



save energy

keep track

anticipate

lower cost

save time

stay tuned

improve performance

feel secure



Holst Centre

Open Innovation by IMEC and TNO

IMEC SMART SYSTEMS

Building a flexible interactive world

Low-power
sensor system technologies
for environmental air-monitoring

Sywert . Brongersma [@imec-nl.nl](mailto:Sywert.Brongersma@imec-nl.nl)

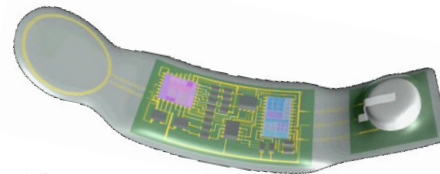
Sr. Principal Scientist



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

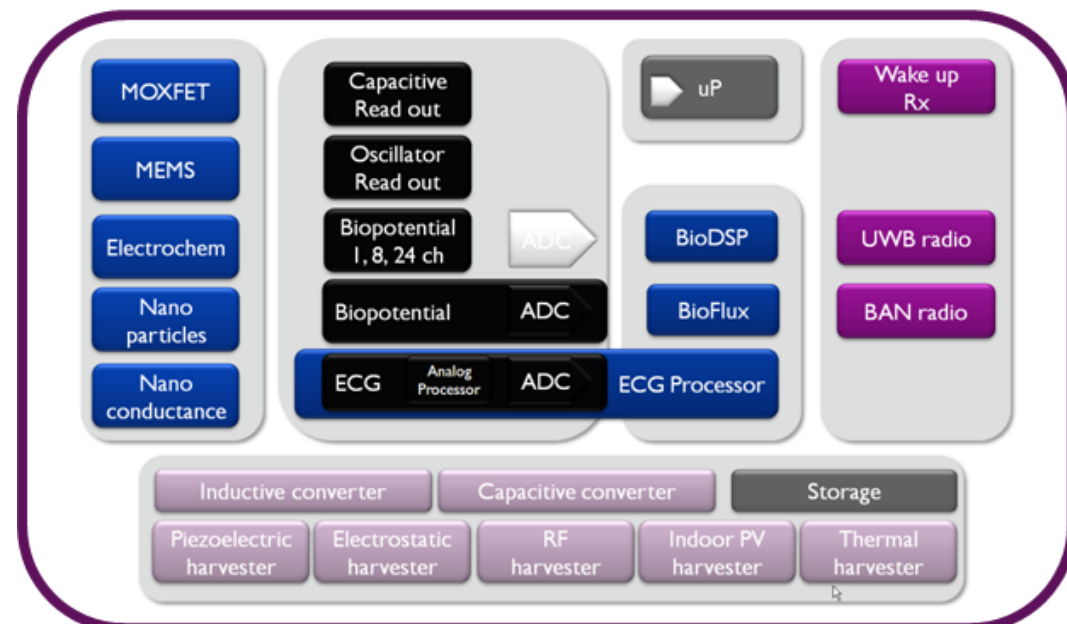


Integration in various form factors

- ▶ 3D stack
- ▶ Flexible / stretchable

Technology drivers

- ▶ Ultra-low power
- ▶ Miniaturization
- ▶ Low cost processes

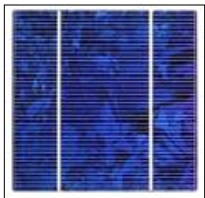
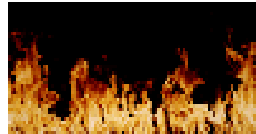


Providing Power to Microsystems

Targets

- ▶ $100\mu\text{W}/\text{cm}^2$ power generation
- ▶ Low Cost: MEMS process-compatibility

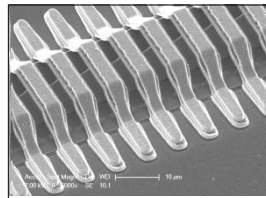
Harvesting Sources Design, Fabrication and Testing



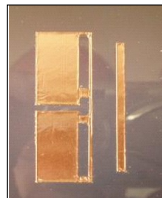
Photovoltaic



Vibration



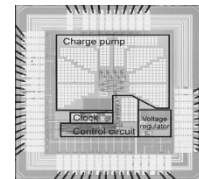
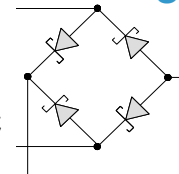
Thermal



RF

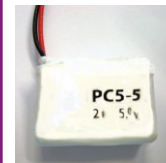
Power management IC Design and Testing

AC/DC



DC/DC

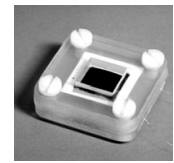
Energy Storage Systems Characterization and Selection



Battery



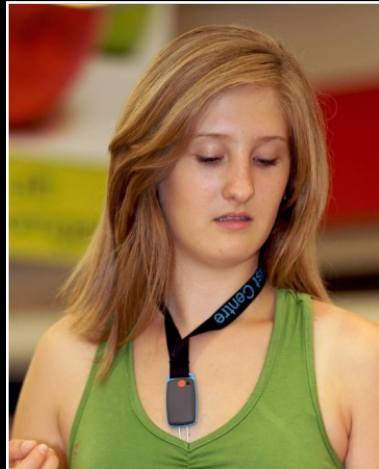
Supercap



Biofuel cell

BODY AREA NETWORKS

Personal Healthcare & Lifestyle Solutions



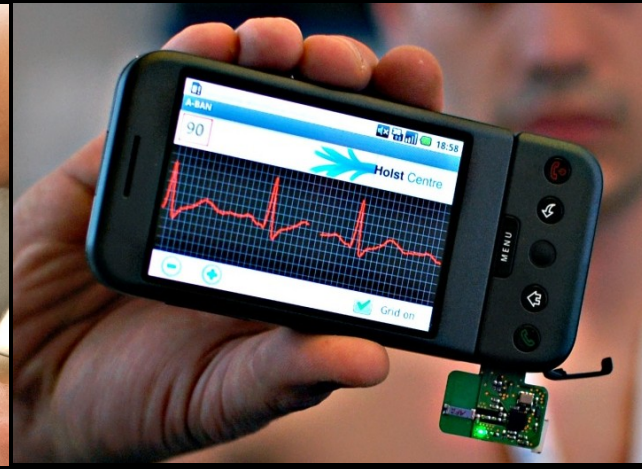
Necklaces/patches



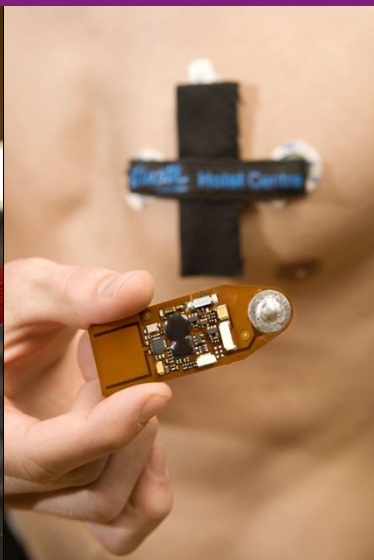
Watch-type

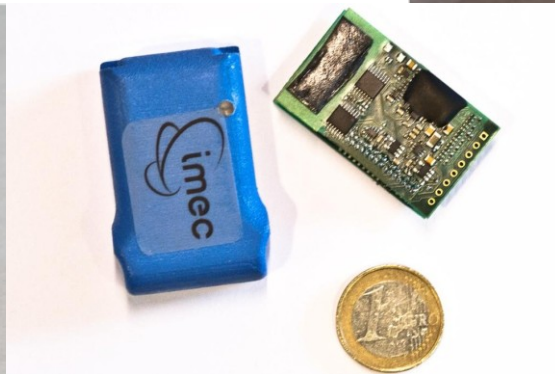
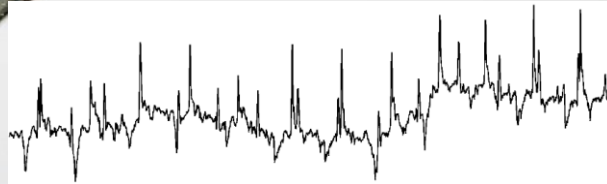
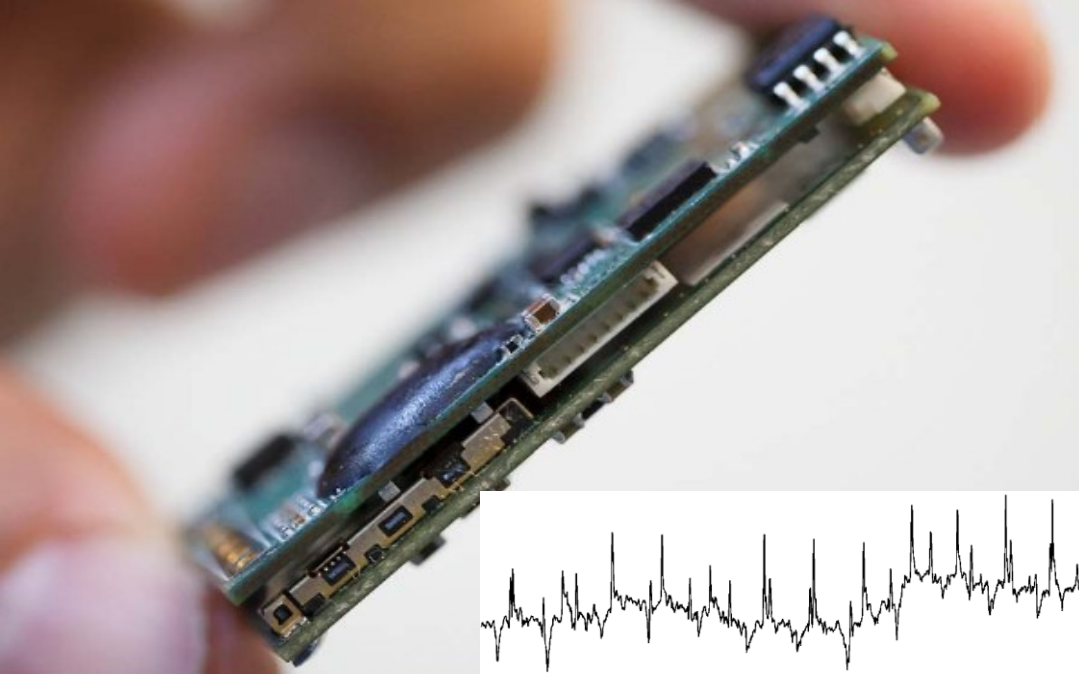


Headsets



Base Stations





Embedded motion
artefact reduction

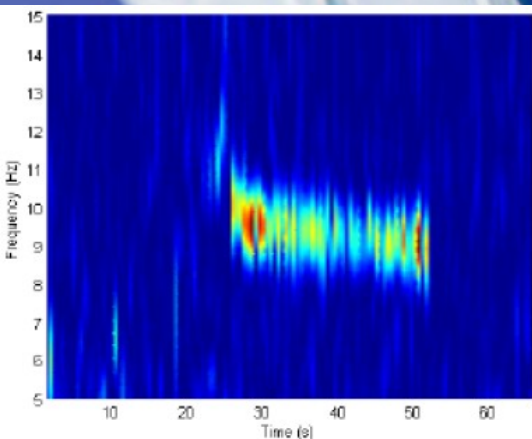
Health Patch Gen-4

EEG headset Gen-2

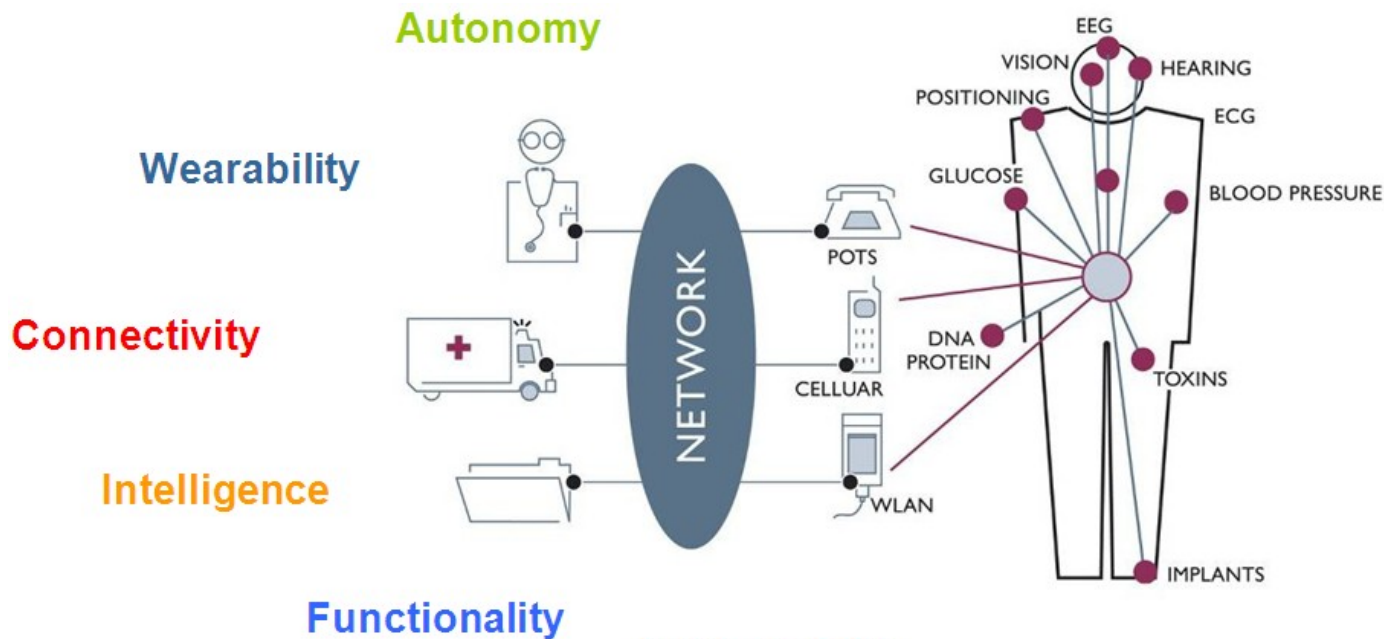
Active dry electrodes

Electrode-tissue contact impedance monitoring

Faster settling time and increased dynamic range



From Body Area Network to Personal Area Network



Vehicles



Living spaces



Open spaces



Industry



Implantability

Office buildings



Working environment



Many Targets for (Bio-)Chemical Sensors

The domestic sector



CO, CO₂, humidity, combustible gases

Medical and wellbeing



diagnostics and patient monitoring

The automotive, industrial, and aerospace sector



NO_x, O₂, NH₃, SO₂, O₃, hydrocarbons, CO₂

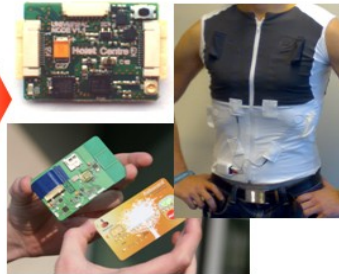
(Personal) Environment

Nitric ox sensor for asthma



State of the art breath analysis

Miniaturized on-body sensors



IMEC wireless technology

Embedded sensors on phone



Next personal generation

Around-body CO₂/NO₂ sensors



Personalized environmental analysis (pollution)



Example: Asthma & Personal Environment

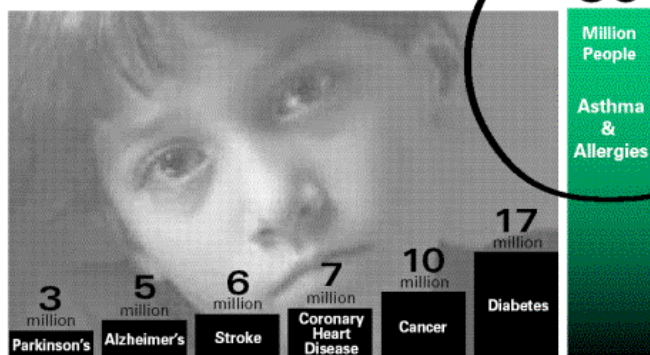


20 million Americans suffer from asthma (1 in 15 Americans) !!

Asthma accounts for one-quarter of all emergency room visits in the U.S.

Annual cost (USA):
\$18 billion

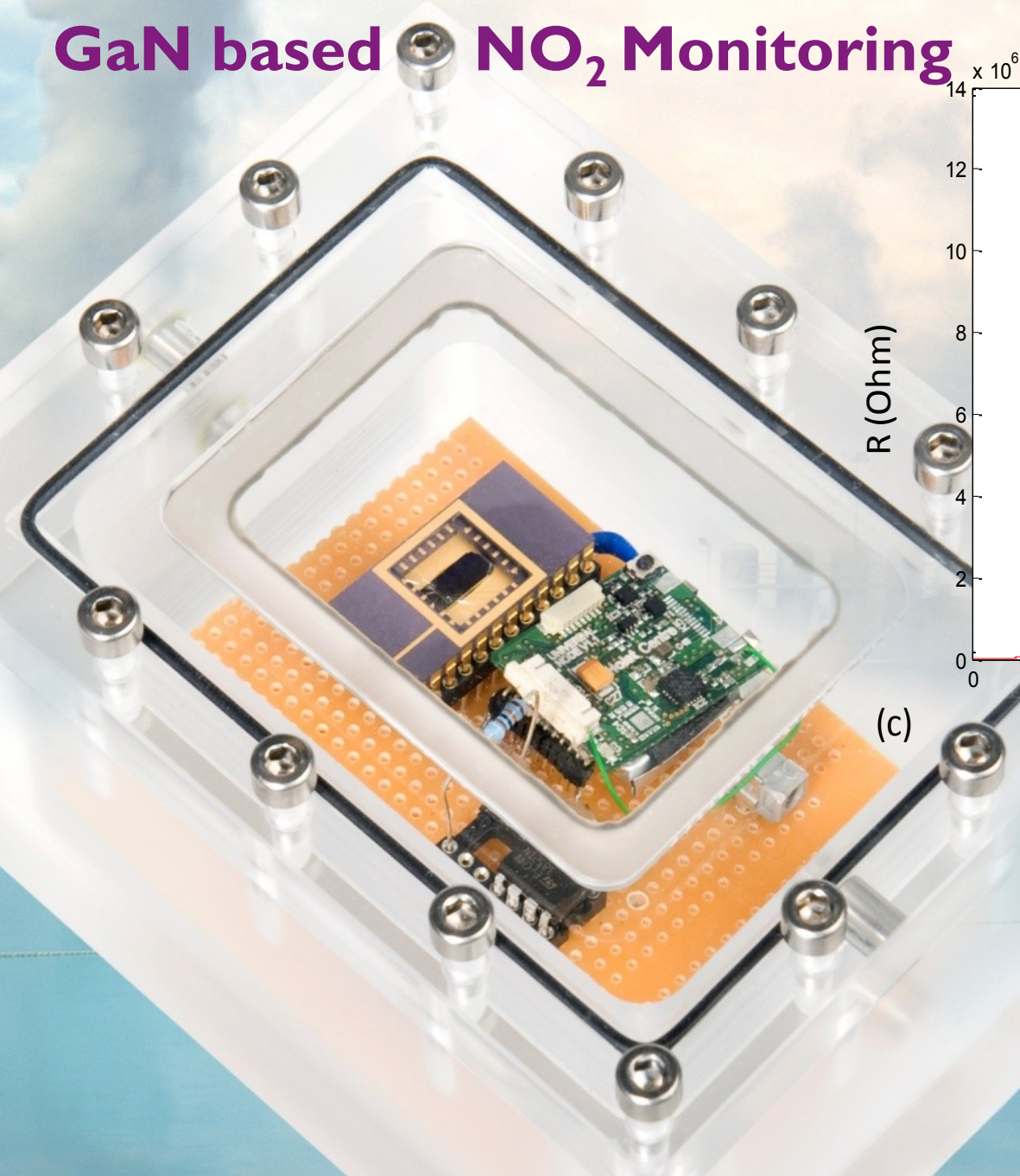
Asthma and allergies strike 1 out of 4 Americans



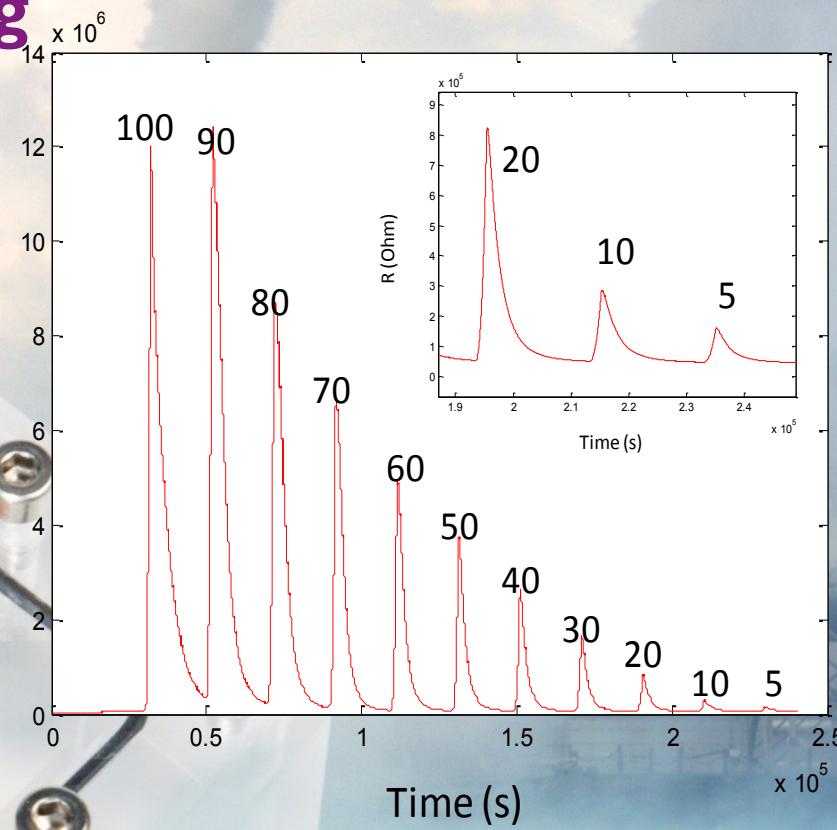
* Annual U.S. Prevalence Statistics for Chronic Diseases

- On January 22, 2010 EPA strengthened ambient air quality standard NO₂ to increase protection of public health
- EPA also is making changes to the NO₂ air quality monitoring network requirements
- Limit short-term exposures to peak NO₂ which often occur near major roads and could worsen asthma symptoms
- Maintain NO₂ below levels associated with respiratory related emergency department visits and hospital admissions

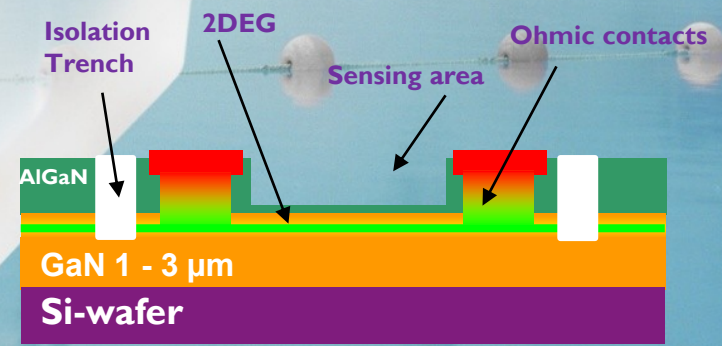
GaN based NO₂ Monitoring



R (Ohm)



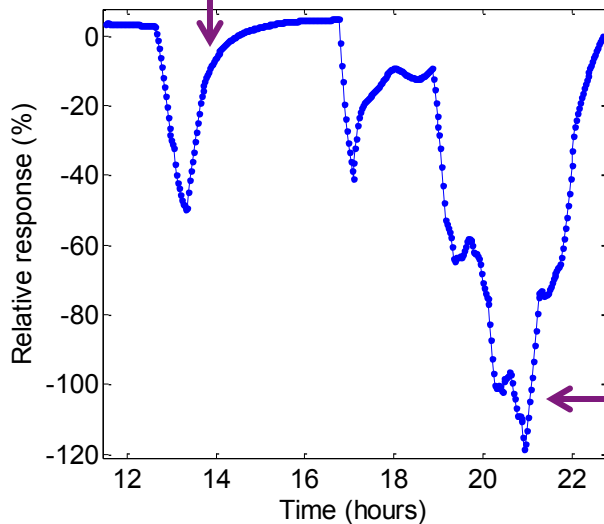
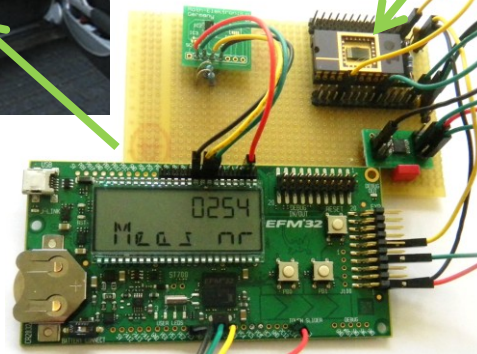
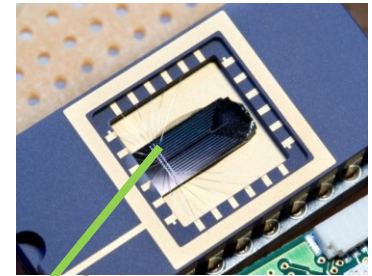
(c)



Low-ppb environmental monitoring



Parking garage

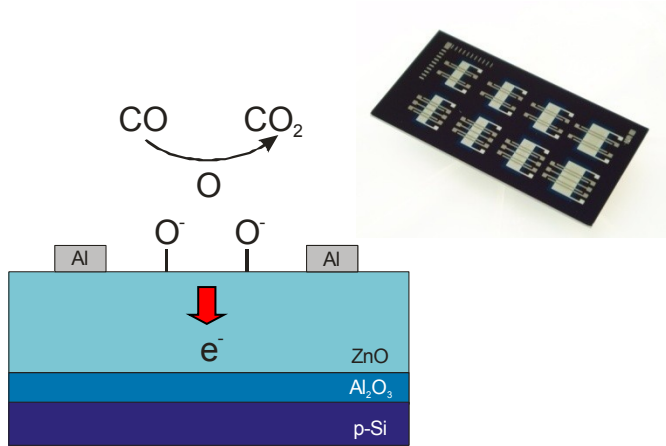


Clean air in nature

- ✓ Battery operated
- ✓ On-chip data storage
- ✓ Humidity and temperature
- ✓ Simple resistive readout
- ✓ Reversible
- ✓ Sub-ppb detection limit
- ✓ Very low cross-sensitive to e.g. SO_2 , CO_2 , NH_3

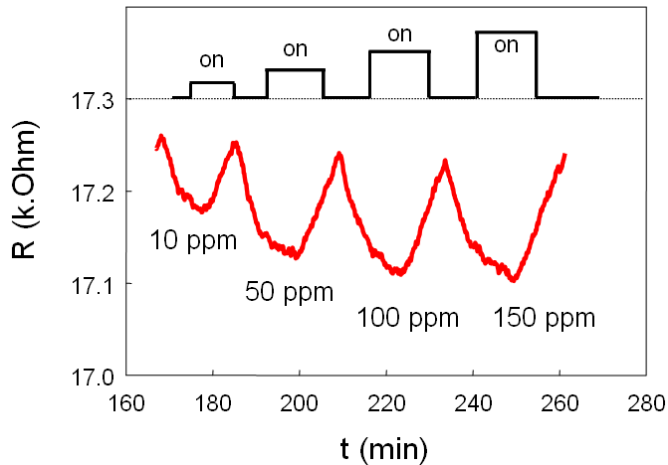
See: IEEE Sensors

Low temperature sensing with thin Metal Oxides

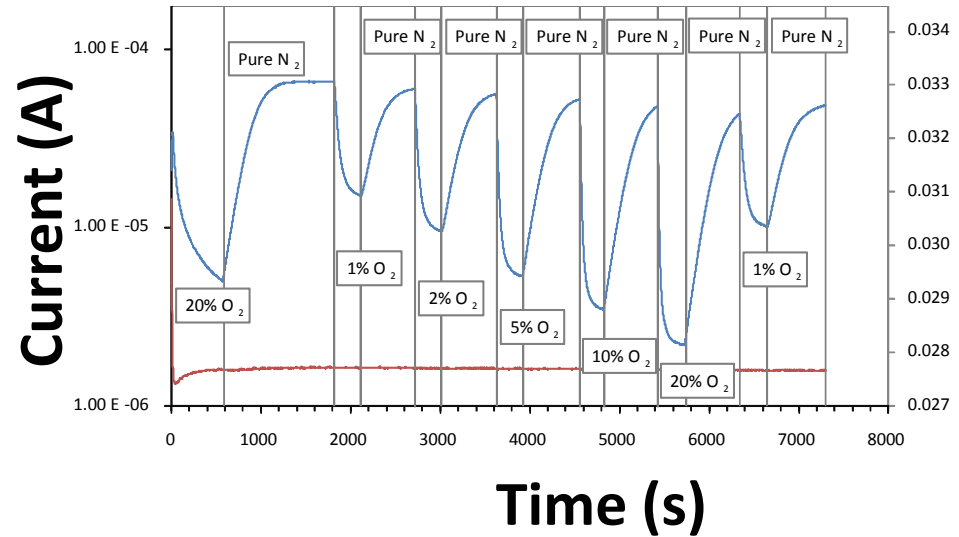


CO ↑ R ↓

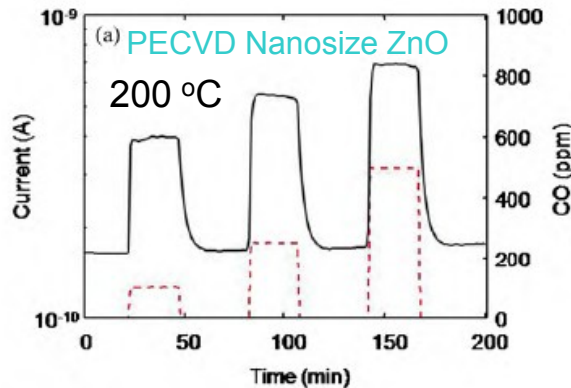
40% RH, CO/air, RT



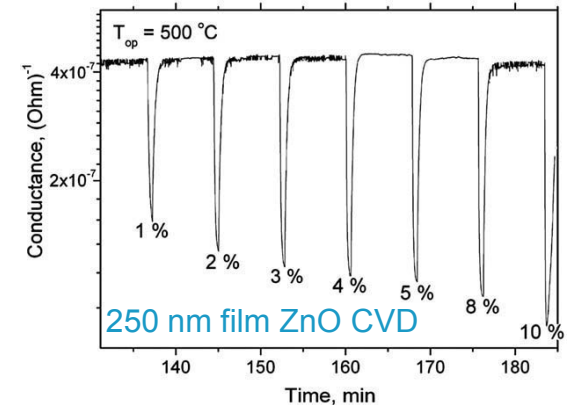
O₂ @ 270°C with 17 nm ZnO



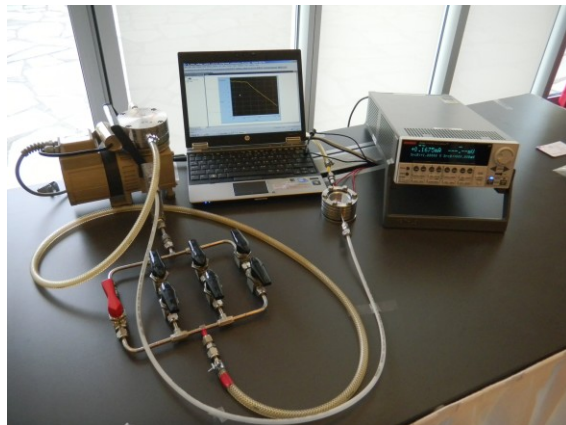
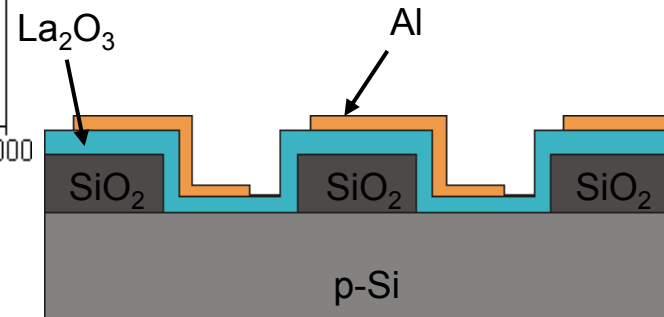
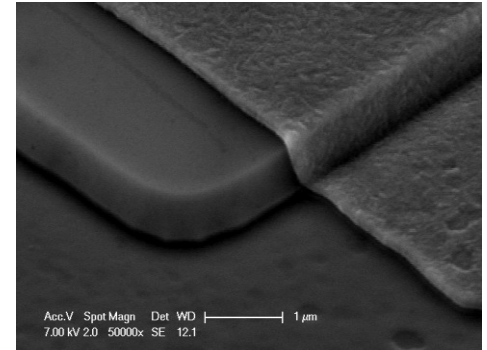
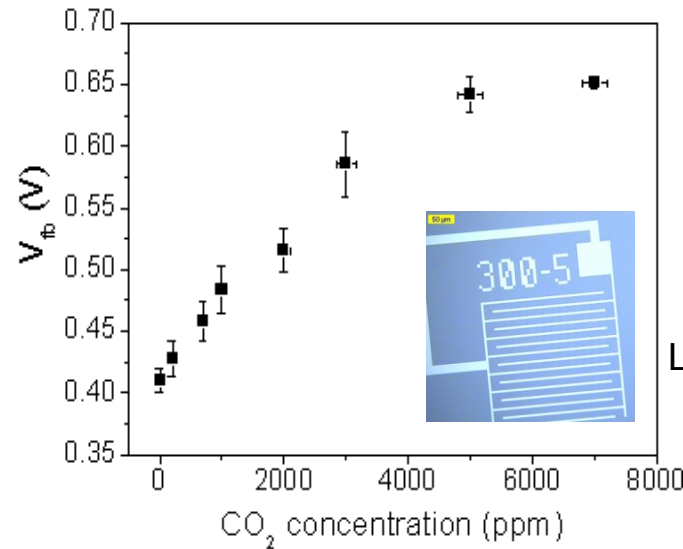
Barreca (2010)



Khranovskyy (2008)

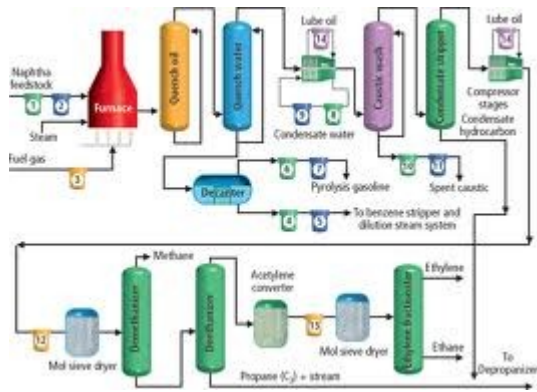


Room Temperature CO₂ for Indoor Air Quality

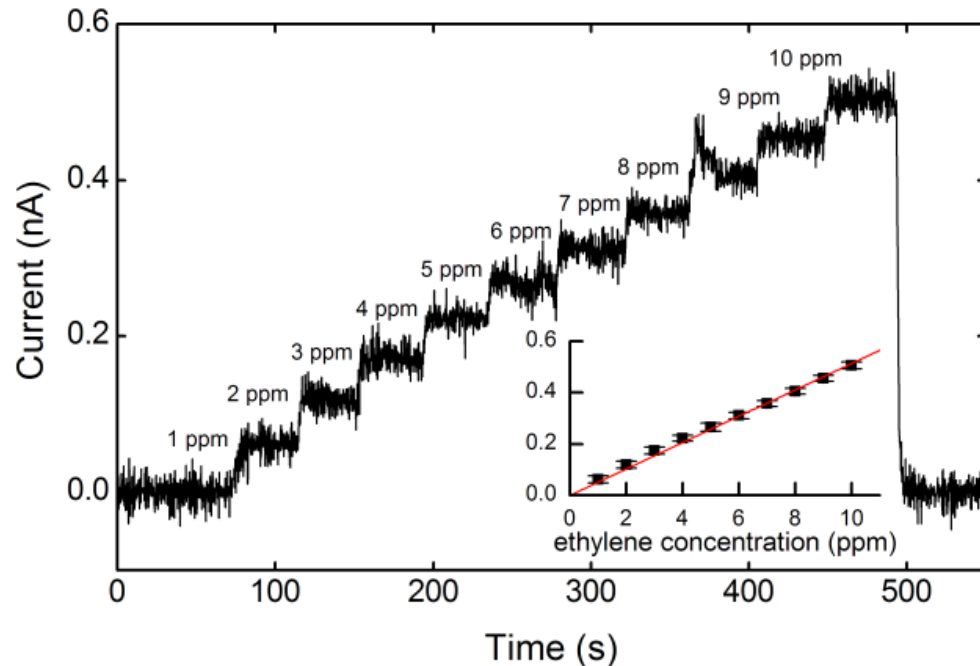
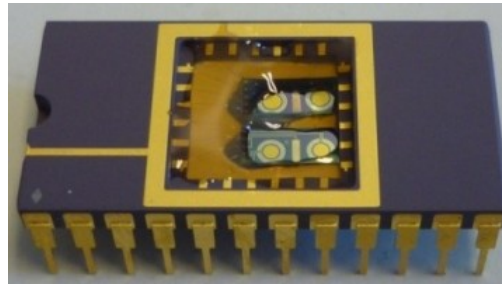


See: ECS PRIME 2012

Ethylene sensing with electrochemical approach

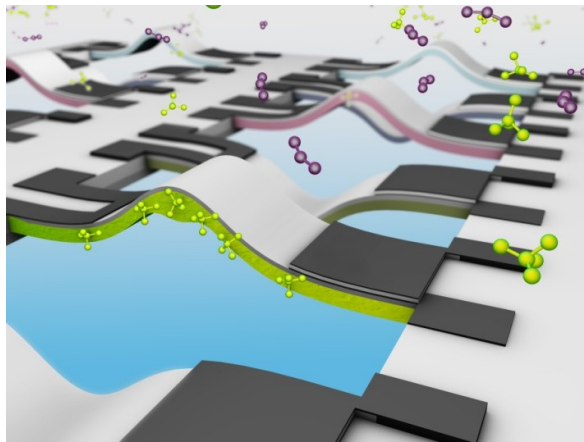


Industrial safety



See: Electrochemical Sensors II (Munich 1 @ 13:30)

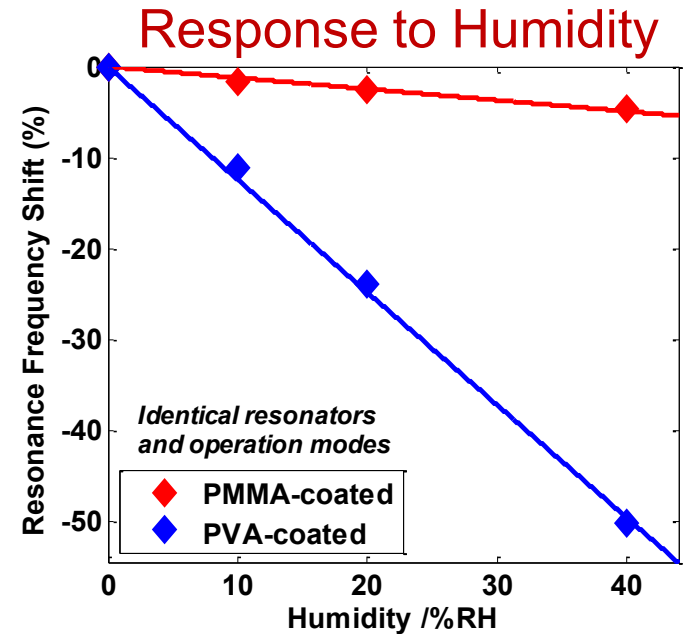
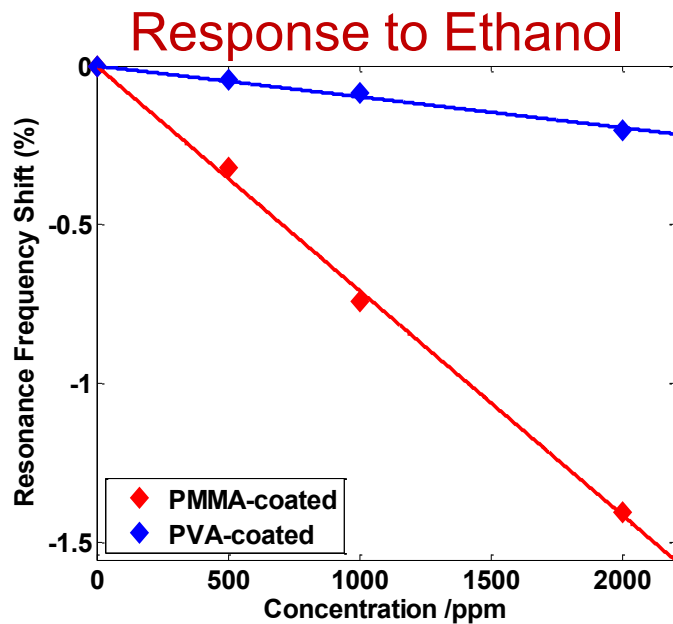
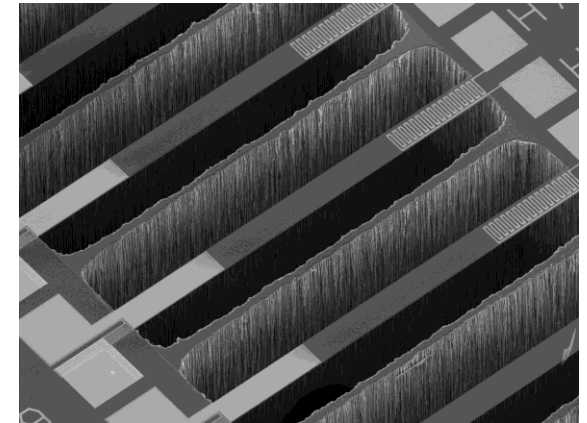
Towards a miniaturized MEMS e-nose



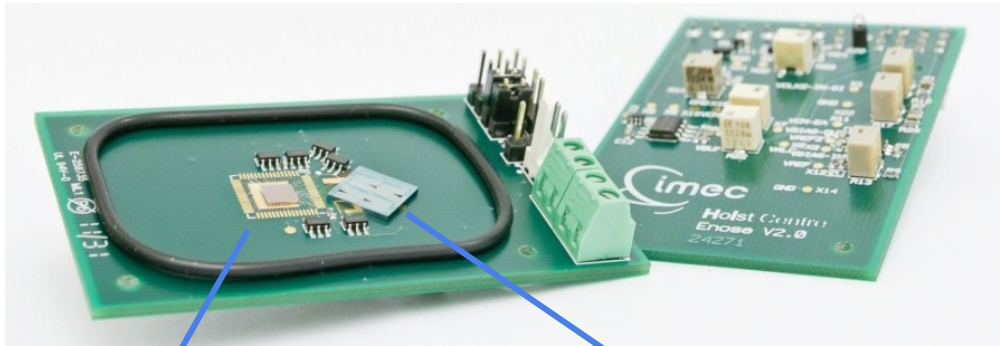
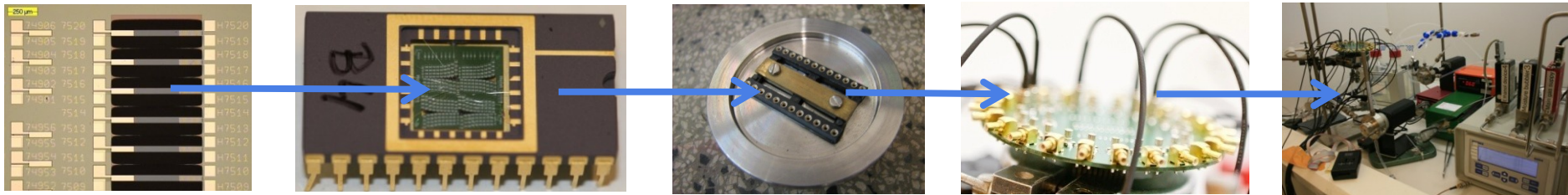
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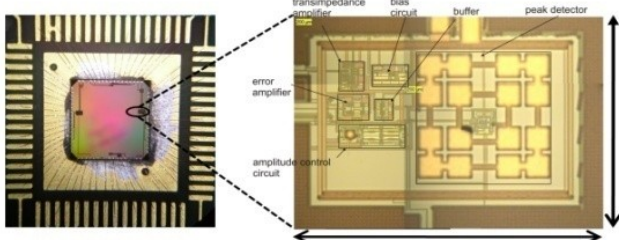


Integrated VOC Monitoring

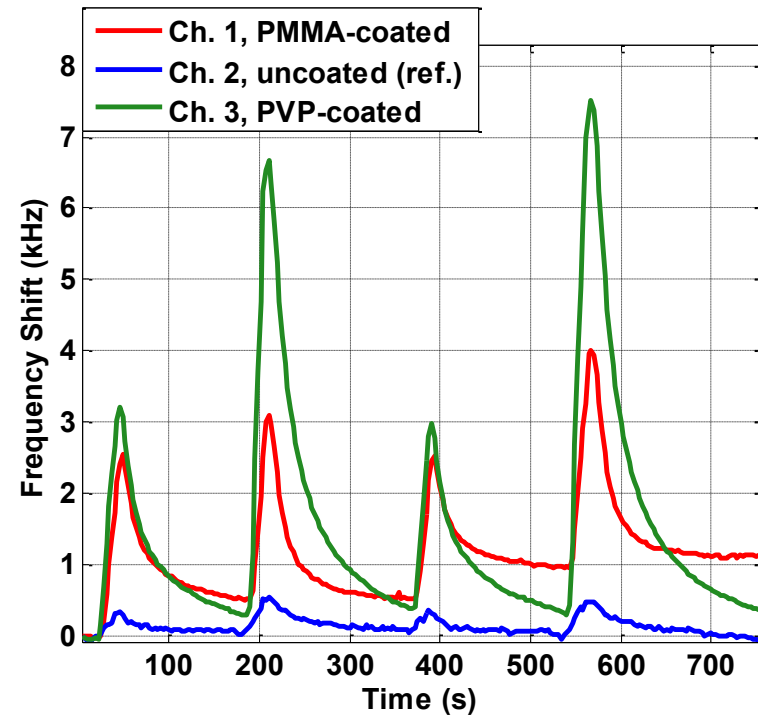
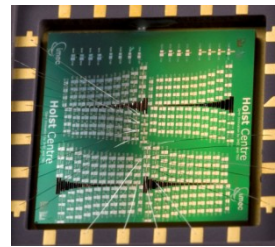


Integrated Read-out Circuit

Resonant MEMS



330 x 217 μm^2



See: Resonant Sensors I (Munich 2 @ yesterday)

Imagine gas sensors in your PAN !



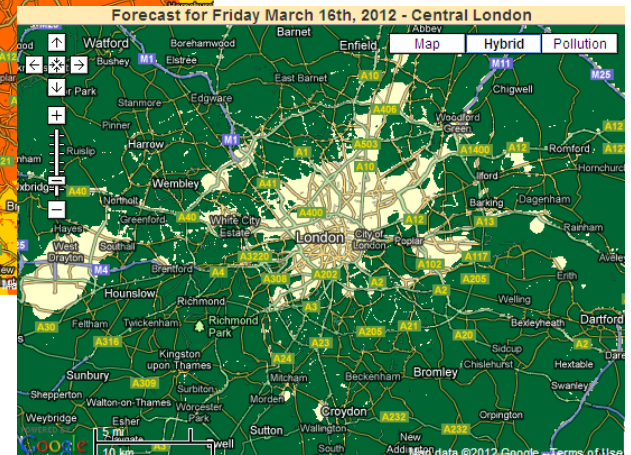
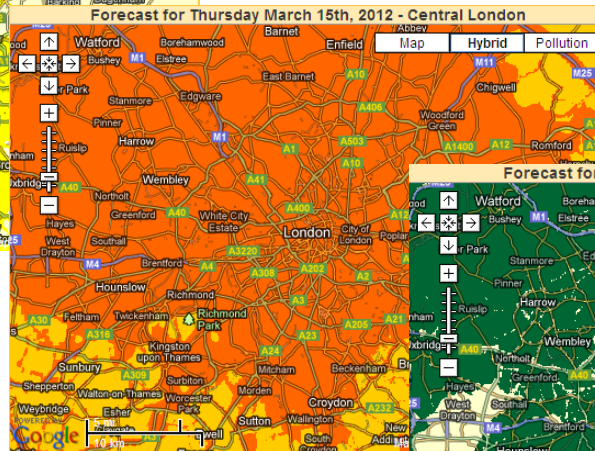
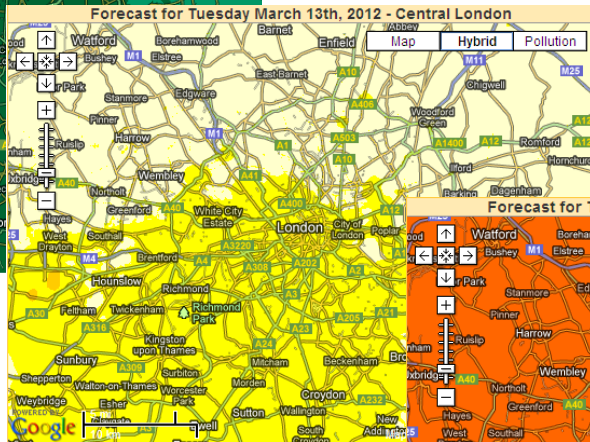
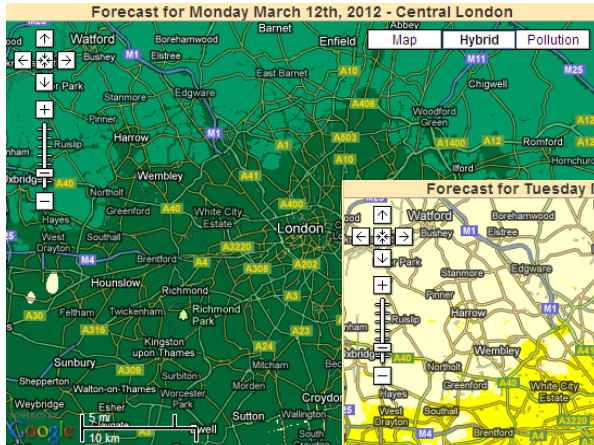
Personal pollutant exposure



Main sources: traffic,
domestic boilers,
industry.

A need for personalized air quality

Main limitations: expensive
low sensitivity
form factor
limited distribution



The City of London has been declared an Air Quality Management Area. Levels of PM₁₀ and NO₂ in the City consistently exceed health-based national objectives.

CITY OF LONDON

The future is coming...!



NASA adapt **iPhone**
to *smell* chemicals
(Nov 17, 2009)



NTT DoCoMo
A Cell Phone that
spots *Bad Breath*



Nokia EcoSensor Concept
Wearable sensor unit to sense
(environment, health..), and a
dedicated mobile phone (not an e-nose yet)



Other concepts:
Health conscious phone
that *smells* food properties

Nokia Scentsory Concept
e-nose samples the odor of
caller environment and transmit
to recipient electronically



A vibrant purple ink splash or smoke effect, starting from the top left and trailing downwards towards the center of the page. The ink is thick and billowing, creating a sense of movement and energy.

**ASPIRE
INVENT
ACHIEVE**

