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Highly Selective and Stable Multivariable Gas Sensors for Enhanced Robustness and Reliability of SOFC Operation

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Abstract

GE Global Research, in partnership with SUNY Polytechnic Institute and GE–Fuel Cells LLC, proposed an 18-month program to develop and perform initial field validation tests of highly stable and gas-selective sensors for in situ monitoring of gases produced with on-site steam reforming in solid oxide fuel cell (SOFC) systems. The knowledge from this sensor will allow accurate SOFC control and will deliver a lower operating cost for SOFC customers.

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Project objective

The program objective is to achieve the highly desired selectivity and stability of sensing of gases for SOFC application by implementing a new generation of gas sensors, known as multivariable sensors [1-6]. This program will culminate with field validation of developed sensors on GE SOFC systems.

In Phase 1, we will develop sensing materials, perform lab tests for sensitivity and stability, downselect sensor designs, and perform field validation of developed sensors on a SOFC system at GE–Fuel Cells.

Phase 1 will advance fundamental understanding of multivariable gas sensing at high temperatures and will enable cost-effective and stable sensors for SOFC applications. In situ data generated by the sensors will allow development of recommendations for Phase 2 deliverables.

(1) Potyrailo et al. *Nat. Photonics* **2007**, *1*, 123-128
(2) Potyrailo et al. *Chem. Rev.* **2011**, *111*, 7315–7354
(3) Carpenter et al. *Anal. Chem.* **2012**, *84*, 5025-5034
(4) Potyrailo et al. *Proc. Natl. Acad. Sci. U.S.A.* **2013**, *110*, 15567–15572
(5) Potyrailo et al. *Nat. Commun.* **2015**, *6*, 7959
(6) Potyrailo *Chem. Rev.* **2016**, accepted

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The team

GE Global Research

Requirements flow-down from optical system design to multi-gas sensing, fabrication of sensors, lab tests for selectivity with gas mixtures, stability tests, sensors downselection, field validation

SUNY Polytechnic Institute

Fabrication of sensors, lab tests for sensitivity with individual gases, characterization of sensing films

GE Fuel-Cells

Field validation assistance, sensor benchmarking, recommendations for Phase 2 plan and deliverables

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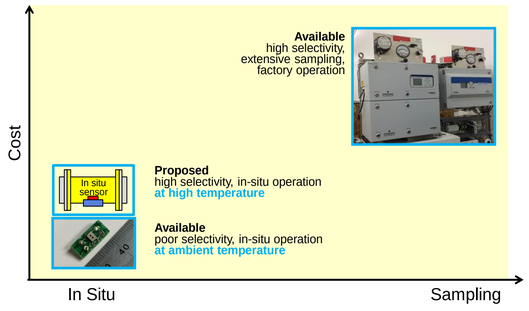
Examples of available offerings and the proposed sensor



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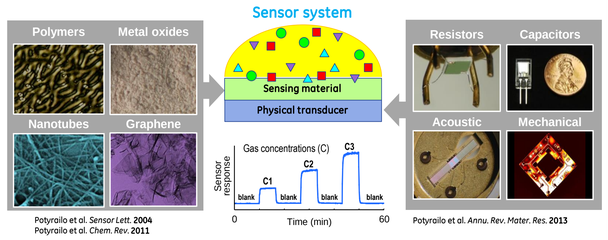
Anatomy of conventional gas sensors



Appropriate pairing of ***transducer + sensing material*** is the key for meeting detection requirements

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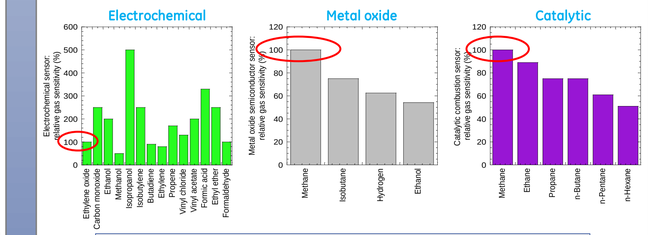
Selectivity challenges in major types of sensors



Non-selective response to different gases is a significant accuracy limitation of conventional sensors
Origin: conflicting requirements for sensor selectivity vs. reversibility

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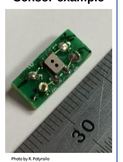
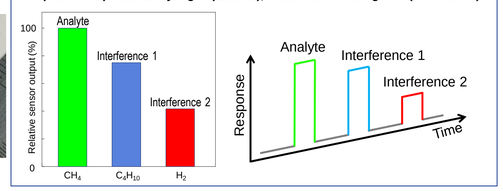
Accuracy demands in gas sensors

Sensor example



Response to specific analyte gas (desired), other interference gases (not desired)



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Origin: conflicting requirements for sensor selectivity vs. reversibility

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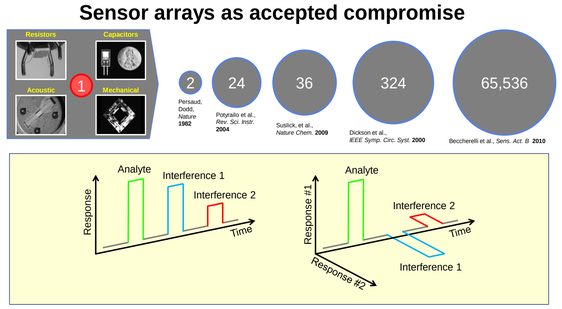
Sensor arrays as accepted compromise



High dispersion of sensor response improves selectivity (= accuracy)

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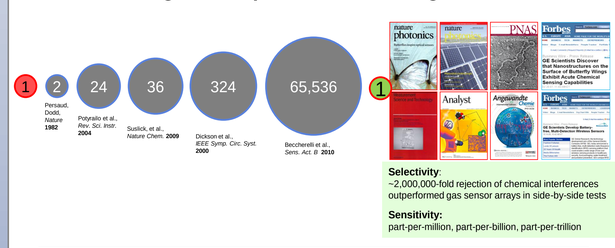
Breaking status quo: multivariable gas sensors



Selectivity:
~2,000,000-fold rejection of chemical interferences outperformed gas sensor arrays in side-by-side tests

Sensitivity:
part-per-million, part-per-billion, part-per-trillion

Individual multivariable sensors:
- Several independent responses from individual sensor
- Disruptively overcome insufficient selectivity of existing sensors

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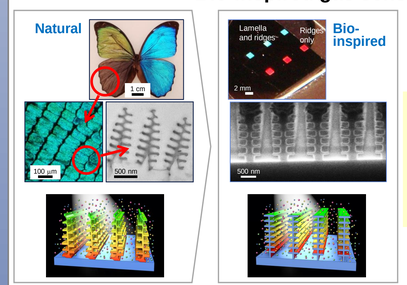
Bio-inspired gas sensors



Design rules for gas-selectivity control:
- Spatial orientation of surface functionalization
- Chemistry of surface functionalization
- Extinction and scattering of nonostructure

Potyrailo et al. *Nature Comm.* **2015**

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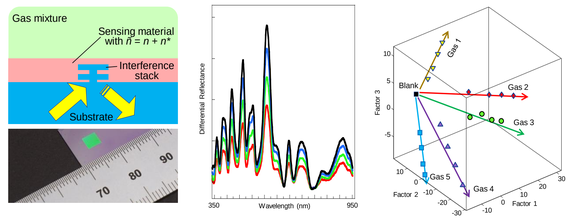
Proposed multivariable optical sensor based on interference stacks



Proof-of concept: Potyrailo et al. *Nature Comm.* **2015**

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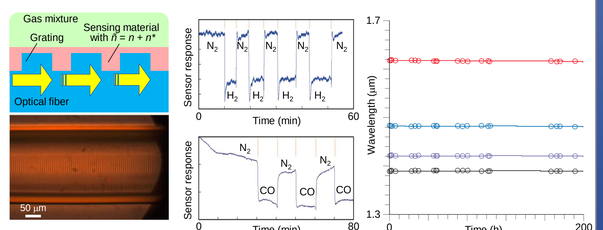
Proposed multivariable optical grating-based sensor



Proof-of concept: Wu, J., Distributed Fiber Optic Gas Sensing for Harsh Environment, Final Report, Department of Energy, NETL, Award DE-FC26-05NT42438 2008, http://www.osti.gov/scitech/servlets/purl/938805

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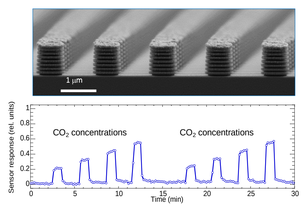
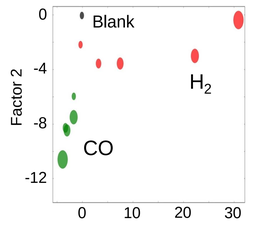
Example of proposed sensing structures and materials for multivariable optical sensors



Proof-of-concept: GE



Proof-of-concept:
Carpenter et al. *Anal. Chem.* **2012**, *84*, 5025-5034.

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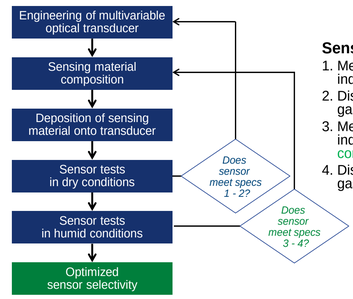
Selectivity optimization of multivariable optical gas sensors



Sensor specifications:
1. Measurement dynamic range for individual gases in dry conditions
2. Discrimination between different gases in dry conditions
3. Measurement dynamic range for individual gases in humid conditions
4. Discrimination between different gases in humid conditions

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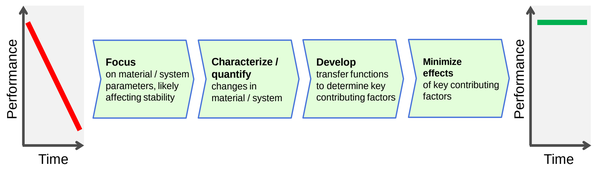
Improvement of material and system stability using a four-step Six Sigma process



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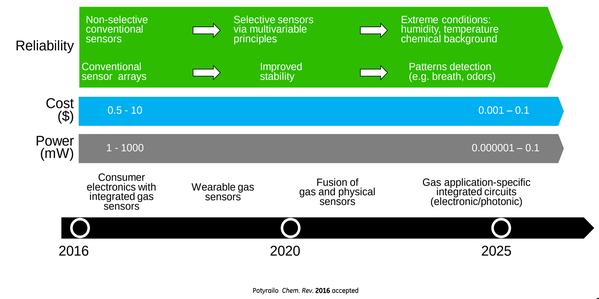
2025 roadmap for gas sensors



Potyrailo *Chem. Rev.* **2016** accepted

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