BIPASS: Low Power Sensors for the Trace Detection of Threats in the Vapor Phase

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Proprietary

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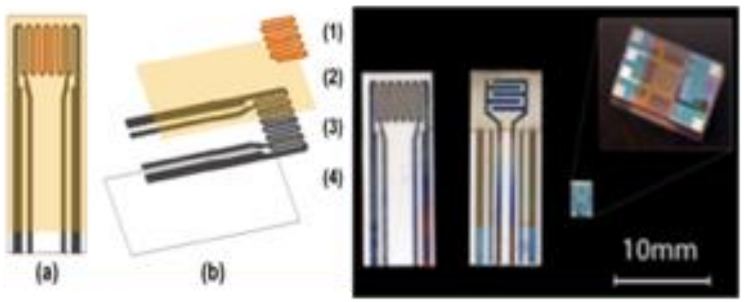
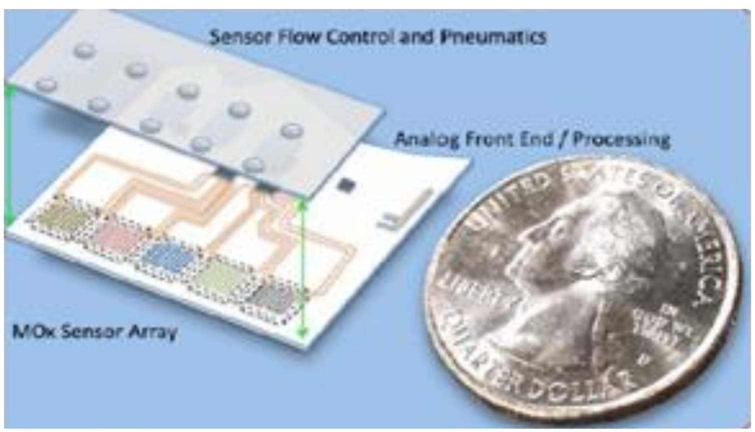
Digital Dog Nose: A Thermodynamic Sensor



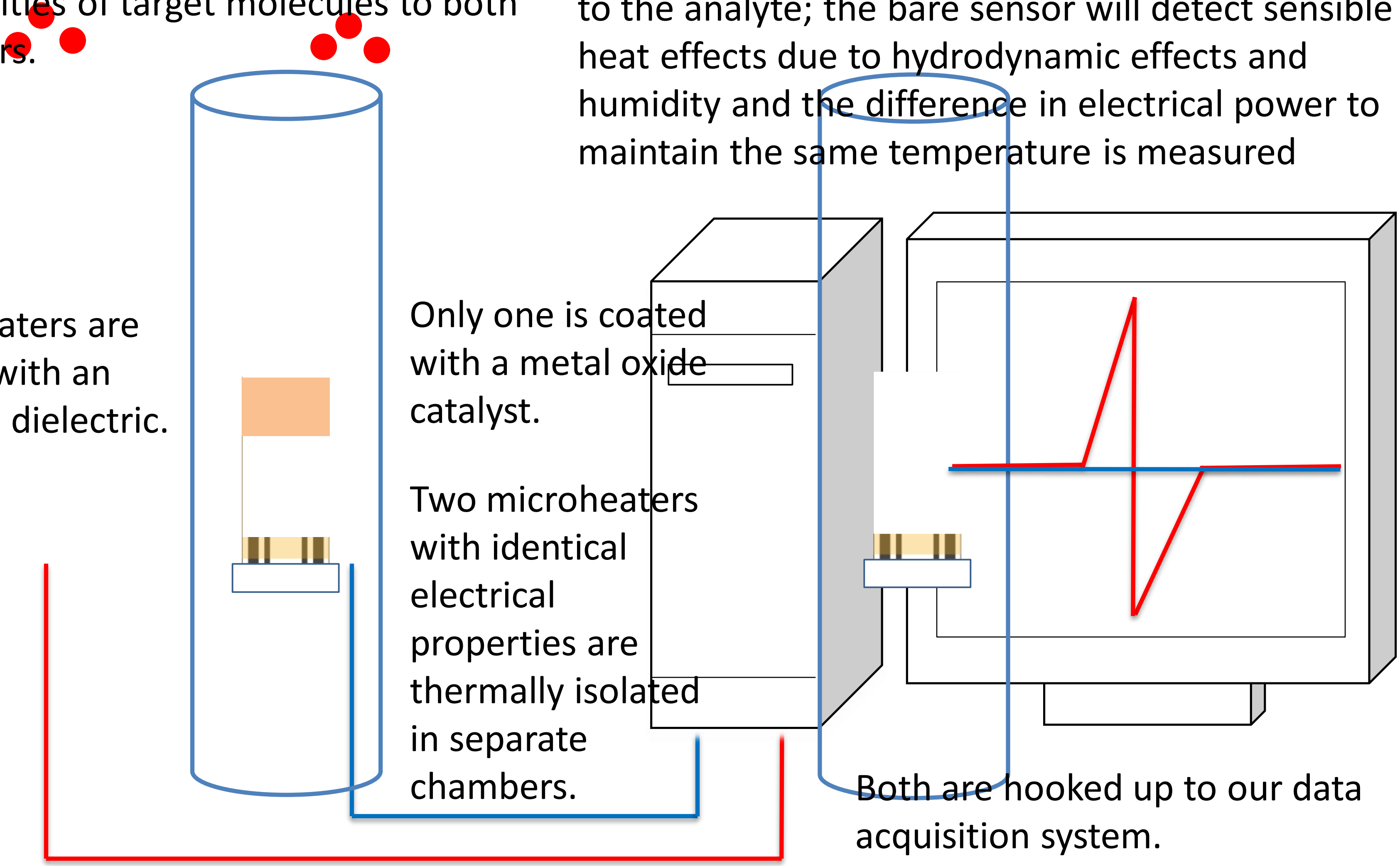


- Our detection system employs a digital control system, which enables two microheaters to be scanned over a selected temperature range
- One microheater is coated with a metal oxide catalyst, which interacts with the target molecule and results in the catalytic decomposition of the molecule: *the measured heat effect*
- The other microheater is not coated and not responsive to the energetic material (acts like a reference); thus, sensible heat effects are subtracted and only the heat effect associated with catalytic decomposition is measured

How Our Sensor Works

Mass flow controllers deliver equal quantities of target molecules to both sensors.

Only the catalyst coated microheater will respond to the analyte; the bare sensor will detect sensible heat effects due to hydrodynamic effects and humidity and the difference in electrical power to maintain the same temperature is measured



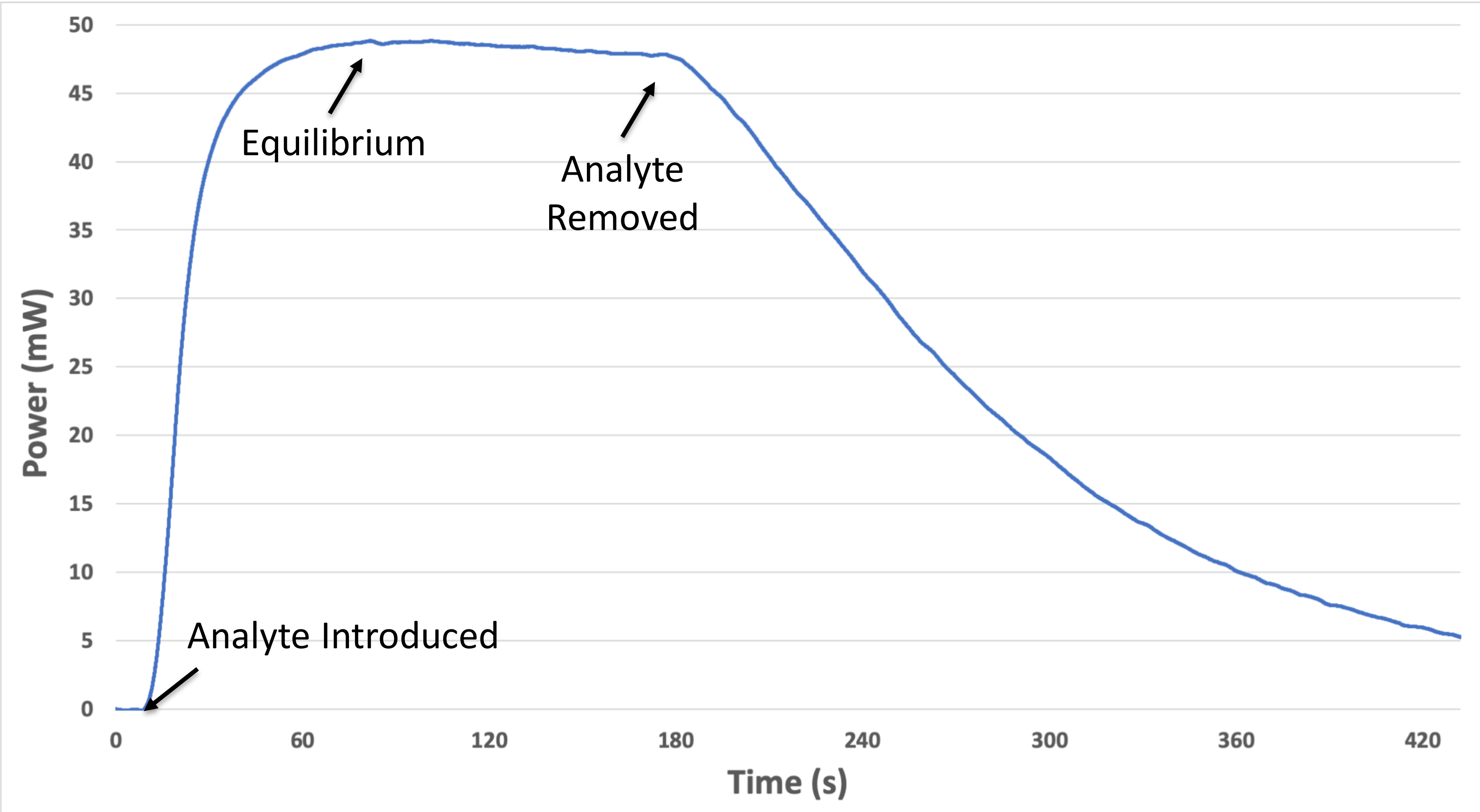
Both heaters are coated with an alumina dielectric.

Only one is coated with a metal oxide catalyst.

Two microheaters with identical electrical properties are thermally isolated in separate chambers.

Both are hooked up to our data acquisition system.

Response of thermodynamic sensor to 20 ppm TATP



The figure above shows a typical response curve for our thermodynamic sensor platform

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Alumina vs YSZ Microheater Comparison: IR Analysis

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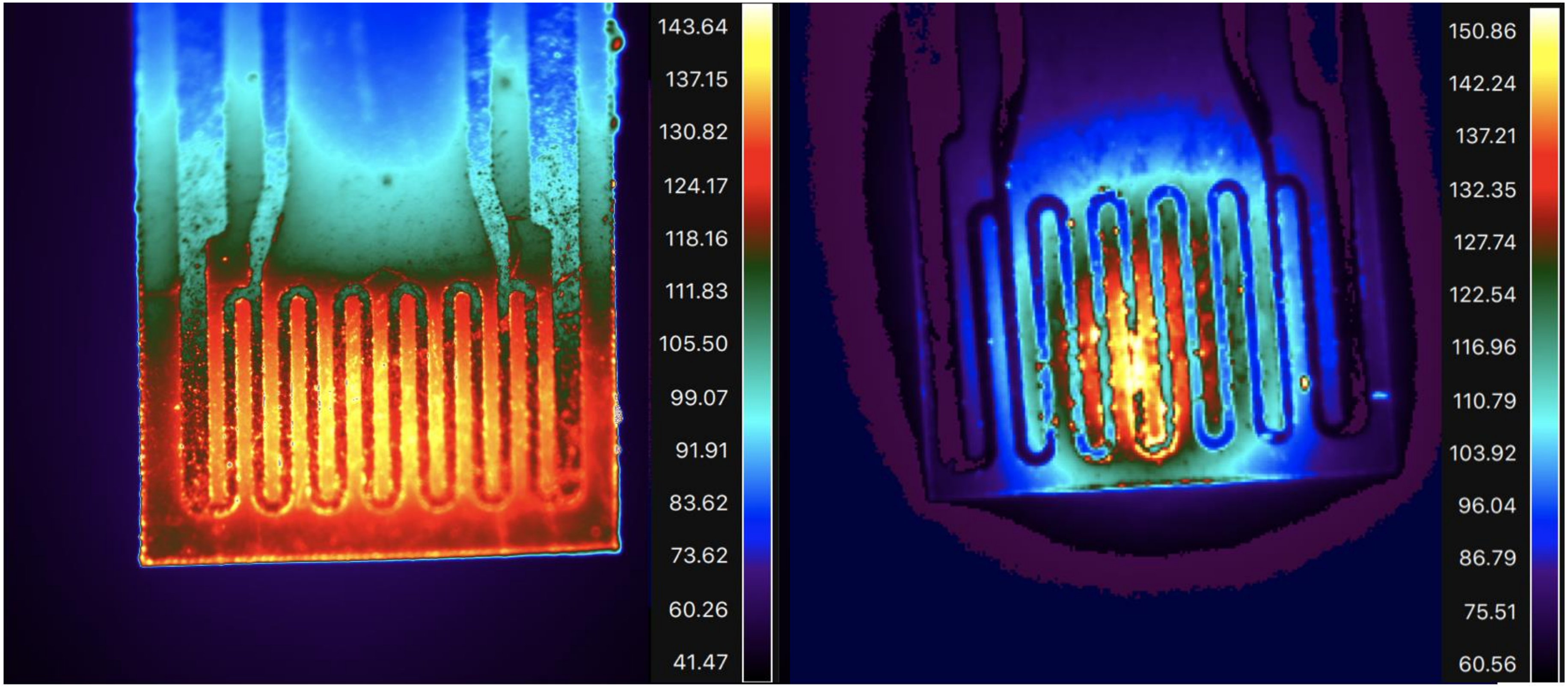
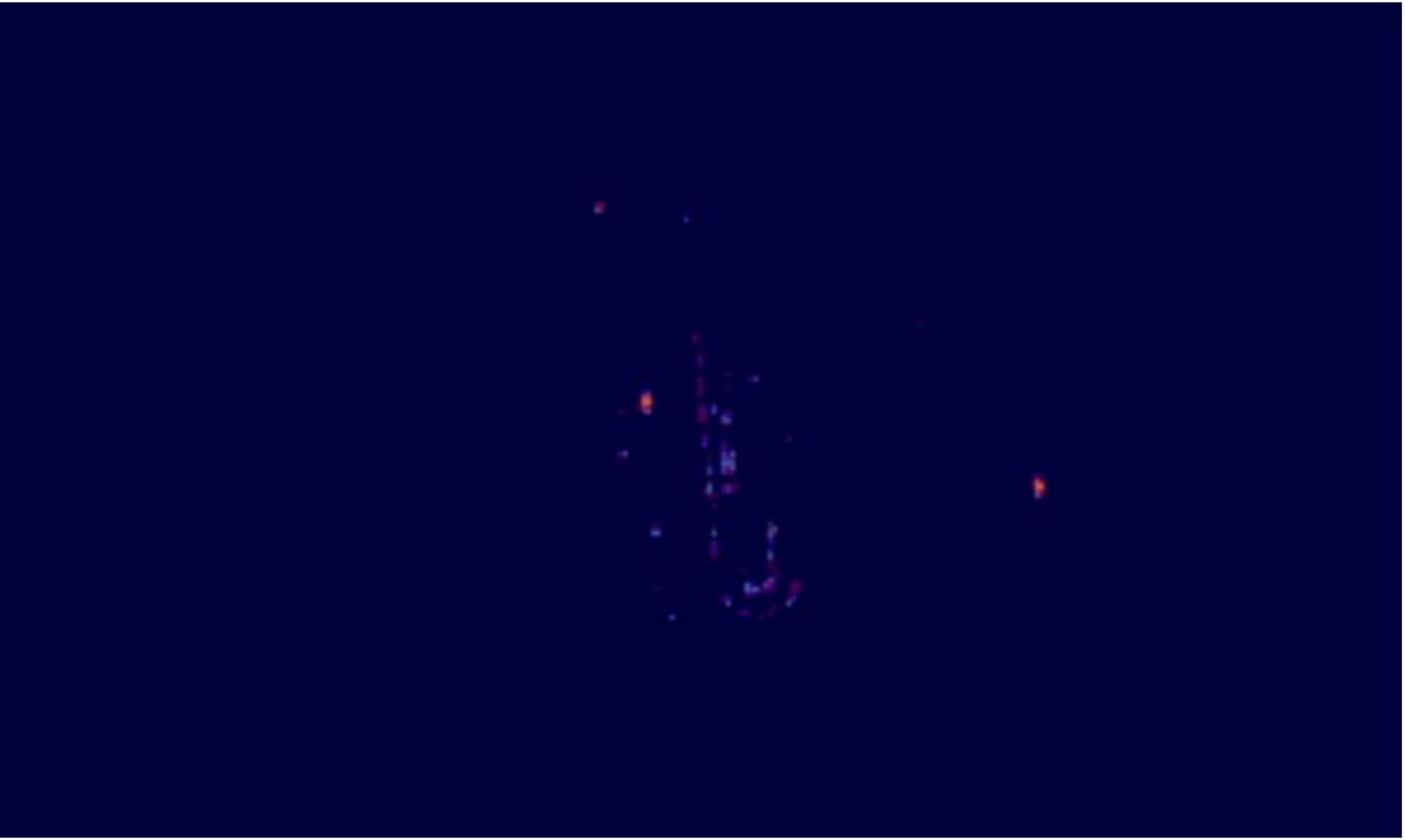


Thin film microheater on 1mm thick alumina substrate

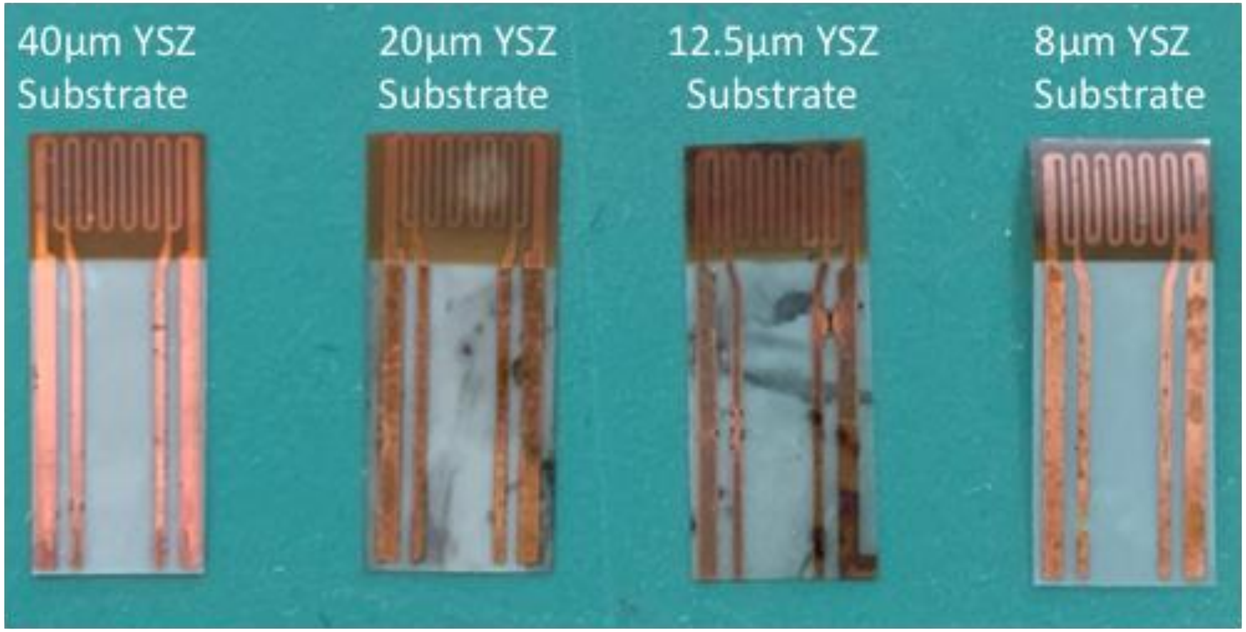
Thin film microheater on ultrathin YSZ substrate

Anisotropy , Lower Thermal Conductivity of YSZ Produces More Localized Heat

Alumina vs YSZ Microheater Comparison: IR Analysis



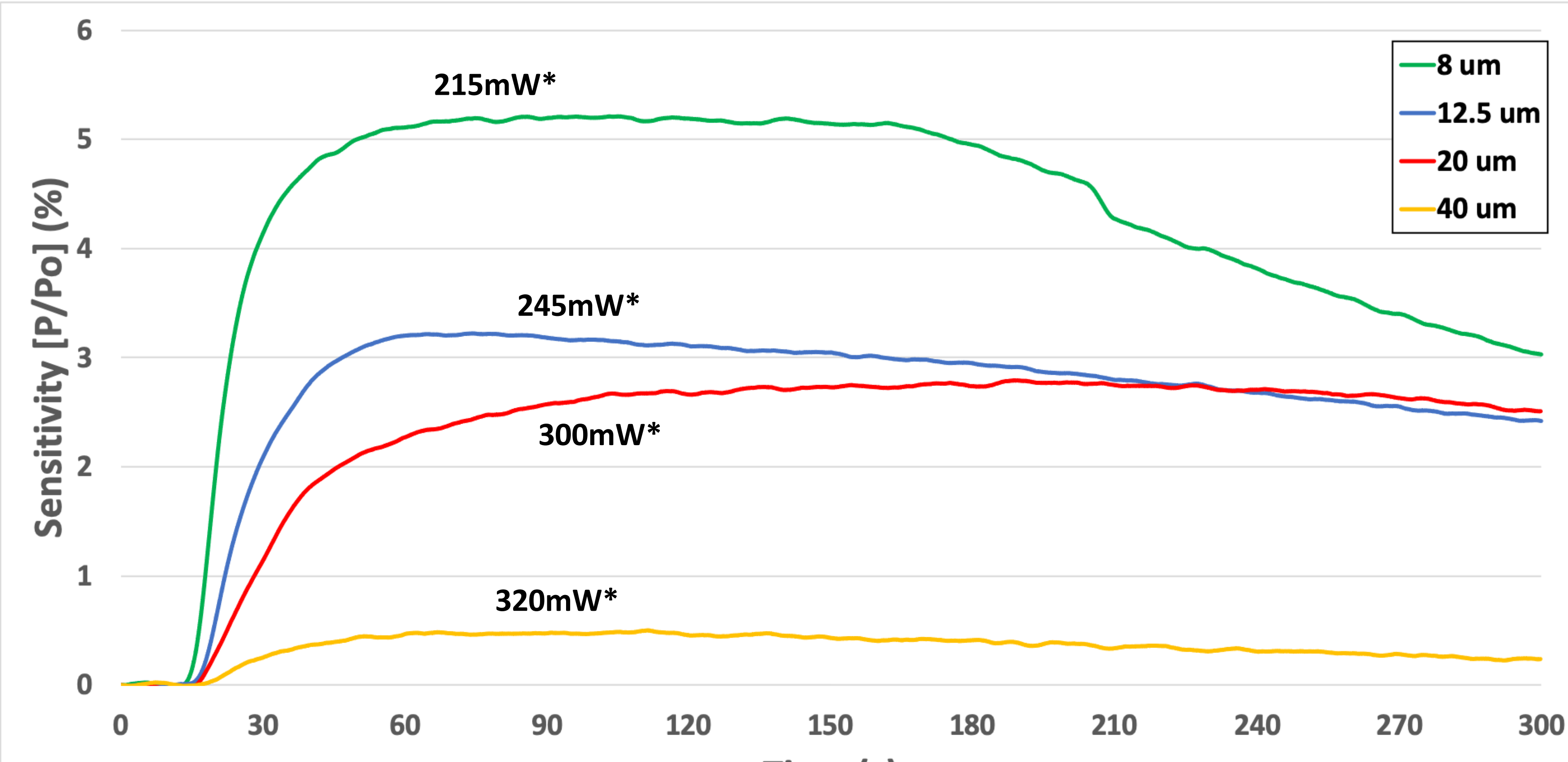
Cu Microheaters Fabricated on Ultrathin YSZ Substrates



Flexing due to compressive stress of the catalyst layer

- The figures above show a series fully fabricated YSZ based microheaters on a variety of thicknesses of YSZ substrate
- The 8µm YSZ microheaters possess an overall thickness of ~11.5µm at the serpentine
- Through continued reduction in thermal mass without a sacrifice in catalyst surface area, further improved sensitivity and response time were expected

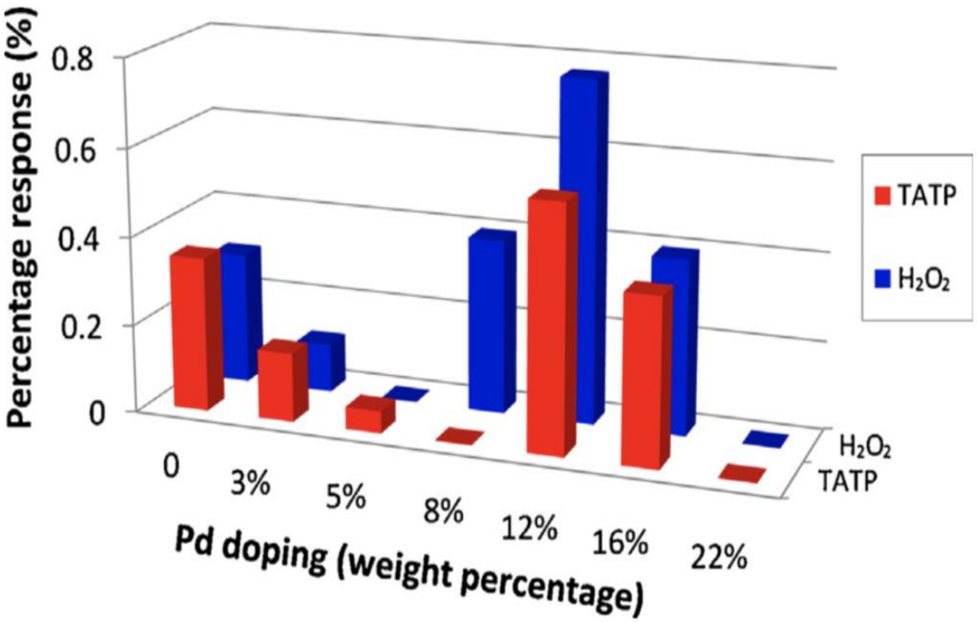
Effect of Substrate Thickness on Sensor Response (20 ppm TATP)

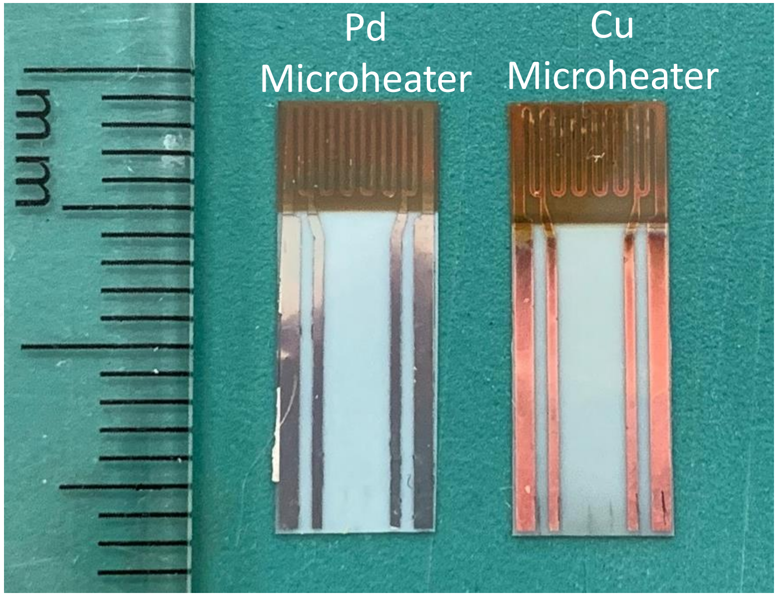


*** Denotes power required to reach 175°C**

The figure above shows a comparison of the responses of four YSZ based microheaters of varying YSZ substrate thickness to 20ppm TATP (T_{op} = 175°C)

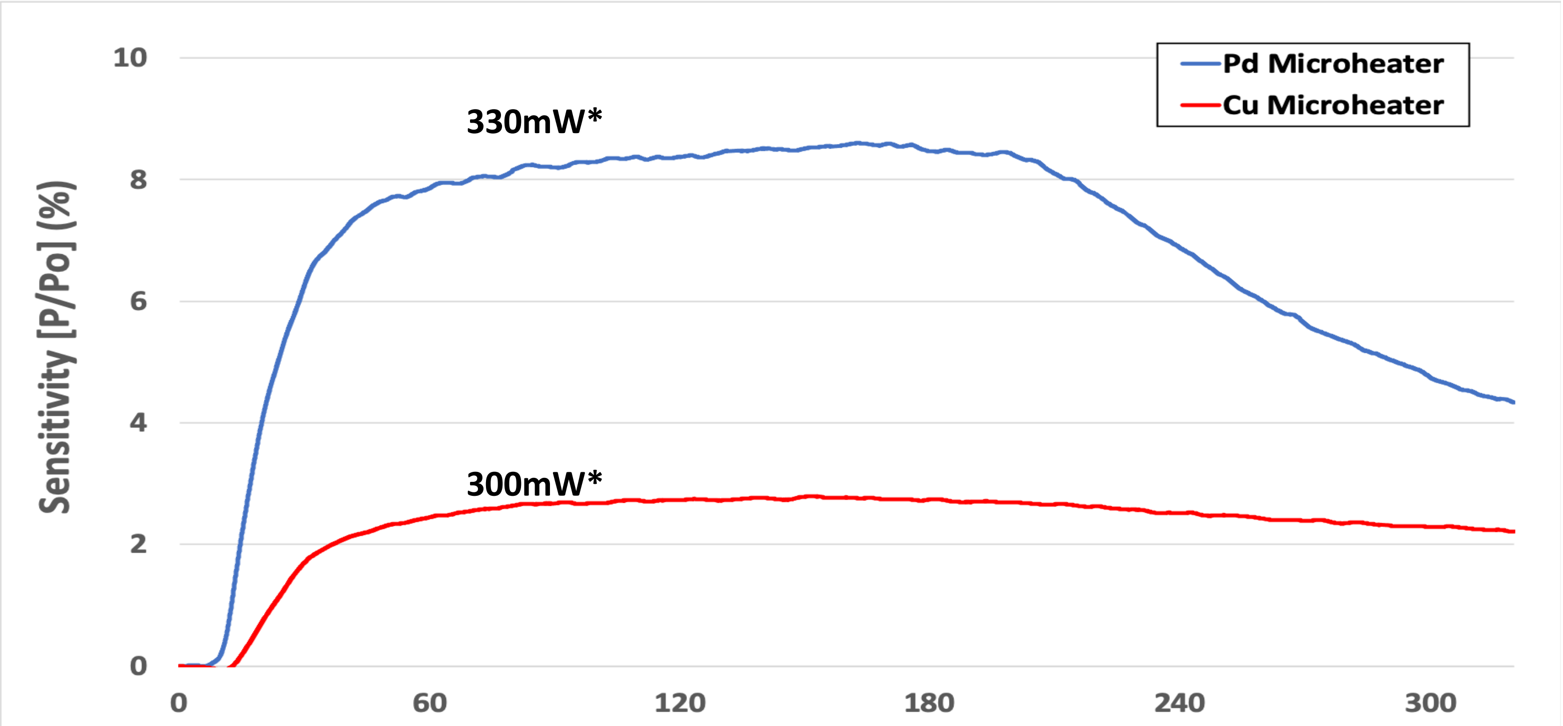
Pd Microheaters Fabricated on Ultrathin YSZ Substrates





- Previous work [Chu et al.] has shown that the presence of Pd nanoparticles within a metal oxide catalyst produce catalyst amplifying properties
- Nanocomposite catalysts fabricated with 12 wt.% Pd and 88 wt.% SnO lead to a maximum in response **(Left)**
- Utilization of Pd as the microheater metallization is expected to display to produce improved sensitivity and response time over previous iterations **(Right)**

Metal oxide "catalyst" on Pd micro-heater sensor response (20 ppm TATP)



* Denotes power required to reach 175°C

- The figure above compares the responses of a Pd-based microheater (blue) and a Cu-based microheater (red) on 20um YSZ substrate to 20ppm TATP (T_{op} = 175°C)
- The catalyst amplifying properties of the Pd microheater allow for improved sensitivity and response time

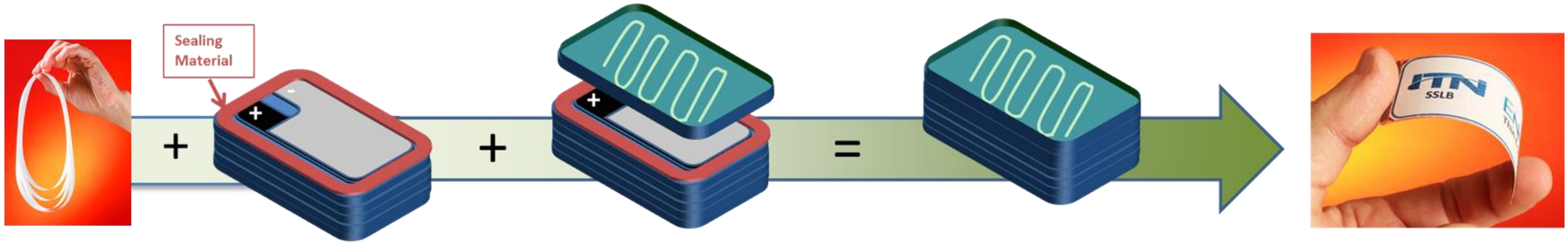
Deposition conditions used to form microheaters on ultrathin YSZ substrates

	Power Requirement (mW)	Sensitivity‡ (%)	Response Time* (s)	Energy (J)
Cu (40 µm YSZ) †	320	**0.5**	**10**	3.2
Cu (20 µm YSZ) †	300	2.75	9	2.7
Cu (12.5 µm YSZ) †	245	3.2	8.5	2.08
Cu (8 µm YSZ) †	**215**	5.2	6	1.29
Pd (40 µm YSZ) †	**370**	4.5	8.75	**3.24**
Pd (20 µm YSZ) †	330	8.5	5	1.65
Pd (12.5 µm YSZ) †	280	10	4.5	1.26
Pd (8 µm YSZ) †	260	**16.2**	**3**	**0.78**

* Response time was arbitrarily determined to be the t10 time or time required to reach 10% of the overall response
† All microheaters fabricated with 0.5µm metallization thickness
‡ All microheaters employed a 0.9µm thick SnO catalyst

- Combination of thinner YSZ substrates and Pd-based metallization has shown to improvement in every category
  - ***Minimize power requirement***: Cu based microheater (8µm YSZ)
  - ***Maximize catalytic response/response time***: Pd based microheater (8µm YSZ)
  - ***Minimize energy requirement***: Pd based microheater (8µm YSZ)

BiPASS Concept



Thin, Flexible YSZ 10-40 μm Thick

Ultra-Thin SSLB Cells/ Stack on 20 μm YSZ

URI Explosives Trace Detector (ETD)/Gas Sensor on 20 μm YSZ

Self-Powered ETD Sensor

- *ITN has a Unique Solid-State Lithium Battery (SSLB) with High Energy Density*
  - *Individual Cells are Deposited on Thin YSZ and Vertically Stacked to Make a Battery*
- *With Funding from the Flex Tech Alliance*, ITN and Partners are Working to Extend the Capability of Paper Thin, Flexible Electronics*
  - *SoP Die Enables Additional Functions, i.e. Sensors/Sensor Systems to be Monolithically Integrated on Top of the Battery*
  - *Combinations of Thin Film Devices, Printed Electronics, and High-Performance Microelectronics*

Projects sponsored by the FlexTech Alliance

Thin Flexible Power Source Based on SSLB (Sept 2016-Feb 2018)

Flexible Integrated Power Pack Integrating CdTe PV with SSLB (Aug 2017-July 2018)

Ultra-Thin, Self-Powered Sensors (Nov 2018-July 2020)

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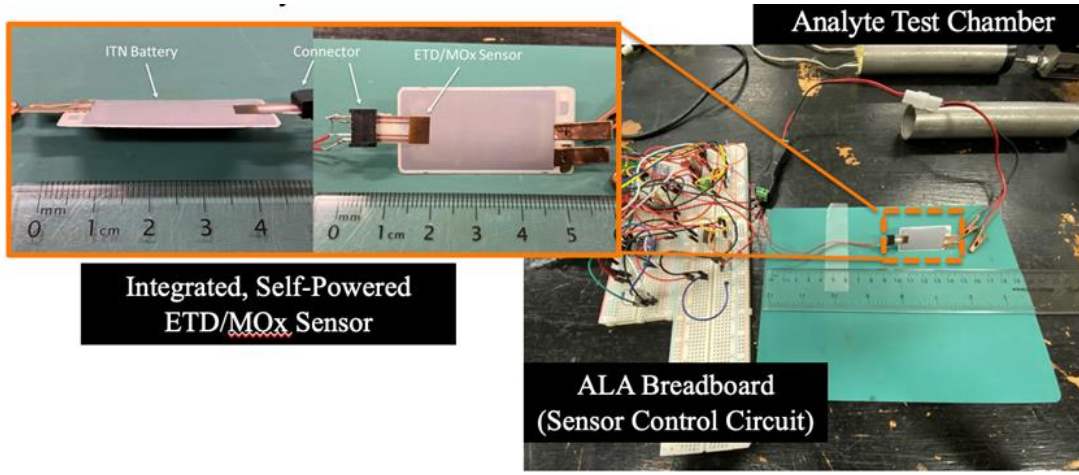
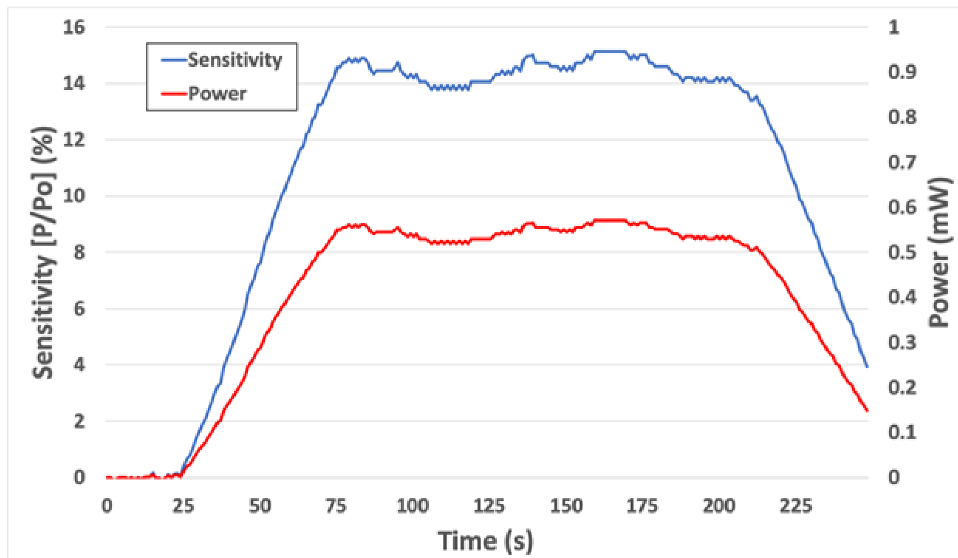
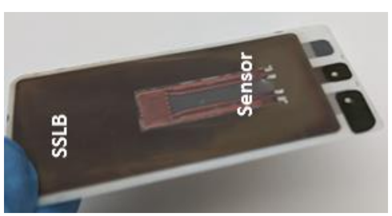
BiPASS Development

- ITN and URI Demonstrated a Self-Powered ETD
  - ETD Sensor Was Optimized for Low Power or Small Battery
  - Acetone Detection
    - 25°C Operation
    - 70ppm
  - Breadboard Electronics
    - Entire Assembly Could be Paper Thin



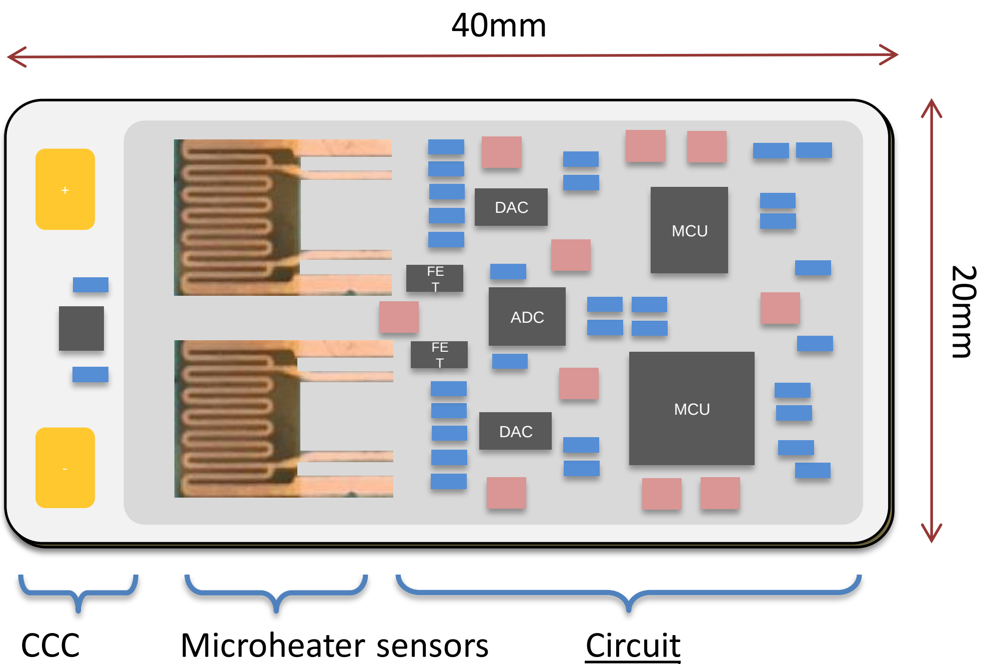




BiPASS Vision

- Over Time, the Entire ETD Sensor System Could be Integrated in a BiPASS Architecture
  - Signal Processing, Telemetry, etc. All Compatible with Paper Thin Circuit

Bill of Materials		
Component	*Technology for FHE form*	*Comments*
1x MCP3424 4-Ch Analog to Digital Converter (ADC)	Thinned Si Die	Need higher resolution than American Semiconductor's ADC_2001
2x MCP4725 Digital to Analog Converters (DAC)	Thinned Si Die	6-lead SOT-23 packaged means very small die
2x IRF530 FET	Thinned Si Die	Low currents mean FETs can be small
1x USB Interface Controller	Thinned Si Die	See American Semiconductor's AS_CY8C20 thinned MCU
1X System Microcontroller	Thinned Si Die	See American Semiconductor's AS_NRF51822 thinned MCU
15-20 Resistors	Printed or Thinned Si Die	See Q3 Molex/Skywater options for Integrated Passive Devices (IPDs)
5-10 SMT ceramic Capcitors	Printed or Thinned Si Die	See Q3 Molex/Skywater options for Integrated Passive Devices (IPDs)
2X LM358 OpAmp	Thinned Si Die	Unnecessary with battery - Substitute CCC
1X LP2985 LDO Regulator	Thinned Si Die	Unnecessary with battery - Substitute CCC
1X NCP1117 LDO Regulator	Thinned Si Die	Unnecessary with battery - Substitute CCC
5X LEDs	Thinned Die	Unnecessary with battery - Substitute CCC
Crystal Oscillator	TBD	Likely unnecessary with internally-clocked MCU
Interconnecting Traces	Printed	Thin film, thick-film are both options



Conclusions

- Fabrication of thin film sensors on ultrathin YSZ substrates enabled a marked reduction in thermal mass w/o sacrificing catalyst surface area. Thin film sensors on YSZ substrates exhibited highly localized heating and cooling due to anisotropy……..*excellent sensitivity and response times*

- These improvements were achieved at reduced operating temperatures and with the reduced power requirements and lower mass, real-time sensing using a drone or wearable platform was possible.

- Electronic Trace Detection (ETD) System was Integrated in a BiPASS Architecture; i.e. sensors, signal processing, electronics, telemetry, etc in an ultrathin package