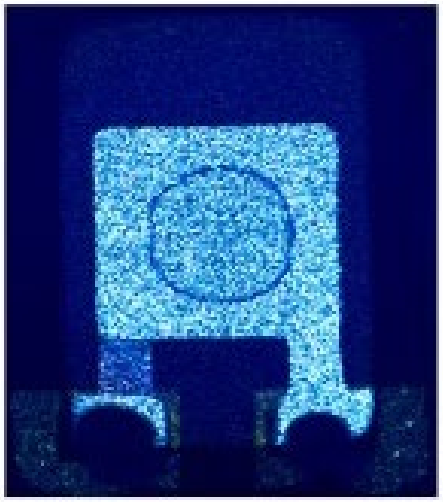
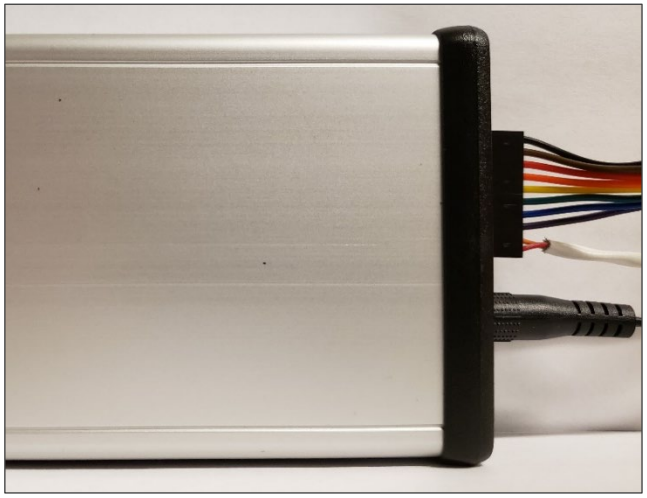
Materials and Devices for Low-Cost Gas and Bioelectronic Sensors





Bryan W. Boudouris

Davidson School of Chemical Engineering and Department of Chemistry

Purdue University

2022 Fall P2SAC Conference
General Safety Session

Thursday, December 15, 2022

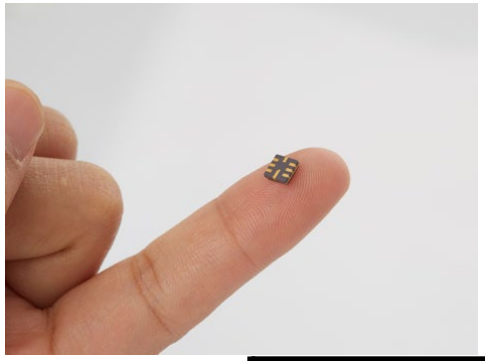
Email: boudouris@purdue.edu; Twitter: @Boudouris_Group

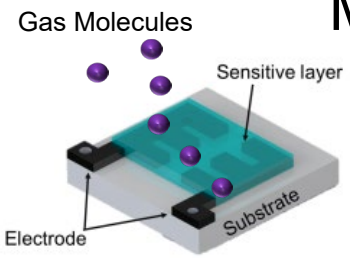
The Focus of Our Work is on Performance and Price

Mass Spectrometry

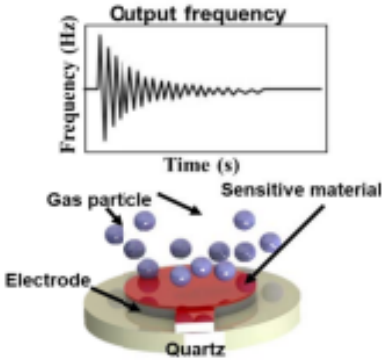
Gas Chromatography

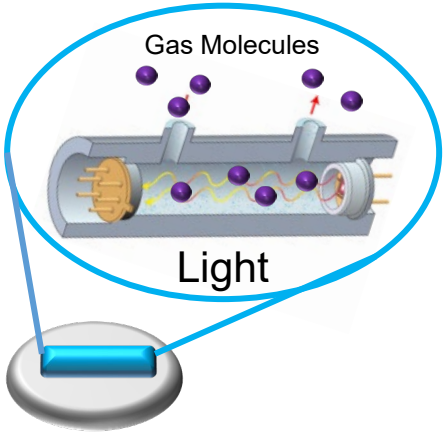
MEMS Offer Low-Cost, Low-Energy Solutions





MEMs

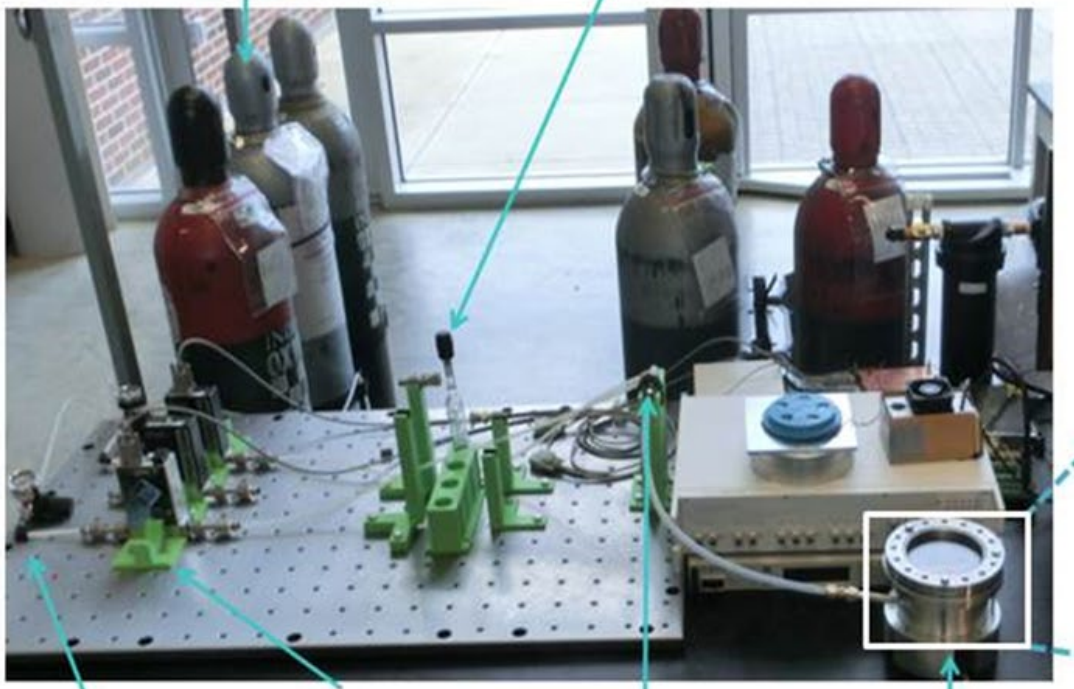


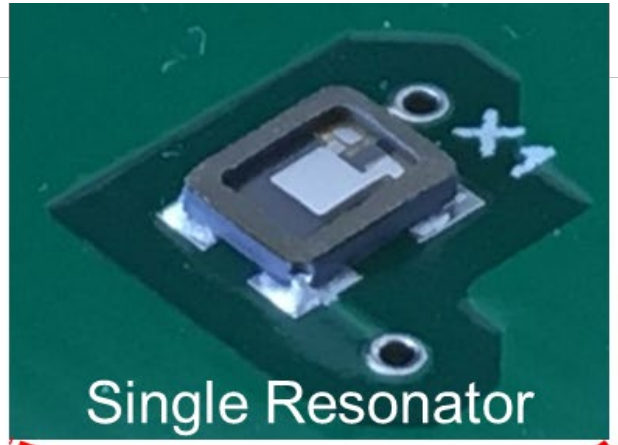


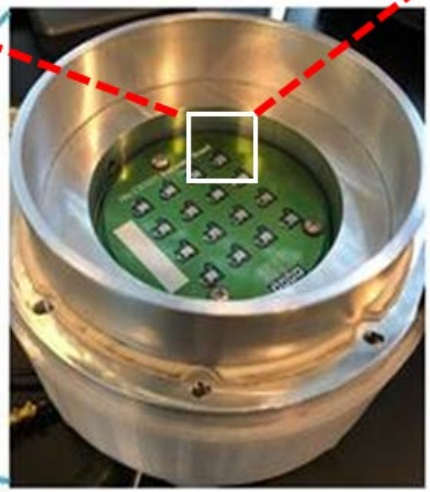
Electrochemical | Electromechanical | Optical

Ahmad Asri, M. I.; et al. *IEEE Sens. J.* **2021**, *21*, 18381–18397.

Simple Testing Chamber with Multiple Resonators on a Board



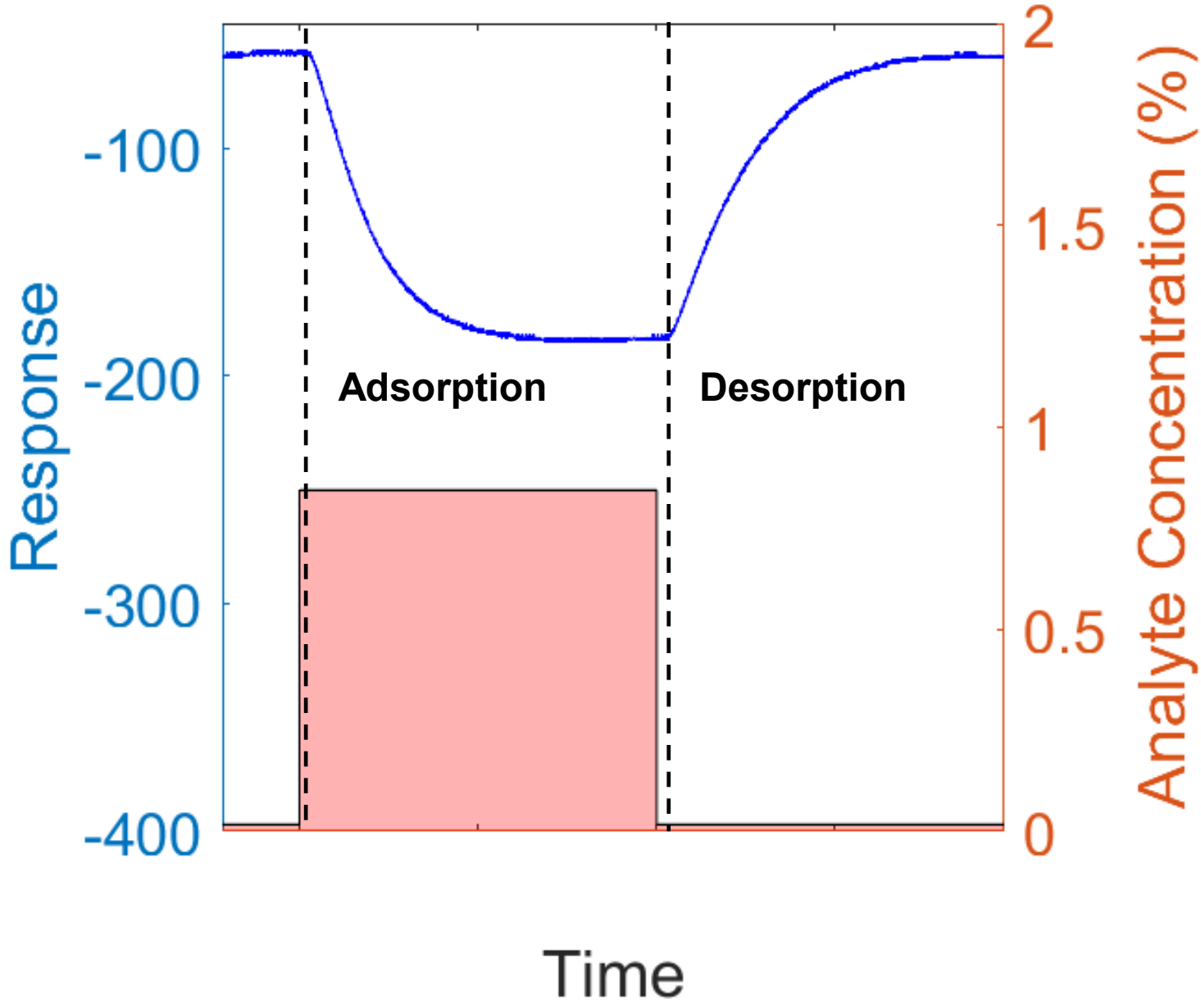




Open test chamber with sensing substrate.

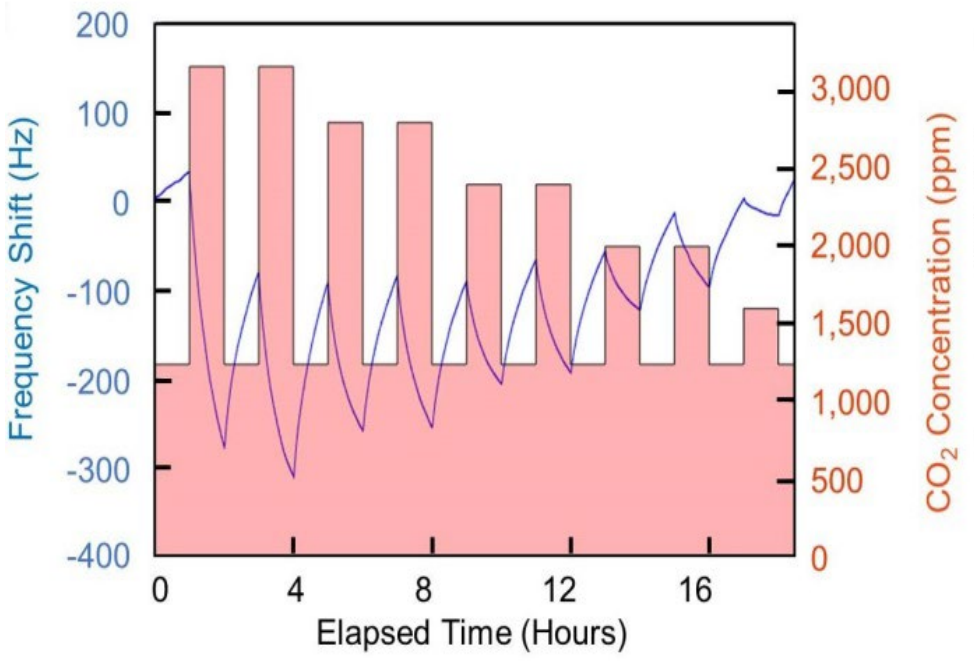
Hodul, J. N.; et al. *ACS Appl. Nanomaterials* **2020**, *3*,10389–10398.

Sorption-based Detection Yields Common Sensing Signals

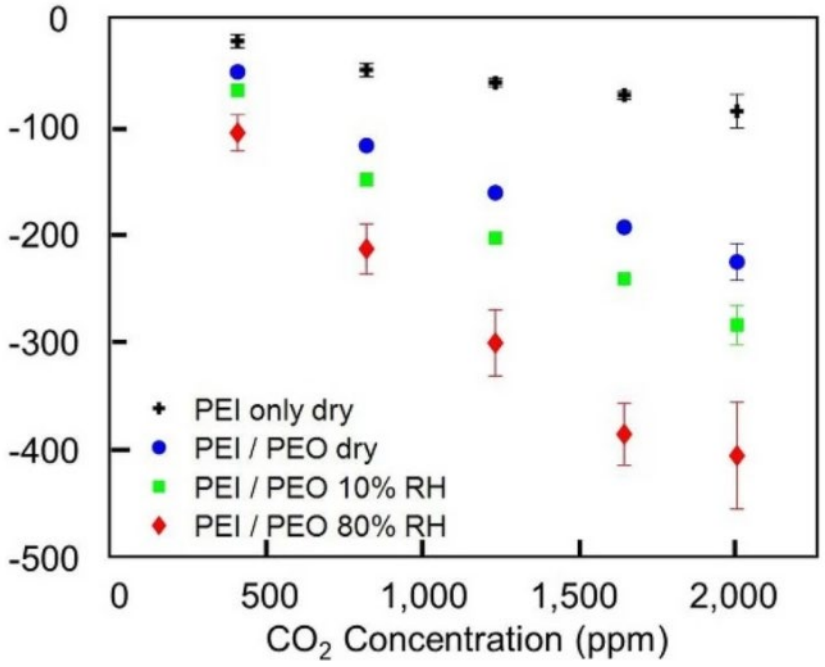


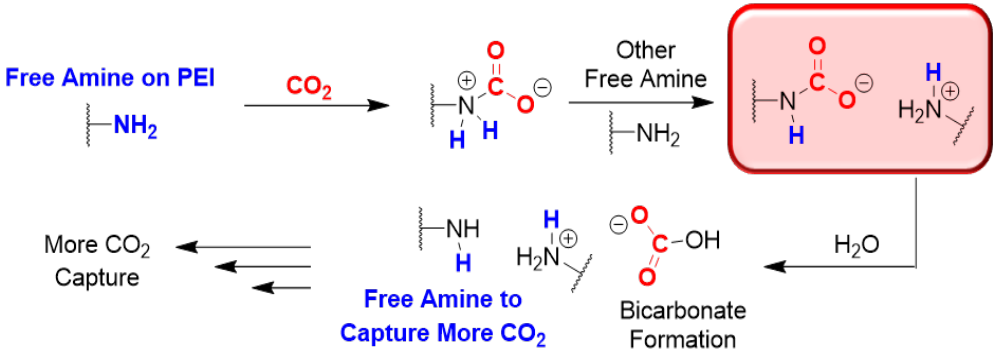
CO_2 Sensor Responds Quickly under a Range of Conditions

PEO-PEI Provides a Real-time Response to CO_2



PEO-PEI Responds in Dry and Humid Environments



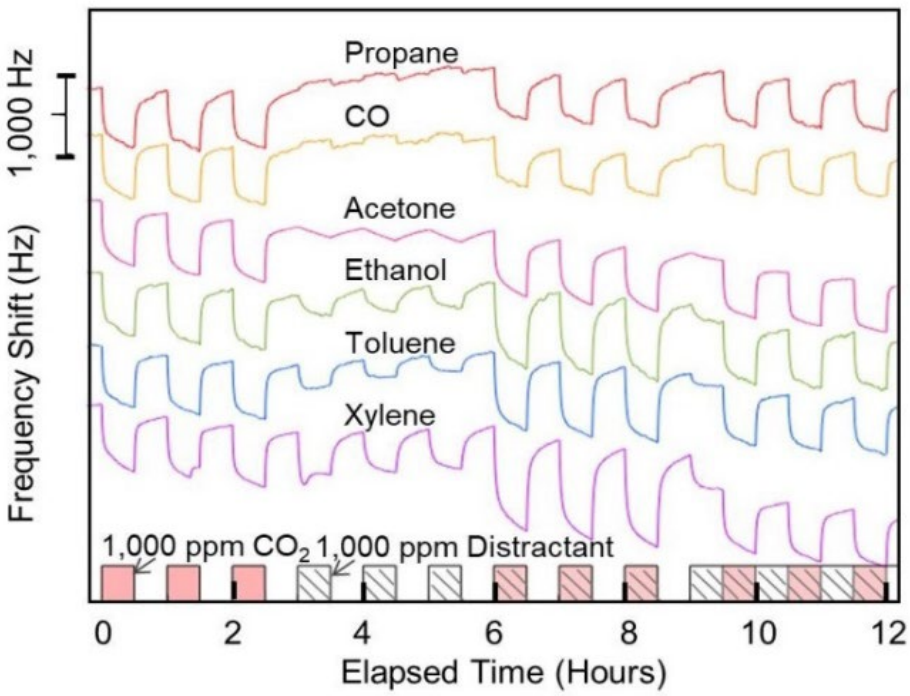


- Sensor detects CO_2
- Performs in both ambient air and nitrogen environments
- Performs in practical environments (i.e., humidity)

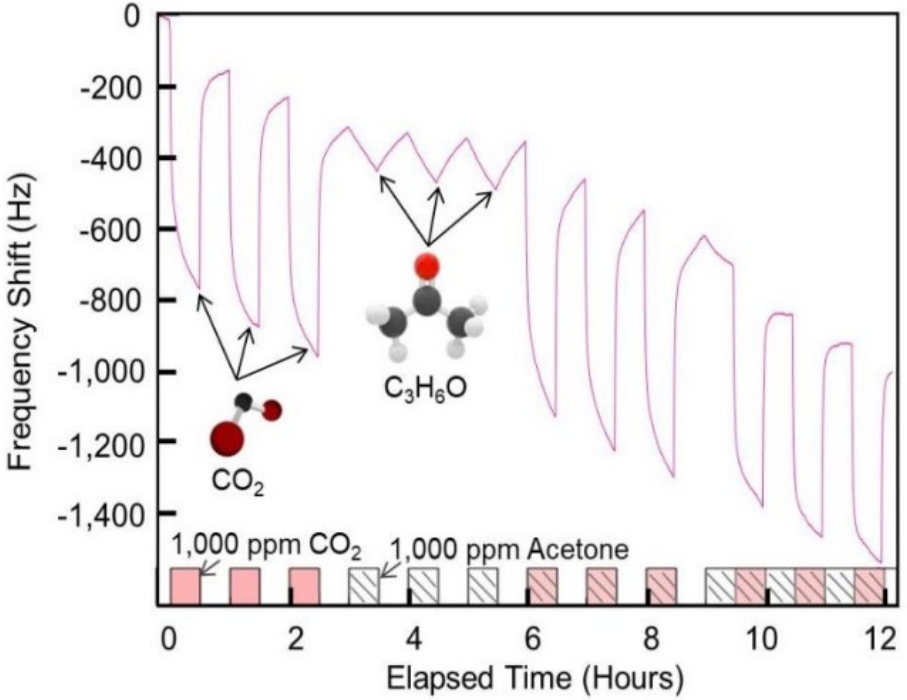
Siefker, Z.A.; Hodul, J.N.; et. al. *Sci. Rep.* **2021**, *11*, 13237.

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

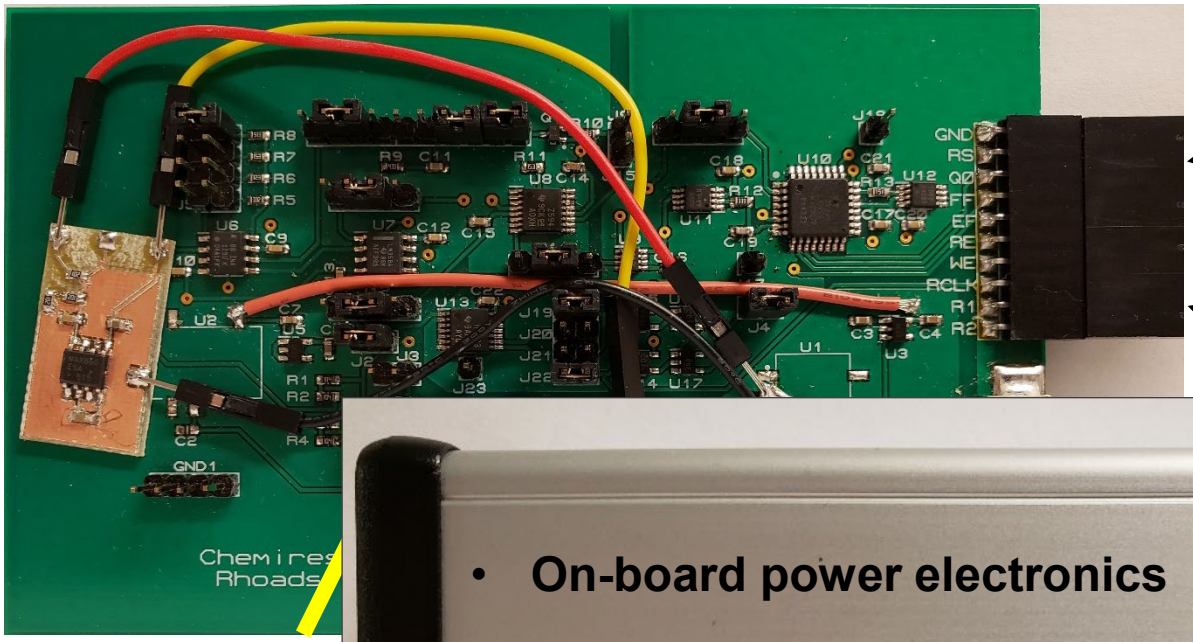


- The distractant gases (i.e., interfering analytes) spanned broad chemical composition and are potentially present in current practical Indoor Air Quality (IAQ) monitoring scenarios.

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

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

Integrated Sensors and the Final, Compact Product



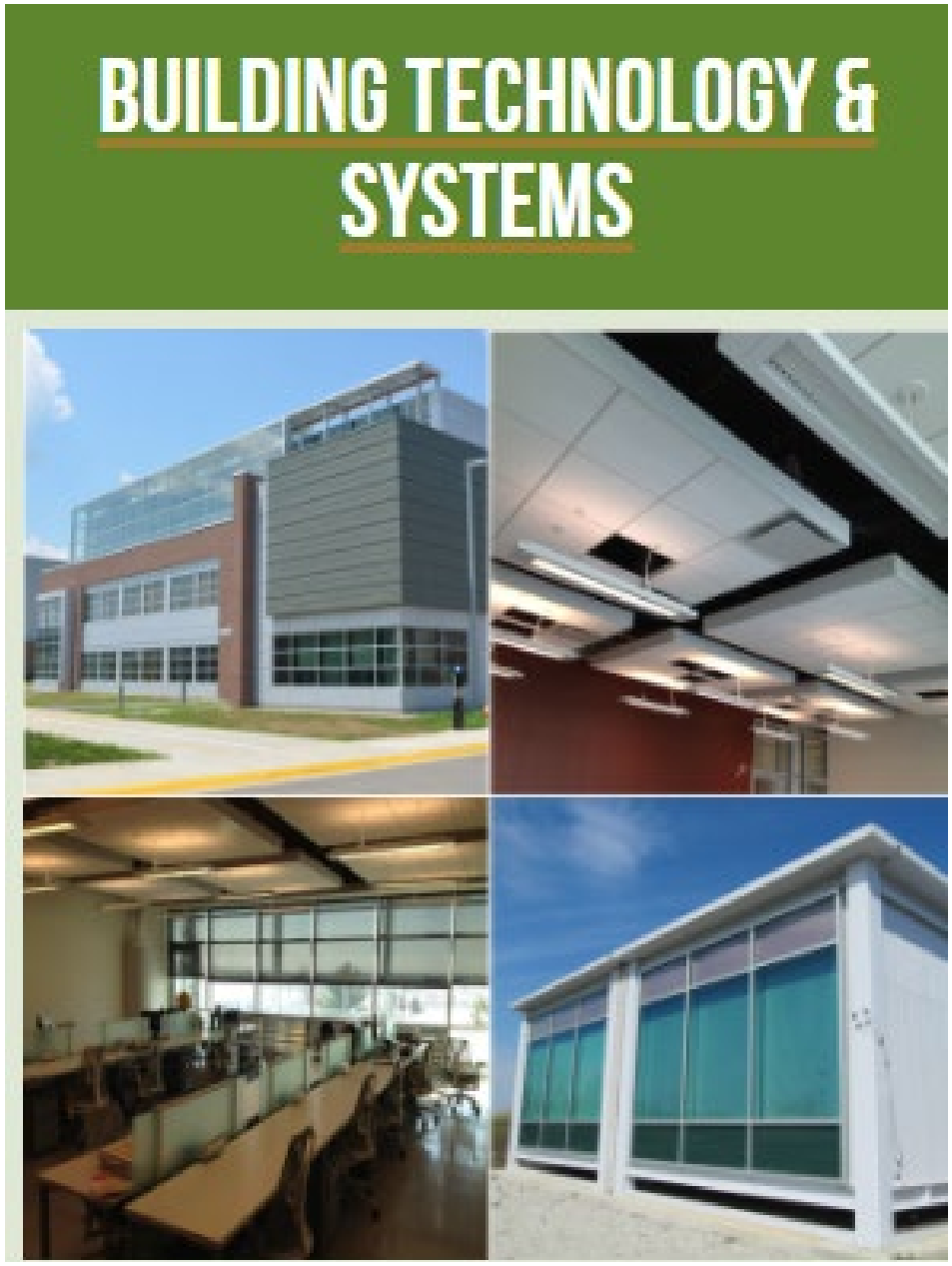
Integrated device output

Wheatstone bridge voltage output

- **On-board power electronics**
- **Oscillators for clock signal generation**
- **Simple input/output interface**
- **Device enclosure**

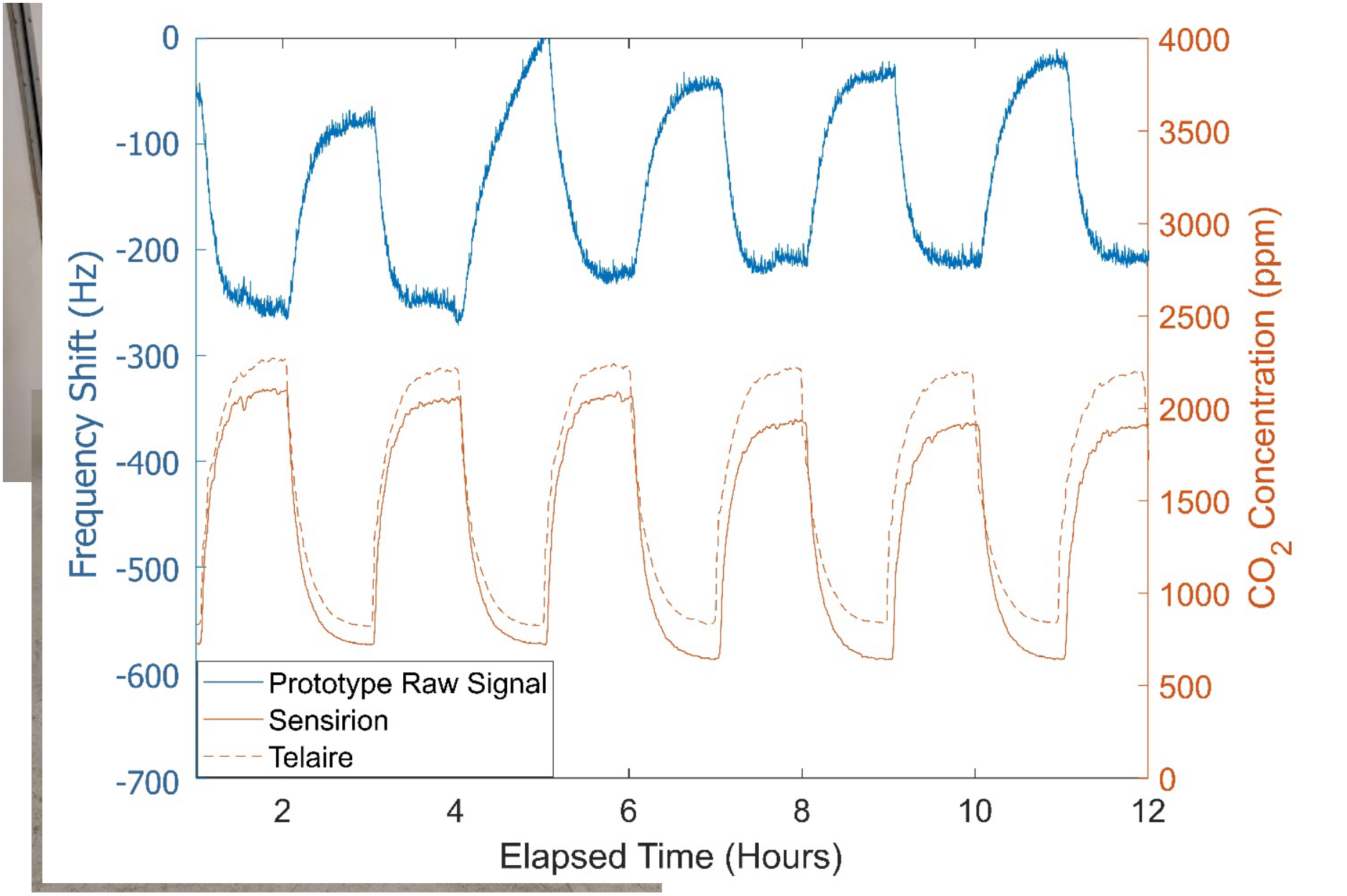
1 in

Testing at the Center for High Performance Buildings



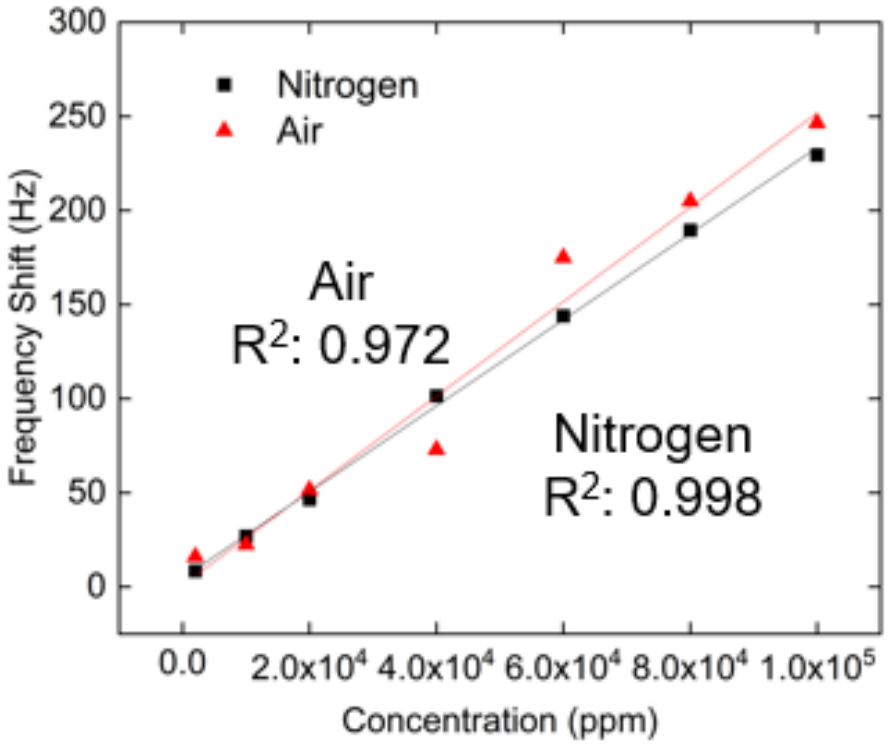
Indoor Air Quality Testing Room

Prototype Sensor Works as Well as COTS Sensor

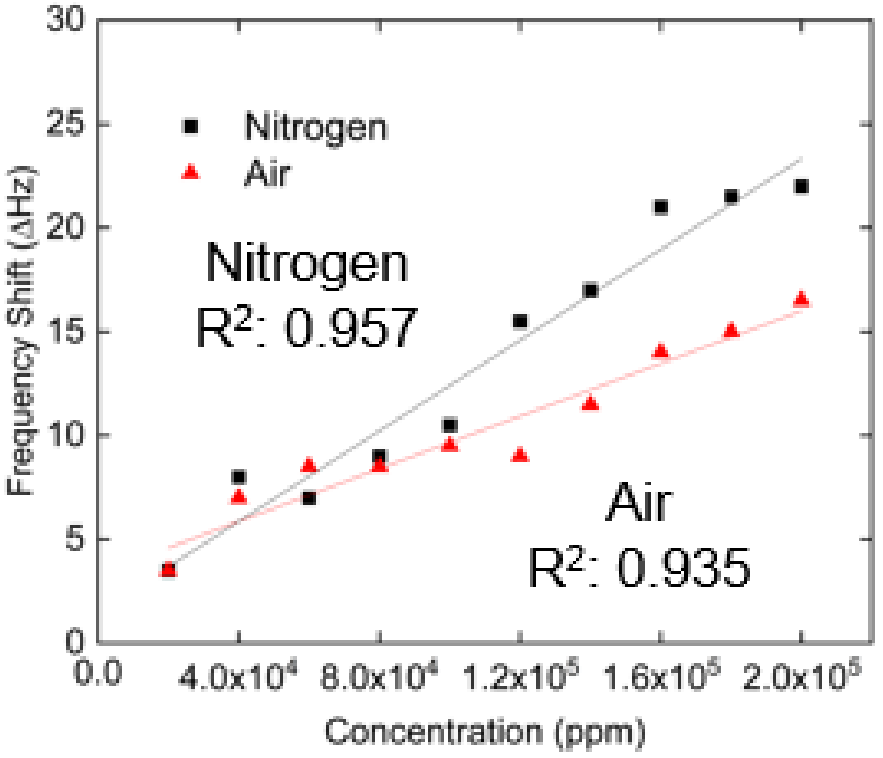


Different Chemistry Detects Flammable Refrigerants

Isobutane (R-600a) Detection



Difluoromethane (R-32) Detection

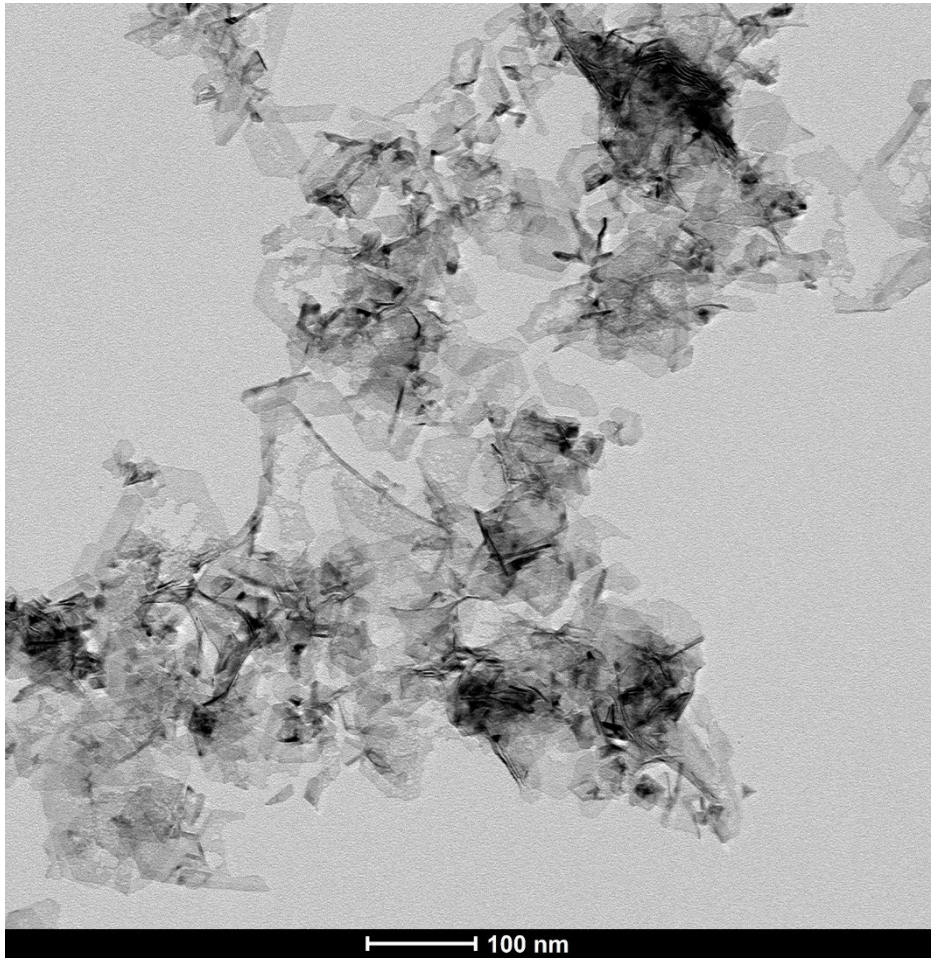


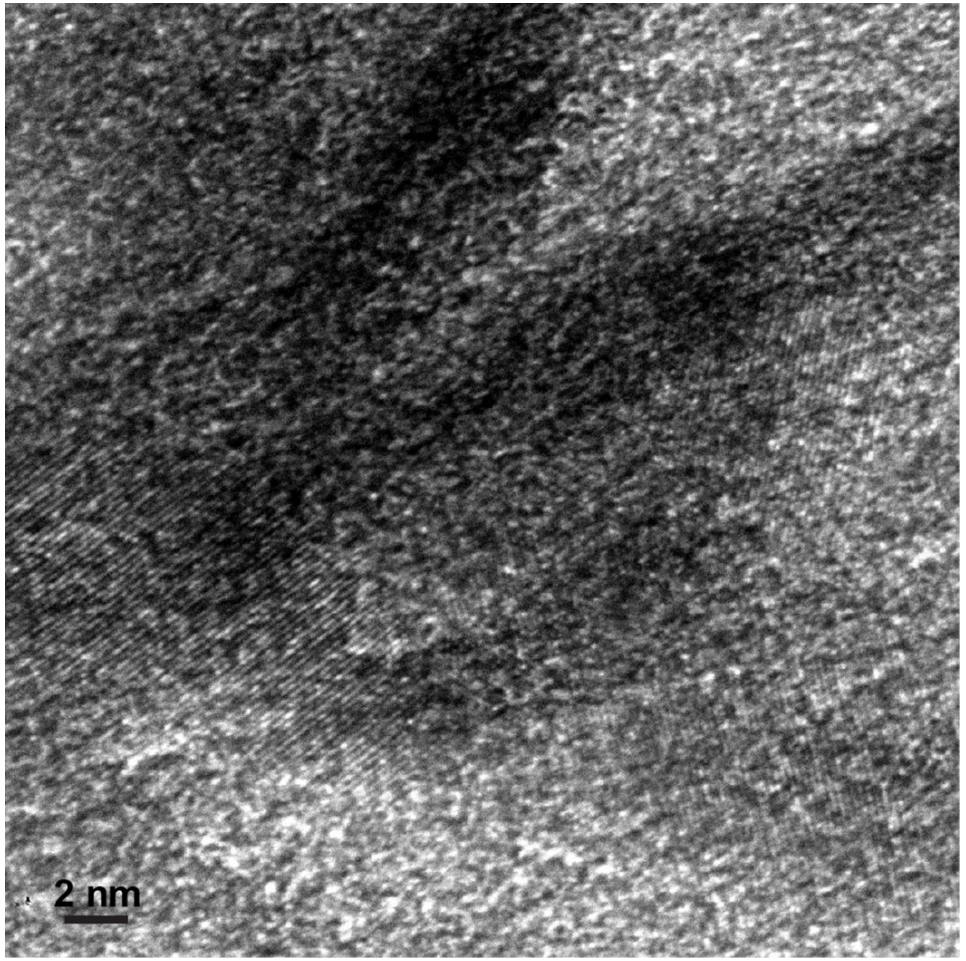
- This detection required the simple printing of a polyaniline (PANI) ink to the top of the mass resonators.

- The customers were interested in detecting at higher concentrations (i.e., near the LFL of the refrigerant gases) based on safety standards.

PdNS are Nanostructured and have High Surface Area

TEM Images of Pd Nanoparticle Sheets

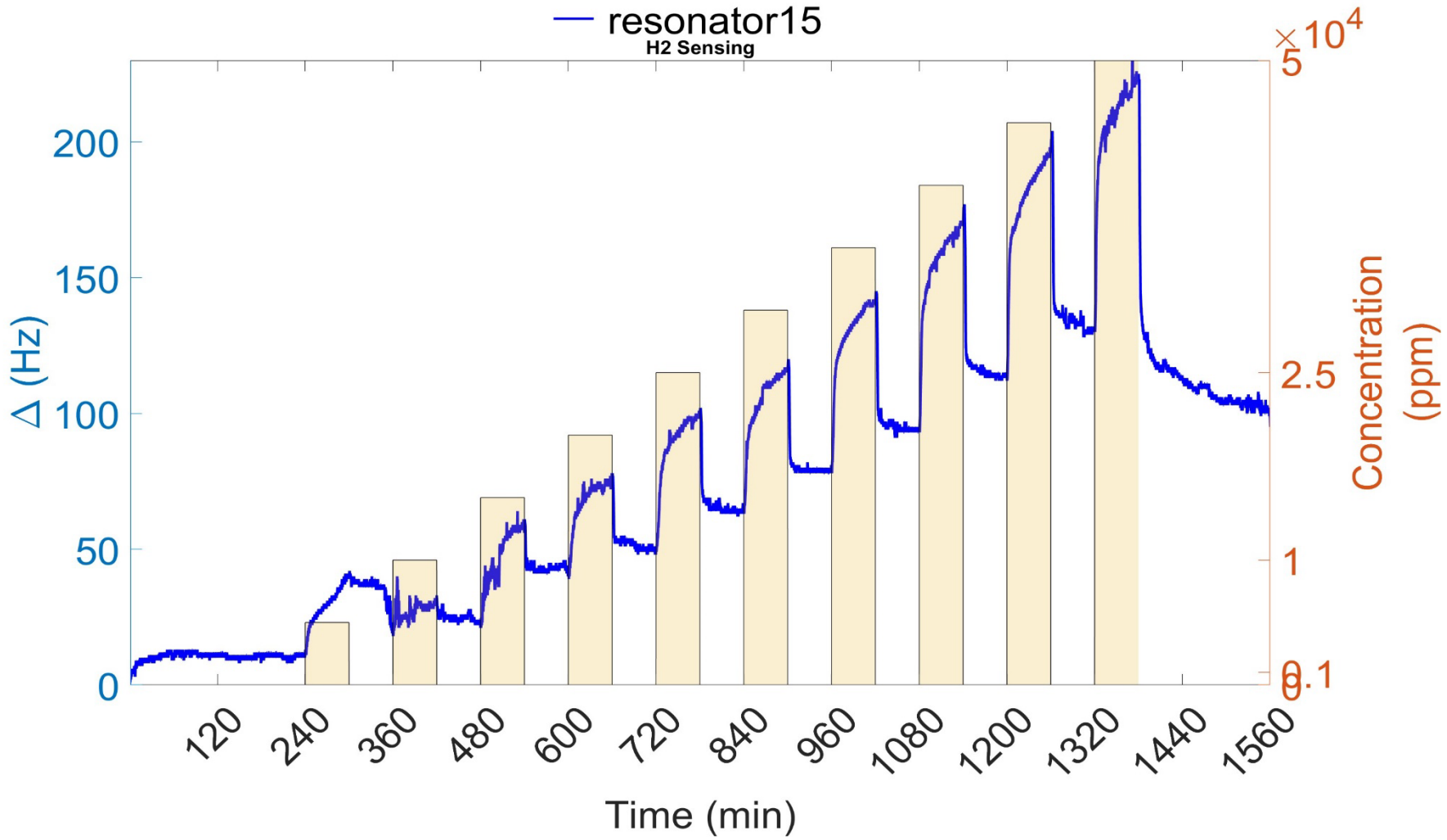




- Chemistry involves simple Pd precursor materials and common ligands that are reacted at 80 °C to yield Pd nanosheets (PdNS), which are suspending in hexanes for printing.

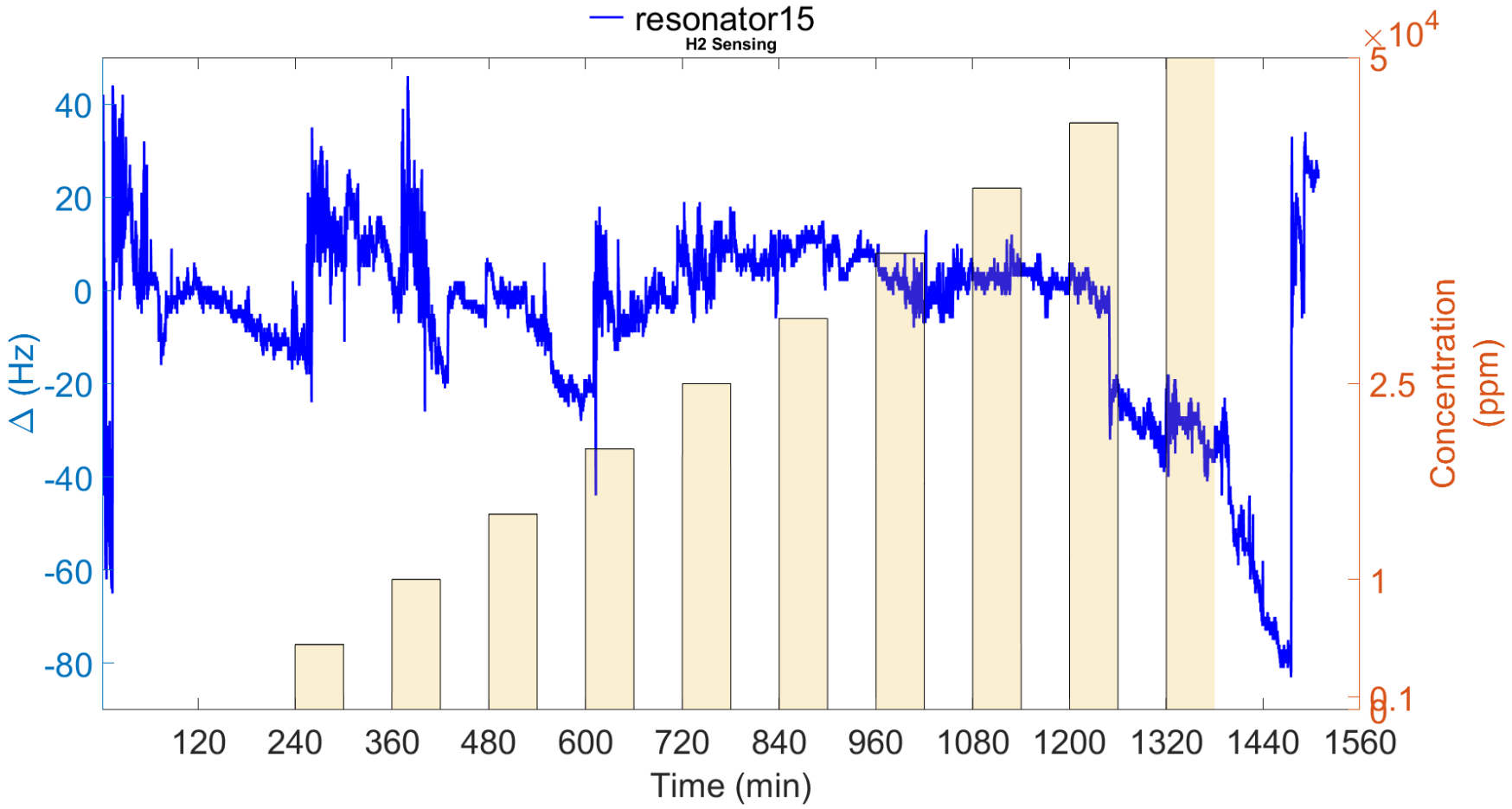
- **< 1 µg of PdNS (i.e., < $0.01 per precursor materials) is used per device.**

Pd Nanosheets (PdNS) Are Great Hydrogen Sensors



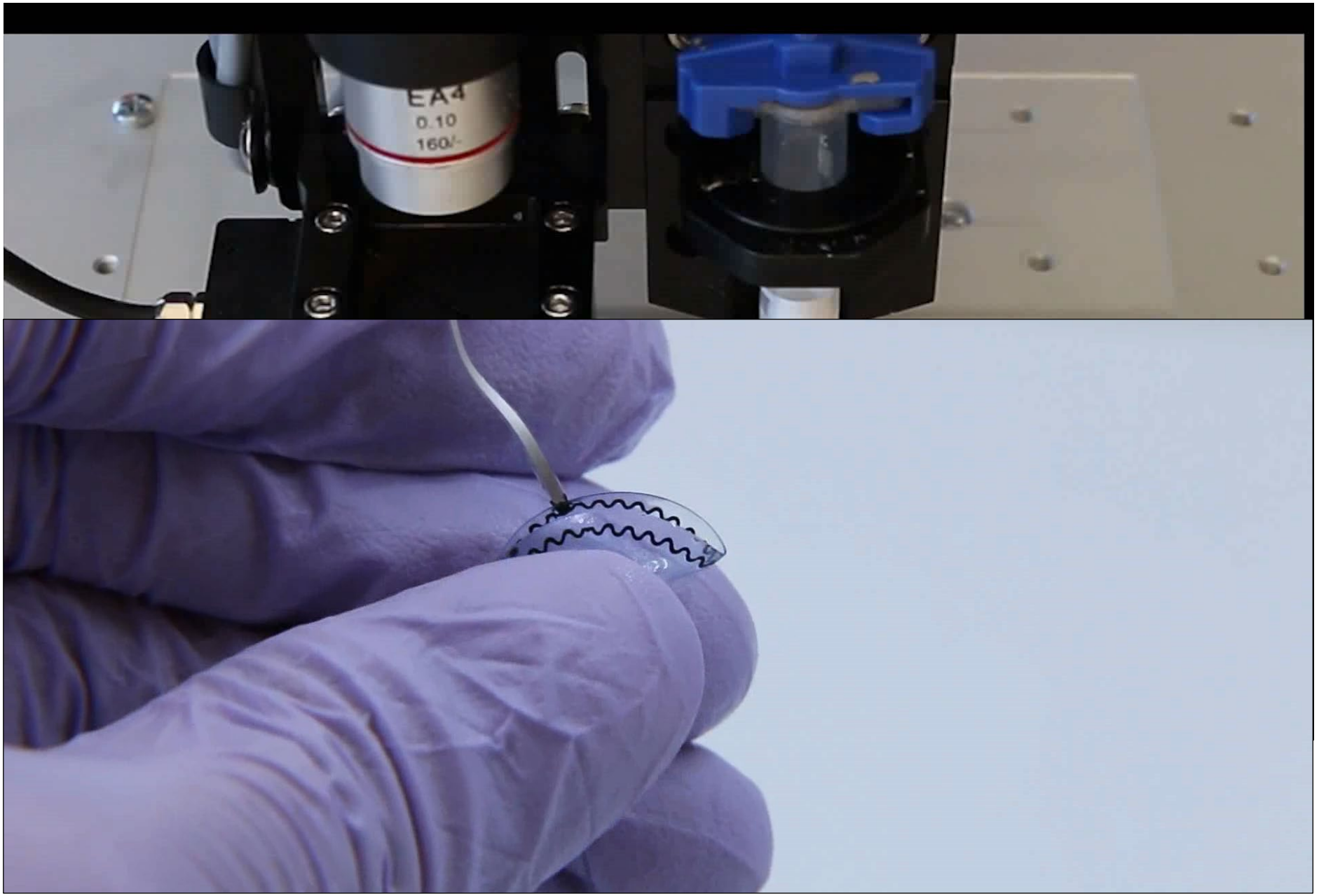
- The BET surface area is somewhat low (i.e., ~50 $m^2\ g^{-1}$).
- **We are looking to increase the surface area to increase the performance to an even greater degree.**

These Sensors are <u>Not</u> Flow Monitors



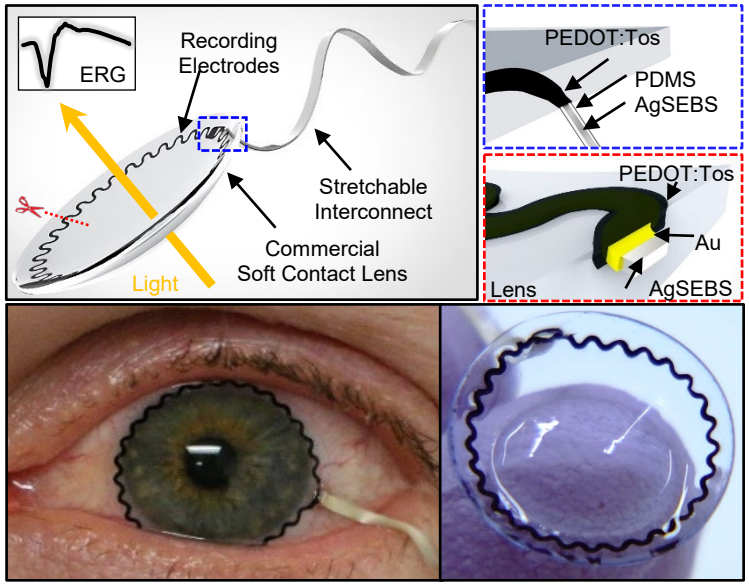
- Currently finalizing calibration curves across a range of hydrogen sensing concentration with and without humidity.
- Ensuring that the sensors do not respond to distractant gases.

Printing Polymers on Contact Lenses for Advanced Biosensors

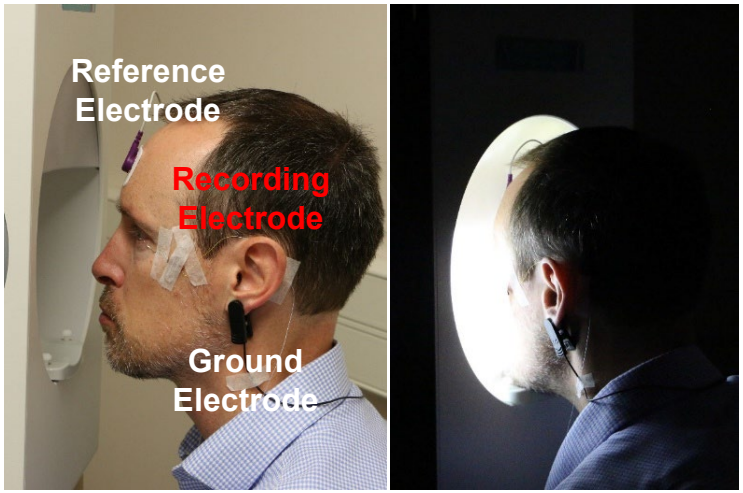


Printing Polymers on Contact Lenses for Advanced Biosensors

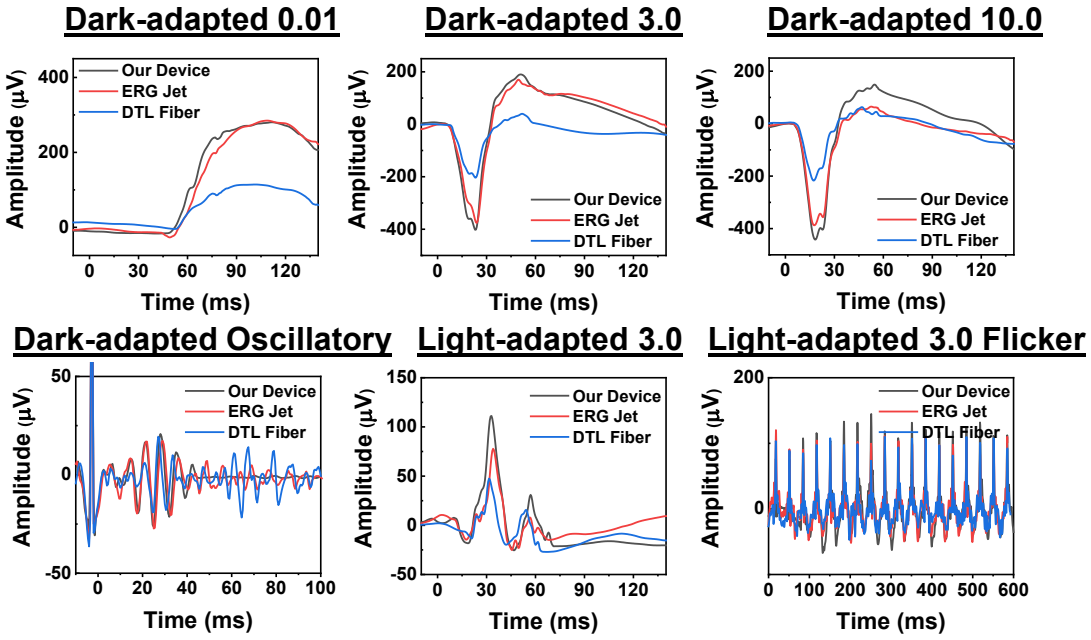
Simple Device Design

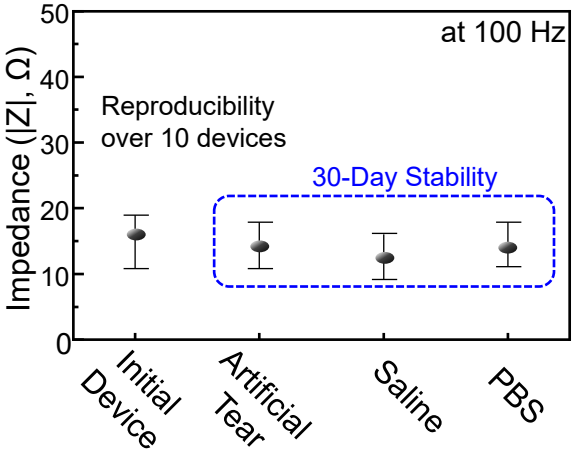


Provides Comfort to the User



Devices Perform Better than the State-of-the-Art



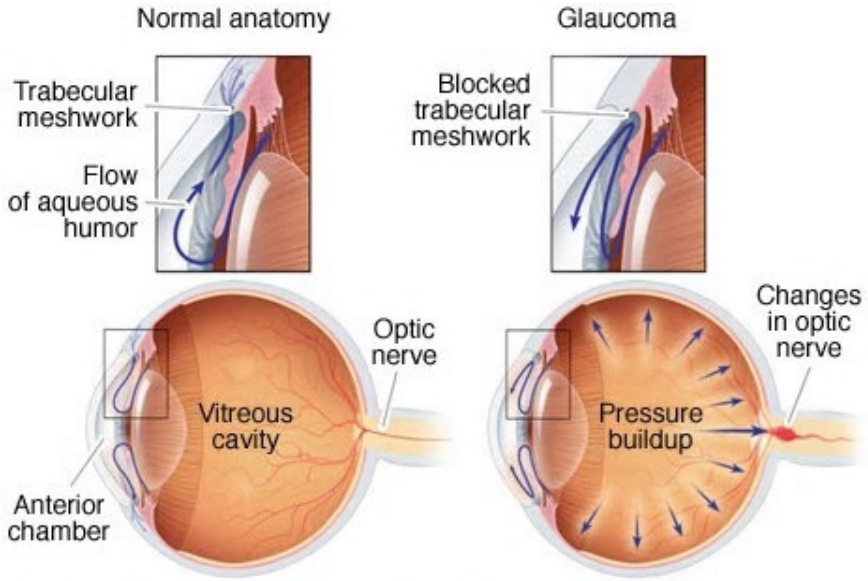


By printing engineered soft polymer electronics onto a commercial soft (i.e., hydrogel) contact lens, the device shows the same stability as one would see for a contact lens when exposed to a variety of environmental conditions.

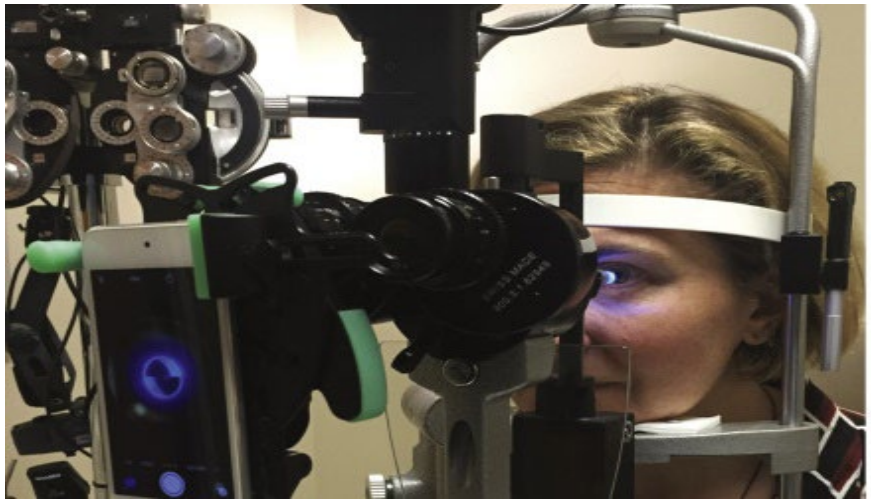
Kim, K.; et al. *Nature Communications* **2021**, *12*, 1544.

Glaucoma is the Leading Cause of Irreversible Blindness

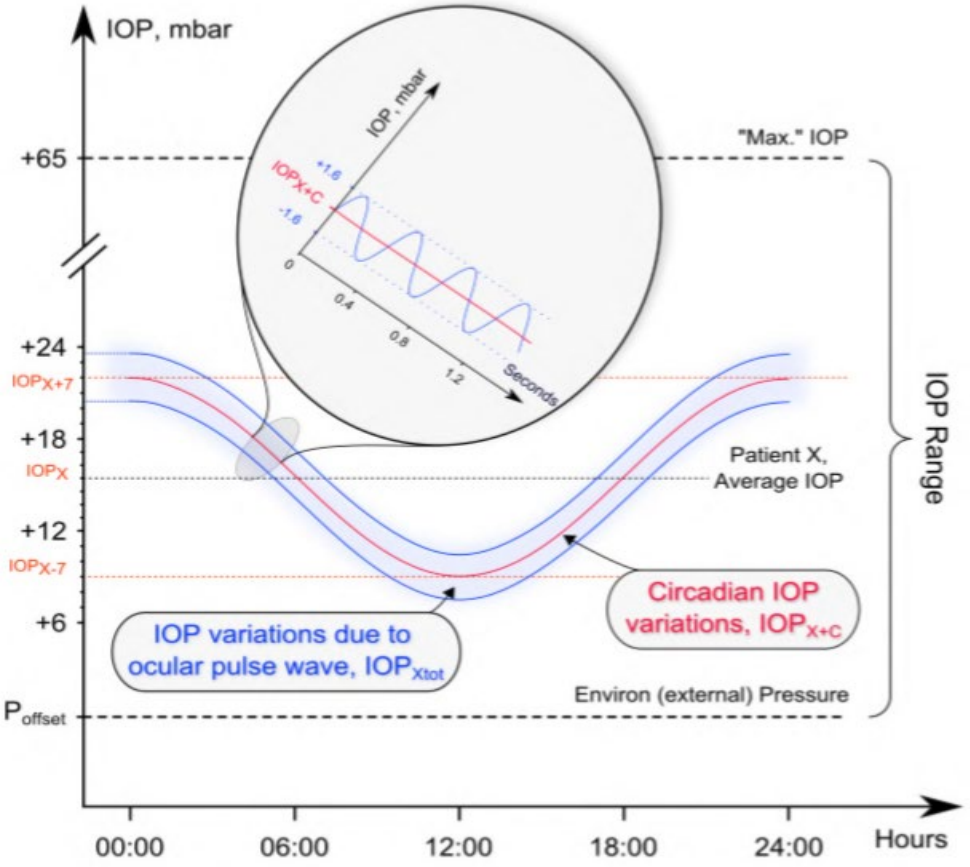
Increased IOP Linked to Glaucoma



Clinical Testing is Nontrivial



IOP Fluctuates throughout the Day

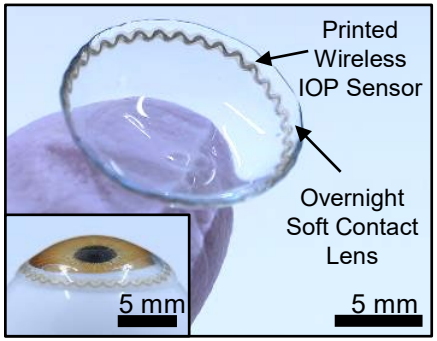


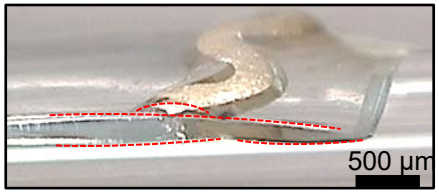
Hughes, E.et al. (2003). *Journal of Glaucoma*, *12*(3), 232-236.

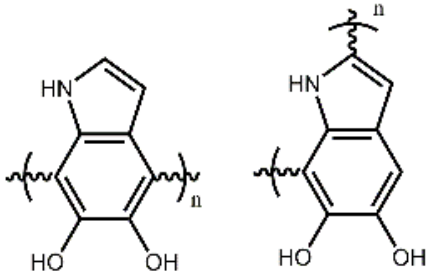
Piffaretti, F., et al. (2013, July). *EMBC* (pp. 3198-3201). IEEE.

Addition of a Polydopamine (PDA) Layer Works Well

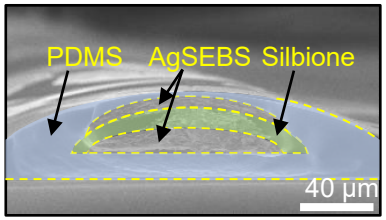
IOP Sensors are Thin and Printed on SCLs



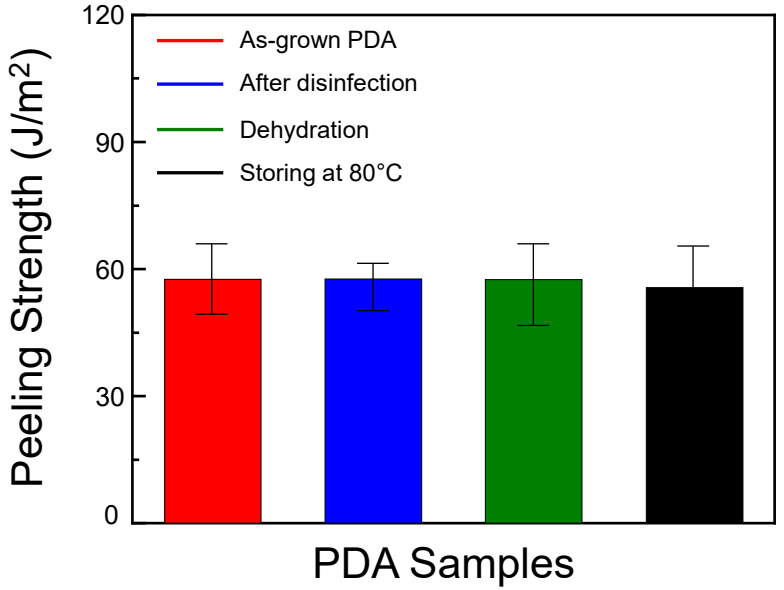




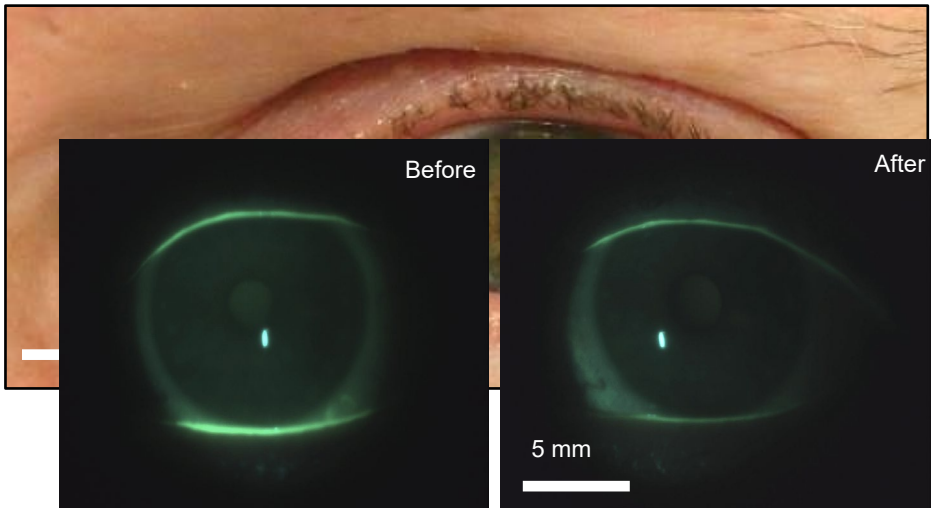
Polydopamine

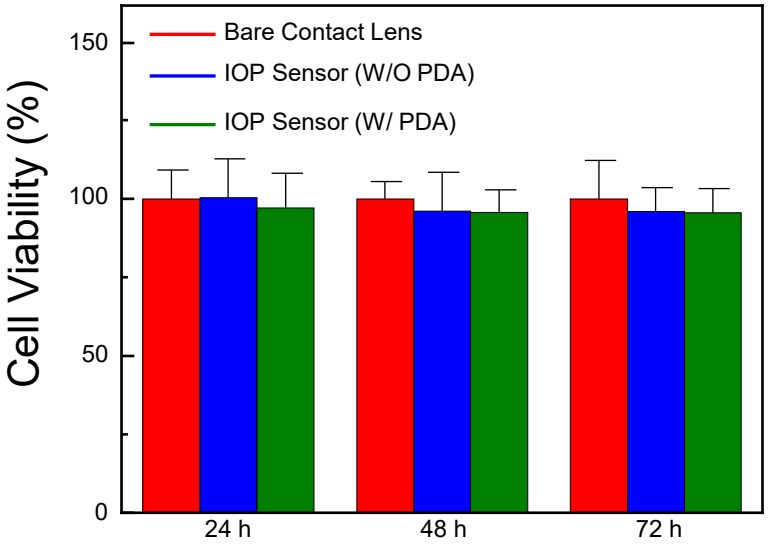


IOP Sensors are Robust and Biocompatible



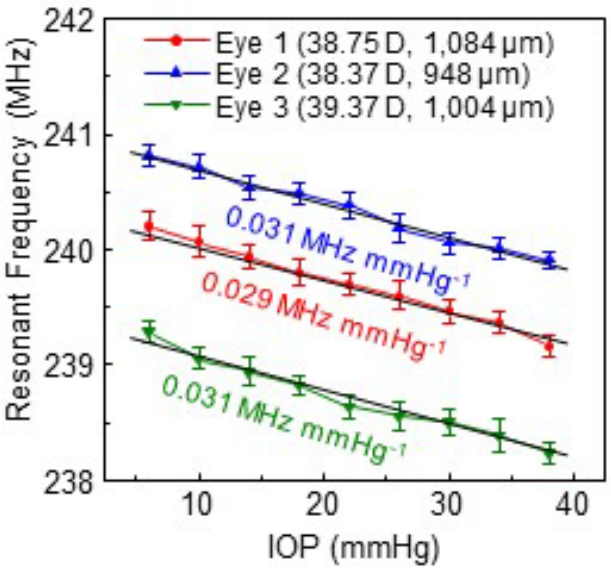
Sensor is Easy to Wear and Comfortable



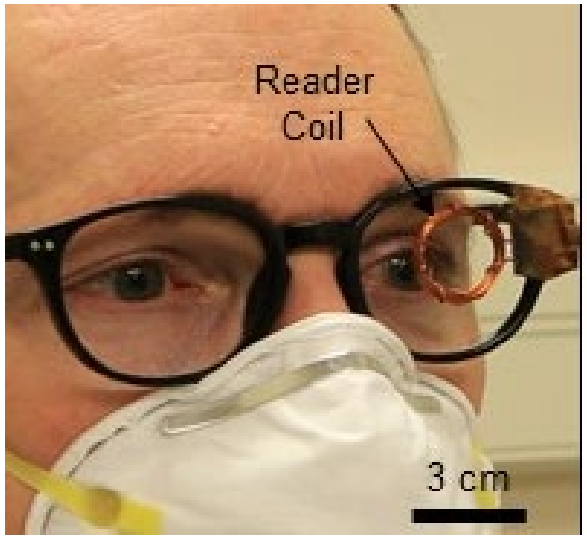


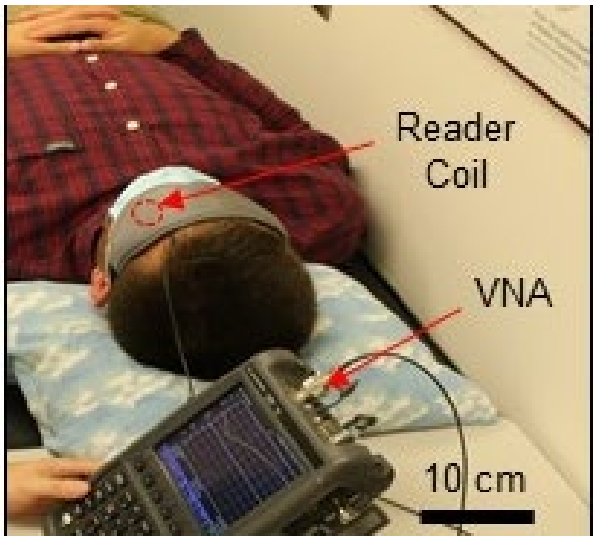
IOP Measurements Work Well in Animals and Humans

Consistent in Porcine Eyes

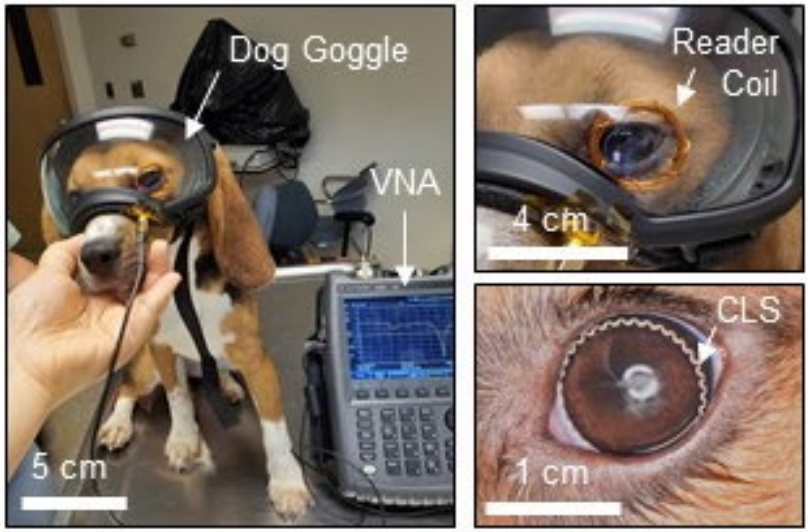


Comfortable to Wear in Sitting and Sleeping Positions

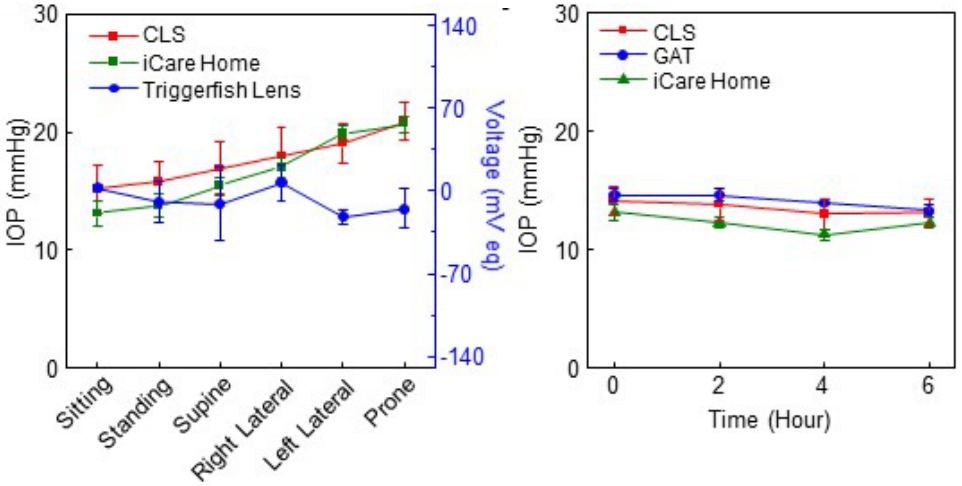




Works Well in Dogs with Glaucoma



Performance on Par with Gold Standards



Zhang, J.; et al. *Nature Communications* **2022**, *13*, 2784.

Acknowledgements

Boudouris Research Group

- Lizbeth Rostro (Dow); Aditya Baradwaj (Intel); Sanjoy Mukherjee (University of California, Santa Barbara); Seung Hyun Sung (LG); Varad Agarkar (Louisiana State University) Ned Tomlinson (Bostik); Martha Hay (Intel); Jaeyub Chung (University of Minnesota); Daniel Wilcox
- Ryan Mulvenna (Dow); Darby Hoss (Intel); Jennifer Laster (Intel); Teng Chi (University of Notre Dame); Xikang Zhao (Chinese National Petroleum Corporation); Teng Chi (University of Notre Dame)

Collaborators

- Jeff Rhoads (ME Purdue)
- Hari Subramani (Chevron)

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

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