UNIVERSITAT DE BARCELONA

TITLE

Low-Power Heating for Conductometric Gas Nano Sensors: Self-Heating Effects and Others …

SPEAKER

O. Monereo, N. Markiewicz, J. Samà, O. Casals, C. Fàbrega, F. Hernandez-Ramírez, A. Cirera, A. Romano-Rodríguez, A. Waag, J.D. Prades

INSTITUTION

MIND/IN^{2}UB, Dept. d'Enginyeria: Electrònica, Universitat de Barcelona, Spain
IHT/EC^2/LENA, Braunschweig University of Technology, Germany

EVENT

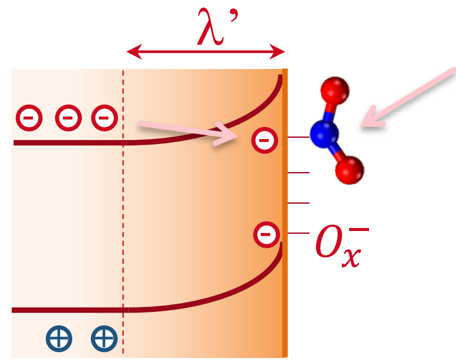
EuNetAir COST Action TD1105
Final Meeting
October 7th, Prague (CZ)

BetterSense
Nanodevice Engineering for a Better Chemical Gas Sensing Technology
an ERC Starting Grant Project

European Research Council

Power Consumption

State of the art



$P \sim {}^{1}/_{4}\ W$

$P \sim 10\ mW$

$P < 10\ \mu W$

J.Daniel Prades
dprades@el.ub.edu

UNIVERSITAT DE BARCELONA

cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY
EuNetAir
European Network on New Sensing Technologies
for Air-Pollution Control and Environmental Sustainability

Heated Gas Sensors

P 3

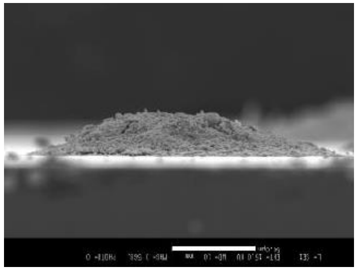
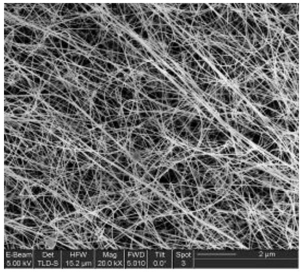
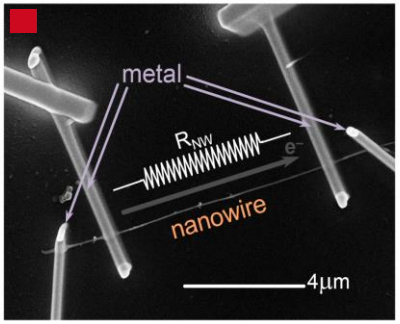
J.Daniel Prades
dprades@el.ub.edu

J.Daniel Prades
dprades@el.ub.edu

Strategy

Miniaturization

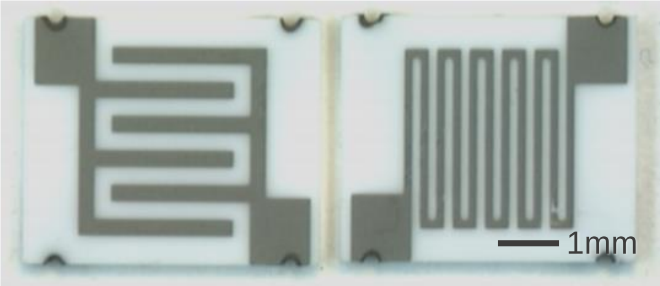
1) Sensing element

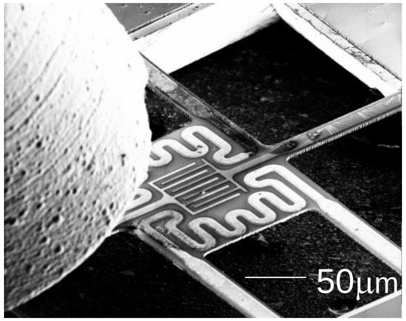




porous layers, bunch of (nano)particles, …

a few nanoparticles

2) Heating element





millimeters scale

microelectronics

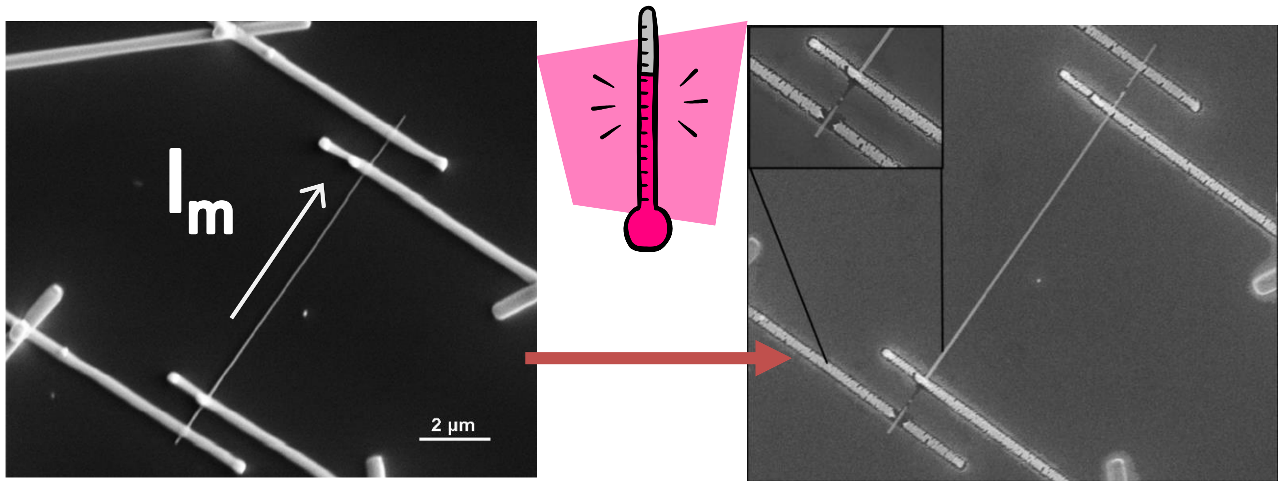
P ~ 10 mW

J.Daniel Prades
dprades@el.ub.edu

Strategy

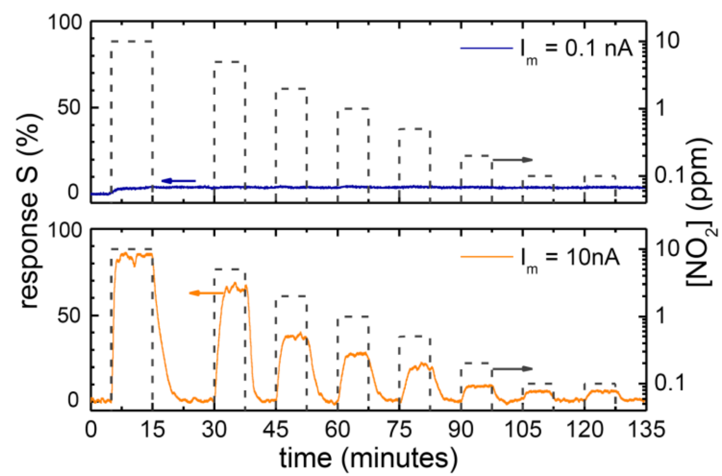
Limits of miniaturization

Appl. Phys. Lett. **93**, 123110 (2008)



efficient
self-heating

P < 10 μW



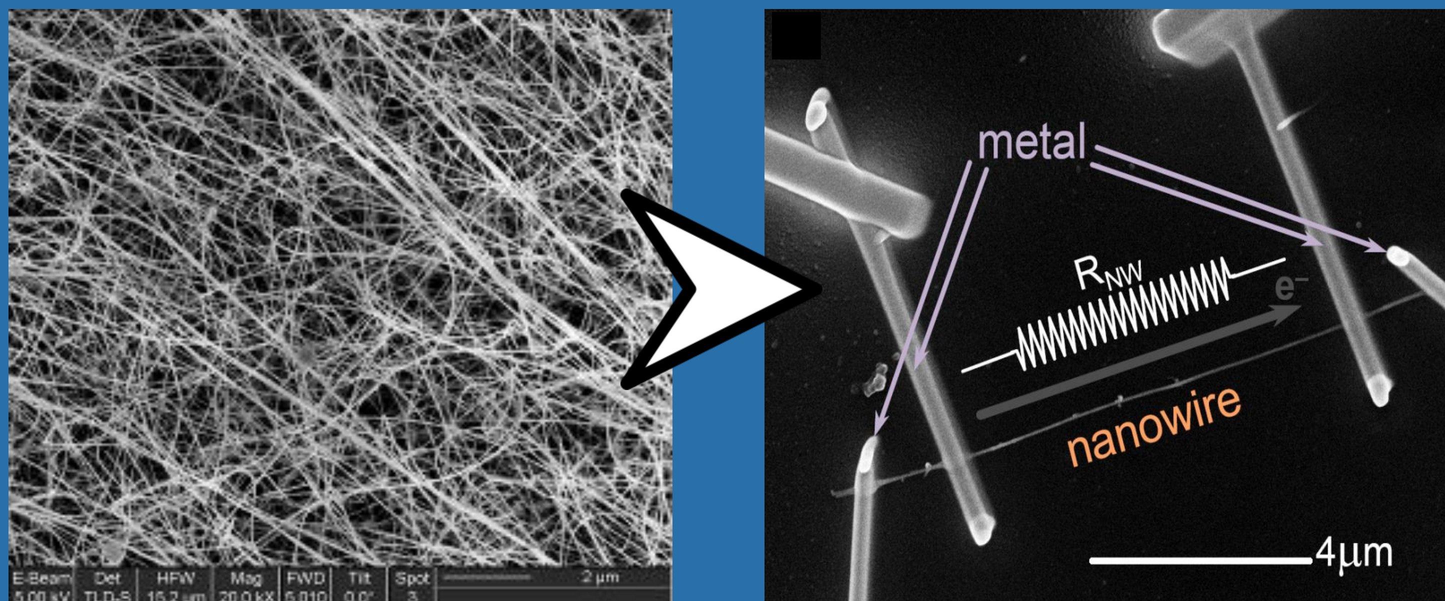
J.Daniel Prades
dprades@el.ub.edu

UNIVERSITAT DE BARCELONA

cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY
EuNetAir
European Network on New Sensing Technologies
for Air-Pollution Control and Environmental Sustainability

Self-heating

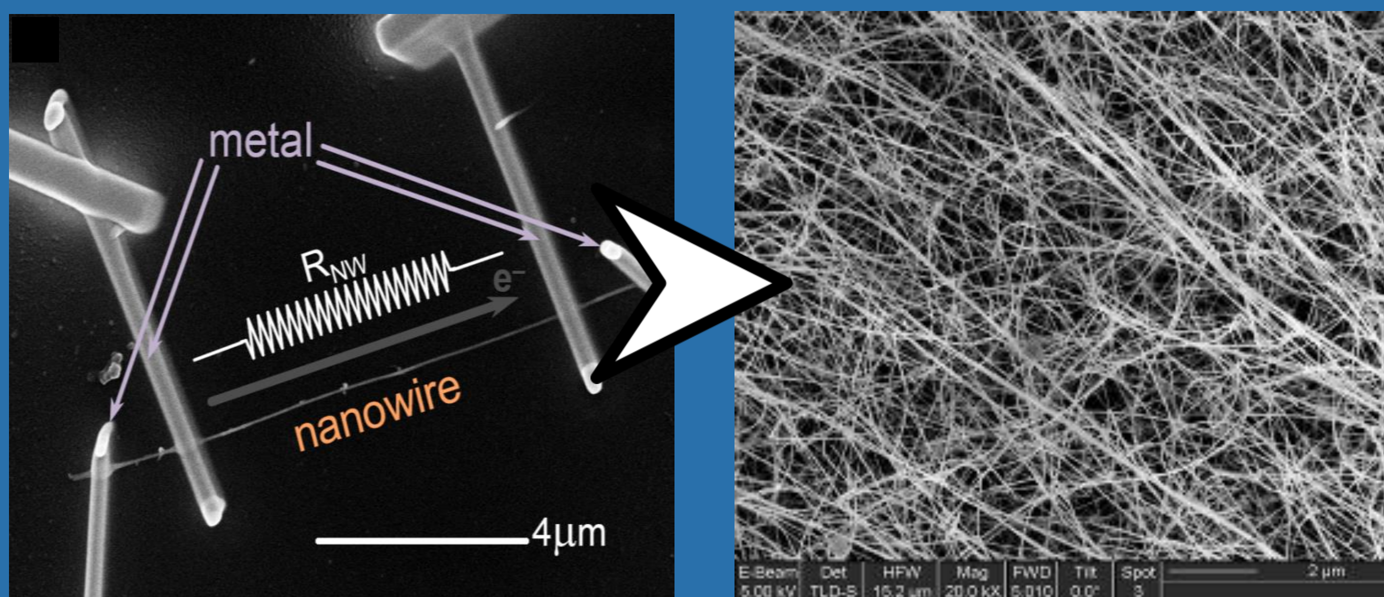
From random wires to single wire.



J.Daniel Prades
dprades@el.ub.edu
Universitat de Barcelona

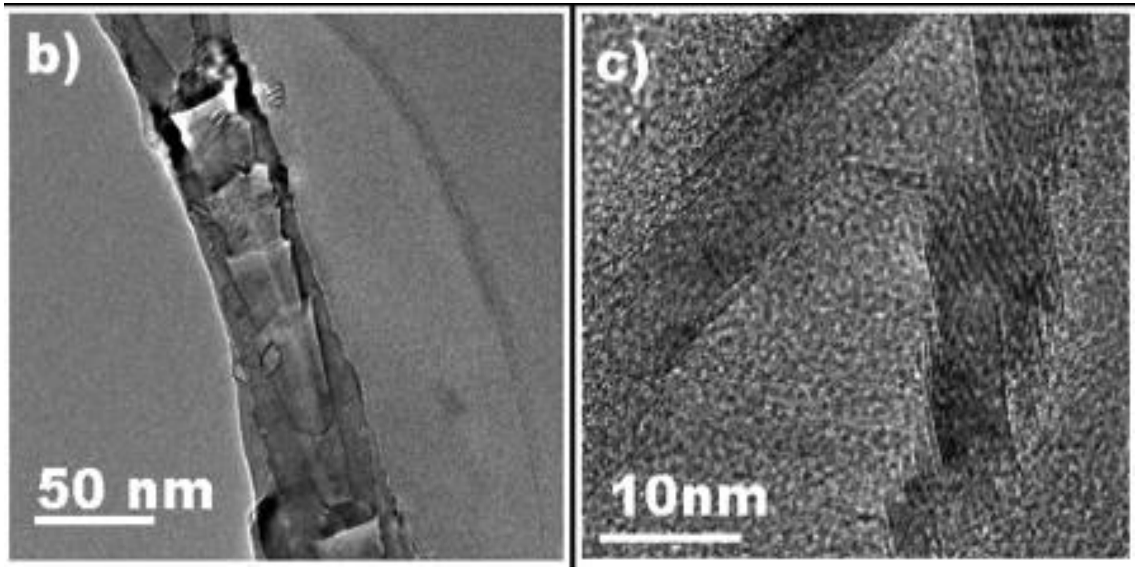
Self-heating

From single wire to random wires ???



J.Daniel Prades
dprades@el.ub.edu

Carbon Nano Fibers (CNF)



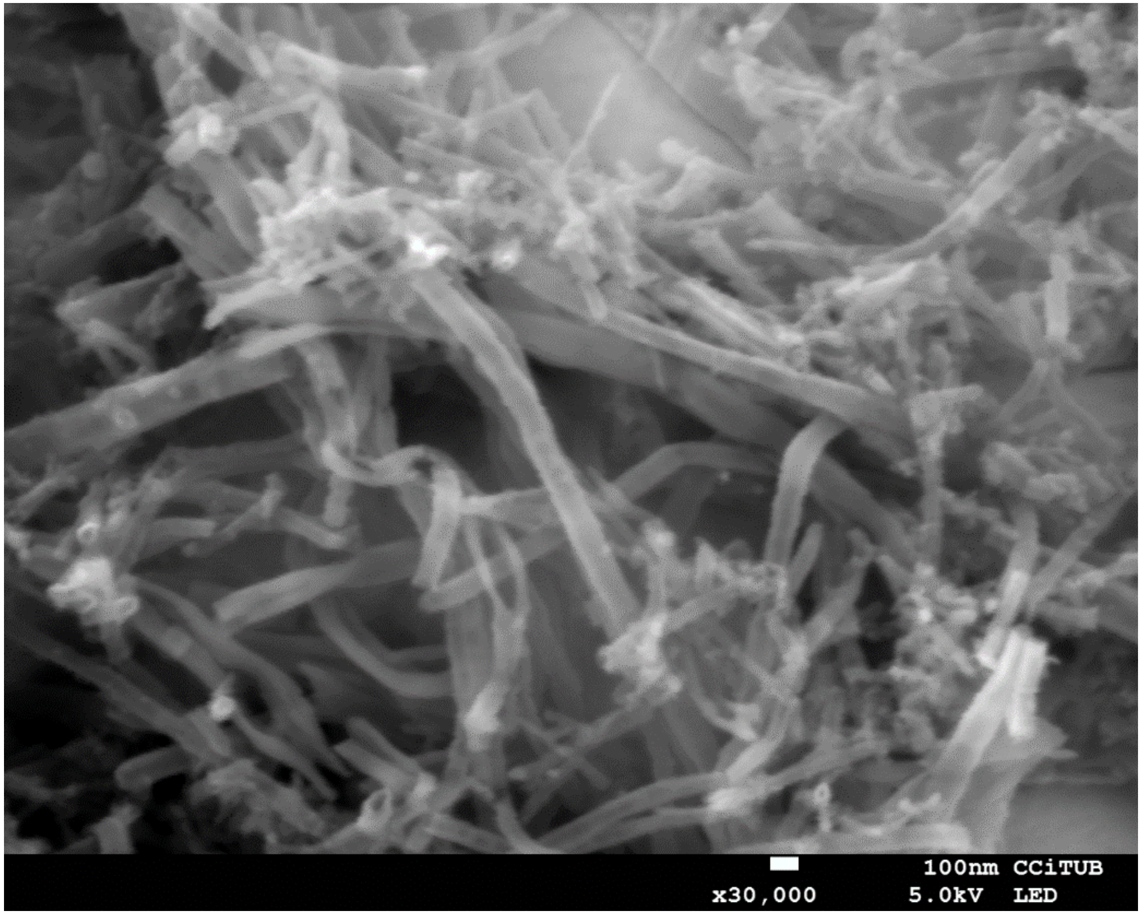
J.Daniel Prades
dprades@el.ub.edu

UNIVERSITAT DE BARCELONA

cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

EUNETAIR
European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability

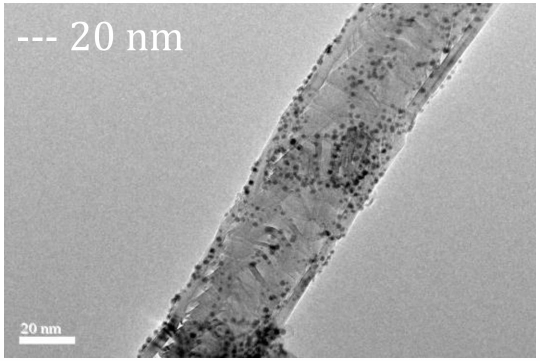
Carbon Nano Fibers (CNF)

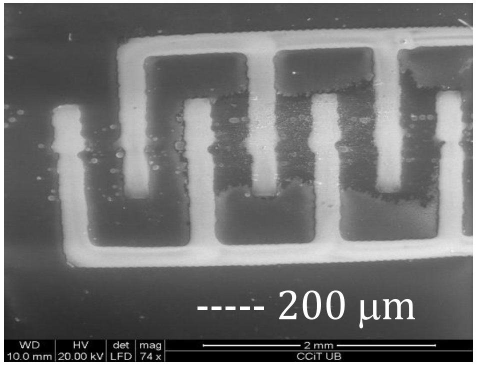


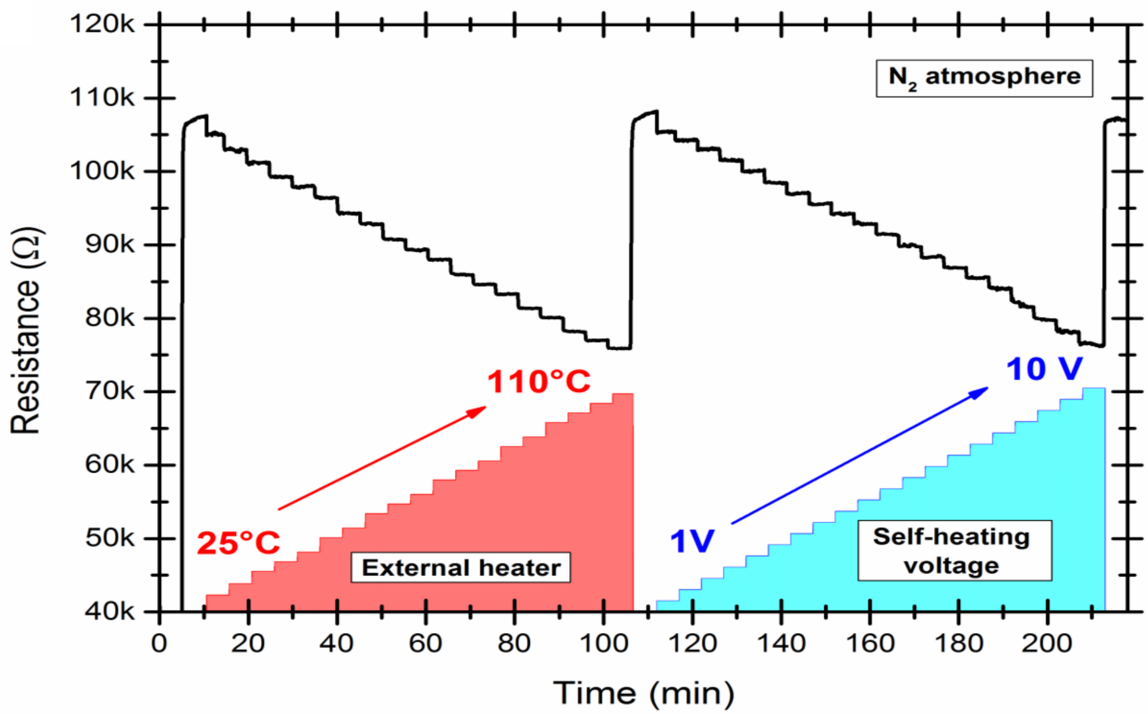
J.Daniel Prades
dprades@el.ub.edu

Self-heating in random wires

Carbon Nano Fibers (CNF) *Sens. Actuators B* **187**, 401 (2013)



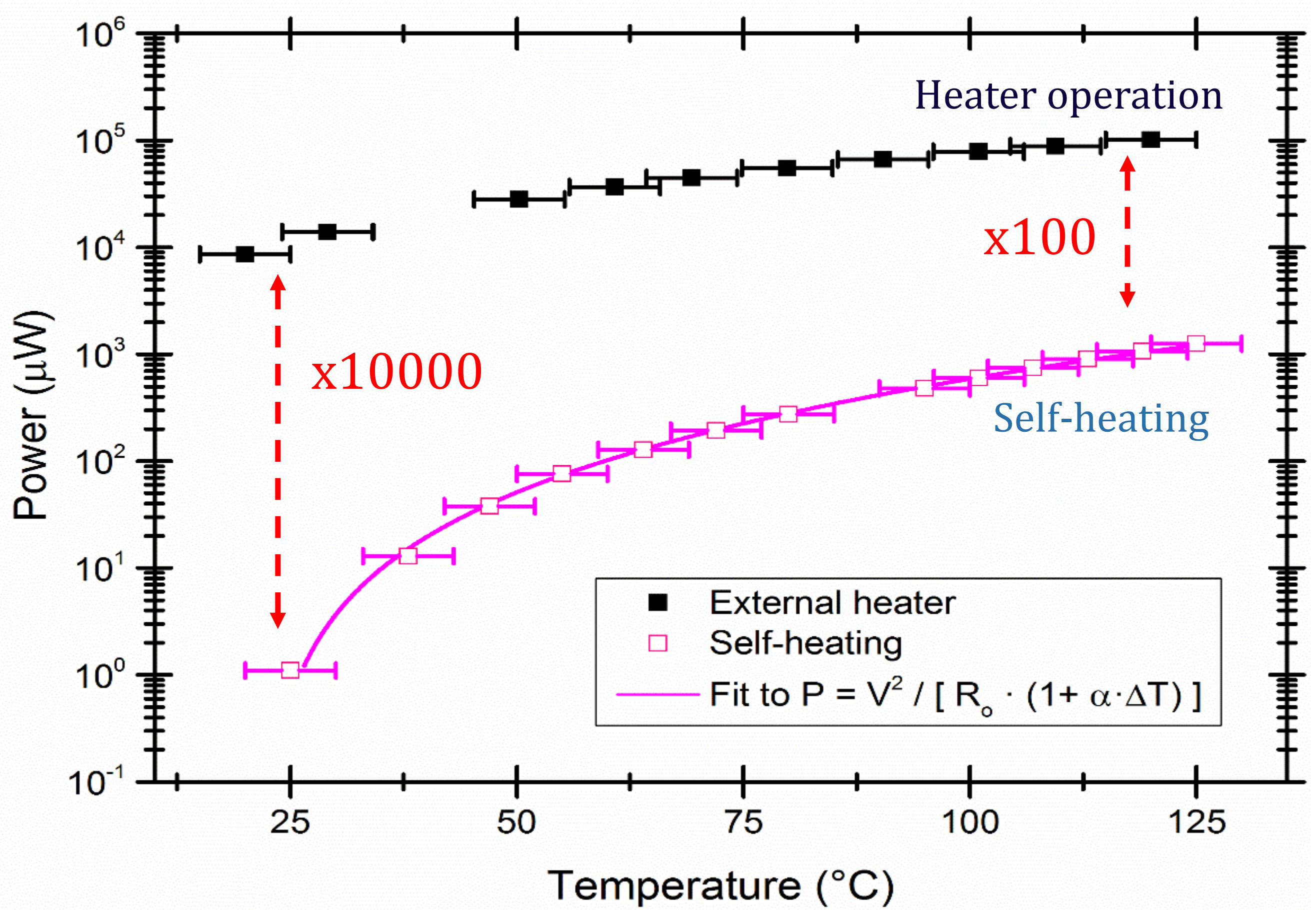




J.Daniel Prades
dprades@el.ub.edu

Self-heating in random CNFs

Power consumption? *Sens. Actuators B* **211**, 489 (2015)



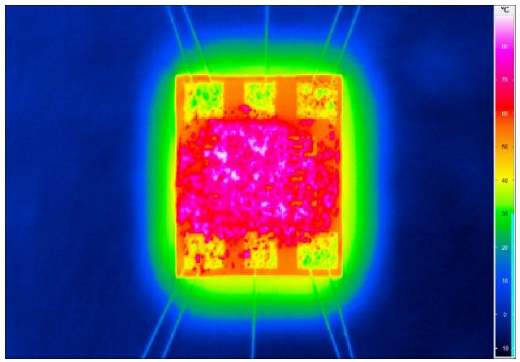
Significant Power Savings
"efficient self-heating"

J.Daniel Prades
dprades@el.ub.edu

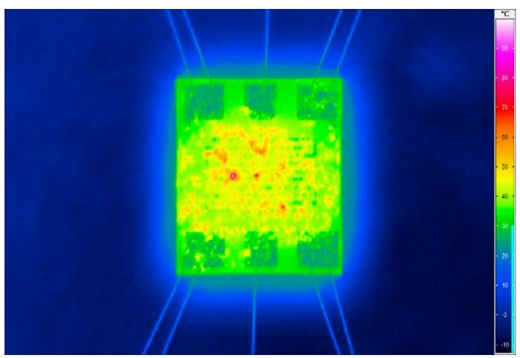
Self-heating in random CNFs

Origin of efficient heating?

Nanoscale **8**, 5082 (2016)



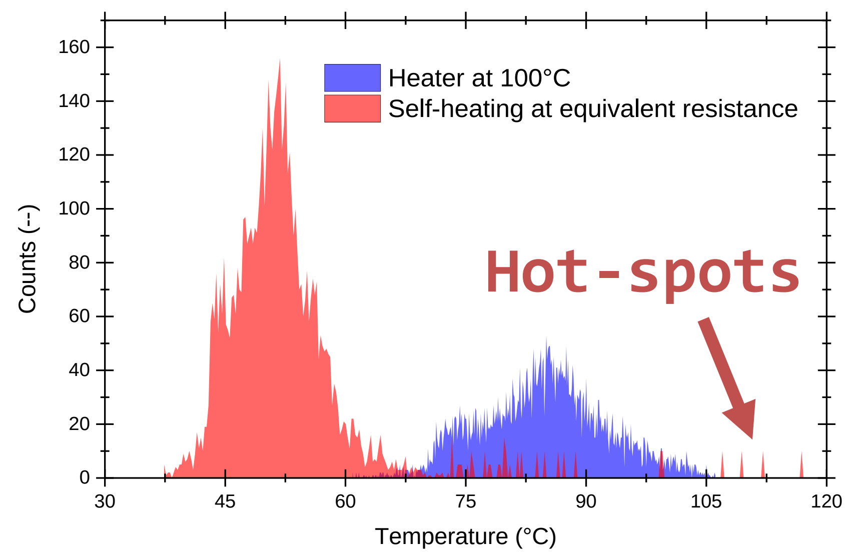
Heater operation



Self-heating

UNIVERSITÄT DES SAARLANDES

Dr. Sauerwald
Prof. Schütze



J.Daniel Prades
dprades@el.ub.edu

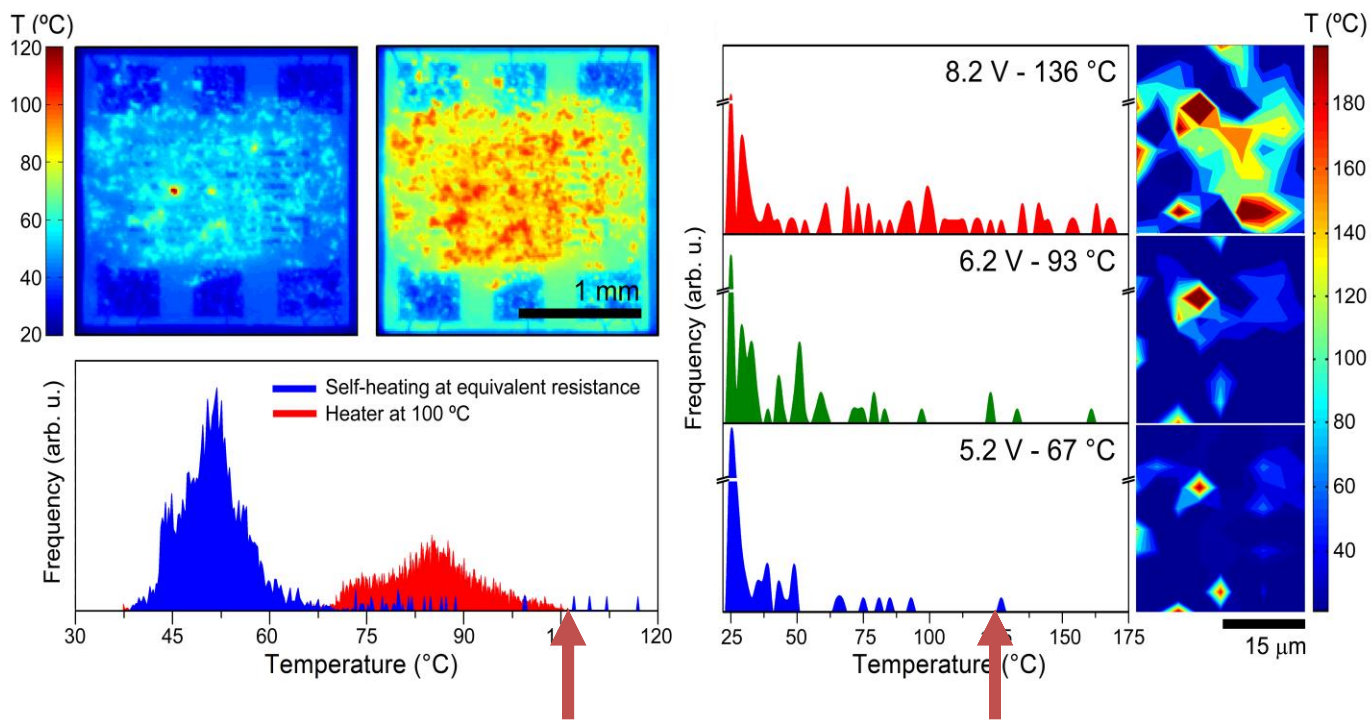
Self-heating in random CNFs

Origin of efficient heating?

Nanoscale **8**, 5082 (2016)

IR Thermography

Raman Shift Mapping



Hot-spots **Hot-spots**

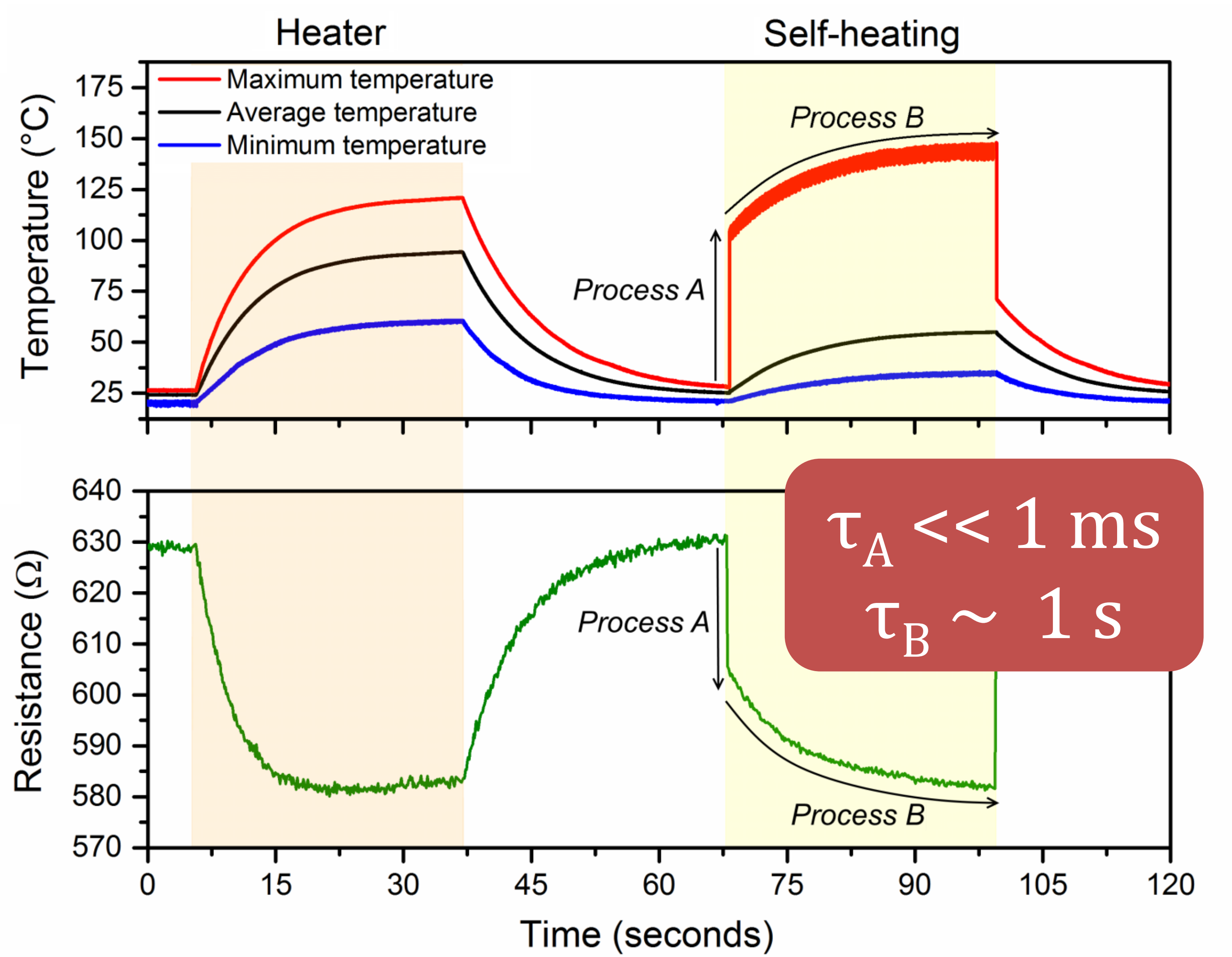
J.Daniel Prades
dprades@el.ub.edu

Universitat de Barcelona

Self-heating in random CNFs

Origin of hot-spots?

Nanoscale **8**, 5082 (2016)



$\tau_A << 1$ ms

$\tau_B \sim 1$ s

COST European Cooperation in Science and Technology

EuNetAir

European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability

J.Daniel Prades
dprades@el.ub.edu

Universitat de Barcelona

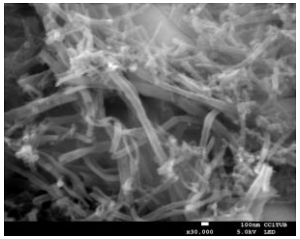
cost EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

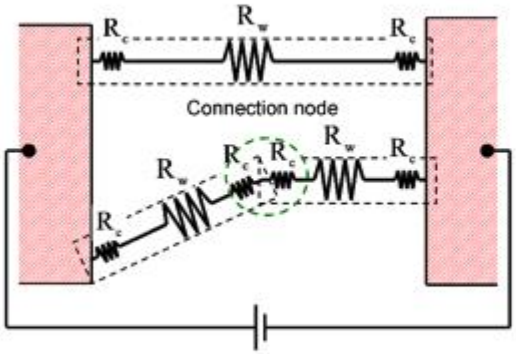
EuNetAir
European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability

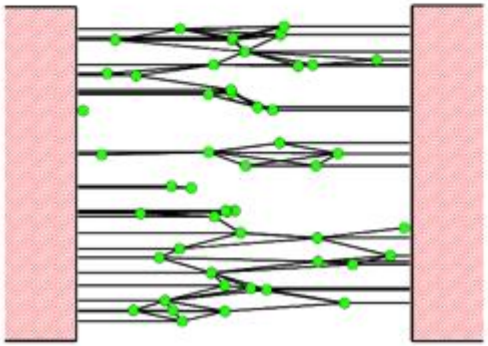
Self-heating in random CNFs

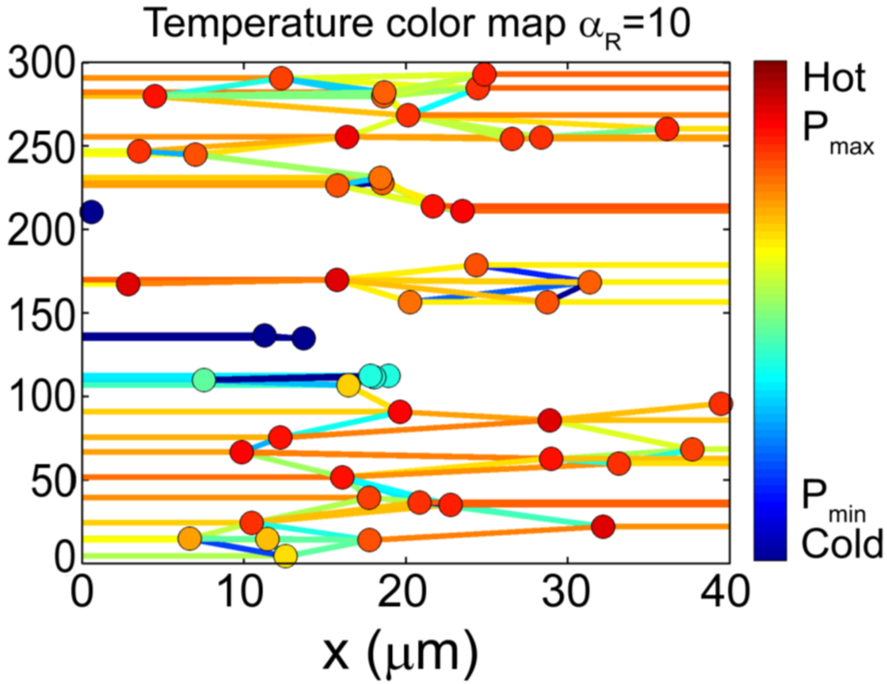
Resistor network model

Nanoscale **8**, 5082 (2016)









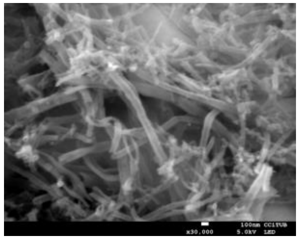
Hot **-spots**

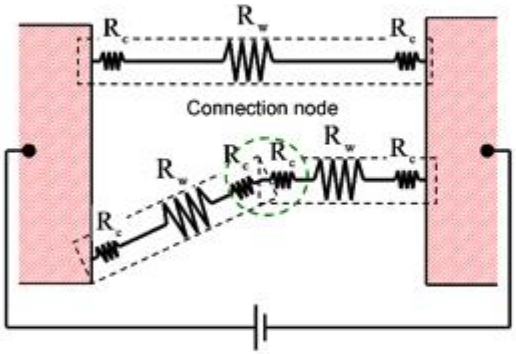
J.Daniel Prades
dprades@el.ub.edu

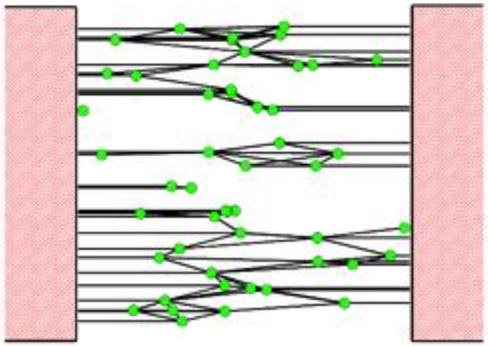
Self-heating in random CNFs

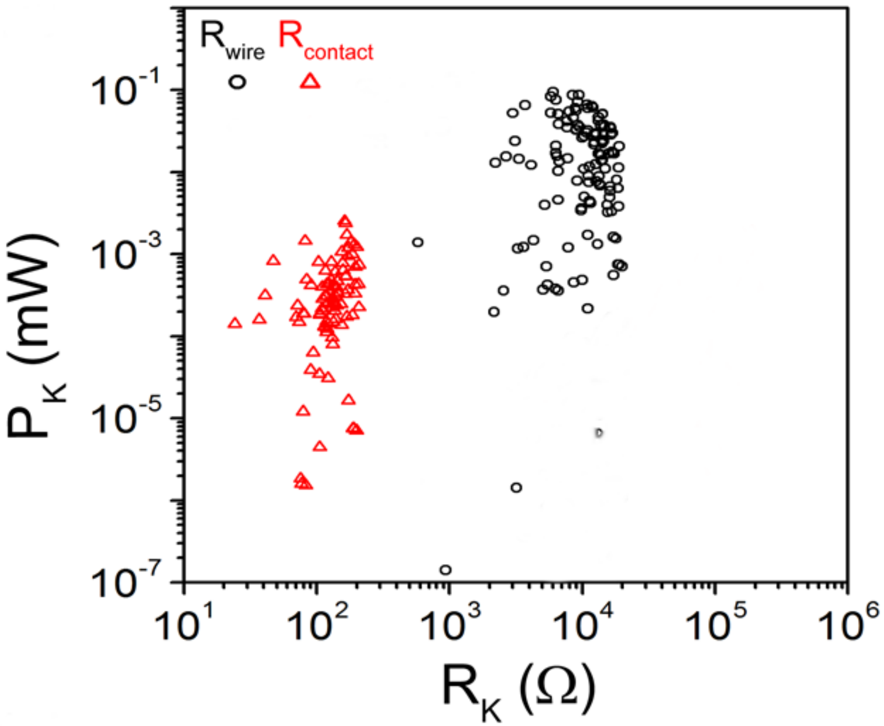
Resistor network model

Nanoscale **8**, 5082 (2016)









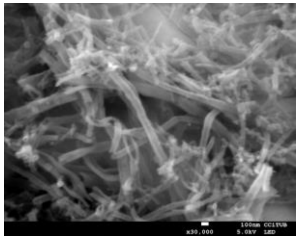
High Resistance **-spots**

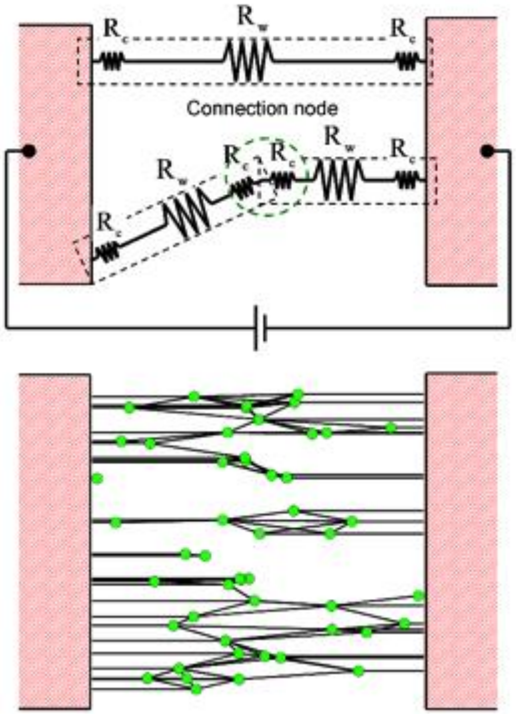
J.Daniel Prades
dprades@el.ub.edu

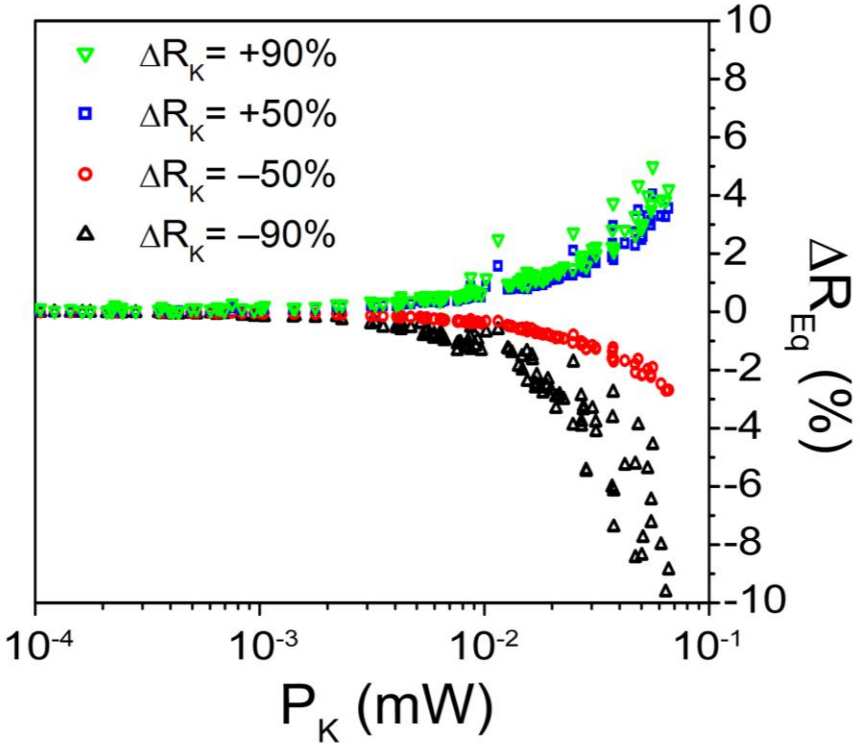
Self-heating in random CNFs

Resistor network model

Nanoscale **8**, 5082 (2016)







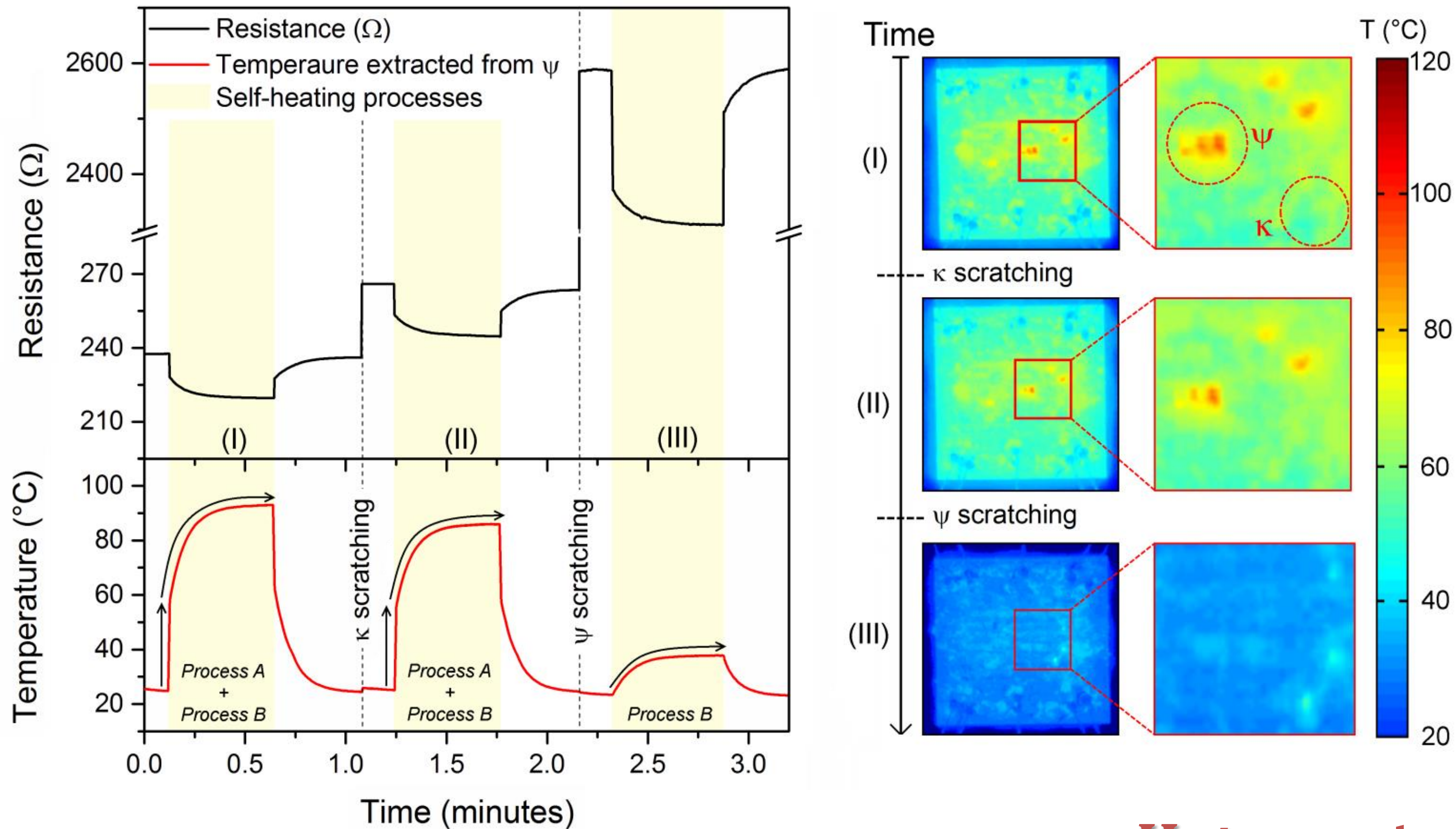
Sensing Resistance -spots

J.Daniel Prades
dprades@el.ub.edu

Self-heating in random CNFs

Validation

Nanoscale **8**, 5082 (2016)



Hot **-spots**

High Resistance **-spots**

Sensing Resistance **-spots**

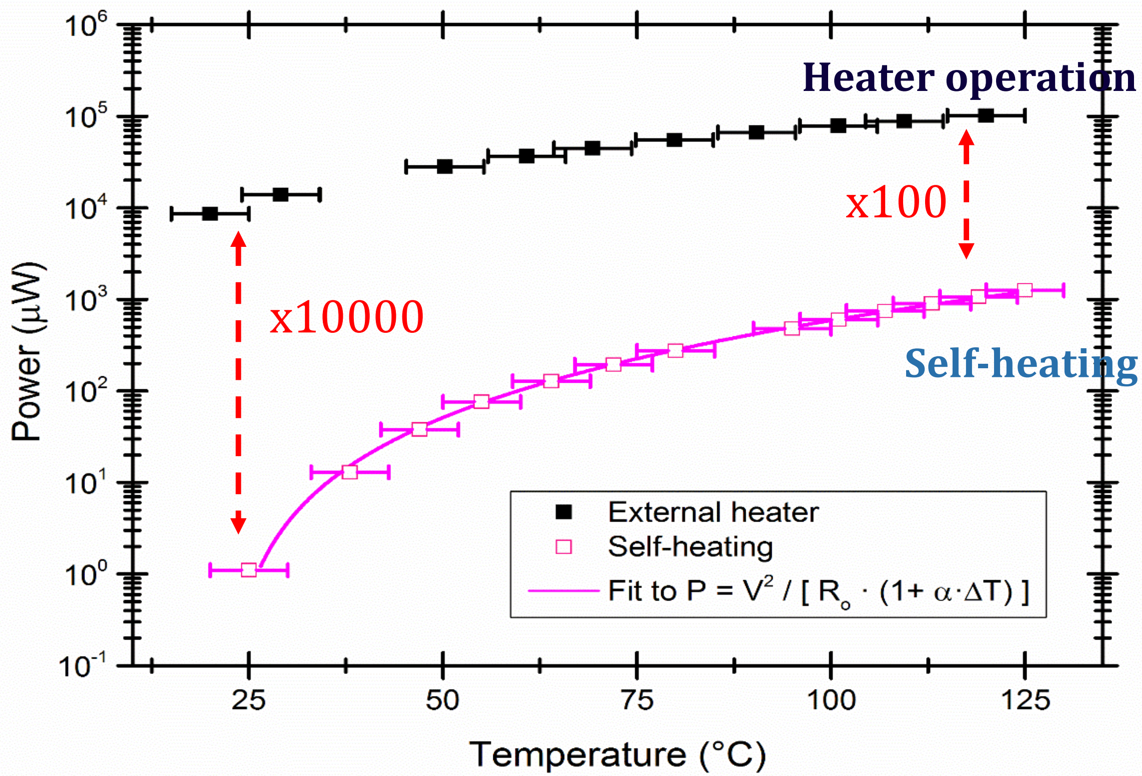
J.Daniel Prades
dprades@el.ub.edu

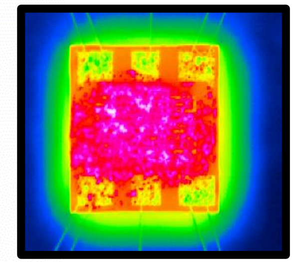
UNIVERSITAT DE BARCELONA

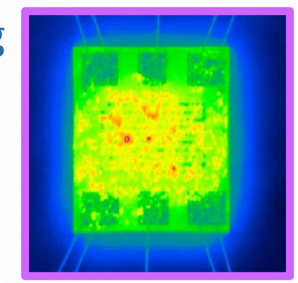
Self-heating in random CNFs

Power consumption?

Sens. Actuators B **211**, 489 (2015)
Nanoscale **8**, 5082 (2016)







efficient self-heating

hot-spots

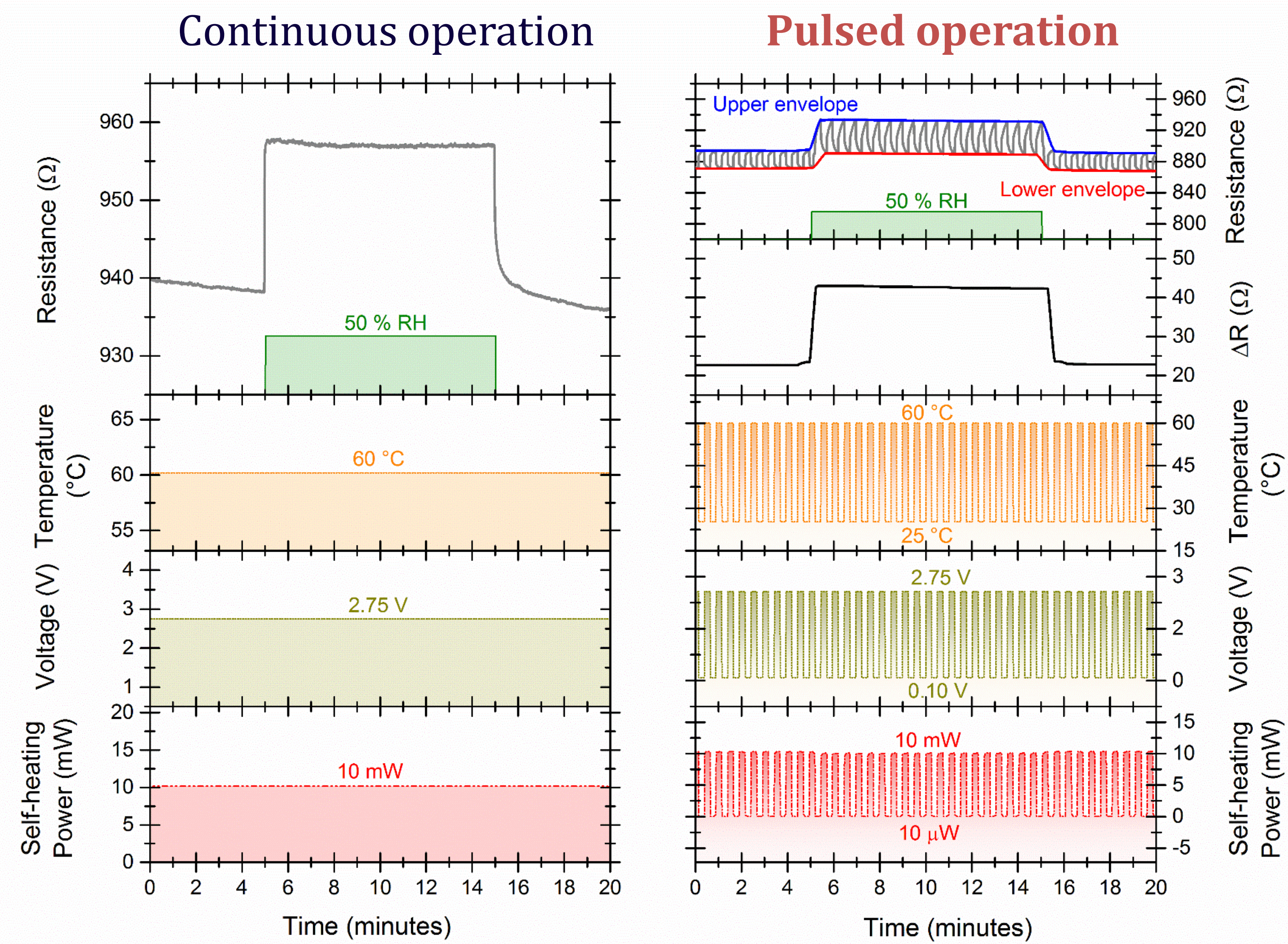
cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY
EuNetAir
European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability

J.Daniel Prades
dprades@el.ub.edu

Self-heating in random CNFs

Pulsed operation?

Sens. Actuators B **226**, 254 (2016)



UNIVERSITAT DE BARCELONA

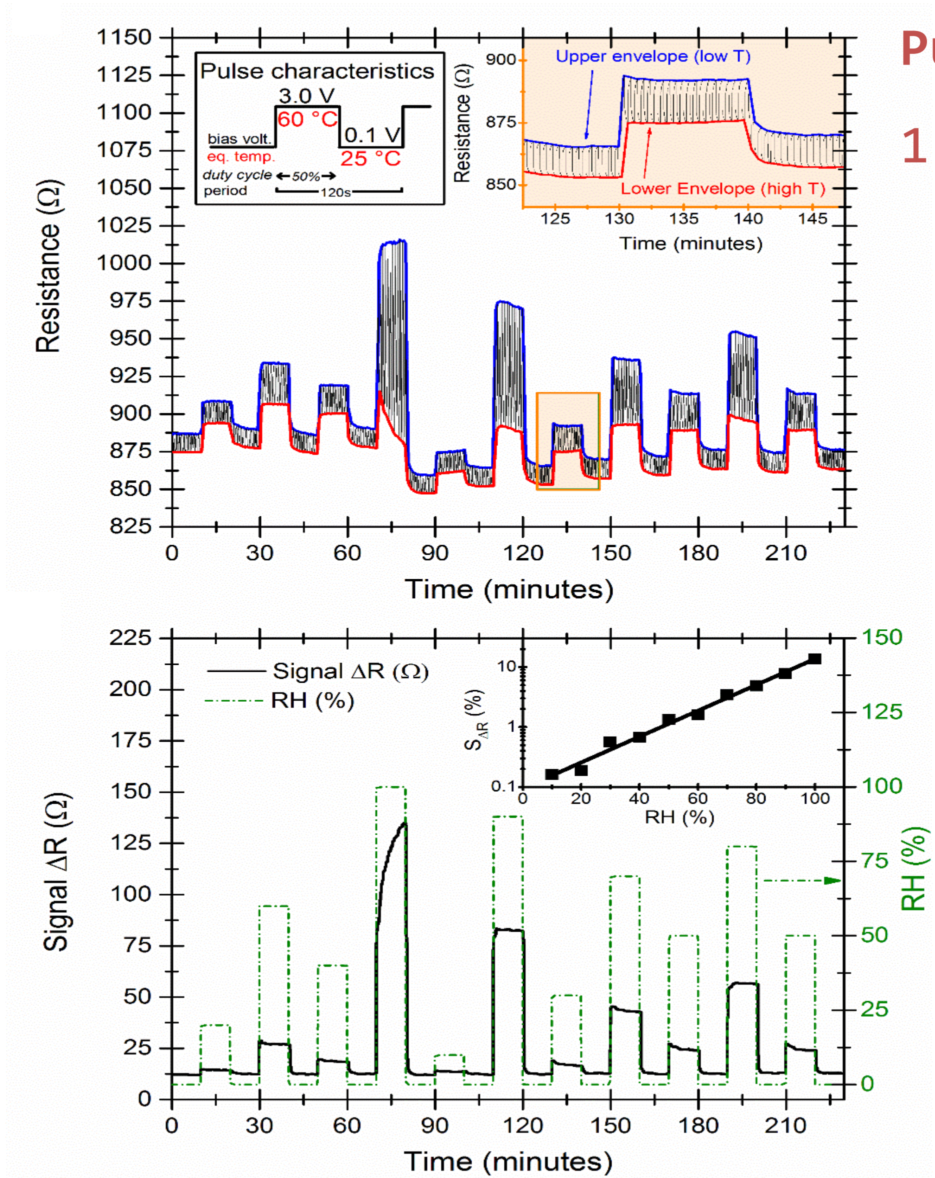
cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY
EuNetAir
European Network on New Sensing Technologies
for Air-Pollution Control and Environmental Sustainability

J.Daniel Prades
dprades@el.ub.edu

Self-heating in random CNFs

Advantages of pulsing

Sens. Actuators B **226**, 254 (2016)



Pulsed-selfheating?

1) Baseline stabiliz.

J.Daniel Prades
dprades@el.ub.edu

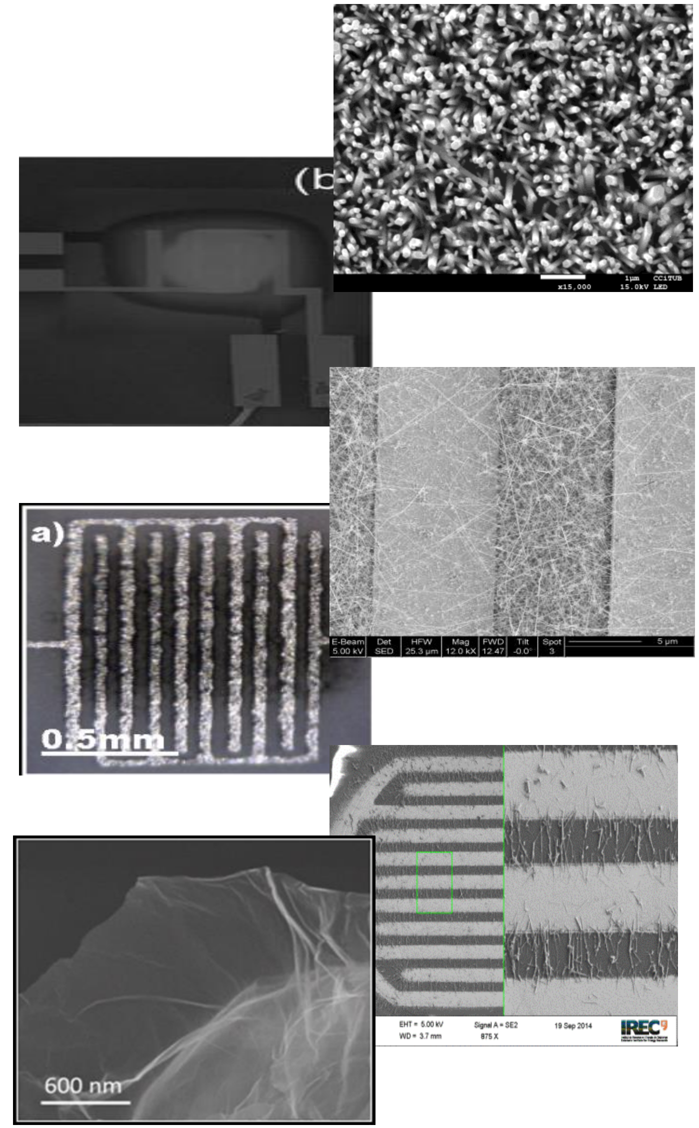
Universitat de Barcelona

cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY
EuNetAir
European Network on New Sensing Technologies
for Air-Pollution Control and Environmental Sustainability

Self-heating in random nanosystems

Is it possible with other materials?

- Materials:
  - Carbon nanofibers
  - Carbon nanotubes
  - Graphene
  - ZnO nanowires
  - TiO_2 nanowires
  - WO_3 nanowies
  - SnO_2 nanowires
  - Ge nanowires
  - Pt nanowires
- Methods:
  - In-situ CVD growth
  - In-situ hydrothermal
  - Drop-casting
  - Electrospray
  - Dielectrophoresis
  - Langmuir Blodgett

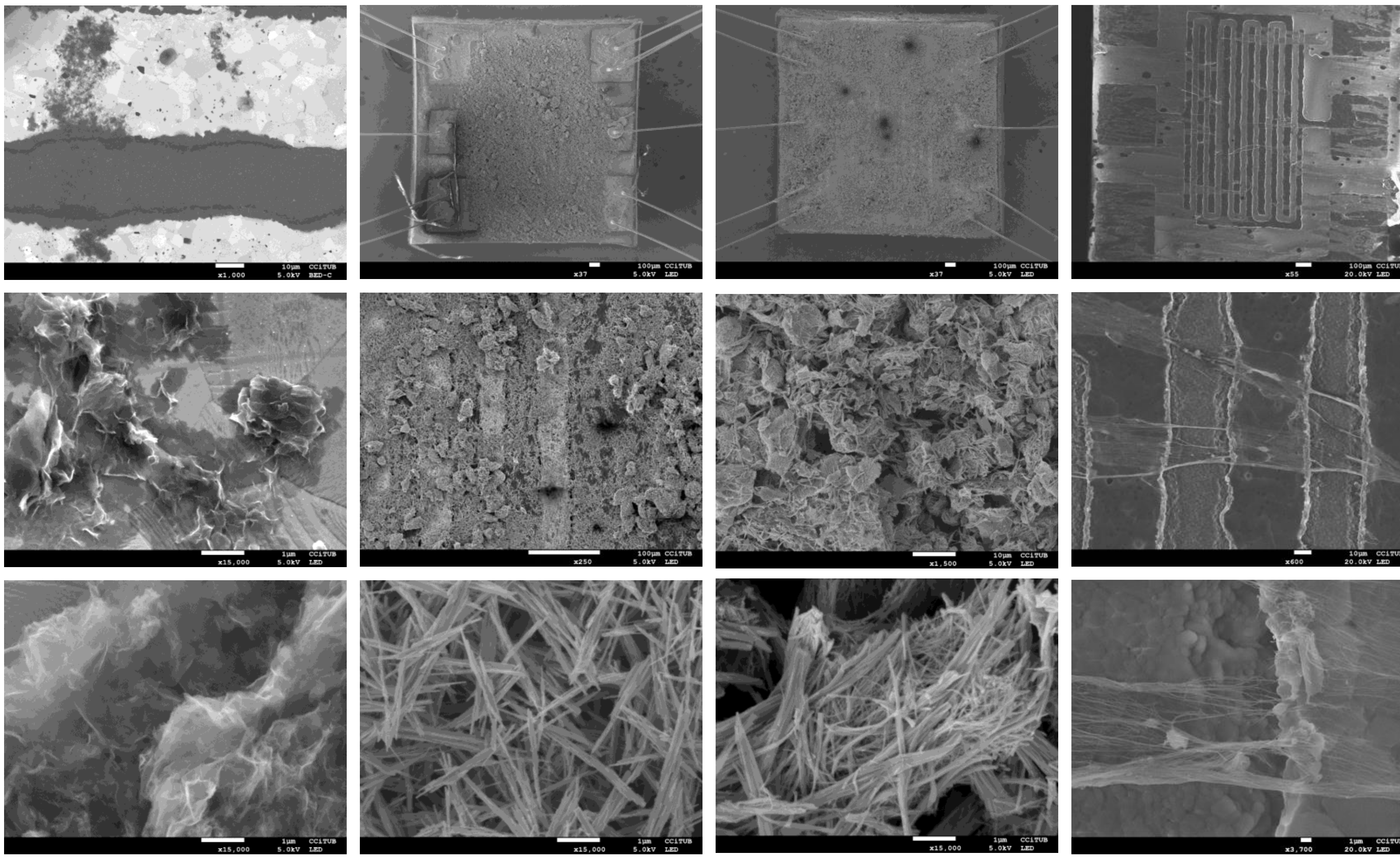


J.Daniel Prades
dprades@el.ub.edu

Self-heating in random MOX

Is it possible with other materials?

Yes, and tricks depend on the material used.



Illuminated Gas Sensors

P 36

J.Daniel Prades
dprades@el.ub.edu

UNIVERSITAT DE BARCELONA

cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

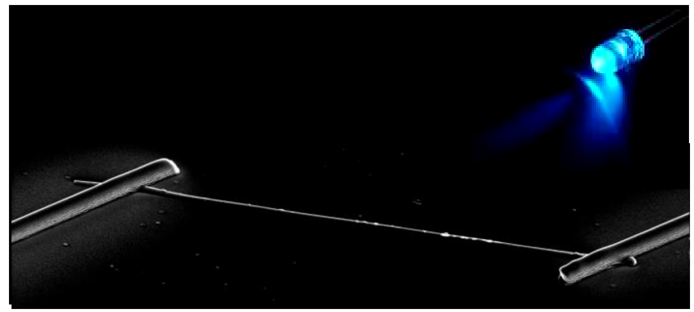
EuNetAir
European Network on New Sensing Technologies
for Air-Pollution Control and Environmental Sustainability

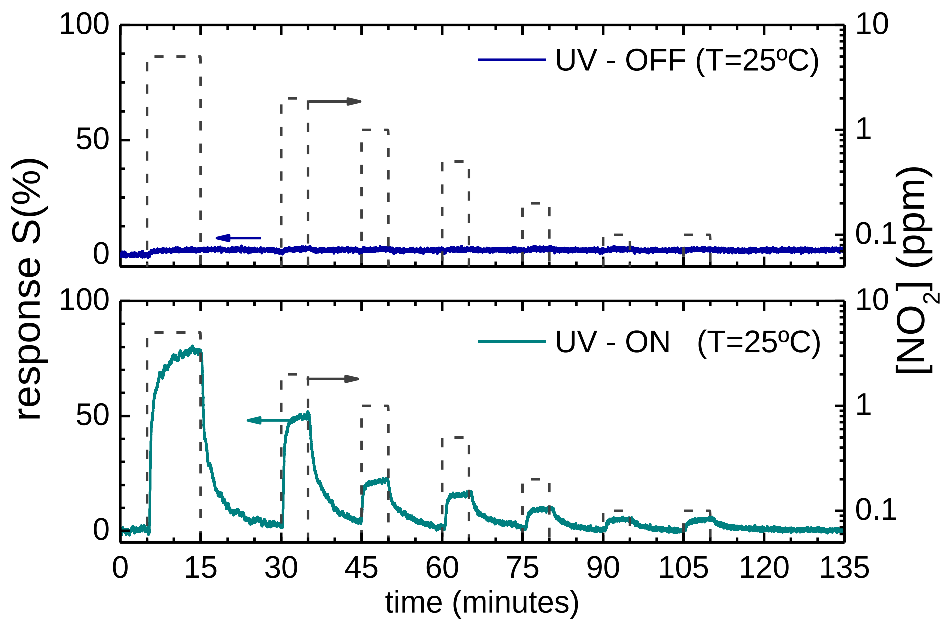
J.Daniel Prades
dprades@el.ub.edu

Light Activated Gas Sensors

Concept

Phys.Chem.Chem.Phys. **11**, 10881 (2009)
Sens Actuators B **140**, 337 (2009)



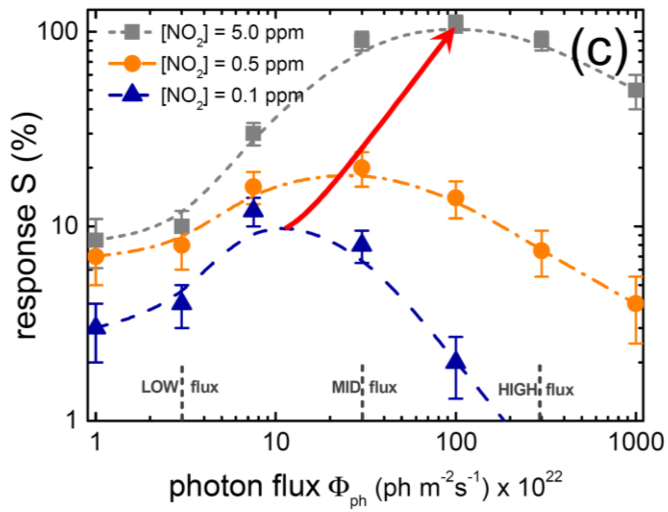


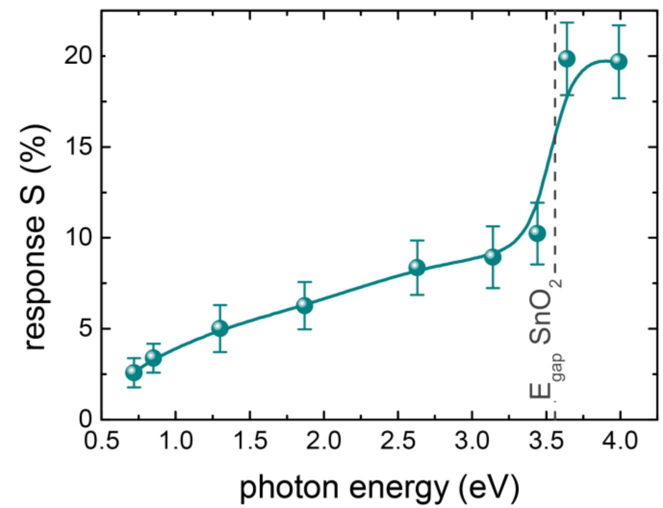
J.Daniel Prades
dprades@el.ub.edu

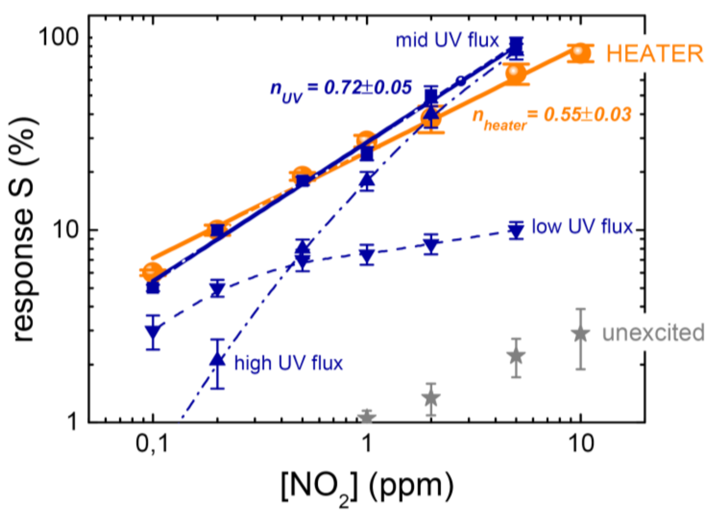
Light Activated Gas Sensors

Features

Phys.Chem.Chem.Phys. **11**, 10881 (2009)
Sens Actuators B **140**, 337 (2009)







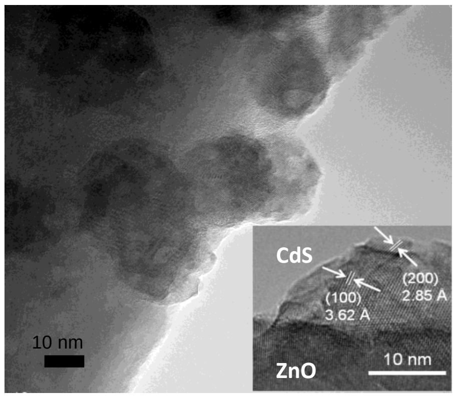
UV only?

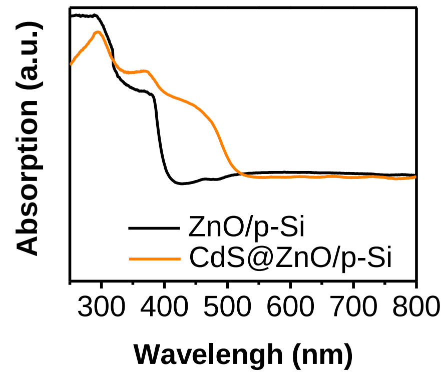
J.Daniel Prades
dprades@el.ub.edu

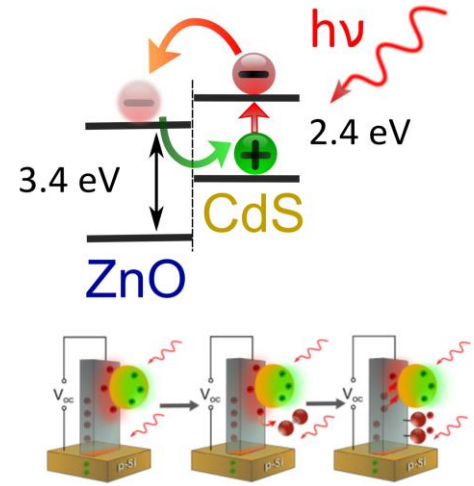
Visible light operation

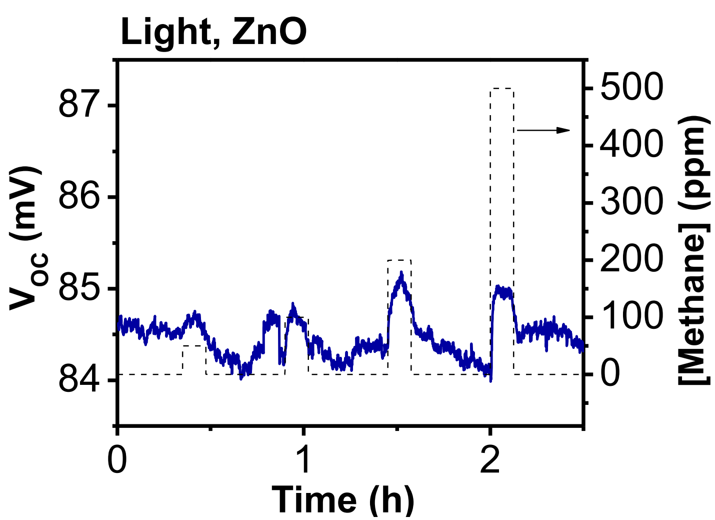
Surface sensitization

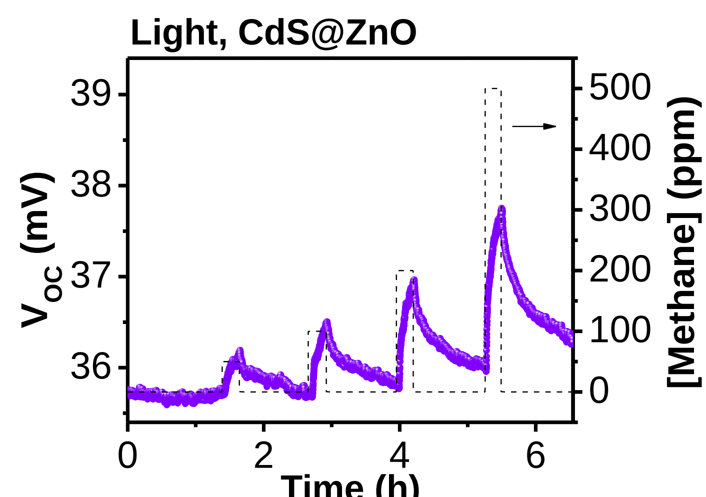
EU-Patent Nr. 11179783.3
Nano Energy **2**, 514 (2013)









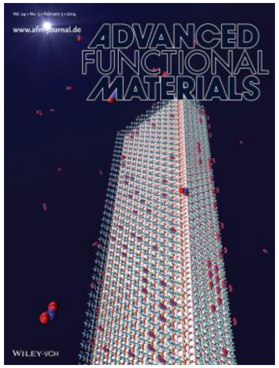


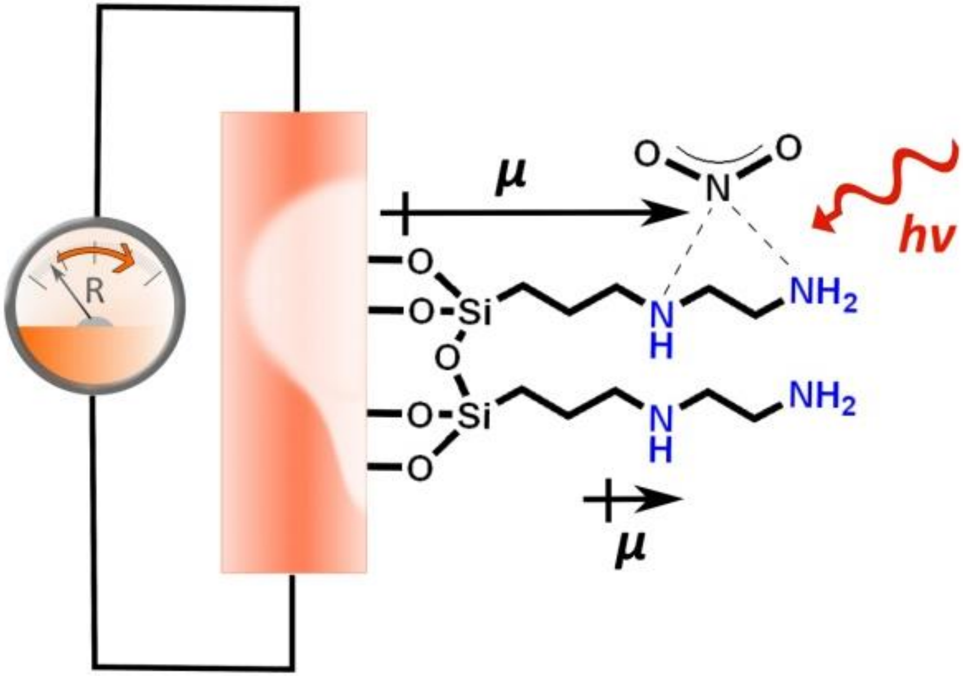
J.Daniel Prades
dprades@el.ub.edu

Visible light operation

Surface functionalization

Adv. Funct. Mater. **24, 595 (2014)**



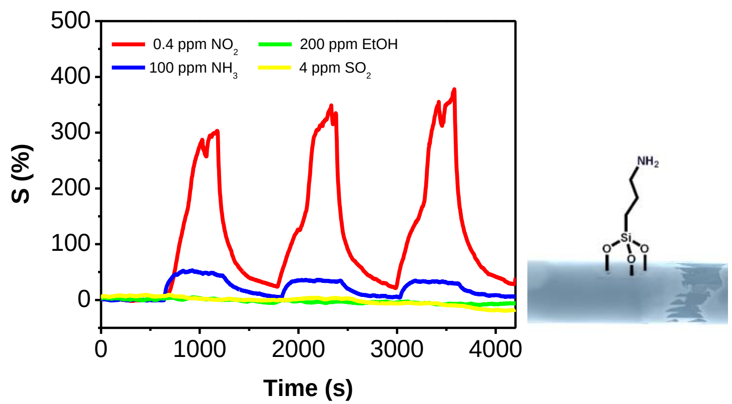


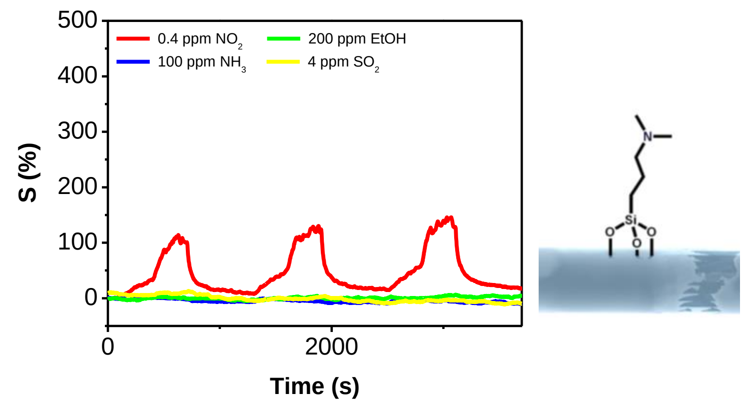
J.Daniel Prades
dprades@el.ub.edu

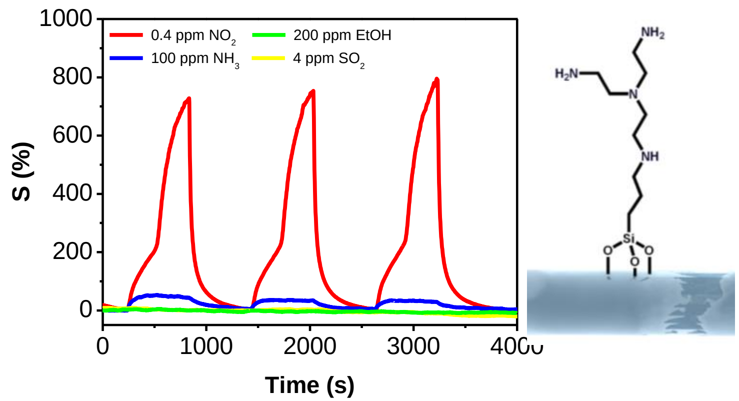
Visible light operation

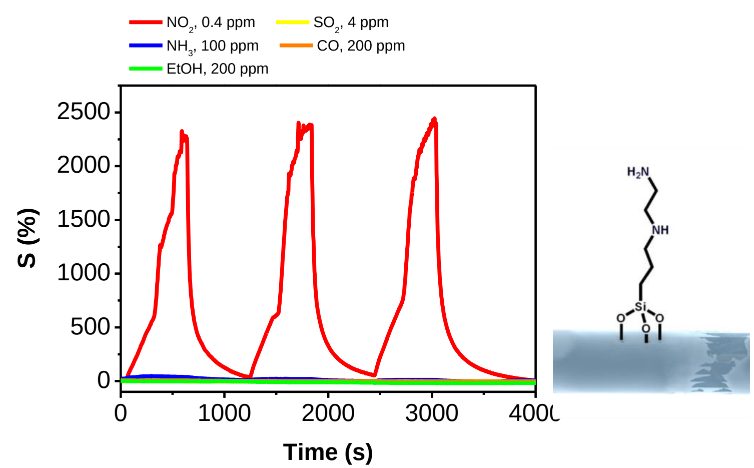
Flexibility

Adv. Funct. Mater. **24, 595 (2014)**







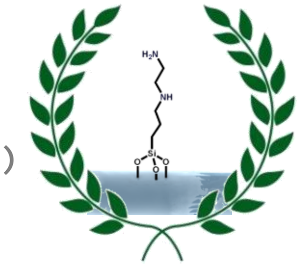


J.Daniel Prades
dprades@el.ub.edu

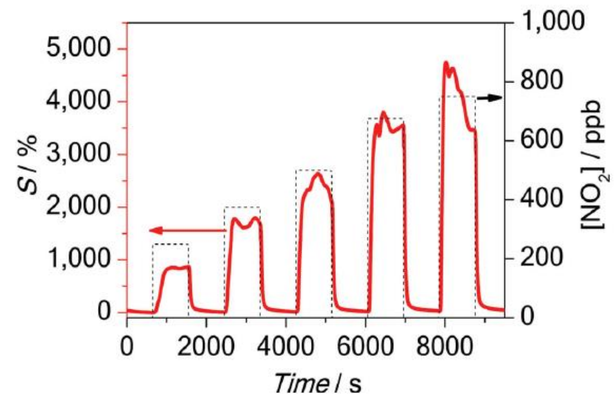
Visible light operation

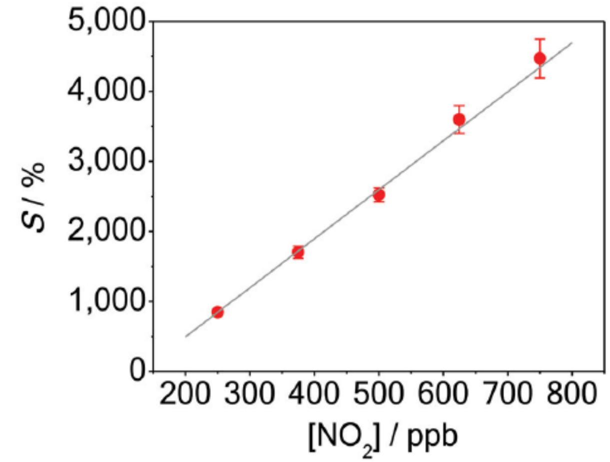
Selectivity?

Adv. Funct. Mater. 24, 595 (2014)

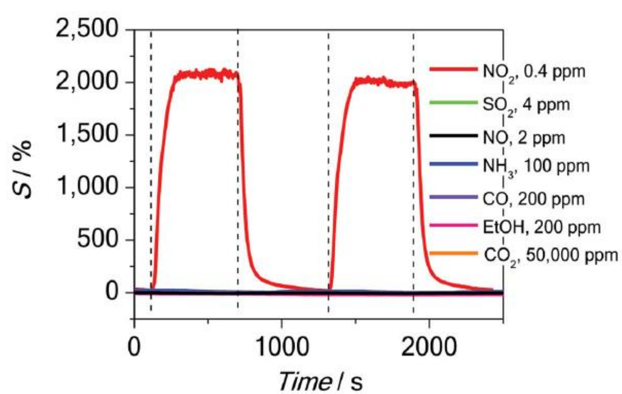


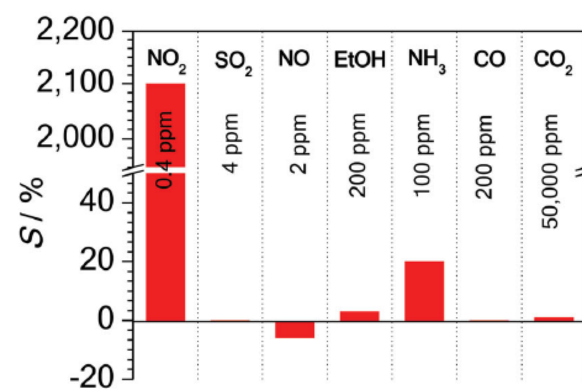
+ Good sensitivity





+ Very good selectivity



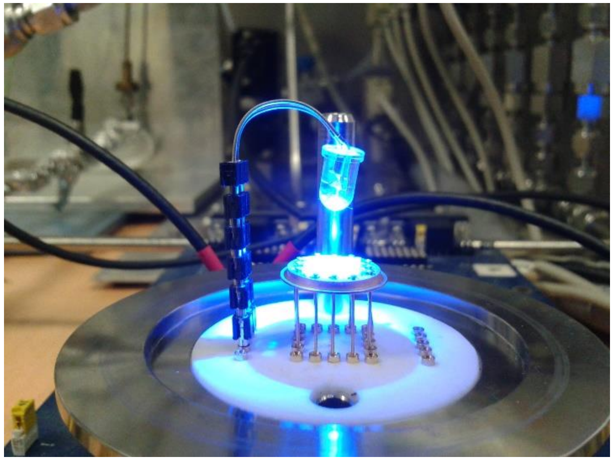


J.Daniel Prades
dprades@el.ub.edu

UNIVERSITAT DE BARCELONA

Light operated sensors

Practical issues



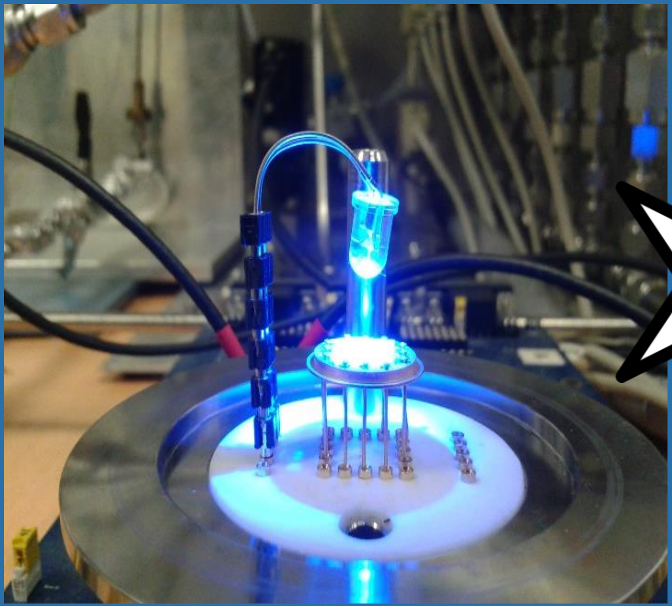
- Poor photon flow control
  - Distance - geometry
  - Only current-controlled

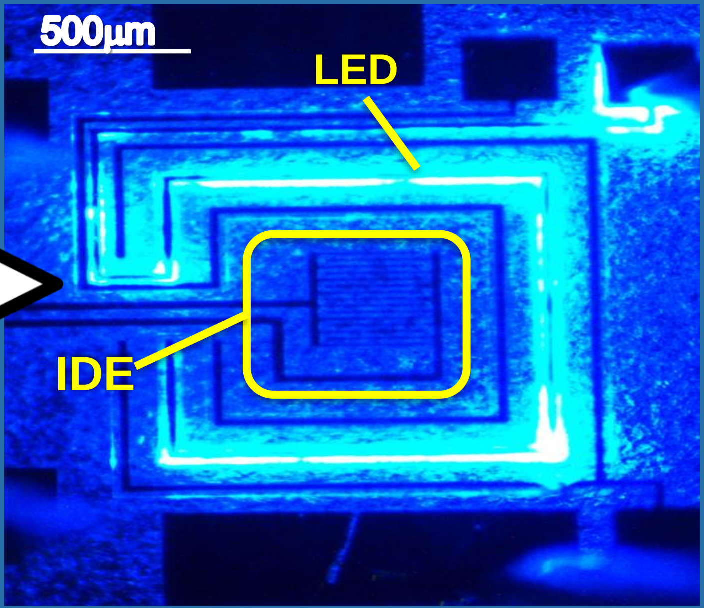
- High power consumption
  - Optical loses
  - >>10mW

cost EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY
EuNetAir
European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability

Light operated sensors

From discret components to monolithic





J.Daniel Prades
dprades@el.ub.edu

J.Daniel Prades
dprades@el.ub.edu

Universitat de Barcelona

cost EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

EuNetAir
European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability

Monolithic integration

OCULUS
FET Open 2016

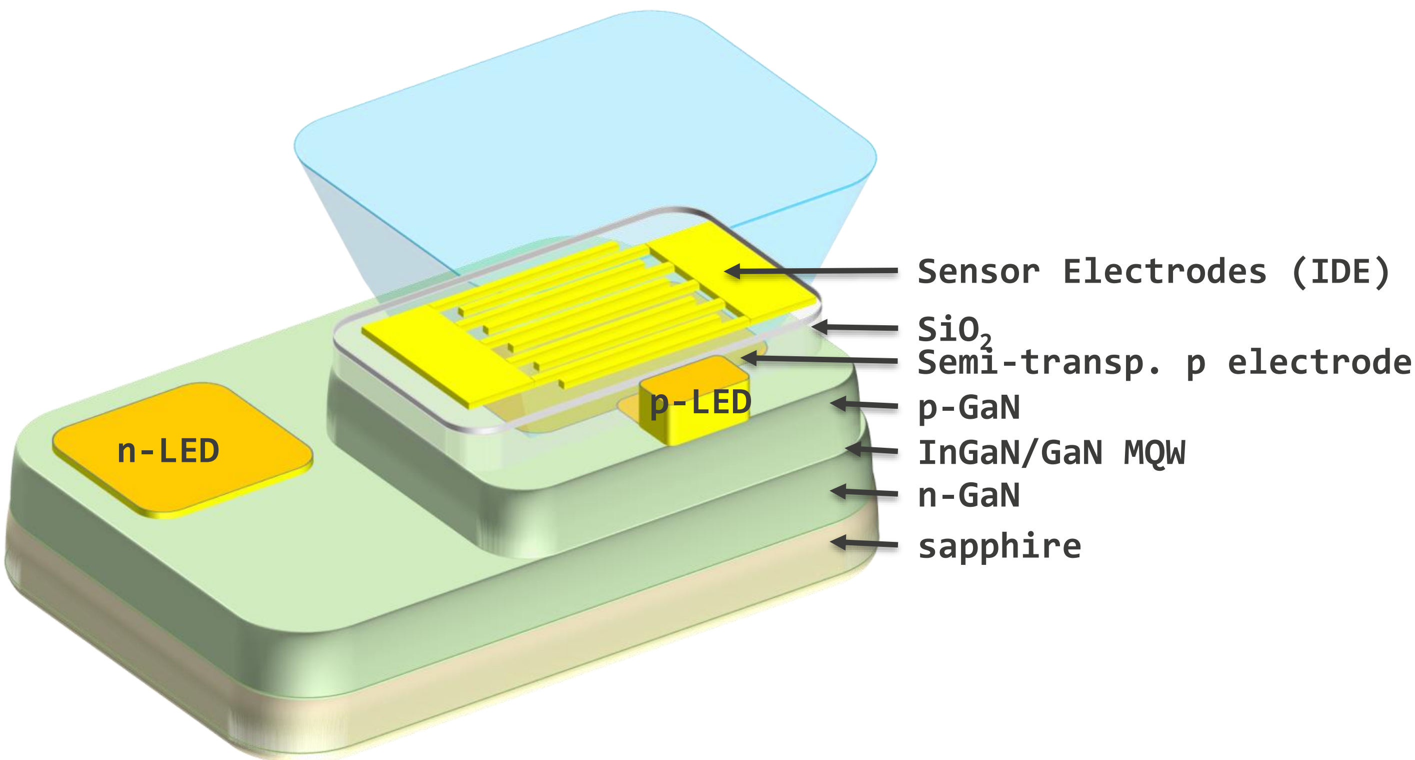
Sensor platform: In:GaN LED + IDE

epitaxy competence center ec²

OSRAM Opto Semiconductors

Technische Universität Braunschweig

https://www.tu-braunschweig.de/iht/ec2

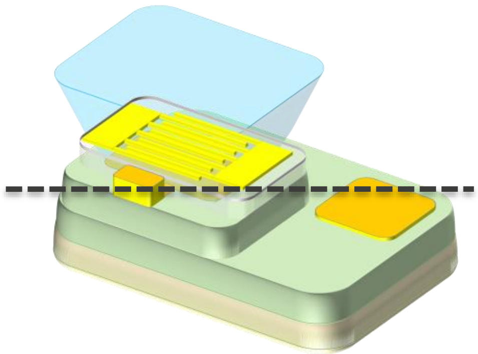


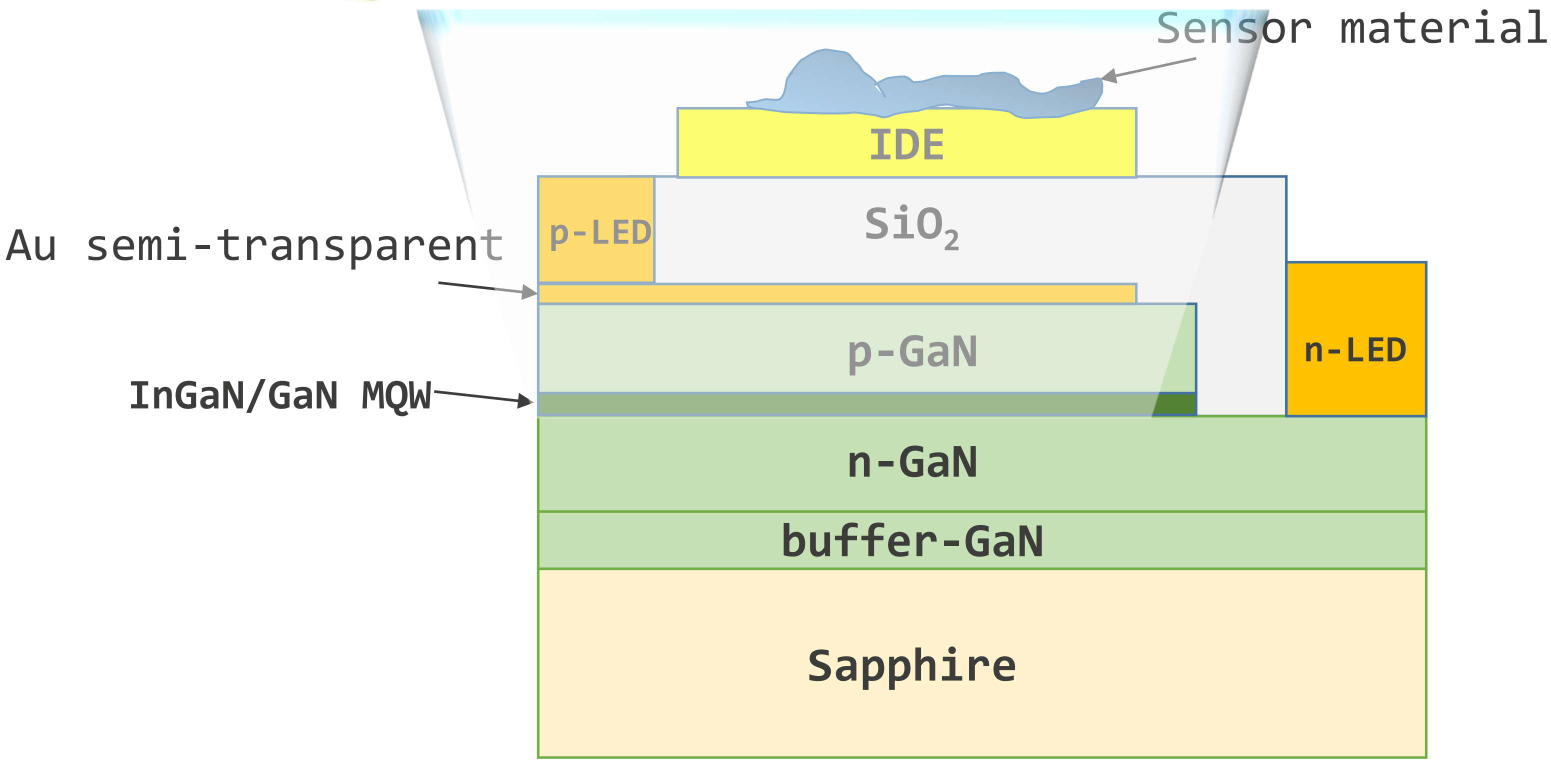
J.Daniel Prades
dprades@el.ub.edu

UNIVERSITAT DE BARCELONA

Monolithic integration

Sensor platform: In:GaN LED + IDE

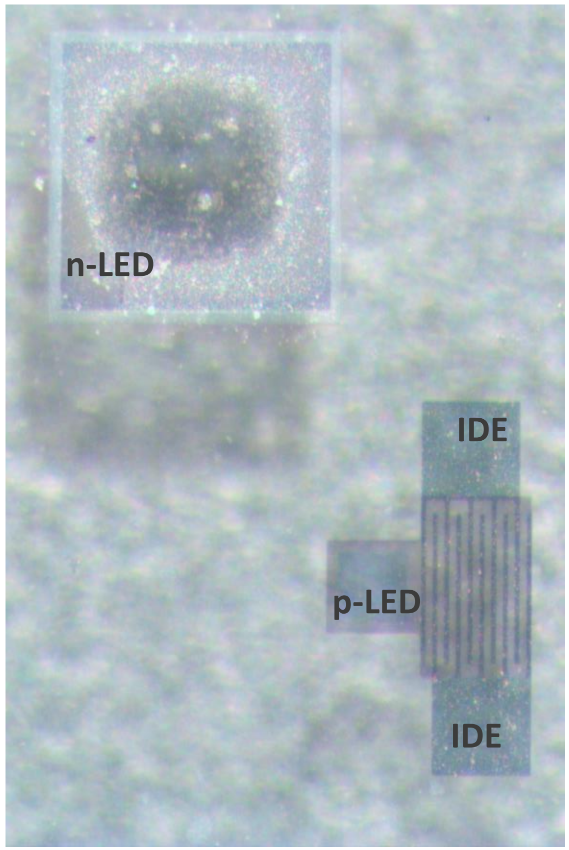


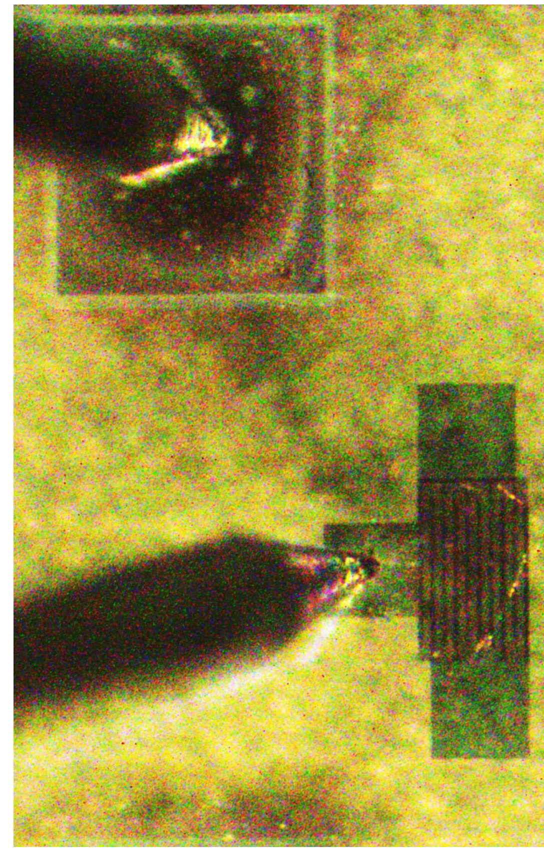


J.Daniel Prades
dprades@el.ub.edu

Monolithic integration

Results: semi-transparent device





1 mm

J.Daniel Prades
dprades@el.ub.edu

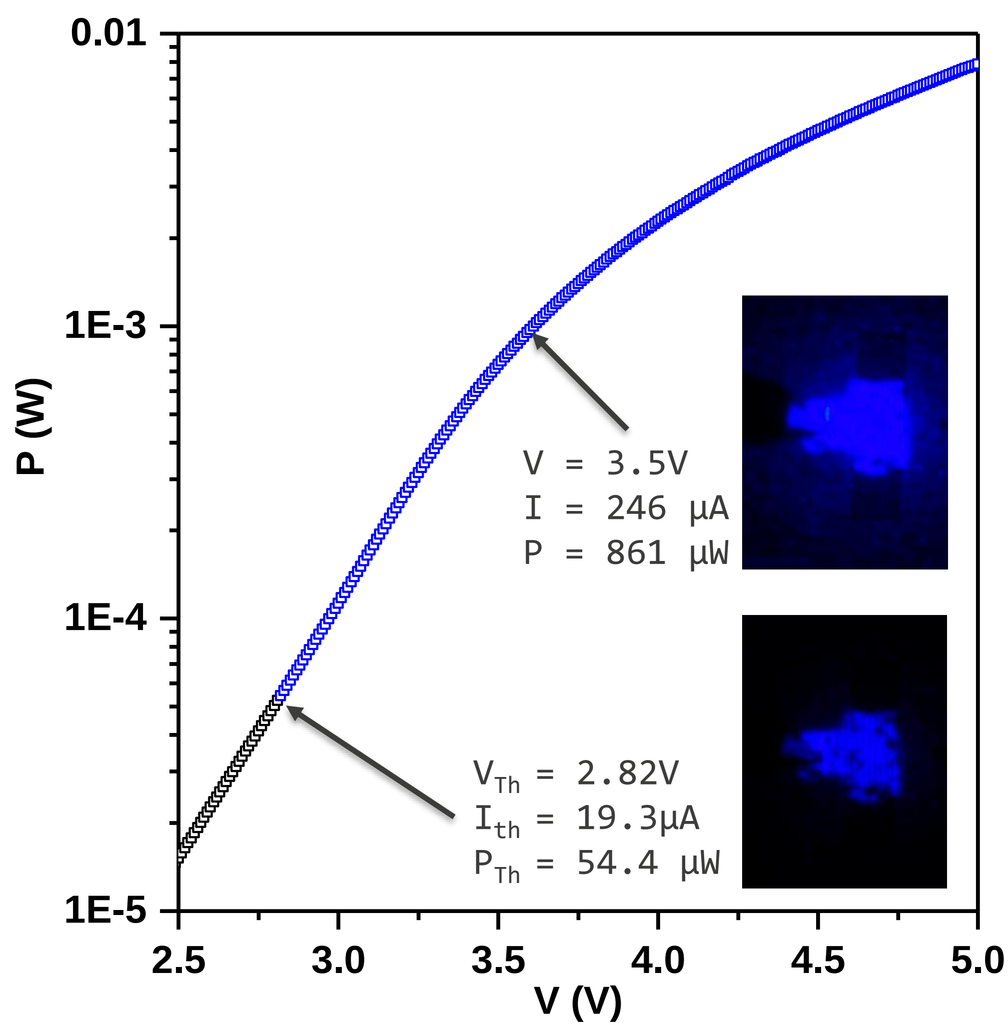
UNIVERSITAT DE BARCELONA

cost EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

EuNetAir
European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability

Monolithic integration

Results: P-V characteristics

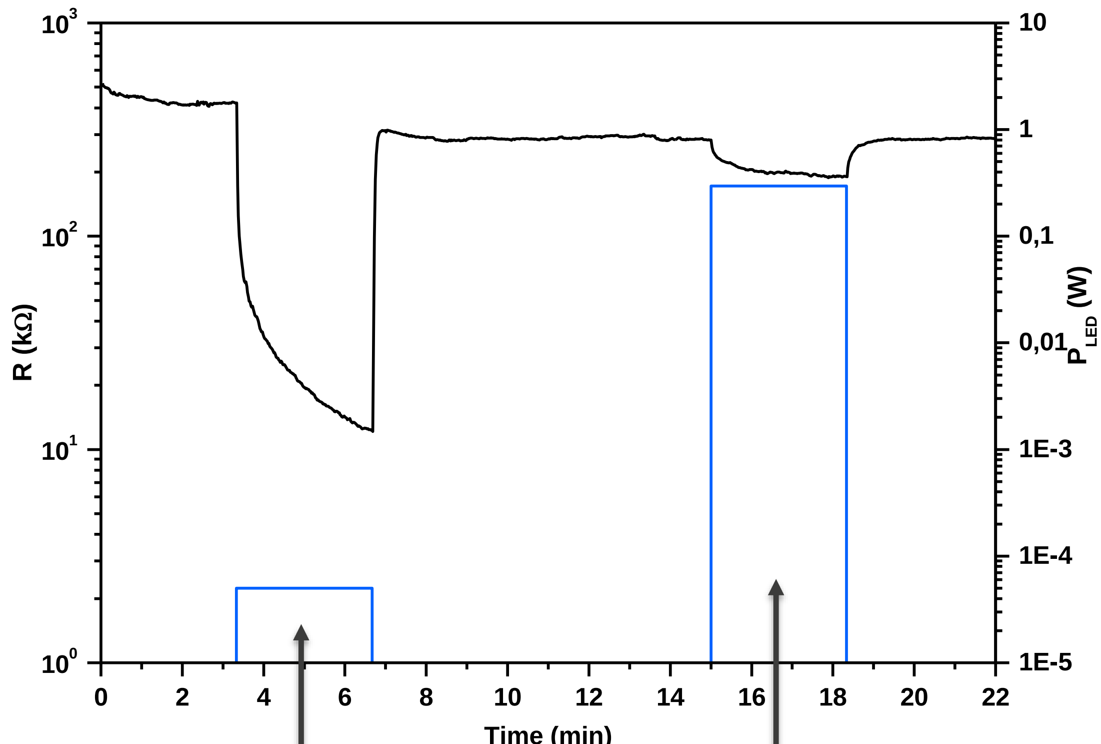


J.Daniel Prades
dprades@el.ub.edu

Monolithic integration

Results: efficiency

+ CNT *photocondutivity* activation



This work
V_{LED} = 2.82 V
I_{LED} = 19.3 µA
P_{Th} = 54.4 µW
Distance ~ 200 nm

Commercial LED
V_{LED} = 2.95V
I_{LED} = 100 mA
P_{Th} = 295 mW
Distance < 5mm

J.Daniel Prades
dprades@el.ub.edu

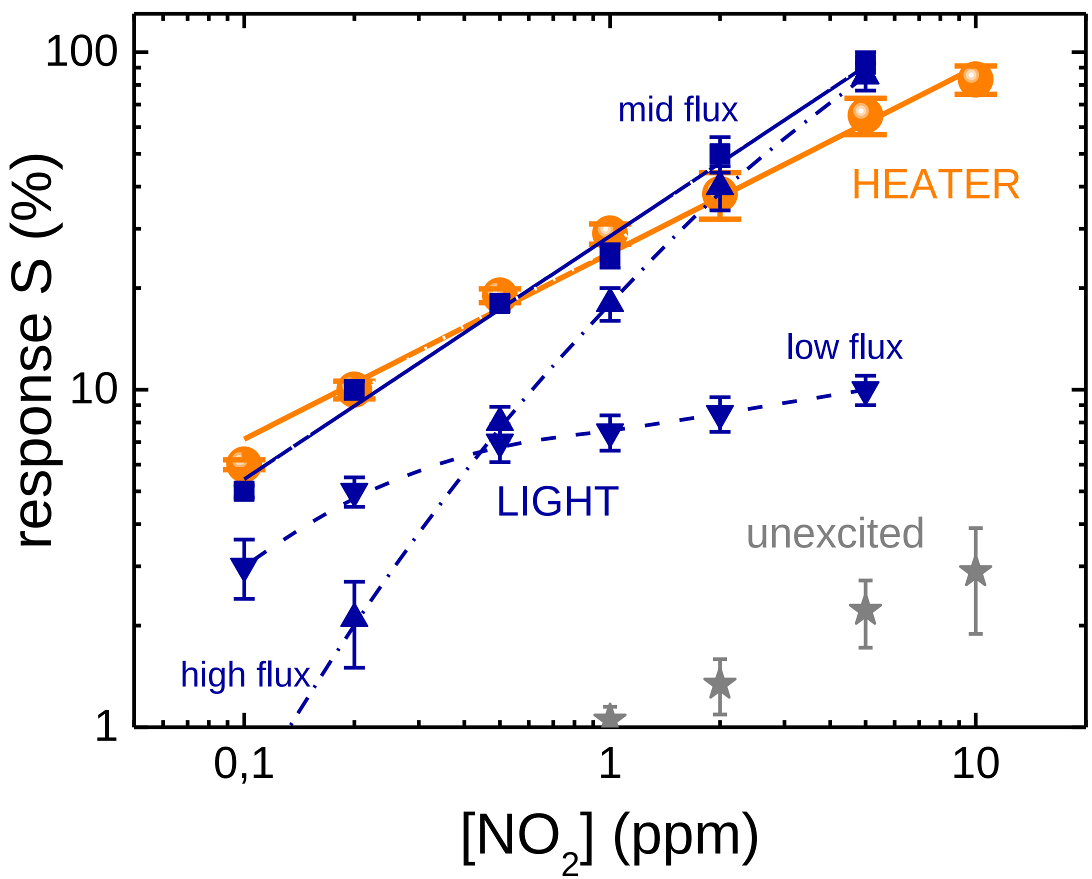
Universitat de Barcelona

Monolithic integration

Result: equivalent responses

P ~ 10mW

P ~ 50µW



Conclusions

Heated sensors

J.Daniel Prades
dprades@el.ub.edu

Efficient self-heating in random nanostructures

***Hot* - spots**
***High Resistance* - spots**
***Sensing Resistance* - spots**

Pulsed - selfheating

1) Baseline stabilization 2) More power savings 3) Faster times

As good at sensing as the material used.

Can be applied to 1D, 2D, carbon, MOXs ....

UNIVERSITAT DE BARCELONA
cost EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY
EuNetAir
European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability

Conclusions

Illuminated sensors

J.Daniel Prades
dprades@el.ub.edu

Potentially equivalent to heated sensors

Surface modification for

- ✓ *Visible operation*
- ✓ *Better Selectivity*

Practical issue: light control

Monolithic integration of LED+IDE:

- ✓ *Full light control, lots of power savings…*
- ✓ *Ready to use!*

UNIVERSITAT DE BARCELONA
cost EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY
EuNetAir
European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability

END

P 62

dprades@el.ub.edu

Thank you

Universitat de Barcelona

- J. Samà
- P. García-Lebière
- O. Monereo
- S. Illera
- N. García-Castelló
- J. Llosa
- A. Varea
- E. Xuriguera
- R. Jiménez-Díaz
- A. Romano-Rodríguez
- A. Cirera
- A. Cornet

Technische Universität Braunschweig

- M.W. Hoffmann
- A.E. Gad
- J. Hartmann
- X. Wang
- H. Shen
- A. Waag

IREC — Institut de Recerca en Energia de Catalunya / Catalonia Institute for Energy Research

- F. Shao
- M. Manzanares
- T. Andreu
- F. Hernández

Universität des Saarlandes

- T. Sauerwald
- A. Schütze

Technische Universität Wien — Vienna University of Technology

- S. Barth

BetterSense

Nanodevice Engineering for a Better Chemical Gas Sensing Technology

an ERC Starting Grant Project

The research leading to these results has received funding from the European Research Council under the European Union's Seventh Framework Programme (FP/2007-2013) / ERC Grant Agreement n. 336917.

European Research Council
Established by the European Commission