Integration and localized growth of metal-oxide nanowires for low power gas-sensing applications

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

COST

Motivation

▪ *Development of high sensitivity, low cost and/or low power consumption solid state gas sensors for safety and control applications*

✓ Chemical sensors world market US$12 billion by 2008

⇒ metal oxide sensors only 15% of market (2008)

Source: Global Industry Analysts "Sensors: A Global Strategic Business Report"

✓ Active field in R&D: looking for a better performance keeping cost down

Better performance?

1. Sensitivity
2. Stability
3. Response time
4. Working temperature
5. Selectivity
6. Power consumption
7. Integration
8. Mass production …

1–3 → **Use of nanowires**

4–5 → **UV-activated sensors**; **E-nose (sensor matrix)**

6 → **Microhotplates; self-heating**

7–8 → **Alignment of nanowires**; **Parallel processing**; **In-situ growth**

Outline

1. Operation principle of MOX nanowire-based gas sensors

2. Gas sensors based one Single Nanowires

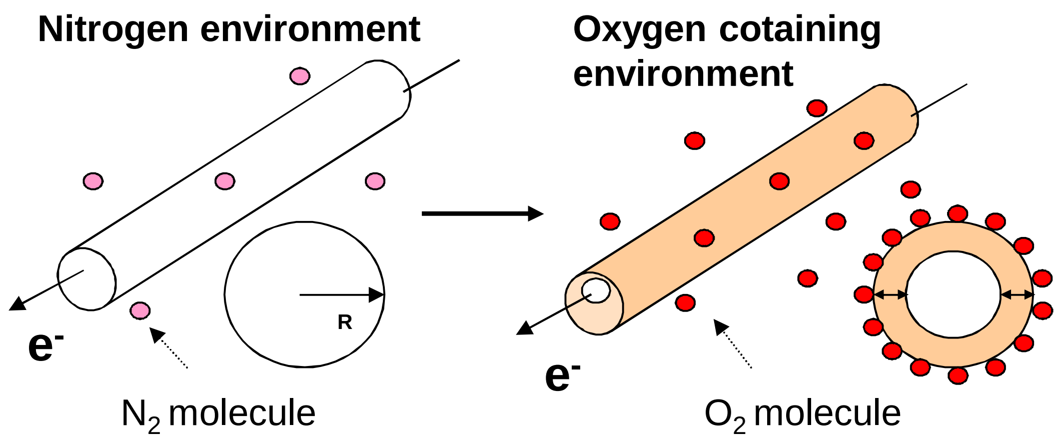
3. Microhotplates: towards low power consumption devices

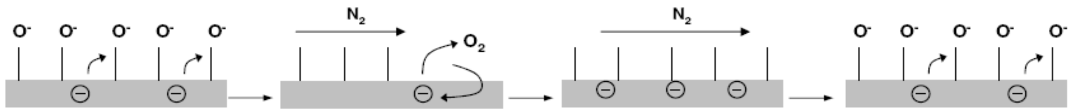
4. Microhotplates: microlaboratories for materials' growth

5. Conclusions

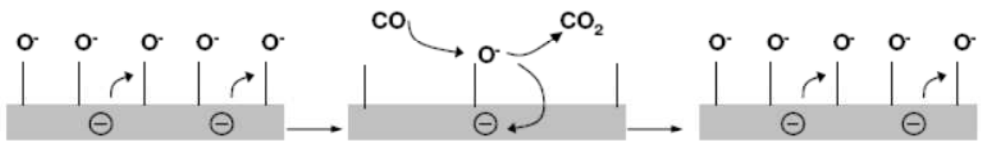
1. MOX NW-based gas sensors

Synthetic Air/Nitrogen (oxidising atmosphere) (T > 200 ºC)





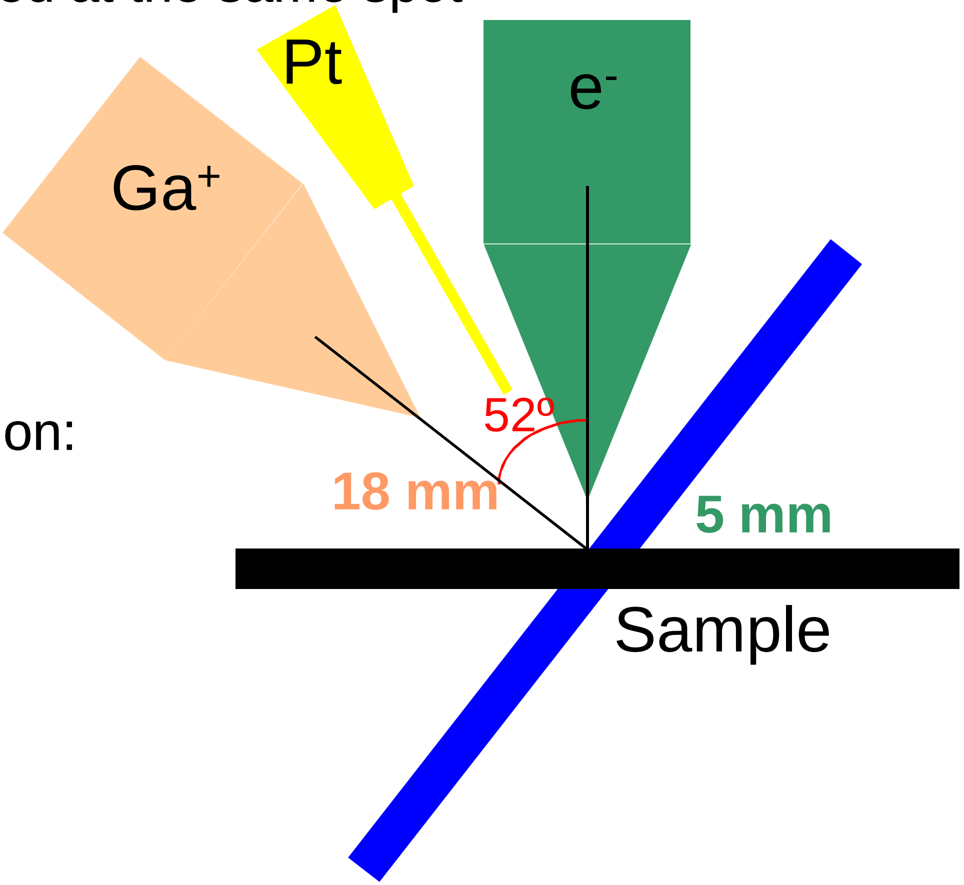
Carbon monoxide (reducing gas)



2. Fabrication of the gas sensors

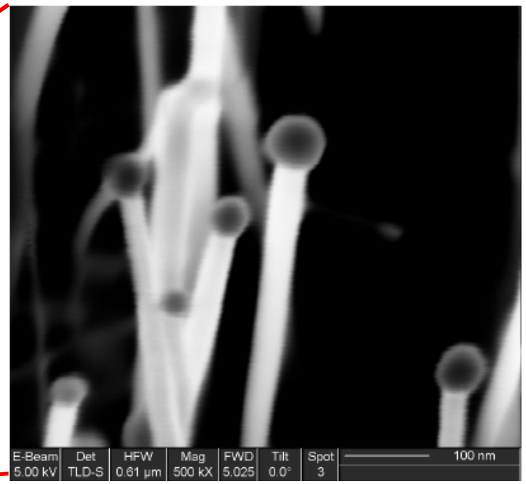
Dual beam focused ion beam machine (FEI Strata DB 235)

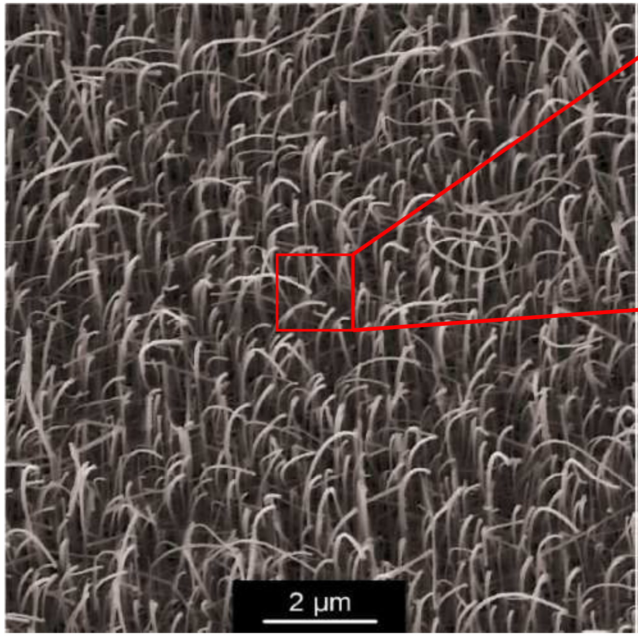
- 2 beams: electrons and ions, focused at the same spot
- Electrons: FEG 0.5-30kV
- Ions (Ga^+): 30 kV, 1pA-20nA
  Projected range (in Si): 26 nm
- Minimum ion beam size: 6 nm
- Metallorganic precursor for deposition: PtC_9H_{16}
- Both electron and ion-assisted deposition can be performed



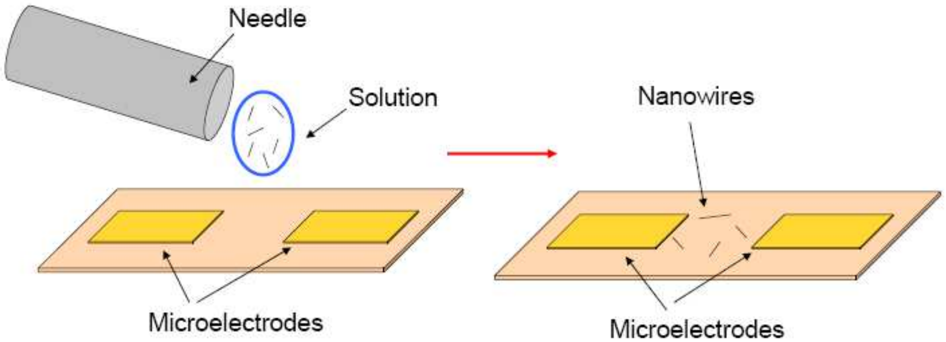
2. Fabrication of the gas sensors

Nanowires are dispersed over a substrate with pre-patterned microelectrodes:





SnO_2 Nanowires



Nanotechnology 17, 5577-5583 (2006)

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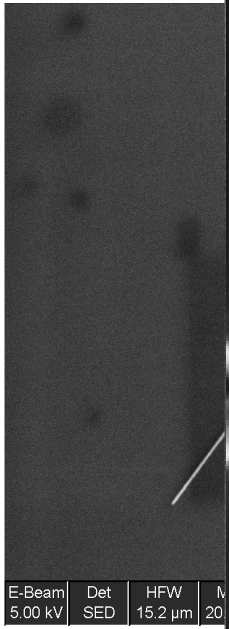
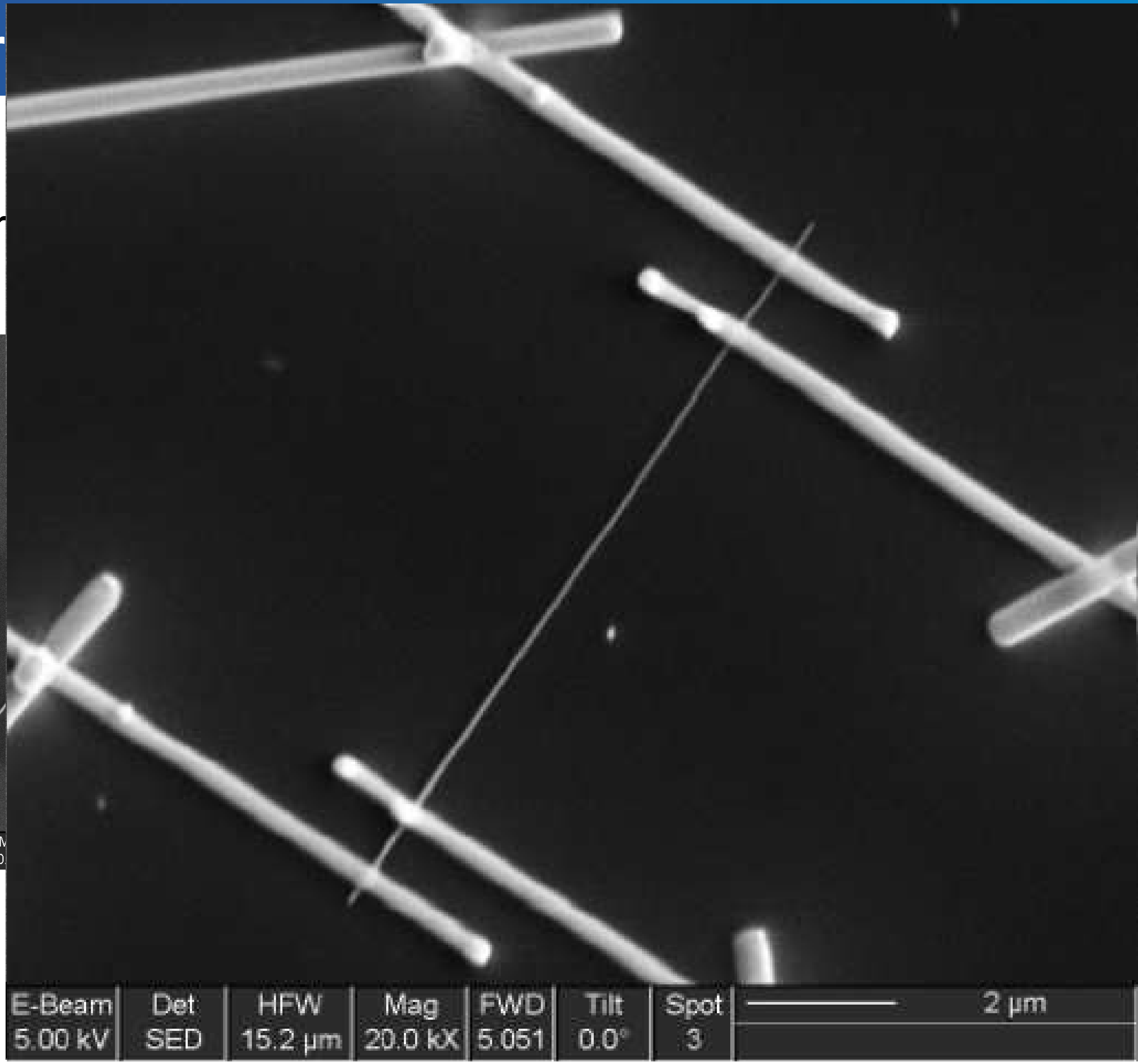
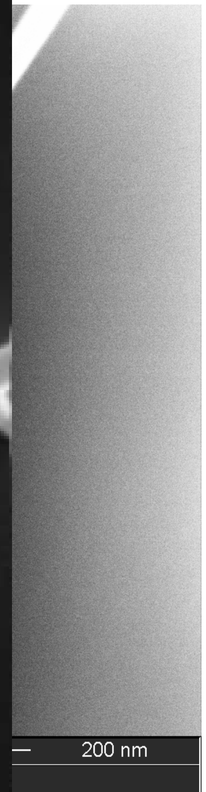






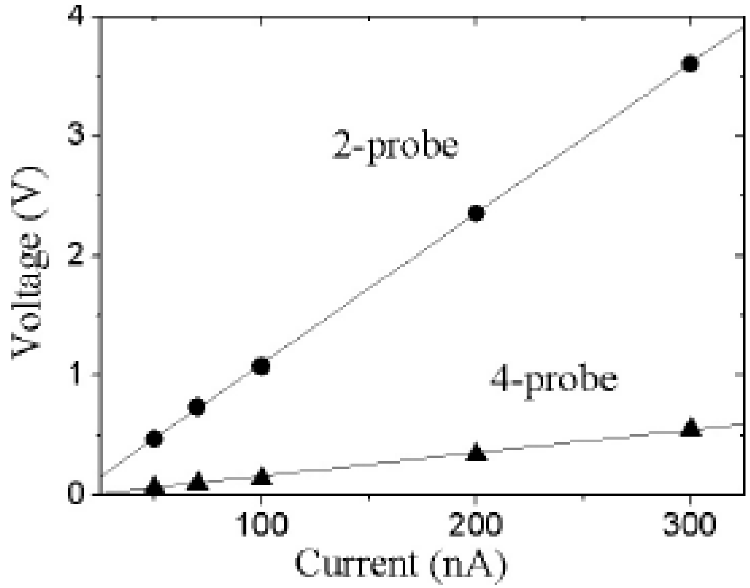
Nanotechnology 17, 5577-5583 (2006)

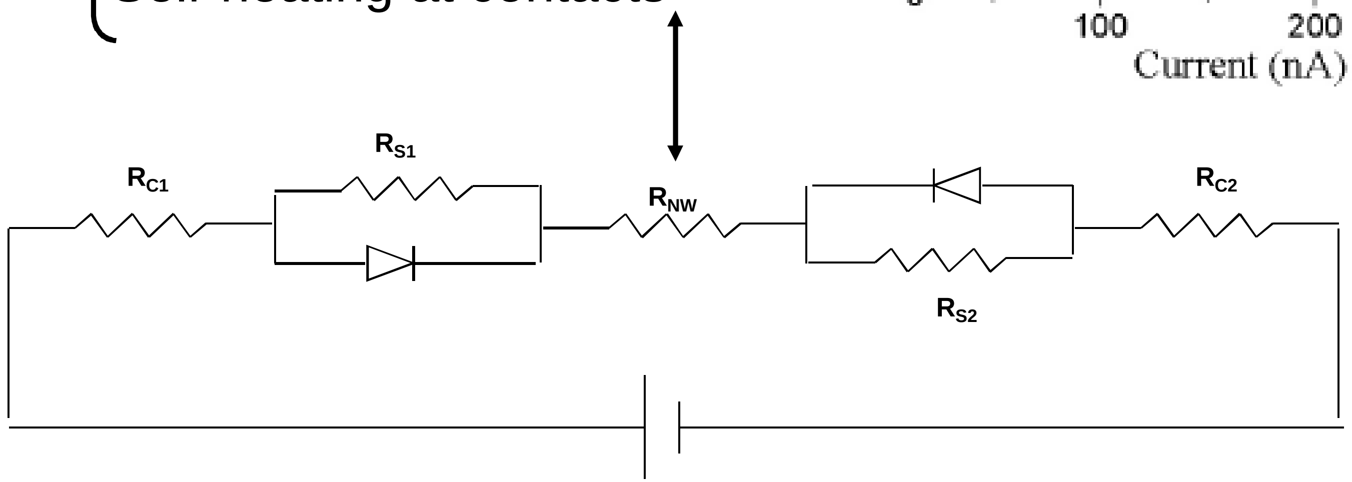
2. Electrical testing of the devices

Electrical Characterisation (2&4 probing)

Semiconductor nanowires:

- Mostly not ohmic responses
- High contact resistances
- Study of the NW requires 4p-p
- Self-heating at contacts

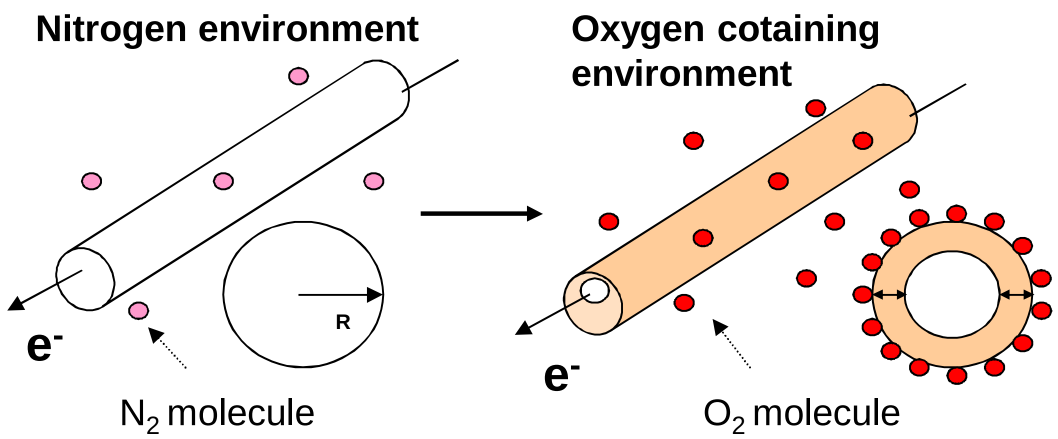


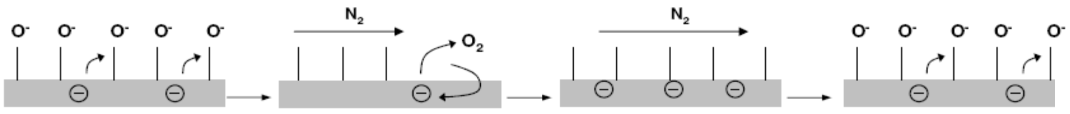


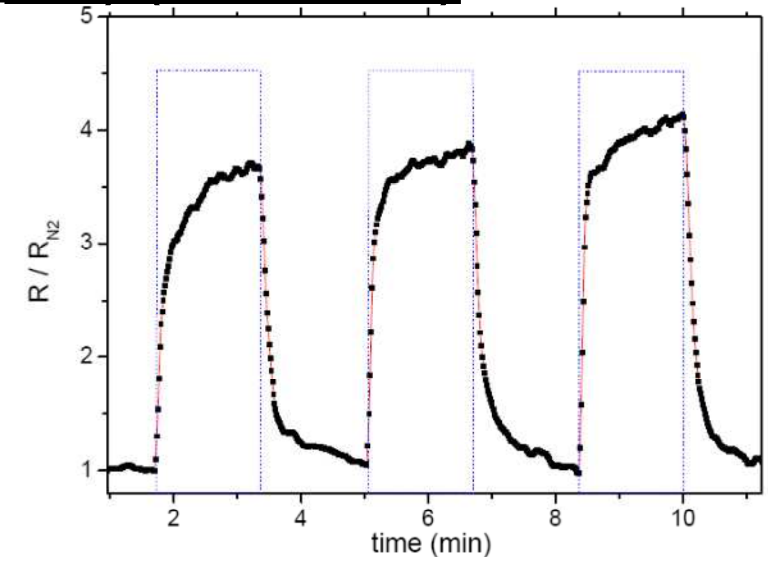
Nanotechnology 17, 5577-5583 (2006)

2. Gas Sensor Measurements

Synthetic Air/Nitrogen (oxidising atmosphere) (T > 200 ºC)







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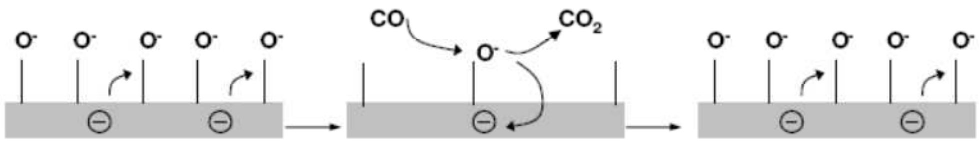

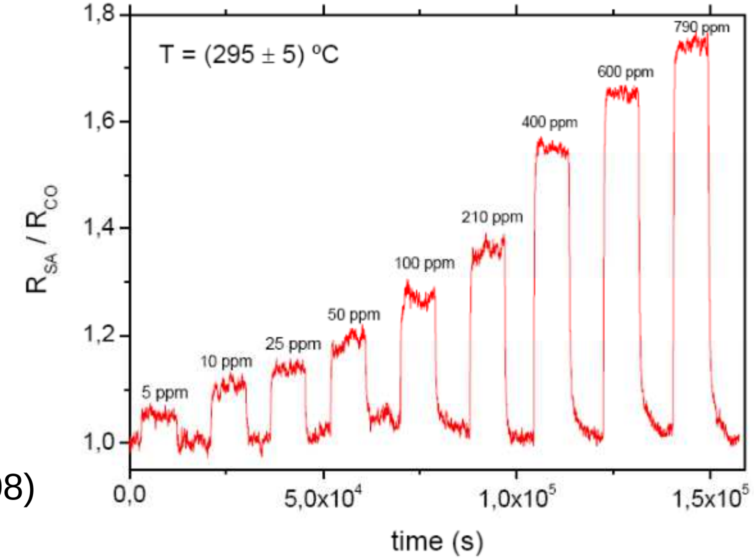

Advanced Functional Materials 18, 2990 (2008)

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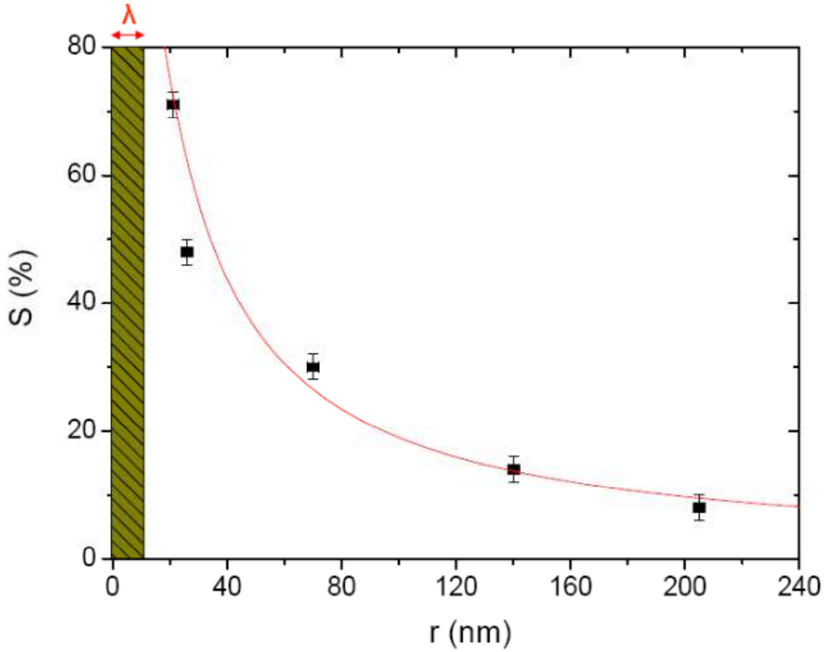
2. Gas Sensor Measurements

Synthetic Air / Nitrogen / Synthetic Air (T > 200 ºC)



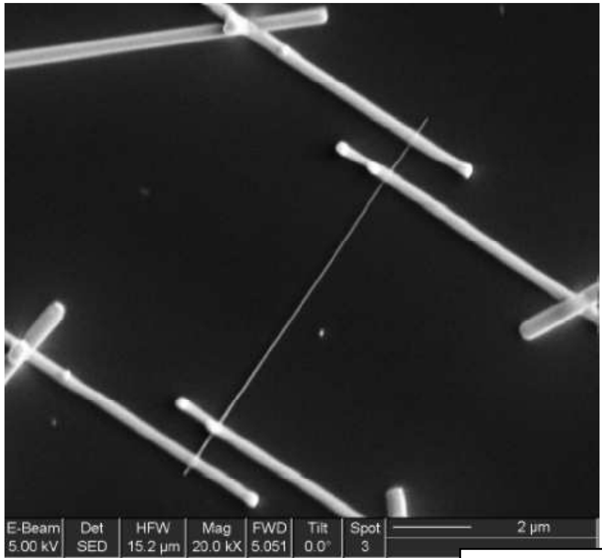
- Higher responses with thinner nanowires
- Raise surface / volume ratio
- Depleted region W = 10 nm

Target Gases	Concentration range	Sensitivity $R_{NW}(gas)/R_{NW}(SA)$	Response time
O_2	0.5ppm – 2·10^{5}ppm	0.4 @ 10^3 ppm	< 10min @ 270ºC
NO_2	0.1ppm – >10ppm	1.3 @ 1 ppm	< 1min @ 180ºC
CO	50 – >1000ppm	0.88 @ 100 ppm	< 1min @ 300ºC
EtOH	10 – 1000ppm	0.1 @ 100ppm	< 1min @ 175ºC
H_2O	2500ppm – 30000ppm	0.6 @ 8000ppm	< 10min @ 295ºC

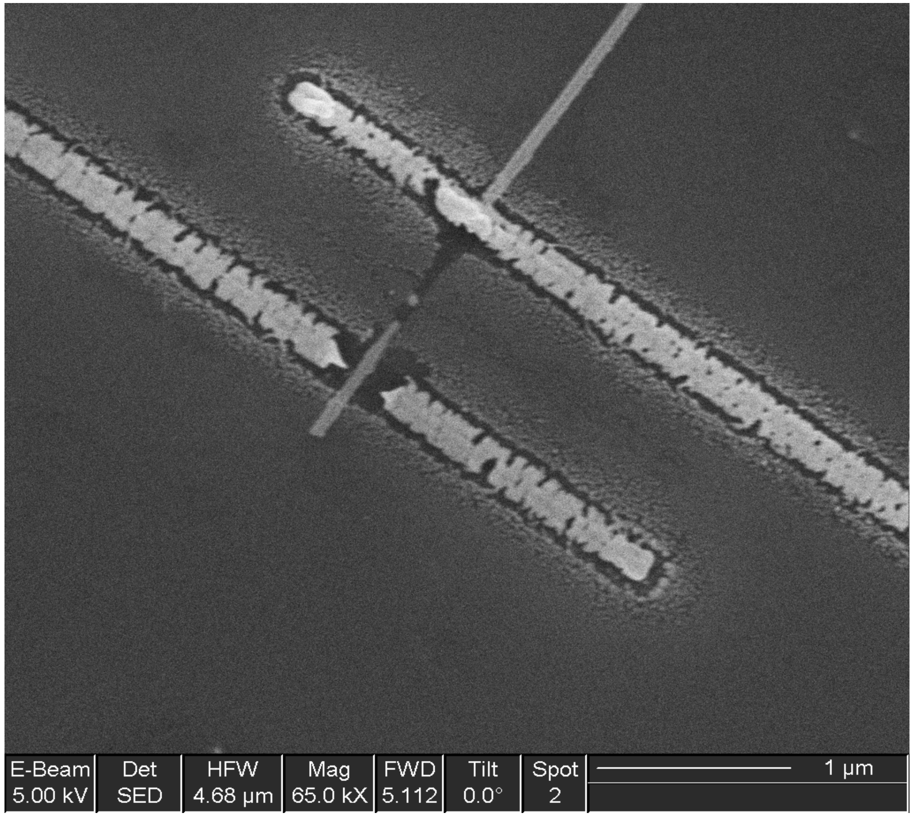
2. Gas Sensor Measurements

<u>Electrical Characterization</u> (self heating)

Negative effects



T = 298 K
V = 4V
I = 21,62 nA
R =185 MΩ
R_{NW} = 76 MΩ
R_{SI} = 109 MΩ

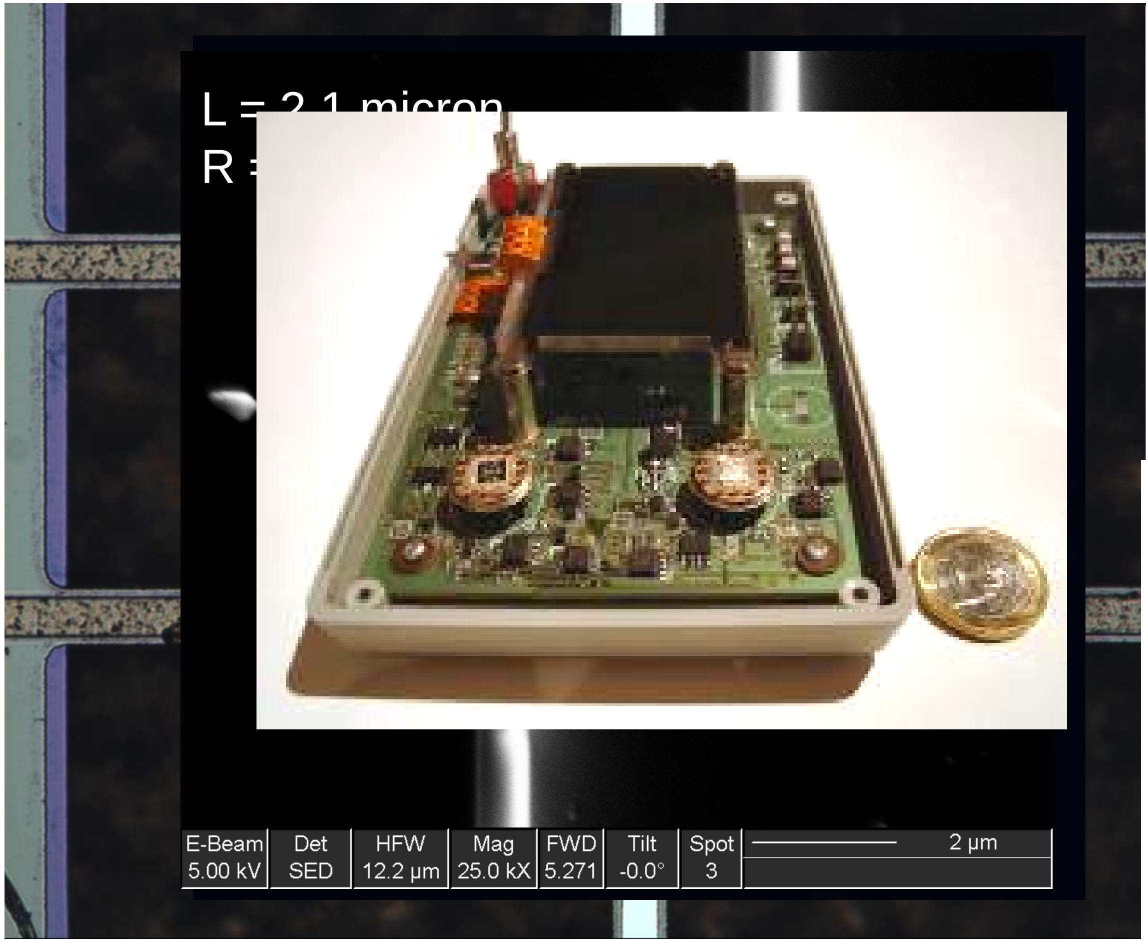


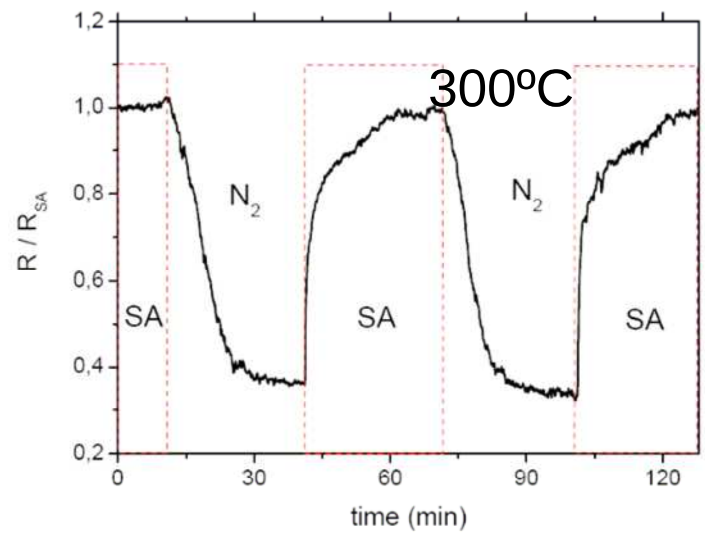
But things are not so bad …
if one is careful: controlled heating

Physical Review B 76, 085429 (2007)

3. Microhotplates for lower power consumption

Contact fabrication on suspended microhotplates with integrated heater





Nanotechnology 18, 495501 (20

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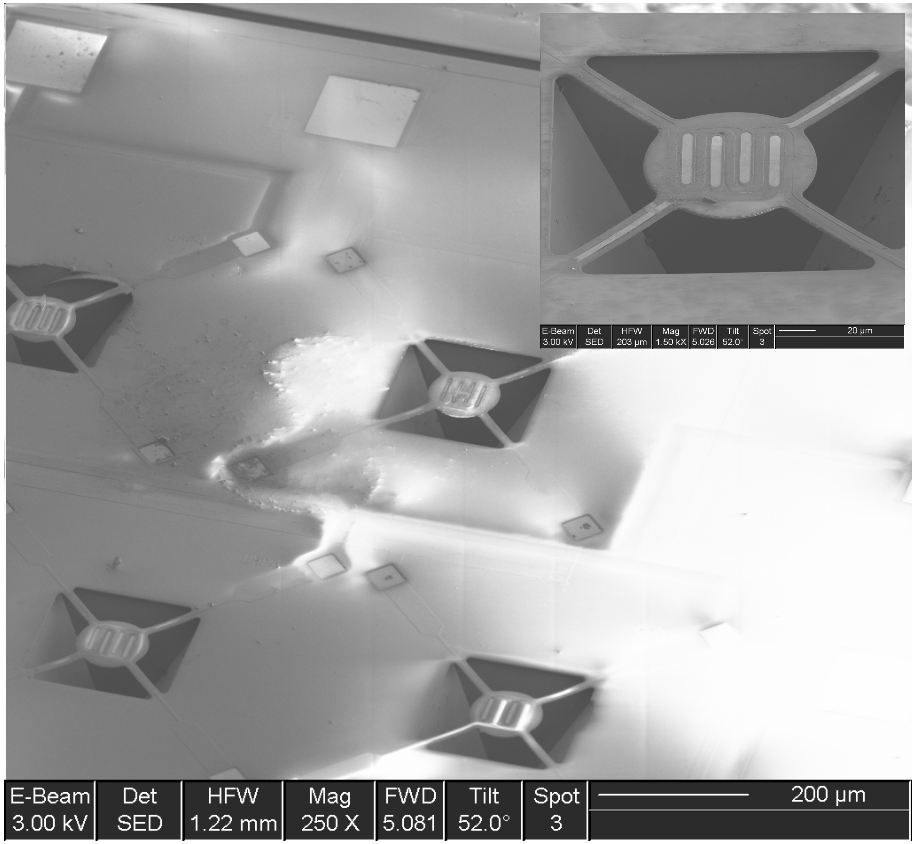

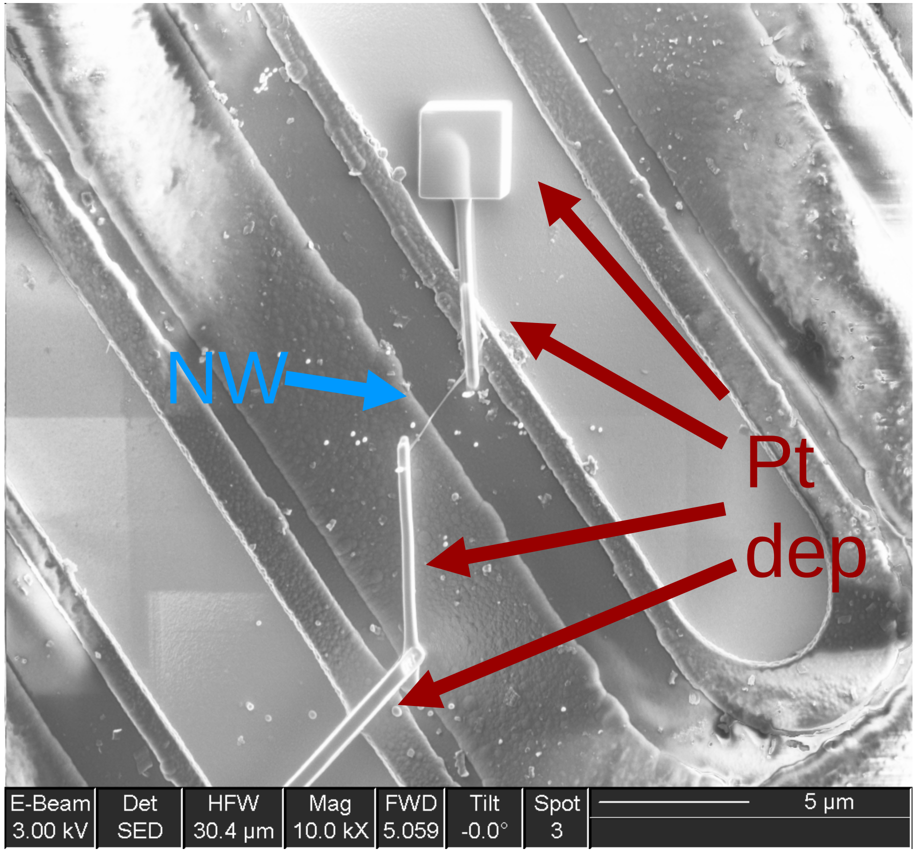

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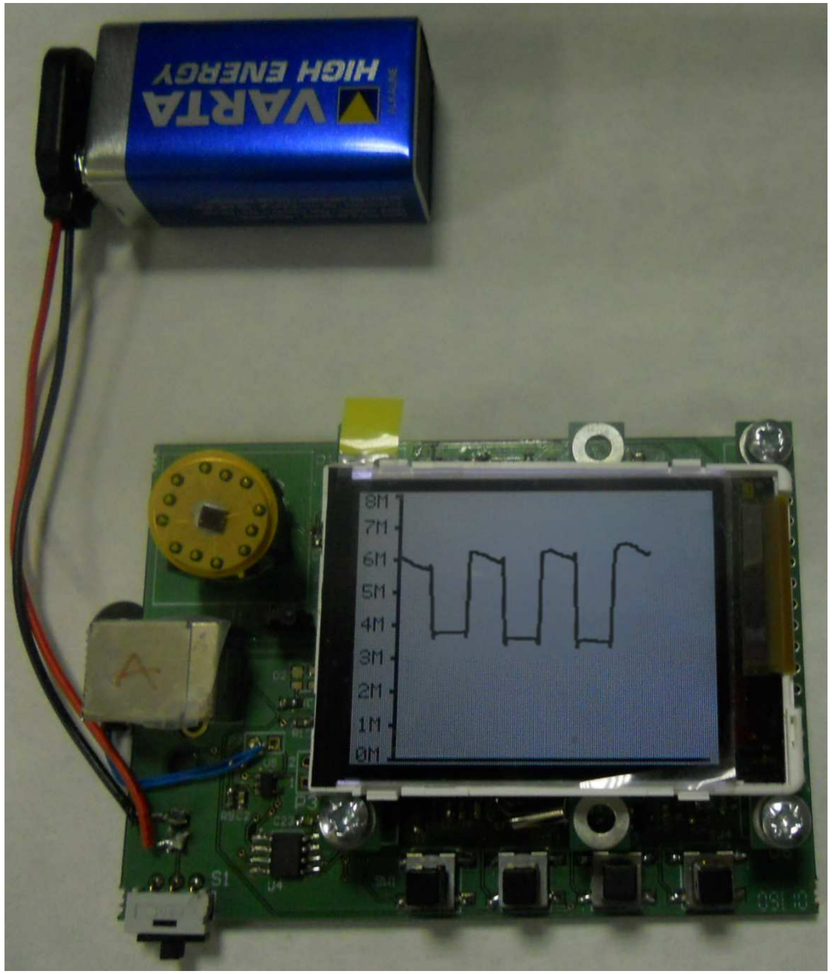
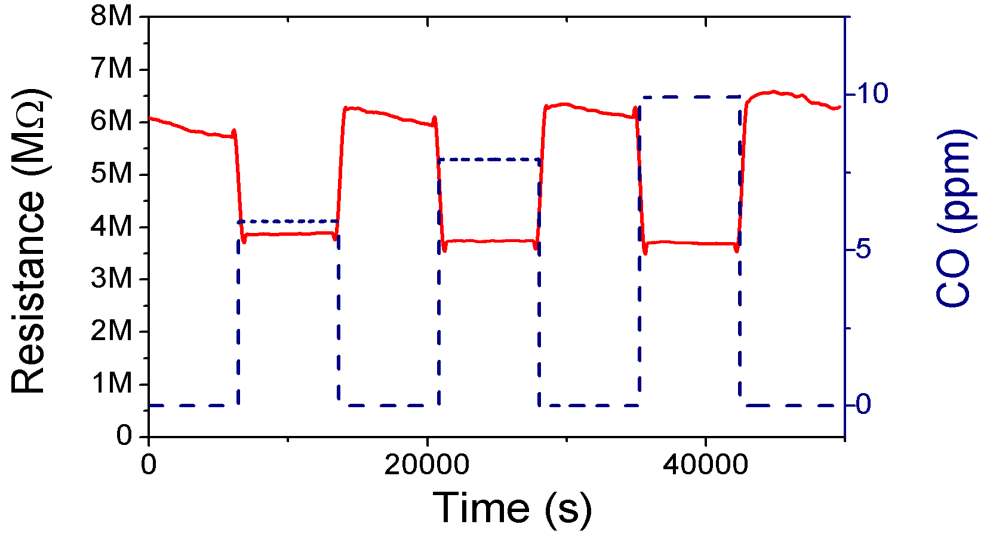
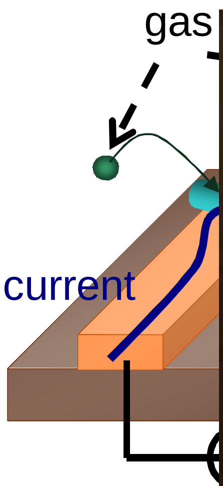
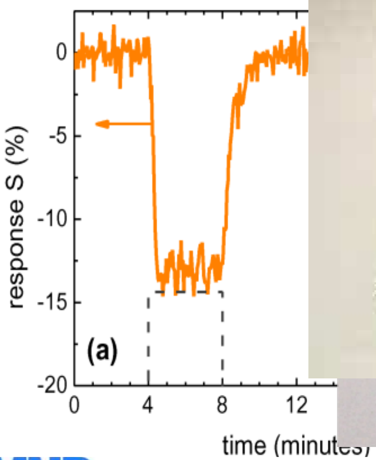


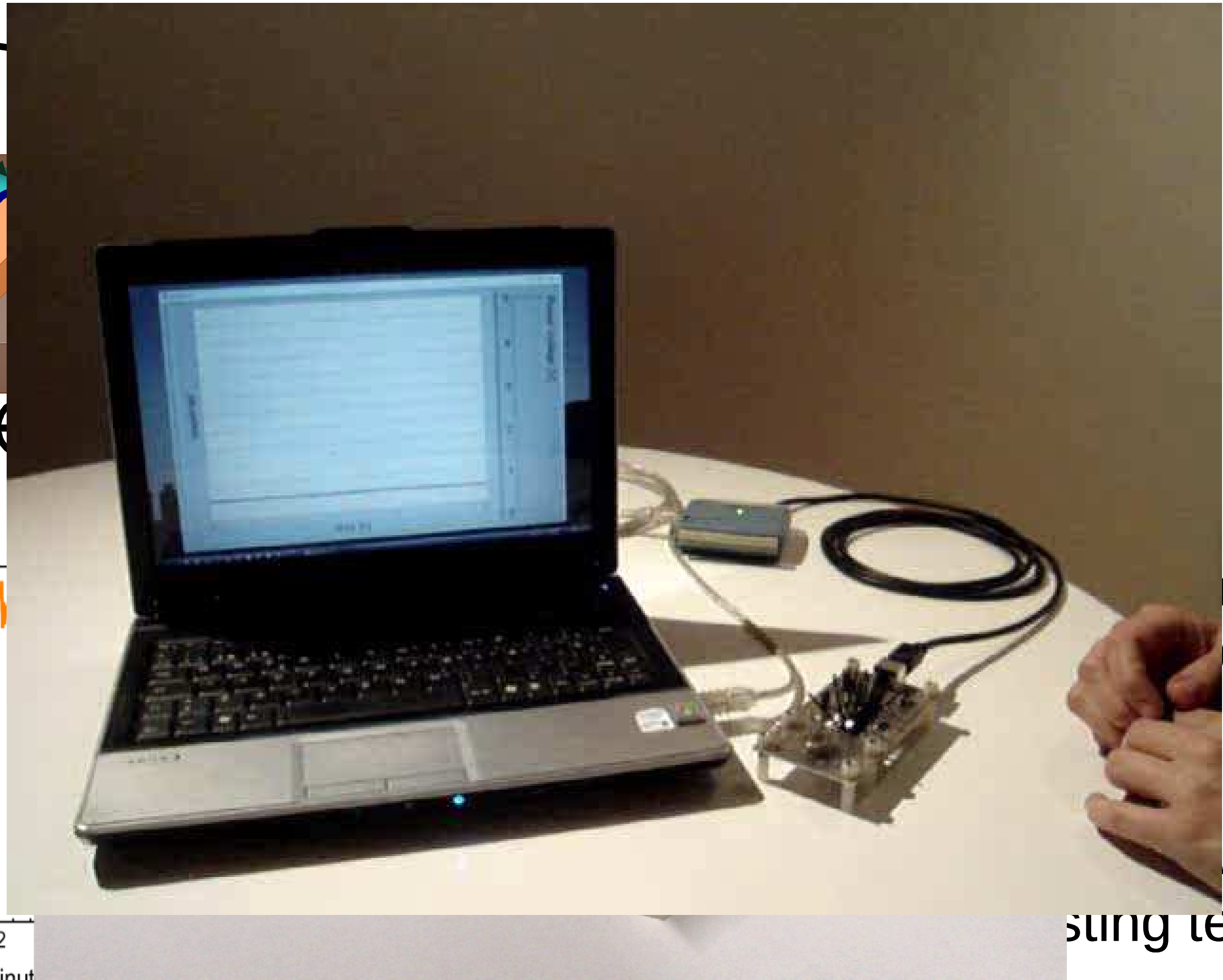


Operative gas sensor system based on nano-technologies.

3. Microhotplates for self-heated devices







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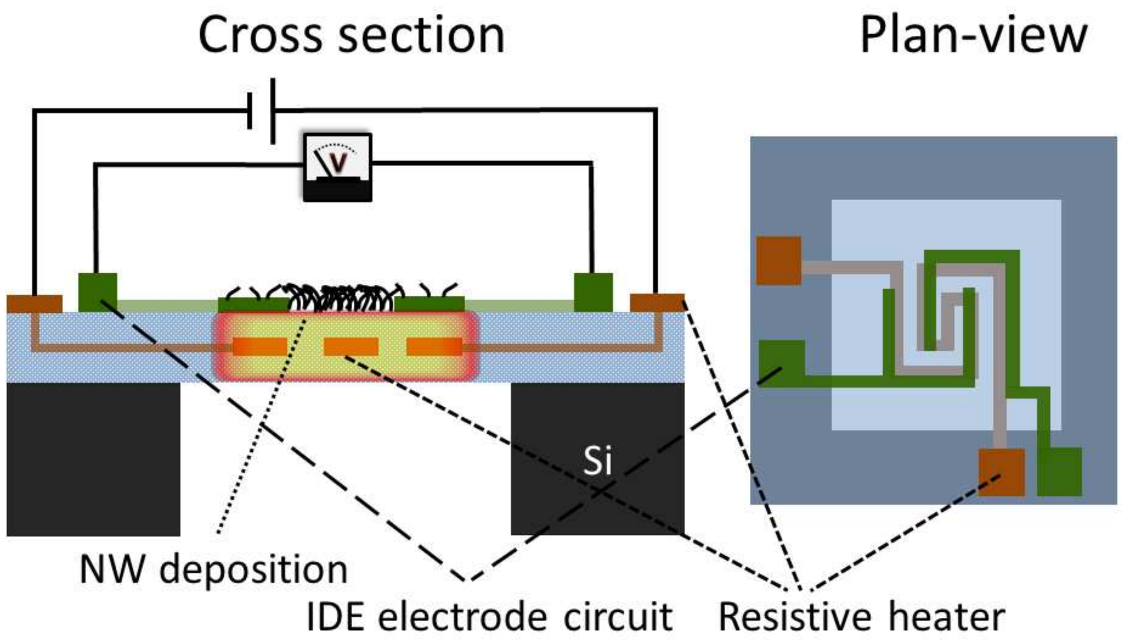
Applied Physics Letters 93, 123110 (2008)

4. In-situ growth and integration on microhotplates

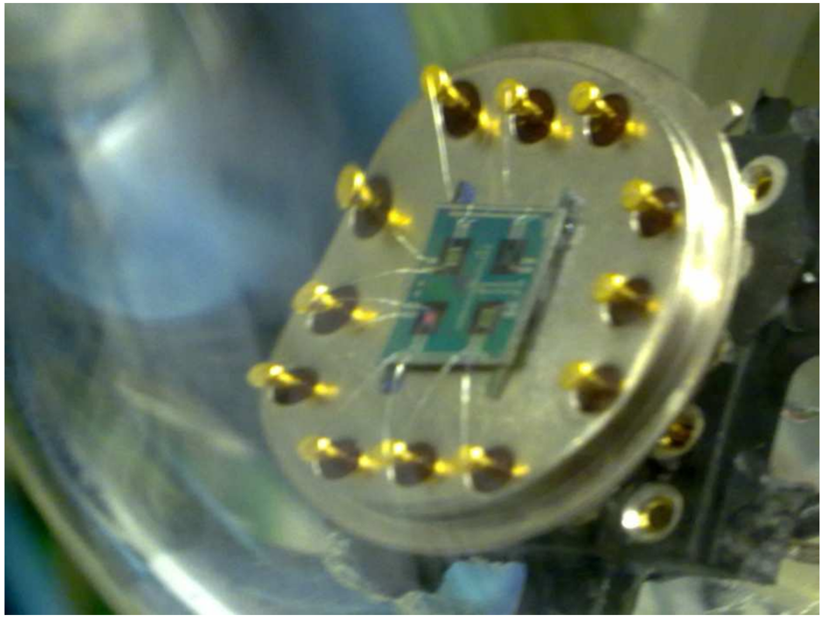
Motivation: use of the microhotplates with integrated heater for in-situ growth and integration of NWs

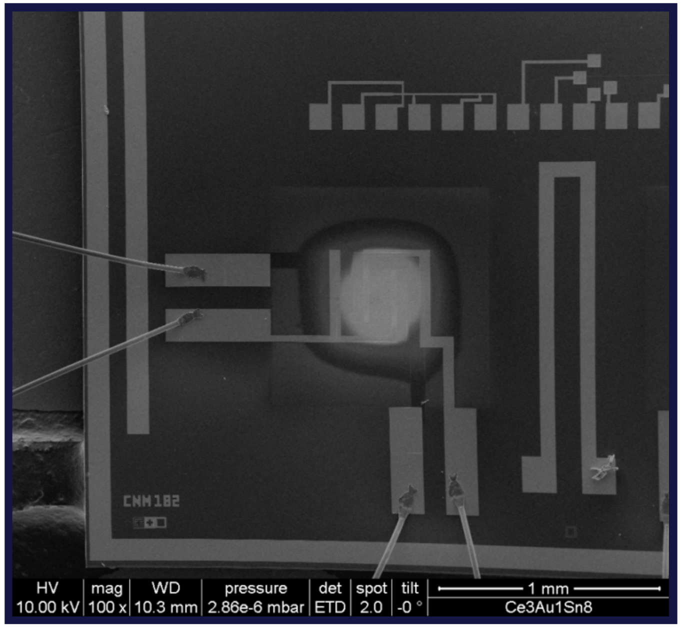


Chemical Communications 48, 4734 (2012)

4. In-situ growth and integration on microhotplates

Membranes with polySi heater fabricated using bulk micromachining





Chemical Communications 48, 4734 (2012)

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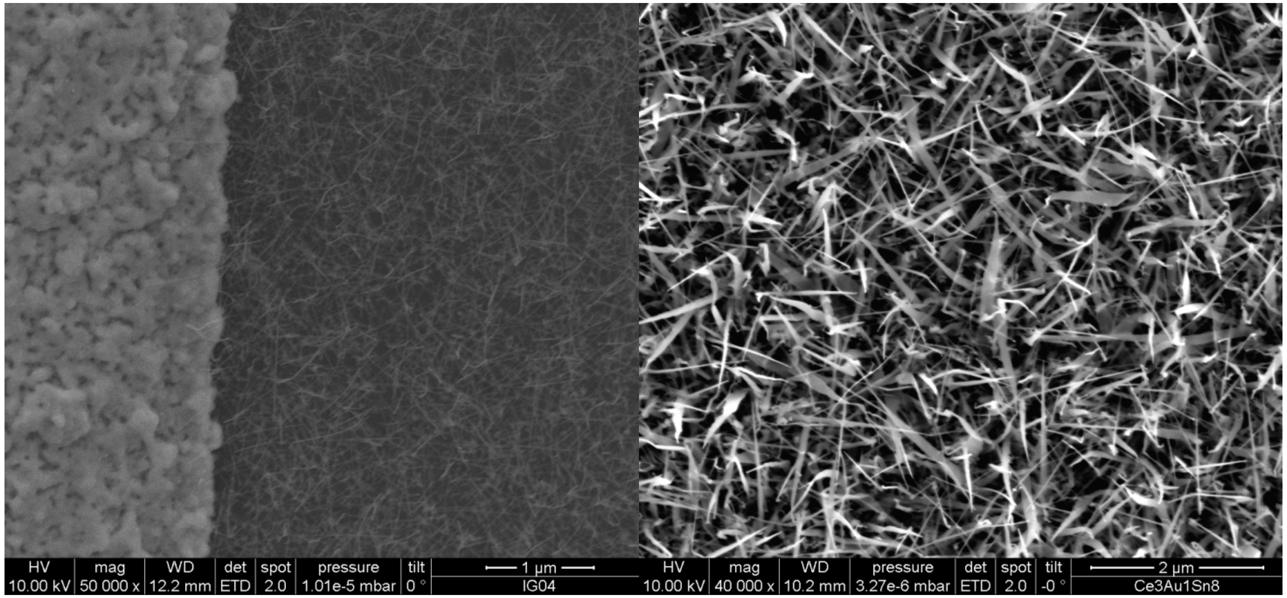
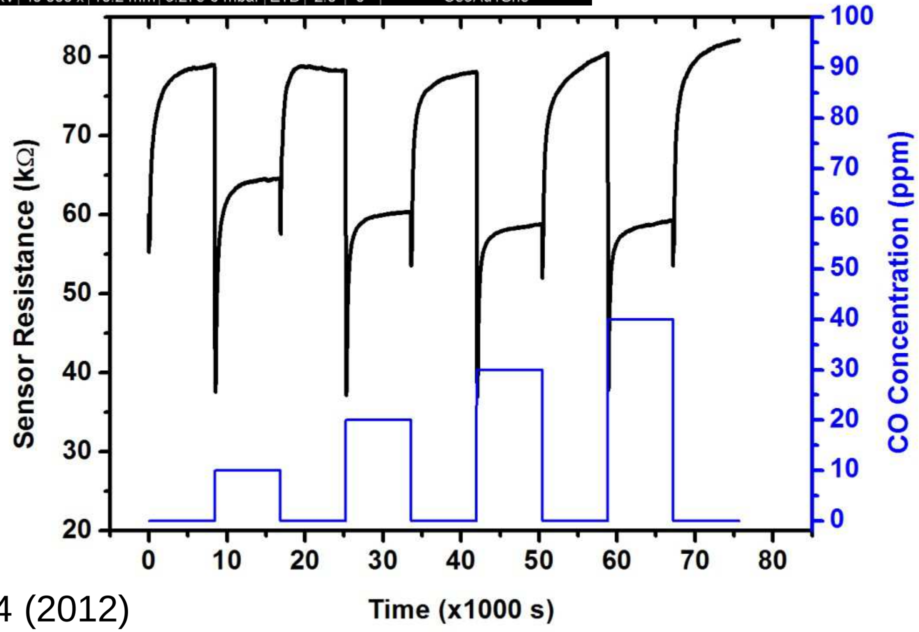


Efficient growth of single-crystal SnO_2 NWs and high response to CO



Chemical Communications 48, 4734 (2012)

5. Conclusions

- Single NWs are electrically contacted with the help of FIB lithography techniques
- Gas nanosensors based on individual NWs with improved properties can be fabricated with this technology
- Extension of the technology to suspended microhotplates for low power consumption
- Controlled self-heating can be used for ultralow power devices
- In-situ growth and integration of NWs has been demonstrated

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