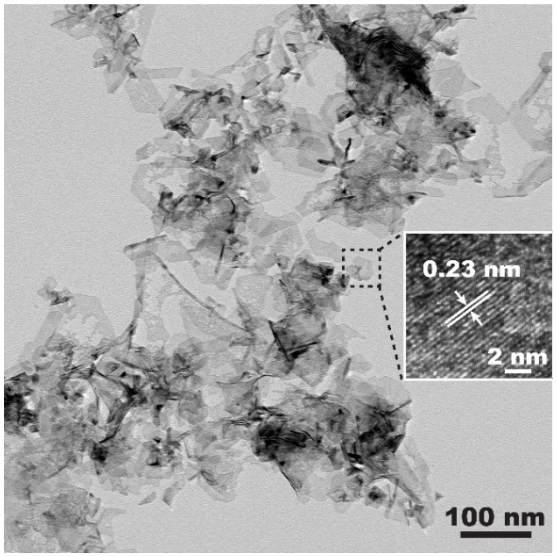
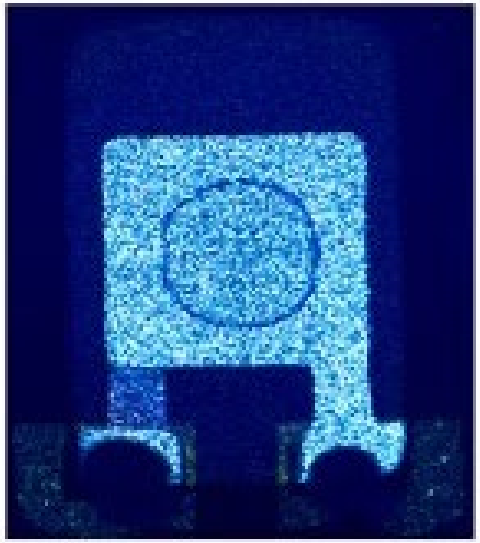
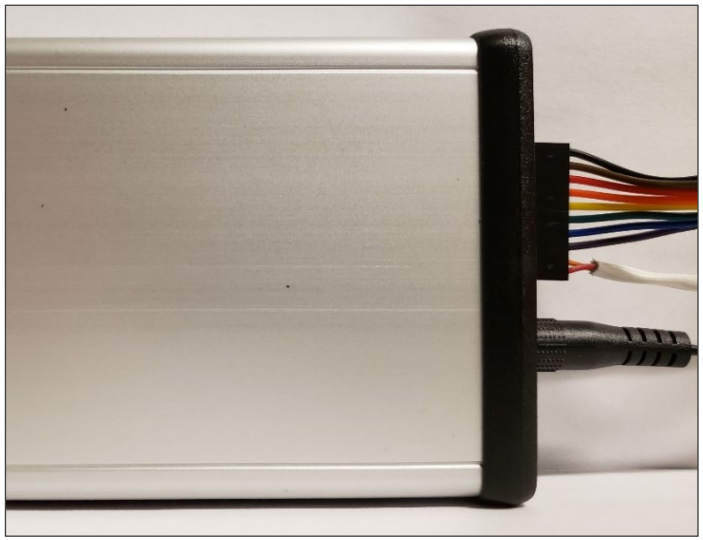
# Nanomaterials for Low-Power, Low-Cost Gas Sensors





**Bryan W. Boudouris**

***Davidson School of Chemical Engineering and Department of Chemistry***

***Purdue University***

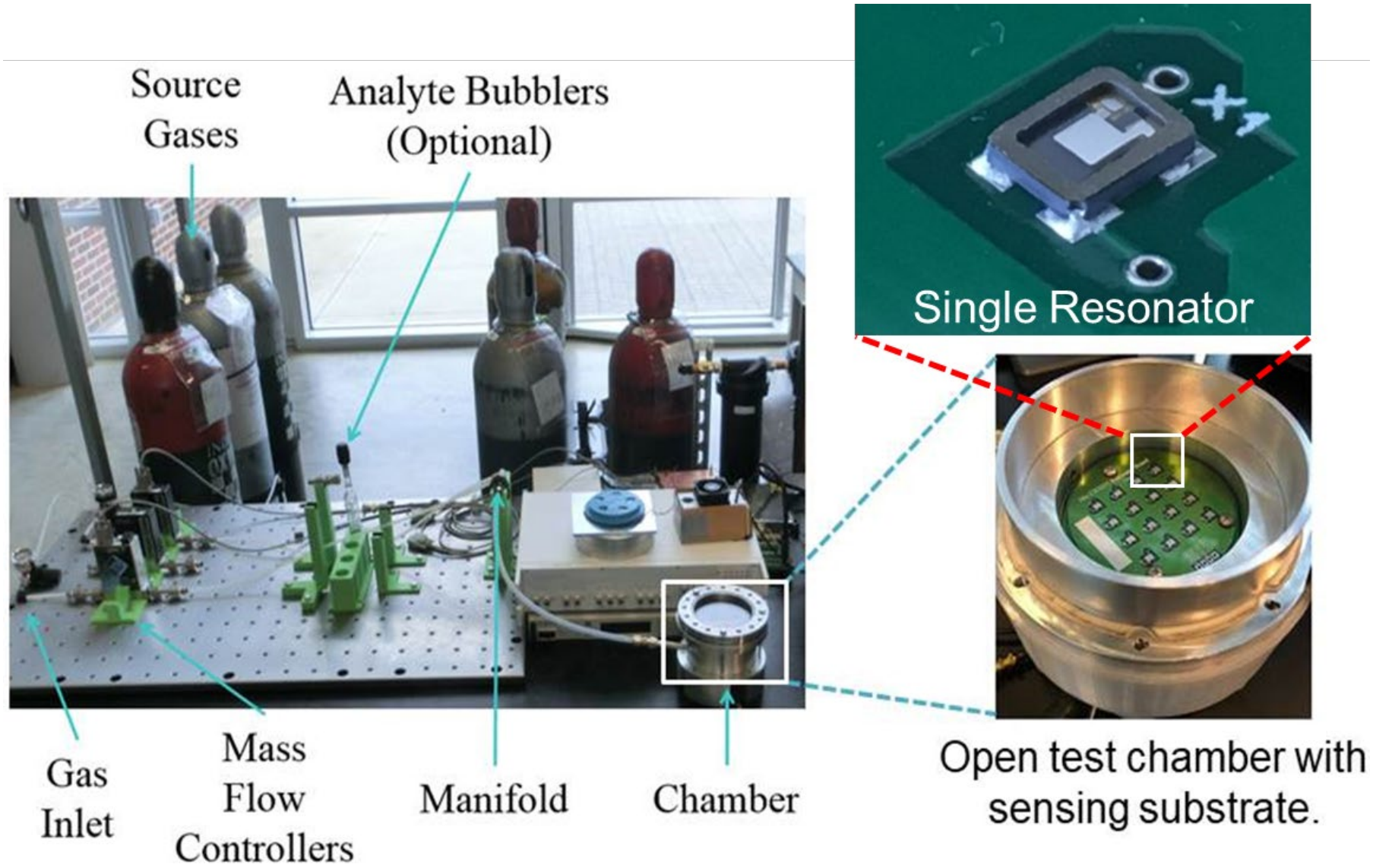
2023 Fall Conference

Purdue Process Safety and Assurance Center

Wednesday, December 6, 2023

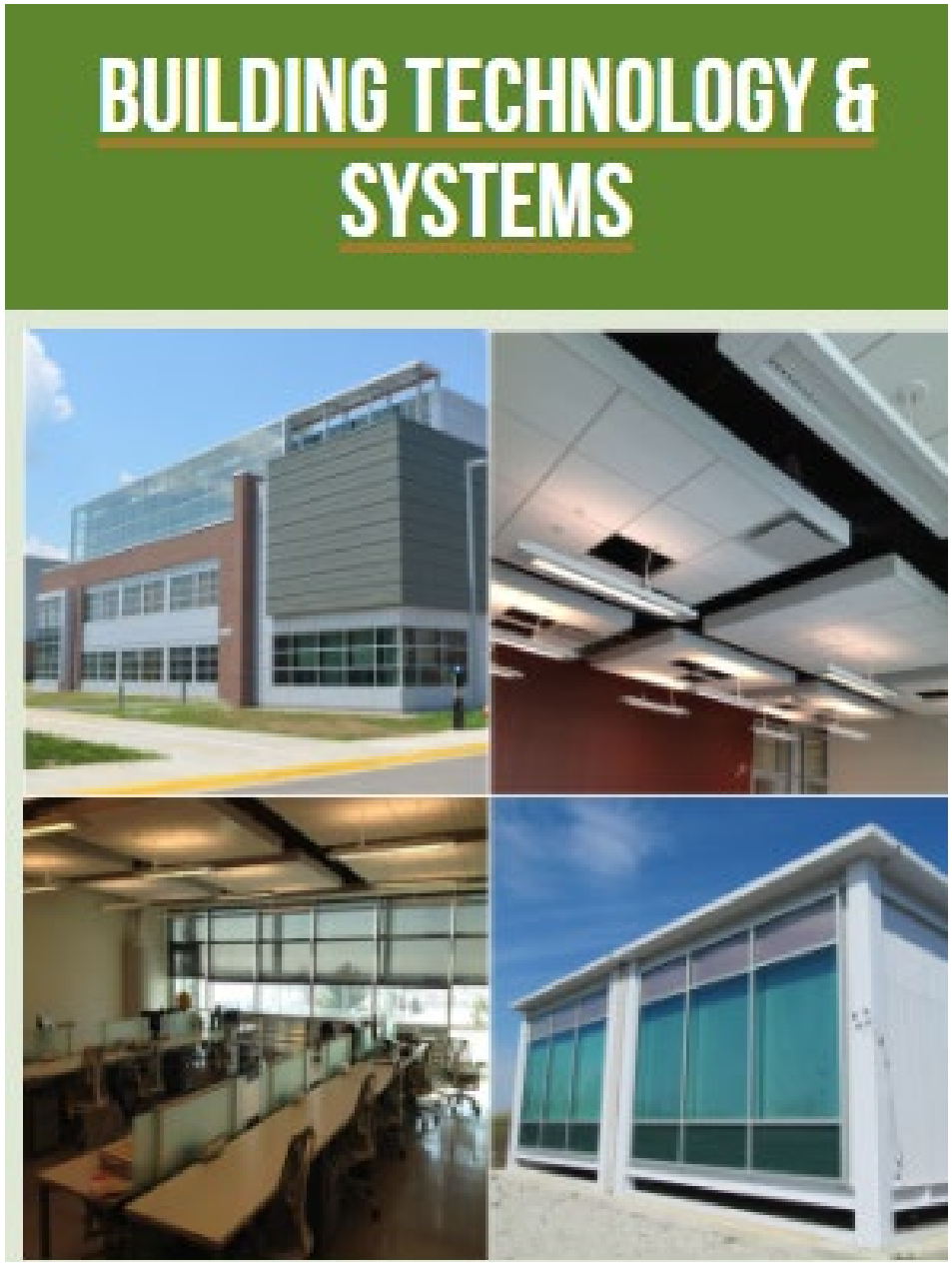
Email: boudouris@purdue.edu

# *Simple Testing Chamber with Multiple Resonators on a Board*



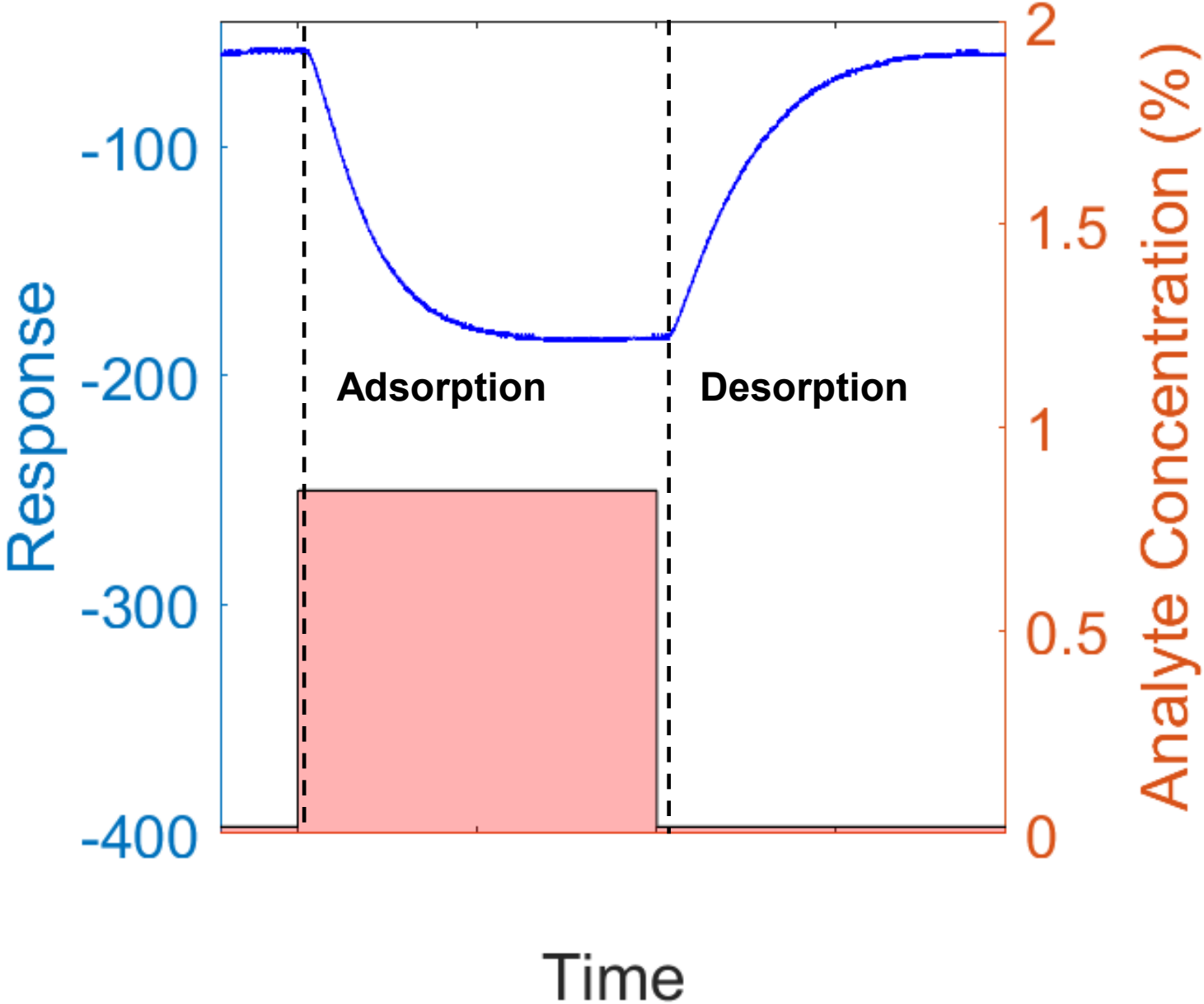

Hodul, J. N.; et al. *ACS Appl. Nanomaterials* **2020**, *3*,10389–10398.

# *Testing at the Center for High Performance Buildings*



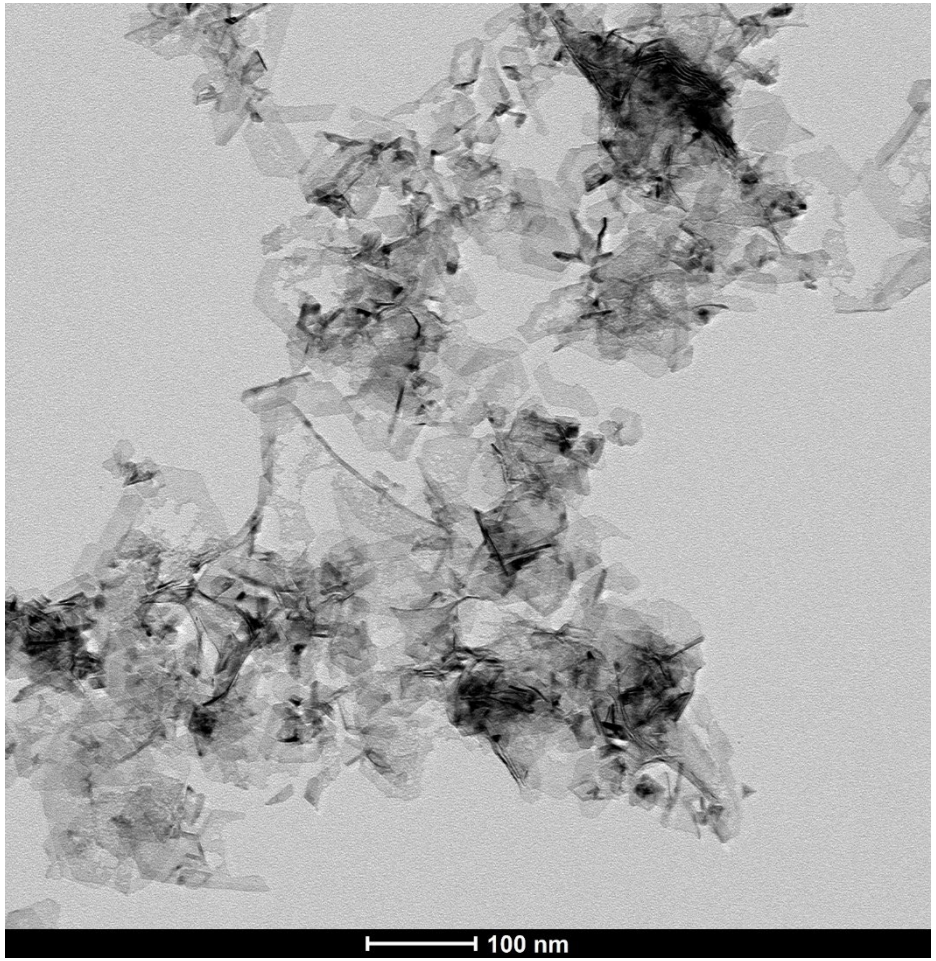

Indoor Air Quality Testing Room

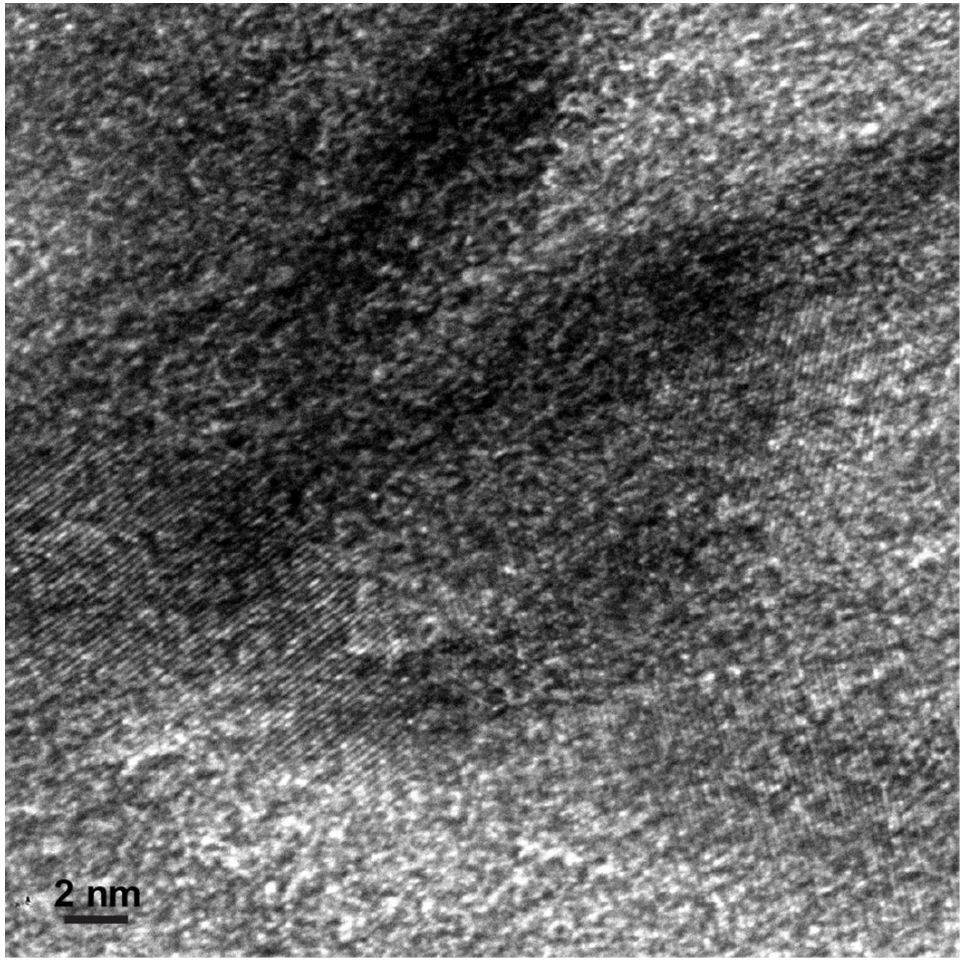
# *Sorption-based Detection Yields Common Sensing Signals*



# *Hydrogen Detection with Palladium Nanosheets (PdNS)*

## TEM Images of Pd Nanoparticle Sheets



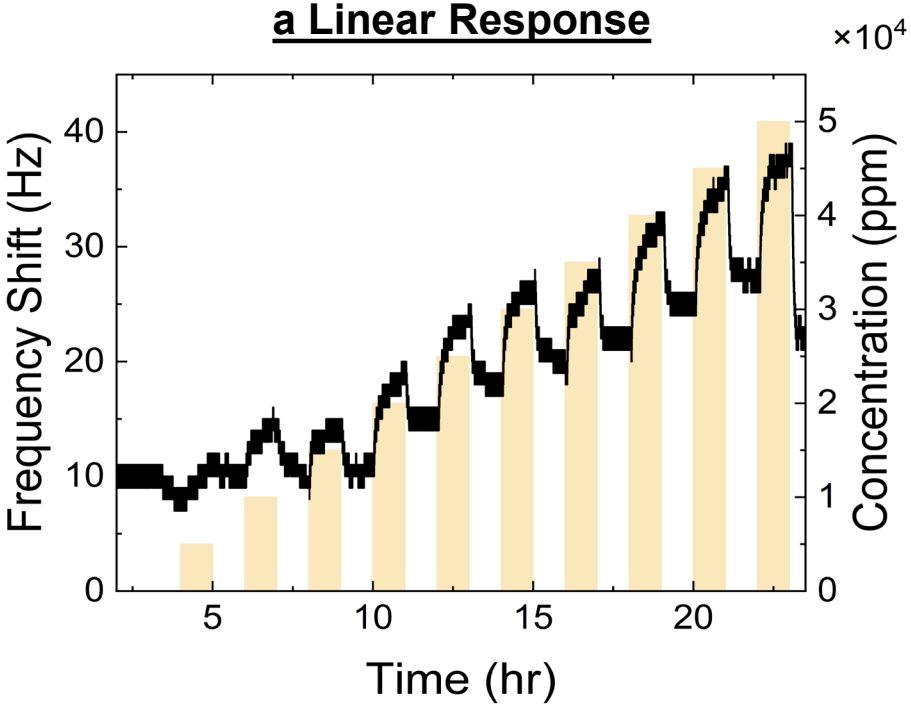




- Chemistry involves simple Pd precursor materials and common ligands that are reacted at 80 °C to yield Pd nanosheets (PdNS), which are suspending in hexanes for printing.

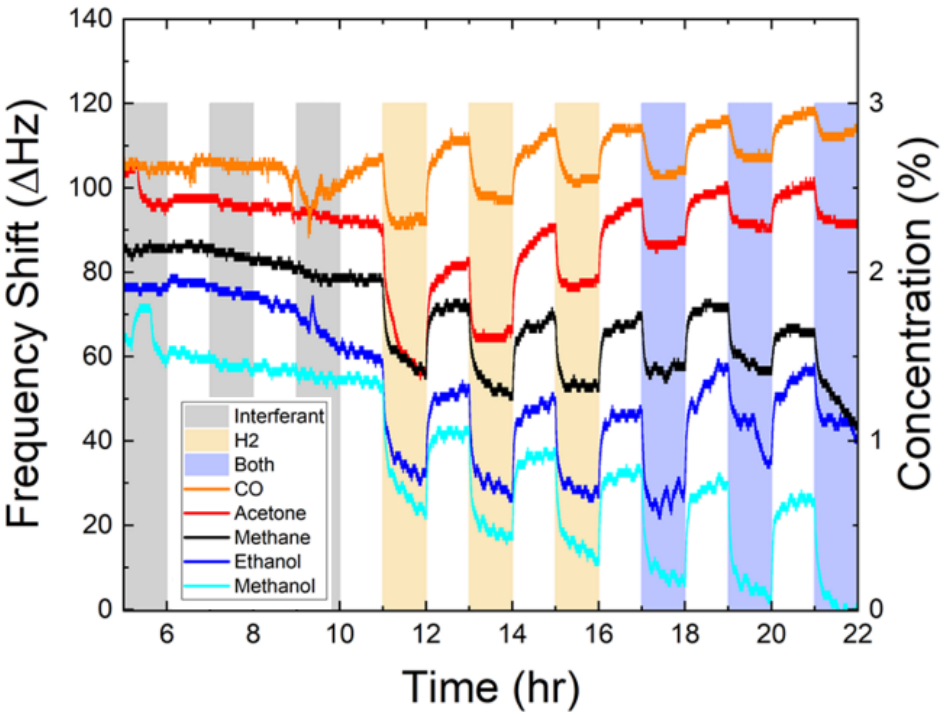
- **< 1 µg of PdNS (i.e., < $0.01 per precursor materials) is used per device.**

# *Hydrogen Detection in in Air and with Interferants*

**Ready Detection of $H_2$ Gas with a Linear Response**



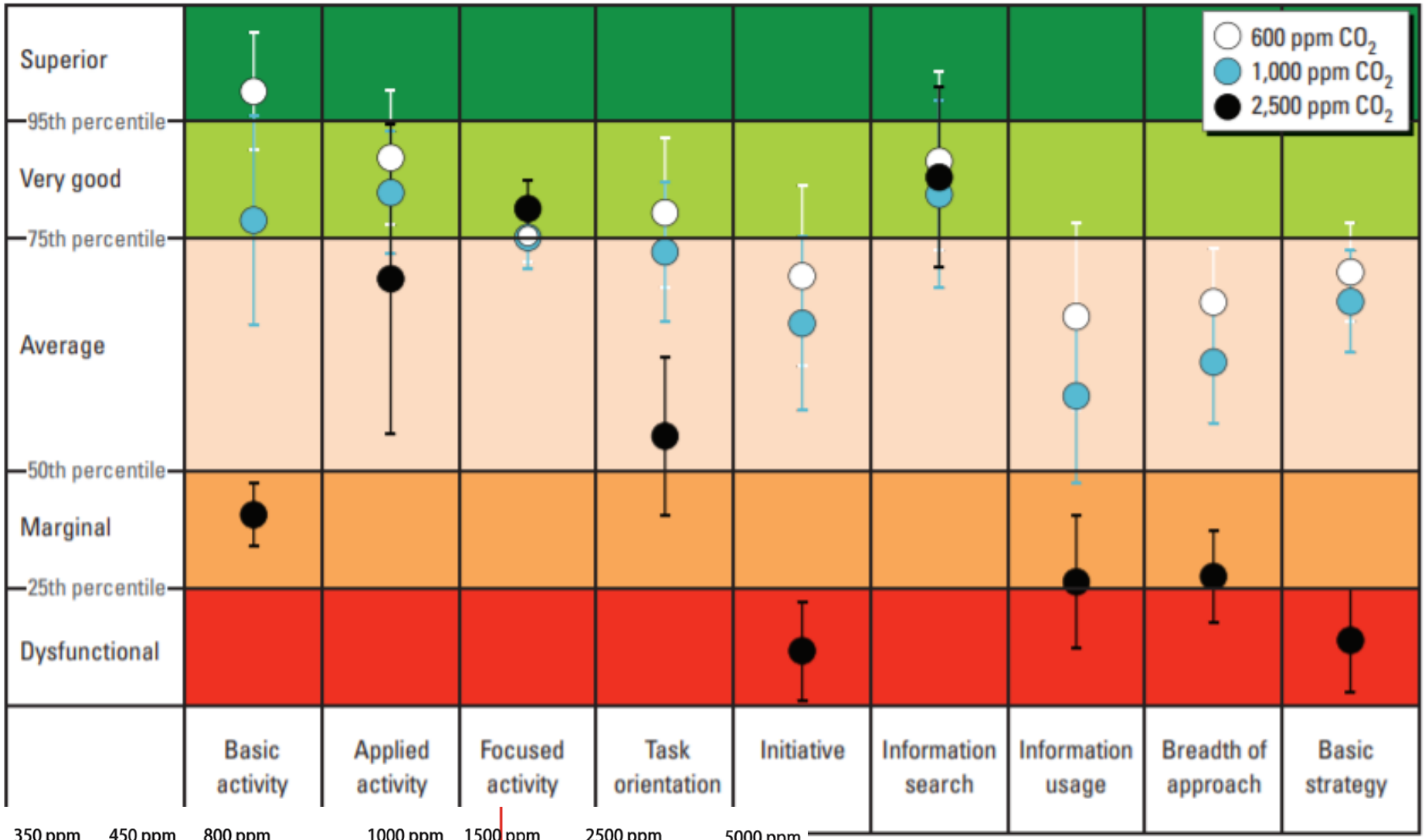

**The PDNS Respond only to $H_2$ and None of the Interferants**

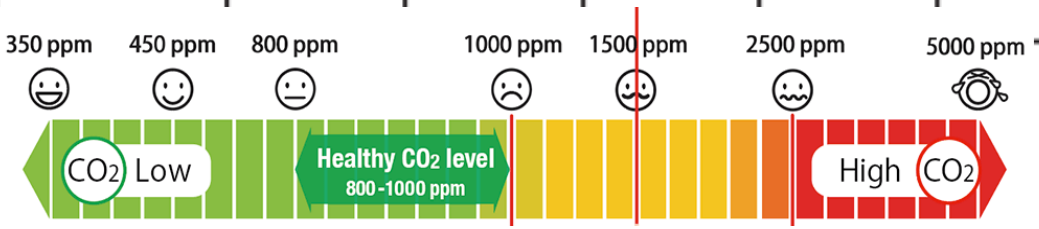



- Detection occurs to concentrations as low as 1% hydrogen in air. It should be noted that the composition of the carrier gas (e.g., air vs. nitrogen) does not impact the response.

- The response is consistent in a variety of relative humidity conditions. However, corrections need to occur at different humidity values.

# $CO_2$ Monitoring is Important, Especially During a Pandemic

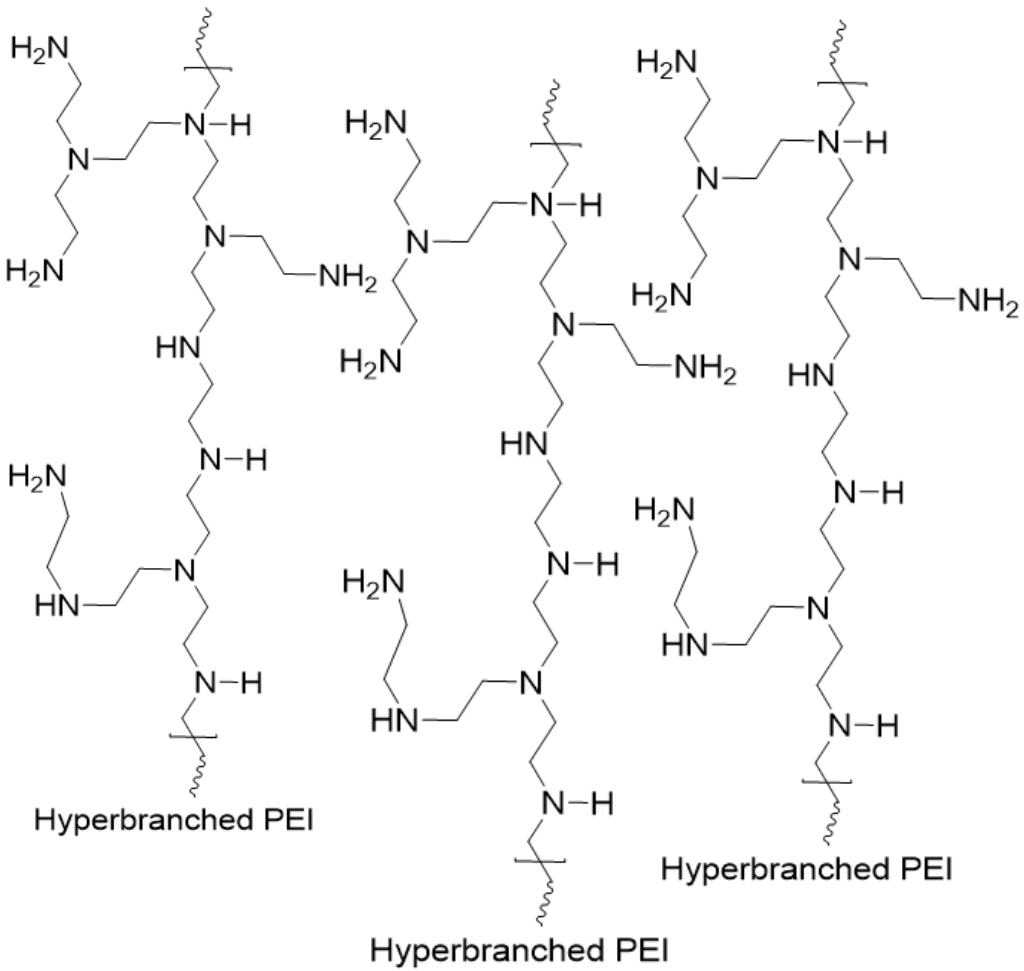


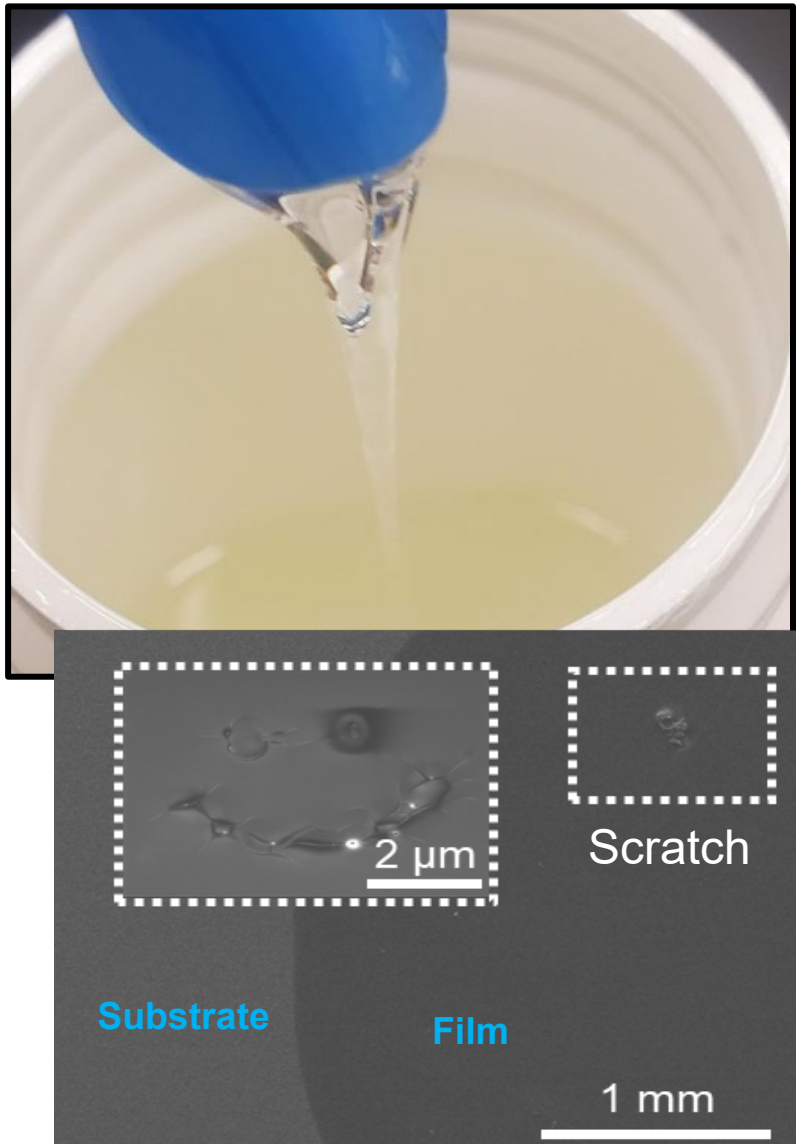

Satish, U.; et al. *Environ. Health Perspect.* **2012**, *120*,1671–1677.

# *PEI Uptakes $CO_2$ Readily, but Has Low Surface Area*

## Many Intermolecular PEI Interactions Exist



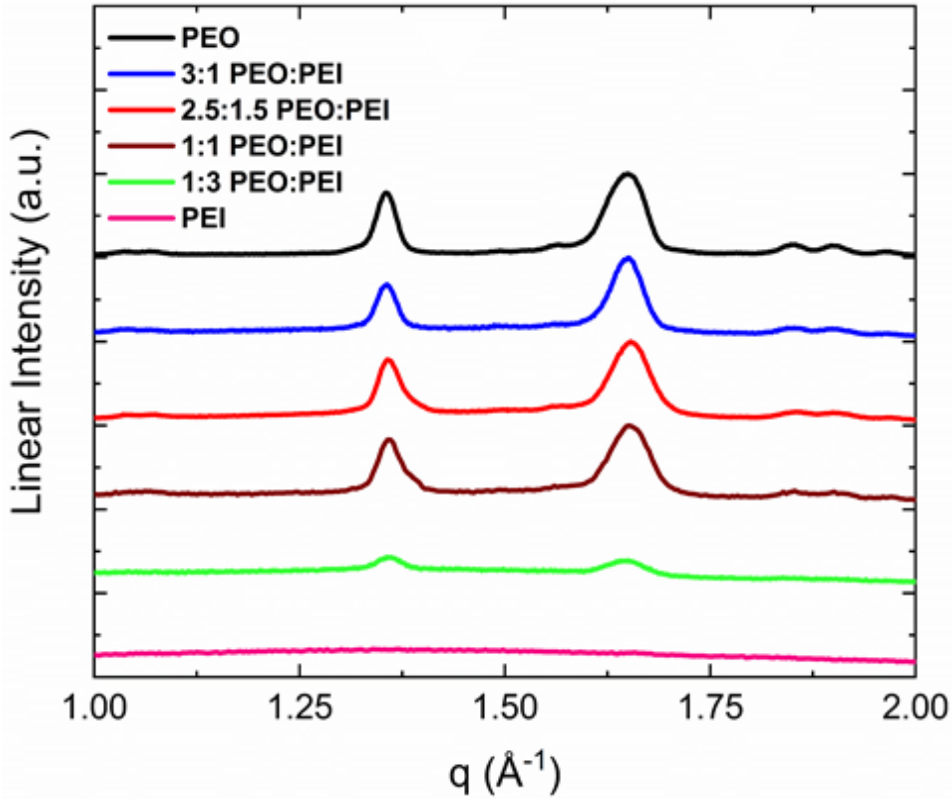

## Highly Viscous Liquid




Siefker, Z. A.; Hodul, J. N.; et al. *Sci. Rep.* **2021**,*11*,13237.

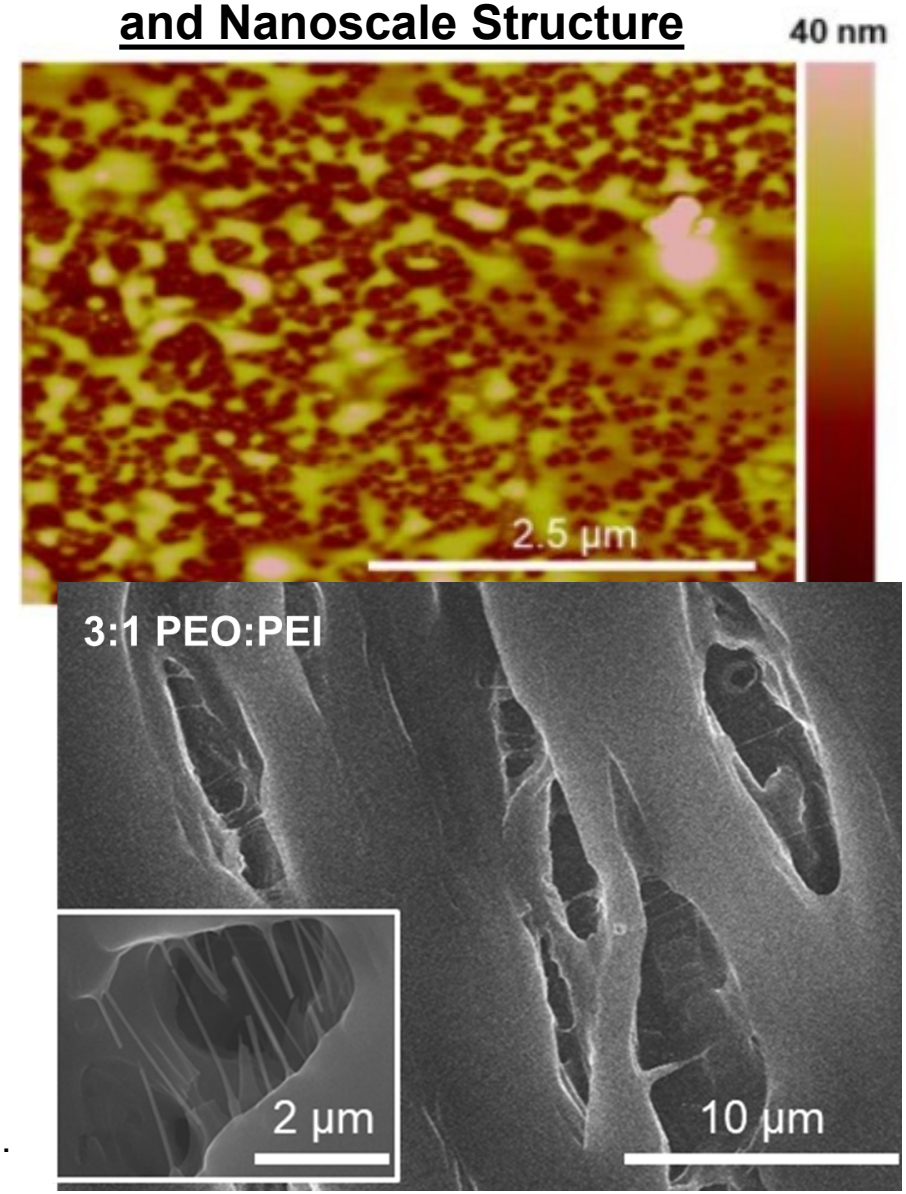
# *Blending in PEO Adds Structure to the Polymer Films*

## PEO Crystallinity Maintained




Presence of the crystalline reflections of the pristine PEO suggests microphase separation between the two moieties

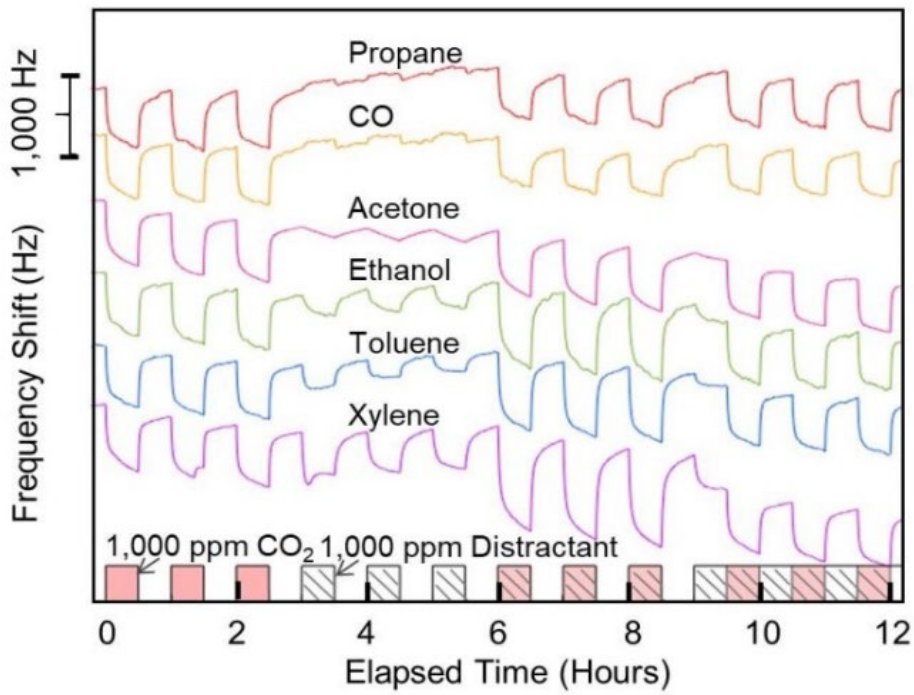
## AFM and SEM Highlight Micro- and Nanoscale Structure



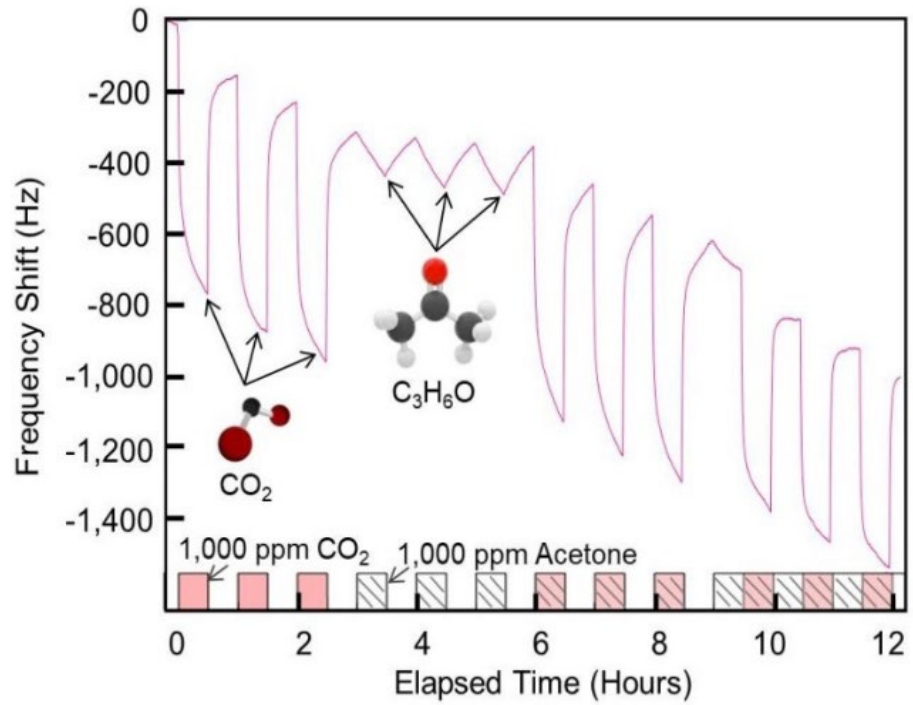

Siefker, Z. A.; Hodul, J. N.; et al. *Sci. Rep.* **2021**,*11*,13237.

# *Selective Towards $CO_2$ Relative to Common Distractants*

**PEO/PEI Chemistry is Unaltered By Potential Interfering Gases**




**Zoomed-in View of Response to Acetone Vapors**

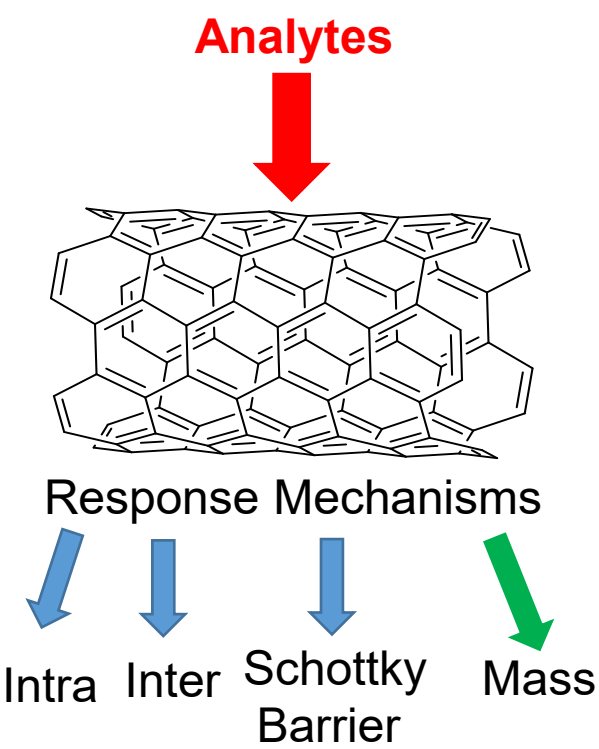



- The distractant gases (i.e., interfering analytes) spanned broad chemical composition and are potentially present in current practical Indoor Air Quality (IAQ) monitoring scenarios.

- <u>The distractant gases are at significantly higher concentrations than what would realistically be present when performing real indoor monitoring tests.</u>

Siefker, Z.A.; Hodul, J.N.; et. al. *Sci. Rep.* **2021**, *11*, 13237.

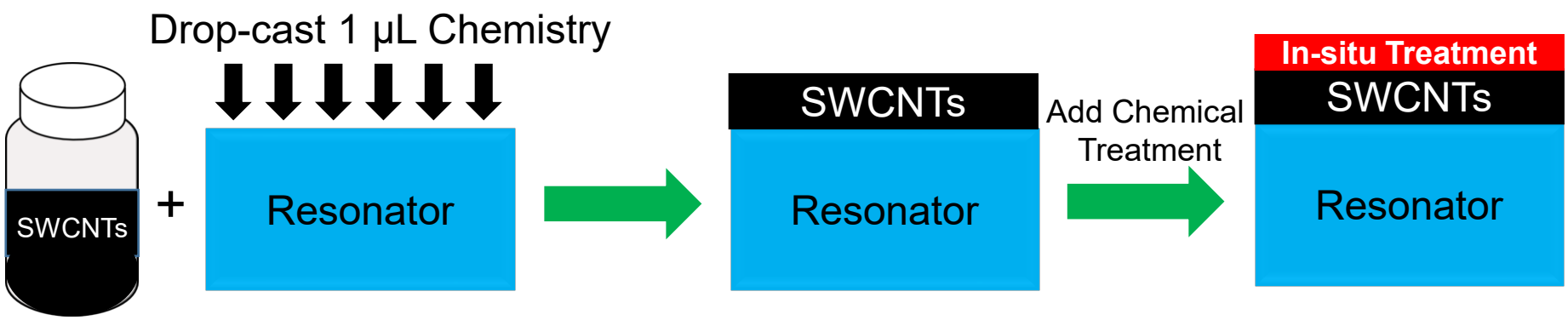
# *SWCNTs are a Promising Functional Chemistry for BTX Detection*



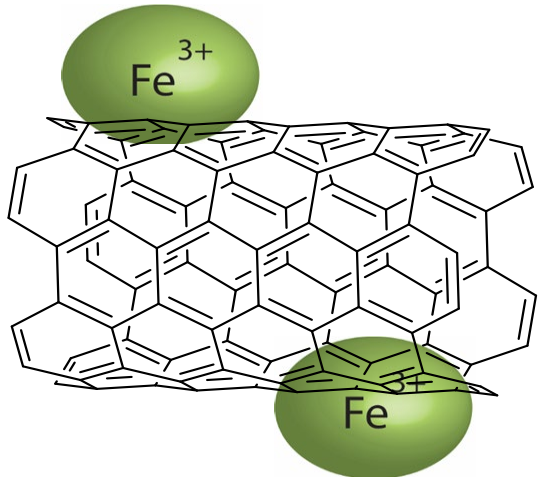

Single Walled Carbon Nanotubes (SWCNT) Sensors Size. Diameter × Length ~2-10 nm × 1-5 μm

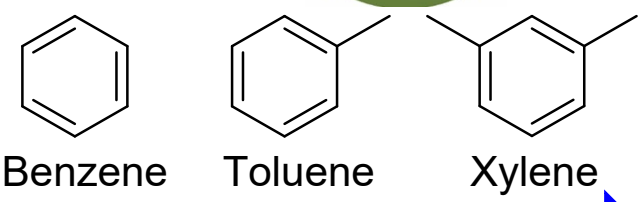
**Advantages**

- Processable, easy-to-use, commercially available
- Offers a conjugated aromatic network
- Offers high surface area to interact with target analytes (i.e., 1300 $m^2/g$)
- Allow for chemical manipulations to selectively target analytes



# *Nitration Doping of Carbon Nanotubes for BTX Detection*



Benzene Toluene Xylene

**Electron Ring Density**

$$FeCl_3 + \begin{matrix} H_2N{-}OH \\ H{-}Cl \end{matrix} \longrightarrow Fe(NH_2OH)^{+3}$$

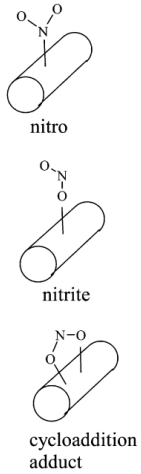
$$Fe(NH_2OH)^{+3} \rightleftharpoons Fe^{+2} \quad NH_2O^{\bullet} \quad H^+$$

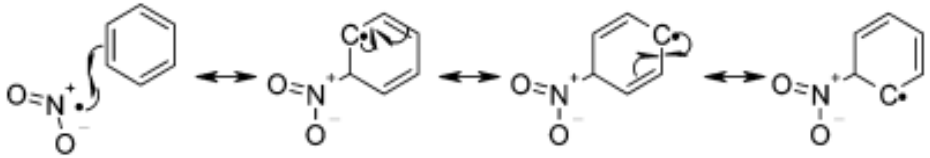
$$Fe^{+3} \rightleftharpoons Fe^{+2} \quad NHO^{\bullet} \quad H^+$$

$$2NH_2O^{\bullet} \longrightarrow N_2 + 2H_2O$$

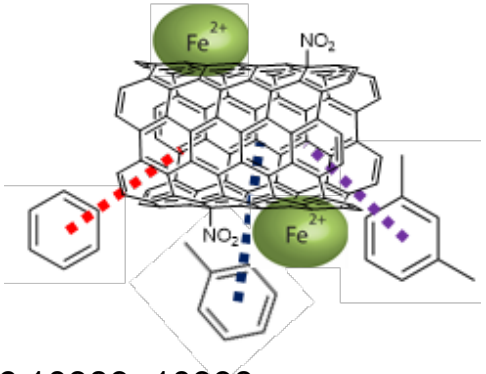
$$2HNO^{\bullet} \longrightarrow NO_2 + H_2O$$

Bengtsson, G.; Fronæus, S.; Bengtsson-Kloo, L. *J. Chem. Soc. Dalt. Trans.* **2002**,*12*, 2548–2552.



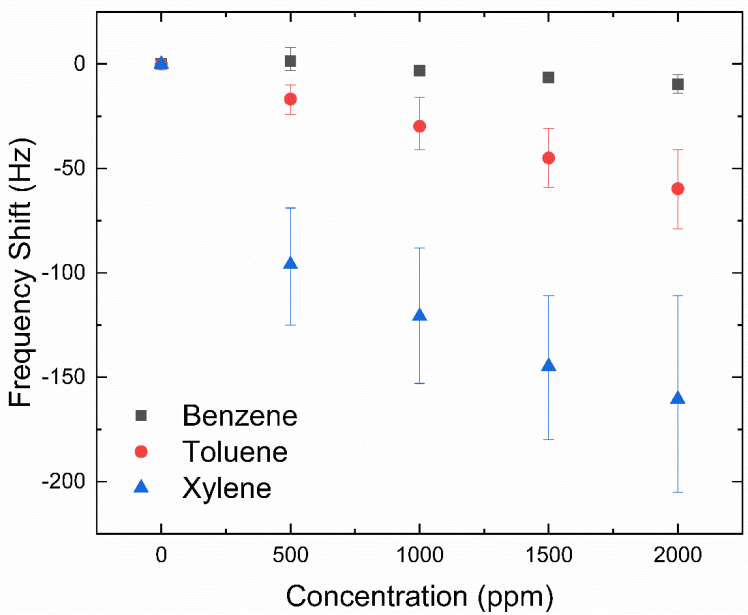



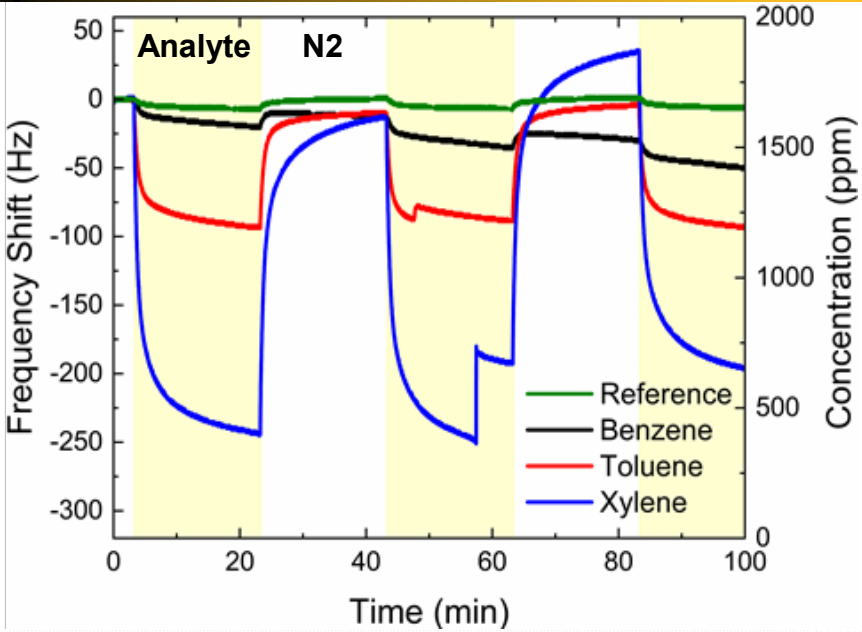
*J. Phys. Chem. B* **2003**, *107*, 9363–9369.
*J. Phys. Chem. B* **2006**, *110*, 22462–22470.

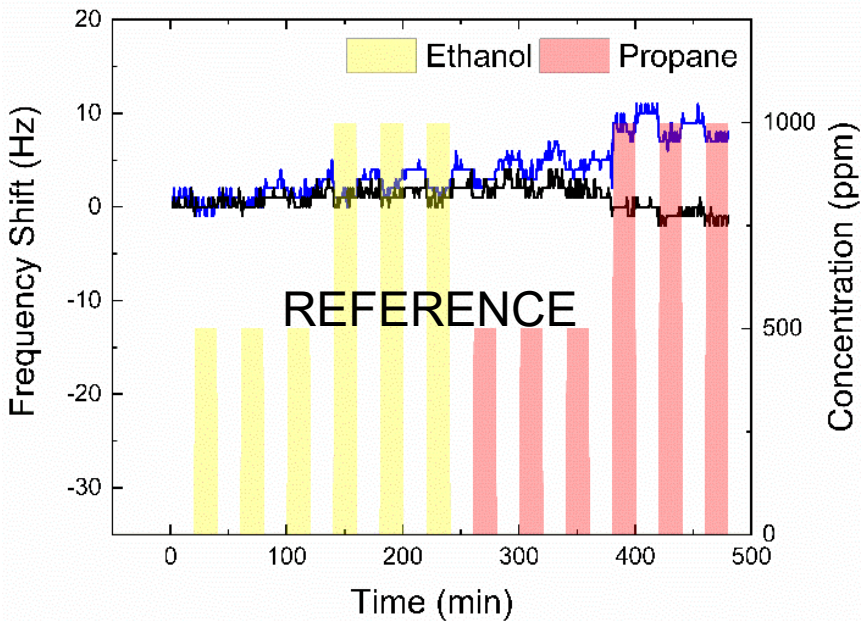


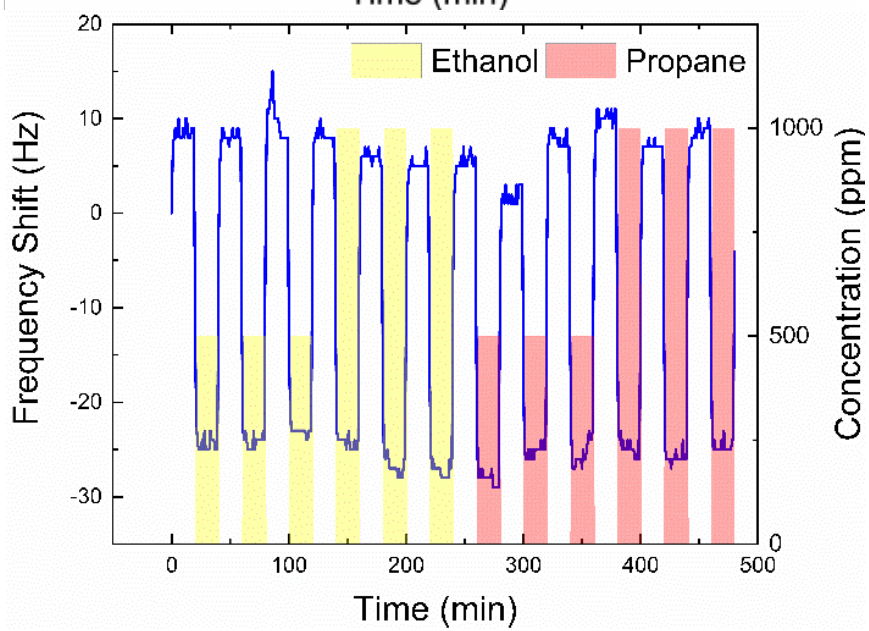

Hodul, J. N.; et al. *ACS Appl. Nanomaterials* **2020**, *3*,10389–10398.

# *HHCl Treated SWCNTs Offer Processable and Selective Chemistry to BTX Analytes*



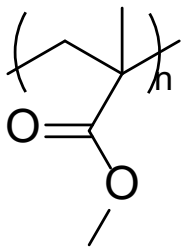



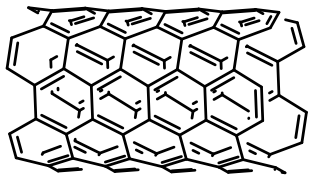

Hodul, J. N.; et al. *ACS Appl. Nanomaterials* **2020**, *3*,10389–10398.

# *PMMA + SWCNTs Work Well for THF Sensing*



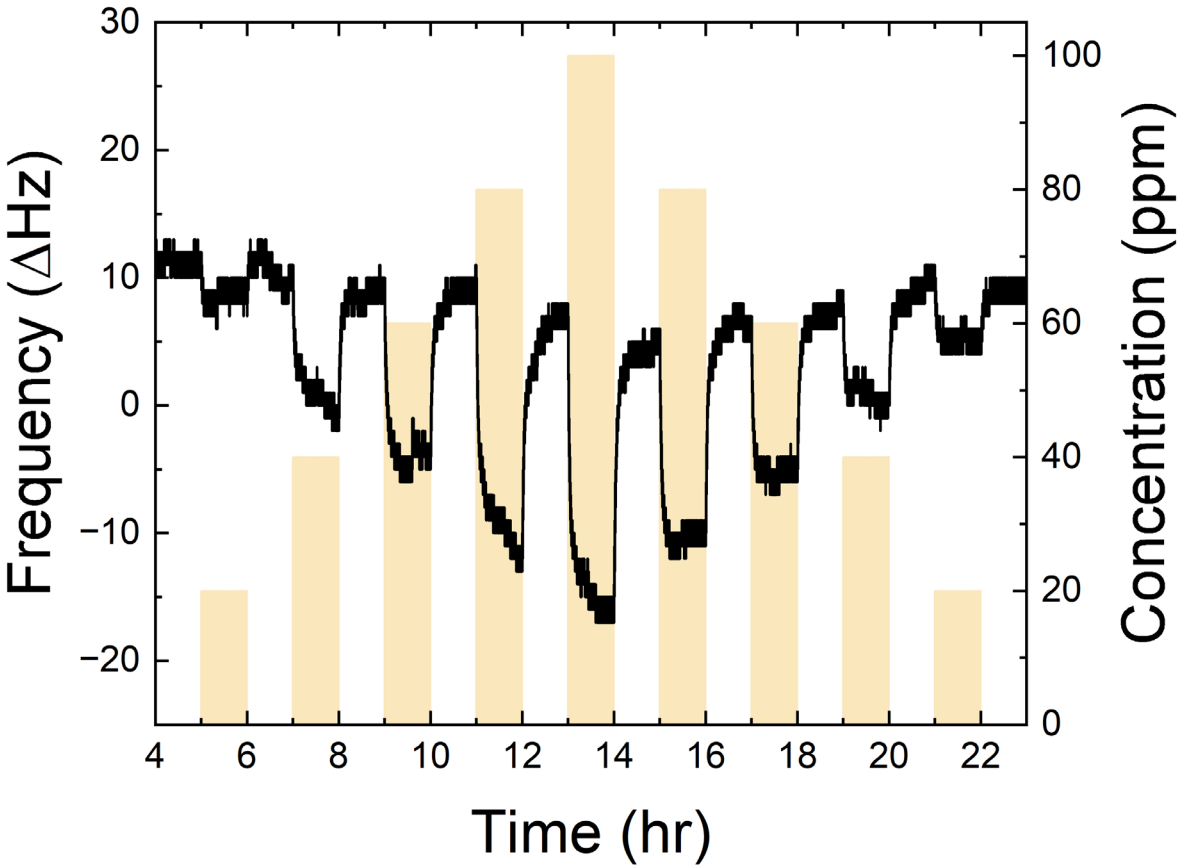

Poly(methyl methacrylate)

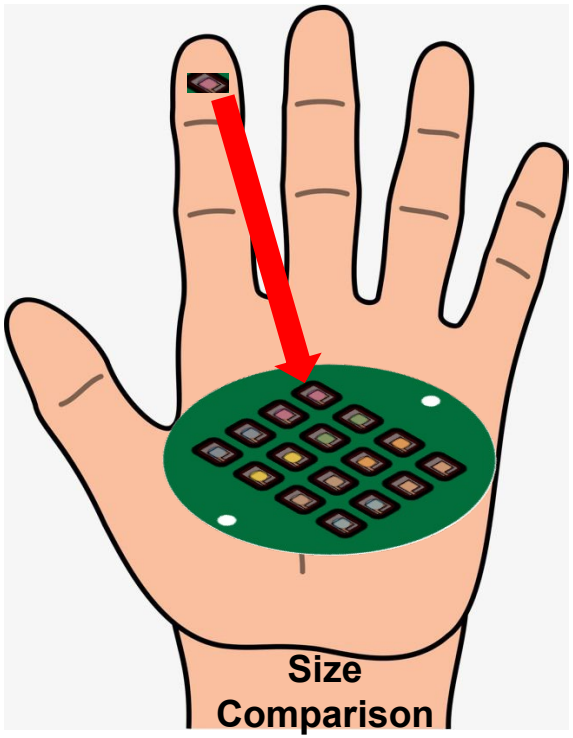
+



Single Walled Carbon Nanotubes

- 9:1 ratio of Poly(methyl methacrylate) (PMMA) to Single Walled Carbon Nanotubes (SWCNT)
- 1 mg $mL^{-1}$ casting solution in Ethanol
- Drop cast 1 μL of casting solution on to resonators



# Acknowledgements

## Boudouris Research Group

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## Collaborators

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- Jim Braun
- George Chiu
- David Corti
- Letian Dou
- Arsineh Hecobian
- Jianguo Mei
- Brett Savoie

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