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

COST Action TD1105

2nd International Workshop *EuNetAir* on

New Sensing Technologies for Indoor and Outdoor Air Quality Control

ENEA - Brindisi Research Center, Brindisi, Italy, 25 - 26 March 2014

Low Power and Portable AlGaN/GaN based Sensor Systems for Air Monitoring

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Function in the Action: Expert

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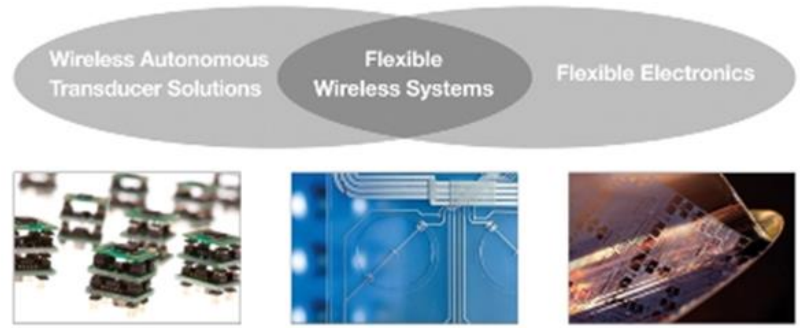
COST is supported by the EU Framework Programme

ESF provides the COST Office through a European Commission contract

Holst Centre Fundamentals

- **Independent, with reputed parents**
  - Founded by imec (1300 fte, Belgium) and TNO (4500 fte, The Netherlands)
  - Operational since 2006
- **Critical mass to create impact**
  - Staff of 180 researchers; >28 nationalities
  - Involving groups of mother organisations
  - 70 industrial and academic residents
- **Focus on relevant topics**
  - Ultra-low-power and flexible electronics
  - Lighting, Solar, Displays, Healthcare
- **Supported by strong eco-system**
  - Global industrial and academic partners
  - Embedded in high-tech region
- **Co-funded by local and Dutch government**
  - Fastest growing R&D consortium in the Netherlands

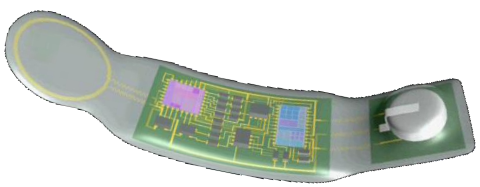


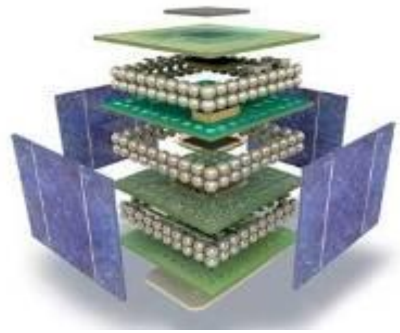
imec

Wireless Autonomous Transducer Solutions

Cover all basic building blocks of a wireless sensor node

- Digital signal processing
- Wireless communication
- Micro-power generation and storage
- Sensor and actuator technology
- Analog IC design



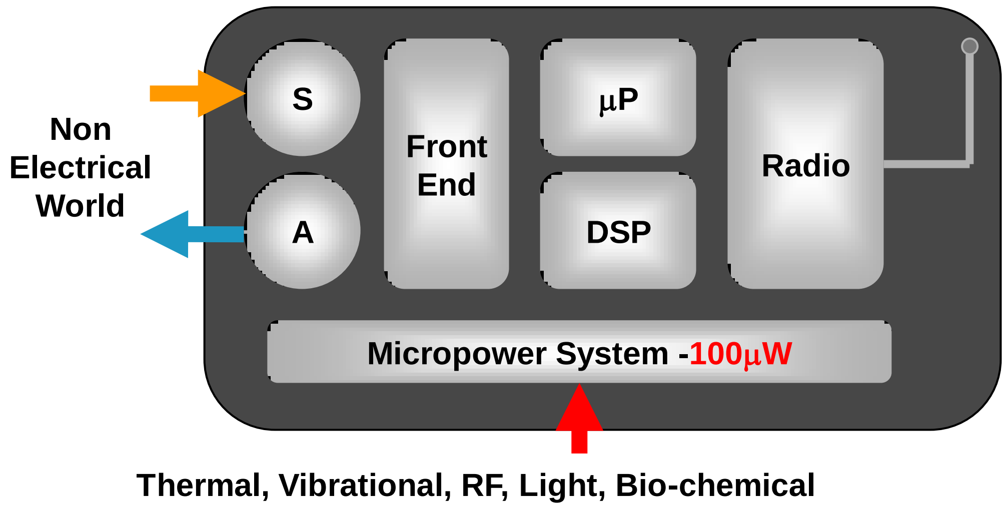


Integration in various form factors

- 3D stack
- Flexible / stretchable

Technology drivers

- Ultra-low power
- Miniaturization
- Low cost processes



From *Body* Area Network to *Personal* Area Network

Autonomy

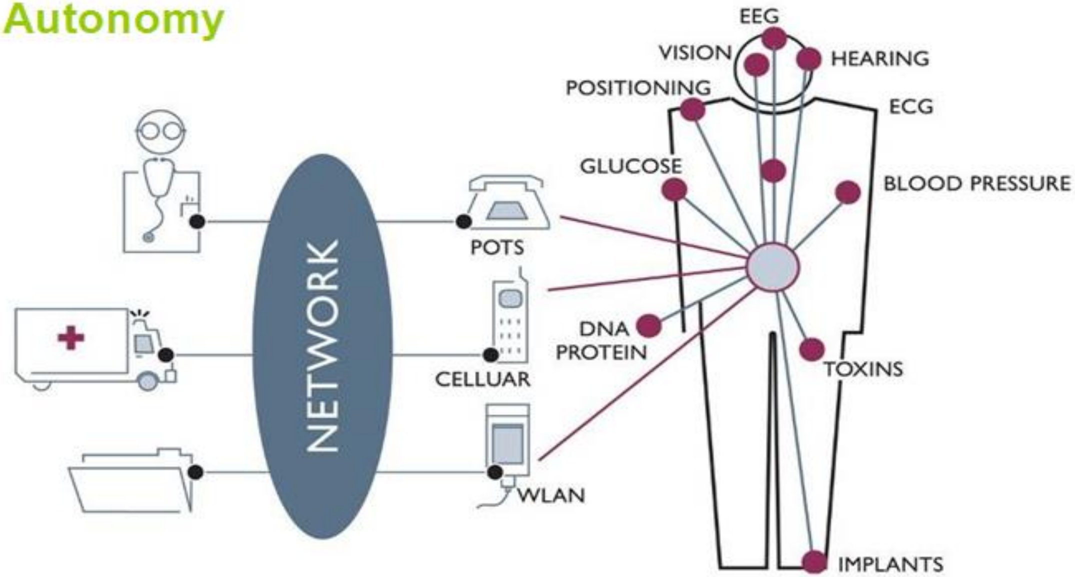
Wearability

Connectivity

Intelligence

Functionality

Implantability



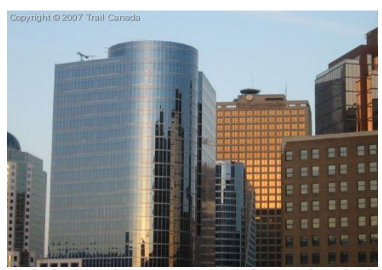
Vehicles

Living spaces

Open spaces

Industry

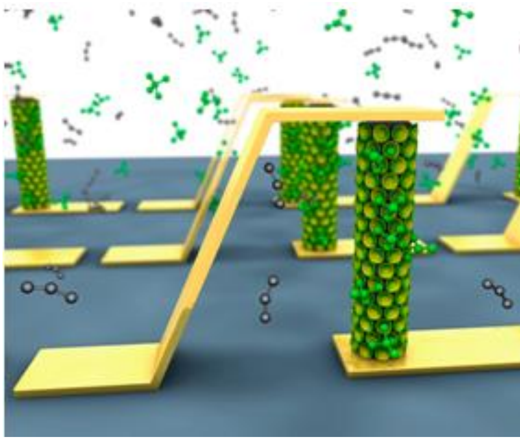
Office buildings

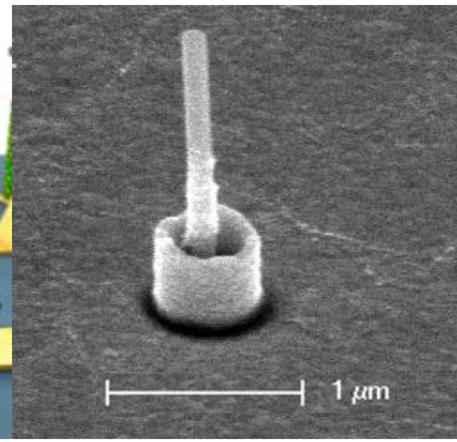


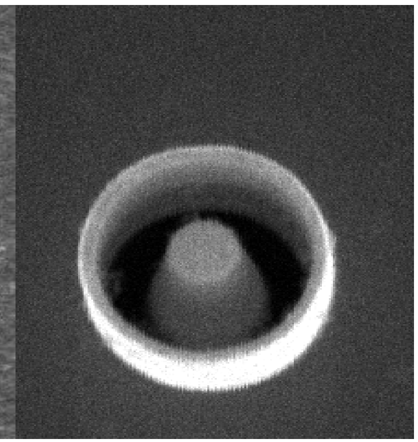
Working environment

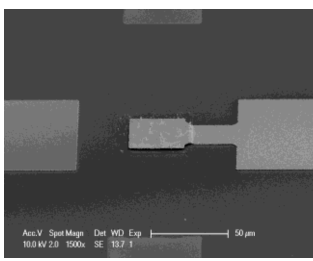
Extend with Compact chemical Sensors

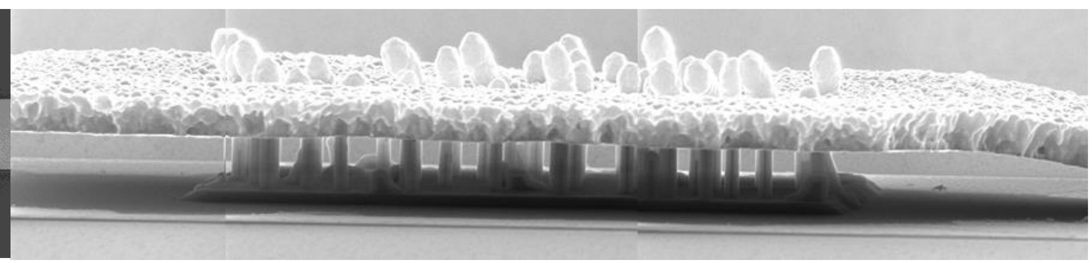
Vertical nanowire devices



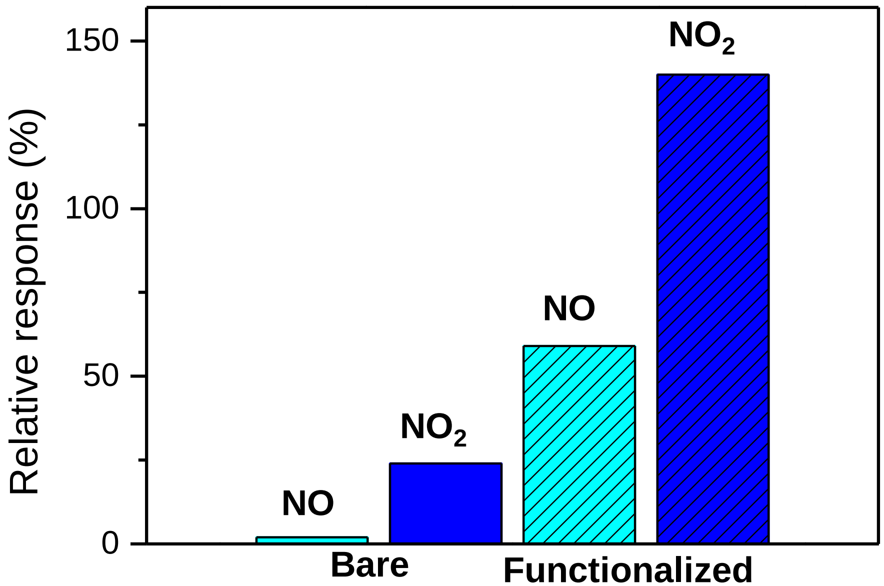


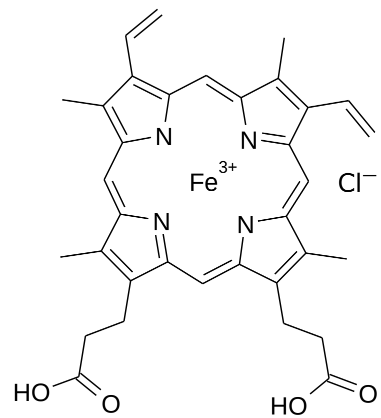






Response tunable through functionalization



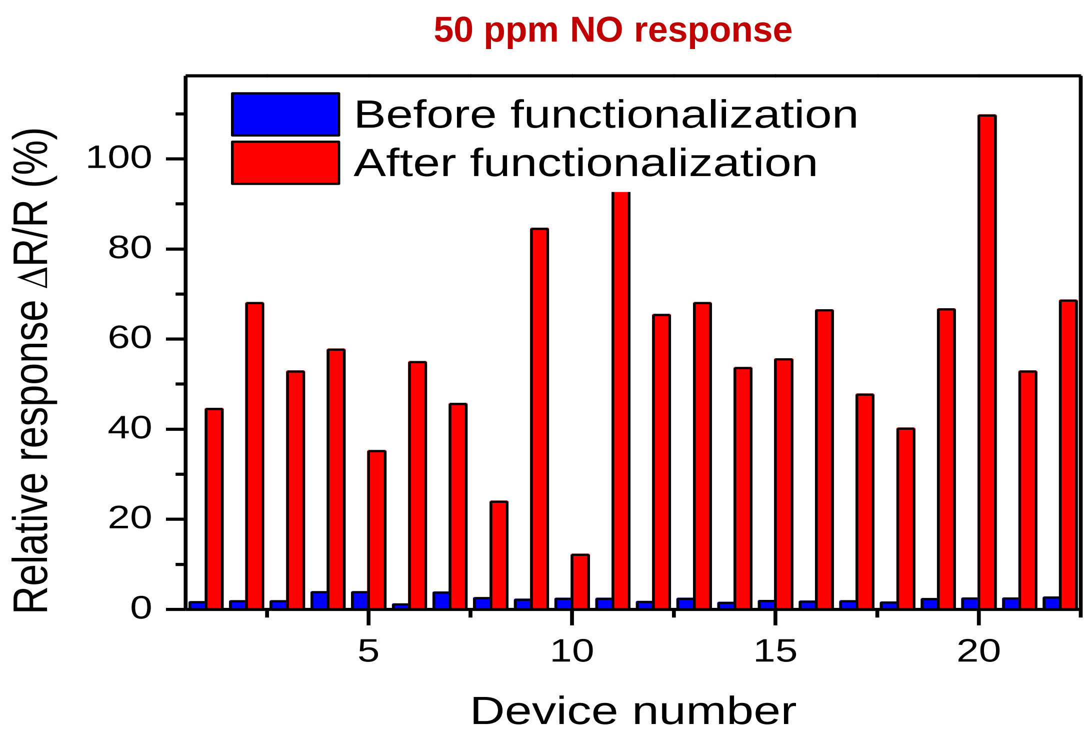


Porphyrin (hemin)

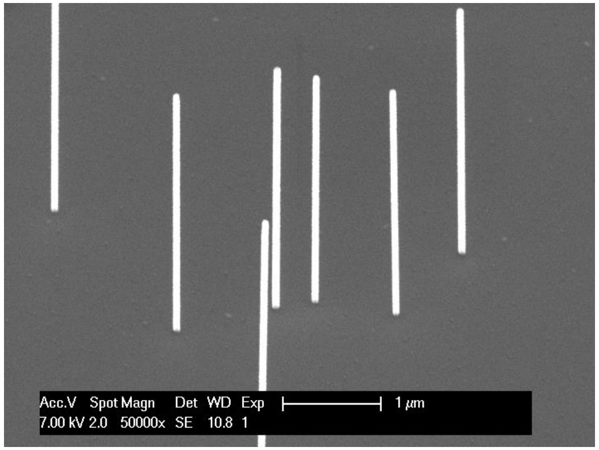
Ratio of NO and NO_2 response can be changed

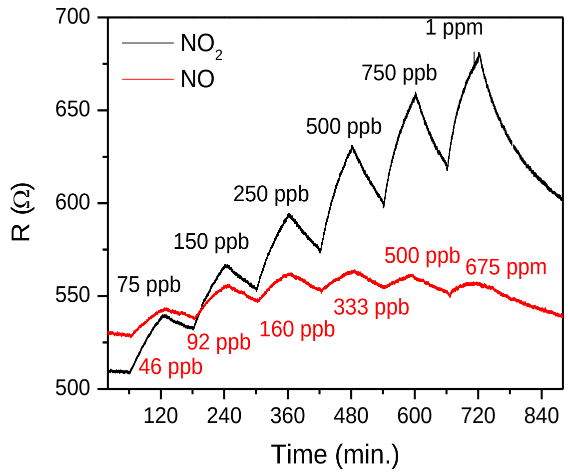
Response can be increased

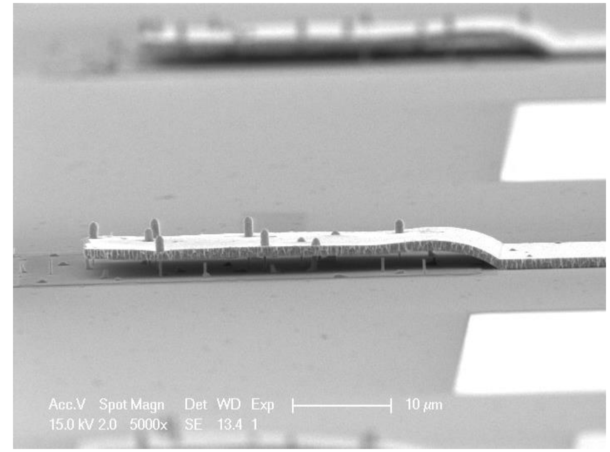
But not very reproducible



And why is InAs working so well ?



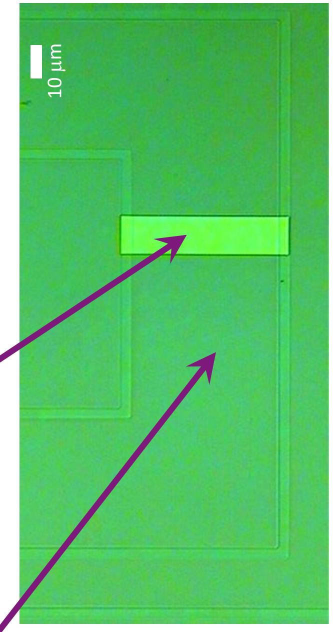




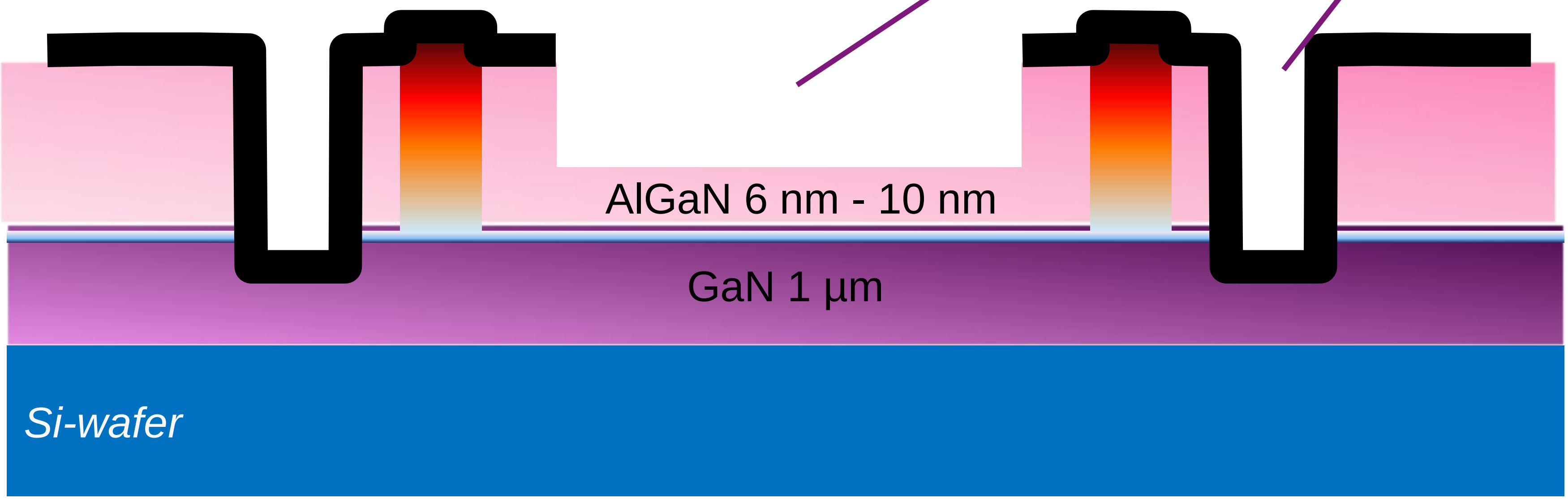
GaAs, GaP, InAs, InP, Si

Best performance related to surface HEMT....

GaN Sensor Fabrication

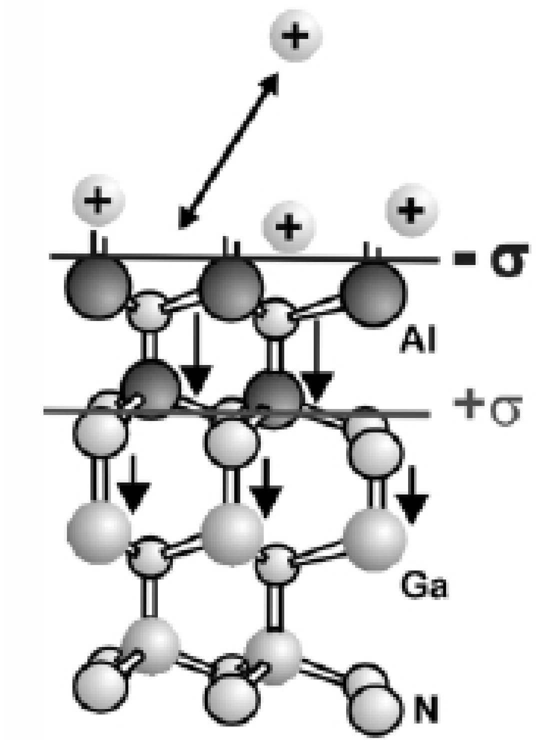


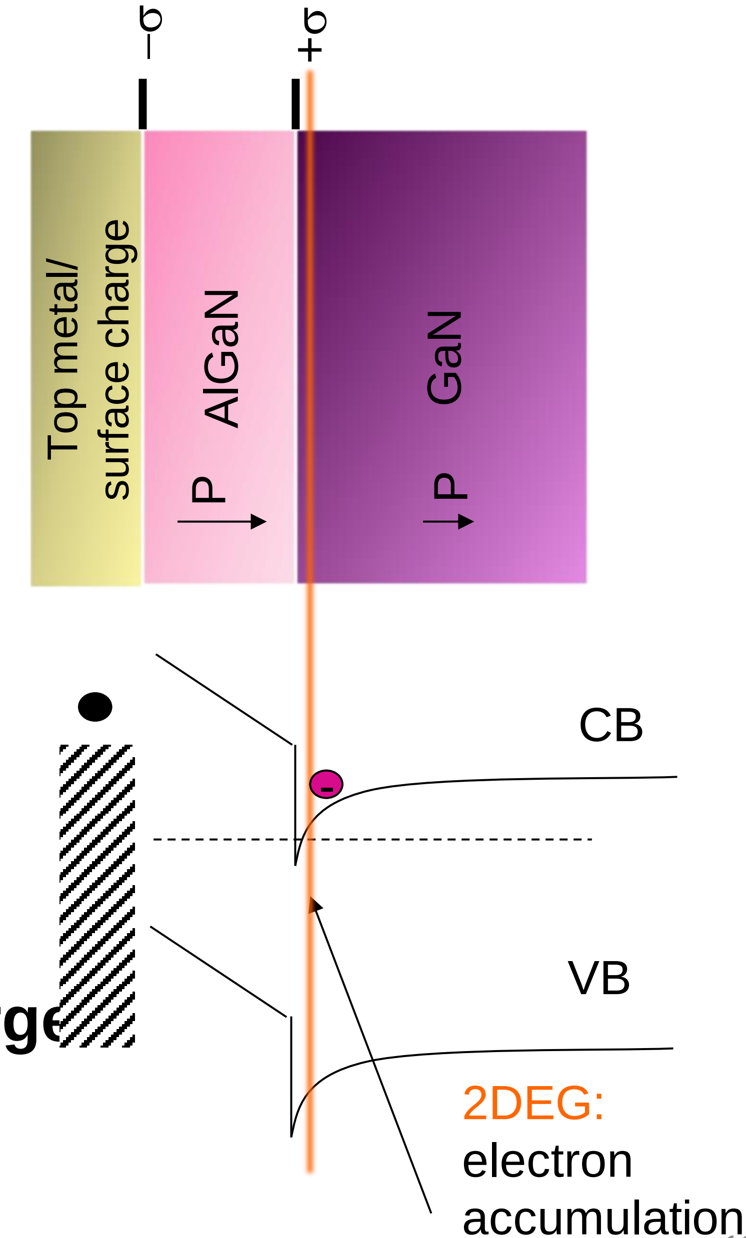
- Etching of isolation trenches
- Deposition and RTA of the ohmic contacts
- Deposition of protective (isolation) layer
- Recess of the AlGaN-layer



Concept

Spontaneous polarization

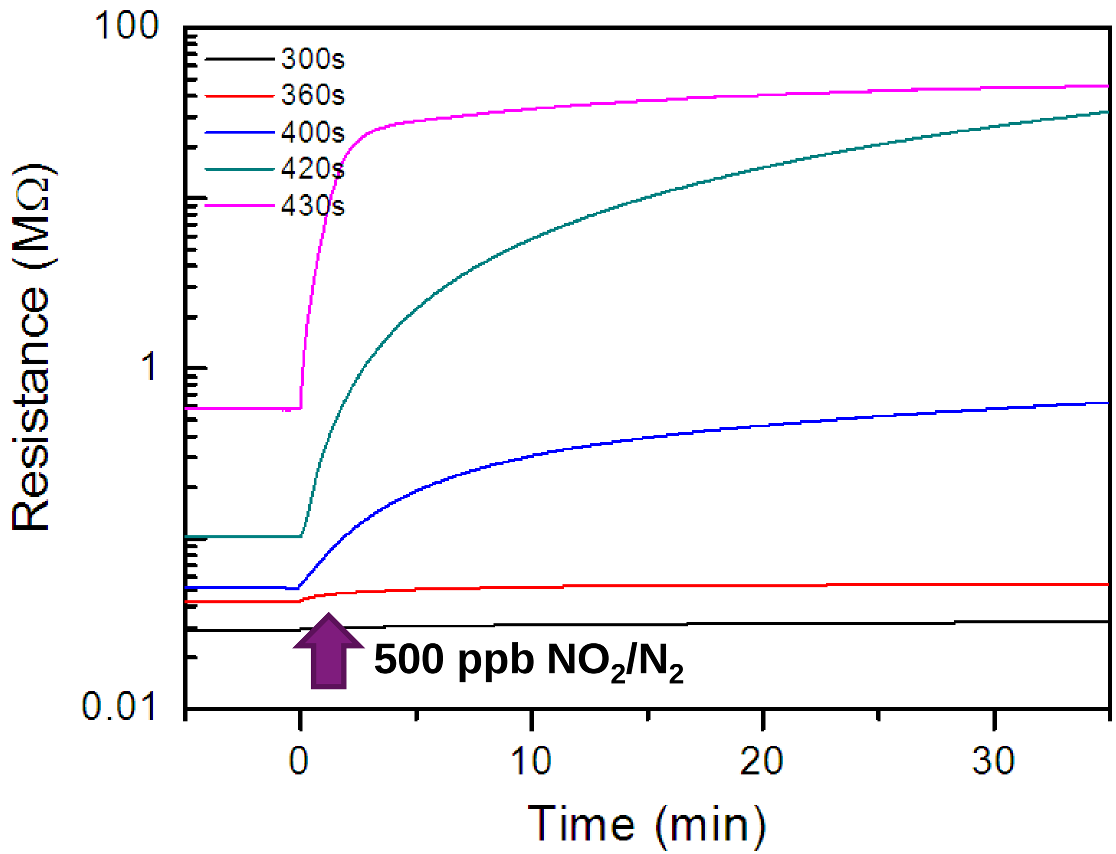




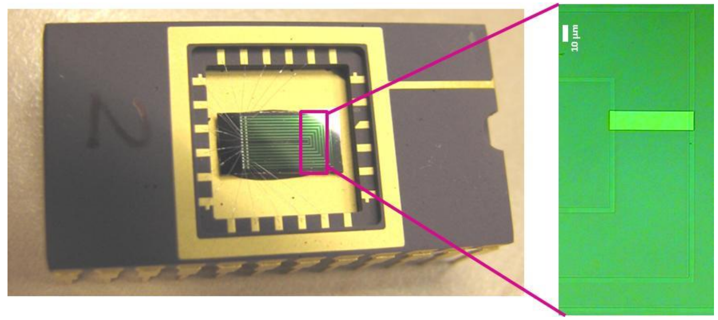
2DEG balanced by **surface charge**

Ionized surface donors

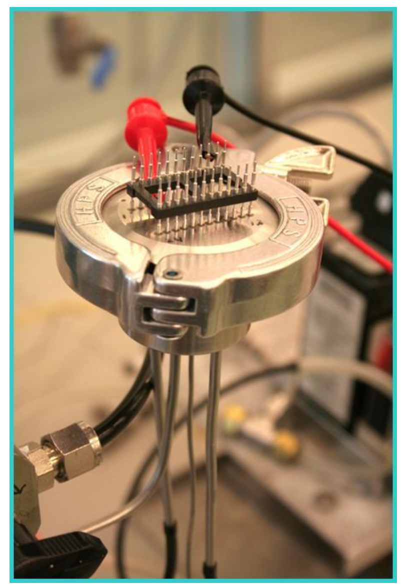
Effect of recess AlGaN



→100x increased sensitivity by recessing!

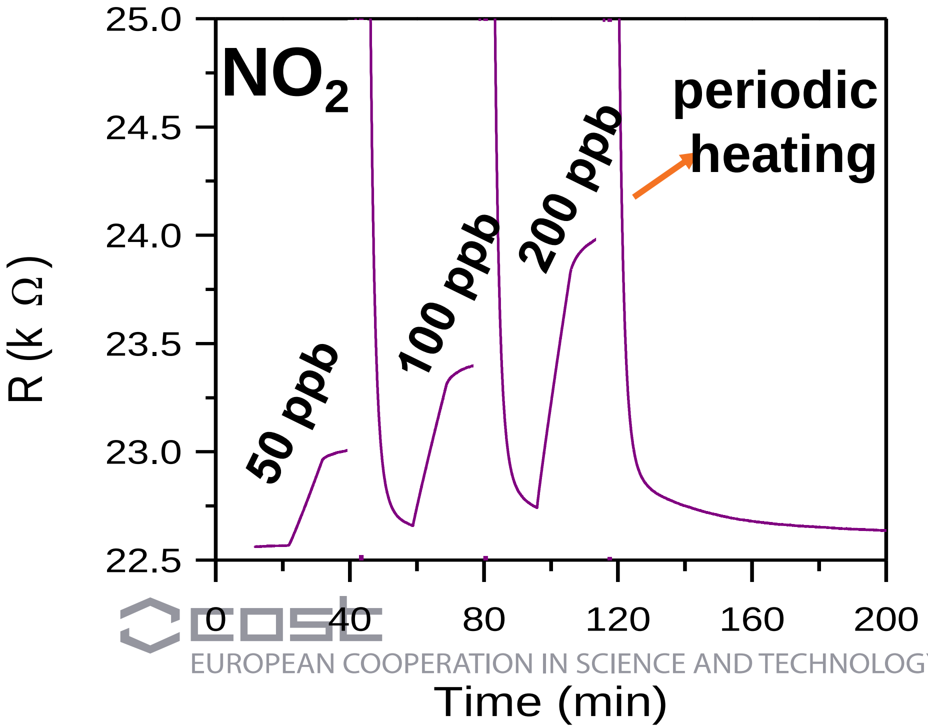


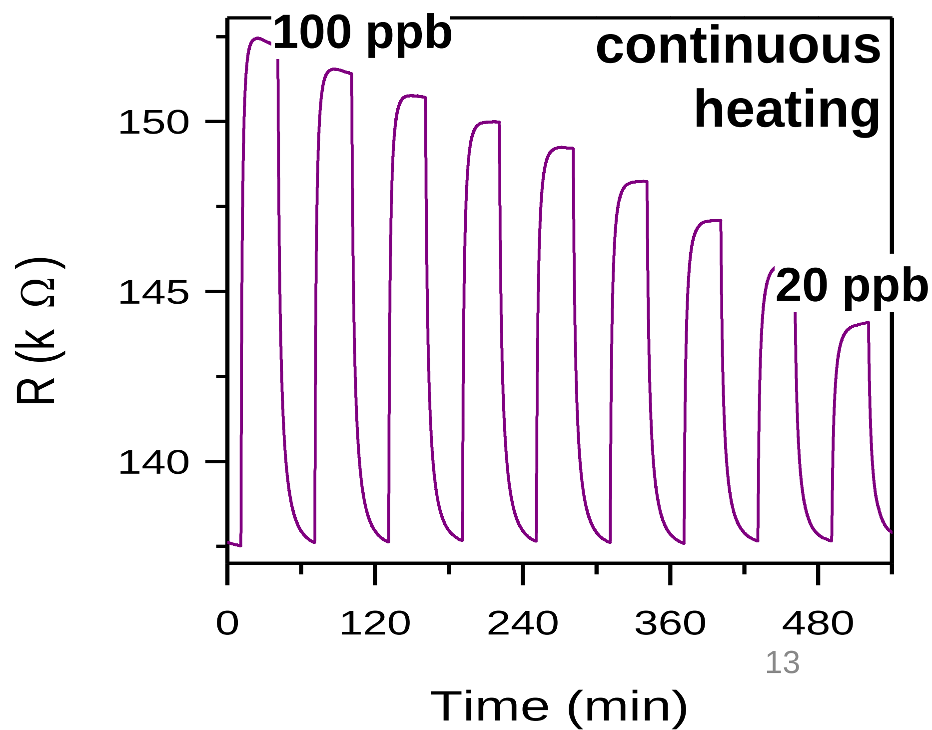
GaN sensor device mounted in DIL package. Inset shows recessed area with high NO_2 sensitivity (light green color).



Gas flow cell for fast device characterization

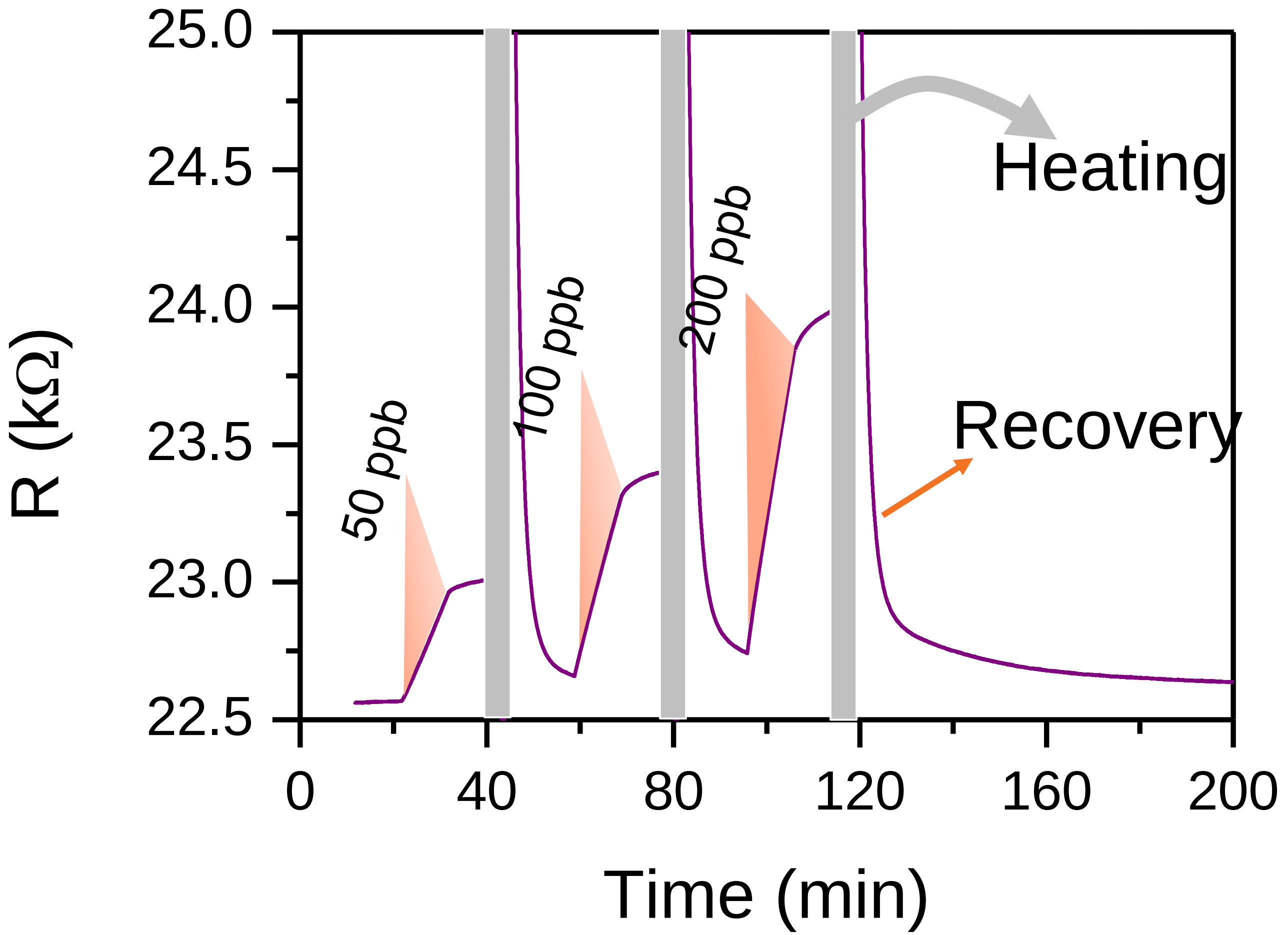
GAN FOR ENVIRONMENTAL SENSING





Solution: Slope-based detection

with Heating-assisted recovery

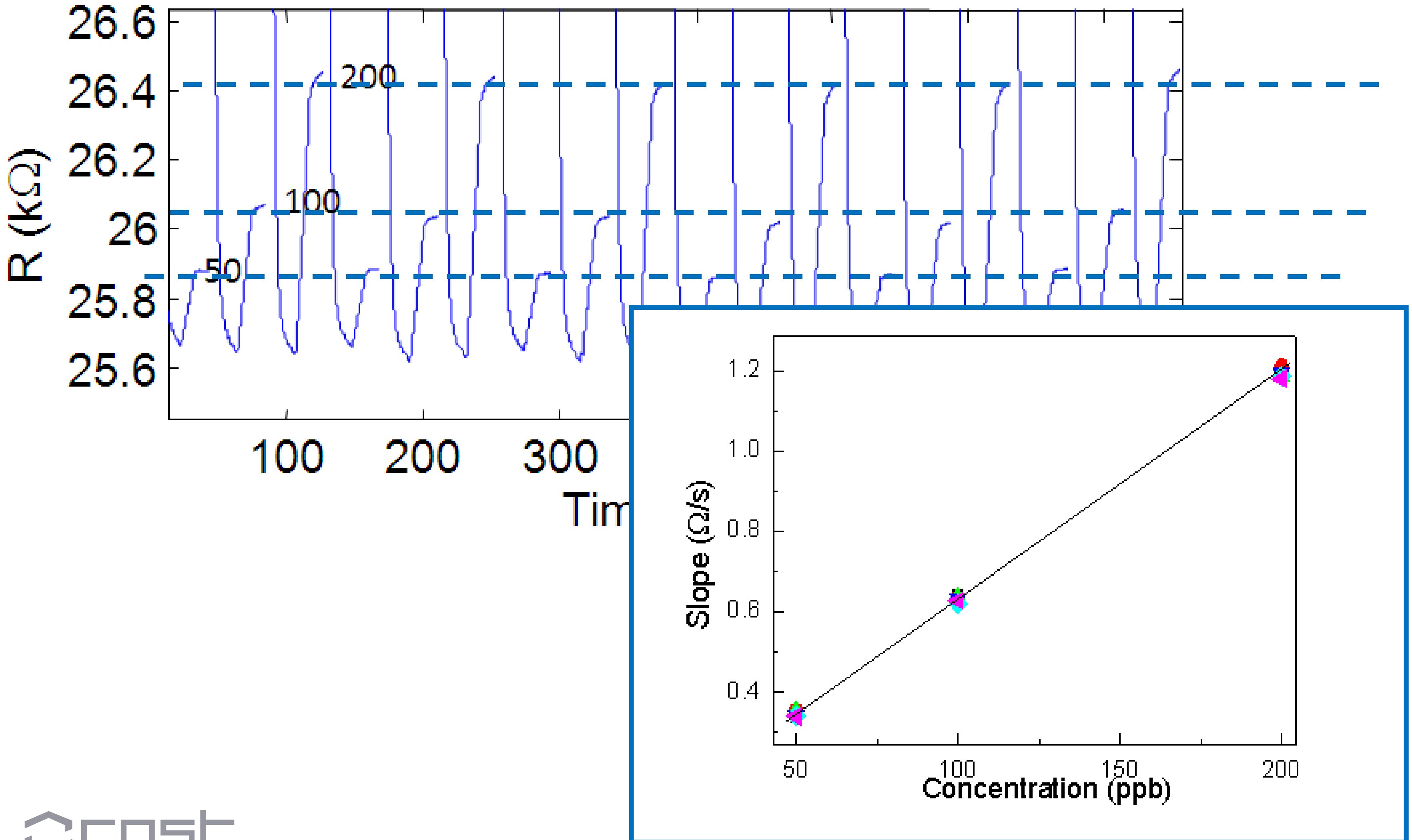


- 50-200 ppb NO_2/Air
- 40% RH
- **Heating** > 100ºC
- 2 min Heating
  (of entire DIL-package)

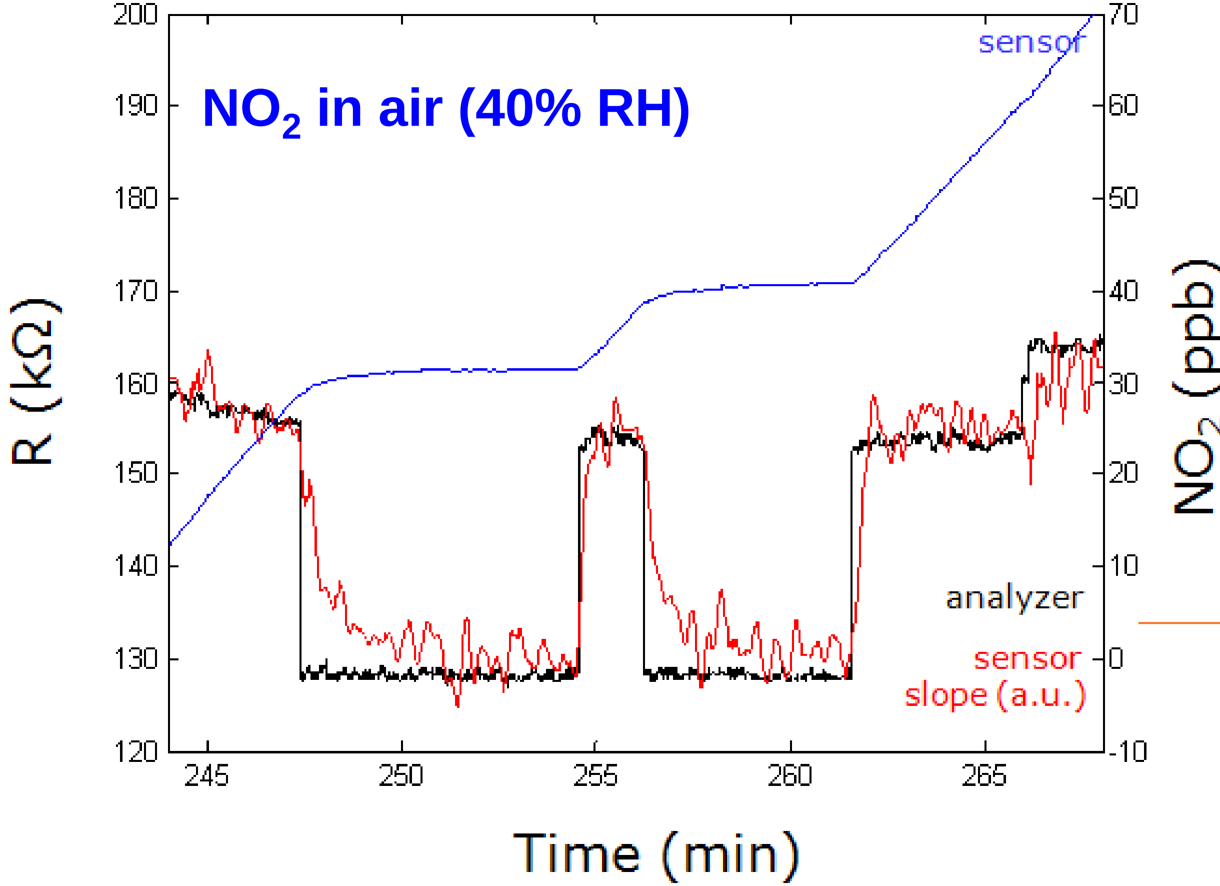
Full sensor recovery by heating within minutes

Solution: Slope-based detection

with Heating-assisted recovery



Test: Comparison to chemiluminescence NO/NO2 analyzer



Urban Environment
& Safety

→ **Slope based detection allows FAST response**
20 seconds for 25 ppb NO_2

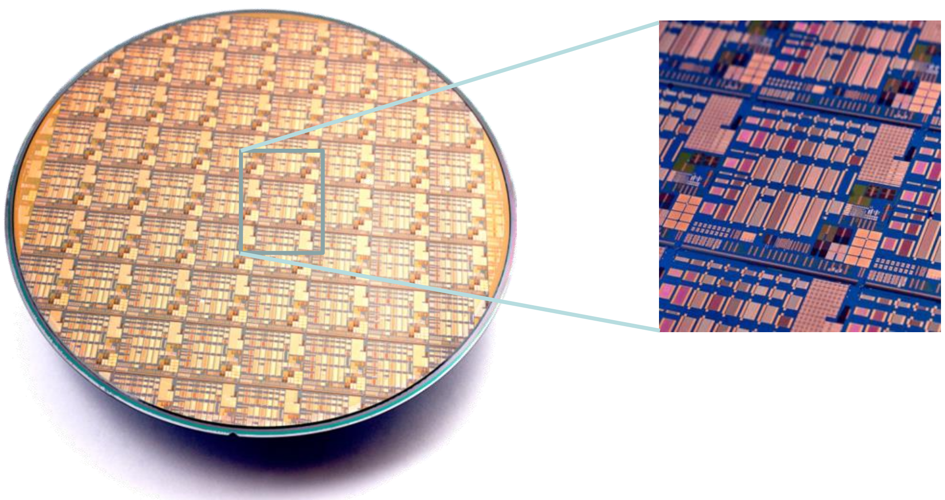
CROSS-SENSITIVITY & HUMIDITY

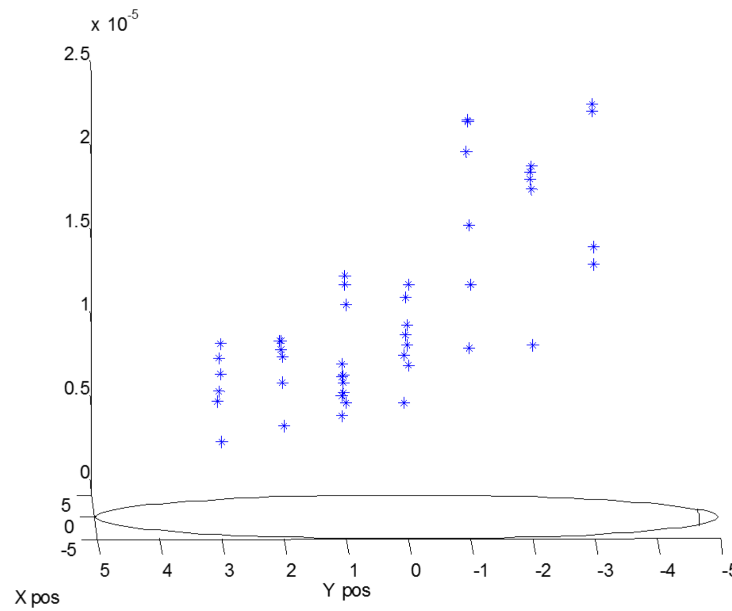
- **Cross-sensitivity testing for NO_2 100 ppb in air 50%RH**
  - **No cross-sensitivity up to 10% CO_2**
  - **No cross-sensitivity up to 200 ppm CO**
  - **No cross-sensitivity up to 50 ppb SO_2**
  - **No cross-sensitivity up to 200 ppb formaldehyde**
  - **Sensitivity to NO 20 to 50 times lower depending on operating temperature**
  - **Ozon testing in progress**

- **Humidity testing performed under room temperature conditions as well as higher temperature (< 300° C)**
  - **Sensitivity depends on humidity even at higher temperature**
  - **Calibration can deal with slow variations in humidity < 90%**

8” wafer fabrication

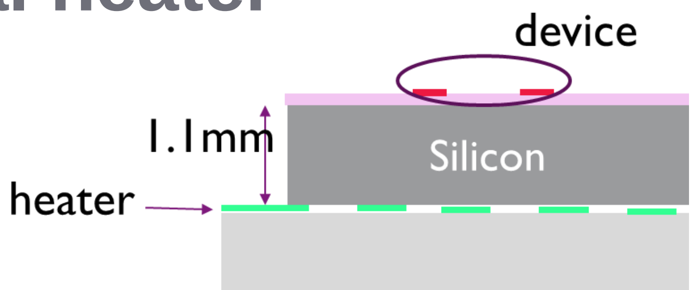
- Device fabrication has been scaled up to 8 inch wafers
- Processing compatible with power-FET
- Detection possible at room temperature (slope-based detection) as well as higher temperature.

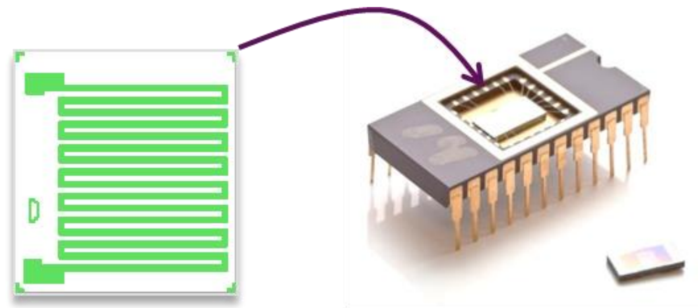




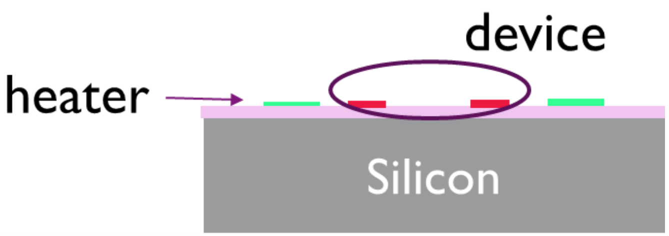
Reduce power consumption

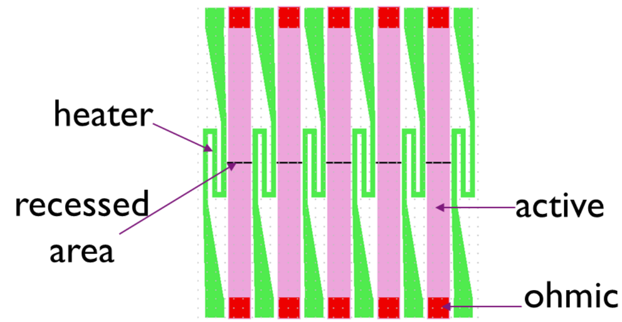
1 external heater



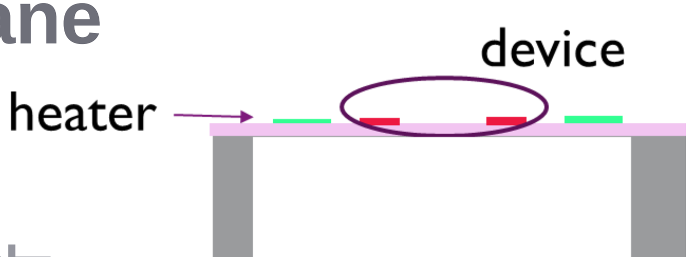


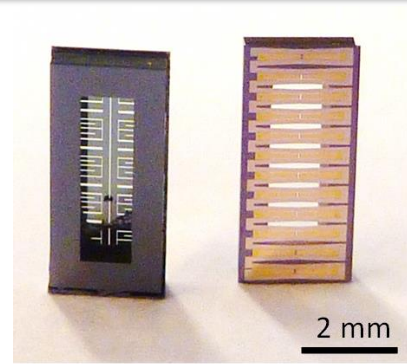
2 integrated heater



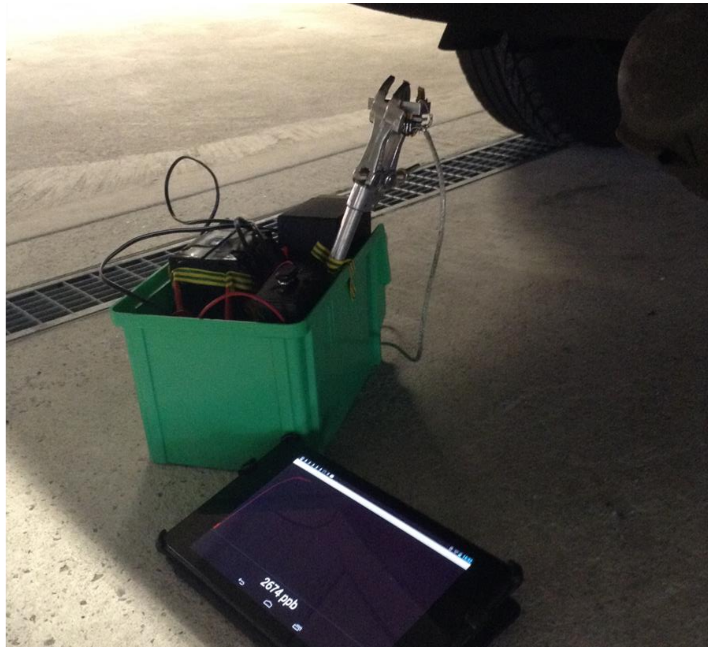


3 membrane





Sensor demo

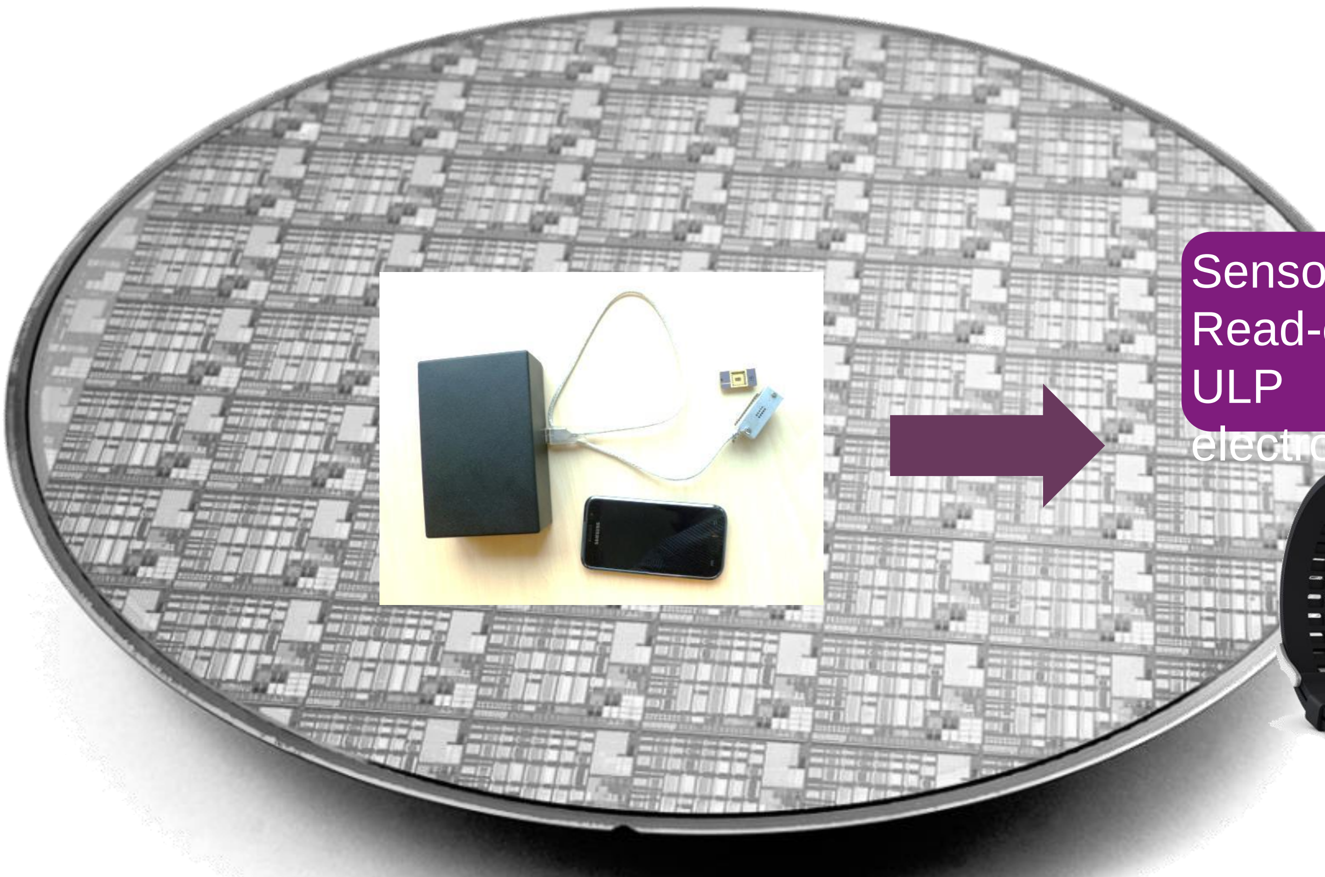


- Miniaturized sensor
- Hand-held sensor demo
- External heater
- Trial test results

Gan sensor PLATFORM

Handheld environmental sensor prototype

- **Functionalization with polymers and metalorganic framework**
- **Transferable 8-inch process GaN-on-Si**
- **Usable for inorganic gasses- H_2, O_3, CO, SO_2, CO_2, NH_3 and hydrocarbons – CH_4, C_2H_4, Ethanol, Formaldehyde**



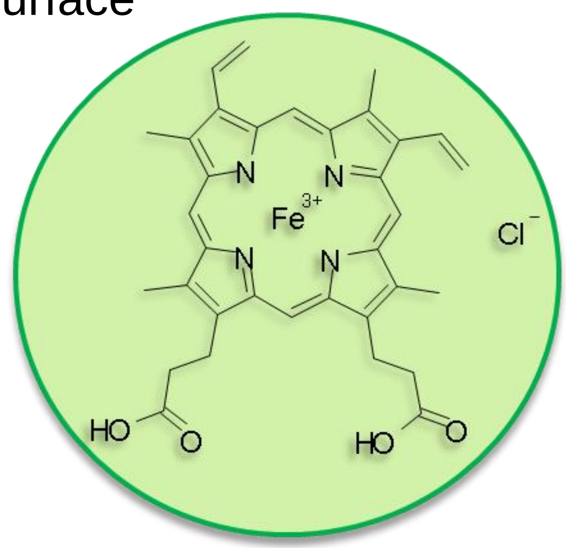
Sensor
Read-out
ULP
electronic

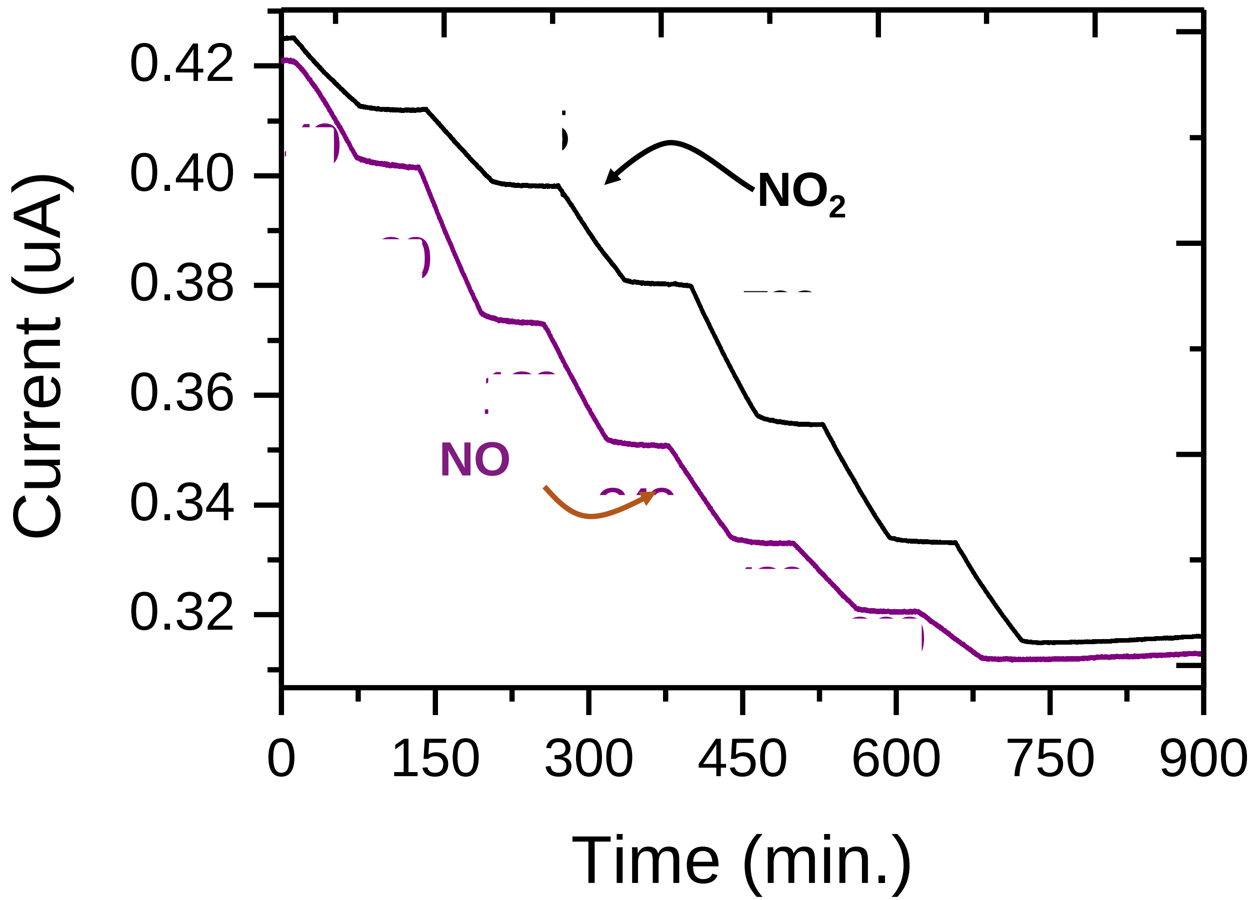
21

Extending the platform to other gases

Functionalization of the surface with redox-active molecules (Porphyrin (hemin))

Formation of **charge transfer complex** induces a **dipole/charge redistribution** at the surface





CONCLUSIONS

- **GaN/AlGaN NOx sensor development**
  - **High sensitivity**
  - **Low cost environmental monitoring**
  - **24/7 monitoring**
- **Extend platform towards different gasses**
  - **Extend to different gasses: NO, CO..**
  - **Functionalization (polymers, metal oxides)**
- **Develop the gas sensor system in a small form factor**
  - **Integrate read-out electronics**
  - **System in package**
  - **Application: integrate gas sensors in personal area network (PAN)**