SENSORS FOR **AIR QUALITY** MONITORING

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SR. RESEARCHER GAS AND ION SENSORS

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Health and Lifestyle as Application Driver

IMPROVE

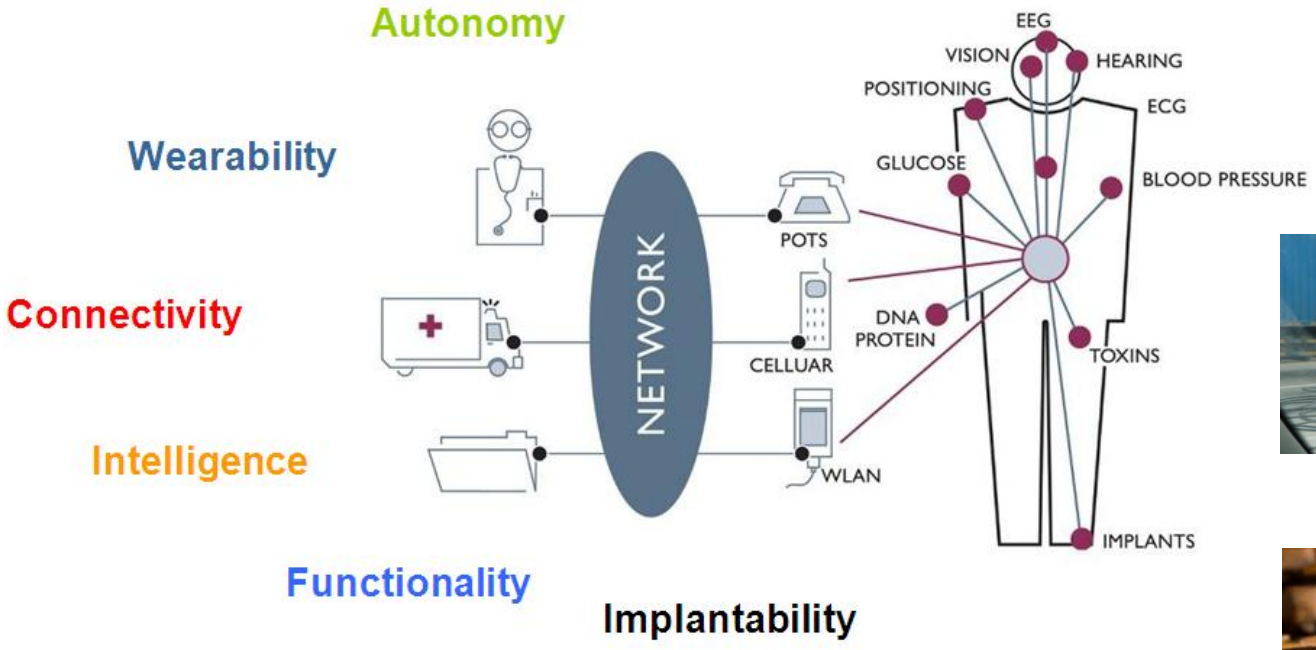
ILLNESS MANAGEMENT

ENABLE

HEALTH MANAGEMENT

What if these systems could sniff?

From *Body* to *Personal* Area Network



Air quality

Food quality

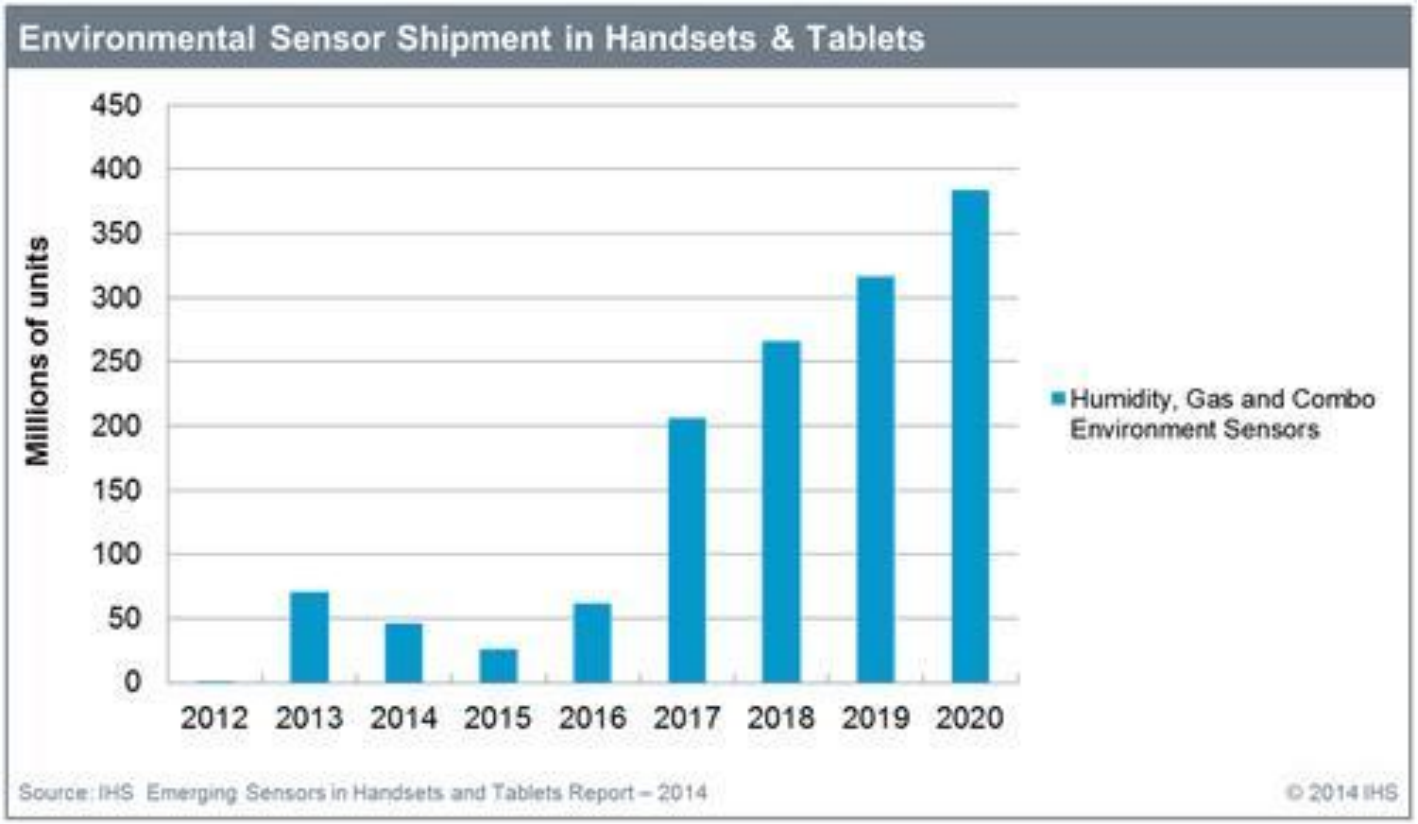
Health status

Product recognition

Open spaces

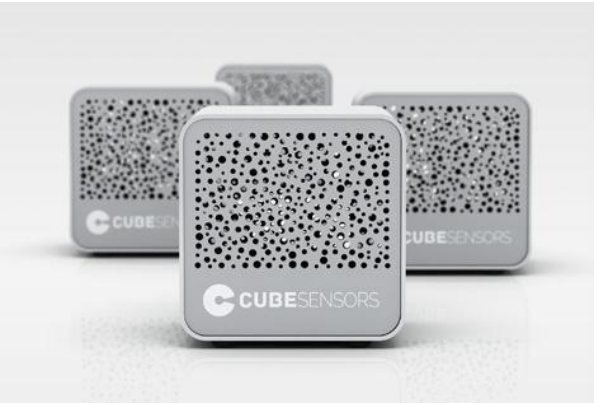
EE TIMES: 2015 YEAR OF THE AIR QUALITY SENSORS

EE Times Connecting the Global Electronics Community



AIR QUALITY GADGETS ARE BOOMING

Cube sensors



- T, RH
- Pressure, noise, light
- VOCs (CO_2 equivalent)

Air quality egg

- T, RH
- Pressure, noise, light
- VOCs, NO_2, ozone, particles

Netatmo

- T, RH
- Pressure
- CO_2

All qualitative indication of air quality: **good**, **medium** or **bad**

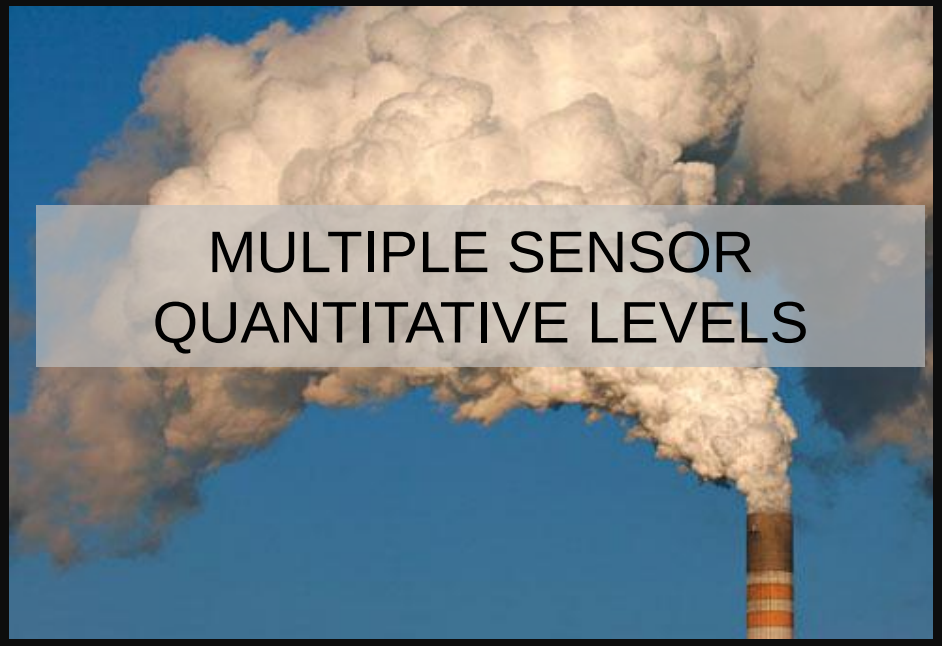
IS GOOD, MEDIUM, OR BAD SUFFICIENT?

Clear recommended levels of exposure

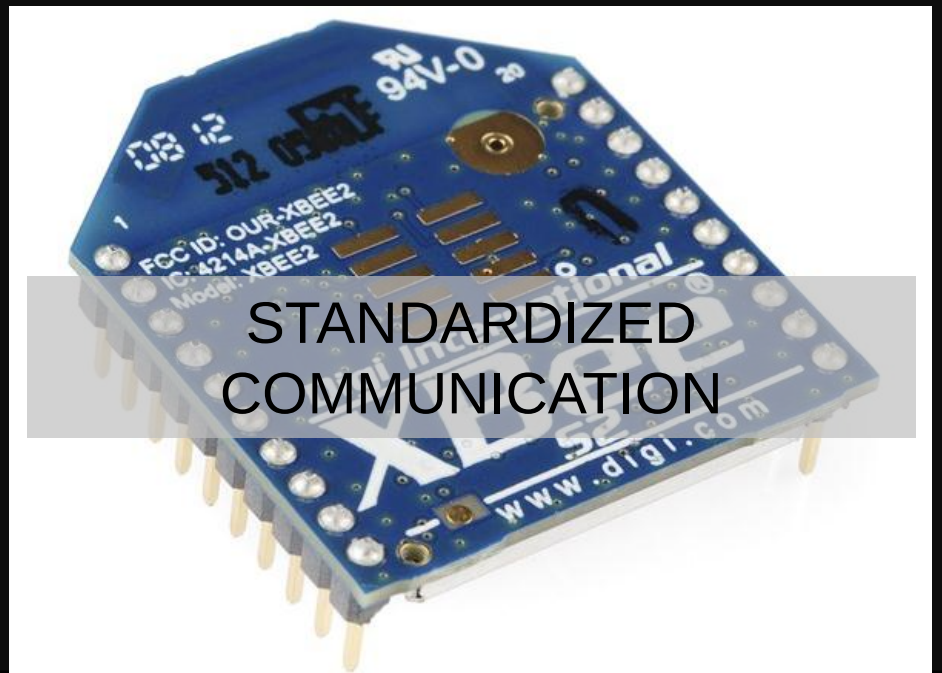
	Pollution	Recommendations	
	CO_2	8 hrs 15 min	5000 ppm 30000 ppm
	CO	24 hrs 1 hr	10 ppm 25 ppm
	NO_2	Annual mean 1 hr	20 ppb 100 ppb
	O_3	8 hrs	20 ppb
VOCs	Formaldehyde	8 hrs 1 hr	40 ppb 100 ppb
VOCs	Toluene	24 hrs 8 hrs	0.6 ppm 4.0 ppm
VOCs	Benzene	As low as possible	
VOCs	Napthalene	24 hrs	1.9 ppb

Source: Health recommendations from Canada, WHO

Imec vision

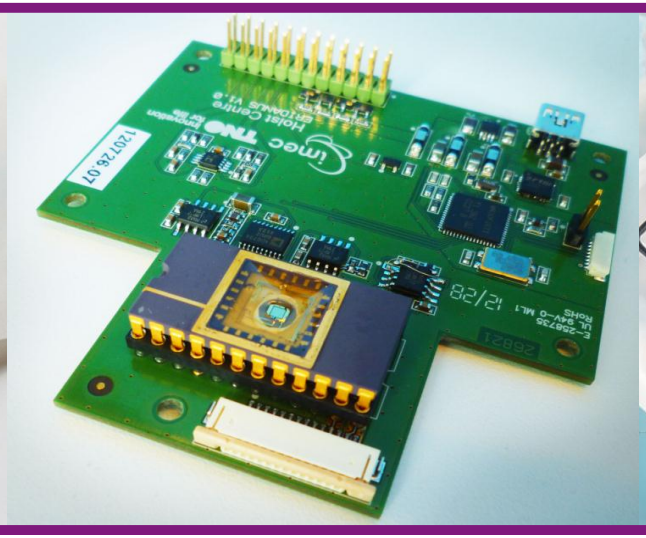

MULTIPLE SENSOR
QUANTITATIVE LEVELS

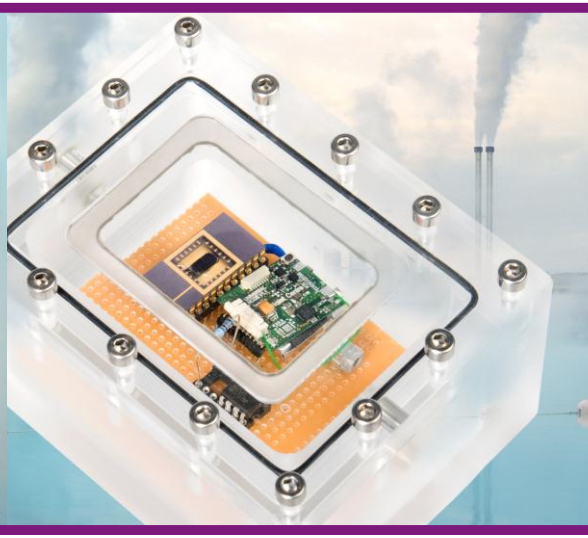

LOW COST BY MASS
FABRICATTION


STANDARDIZED
COMMUNICATION


LOW
POWER

IMEC SENSOR PLATFORMS





Ion Sensor

‘Health patch’

Gasses
(Ionic Liquid): Ethylene, CO_2,..

Fruit monitoring
Air quality monitoring

GaN sensor:
NO_2, NO,..

Environmental monitoring

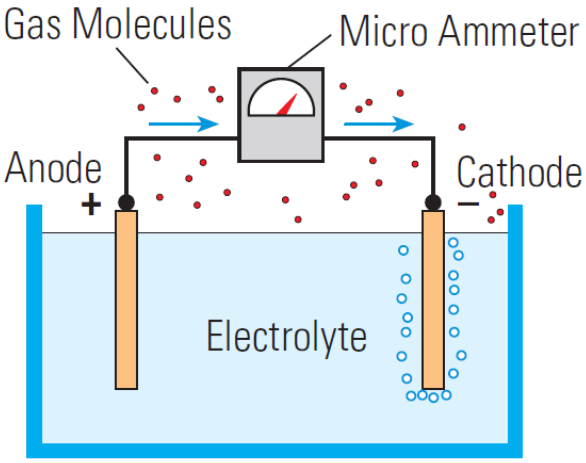
AIR QUALITY SENSORS TODAY

Form factor suitable for indoor air quality monitoring:

- Electrochemical gas sensors
- NDIR sensors
- Metal oxide sensors

Not about lab equipment (GC-MS, Flame ionization, Laser based spectroscopy Chemiluminescence)

ELECTROCHEMICAL GAS SENSORS



Electrochemistry

- apply potential to working electrode
- oxidation/reduction of analyte at electrode
- electron transfer to/from electrode
- inverse reaction at counter electrode
- current depends on analyte concentration

Pros

- low power consumption (< 1 μW)
- Selective (voltage, WE material)
- Sensitive down to ppm range

Cons

- large form factor (liquid electrolyte)
- evaporation → drift, lifetime ~1-2 yrs
- electrochemically active gasses (CO, H_2S, NH_3)

NDIR SENSORS

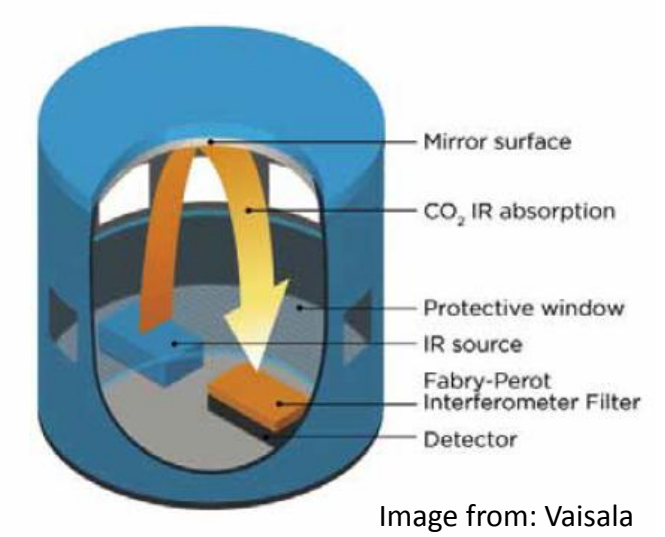


Image from: Vaisala

- Some gasses absorbs IR light, e.g. CO_2 and CH_4
- IR light source is directed through sample and absorption is measured
- Components of NDIR sensor:
  - Light source
  - Optical filter
  - Photodiode detector
  - Reaction volume / optical pathway

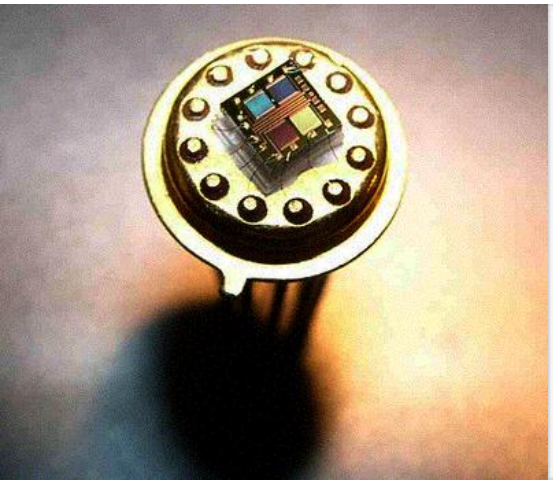
Pros:

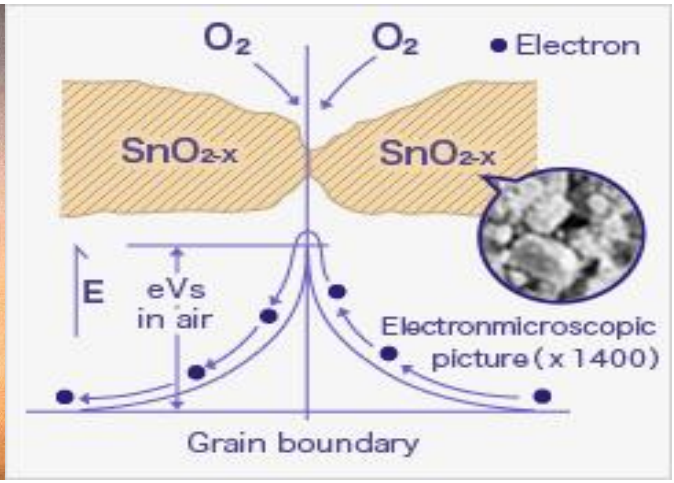
- Good selectivity: gas absorbs light only at specific wavelengths, but requires specific optical filter in front of detector
- Long lifetime (>5 yrs)

Cons:

- Light source needed → high power: typically >200mW. Light source needs warm-up & stabilization time (1-10 min)
- Form factor: high sensitivity only if light can interact with gas over long pathway: typically >5 cm
- Concentration of CO_2 in air depends on temperature and pressure → p and T compensation needed

METAL OXIDE GAS SENSORS





- At elevated temperature O_2 as adsorbed at metal oxide surface
- Free electrons are transferred to O_2 → resistance increase
- Gasses interact with surface O_2 → resistance decreases

Pros:

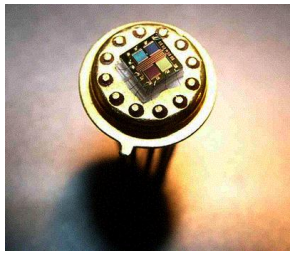
- Sensitive & inexpensive
- Small form factor

Cons:

- High power consumption (> 200 mW due to continuous heating)
- Cross-sensitive (LPG, methane (CH_4), carbon monoxide (CO), other hydrocarbons)

Metal oxide sensors are typically used in air quality sensors
Cross-sensitivity is expected!

COMPARISON



	ECHEM	NDIR	MOX
Sensitivity (ppm-range)	🟢	🟢	🟢
Sensitivity (sub ppm)	🟠	🔴	🔴
Selectivity	🟢	🟢	🔴
Life-time	🟠	🟢	🟢
Form-factor	🟠	🟠	🟢
Power consumption	🟢	🔴	🔴
Cost	🟠	🔴	🟢

No perfect sensor!

EXPOSURE TO GASSES

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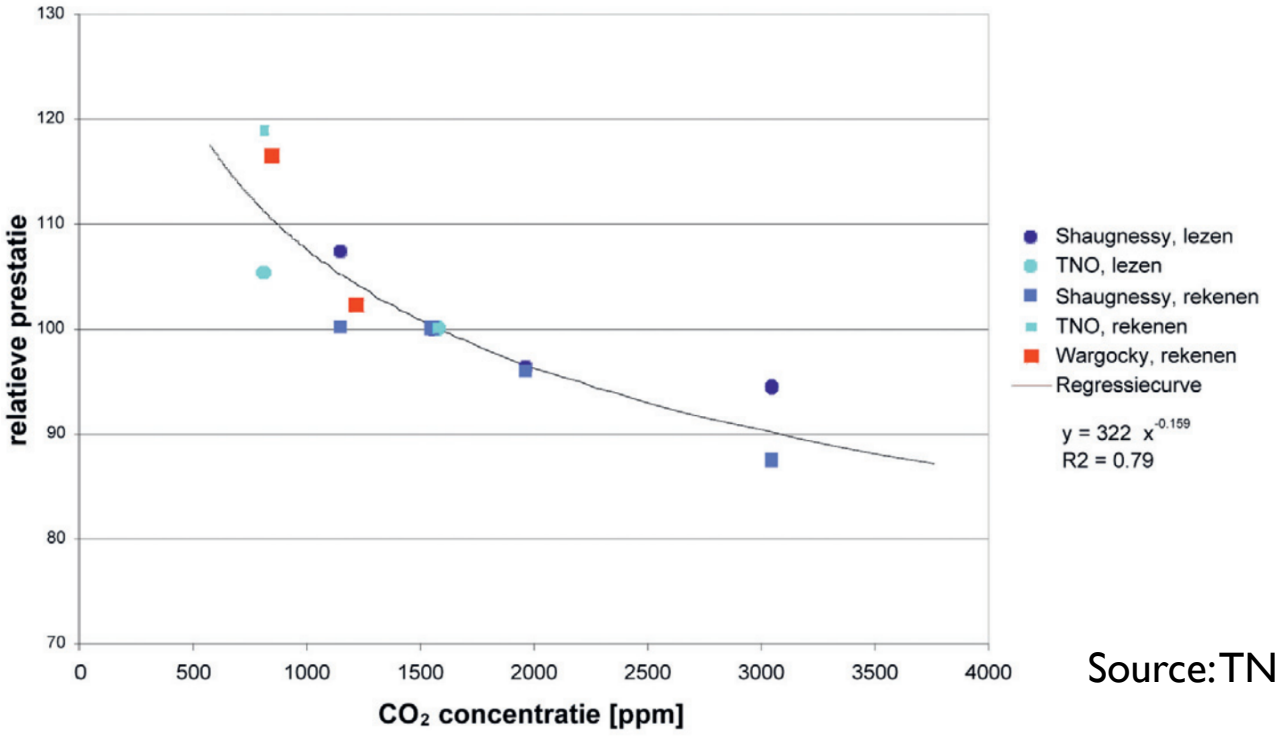
CO_2- EXPOSURE LIMITS

CO2 %	Effect
20.0	Death within a few seconds
10.0	Convulsion, Unconsciousness, Death
7.0	Dizziness, Vomiting, Headache, Reduced blood supply to brain
4.0	IDLH -Immediate Danger to Life and Health
3.0	Normal exhale concentration; increased breath and pulse rates
1.5	Shortness of breath possible
0.5 (5000 ppm)	Maximum for working conditions (Time Weighted Average <5000 ppm for 8 hrs)
0.1-0.3 (1000 – 3000 ppm)	High values in office
0.04 (400 ppm)	Fresh air

CO_2 LEVELS AND HEALTH

- Elevated CO_2 concetration of 1000 ppm above increase sick leave of 10 tot 20 procent (Shendell et al., 2004).
- Effect on learning

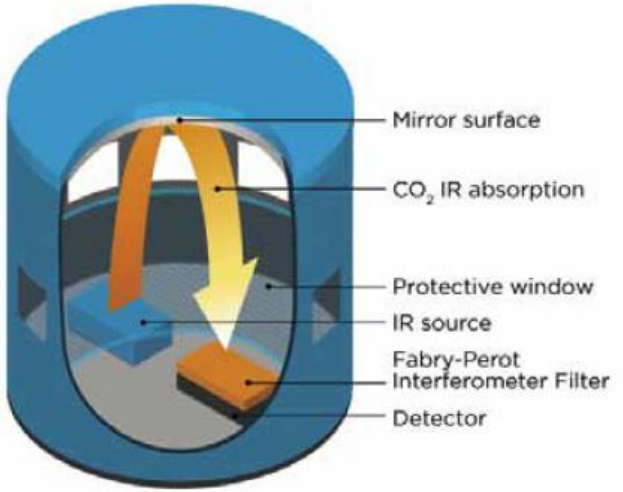


Source: TNO

TNO recommends CO_2 level < 800 ppm

NDIR CO_2 SPECIFICATIONS

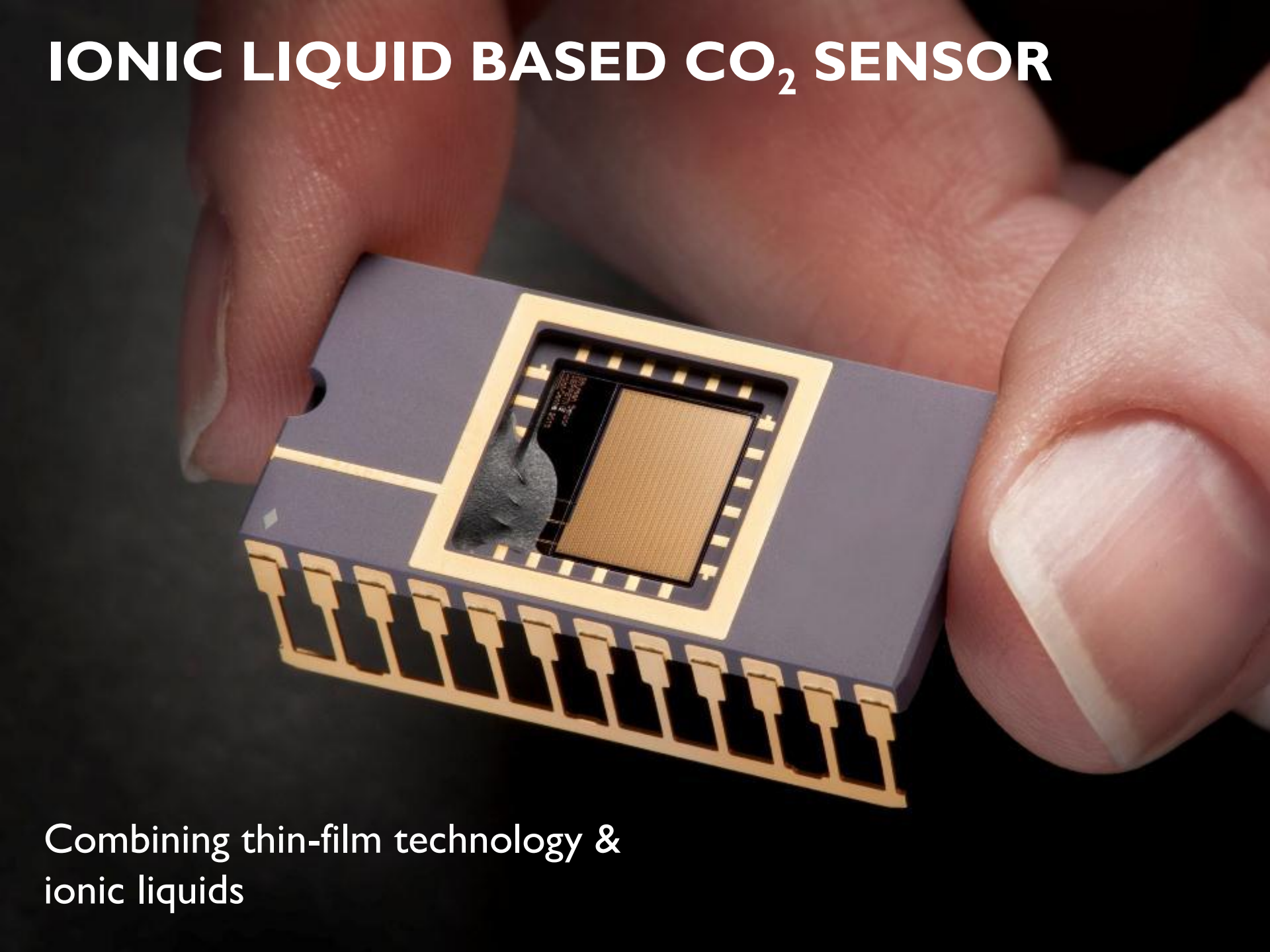
- Range: 0 -10000 ppm
- Accuracy: ±50 ppm ±5% of reading
- Life-time > 5yrs
- Recalibration possible with background CO_2 concentration (400 ppm)



Good enough for indoor air quality monitoring!

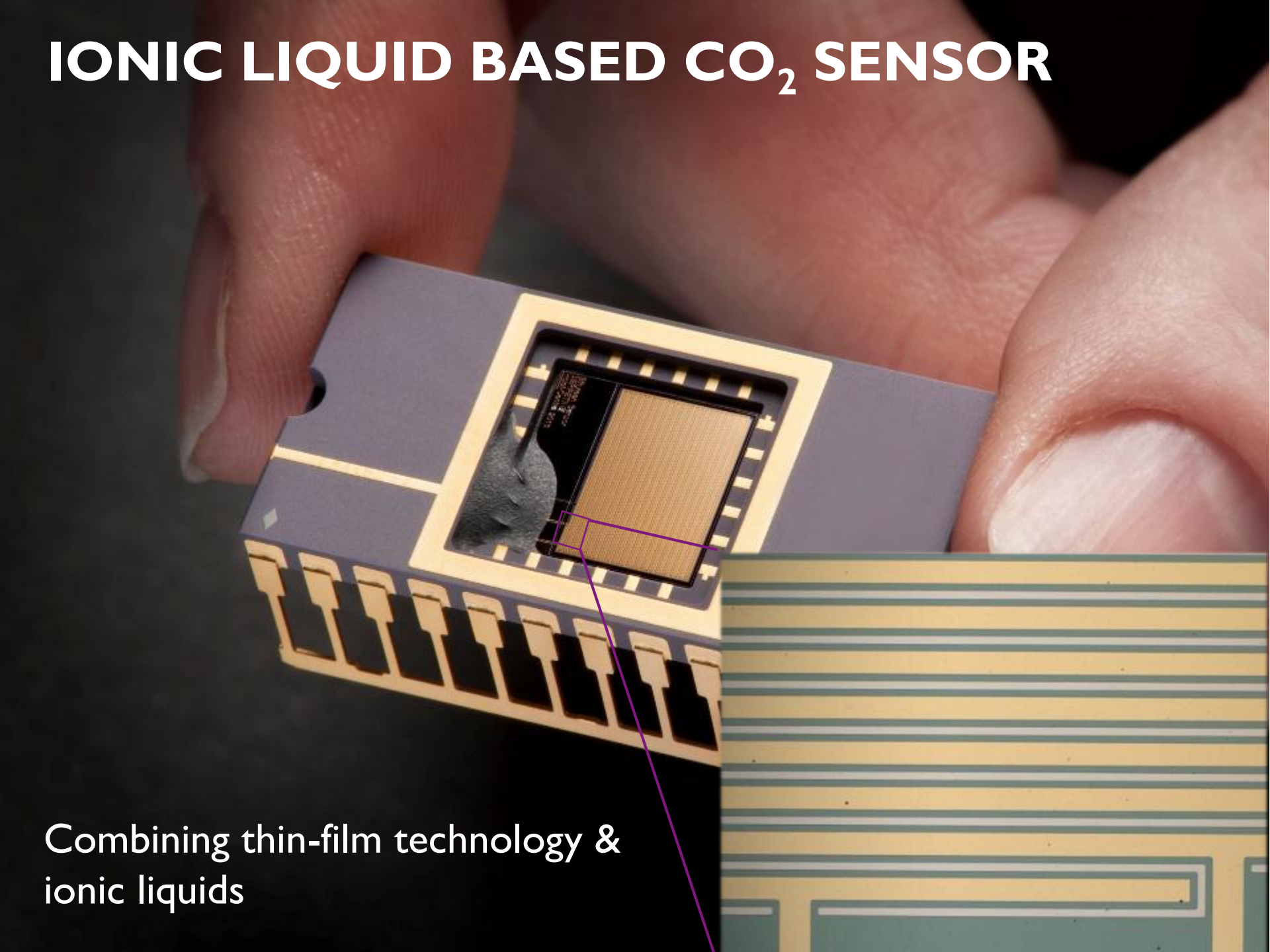
Optical path & power consumption hinders further minitiarization...

IONIC LIQUID BASED CO_2 SENSOR



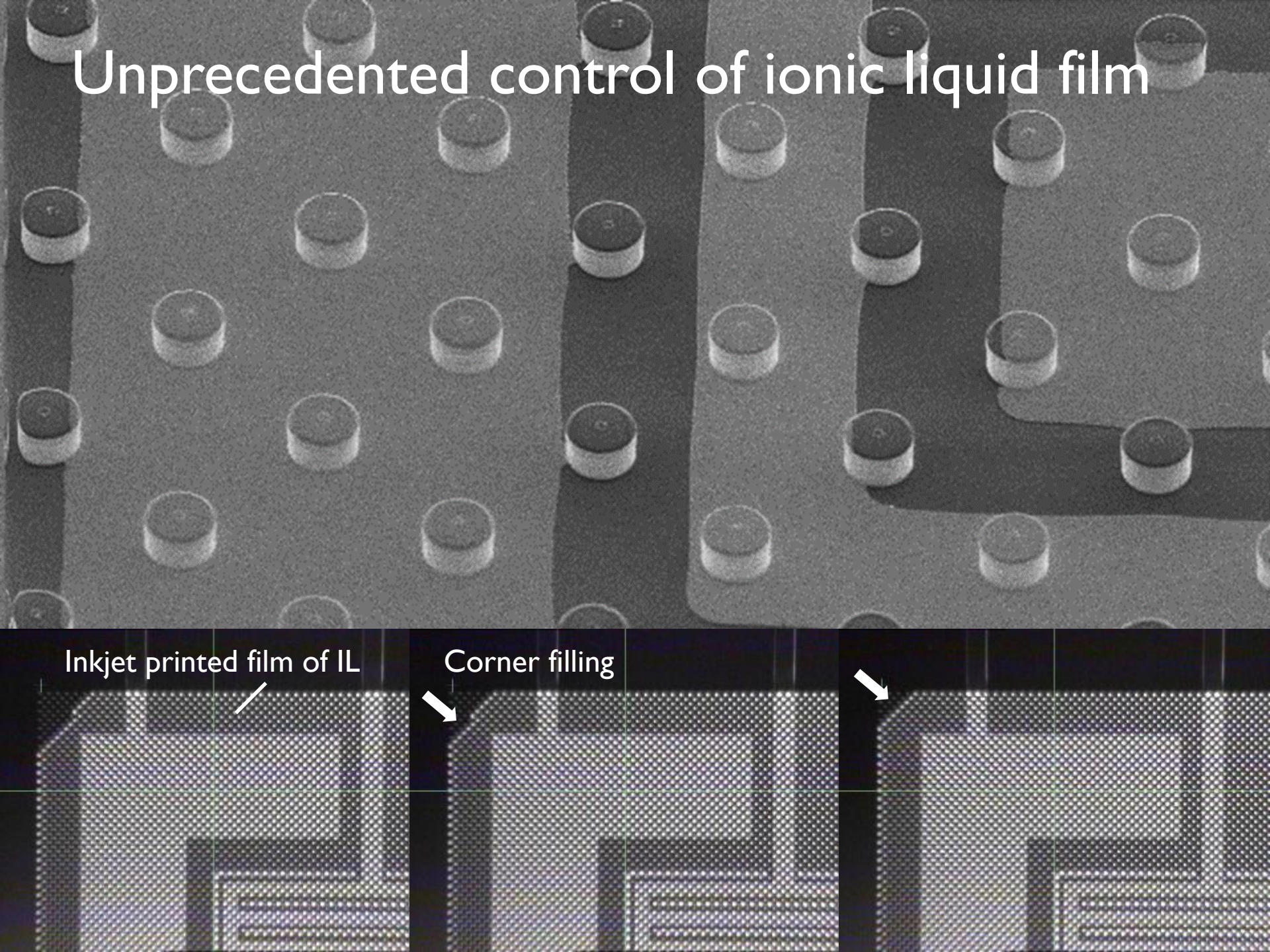
Combining thin-film technology &
ionic liquids

IONIC LIQUID BASED CO_2 SENSOR



Combining thin-film technology &
ionic liquids

Unprecedented control of ionic liquid film



NO_2- EXPOSURE LIMITS

NO_2 (ppb)	Effect
200-300	Avoid *all* outdoor exertion: • People with lung disease, such as asthma • Children and older adults Everyone else should limit outdoor exertion.
150-200	Avoid *prolonged* outdoor exertion: • People with lung disease, such as asthma • Children and older adults Everyone else should limit *prolonged* outdoor exertion
100-150	Limit prolonged outdoor exertion: • People with lung disease, such as asthma • Children and older adult
50-100	Individuals who are unusually sensitive to nitrogen dioxide should consider limiting prolonged outdoor exertion.
0-50	No health impacts are expected when air quality is in this range.

Source: EPA

WHO guidelines: 20 ppb annual mean /100 ppb 1-hour mean

Precursor for ozone and nitrate particle formation

AIR QUALITY (NO_2) MONITORING
STATE OF THE ART EXAMPLES

Absorption tubes
- Sampling time: 1 month
- Needs chemical analysis

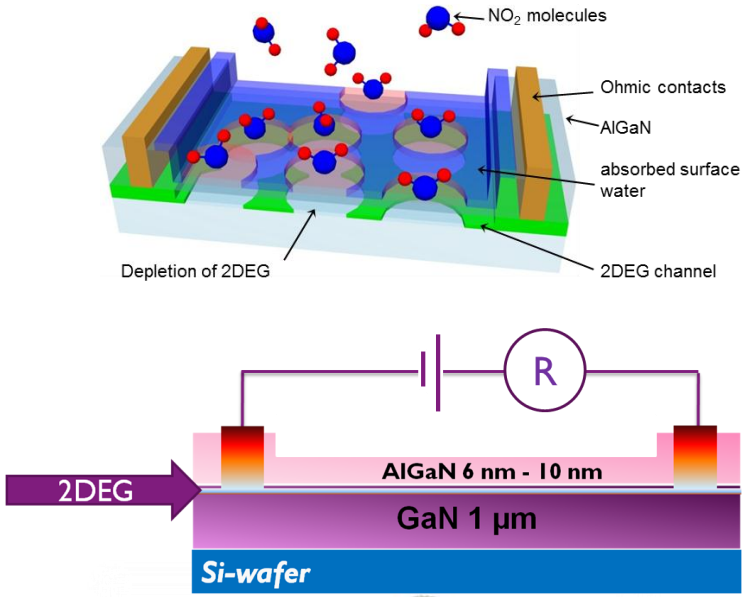
Electrochemical
- Expensive
- Not very small
- > 20 ppb

NOx lambda sensor
- Exhaust sensor
- High temp
- ppm level

Chemiluminescence analyzer
- High power
- Large and very expensive

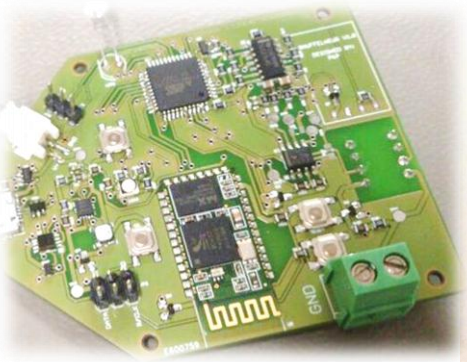
→ There is a need for small but sensitive NO_2 sensors

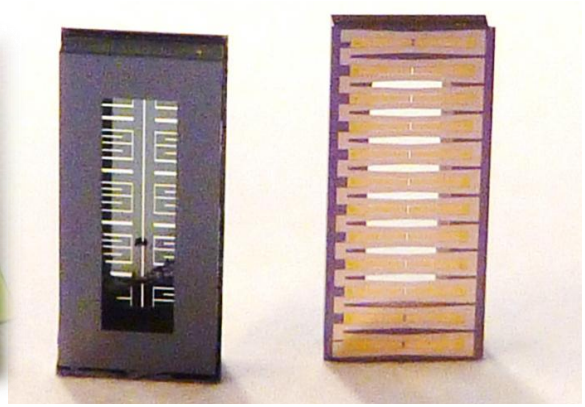
GAN SENSOR



Available today

- **NO2,** NO; ppb sensitivity
- Miniaturized sensor on Si
  - 8" process flow
- Hand-held sensor demo with readout
- Trial test results in outdoor environment





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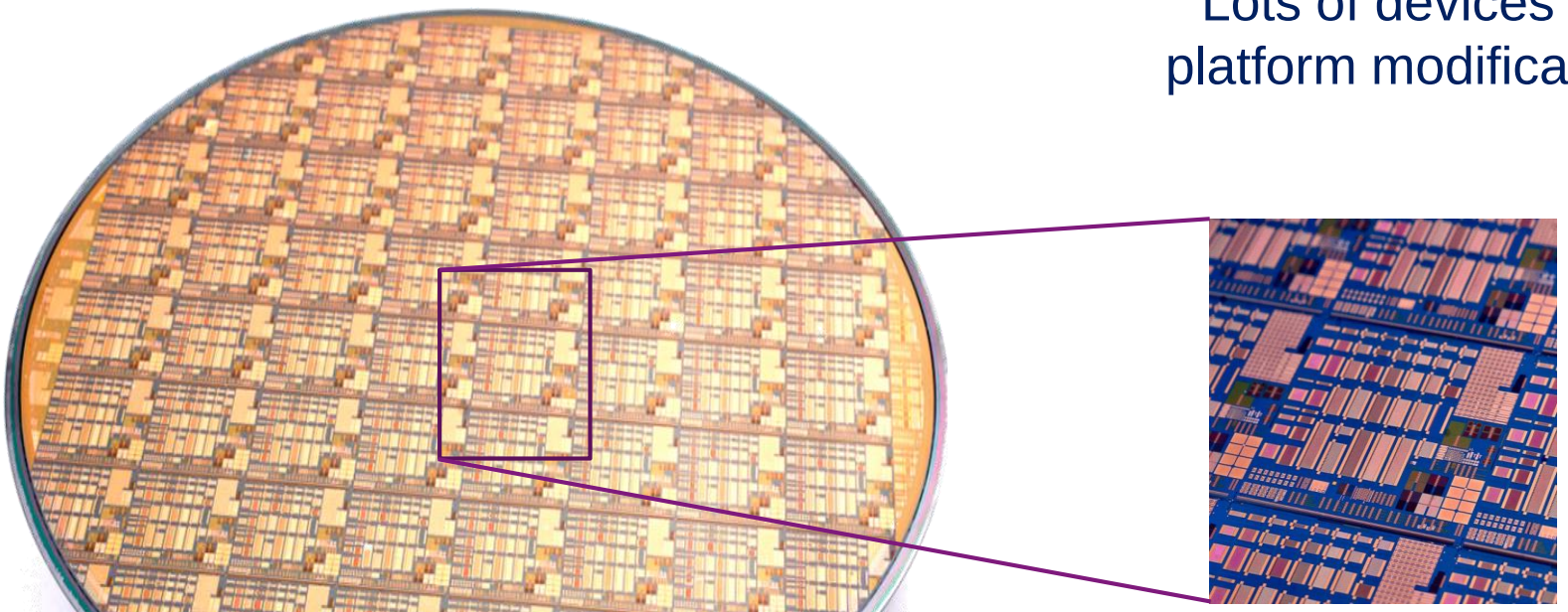
FULL WAFER DEVICE FABRICATION

Lots of devices for
platform modifications



8 inch wafer
GaN-on-Silicon technology

GAN SENSORS: EXTENSION TO OTHER GASSES

- Functionalization with polymers, ionic liquids and metalorganic framework
- Usable for inorganic gasses- H_2, O_3, **CO_2**, NH_3 and Volatile Organic Compound (**VOC**) – BTX, Formaldehyde

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PARTICLE MATTER

pm10: particles smaller than 10µm → coarse particles

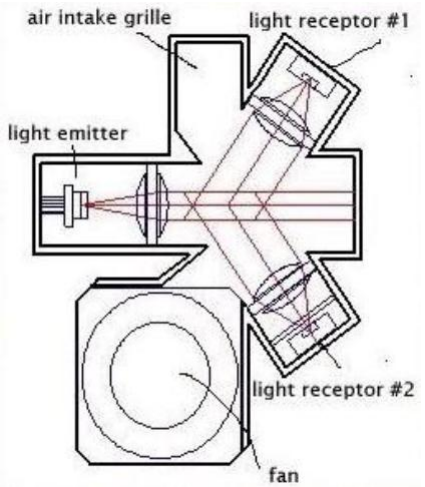
- Reach trachea (upper throat) or the bronchi
- EU regulation: max 50 µg/m3 → 38 particles/liter

pm2.5: particles smaller than 2.5µm → fine particles

- Reach the alveoli in the lungs
- EU regulation: max 25 µg/m3 → 1200 particles/liter

pm0.1: particles smaller than 0.1µm → ultra-fine particles

- Usually exhaled, but can pass cell membranes and get into the blood stream → effects unclear & more research
- Currently no air quality standard for pm0.1 (!)



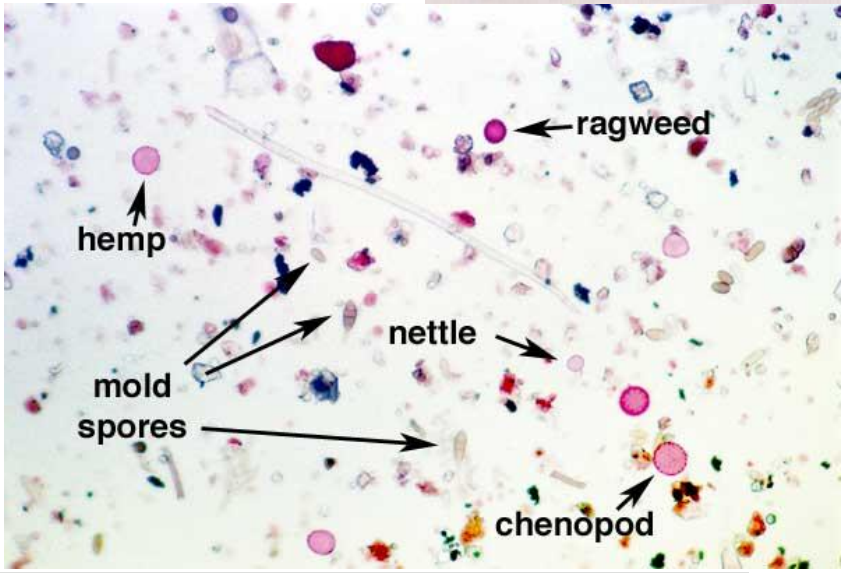
- Some sensors available based on light scattering

CONVENTIONAL POLLEN DETECTOR

- Diameter range 6-100µm
- Concentrations:
  - Low: < 30 pollen/m^3
  - Moderate: 30 to 49 pollen/m^3
  - High: 50 to 149 pollen/m^3
  - Very High: > 150 pollen/m^3
- Air flow of 1 L/min at low concentration → 1 pollen every 30 sec

Burkard volumetric spore trap

- 10 L/min airflow
- Microscope slide with grease per two hours
- Counting a slide takes more than one hour



The Netherlands:

- 2 stations (!)
- Rotating roll with sticky tape for one week
- Counting once per week (one sample accounts for 1 day)

WIRELESS SENSOR NETWORK

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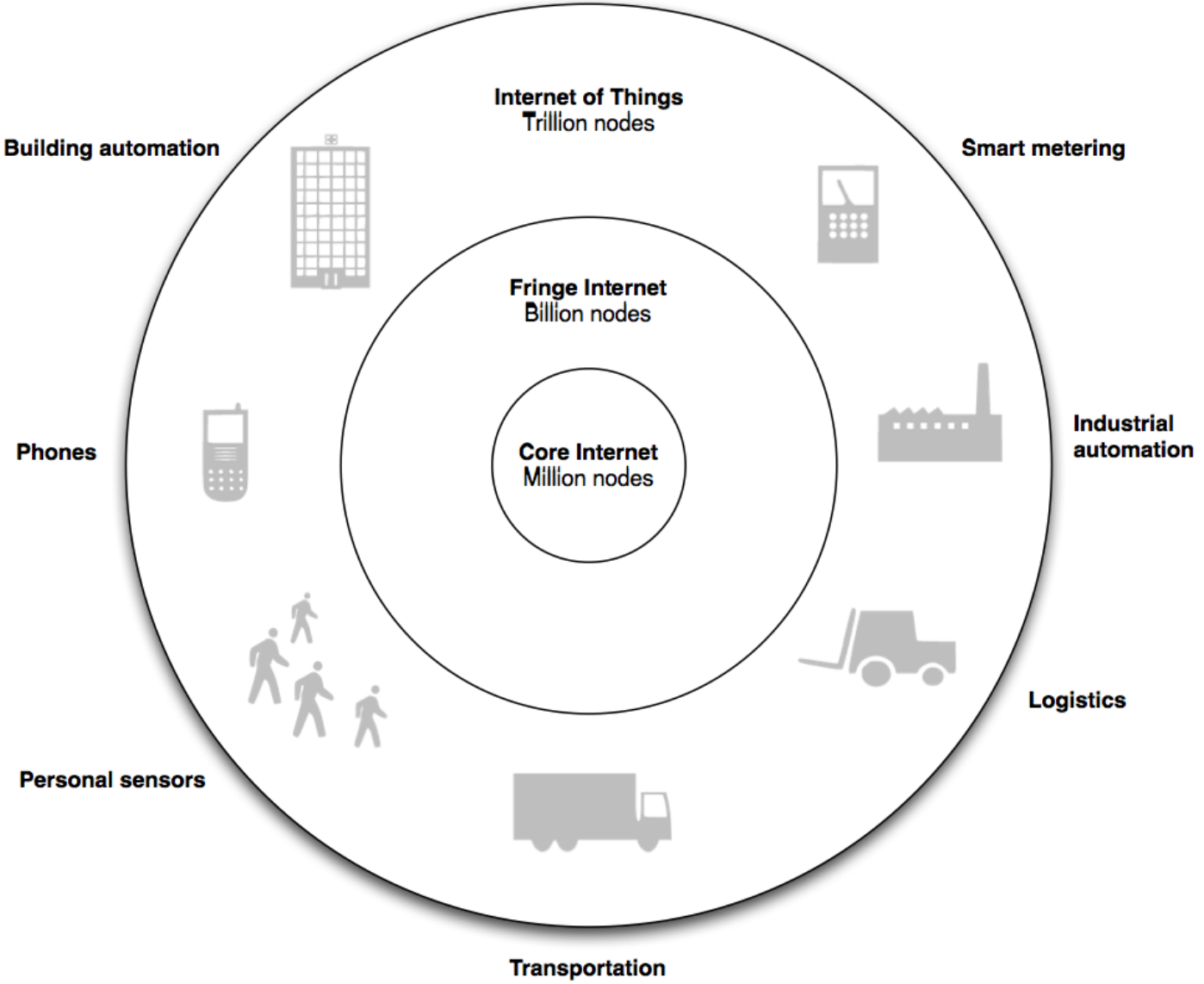
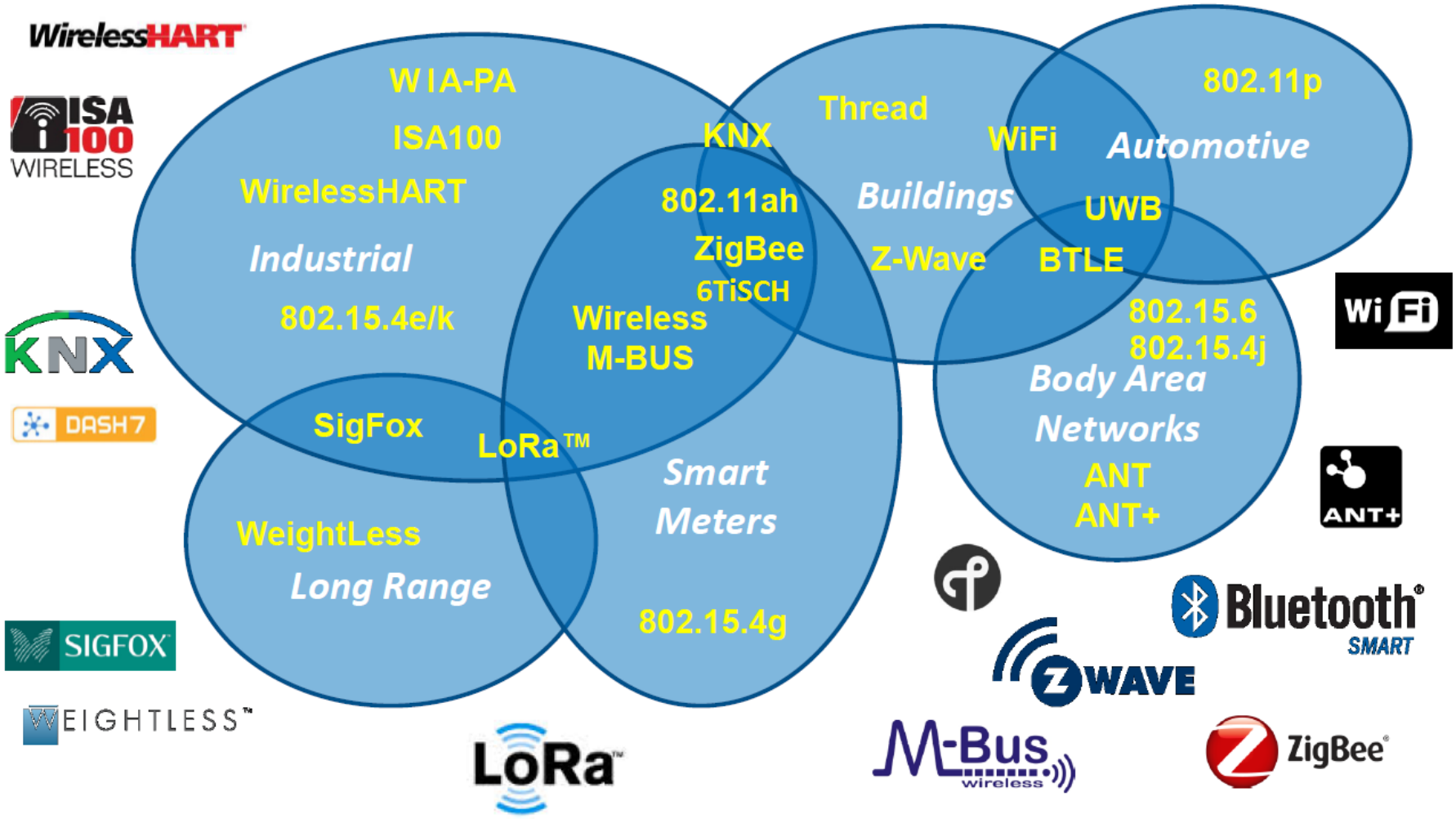
INTERNET OF THINGS & AIR QUALITY



IOT RADIO APPLICATION DOMAINS



Porret, A.-S. Wireless sensor networks / iot: An overview of wireless technologies.

OPEN ACCESS IS KEY!

IFTTT

ifthisthenthat

ASPIRE
INVENT
ACHIEVE

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