RADICAL

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

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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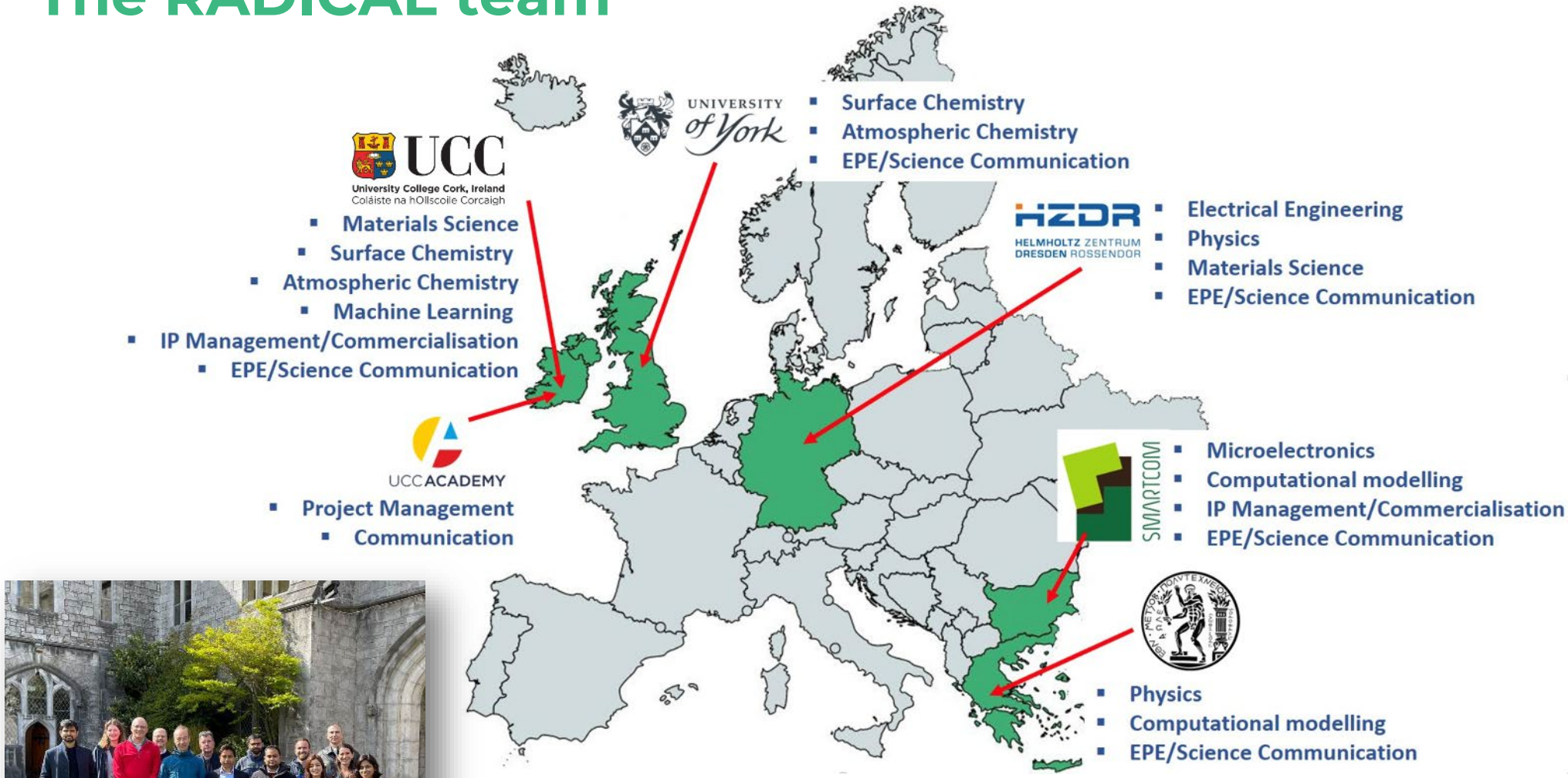
The RADICAL team



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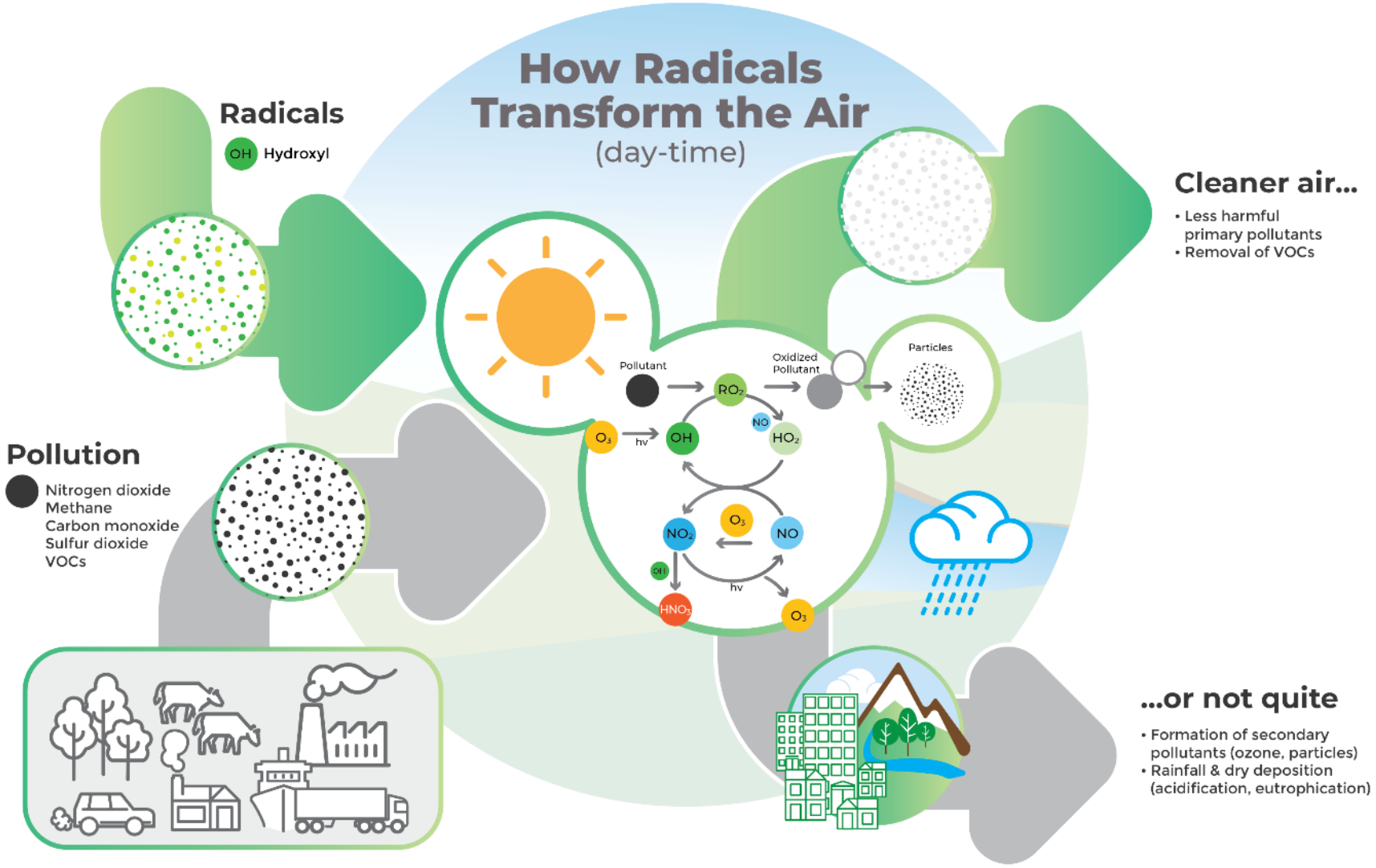
Role of radicals in air pollution



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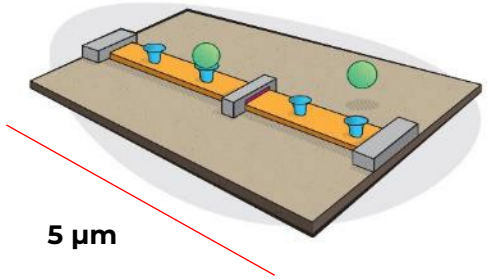
Challenge of detecting radicals

Challenges

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

1.5 m

Future?



5 µm

NOW

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

FUTURE

- Breakthrough way of radical detection:
  - Smart electronic sensors
  - Easy to use and cheap to produce
  - Potential for global deployment

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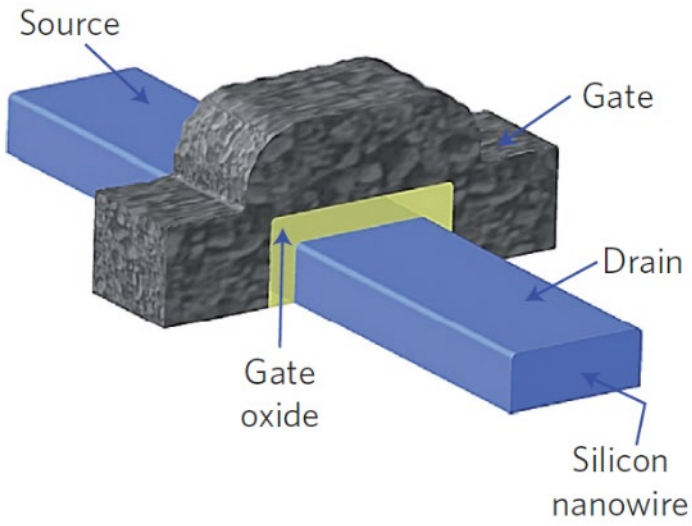
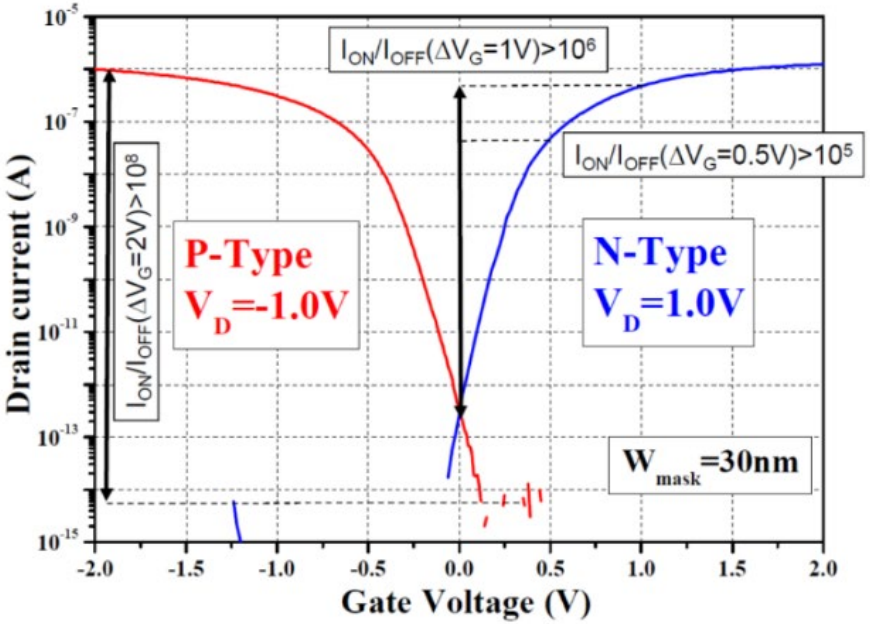
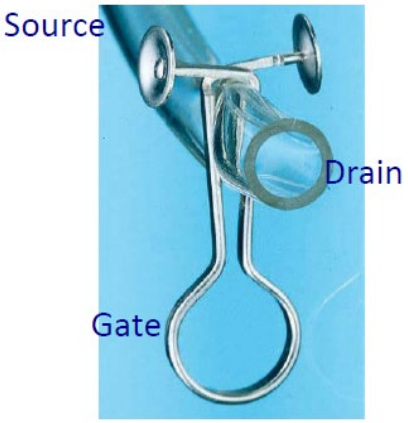
Si nanowire junctionless transistor (JNT)





Advantages

- No ultra-steep doping profile (no junctions)
  - Uniformly doped NWs (10^{18} to 10^{19} atoms/cm^3)
  - Resistor – mobile carrier density modulated by a gate
- Simplified fabrication process
  - CMOS compatible
  - Operate over a wide temperature range



Challenges

- Rely on gate electrostatics
- Leakage

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

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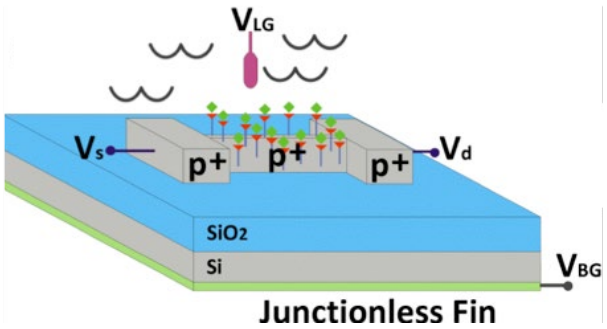
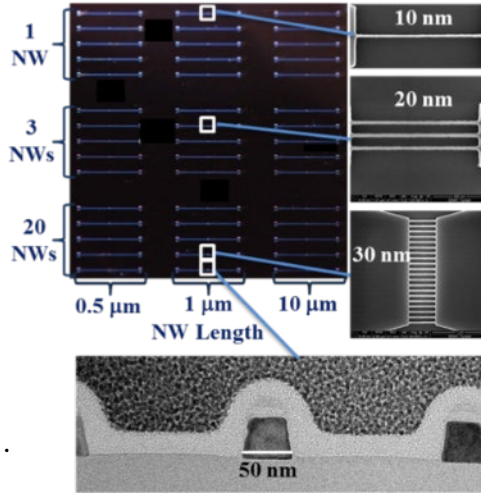
Sensing with Si NW JNTs

Previously: Si NW JNTs to detect proteins in liquids





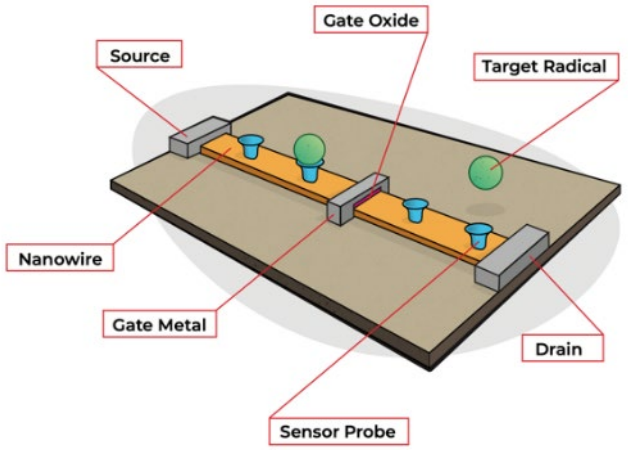
Y. M. Georgiev *et. al.*, *Nanotech.*, **2019**, *30*, 324001.

Streptavidin:

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

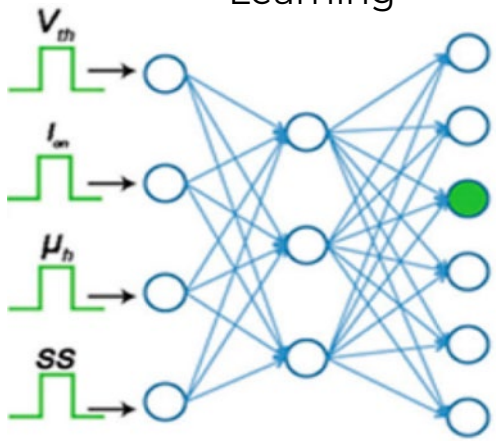
Goal: Gas phase detection of radicals

Arrays of Sensors



Parameters

Machine Learning



Detection

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

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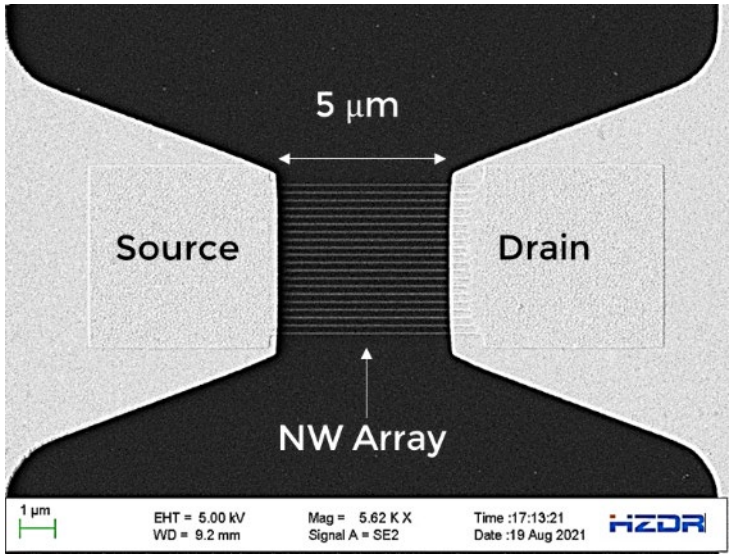
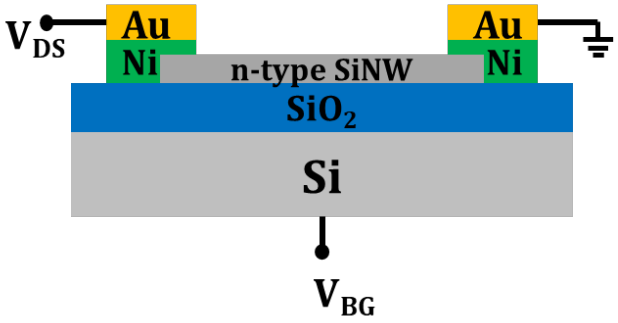
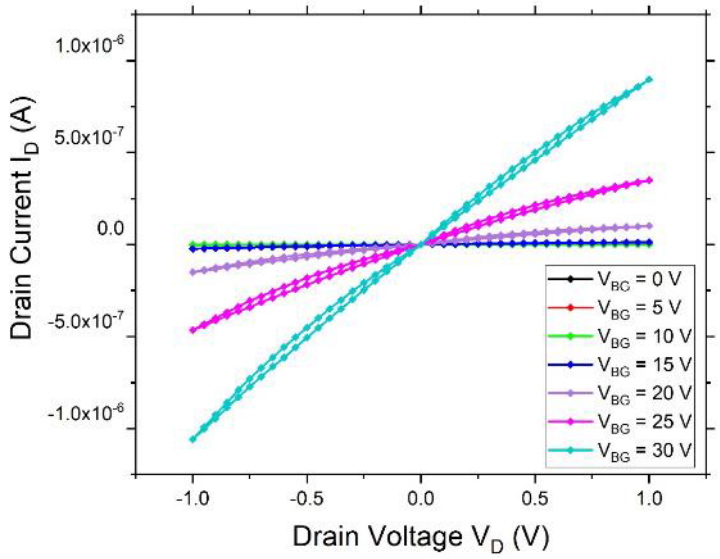
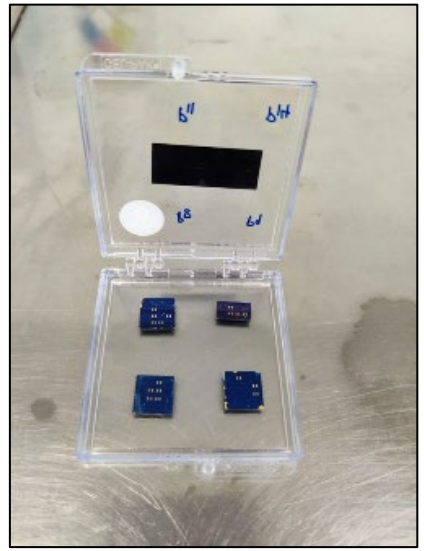
Initial Si NW JNT devices (back gated)





- NWs: ~20 nm wide, 5 µm length
- Contacts: Ni (40 nm) & Au (120 nm)





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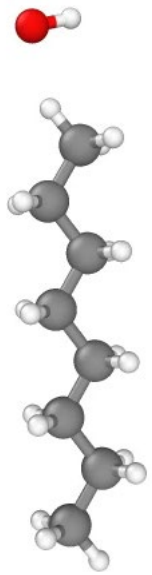
Theoretically guided surface functionalisation

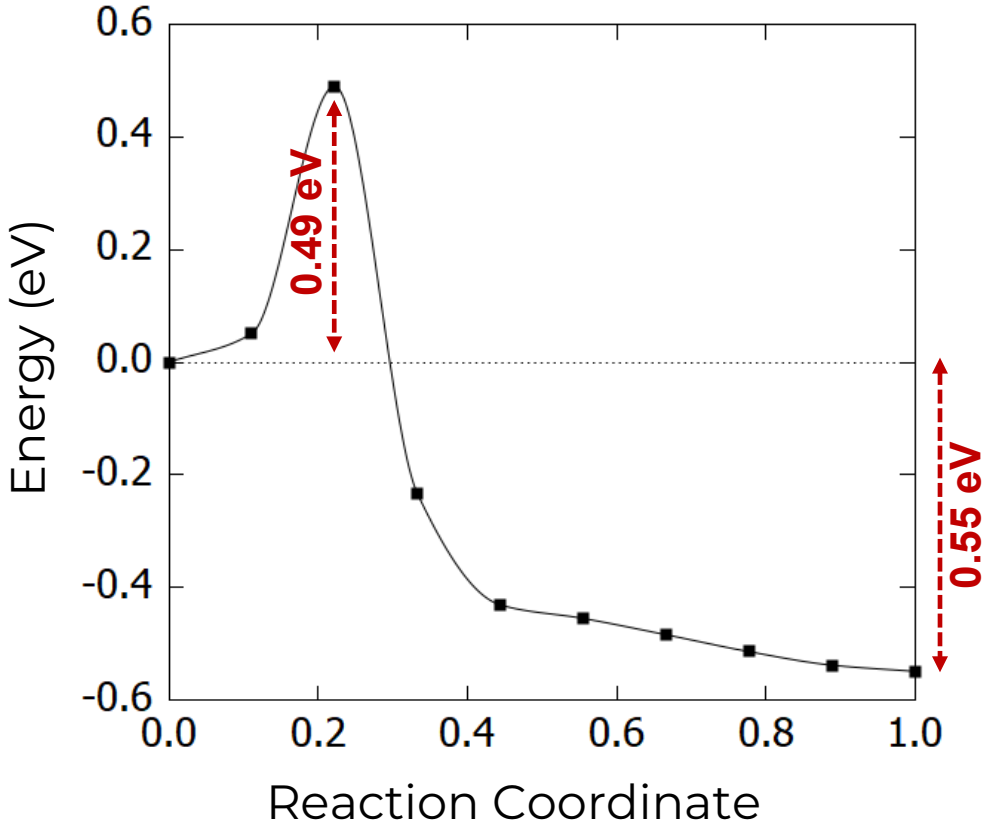
Hydrogen Abstraction



Dipole change ~Δμ = 0.47 D

Energy Barrier

Nudged Elastic Band Calculations



- Investigating the reactions of •OH, •NO_3, O_3 with alkanes, alkenes *etc.*

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Atmospheric chambers for testing devices

Selected chamber for initial testing

- Teflon FEP foil (6.5 m^3)
- Atmospheric P and T
- Humidity control 0-60 %
- In use for preliminary tests

The Irish Atmospheric Simulation Chamber (IASC)

- Teflon FEP foil, 3.9 × 2.4 × 3.0 m (27 m^3)
- ~ 10 Pa above atmospheric Pressure
- Temperature (15-25°C)
- Relative humidity (0-60 %)
- In situ •NO_3 and •OH detection

https://www.youtube.com/watch?v=xlBxha-aC54

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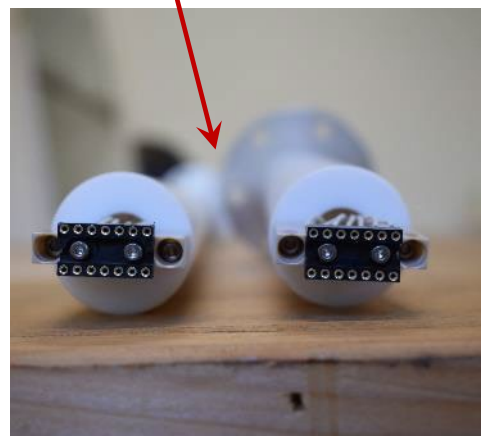
Interfacing sensing platforms

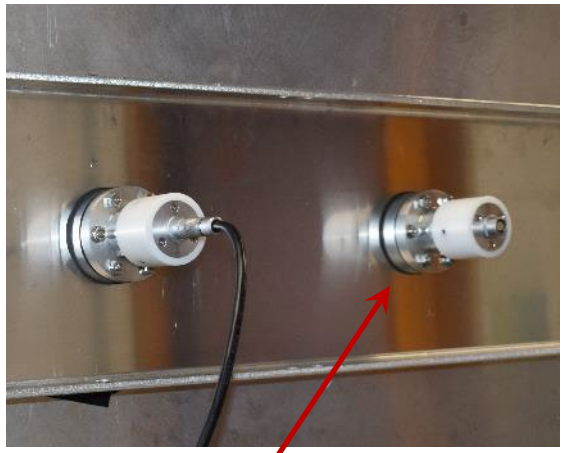
Sensor Mounting Platforms

- PTFE cylindrical tube host the cable assembly, fabricated via PCB method.
- Two holders; 15 and 50 cm in length, can be pulled out via loosening the vacuum flanges to change the JNT sensor chip.
- Cable assembly connects the dual in-line package (DIP) holders at the top to a 12 pin Fischer Connector at the end of the cylinder.

Sensor holders inside the chamber

Chip holders





Outer part of holders attached at the chamber wall

Sensor holder connected to electrical setup

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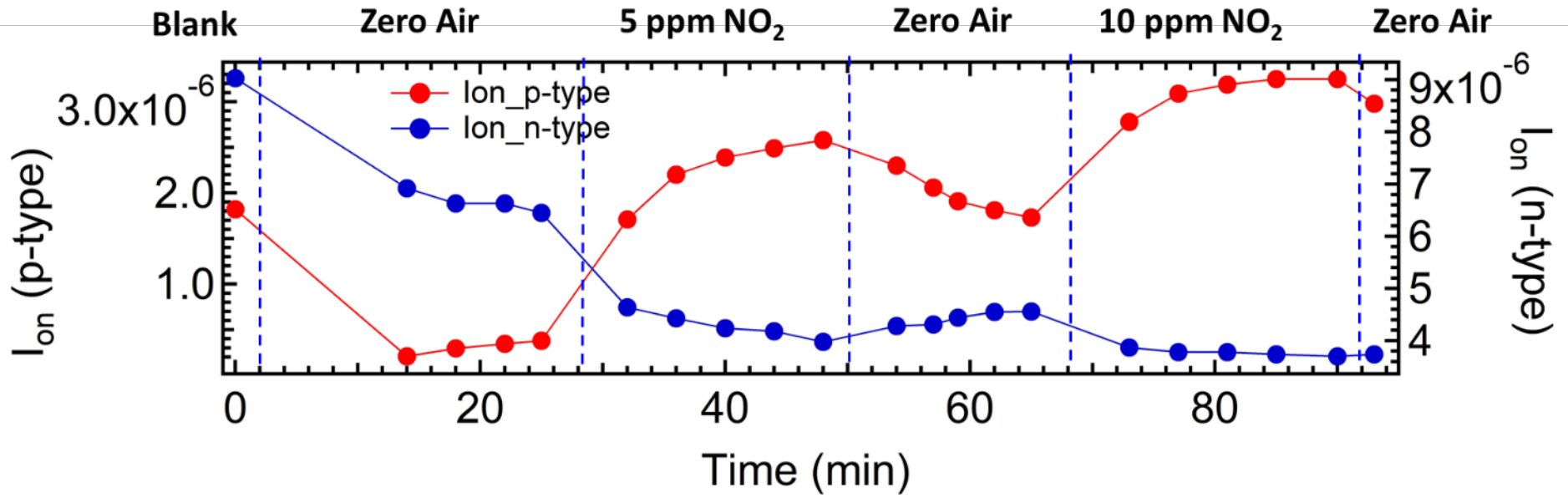
Initial sensor testing: NO_2 exposure

SOI device with native oxide (FLA), unipolar, 12 Nanowire Array



An increase in the hole mediated current and a decrease in the electron mediated current in NO_2 atmosphere

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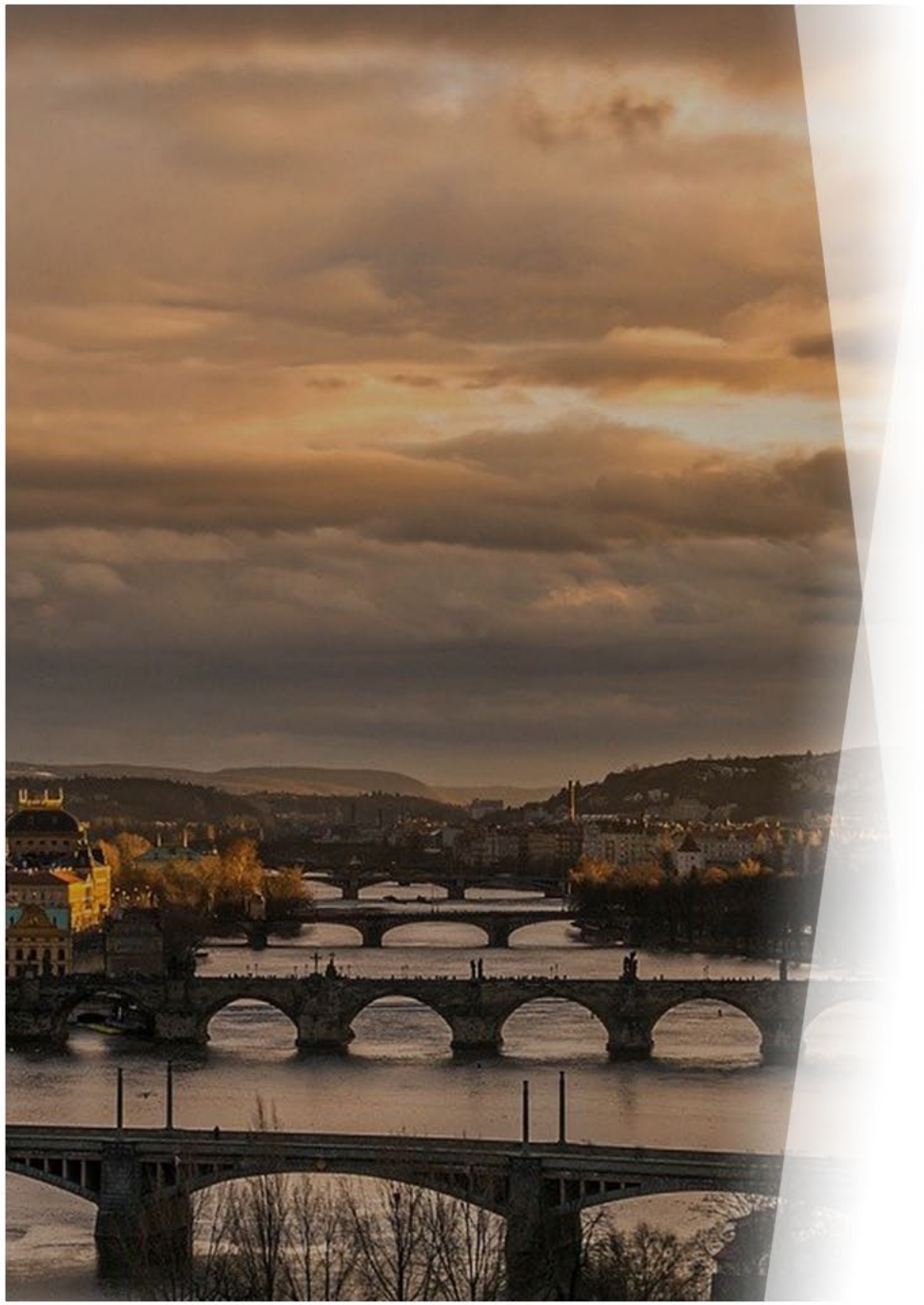

- Want to know more?
- Interested in collaborating?
- Interested in the technology?

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