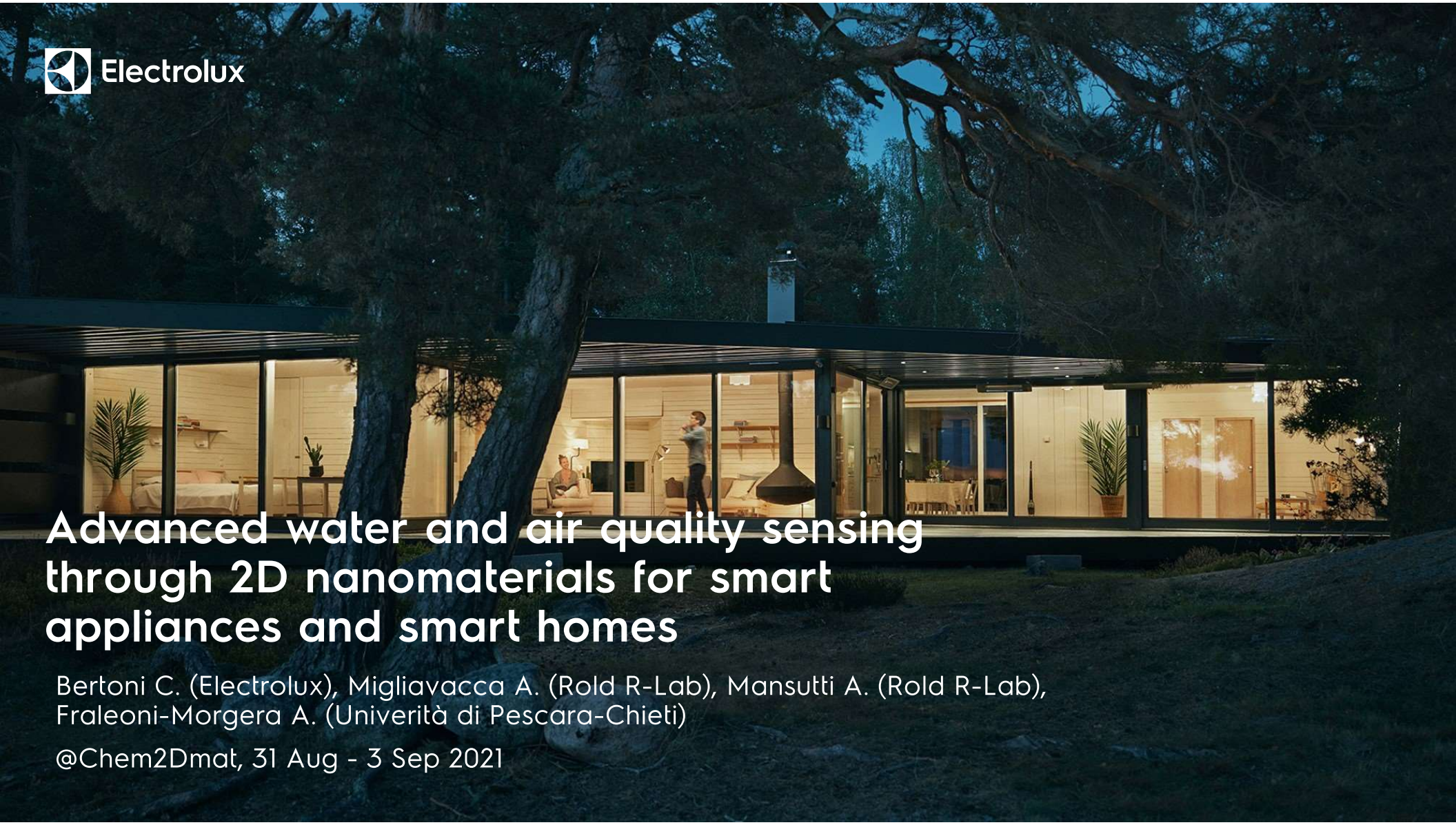


Advanced water and air quality sensing through 2D nanomaterials for smart appliances and smart homes

Bertoni C. (Electrolux), Migliavacca A. (Rold R-Lab), Mansutti A. (Rold R-Lab), Fraleoni-Morgera A. (Univerità di Pescara-Chieti)

@Chem2Dmat, 31 Aug - 3 Sep 2021

Who we are

Electrolux is a leading global appliance company that has shaped living for the better for more than 100 years. We reinvent taste, care and wellbeing experiences for millions of people, always striving to be at the forefront of sustainability in society through our solutions and operations. Our main strategic drivers are to act sustainably, create better experiences and always improve!

119
billion SEK in sales

120
markets reached

60
million products sold annually

49,000
employees

Addressing drivers and trends

DRIVERS

New economies

Life at home

Human-scaled urban design

Climate change

Constrained resources

Breakthrough technologies

TRENDS

The smart home

Professional consumers

Eco for the masses

New Hygiene practices

Reduction in incomes

On-line shopping

Hyper-personalization

Applications and requirements

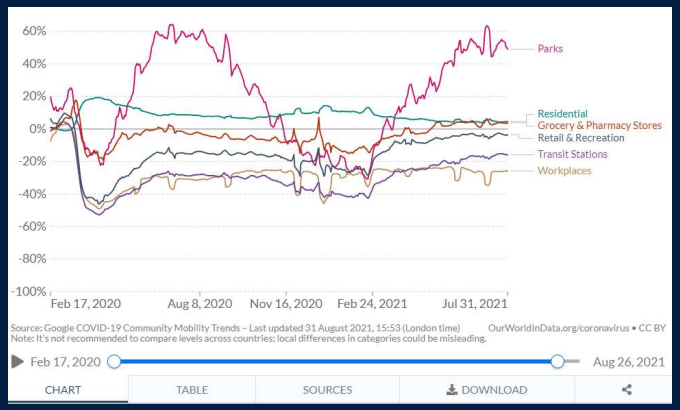
Air quality

- Applications
  - ❑ air purifiers
  - ❑ air conditioners
- Requirements
  - ❑ Sensitivity (from ppm)
  - ❑ Selectivity (gas vs odors)
  - ❑ Fast response
  - ❑ Reliability
  - ❑ Low-cost

H2O quality

- Applications
  - ❑ water purifiers
  - ❑ water dispensers
  - ❑ PoU water systems
- Requirements
  - ❑ In-line operation
  - ❑ Real-time response
  - ❑ Low-cost

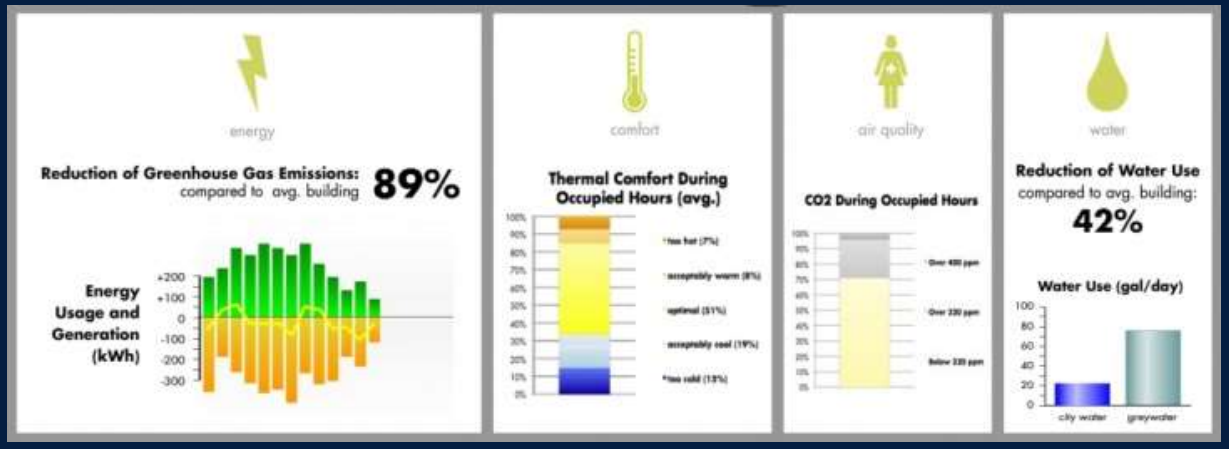
Indoor life



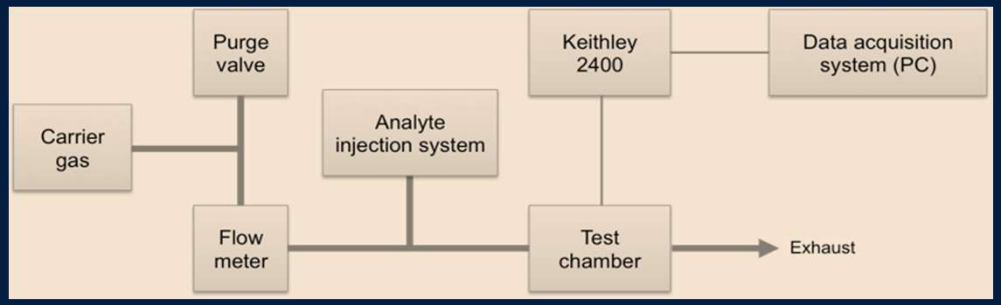
Google Mobility trends up to Sep the 25th

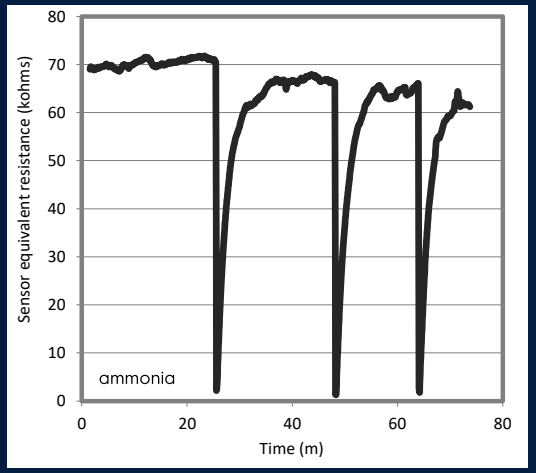
Indoor environment

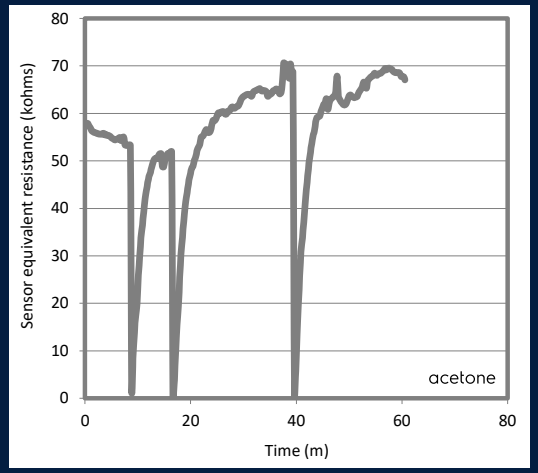
- Pandemic increased the time spent at home (US, transit stations –16%, workplaces -26% since Feb 2020)
- Indoor well-being is determined by indoor environmental quality which in turn encompasses several aspects, like sound, lighting, odor, thermal comfort
- Air quality at home is as important as other parameters of interest such as energy usage and generation, heating equipment performances and water usage



Commercial solid-state gas sensor



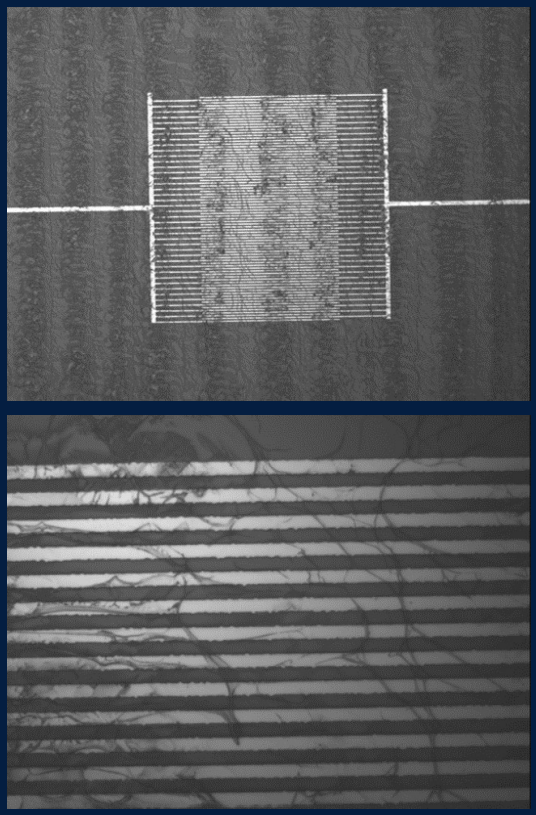




- setup to test sensor dynamic response to gas targets in air as the gas carrier
- acetone and ammonia handling/safety facilitating lab testing
- commercial sensors show long recovery time and no selectivity

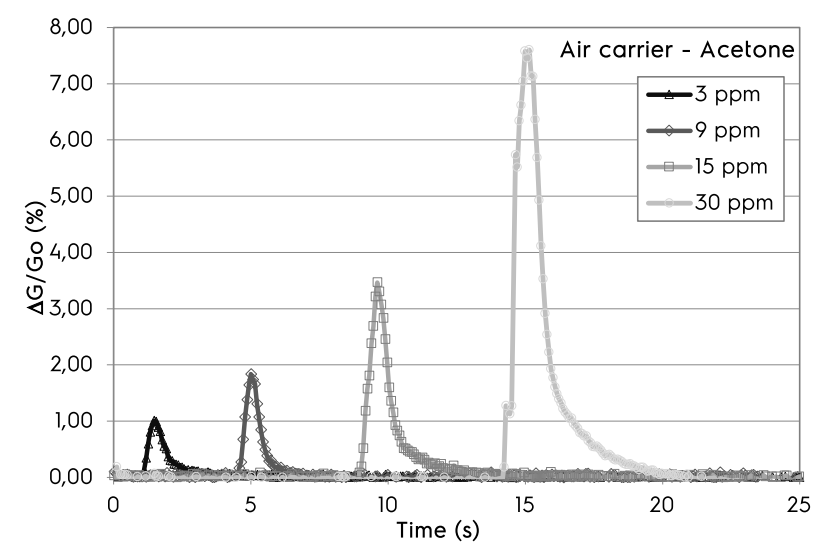
Organic nanostructured ASB-SANS sensors for gas sensing applications

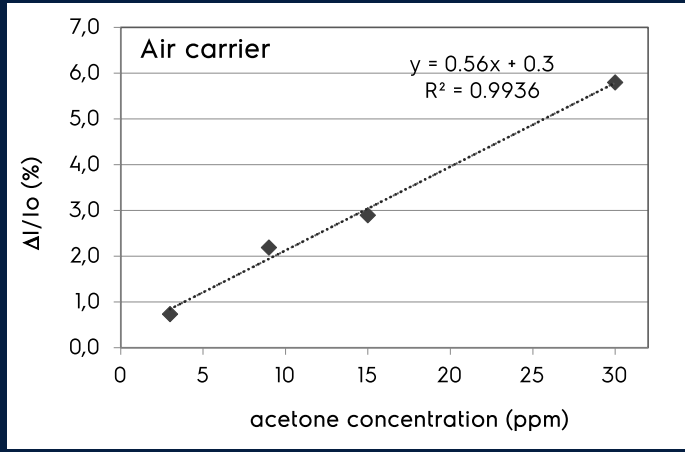
- organic nanostructured sensors can be easily fabricated by self-assembly using a novel technique called **ASB-SANS**
- ASB-SANS allows fabricating 2D nanofiber patterns with **controlled topology** over **large areas**, **within minutes** at normal conditions, with **no need for sophisticated equipment**
- nanostructures obtained by ASB-SANS out of P3HT present a **remarkably high degree of self-organization and crystallinity** (no need for any post-production treatment)



A. Fraleoni-Morgera, Small, vol. 7, pp. 321-325, 2011.

ASB-SANS P3HT sensors tested in-line

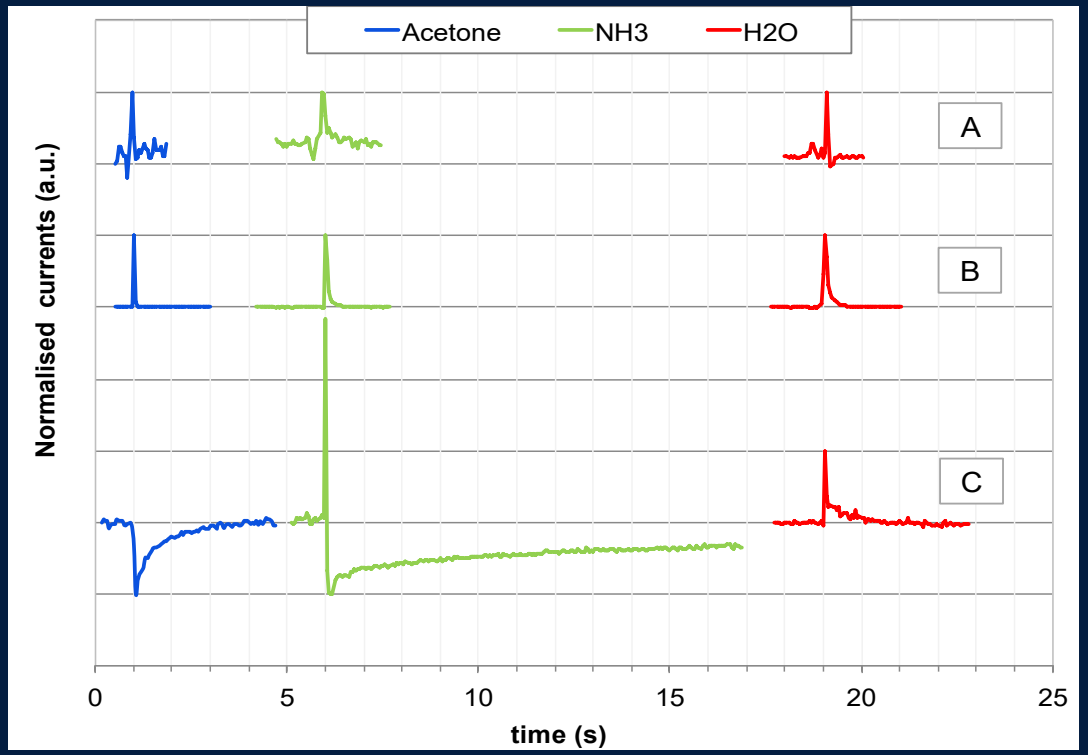




- Response change versus increasing acetone concentrations in air as the gas carrier
- Current's peak-to-baseline ratio linear in the gas concentrations range of interest

C. Bertoni *et Al.*, Sensors 2019, 19, 1296.

ASB-SANS P3HT sensors response to other gases

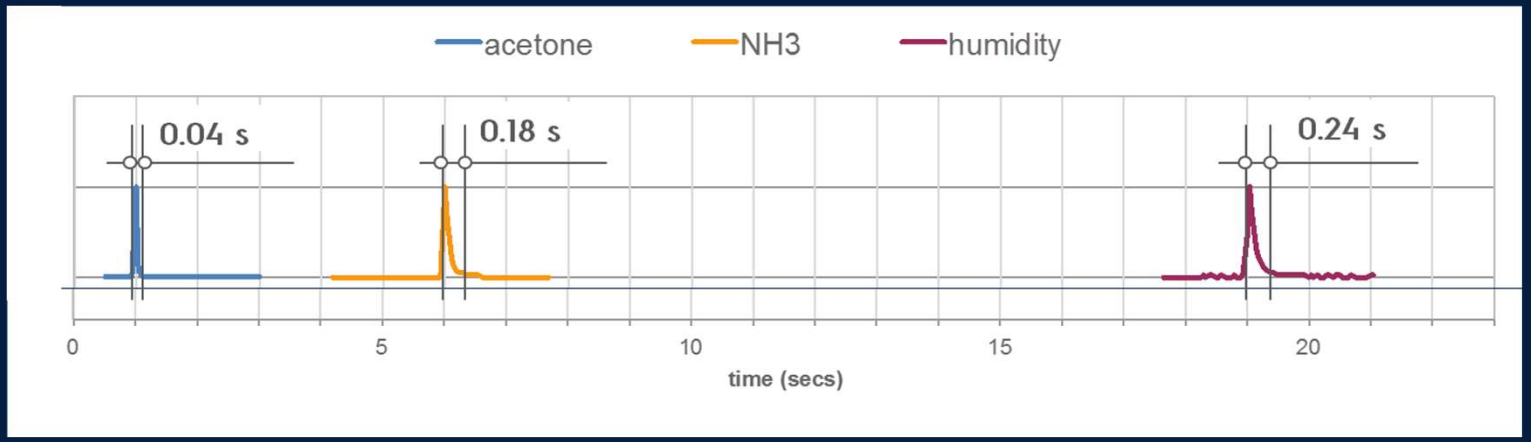


A bare interdigit B ASB-SANS P3HT C plain P3HT

- ASB-SANS P3HT showed much **shorter recovery times** (below 1 second) with respect to plain film
- No analyte permeation within the nanostructured polymer layer (conductivity always increased with the analyte) clearly pointing towards a **response dictated by surface effects**
- **No baseline drift** after repeated exposures to different analytes

E. Viviani *et Al., IEEE Prime, 29 June-2 July 2015, Glasgow*

ASB-SANS P3HT sensors response to other gases



- recovery times slightly increase with decreasing analyte polarizability (acetone = 6.4 A3; NH3 = 2.16 A3; H2O=1.47 A3)

E. Viviani *et Al., IEEE Prime, 29 June-2 July 2015, Glasgow*

Conclusions and Future Works

Air quality

- Organic and inorganic nanostructures can be easily fabricated by self-assembly using a **novel technique called ASB-SANS**
- ASB-SANS allows fabricating 2D **nano-patterns with controlled topology over large areas**, in a short time and with no need for sophisticated equipment
- **Experimental proof-of-concept** on the use of ASB-SANS nanostructures for gas sensing
- Other applications such as **artificial skin** can be addressed

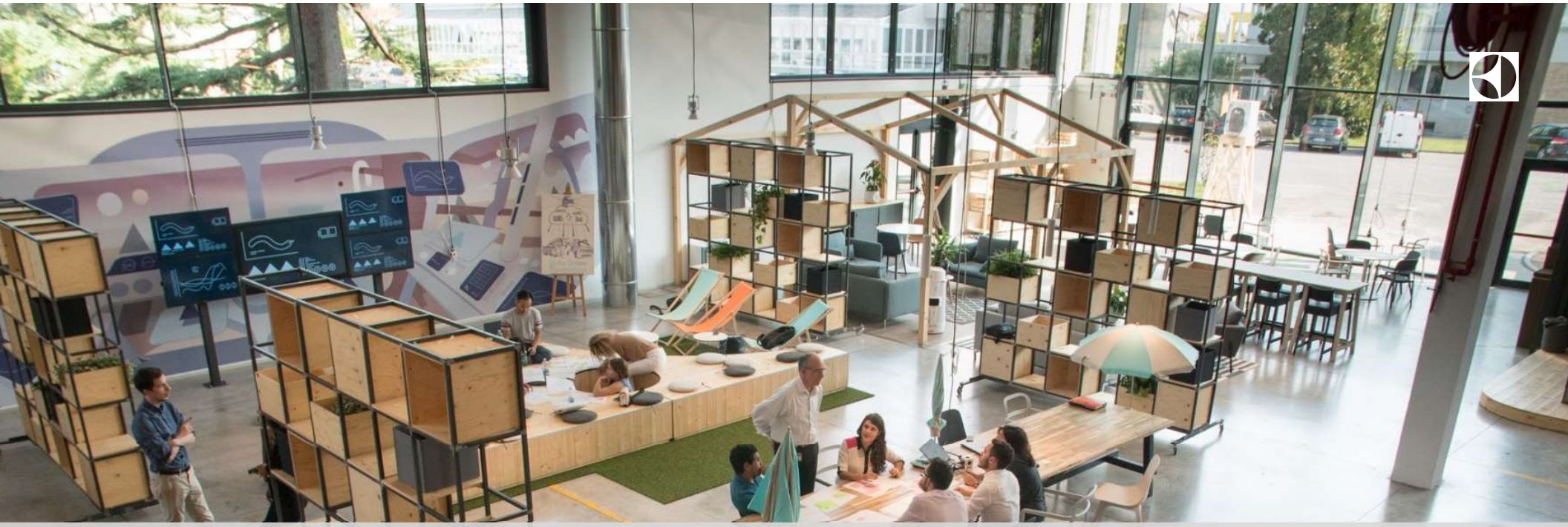
Applications and requirements

Air quality

- Applications
  - air purifiers
  - air conditioners
- Requirements
  - Sensitivity (from ppm)
  - Selectivity (gas vs odors)
  - Fast response
  - Reliability
  - Low-cost

H2O quality

- Applications
  - water purifiers
  - water dispensers
  - PoU water systems
- Requirements
  - In-line operation
  - Real-time response
  - Low-cost



INNOVATION FACTORY

We want to ACCELERATE INNOVATION by fostering pioneering COLLABORATIONS between ELECTROLUX and external INNOVATIVE ECOSYSTEMS

GLOBAL TECHNOLOGY ORGANIZATION I OPEN INNOVATION

WHO we are

- Worldwide Business Company
- Established 1963
- Turnover 2020 ca. 40 M€
- 240 employees
- 3 Production Plants
- 2 Business Units
- 1 Innovation Lab
- 1 Academy

Rold appliance Rold industrial R{Lab} Rold ACADEMY

Roldappliance

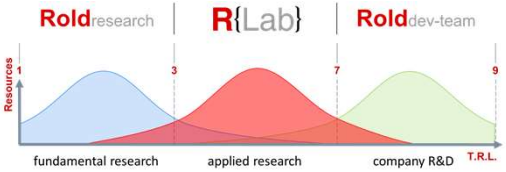
We produce **mechatronic components** for household appliances since 1963 with a high level of automation

Roldindustrial

We designed an **I4.0 Platform** for manufacturing companies with all the features that are actually useful

R{Lab}

We have a **multidisciplinary Innovation Lab**, where research activities are carried out to ideate innovative solutions



Rold ACADEMY

Rold Academy fosters **knowledge sharing** within and outside Rold, by **cross-contamination** between diverse skills and competences

Joint Project

ROLD + Electrolux

Develop an innovative filtering and sensing membrane receptive of a generic target able to sense and to filter molecules or particulates.

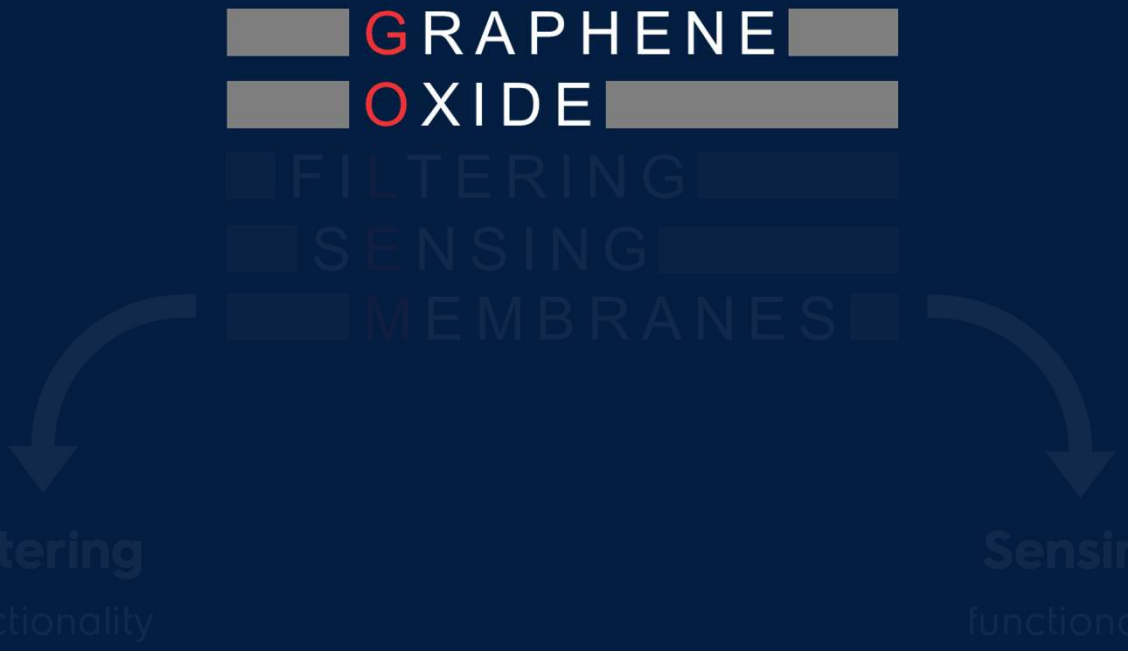
GRAPHENE
OXIDE
FILTERING
SENSING
MEMBRANES

ELECTROLUX INNOVATION FACTORY

GOLEM functionalities

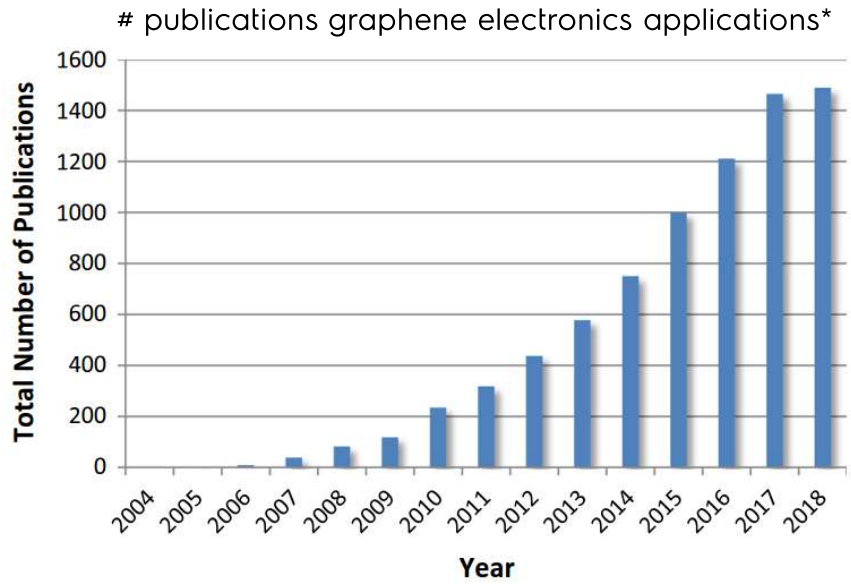
ELECTROLUX INNOVATION FACTORY

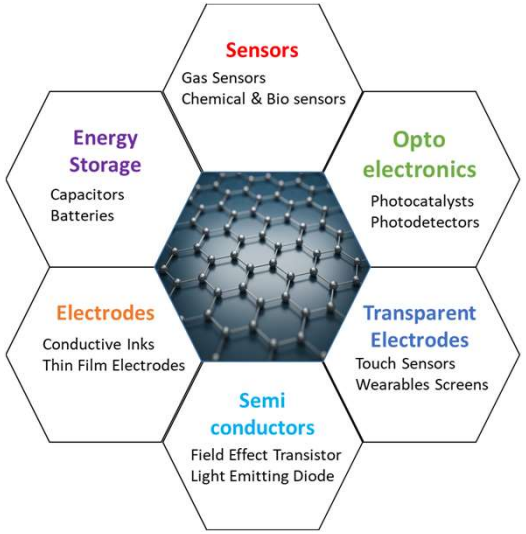
GOLEM functionalities



ELECTROLUX INNOVATION FACTORY

Graphene applications

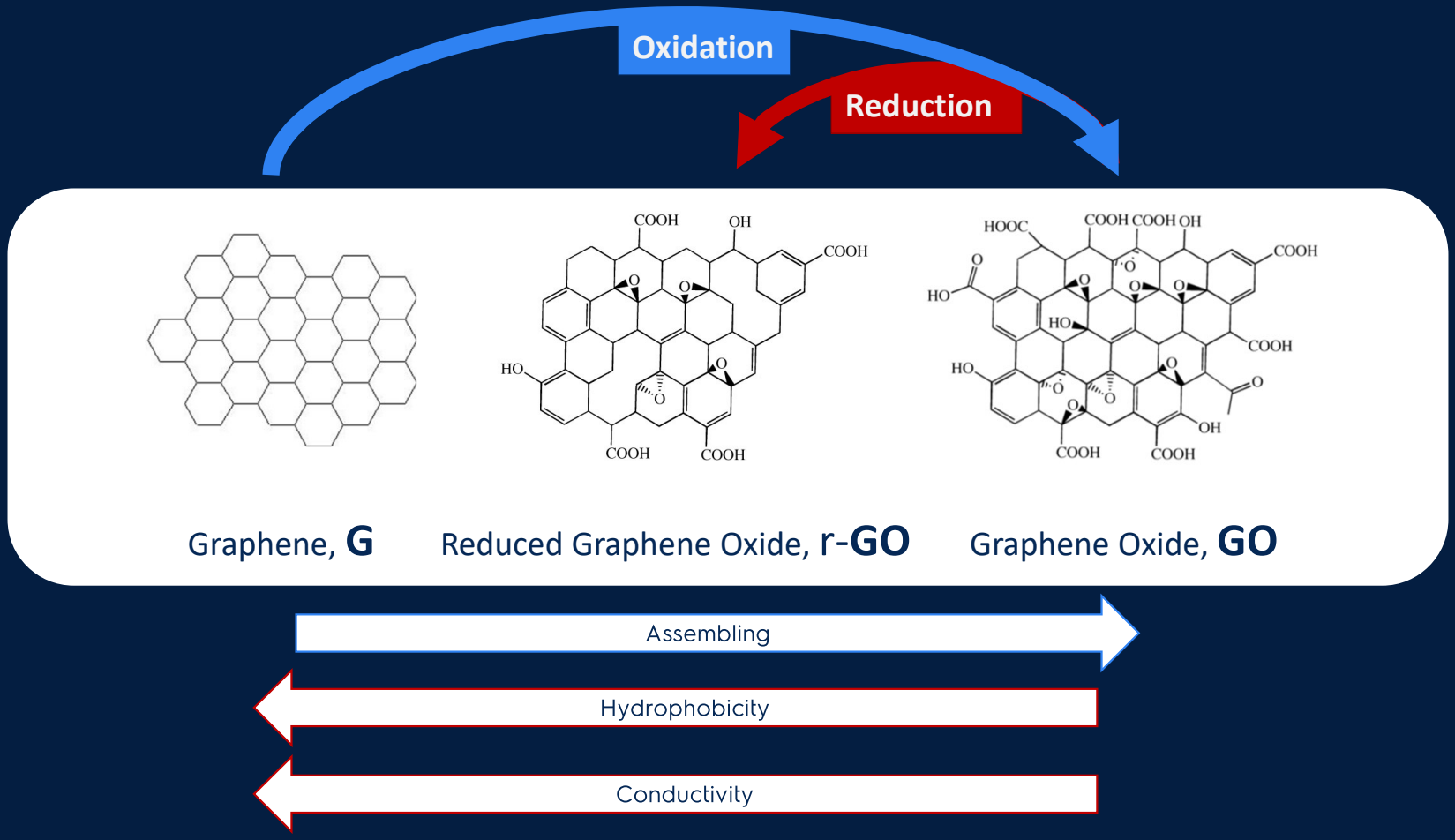




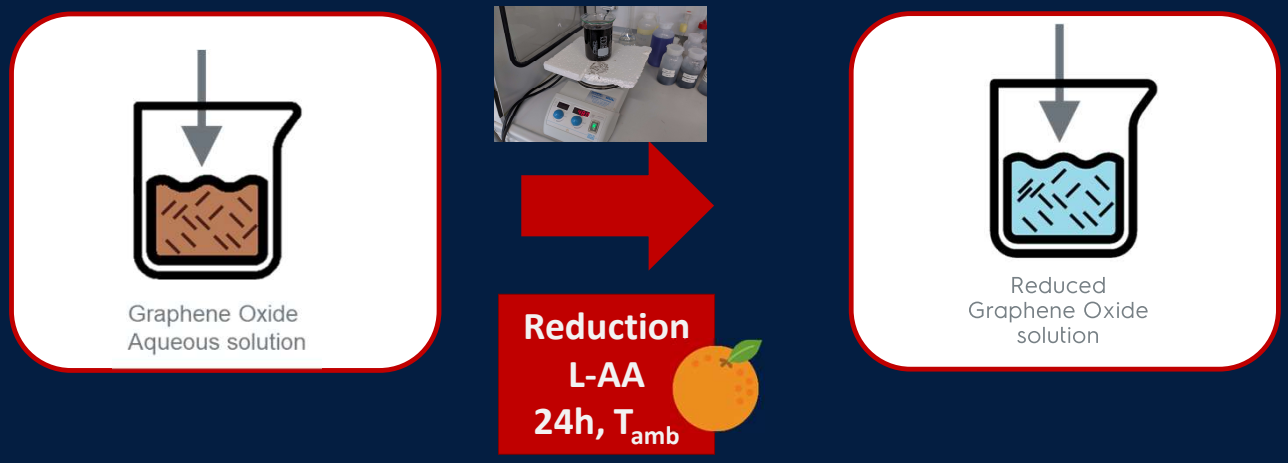
Graphene, and related materials, are in industrial and technological ramp-up phase.
According to the Graphene Flagship roadmap, by 2023 graphene-based sensors will be more affordable.

*Zhu et al, 2020

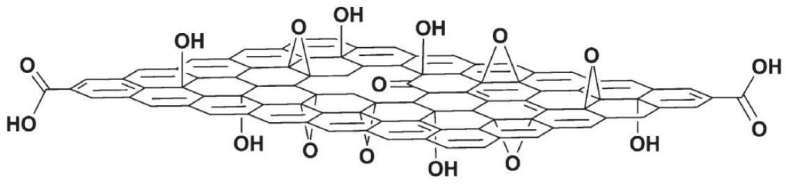
Graphene Derivatives



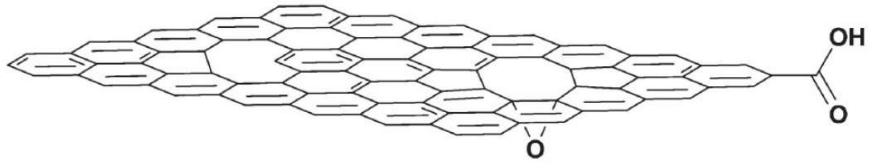
r-GO production by acid ascorbic reduction *



Graphene Oxide (**GO**)

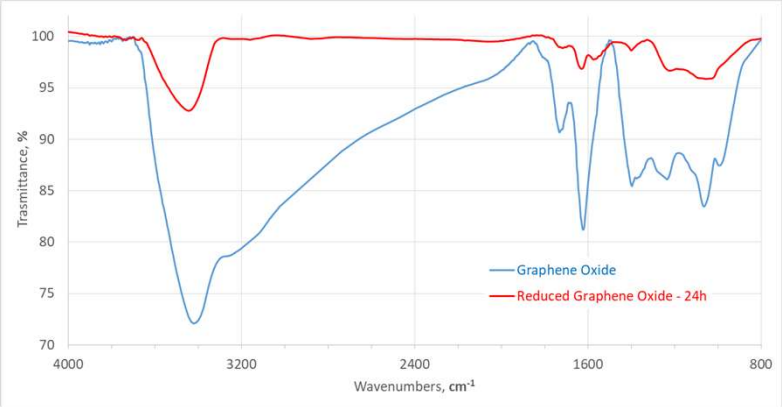


Reduced Graphene Oxide (**rGO**)



* Migliavacca et al., 2017

r-GO production by acid ascorbic reduction - results



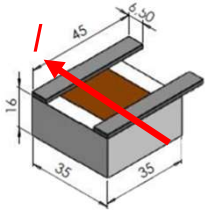
Characterization: FTIR Spectroscopy

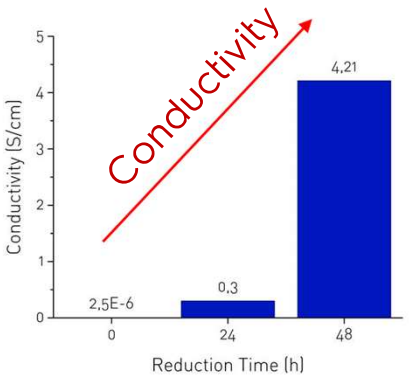
Restoring of graphene - like structure after reduction by ascorbic acid

Chemical POV

Characterization: Electrochemical Impedance Spectroscopy

Restoring of conductivity passing to reduced graphene oxide





"Electrical" POV

GOLEM functionalities

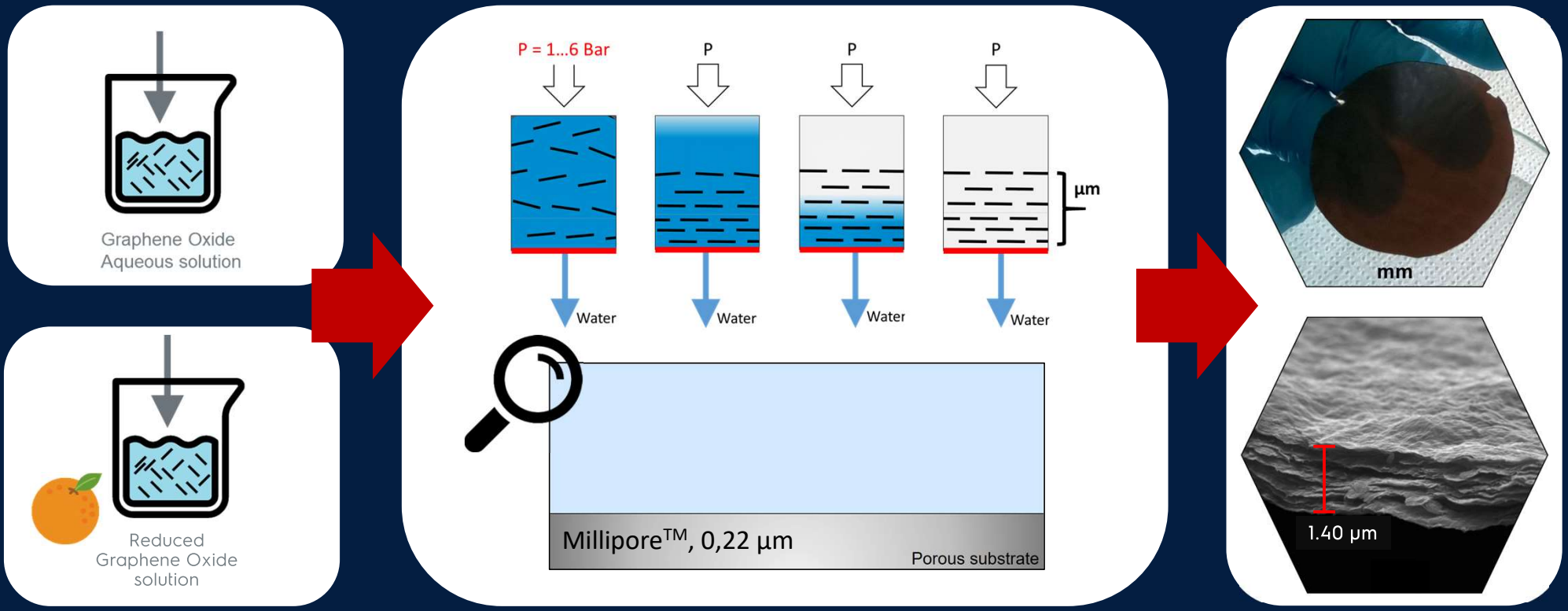
GRAPHENE
OXIDE
FILTERING
SENSING
MEMBRANES

Filtering
functionality

Sensing
functionality

ELECTROLUX INNOVATION FACTORY

Graphene based Membranes Production



GOLEM functionalities

ELECTROLUX INNOVATION FACTORY

GOLEM functionalities

GOLEM functionalities

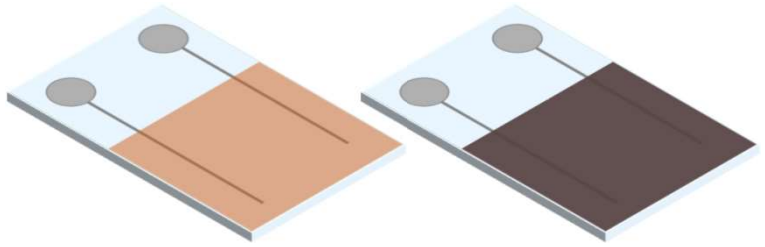
Filtering
functionality

Sensing
functionality

ELECTROLUX INNOVATION FACTORY

Sensing Functionality

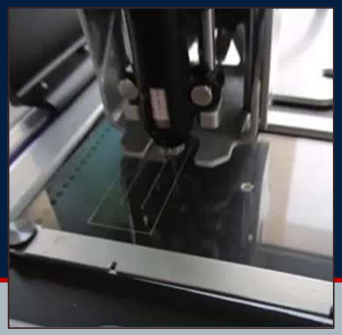
Goal ► test the electrical behavior of a **graphene-based** sensor when exposed to the target

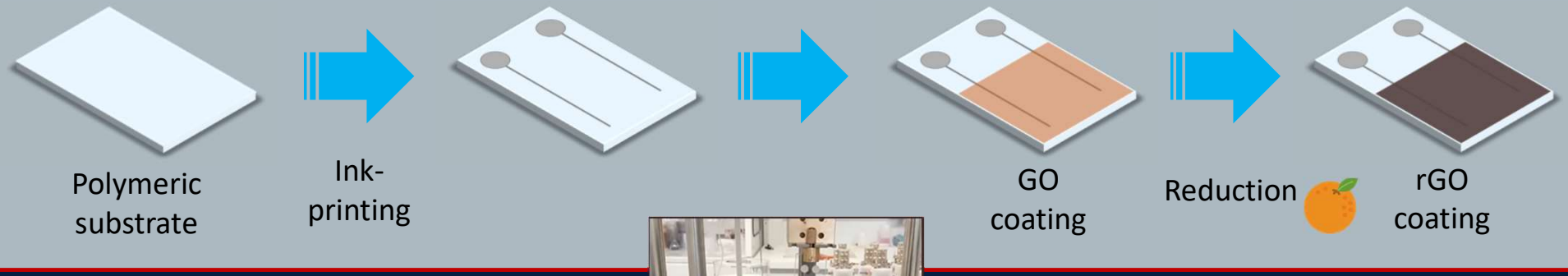


Graphene oxide
GO

Reduced
Graphene oxide
rGO

Graphene-based sensor production





Sensing Functionality

Characterization: Electrochemical Impedance Spectroscopy, **EIS**

Test parameters

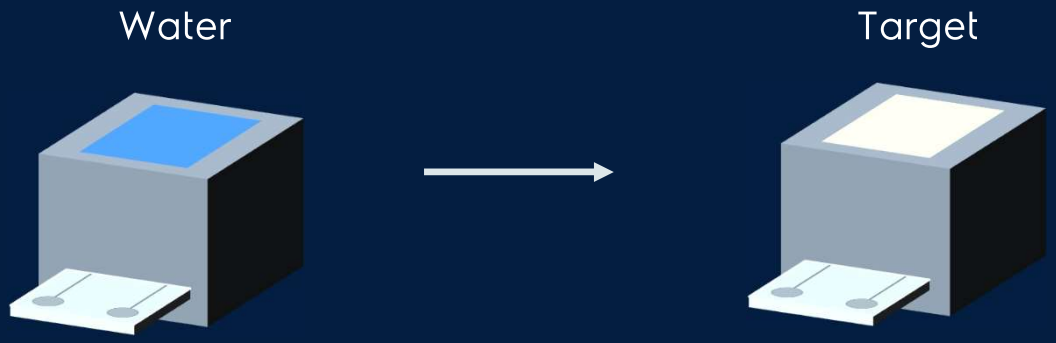
Tension, V = 1 V

Frequency, f = 200 Hz – 2 MHz

Water Characteristics

pH = 5

Conductivity = 767 µS/cm

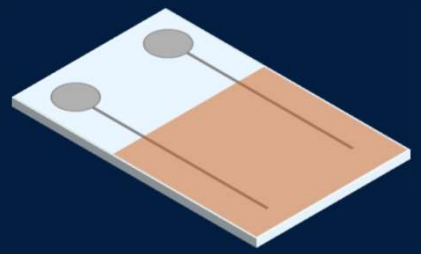


Test Description

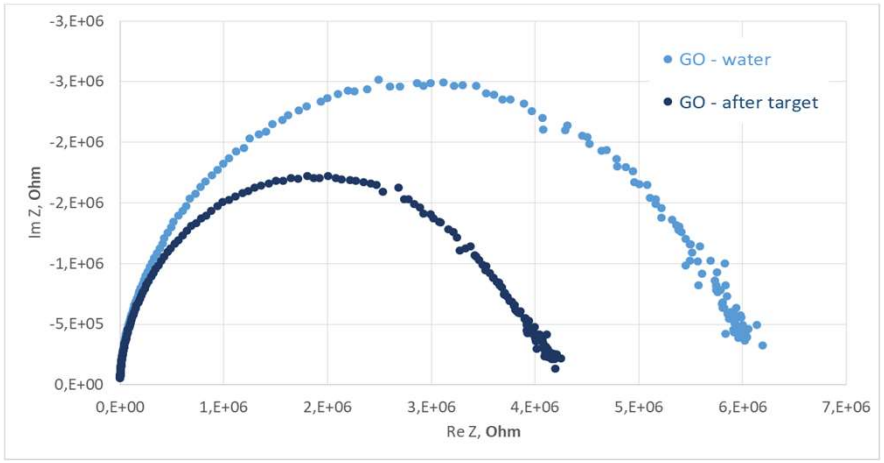
Bode diagrams on 10 ml of water → Removing 5 ml of water → Pouring 5 ml of target water → Bode diagrams on 10 ml of target water

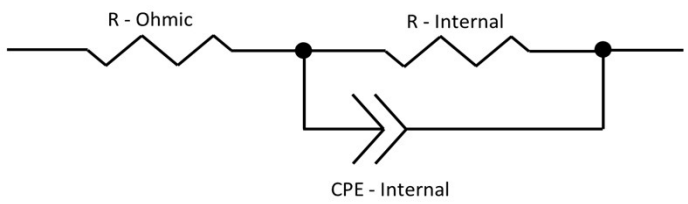
Sensing Functionality

Characterization: Electrochemical Impedance Spectroscopy, EIS



GO sensor





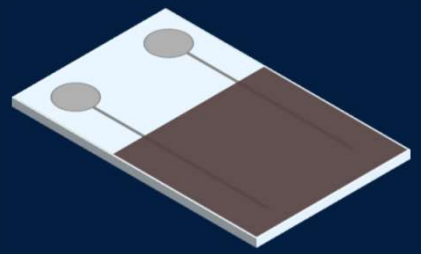
Water — R-internal = 6,1 MΩ

After Target — R-internal = 4,2 MΩ

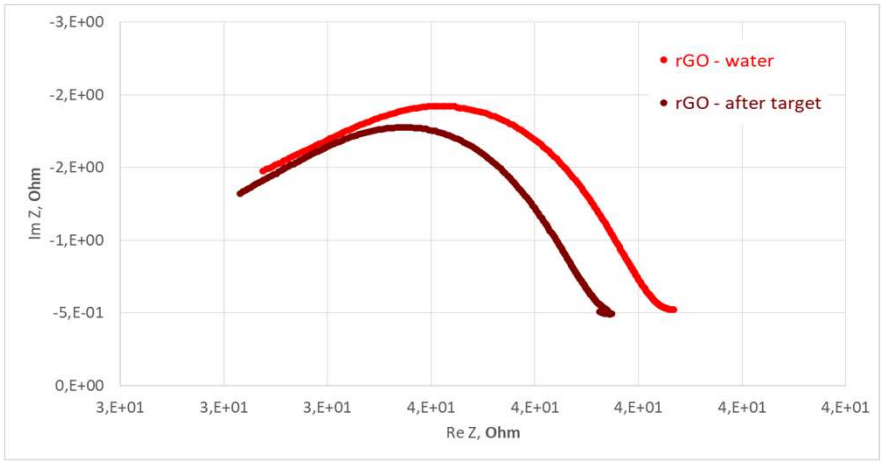
Real time response to target

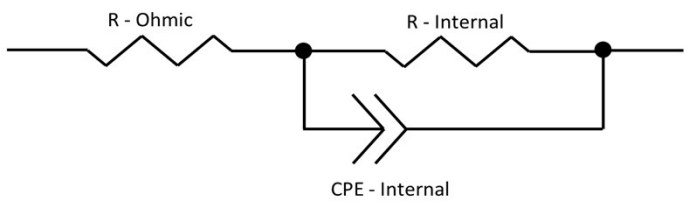
Sensing Functionality

Characterization: Electrochemical Impedance Spectroscopy, EIS



rGO sensor





Water — R-internal = 13 Ω

After Target — R-internal = 11 Ω

Real time response to target

Concluding remarks and envisaged developments

Graphene technology

- Graphene-based sensors is an emerging technology
- A graphene-based membrane can be the base for a system able to filter and sense
- The ductility of graphene and related materials will allow modular solutions in appliance

ROLD I R-Lab I Alessandro Migliavacca

- Nanostructured sensors for water and air quality are a promising technology for smart, integrated home appliances at acceptable costs for the user
- Move to cognition via integration of heterogeneous intelligent devices into a distributed architecture

ELECTROLUX I GTO I SENSORS & AI I Cristina Bertoni