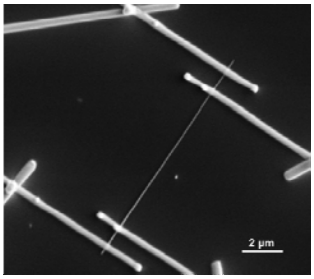
Parallel Alignment of Nanowires for Fast Fabrication of Nanowire Based Gas Sensors



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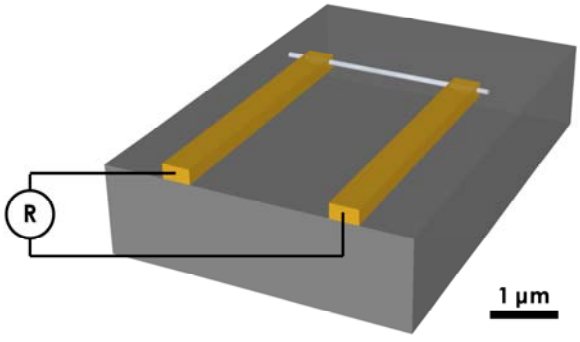
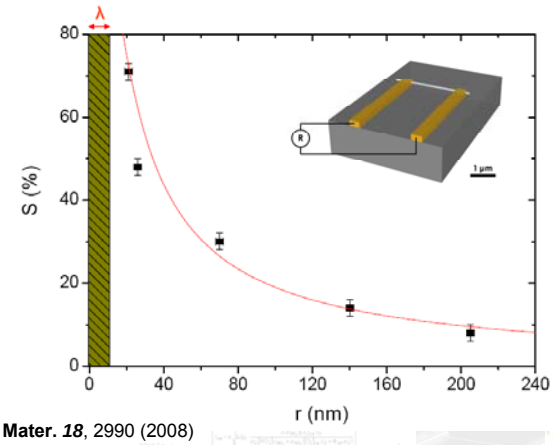
Previous work

Nanowires offer attractive features to improve many of the issues in solid state gas sensors



Previous work

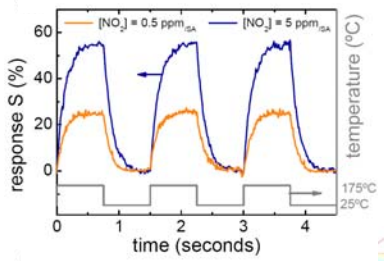
Sensitivity

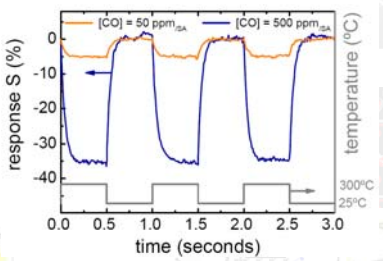


Adv. Funct. Mater. *18*, 2990 (2008)

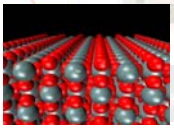
Previous work

Stability



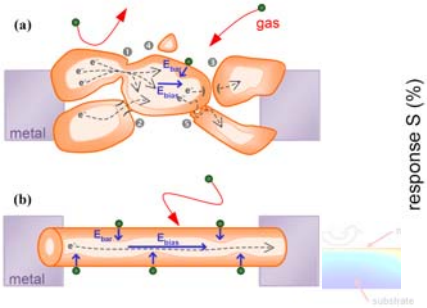


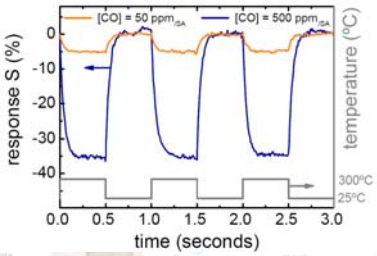
Nanotechnol. *18*, 495501 (2007)
Sens.Actuatators B *144*, 1 (2010)



Previous work

Response time

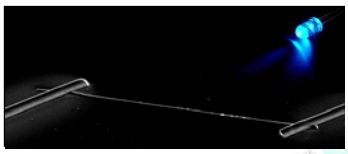


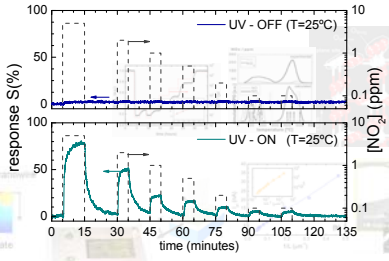


PCCP *11*, 7105 (2009)

Previous work

Working temperature





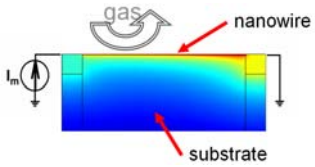
Sens. Actuators B *140*, 337 (2009)
PCCP, in press (2010)

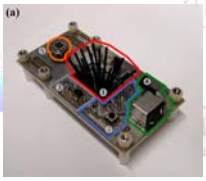
Previous work

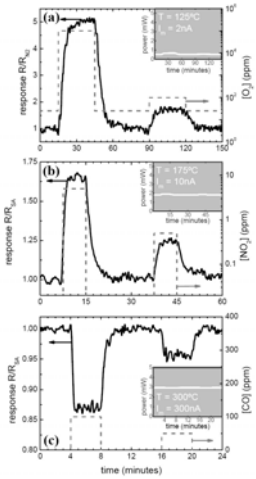
Power consumption

"very low power consumption: less than 20μW"

(measurement AND HEATING included!!!)







APL *93*, 123110 (2008)
APL *95*, 053101 (2009)

MIND Micro-nanotecnologies i Nanoscopies per Dispositius electrònics i fotònics

Previous work

Nanowires offer attractive features to improve many of the issues in solid state gas sensors

Sensitivity	radius ↓	⇒ response ↑
Stability	pristine surface	⇒ fully reversible response
Response time	indiv. nanowire	⇒ no gas diffusion
Working temperature	UV light	⇒ room temperature operation
Power consumption	indiv. nanowire	⇒ self-heating effect
		⇒ ultra-low power consumption
		⇒ fully autonomous gas sensors
		⇒ faster devices

Challenge: dealing with nanofabrication issues…

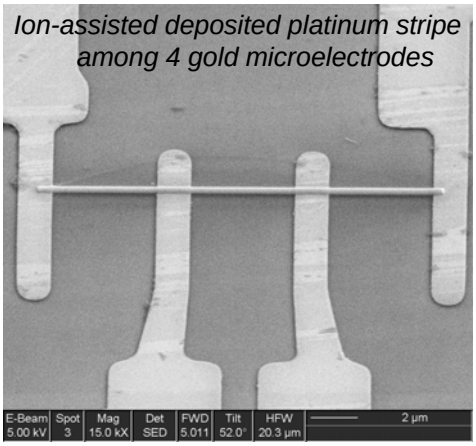
MIND Micro-nanotecnologies i Nanoscopies per Dispositius electrònics i fotònics

Contacting & Measuring One Single Nanowire

- Dual-beam Focused-Ion Beam
- Deposit Pt-containing material (from PtC_9H_{16})
  - Auger Electron Spectr.: C (67%) + Pt (27%)
- With ions or with electrons
  - $\rho_{ions} = 100\ \rho_{Pt\text{-}metal}$

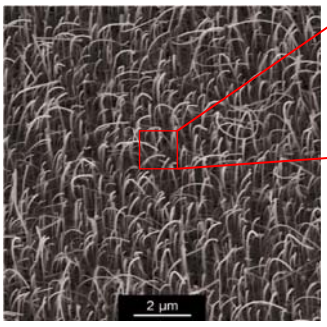
    $\rho_{electrons} = 10^5\ \rho_{Pt\text{-}metal}$
- Breakdown @ 10^{10} A/m^2
- Thermally stable up to 625 K

Ion-assisted deposited platinum stripe among 4 gold microelectrodes



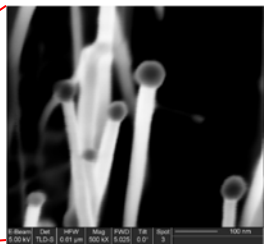
Contacting & Measuring One Single Nanowire

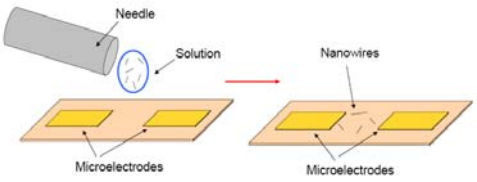
Nanowires are dispersed over a substrate with pre-patterned µelectrodes



SnO_2 Nanowires

Nanotechnology 17, 5577-5583 (2006)

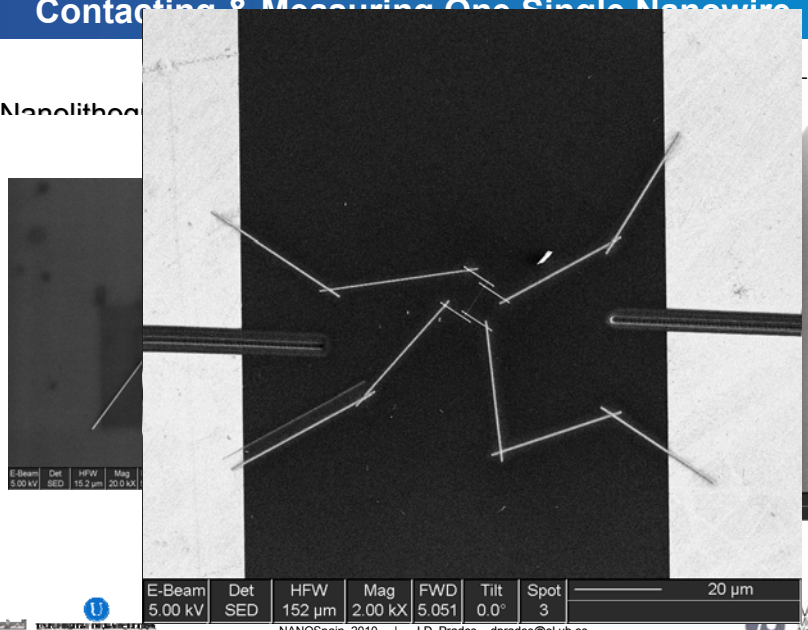


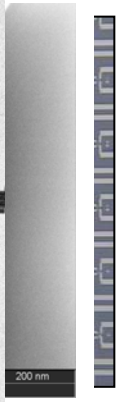


Contacting & Measuring One Single Nanowire

Nanolithog

-5583 (2006)



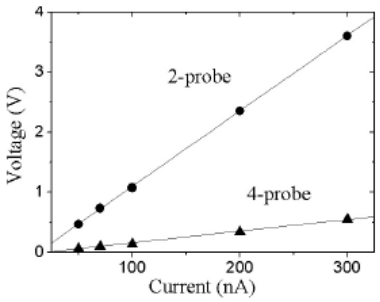


MIND Micro-nanotecnologies i Nanoscopies per Dispositius electrònics i fotònics

Contacting & Measuring One Single Nanowire

Electrical Characterization (2- & 4-probes)

Metal oxide NW
- Mostly non-ohmic responses
- High contact resistances
- Study of the NW requires 4p
- Self-heating at contacts



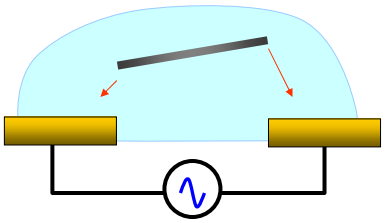
Nanotechnology 17, 5577-5583 (2006)
Physical Review B 76, 085429 (2007)

MIND Micro-nanotecnologies i Nanoscopies per Dispositius electrònics i fotònics

Dielectrophoretic alignment of NWs

Self-assembly technique

"When a polarizable NW is subject to a non-uniform electric field a dipole moment is induced that tends to align the nanowire in the direction of the electric field"

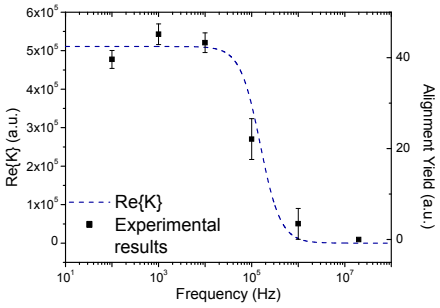


Proof of concept experiments

Dielectrophoretical force when applying an electrical field in a dielectric medium:

$$F_{DEP} = \frac{1}{2}\pi r^2 l \varepsilon_m \mathrm{Re}\{K\} \nabla E^2_{RMS}$$

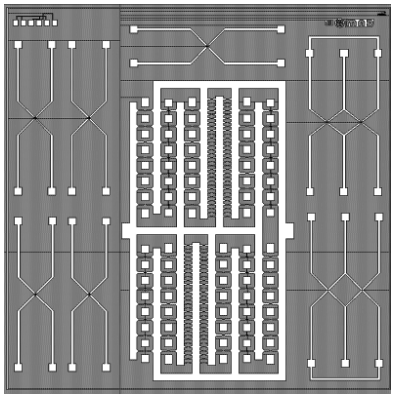
$$\mathrm{Re}\{K\} = \frac{\omega^2(\varepsilon_m\varepsilon_p - \varepsilon_m^{\ 2}) + (\sigma_m\sigma_p - \sigma_m^{\ 2})}{\varepsilon_m^{\ 2}\omega^2 + \sigma_m^{\ 2}}$$

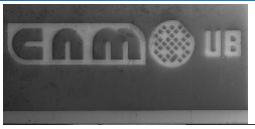


Dielectrophoretic alignment of NWs

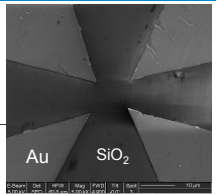
Design of electrodes

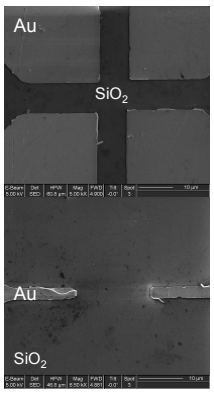
Based on 2 big electrodes with sharp tips opposed.

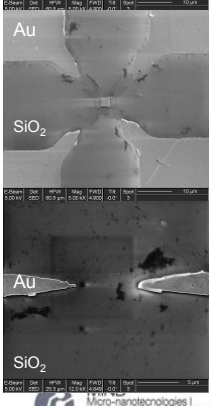




Gaps of different lengths

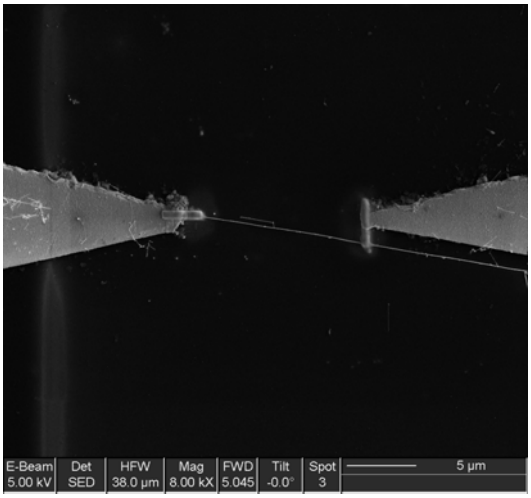






Dielectrophoretic alignment of NWs

•Results on alignment of nanowires:



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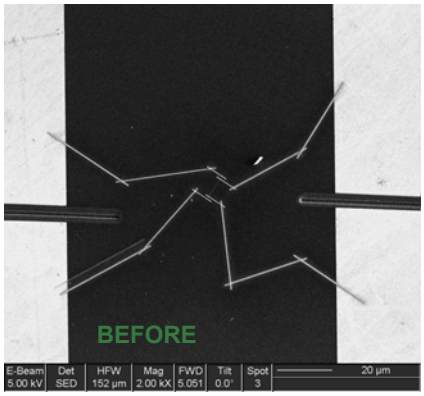
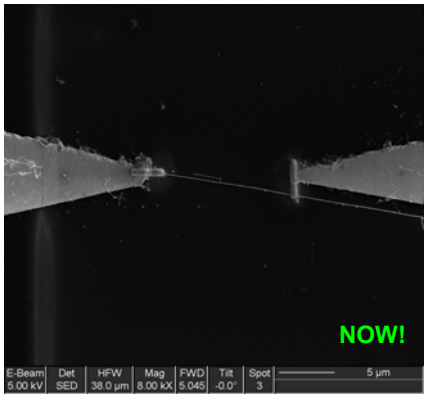
Dielectrophoretic alignment of NWs

• Big difference!





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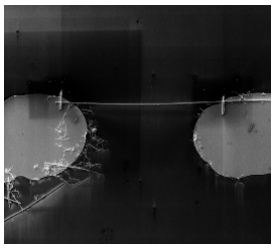
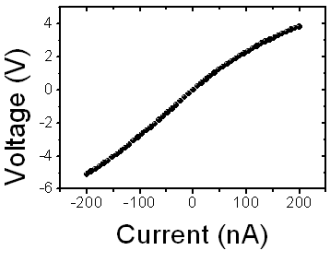
Dielectrophoretic alignment of NWs

2-probes configuration

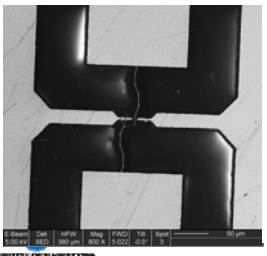


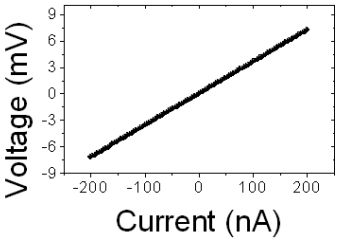


- rectifying behavior
- 2 Schottky diodes
- (NW // Pt FIB).

Phys.Rev.B 76, 085429 (2007)

4-probes configuration





SnO_2-NW

ρ_{EIB} = 0.40 ± 0.02 $(\Omega cm)^{-1}$

ρ_{DEP} = 0.38 ± 0.02 $(\Omega cm)^{-1}$

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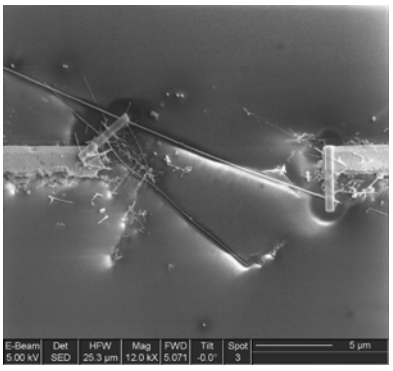
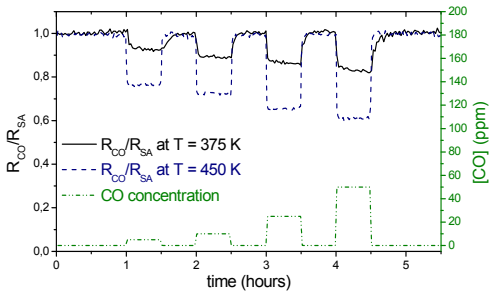
Gas Sensor Measurements

Carbon monoxide

- Aligned SnO_2-NW
- Diameter: 90nm





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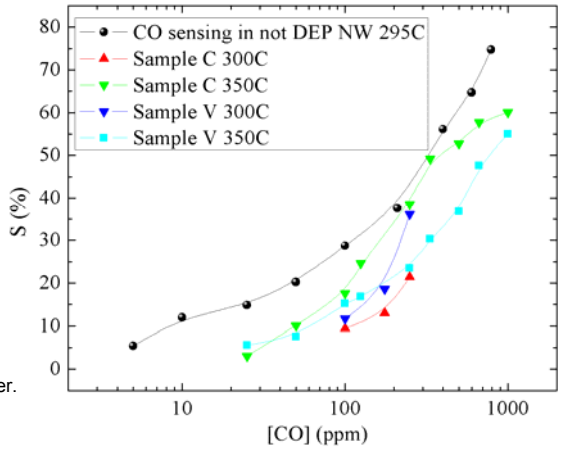
Gas Sensor Measurements

• Comparison with non-DEP experiments:



Adv. Funct. Mater. 18, 2990 (2008)

Conclusions

- Individual NWs can be electrically contacted with the help of FIB lithography techniques
- Gas nanosensors can be fabricated using these techniques, responding to different gases (SA, N_2, CO, H_2O)
- Alignment of nanowires by dielectrophoretic techniques is feasible
- Gas nanosensors with equivalent properties as non-DEP aligned NWs can be fabricated
- This allows the increase of the throughput in gas sensor fabrication based on individual NWs

Acknowledgments

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- Spanish Ministry of Science and Technology, through the projects MAGASENS, CROMINA and NAWACS (NanoSciERA programme) and FPU grants.

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Thank you all for your attention!