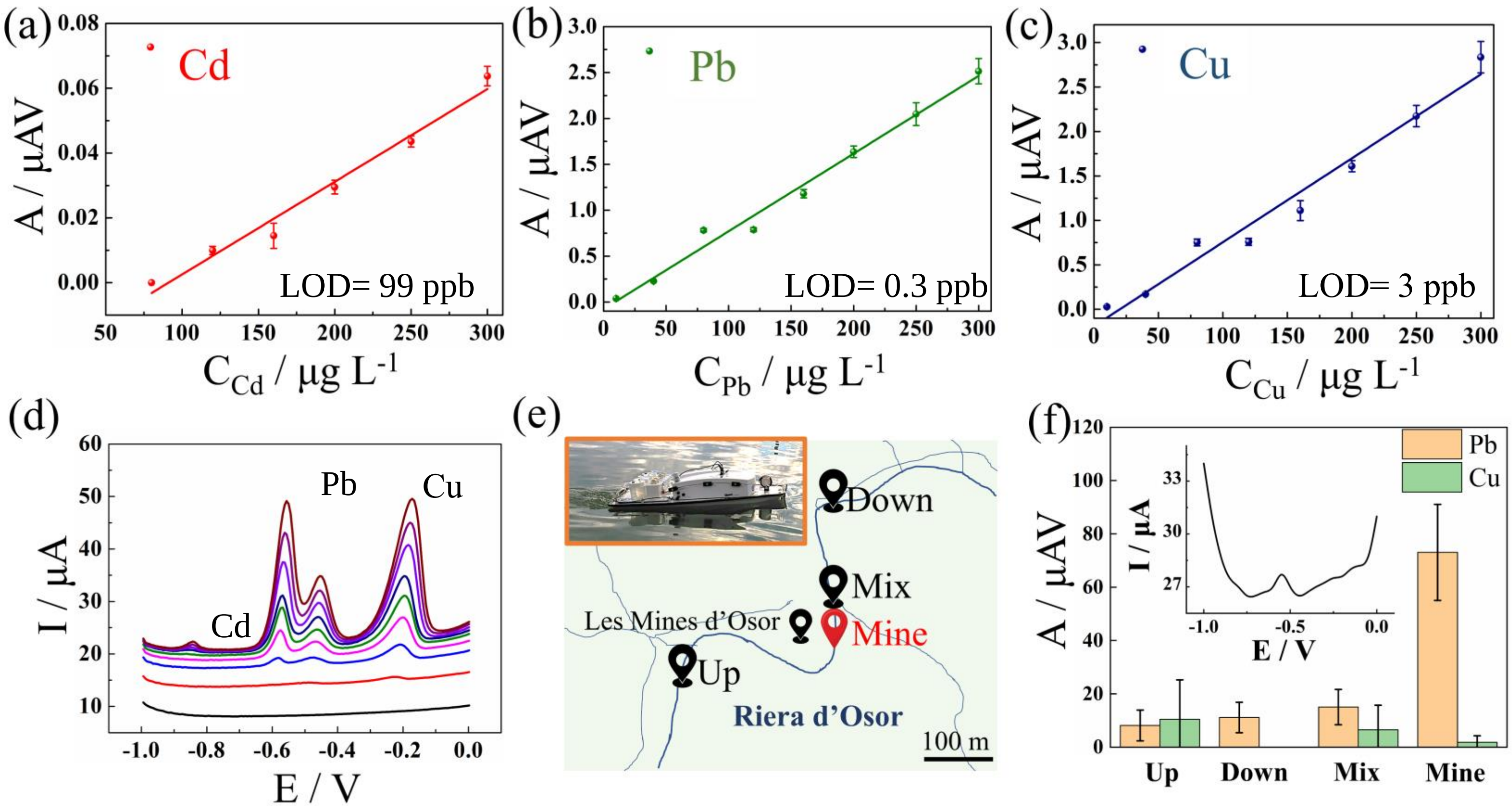
Biodiversitat, Ecologia, Tecnologia Ambiental i Alimentària

BOKU
University of Natural Resources and Life Sciences, Vienna




**originated from F–Ba–Pb–Zn mine vein**

*Yang, Qiuyue, Merkoçi et al. "Development of a heavy metal sensing boat for automatic analysis in natural waters utilizing anodic stripping voltammetry." ACS ES&T Water 1.12 (2021): 2470-2476.*

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## Navigating performance

University of Natural Resources and Life Sciences, Vienna

# Conclusions

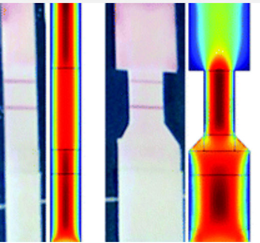
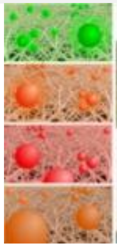
**Nanobiosensors** represent a great alternative for environment monitoring

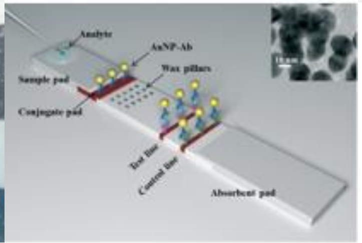
**These devices** and related fabrication technologies offer unpresented alternative for the democratization of monitoring systems

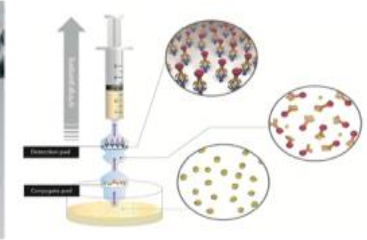
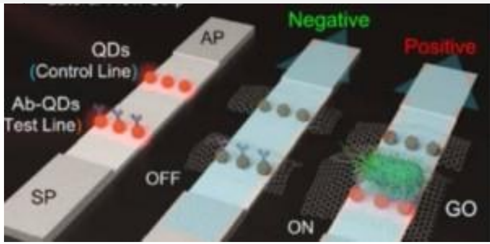
**Nanomatarials** can be easily coupled to paper-based  platforms to build cost/efficient nanobiosensors

**Nanomaterials** exhibit unprecedented properties as either electrical or optical transducer for biosensing applications

**Their properties and related platforms can enable**:
- Connection to a variety of (bio)receptors and nanomaterials
- Simple assay procedures and avoid time consuming labours
- Compatibility with mobile phone technology and other smart environment monitoring systems.



# Our review articles

NANO Bioelectronics & Biosensors Group
www.nanobiosensors.org

CHEMICAL REVIEWS — REVIEW — pubs.acs.org/CR

**Recent Trends in Macro-, Micro-, and Nanomaterial-Based Tools and Strategies for Heavy-Metal Detection**

Gemma Aragay,[†,‡] Josefina Pons,[‡] and Arben Merkoçi*[†,§]

[†]Nanobioelectronics & Biosensors Group, Institut Català de Nanotecnologia (CIN2, ICN-CSIC), 08193, Bellaterra, Barcelona, Spain
[‡]Departament of Chemistry, Universitat Autònoma de Barcelona, 08193, Bellaterra, Barcelona, Spain
[§]ICREA, Barcelona, Spain

Chemical Reviews, 111, 3433-3458, 2011.

ACS Nano, 2012, DOI: 10.1021/nn301368z

**Nanochannels Preparation and Application in Biosensing**

Alfredo de la Escosura-Muñiz[†] and Arben Merkoçi[†,‡,*]

nature protocols — REVIEW ARTICLE

https://doi.org/10.1038/s41596-020-0357-x

Check for updates

**Tutorial: design and fabrication of nanoparticle-based lateral-flow immunoassays**

Claudio Parolo[1,5], Amadeo Sena-Torralba[1,5], José Francisco Bergua[1], Enric Calucho[1], Celia Fuentes-Chust[1], Liming Hu[1], Lourdes Rivas[1], Ruslan Álvarez-Diduk[1], Emily P. Nguyen[1], Stefano Cinti[2], Daniel Quesada-González[3] and Arben Merkoçi[1,4]

CHEMICAL REVIEWS — Review — pubs.acs.org/CR

Chemical Reviews, 2012, 112, 5317–5338

**Nanomaterials for Sensing and Destroying Pesticides**

Gemma Aragay,[†] Flavio Pino,[†] and Arben Merkoçi*[†,‡]

CHEMICAL REVIEWS — Review — pubs.acs.org/CR

Chemical Reviews, 114 (12), 6285–6322 (2014)

**Nano/Micromotors in (Bio)chemical Science Applications**

Maria Guix,[†] Carmen C. Mayorga-Martinez,[†] and Arben Merkoçi*[†,‡]

[†]Nanobioelectronics & Biosensors Group, Institut Català de Nanosciencia i Nanotecnologia (ICN2), UAB Campus, 08193 Bellaterra, Barcelona, Spain
[‡]ICREA, Passeig de Lluís Companys, 23, 08010 Barcelona, Spain

ACS NANO — PERSPECTIVE — www.acsnano.org

**Toward Nanotechnology-Enabled Approaches against the COVID-19 Pandemic**

Carsten Weiss, Marie Carriere, Laura Fusco, Ilaria Capua, Jose Angel Regla-Nava, Matteo Pasquali, James A. Scott, Flavia Vitale, Mehmet Altay Unal, Cecilia Mattevi, Davide Bedognetti, Arben Merkoçi, Ennio Tasciotti, Açelya Yilmazer, Yury Gogotsi, Francesco Stellacci, and Lucia Gemma Delogu*

Cite This: ACS Nano 2020, 14, 6383–6406 Read Online

Chem Soc Rev — Dynamic Article Links

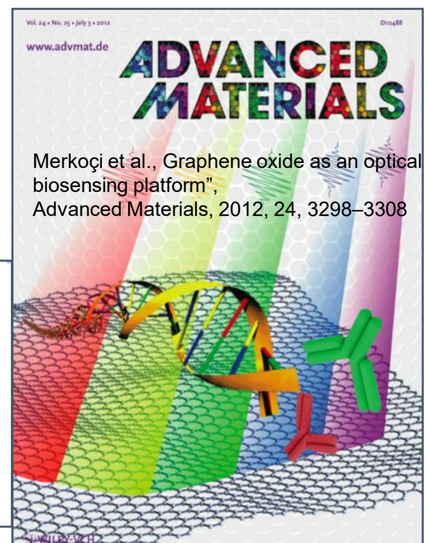
Cite this: Chem. Soc. Rev., 2012, 41, 2606–2622

www.rsc.org/csr

TUTORIAL REVIEW

**Cancer detection using nanoparticle-based sensors†**

Maëlle Perfézou,[ab] Anthony Turner[bc] and Arben Merkoçi*[ad]




Merkoçi et al., Graphene oxide as an optical biosensing platform",
Advanced Materials, 2012, 24, 3298–3308

ACS NANO — REVIEW — www.acsnano.org

**Nanomaterials for Nanotheranostics: Tuning Their Properties According to Disease Needs**

Xin Yi Wong, Amadeo Sena-Torralba, Ruslan Álvarez-Diduk, Kasturi Muthoosamy,* and Arben Merkoçi*

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Cite this: DOI: 10.1039/c2cs35255a

www.rsc.org/csr

TUTORIAL REVIEW

**Paper-based nanobiosensors for diagnostics**

Claudio Parolo[a] and Arben Merkoçi*[ab]

Received 11th July 2012
DOI: 10.1039/c2cs35255a


**Graphene-Based Biosensors: Going Simple**

Eden Morales-Narváez, Luis Baptista-Pires, Alejandro Zamora-Gálvez and Arben Merkoçi

Advanced Materials, 2016 in press

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REVIEW

## Nanodiagnostics to Face SARS-CoV-2 and Future Pandemics: From an Idea to the Market and Beyond

Giulio Rosati, Andrea Idili, Claudio Parolo, Celia Fuentes-Chust, Enric Calucho, Liming Hu, Cecilia de Carvalho Castro e Silva, Lourdes Rivas, Emily P. Nguyen, José F. Bergua, Ruslan Alvárez-Diduk, José Muñoz, Christophe Junot, Oriol Penon, Dominique Monferrer, Emmanuel Delamarche, and Arben Merkoçi*

Cite This: ACS Nano 2021, 15, 17137−17149

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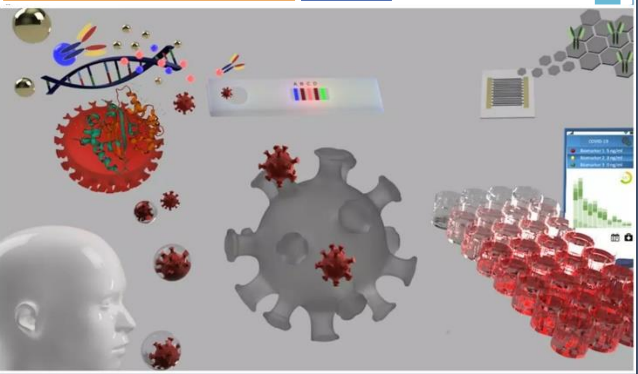
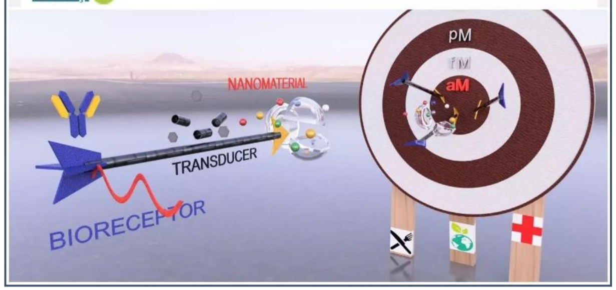


Chem Soc Rev

Chemical Society Reviews

## Attomolar analyte sensing techniques (AttoSens): a review on a decade of progress on chemical and biosensing nanoplatforms

Sruthi Prasood Usha,[a] Hariharan Manoharan,[a] Rehan Deshmukh,[a] Ruslan Álvarez-Diduk,[b] Enric Calucho,[b] V. V. R. Sai *[a] and Arben Merkoçi *[bc]

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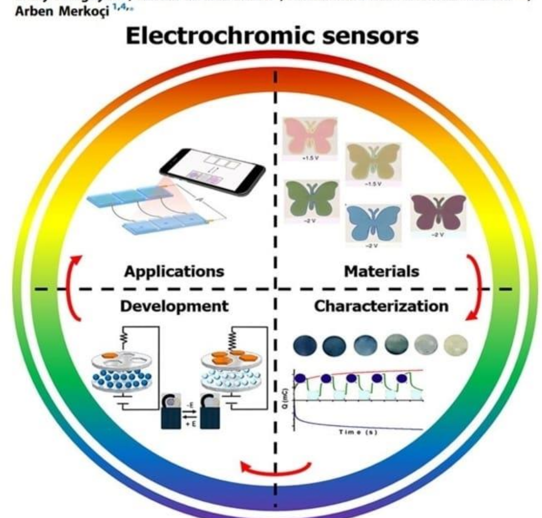
## Electrochromism: An emerging and promising approach in (bio)sensing technology

Mohammad Amin Farahmand Nejad [1,2,†], Saba Ranjbar [1,†], Claudio Parolo [1], Emily P. Nguyen [1], Ruslan àlvarez-Diduk [1], Mohammad Reza Hormozi-Nezhad [2,3], Arben Merkoçi [1,4,*]




Trends in Chemistry

Available online 25 April 2022

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Review

## Paper-based biosensors for cancer diagnostics

Claudia Pereira [1, 2, 3, 9], Claudio Parolo [1, 4, 9], Andrea Idili [1, 5], Roger R. Gomis [6, 7], Lígia Rodrigues [3, 8], Goreti Sales [2], Arben Merkoçi [1, 7]

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# Thank you!

Contacts:

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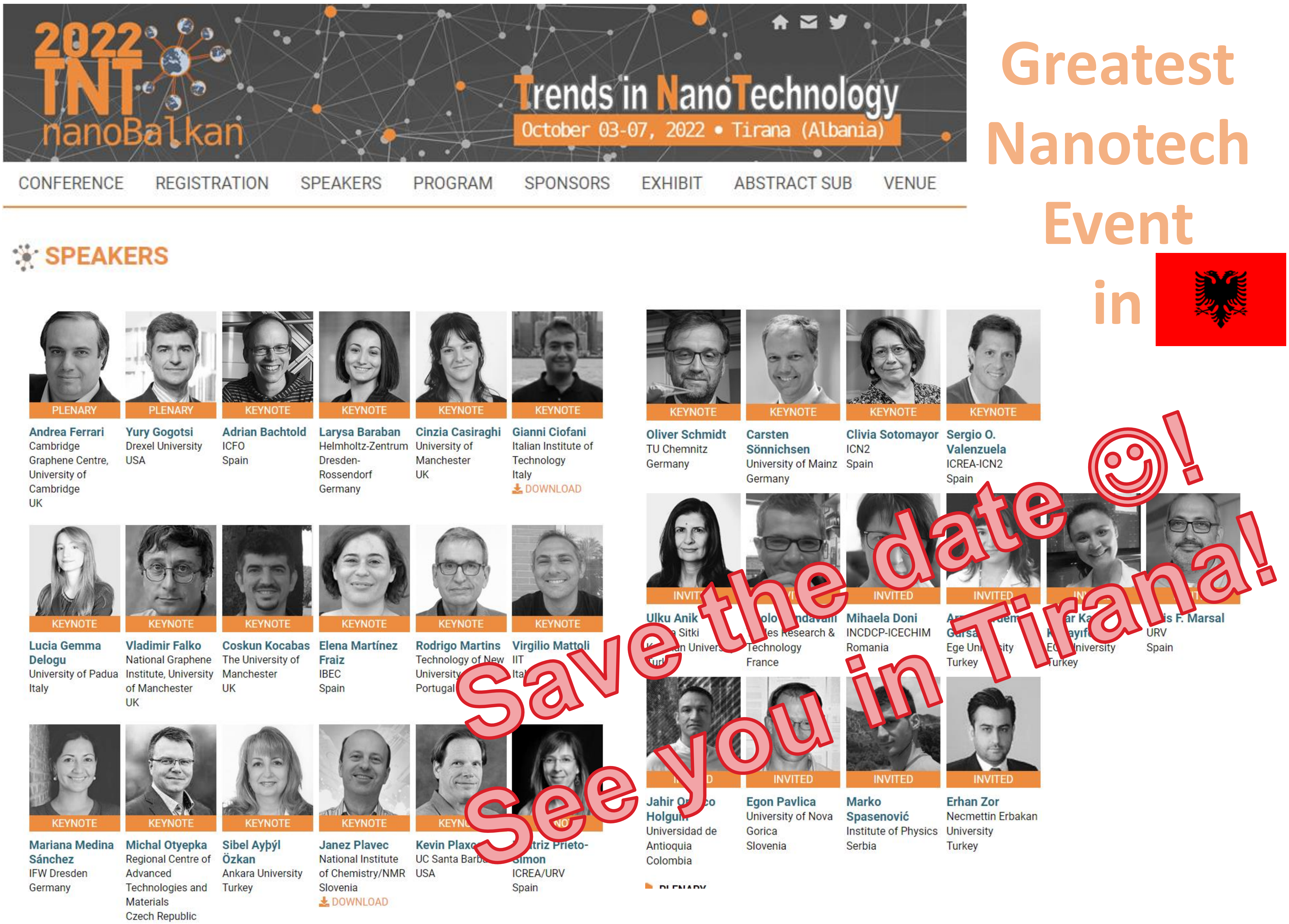
@ Arben Merkoçi / @ Merkoci_research_group



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