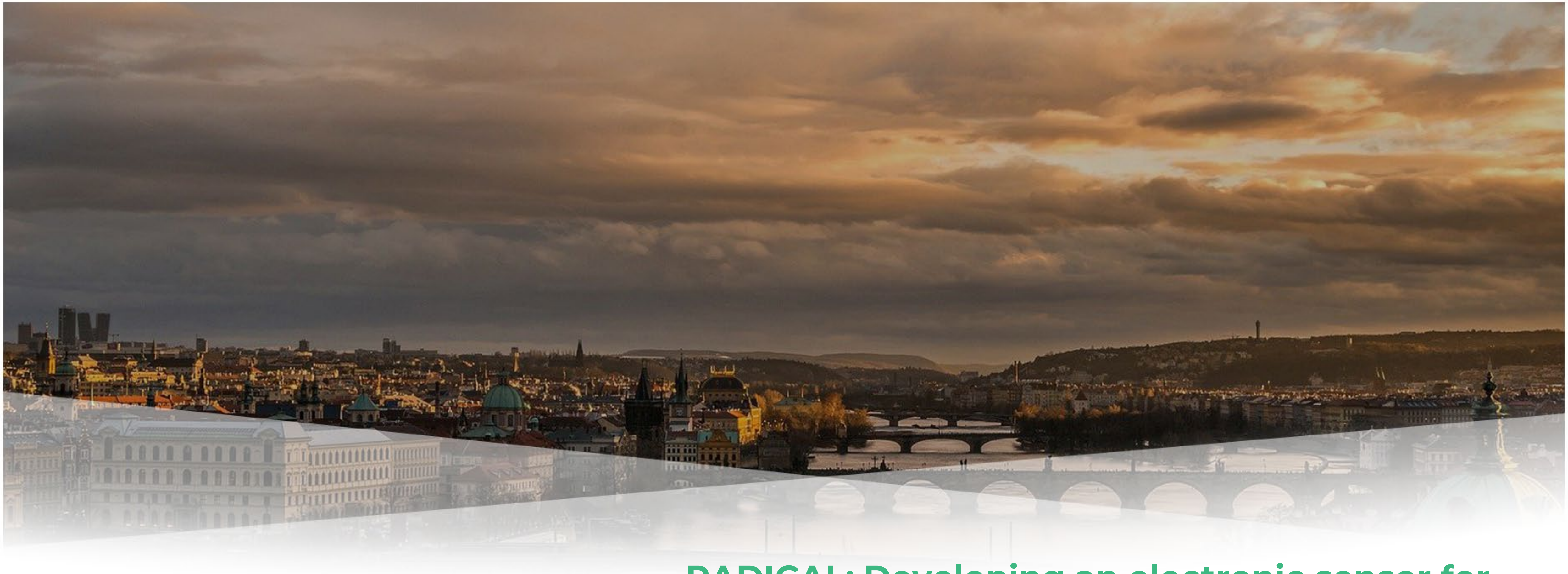

RADICAL: Developing an electronic sensor for detecting atmospheric radicals and gases

Vaishali Vardhan, Subhajit Biswas,
Stig Hellebust, John Wenger, Justin Holmes

University College Cork, Ireland

The RADICAL project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 899282.

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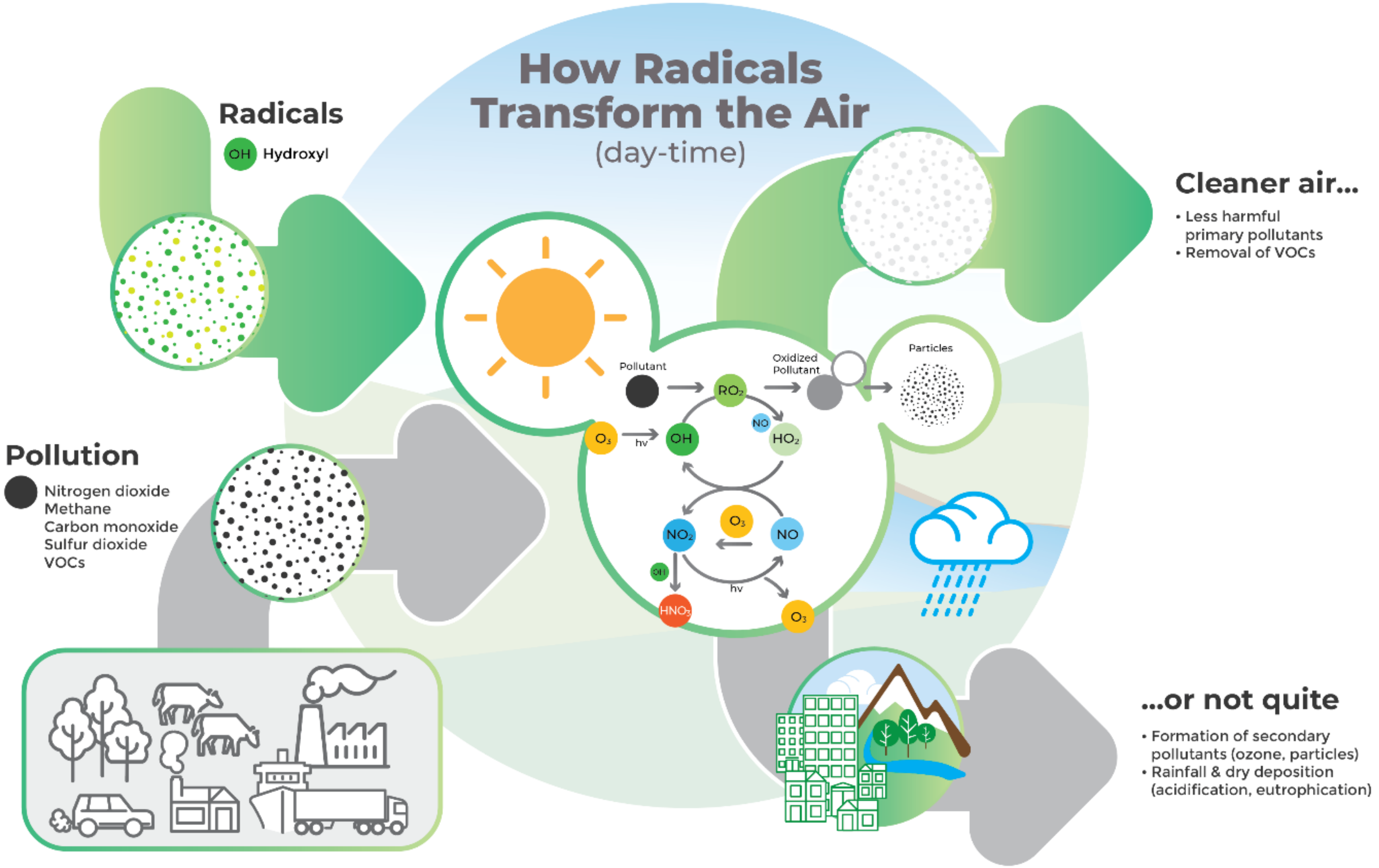
RADICAL

Developing an electronic sensor for detecting short-lived atmospheric radicals and other gases

John Wenger
University College Cork

Role of radicals in air chemistry



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University College Cork

Challenge of detecting radicals

Challenges

- Low mixing ratios (pptv)
- Short lifetime (1 s for •OH)
- Surface losses during sampling

NOW

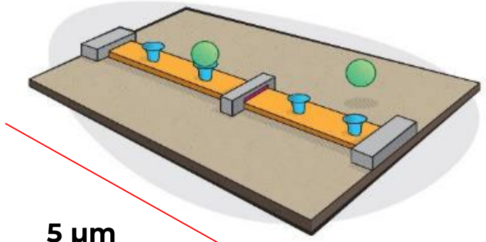
- Detecting radicals is complex, cumbersome and expensive
- Only a few labs worldwide can detect radicals

FUTURE

- Breakthrough way of radical detection:
  - Detection on a **silicon chip**
  - Smart **electronic** sensors
  - Easy to use and **cheap** to produce
  - Potential for **widescale deployment**

5 m

Future?



5 μm

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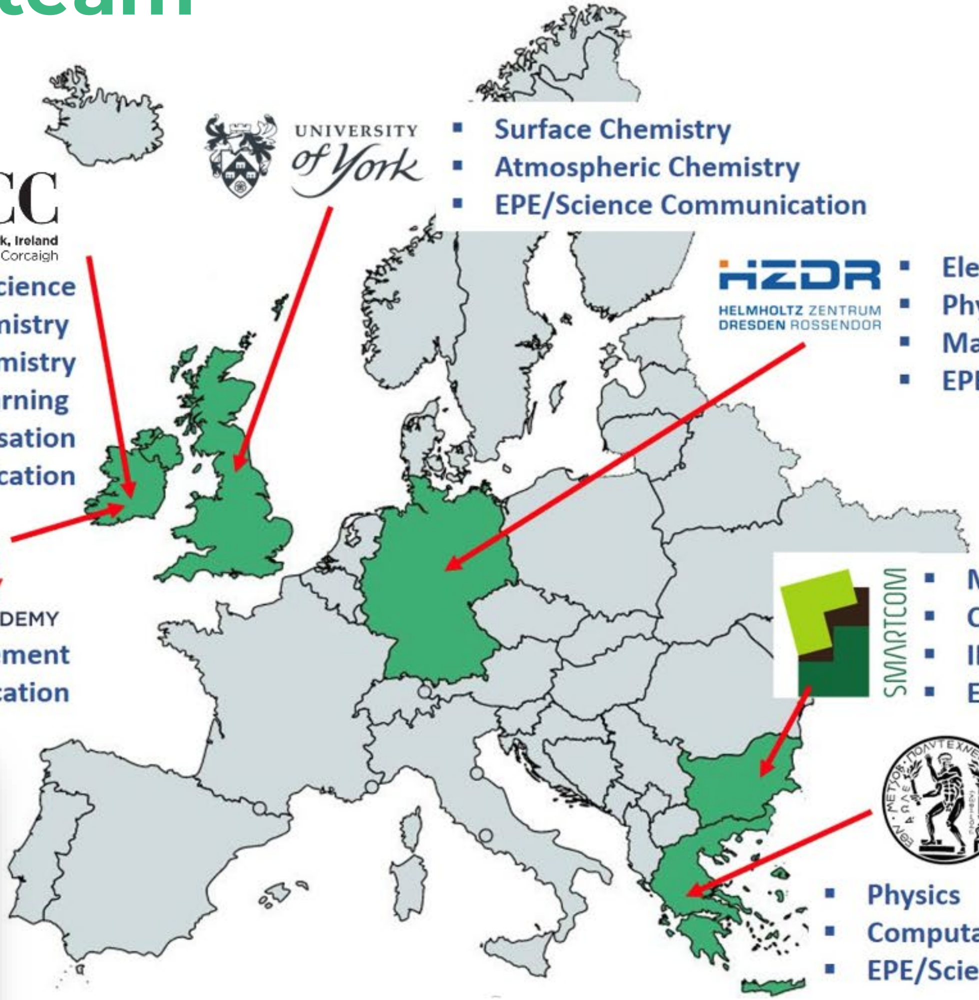
The RADICAL team



UCC
University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

- Materials Science
- Surface Chemistry
- Atmospheric Chemistry
- Machine Learning
- IP Management/Commercialisation
- EPE/Science Communication

UNIVERSITY of York

- Surface Chemistry
- Atmospheric Chemistry
- EPE/Science Communication

HZDR
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

- Electrical Engineering
- Physics
- Materials Science
- EPE/Science Communication

UCC ACADEMY

- Project Management
- Communication

SMARTCOM

- Microelectronics
- Computational modelling
- IP Management/Commercialisation
- EPE/Science Communication

- Physics
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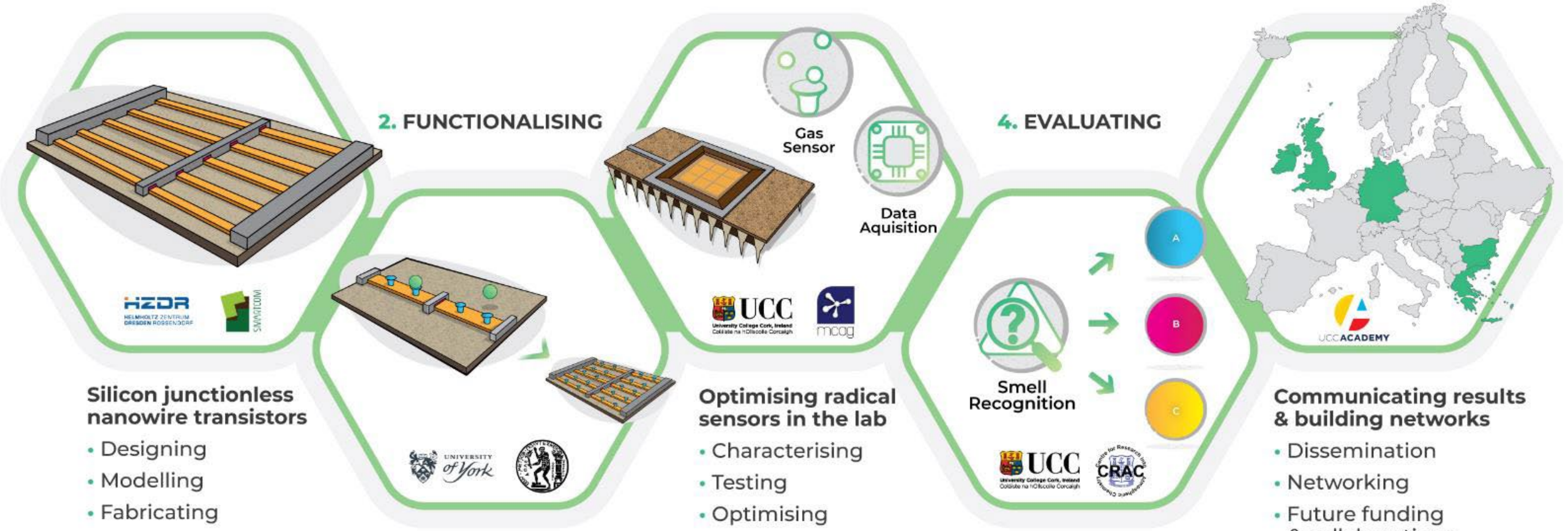

1. FABRICATING

Silicon junctionless nanowire transistors

- Designing
- Modelling
- Fabricating

2. FUNCTIONALISING

Organic layer to trap atmospheric radicals

- Simulating
- Testing

3. OPTIMISING

Optimising radical sensors in the lab

- Characterising
- Testing
- Optimising

4. EVALUATING

Testing sensors in air

- Atmospheric chambers
- Outdoors

5. SHARING

Communicating results & building networks

- Dissemination
- Networking
- Future funding & collaborations

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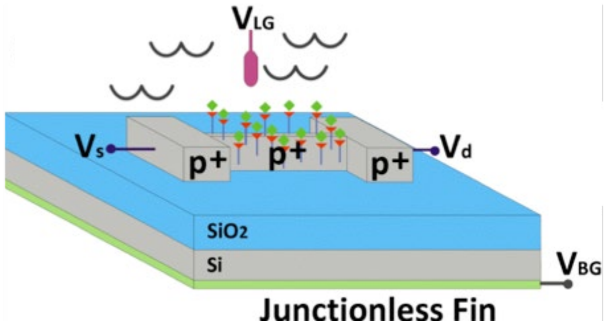
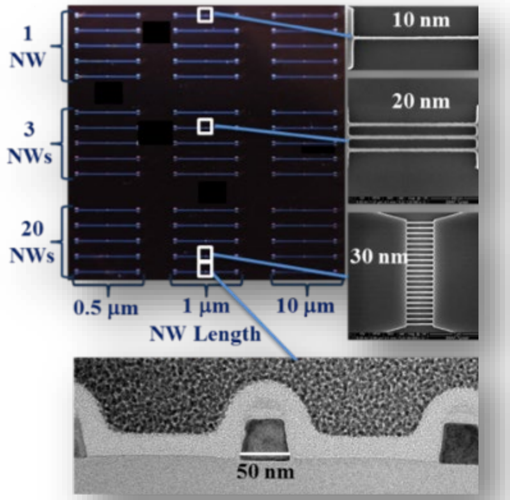
Sensing with Silicon Nanowire Transistors (JNTs)

Previously: Si NW JNTs to detect proteins in liquids





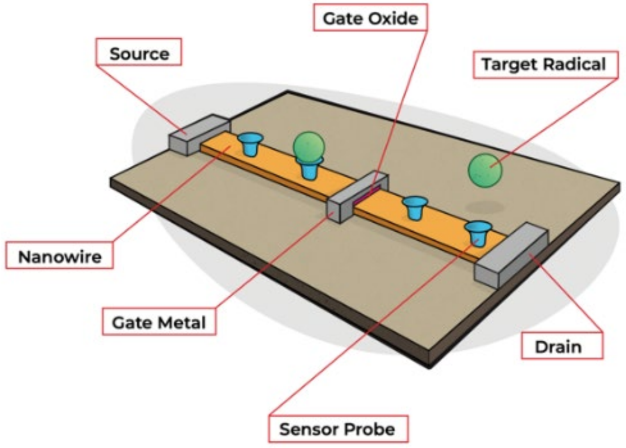
Streptavidin:

- 580 zM (580 × 10^{-21} M)
- Approaching single molecule detection

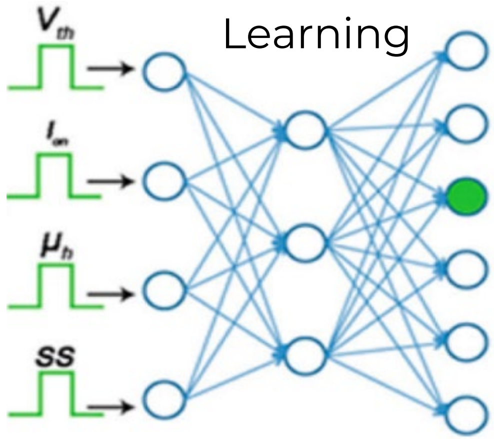
Y. M. Georgiev *et. al.*, *Nanotech.*, **2019**, *30*, 324001.

Goal: Gas phase detection of radicals

Arrays of Sensors



Machine Learning



Parameters

Detection

B. Wang *et. al.*, *Nano Letts.*, **2014**, *14*, 933.

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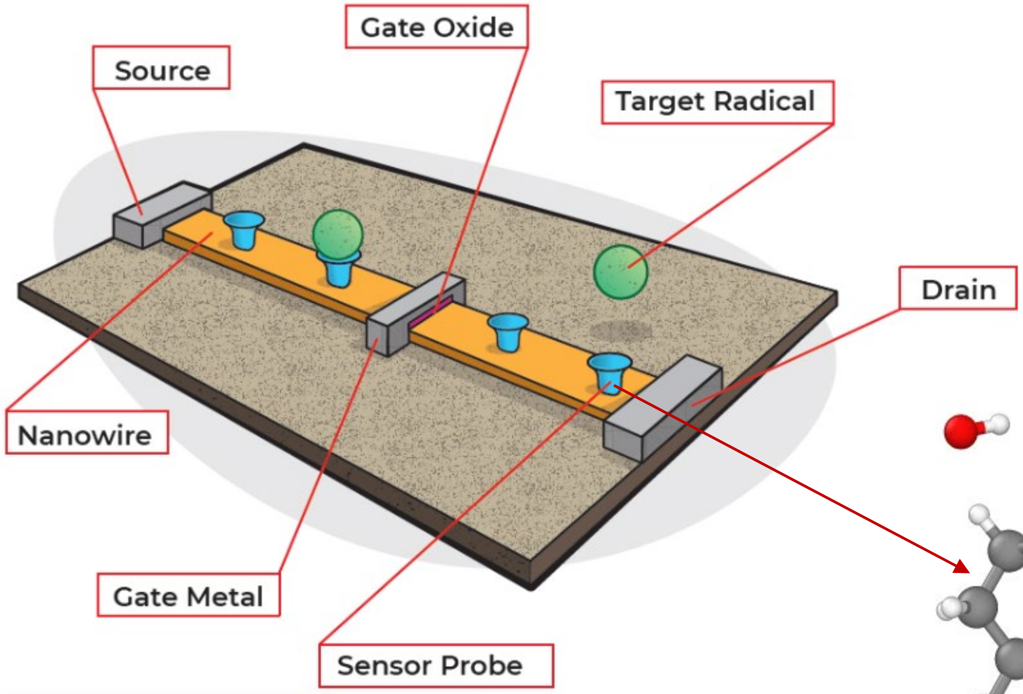
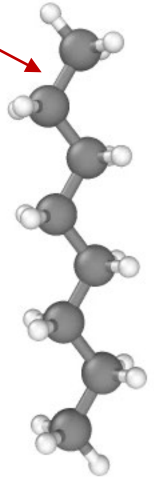
The Radical sensor

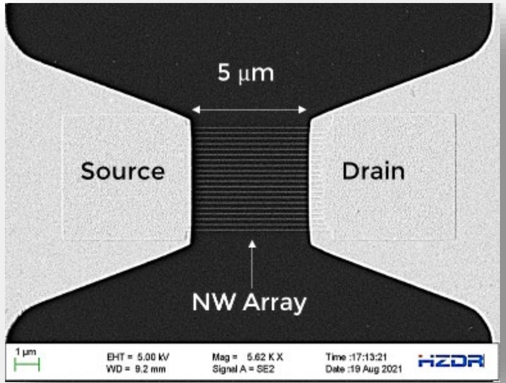
- **Si Nanowire junctionless transistor** (JNT) sensor platform
- Organic coating: to **selectively** trap radicals
- Theoretically guided **surface functionalisation** – reactions of •OH, •NO_3, O_3 with alkanes, alkenes *etc.*
- Measurement of **a change in the JNT parameters** upon radical interaction
- Sensor tests in atmospheric chambers





•OH radical with alkanes

Dipole change ~Δμ = 0.47 D



J. P. Colinge *et. al.*, *Nature Nanotech.*, **2010**, *5*, 225.

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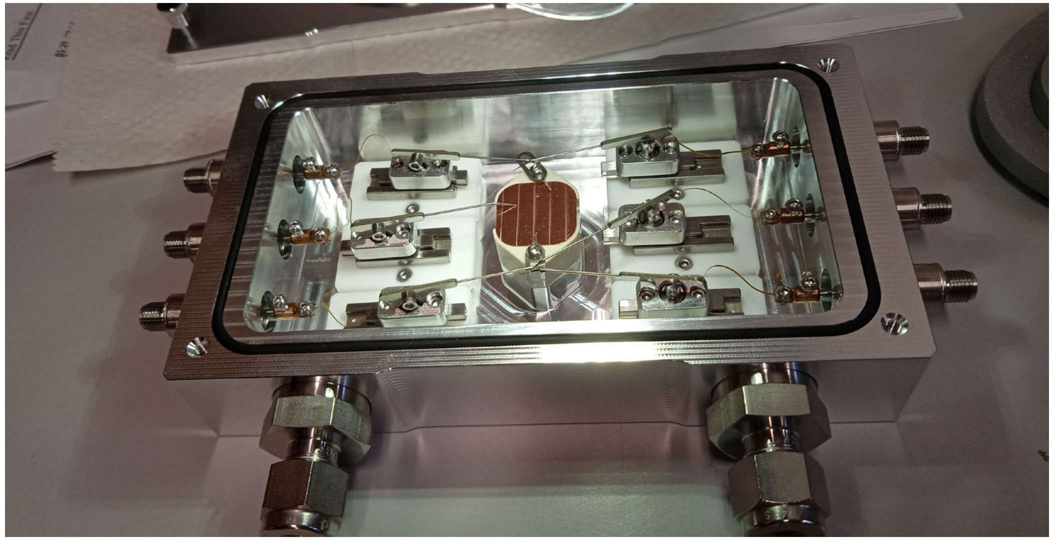
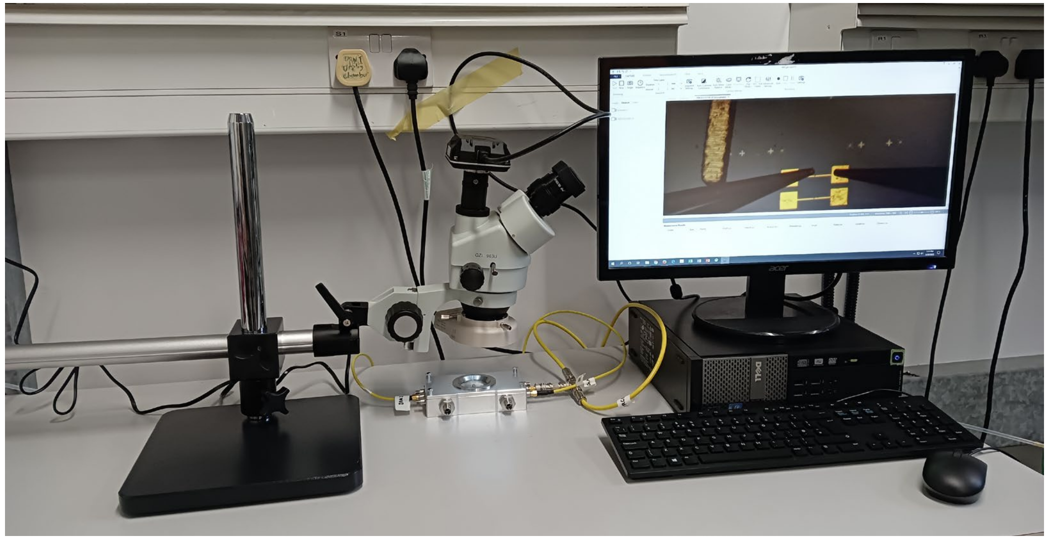
Sensor testing in the microprobe station

- 100 cm^3 volume, gas flows in and out
- 6 probes for two sensor devices without any wiring or mounting
- Small glass window for UV-light
- Temperature and humidity sensor
- Connected with Optical microscope and electrical setup





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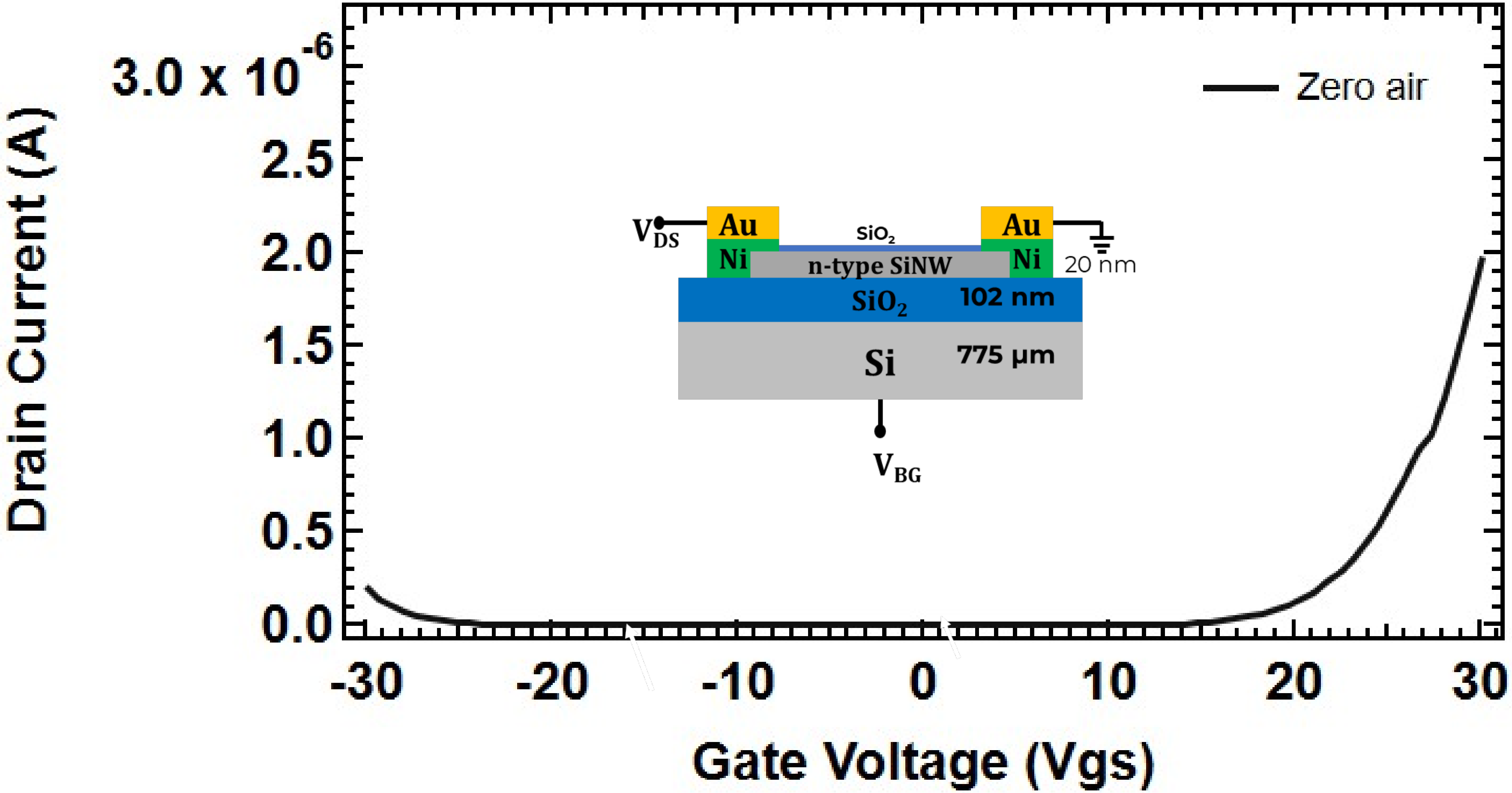
Sensor response to clean air



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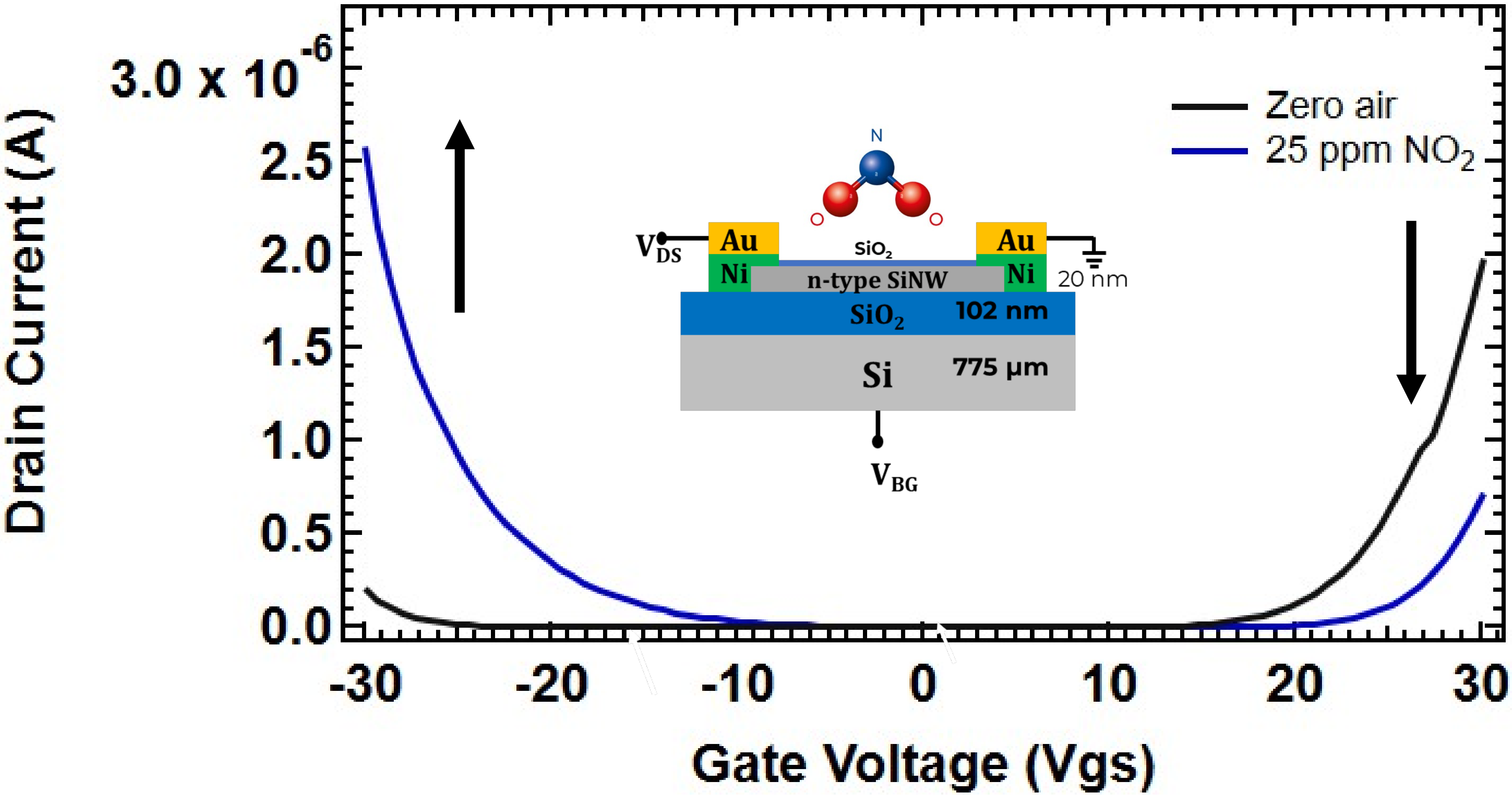
Detection of NO_2

- Change in current on both p- and n-side of the **ambipolar device** with NO_2 Si-JNT interaction.



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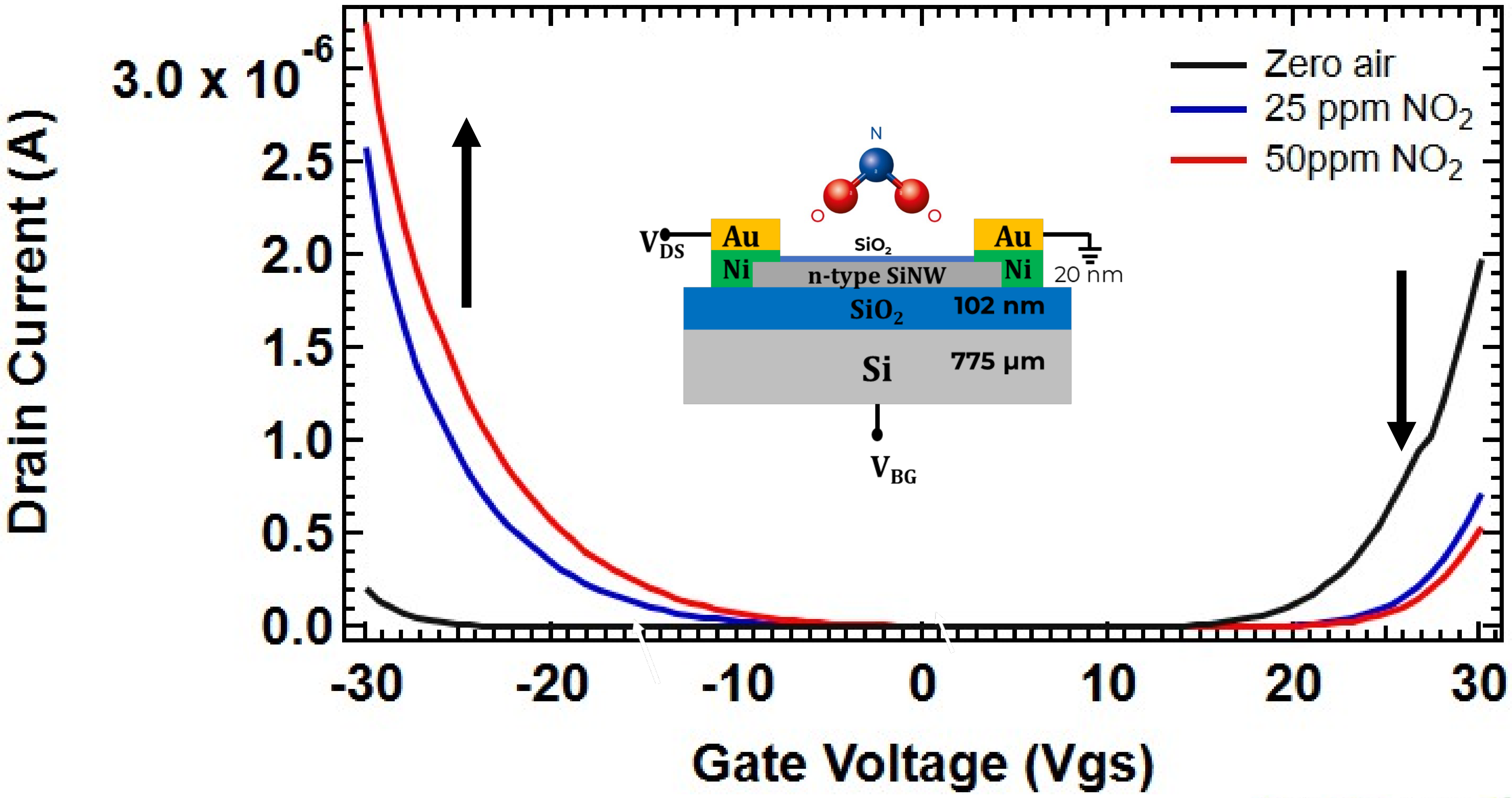

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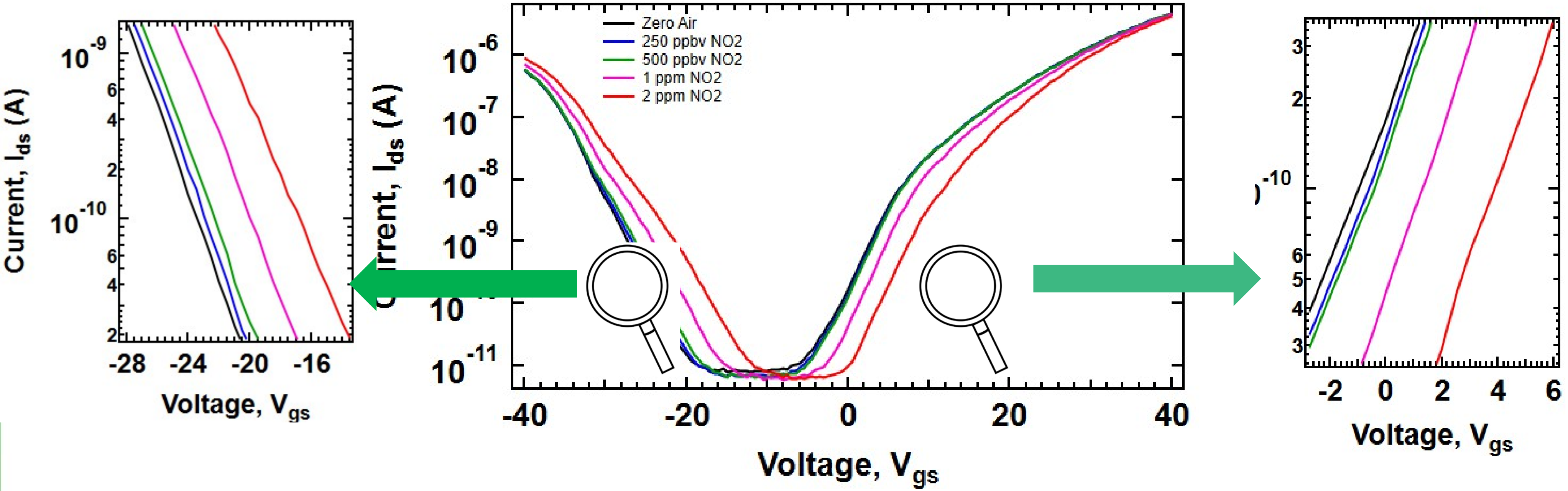
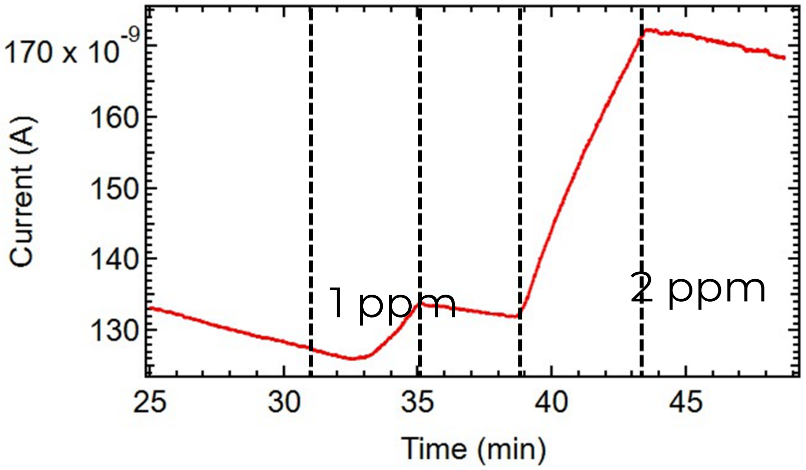
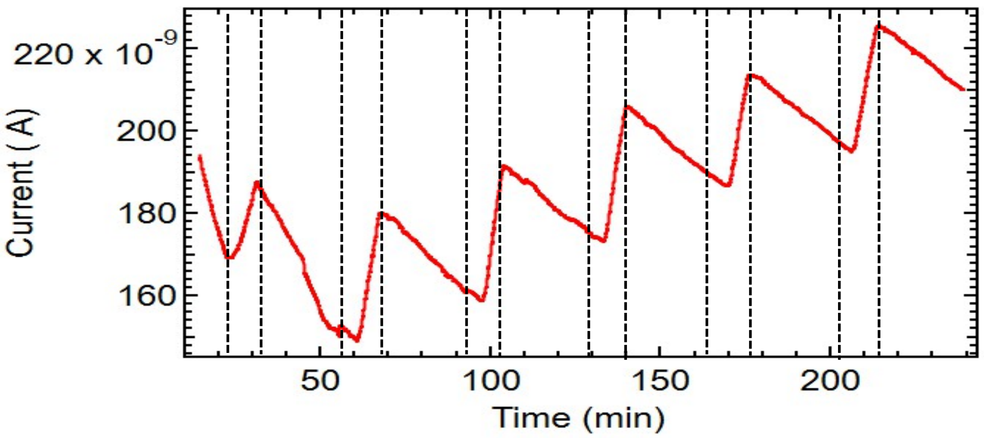
Si-JNT: Sensing NO_2 at sub-ppm level





- **Sensitivity** test: different NO_2 concentration at Vgs= -40 V, Vsd=1 V



Repeatability test: 1 ppm NO_2 on p-side at Vgs= -40 V, Vsd=1 V

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Variation of Si-JNT parameters with NO_2 exposure

On-current
Adsorption induced charge transfer

- **Threshold Voltage (Vth)**

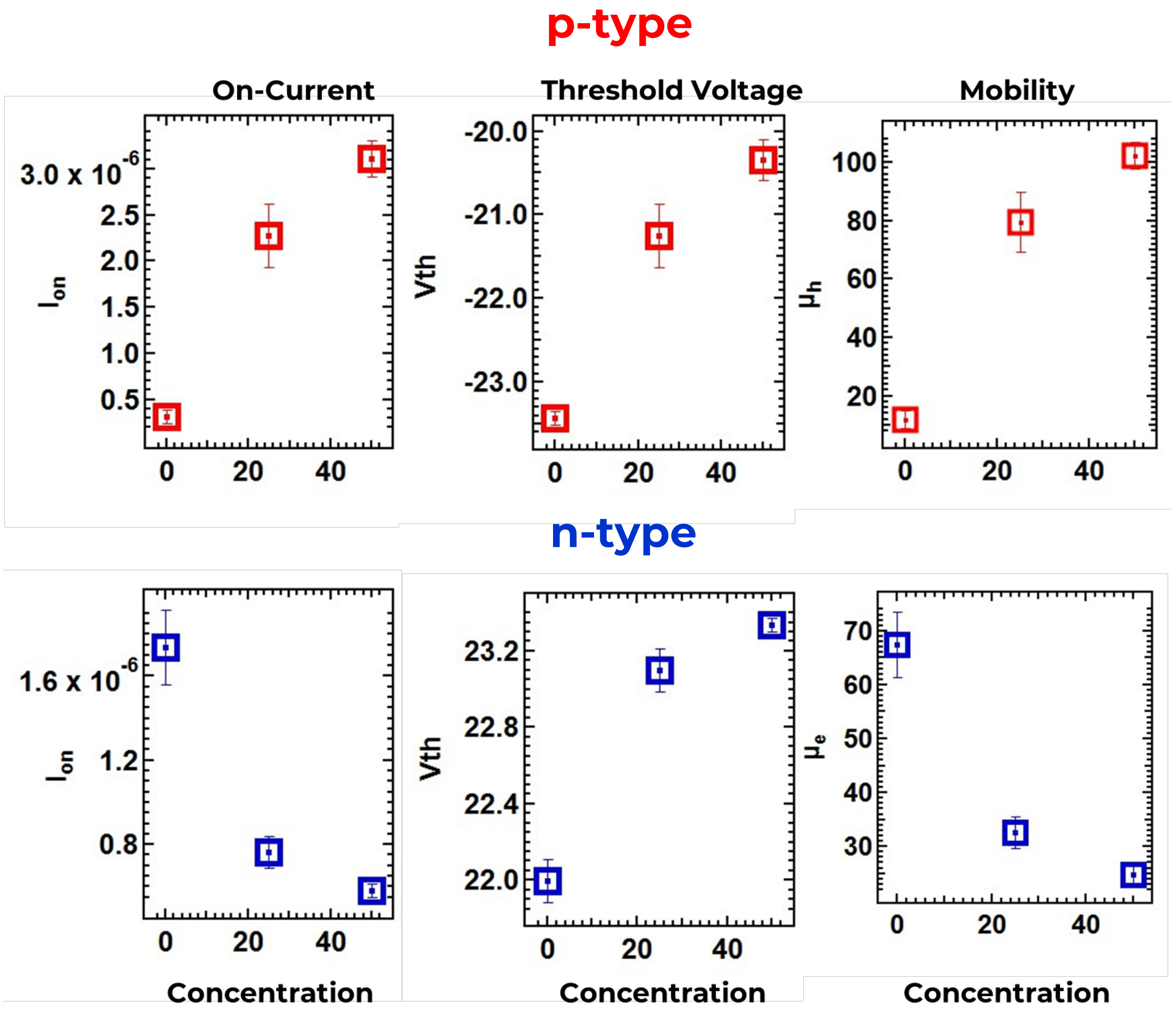
Voltage needed to switch the gate on for the p-conduction
=> Vth decreases with exposure

Due to electron deficiency at surface, more turn-on voltage needed for n-conduction
=> Vth increases with exposure

- **Mobility**

Pseudo passivation effect of Si NW by NO_2
=> μ_h increases with exposure

Surface accumulation of electron and resulted scattering effect for bulk electron conduction
=> μ_e decreases with exposure



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RAD:CAL

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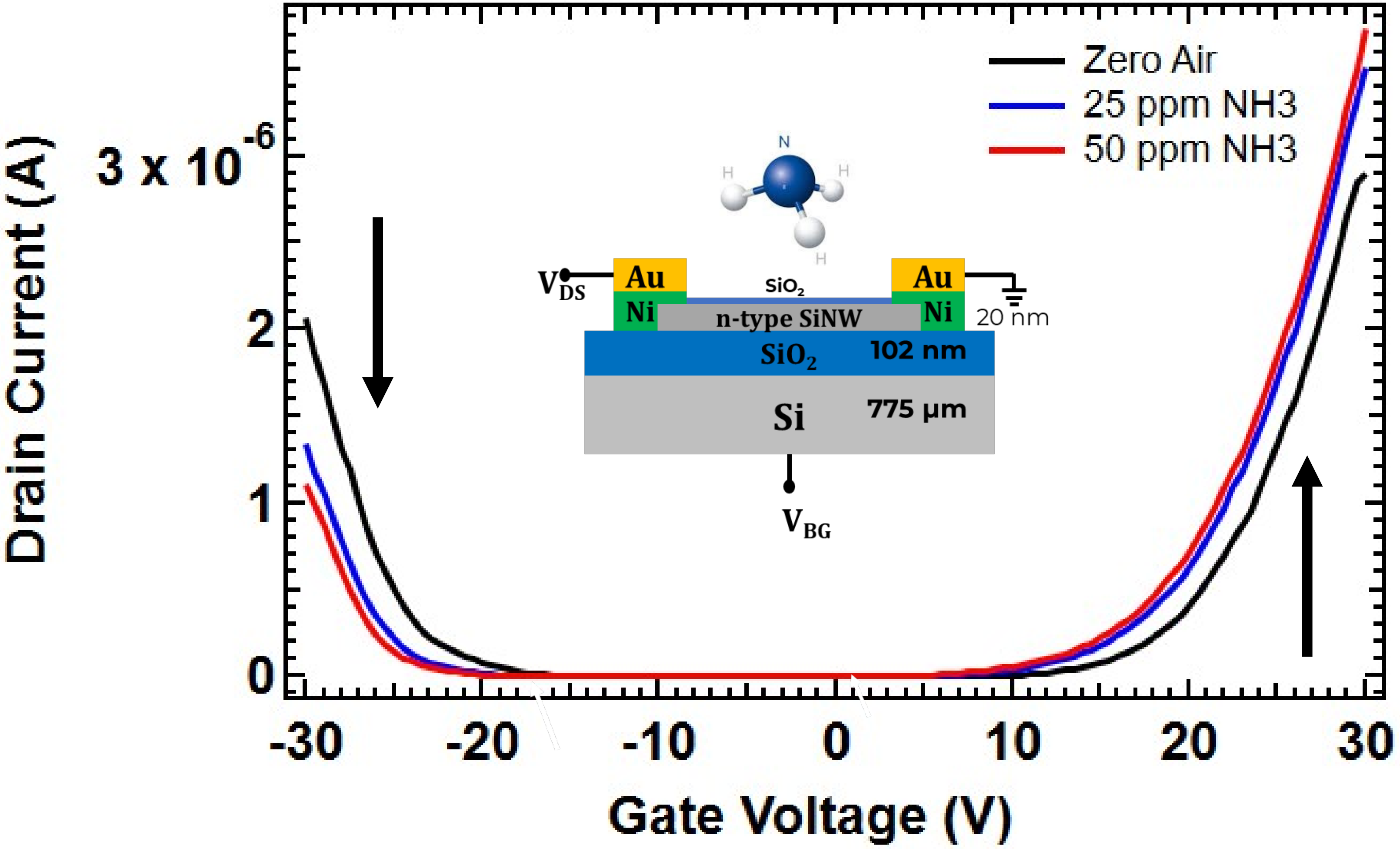
Detection of NH_3

- NH_3 interaction changes the current on both p- and n-side of the **ambipolar device** but in the opposite way to NO_2



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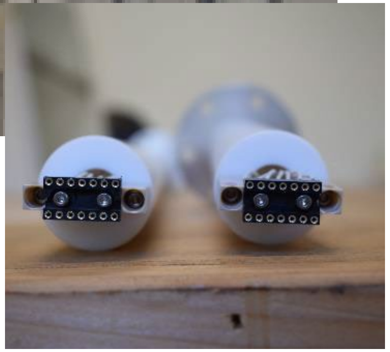
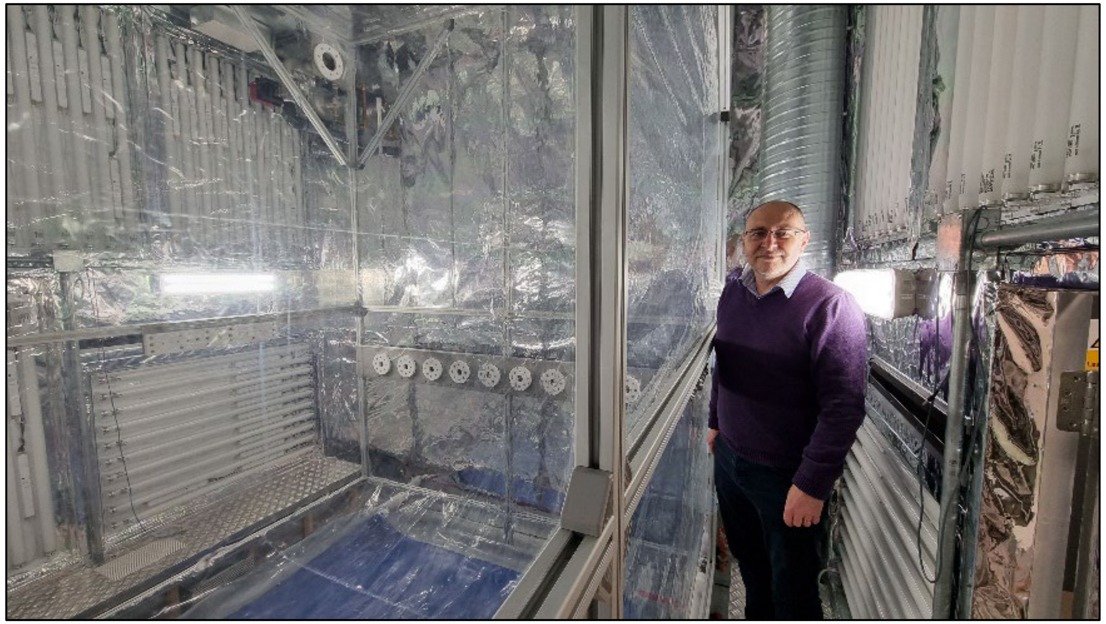
Summary and Next Steps

- Principle of **electrical detection** of gases by silicon nanowire JNTs demonstrated for NO_2, NH_3, SO_2, CH_4
- Modify size of wire, oxide coating etc. to **increase sensitivity**
- Add coating to **improve selectivity** towards OH radicals
- **Test devices** to detect gases and RADICALS under a variety of controlled conditions in an atmospheric simulation chamber





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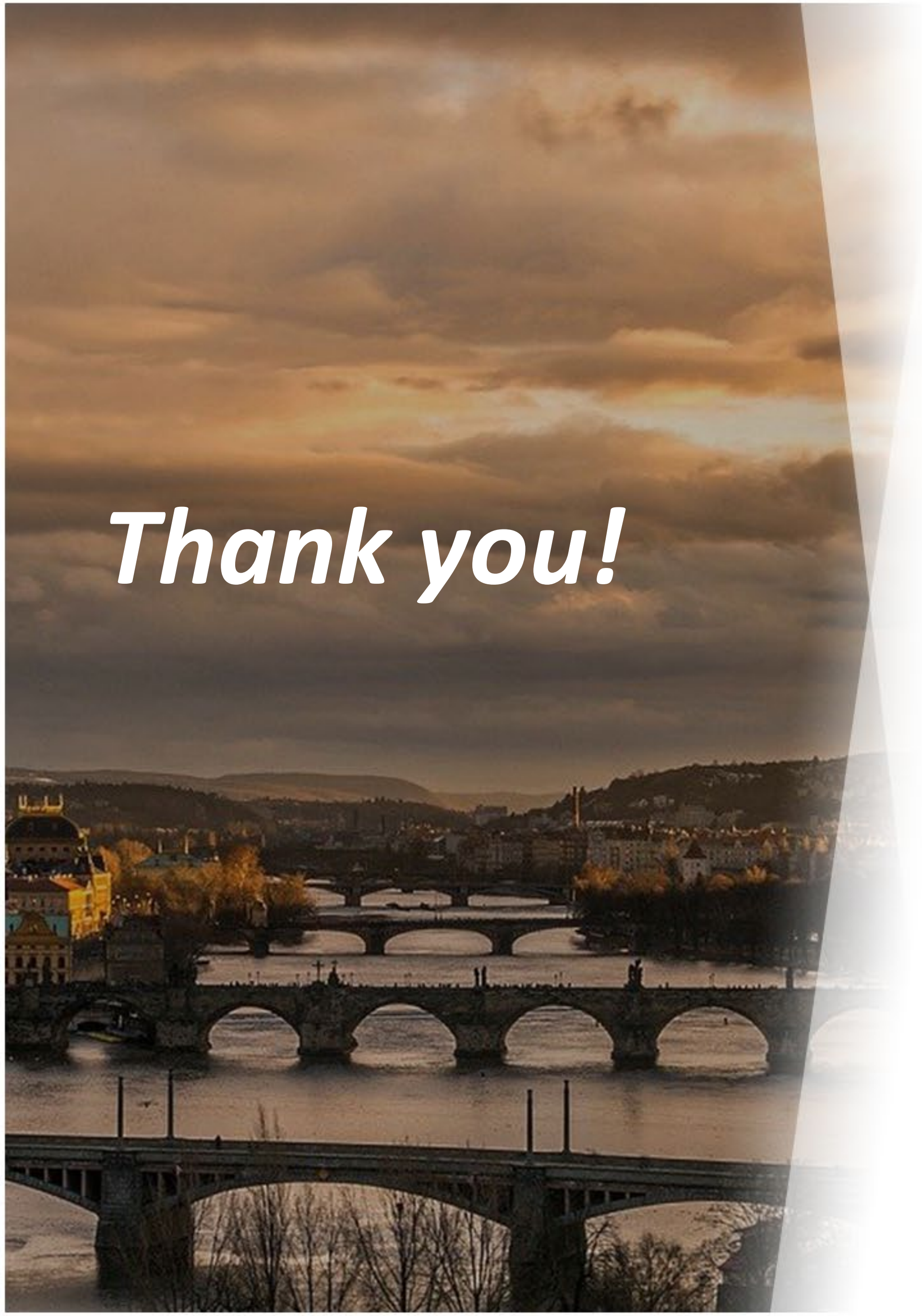

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