

Nanostructured Material Sensor Processing Using Microfabrication Technology

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Transformational Tools and Technologies Project (T3)

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Smart Sensors and Electronics Systems Branch (LCS)

Description

Conducts research and development of **adaptable instrumentation to enable intelligent measurement systems** for ongoing and future aerospace propulsion and space exploration programs. Emphasis is on smart sensors and electronics systems for diagnostic engine health monitoring, controls, safety, security, surveillance, and biomedical applications**; often for high temperature/harsh environments**.



Microsystems Fabrication Facility

Facilities/Labs

- Microsystems Fabrication Facilities
  - Class 100 Clean Room
  - Class 1000 Clean Room
- Chemical vapor deposition laboratories
- Chemical sensor testing laboratories
- Harsh environment laboratories
  - Nanostructure fabrication and analysis
  - Sensor and electronic device test and evaluation

Core Capabilities (technical areas)

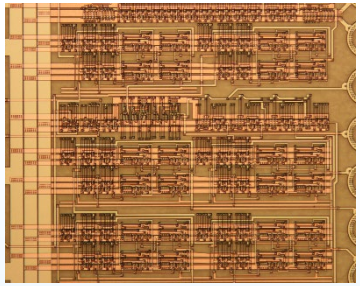
•Silicon Carbide (SiC) - based electronic devices
- Sensors and electronics for high temp (600°C) use
- Wireless sensor technologies, integrated circuits, and packaging

•Micro-Electro-Mechanical Systems (MEMS)
- Pressure, acceleration, fuel actuation, and deep etching

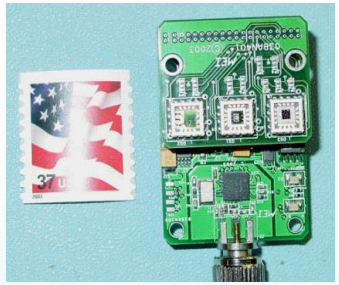
•Chemical gas species sensors
- Leak detection, emission, fire and environmental, and human health monitoring

•Microfabricated thin-film physical sensors
- Temperature, strain, heat flux, flow, and radiation measurements

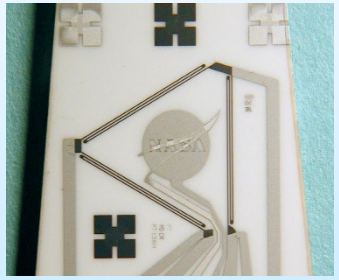
•Harsh environment nanotechnology
- Nano-based processing using microfabrication techniques
- Smart memory alloys and ultra low power devices



SiC Signal Processing



Leak Detection Sensors



Thin Film Physical Sensors

Facilities and Laboratories







Microsystems Fabrication Facility (Class 100 Cleanroom Facility)

Features:

- 3000 square feet class 100 and class 1000 cleanroom space, Photolithography tools suitable for 2 micrometer linewidths Chemical work stations for substrate cleaning and wet etching
- Physical vapor thin film deposition systems, Plasma etchers, including deep reactive ion etcher for SiC micromachining
- Low pressure chemical vapor deposition system for silicon dioxide films
- Annealing and oxidation furnaces, Rapid thermal annealers

Research Projects:

- SiC electronic devices –worlds first 500°C integrated circuit
- High temperature wireless sensors using 500°C SiC electronics
- Chemical sensors for safety, active emissions control and health monitoring
- Thin film sensors in-situ monitoring of high temperature processes
- High temperature SiC pressure sensors for active combustion control
- SiC microactuators for control of fuel flow to minimize combustion instability

BASE PLATFORM SENSOR TECHNOLOGY

Integration of Micro Sensor Combinations into Small, Rugged Sensor Suites

Example Applications: AEROSPACE VEHICLE FIRE, FUEL LEAKS, EMISSIONS, ENVIRONMENTAL MONITORING, CREW HEALTH, SECURITY

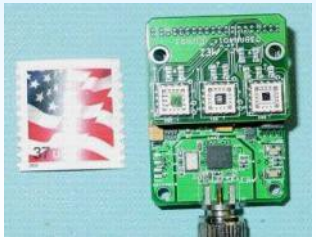
Multi Species Fire Sensors for Aircraft Cargo Bays and Space Applications



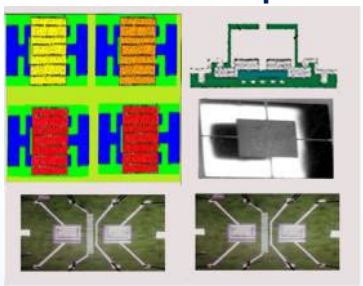
Environmental monitoring (ISS Whitesand Testing)

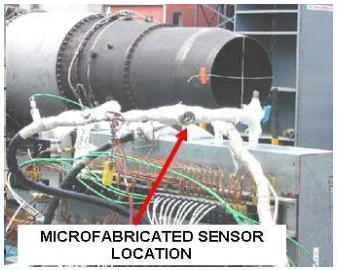


"Lick and Stick" Space Launch Vehicle Leak Sensors with Power and Telemetry



Aircraft Propulsion Exhaust High Temperature Electronic Nose

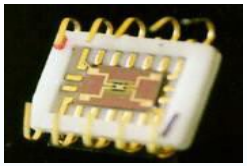




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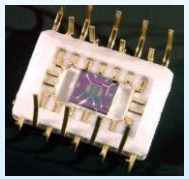
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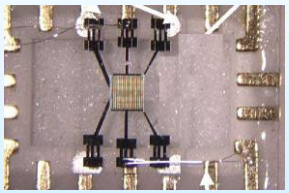
Oxygen Sensor



SiC Hydrocarbon Sensor



H2 Sensor



Nanocrystalline Tin Oxide NOx and CO Sensor

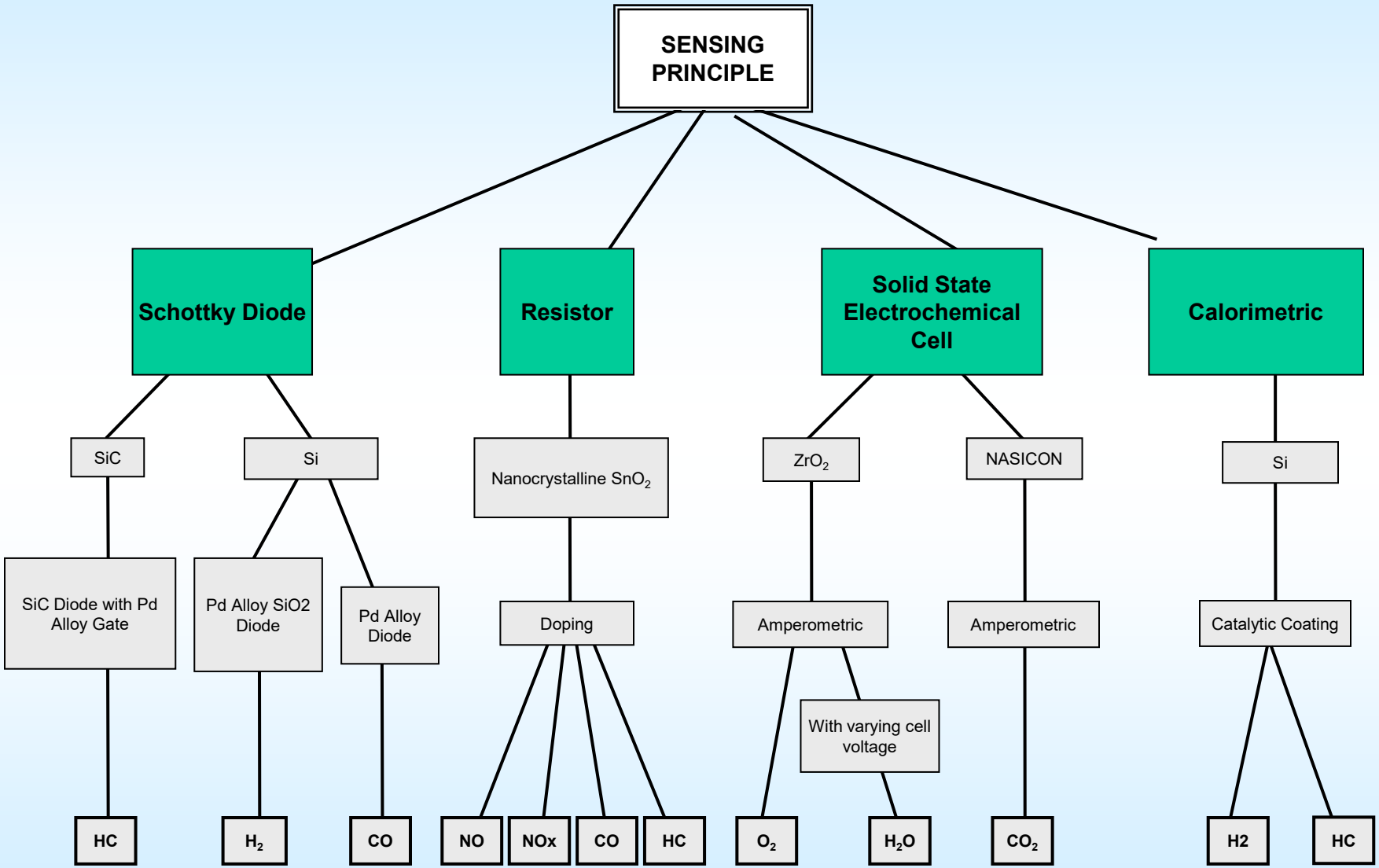




Breath Sensor System Including Mouthpiece, PDA Interface, And Mini Sampling Pump

Hydrazine EVA Sensors (ppb Level Detection)

CHEMICAL SENSOR "FAMILY TREE"

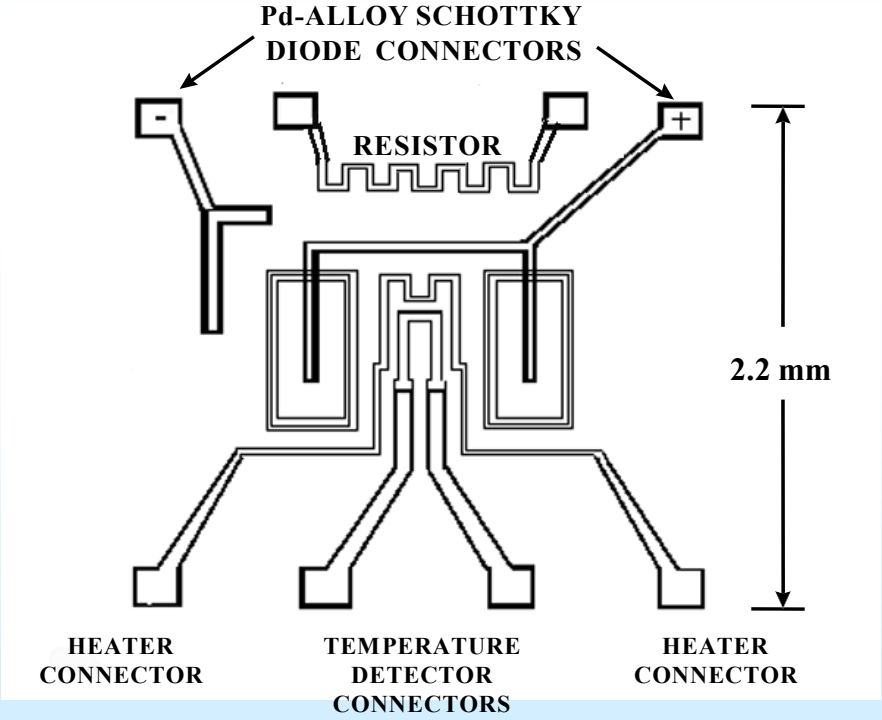


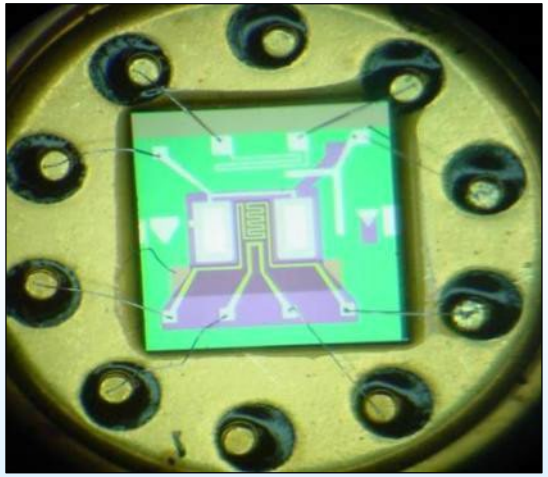
BASIC APPROACH:
MAKE AN INTELLIGENT SYSTEM FROM SMART COMPONENTS
POSSIBLE STEPS TO REACH INTELLIGENT SYSTEMS

- **"LICK AND STICK" TECHNOLOGY (EASE OF APPLICATION)**
  - **Micro and nano fabrication to enable multipoint inclusion of sensors, actuators, electronics, and communication throughout the vehicle without significantly increasing size, weight, and power consumption. Multifunctional, adaptable technology included.**
- **RELIABILITY:**
  - **Users must be able to believe the data reported by these systems and have trust in the ability of the system to respond to changing situations e.g. decreasing sensors should be viewed as decreasing the available information flow about a vehicle. Inclusion of intelligence more likely to occur if it can be trusted.**
- **REDUNDANCY AND CROSS-CORRELATION:**
  - **If the systems are easy to install, reliable, and do not increase weight/complexity, the application of a large number of them is not problematic allowing redundant systems, e.g. sensors, spread throughout the vehicle. These systems will give full-field coverage of the engine parameters but also allow cross-correlation between the systems to improve reliability of sensor data and the vehicle system information.**
- **ORTHOGONALITY:**
  - **Systems should each provide a different piece of information on the vehicle system. Thus, the mixture of different techniques to "see, feel, smell, hear" as well as move can combine to give complete information on the vehicle system as well as the capability to respond to the environment.**

HYDROGEN LEAK SENSOR TECHNOLOGY

- MICROFABRICATED USING MEMS-BASED TECHNOLOGY FOR MINIMAL SIZE, WEIGHT AND POWER CONSUMPTION
- DESIGNED TO OPERATE WITHOUT OXYGEN AND IN VACUUM ENVIRONMENTS
- HIGHLY SENSITIVE IN INERT OR OXYGEN-BEARING ENVIRONMENTS, WIDE CONCENTRATION RANGE DETECTION
- TWO SENSOR SYSTEM FOR FULL RANGE DETECTION: FROM PPM LEVEL TO 100%

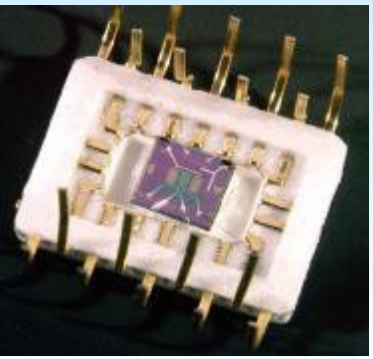




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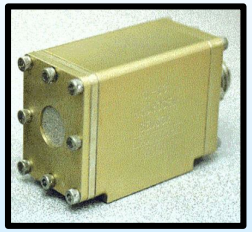
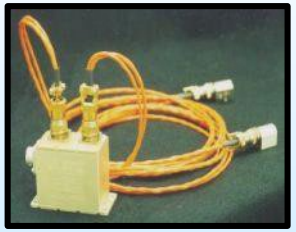
HYDROGEN LEAK SENSOR TECHNOLOGY



- **STATUS: OPERATIONAL SYSTEM ON ISS WITH ASSOCIATED HARDWARE**
- **AVAILABLE FOR POSSIBLE LAUNCH VEHICLE IMPLEMENTATION**

R&D 100 AWARD WINNER

NASA TURNING GOALS INTO REALITY SAFETY AWARD

Shuttle	X33	X43	Helios	ISS
				
				
Aft Compartment Hydrogen Monitoring	Hydrogen Safety Monitoring	Hydrogen Safety Monitoring	Fuel Cell Safety and Process Monitoring	Life Support Process and Safety Monitoring

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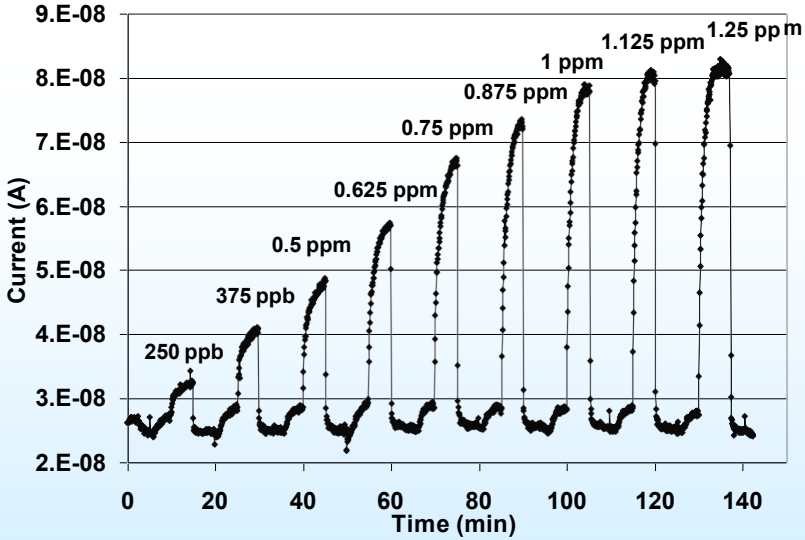
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SiC-BASED GAS SENSOR DEVELOPMENT

- THE USE OF SiC SEMICONDUCTORS ALLOWS SENSOR OPERATION AT TEMPERATURES WHICH ALLOW THE DETECTION OF HYDROCARBONS AND NOx
- INERT MATERIAL OPERATIONAL IN HIGH TEMPERATURE, CORROSIVE ENVIRONMENTS
- SCHOTTKY DIODE DESIGN FOR HIGH SENSISTIVITY
- WIDE RANGE OF APPLICATIONS
  - EMISSION MONITORING
  - ENGINE HEALTH MONITORING
  - ACTIVE COMBUSTION CONTROL
  - HYDROCARBON FUEL LEAK DETECTION
  - FIRE SAFETY
- SENSOR TESTED IN ENGINE ENVIRONMENTS
- APPROACHES
  - ALLOY ON SiC SUBSTRATE
  - REACTIVE INSULATOR APPROACH
  - BARRIER LAYER
  - ATOMICALLY FLAT SiC
- NOMINATED FOR NASA INVENTION OF THE YEAR IN 2016

PACKAGED SiC-BASED SENSOR

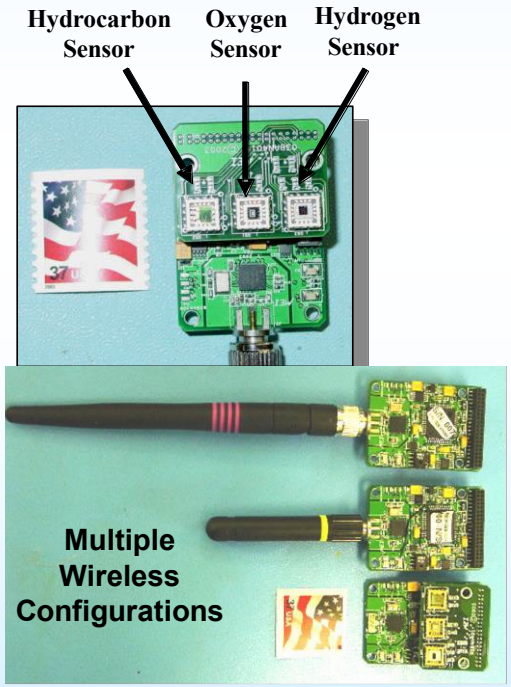




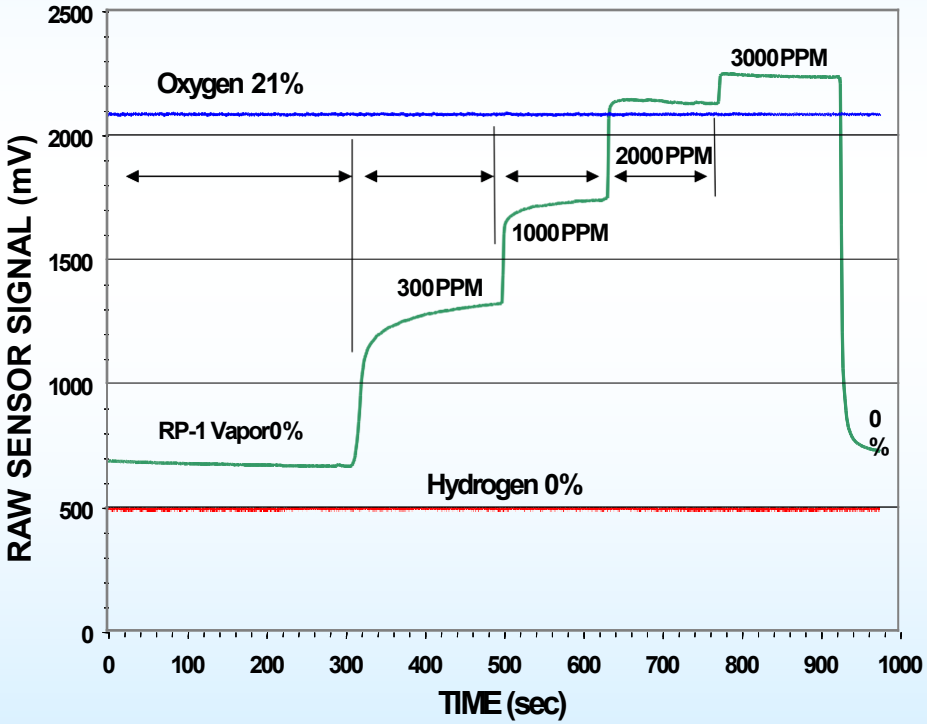
OUTPUT CURRENT OF $Pd/PdO_X/SiC$ SENSOR TO HYDROGEN BIASED AT 0.45 V AT180°C

"LICK AND STICK" SENSOR SYSTEM

- SENSORS, POWER, AND TELEMETRY SELF-CONTAINED IN A SYSTEM NEAR THE SURFACE AREA OF A POSTAGE STAMP
- MICROPROCESSOR INCLUDED/SMART SENSOR SYSTEM
- ADAPTABLE CORE SYSTEM WHICH CAN BE USED IN A RANGE OF APPLICATIONS
- MULTIPLE CONFIGURATIONS AVAILABLE, INCLUDING BATTERY OR CONNECTED POWER
- IN-FLIGHT AND GROUND OPERATION APPLICATIONS



Wireless Data Transmission/ Orthogonal Detection

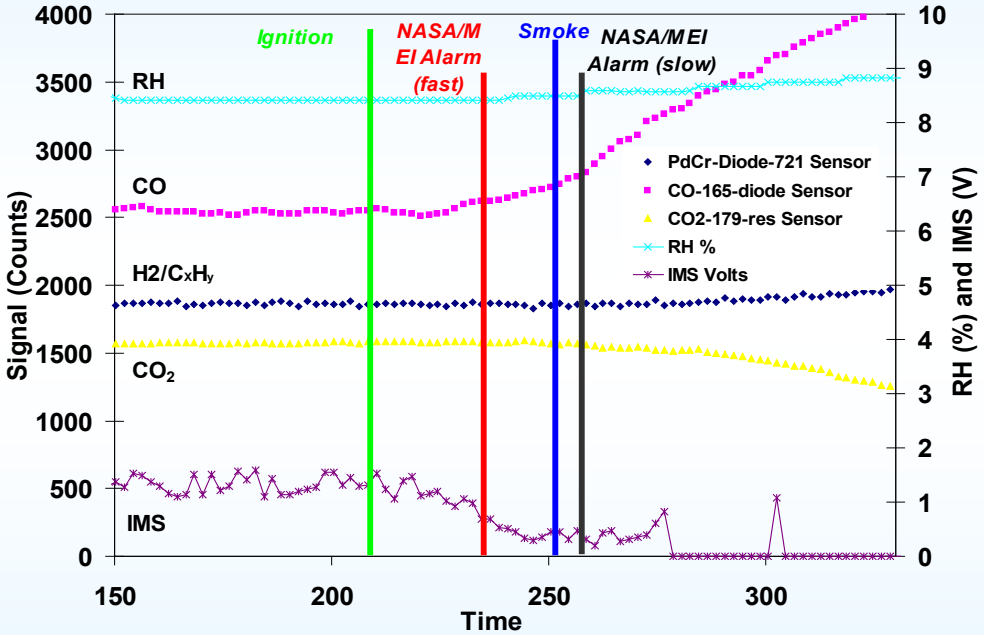


BASIC APPROACH: MEET THE NEEDS OF MULTIPLE APPLICATIONS BUILDING FROM A CORE SET OF SMART MICROSENSOR TECHNOLOGY

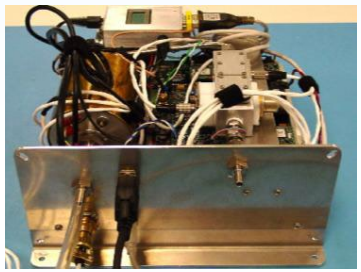
Micro-Fabricated Gas Sensors for Low False Alarms
FAA Cargo Bay Fire Simulation Testing
No False Alarms/Consistent Detection of Fires

R&D 100 AWARD WINNER

TURNING GOALS INTO REALITY AA's CHOICE AWARD



FAA Cargo Bay Fire Test Data

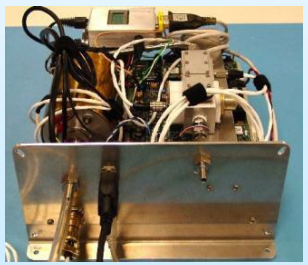


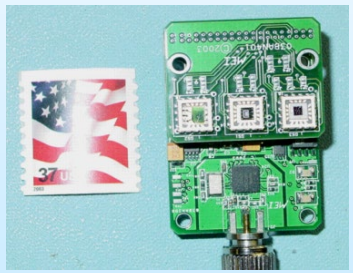
Prototype MultiParameter Fire Detection System



FAA Cargo Bay Fire Simulation Aircraft

TRANSITION AERONAUTICS HARDWARE INTO CORE "LICK AND STICK" SPACEFLIGHT HARDWARE PLATFORM





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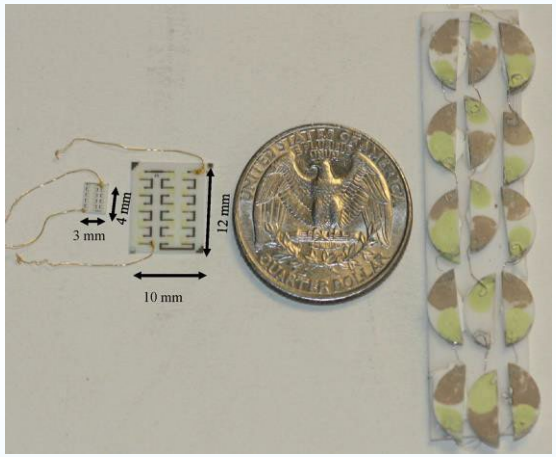
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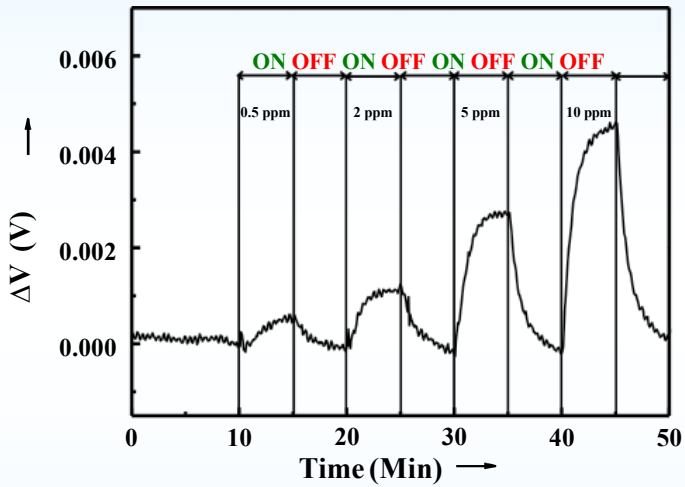
EXHALED NO ANALYSIS USING ELECTROCHEMICAL SENSOR MINIATURIZATON EXAMPLE

- Nitric Oxide Sensor Core To Portable Asthma Monitoring Approach
- Sensor Miniaturization Using Silicon Processing Techniques
- Electrochemical Cells In Series To Reach High Levels Of Sensitivity (500 Ppb) With More Than An Order Of Magnitude Size Reduction
- Fundamental Understanding Of Sensing Mechanism Needed

Sensors and Actuators B 204 (2014) 183–189



Miniaturization Activity: Hand fabricated sensor (baseline), shadow mask sensor, and photoresist processed sensor



Sensor response of photoresist version sensor with 15 sensor arrays for 0.5–10 ppm in 20% O2with 200 cm3/min total flow rate at 550◦C

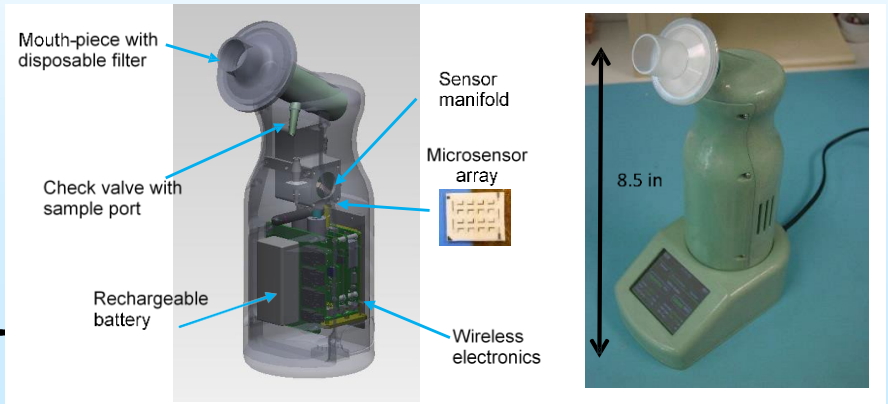
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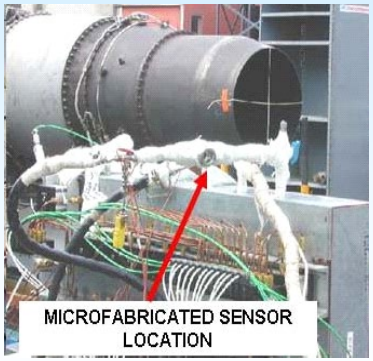
The core components for a notional home use portable breath monitor, and mounting in a charging unit with a display.



A WIDE RANGE OF SYSTEM DEMONSTRATIONS AND APPLICATIONS
"LICK AND STICK" CORE HARDWARE

MAKEL ENGINEERING

Jet Engines Emissions



Aircraft Fire Detection



Exercise Monitoring



NASA Helios Fuel Cells



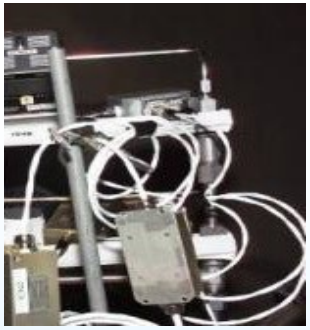
International Space Station Safety System



Rocket Engine Teststands



Environmental Monitoring



Cryogenic Fuel Line Monitoring



Launch Vehicle Leak Detection



Human Health Breath Monitoring

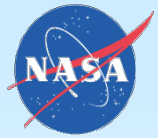


Long Lived Venus Surface Missions



First Responder Monitoring

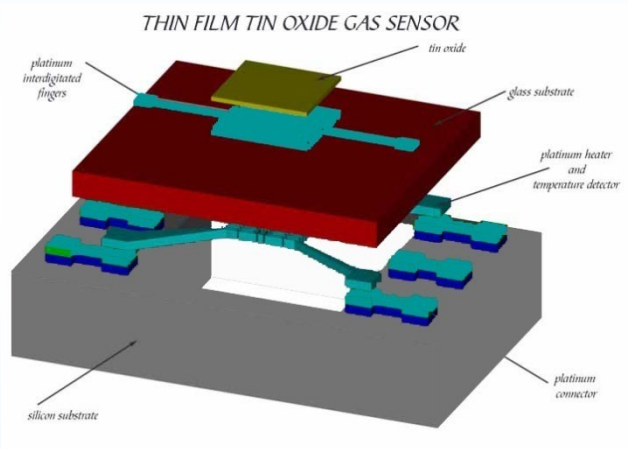


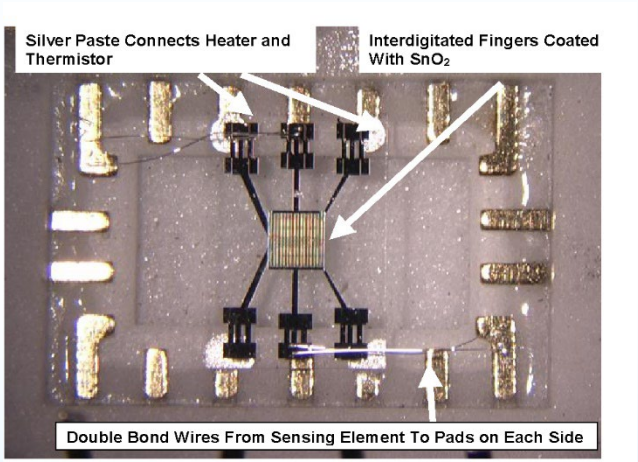


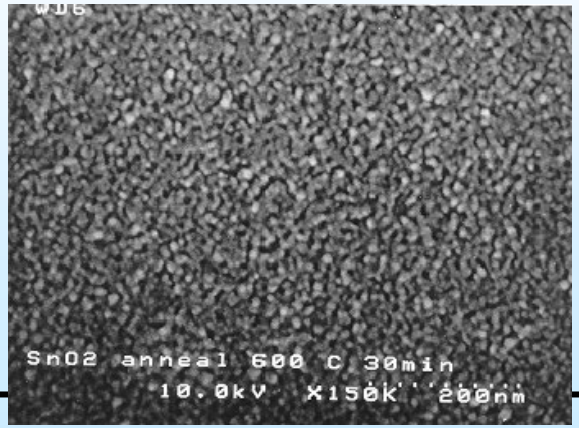
MICROSENSORS BASED ON NANOSTRUCTURED MATERIALS

MICROFABRICATED NANOCRYSTALLINE TIN OXIDE NOx AND CO SENSOR TECHNOLOGY

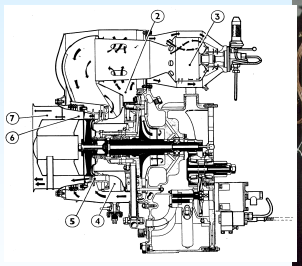
- MICROFABRICATED FOR MINIMAL SIZE, WEIGHT AND POWER CONSUMPTION
- MICROMACHINED TO MINIMIZE POWER CONSUMPTION AND IMPROVE RESPONSE TIME
- TEMPERATURE DETECTOR AND HEATER INCORPORATED INTO SENSOR STRUCTURE
- NANOFABRICATION OF TIN-OXIDE TO INCREASE SENSOR STABILITY







DEMONSTRATION TESTING OF NANOCRYSTALLINE NOx SENSOR IN GAS TURBINE EXHAUST STREAM

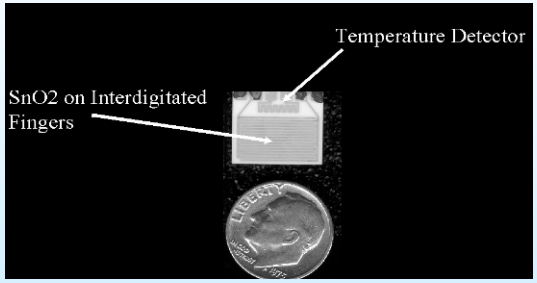


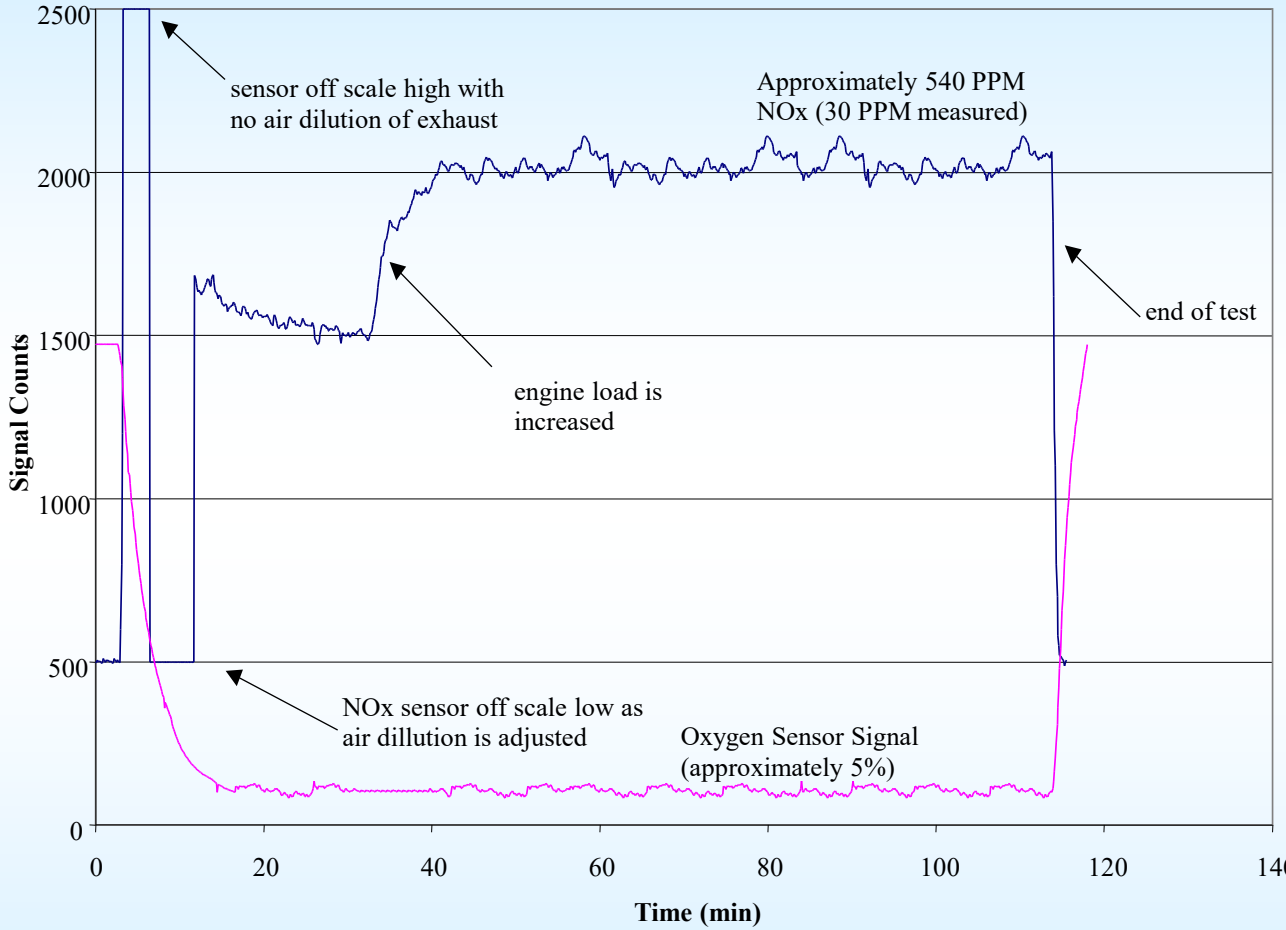
50 Hp Gas Turbine



Industry Standard Continuous Emission Monitoring Equipment

REPLACE INSTRUMENT RACK SIZED SYSTEM WITH DIME SIZED SENSOR AND ACCOMPANYING ELECTRONICS

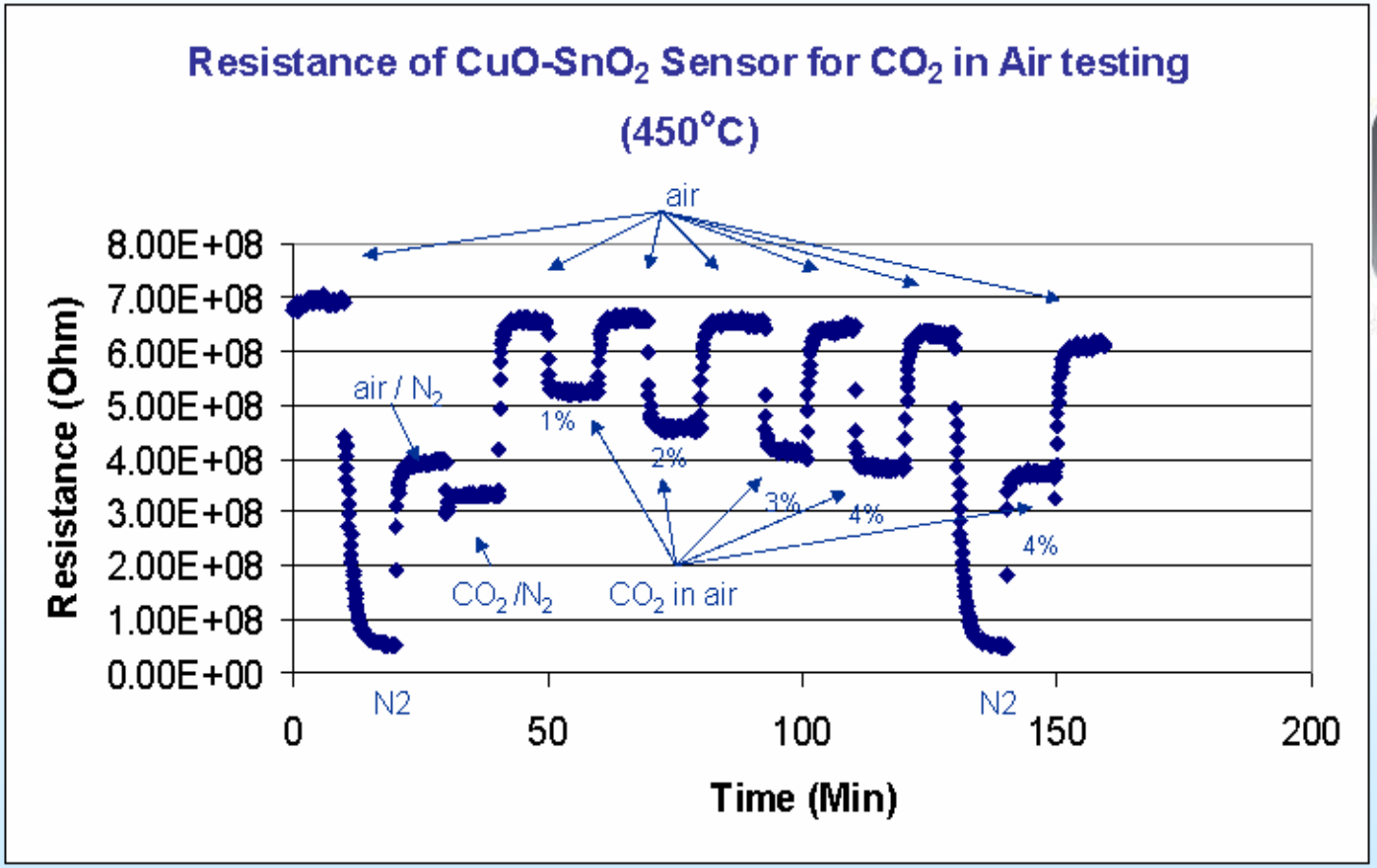




Species	CEM Measurement	MSES Measurement
NOx	593 PPM	540 PPM
CO	3000 PPM	N/A
O_2	4.57%	5%

NOVEL CARBON DIOXIDE SENSING MATERIAL: CuO DOPED SnO_2 NANOMATERIALS

- First demonstration of doped SnO_2 response to oxidizing gas CO_2 in a meaningful way
- One sensing material system, batch fabrication, and low cost.
- Linear response



Nanotech Briefs
Nano50
AWARDING THE BEST IN SMALL TECH

NANO DIMENSIONAL CONTROL PREVALENT IN CHEM/BIO SENSOR DEVELOPMENT

- Nano Control Of Chemical Sensor Structures Strongly Preferred Even If Sensor Isn't Labeled A "Nano Sensor"
  - We Are Measuring Varying Numbers Of Molecules
- If Nanotechnology Already Present In Chem/Bio Sensor Development, Then:
  - What Stays The Same And What's New?
  - What Are The Challenges In Nanotechnology Development?
  - What Is The Role/Advantage Of Nano Technology

SAME

- Applications Don't Care That Is Nano, Need Improved Capabilities
- Standard Sensor Technology Requirements, Potential, And Directions Set By The Advent Of Microtechnology Remain Constant
- Sensitivity, Selectivity, Stability, Response Time, Tailor For The Application, "Lick And Stick", Etc.
- Packaging Still Significant Component Of System
- As With Micro, Can Only Go As Far As The Supporting Technologies
- Multiple Sensor Platforms May Still Be Necessary Depending On The Application/Environment

OBJECTIVE: ENABLE FULL IMPLEMENTATION OF "LICK AND STICK"TECHNOLOGY

Metal Oxide Nanostructures for Chemical Sensor Development Move Towards Nanostructure e.g. Tubes, Rods, Ribbons

- Develop Basic Tools To Enable Fabrication Of Repeatable Sensors Using Nanostructures
- Approach 3 Basic Problems In Applying Nanostructures As Chemical Sensors

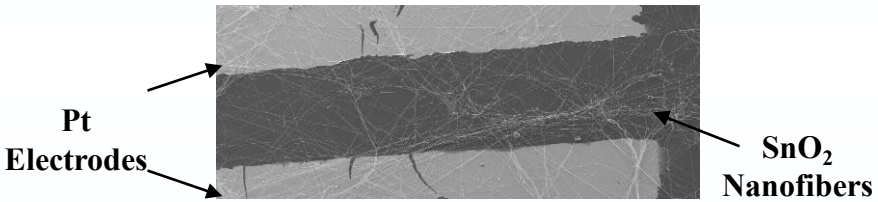
► *Micro-Nano Contact Formation*

► *Nanomaterial Structure Control*

► *Range Of Nano Structured Oxides Available*

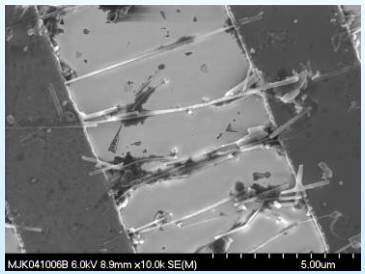
IMPROVE NANOSTRUCTURE TO MICROELECTRODE CONTACTS

Electrospinning



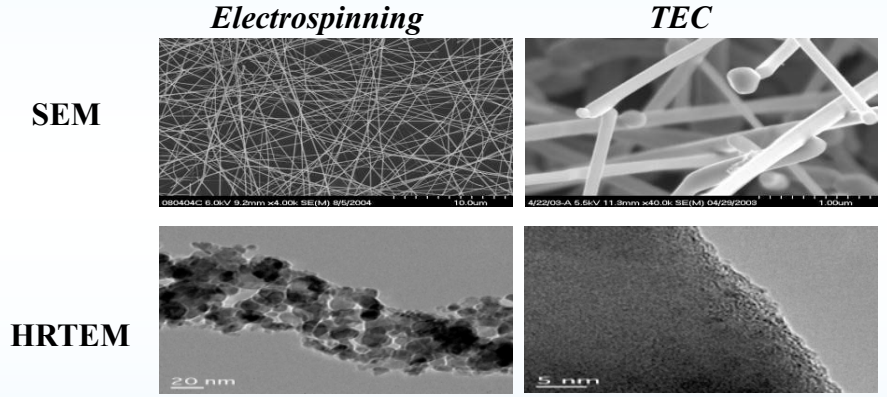
Bridging of electrospun SnO_2 nanofibers across electrodes.

Dielectrophoresis



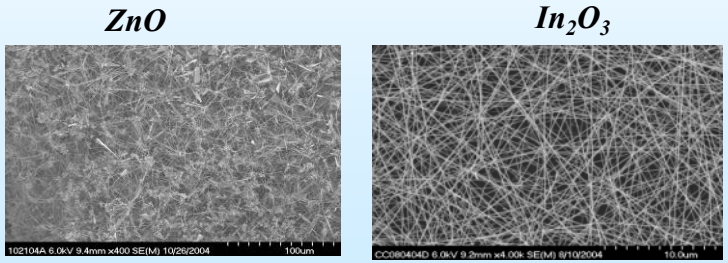
TiO_2 Nanorods aligned by dielectrophoresis across interdigitated electrode patterns.

NANOMATERIAL STRUCTURE CONTROL



Different Processing of nanostructures produces different crystal structures

EXPAND RANGE OF NANOSTRUCTURES AVAILABLE

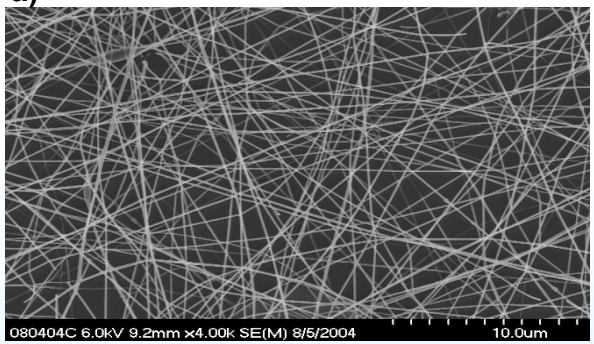
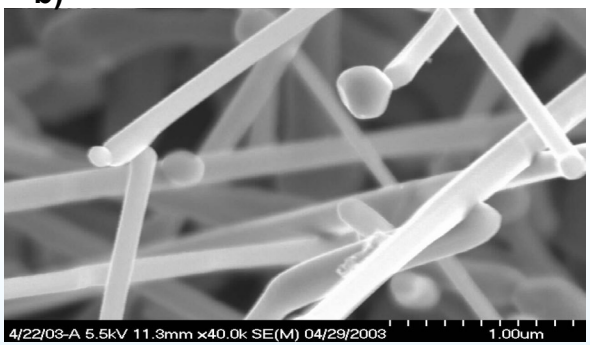
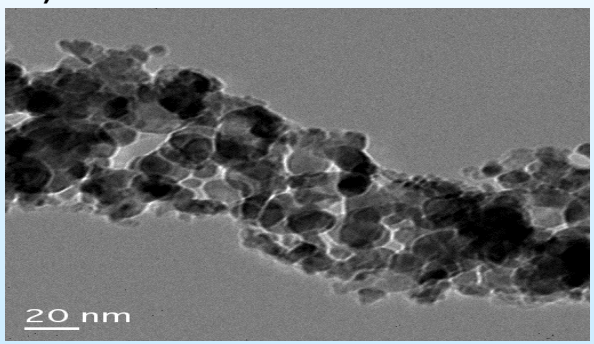
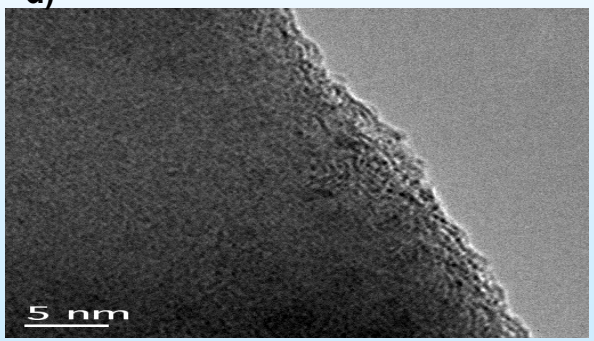


Multiple oxide nanostructured materials fabricated

APPROACH: CONTROL OF BASIC SENSOR PROPERTIES CORE TO REACHING TECHNOLOGY POTENTIAL

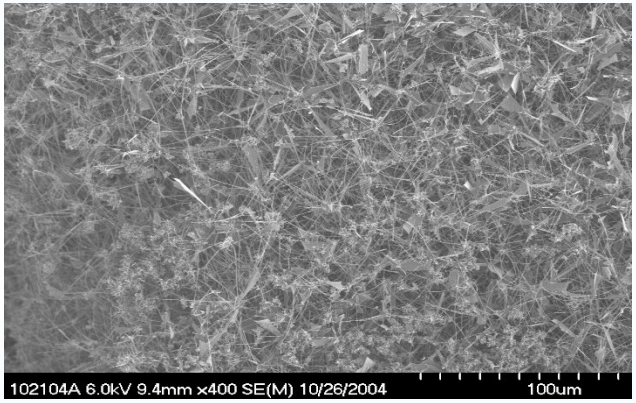
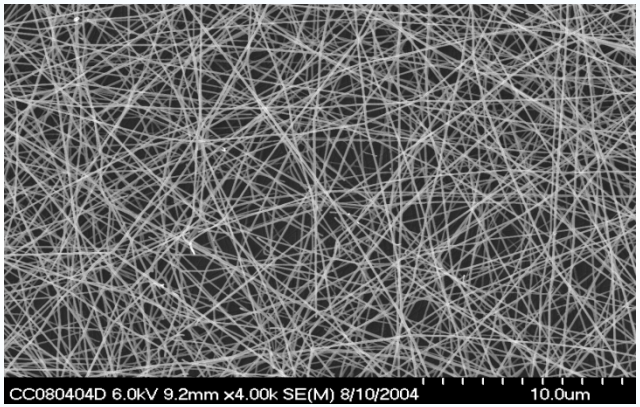
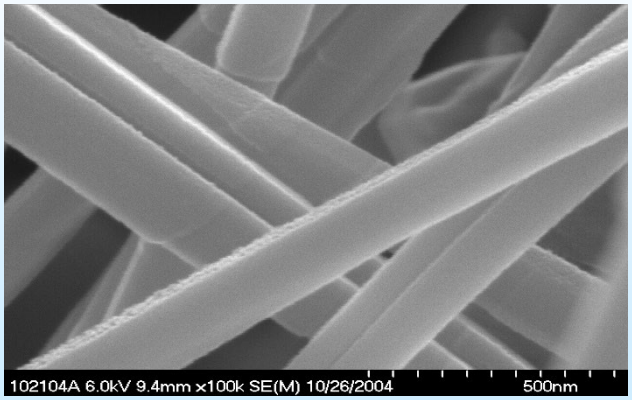
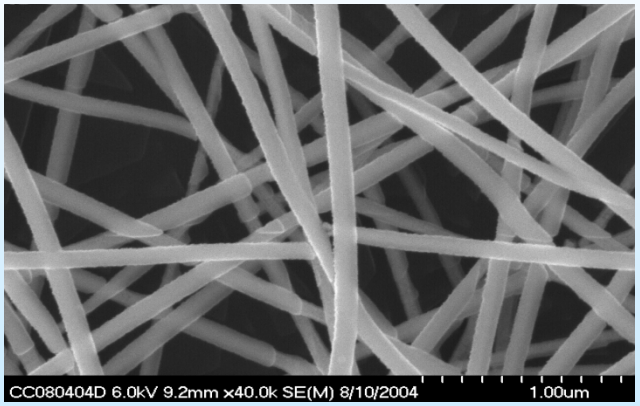
NANOMATERIAL STRUCTURE CONTROL

- **Different Processing Techniques Result In Very Different Crystal Structures.**
  - **Approach: Control Nanomaterial Crystal Structure Formation To Control Sensor Response**
  - **SnO_2: Sensor Response Is Grain Dependent For Micro/Nano Grained Material**
  - **Crystal Structure Dependent on Processing Approach**

	Electrospinning	TEC Condensation
SEM	a) 	b) 
HRTEM	c) 	d) 

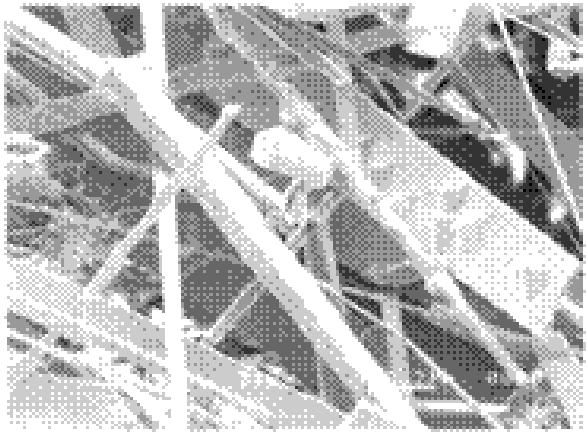
EXPAND THE RANGE OF NANOSTRUCTURES AVAILABLE

- **Same Approaches To SnO_2 Fabrication Can Be Used, With Appropriate Modification, For Fabrication Of Other Oxide Materials**
- **Zinc Oxide (ZnO), Indium Oxide (In_2O_3), and Iron Oxide (Fe_2O3)**

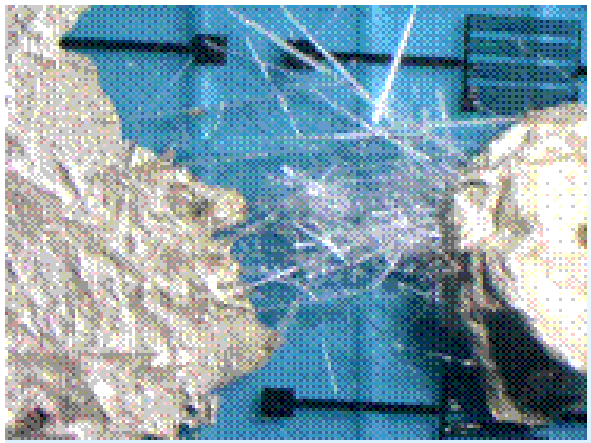
	ZnO	In_2O_3
Electrospinning		
TEC		

MICRO-NANO CONTACT FORMATION

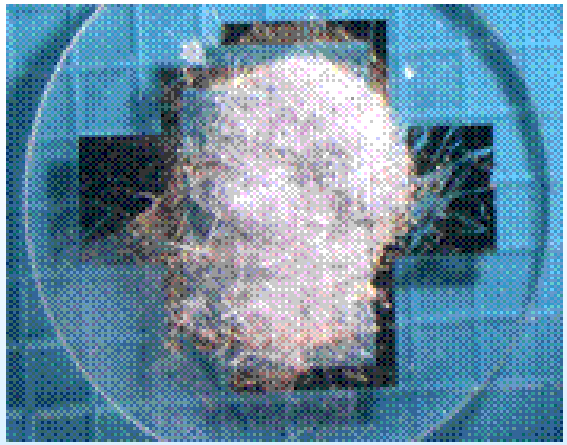
- No Matter How Good The Sensor, If You Cannot Make Contact With It, Then It Will Be Ineffective
- Micro-nano Integration/Contacts
  - Major Question For Nanostructured Based Sensors: Optimizing Nanostructured Materials Integration Into A Micro/Macro Structure
- Manual Methods Generally Involve Repeatability Issues e.g.,
  - Density Of The Nanorod Materials,
  - Quality Of The Contact
  - Variation Of Baseline Material Properties



Thermal Evaporation-condensation Process.



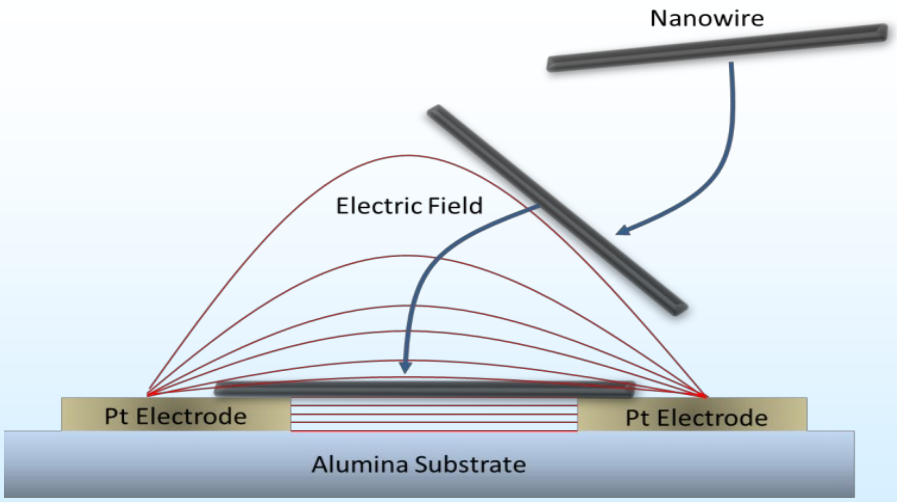
Nanorods Contacted With The Substrate Via A Silver Epoxy



Nanorods Precipitated Onto Substrate Between Two Electrodes.

MICRO-NANO CONTACTS DIELECTROPHORESIS

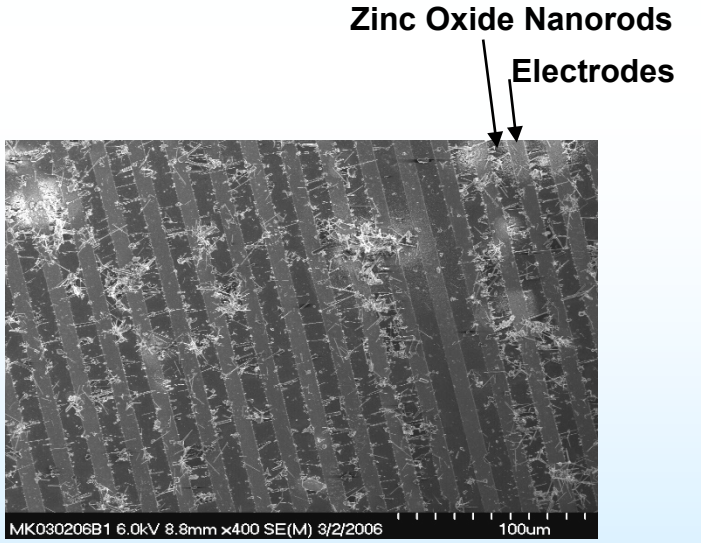
- **Dielectrophoresis (Dielectric Field Differences) Exploits The Dielectric Difference Between The Solvent And The Nanostructures In The Solvent To Induce Temporary Dipoles That Align With The Imposed Electric Field.**
- **AC Voltage is Applied Across The Electrode Grid Using A Function Generator. Nanorod Deposition Frequency/Size Dependent**
- **Solvent Is Allowed To Evaporate With The Voltage Applied To The Grid. The Resistance Across The Grid Is Measured After The Solvent Completely Evaporates**



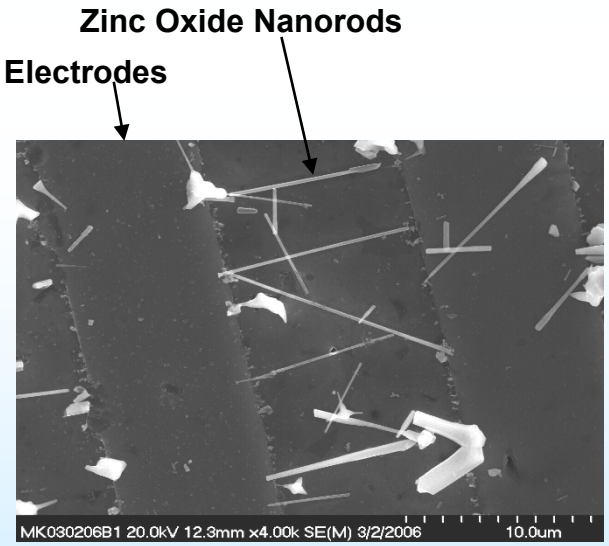
Schematic representation of dielectrophoretic alignment of nanotubes between two parallel plate electrodes.

MICRO-NANO CONTACTS DIELECTROPHORESIS

- Apply dielectrophoresis (DEP) to alignment of oxide nanostructures
- Concentrate on oxides and whole wafer fabrication
- Nonuniform nanostructure distribution in some areas/Single structure alignment in other areas



Zinc oxide nanorods after dielectrophoresis across a pattern of interdigitated fingers



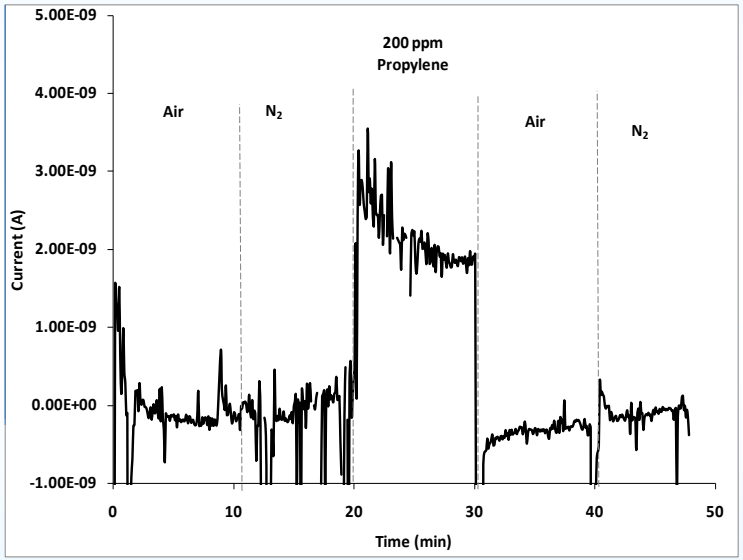
Magnified view showing parallel alignment of the nanorods across the electrodes.

NANOSTRUCTURES FOR EMISSIONS MONITORING

Demonstrate Nanostructured Oxide Sensors In Microsensor Platform Operating Temperature Up To 600°C Measuring Hydrocarbons

- Use Single Oxide Nano Structured Materials To Demonstrate Capability
  - Tin Oxide Standard Material
  - Sensitivity Can Improved As Necessary By Catalyst Deposition (Doping)
- Control Alignment Of Sensor Structures
  - Sawtooth Interdigitated Finger Pattern Used
  - Dielectrophoresis To Control Alignment And Deposition Of Materials

SnO_2 Nanowires
T= 600^{0}C, V= 0.8 V
After 75 hours



Operational Sensor With Aligned Structures On The Surface

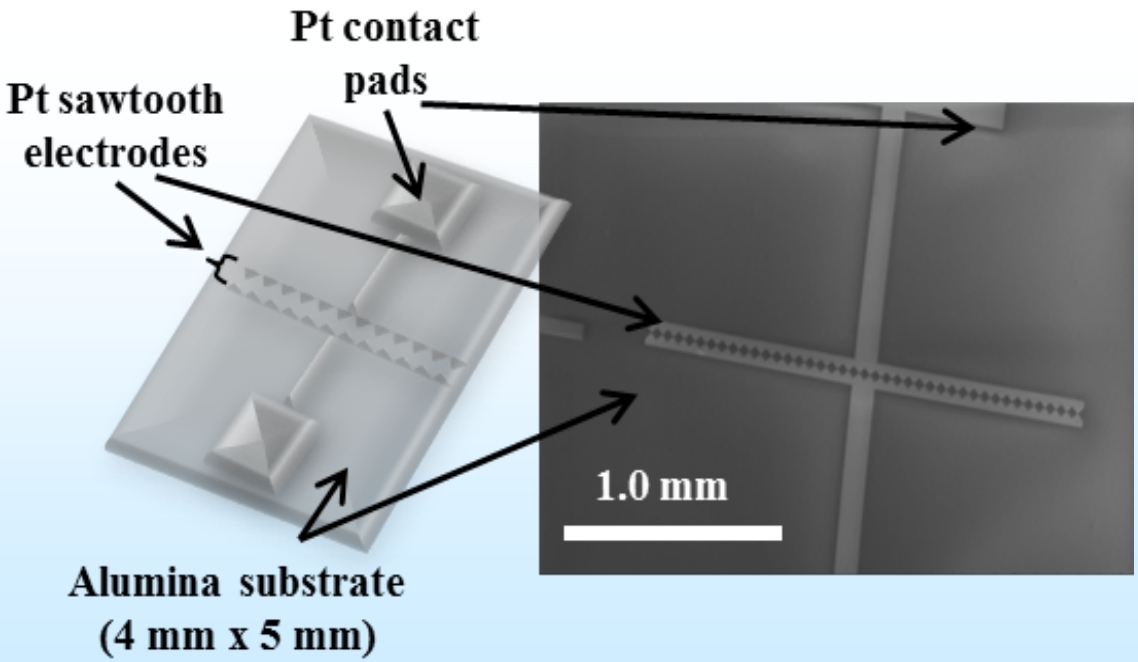
- Surface Contact Of Nanostructure With Electrodes
- Random Control Over The Surface Density On Nanostructures
- Inclusion Of Nanostructures Not Part Of Standard Device Processing

Addressing These Shortcomings Core To Patented Approach

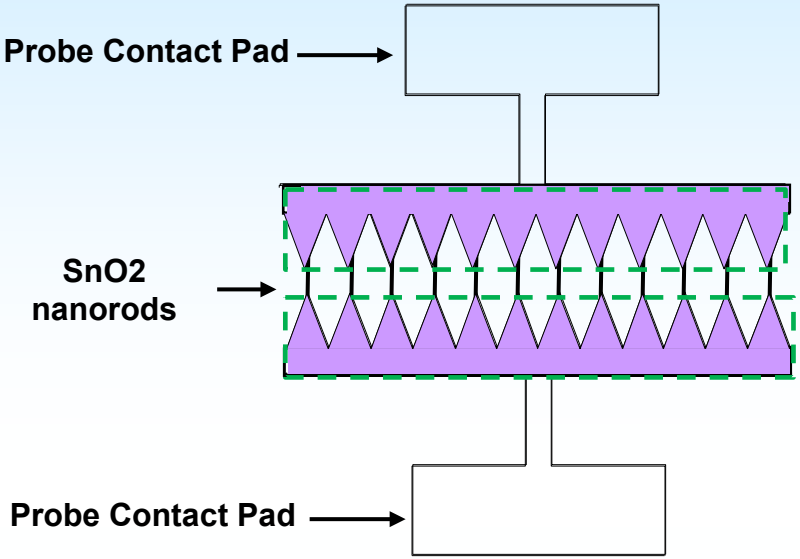
NEXT STEPS TOWARD CONTROL OF PROCESSING OF NANOSTRUCTURES

- Still based on Dielectrophoresis (DEP) to controllably align nanorods between electrodes
  - However, change the way the nanostructures are implemented on the microstructure
- Novel solution used for suspension of nanostructures
  - Photoresist instead of the typical imethylformamide or light alcohol
- Sensor layout designed to strengthen DEP effect
- Encase nanorod ends in two layers of metal
  - Electrical contact between nanorods and electrodes stabilized
- Mass production of sensor arrays possible

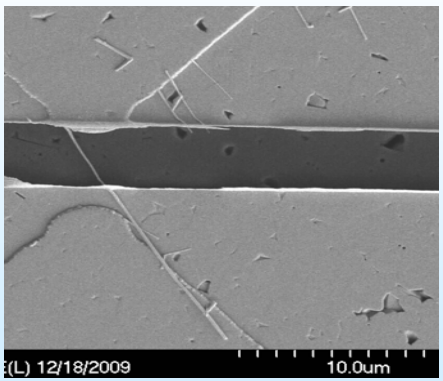
A scanning electron microscope (SEM) image, with a corresponding schematic diagram of the sensor design

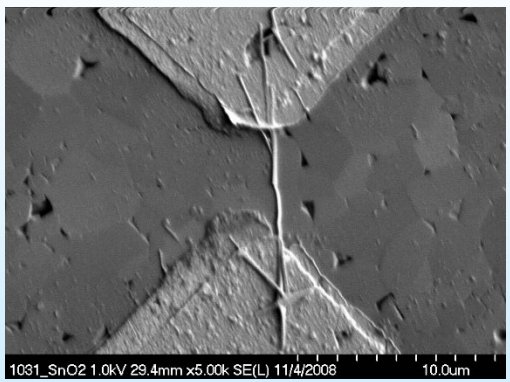


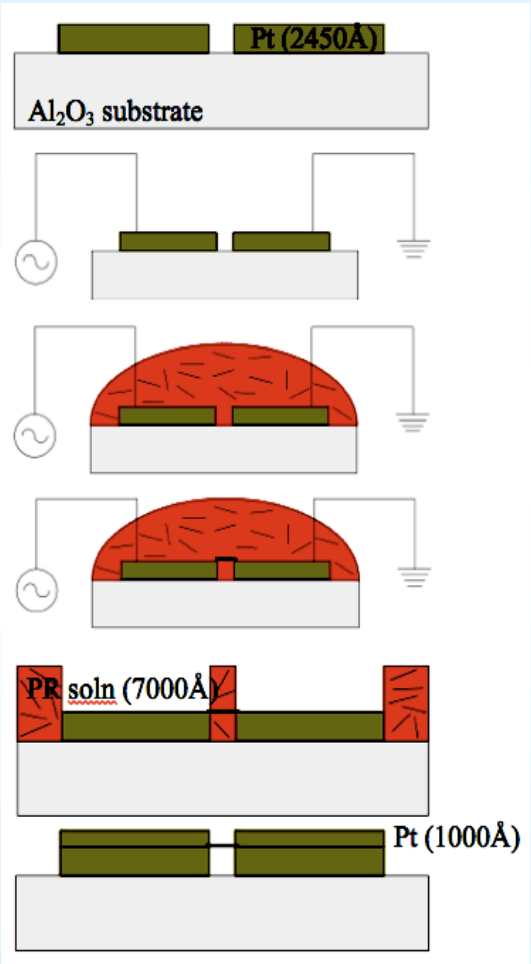
MICRO-NANO CONTACTS
OVERVIEW: MICROFABRICATION APPLIED TO NANOTECHNOLOGY



Sensor structure





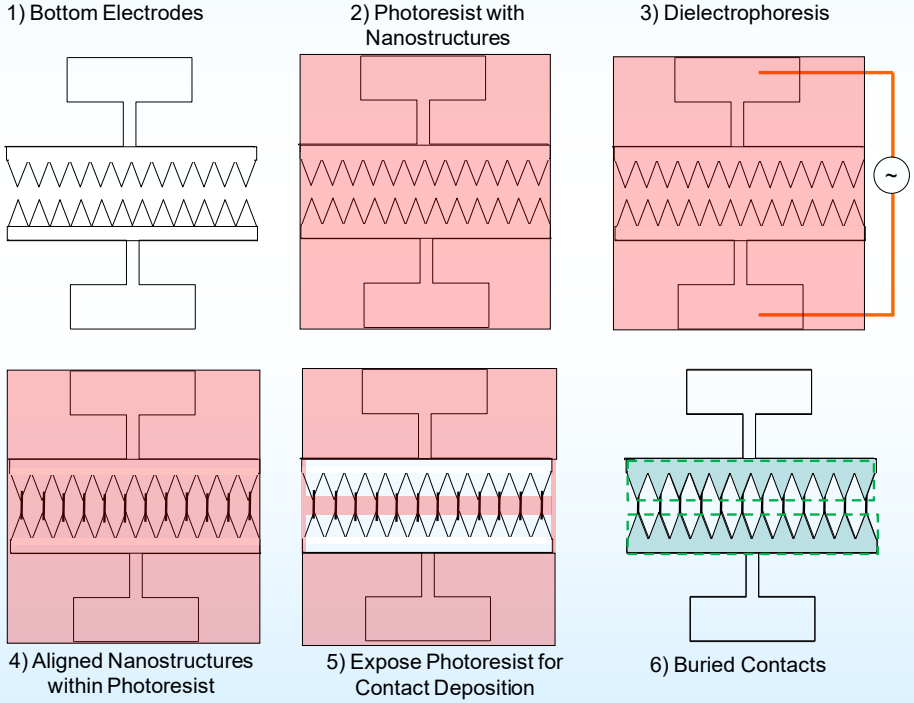


Processing approach

Aligned nanostructures with buried contacts

MICROFABRICATION TECHNIQUES APPLIED TO NANOTECHNOLOGY

- Integration of standard microfabrication techniques with the alignment of nanostructures
- Core of the approach is to Mix Nanomaterials into the Photoresist Standardly Used for Microfabrication, Followed By Dielelectrophoresis for Alignments
- Implies that Nanostructures Can Be Integrated into Standard Microfabrication Processing At Multiple Stages in Sensor/Device Processing



1) Deposit opposing sawtooth patterns on a substrate using standard photolithographic techniques.

2) Coat the electrodes with a photoresist mixture containing nanostructures.

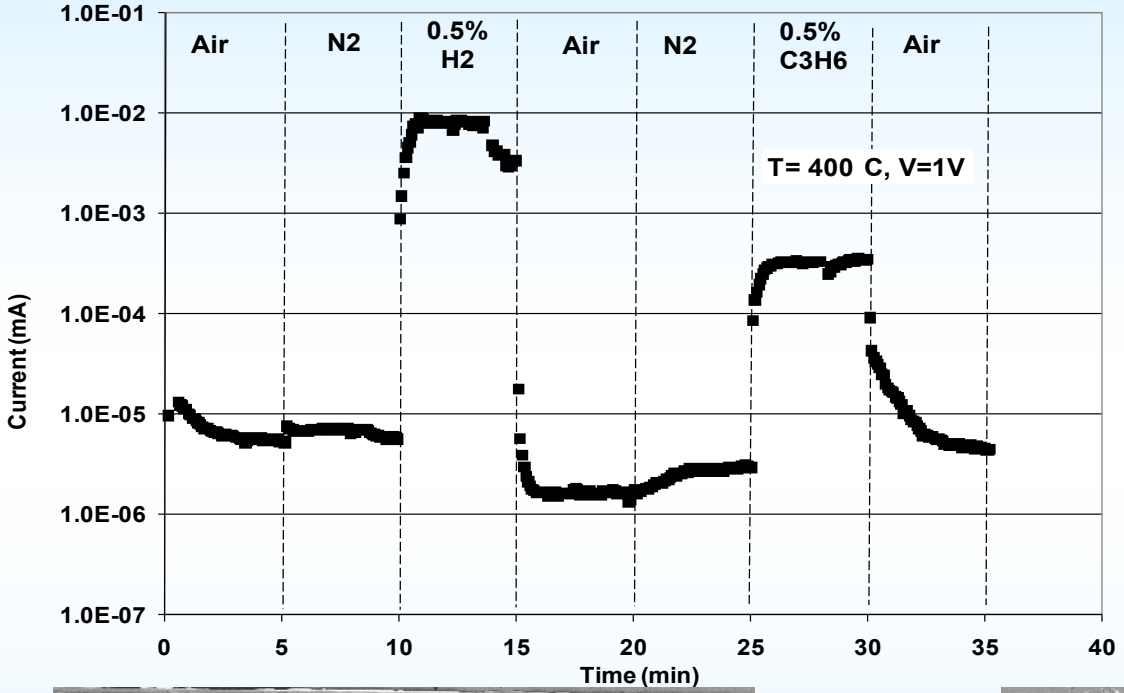
3-4) Use the sawtooth electrodes and dielectrophoresis to align the nanostructures.

5) Expose the electrodes while the nanostructures are held in place with photoresist.

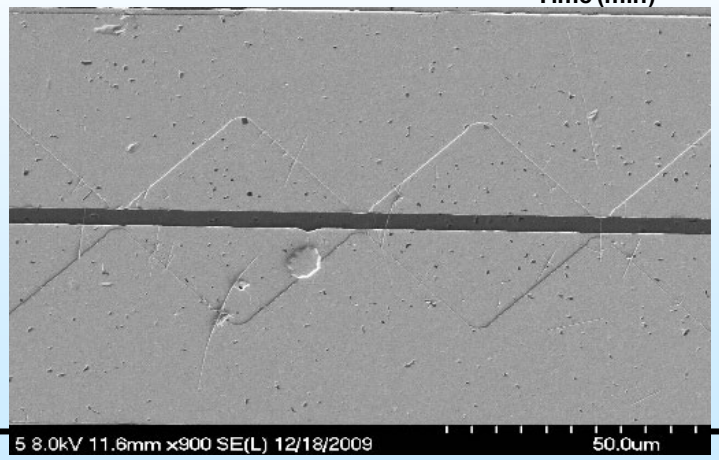
6) Deposit the top metallic layer over the bottom sawtooth electrode pattern leaving nanostructures buried in the electrodes and complete photoresist removal. The dotted line is an alternate pattern for the top metallic layer that broadly covers the bottom electrodes in a rectangle, rather than the sawtooth electrode pattern.

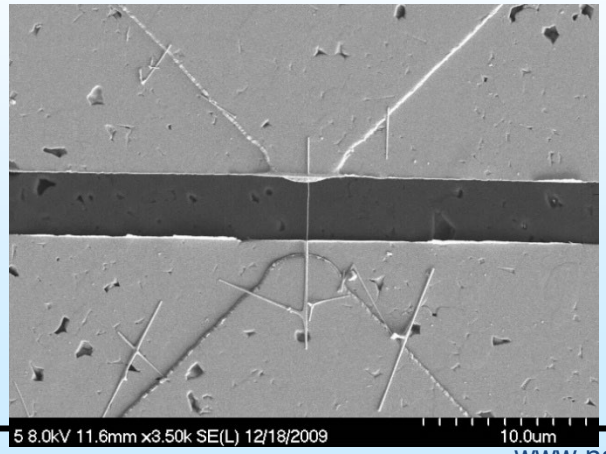
- **G.W. Hunter, et. al. Nanostructured Material Sensor Processing Using Microfabrication Techniques, Sensor Review 32/2 (2012) 106-117. (Paper of the year)**
- **Patent US 8,877,636 B1, Processing Of Nanostructured Devices Using Microfabrication Techniques, Nov. 4, 2014**

MICROFABRICATION APPLIED TO NANOTECHNOLOGY
Operational Sensors Demonstrated
High Temperature H2 and Propene

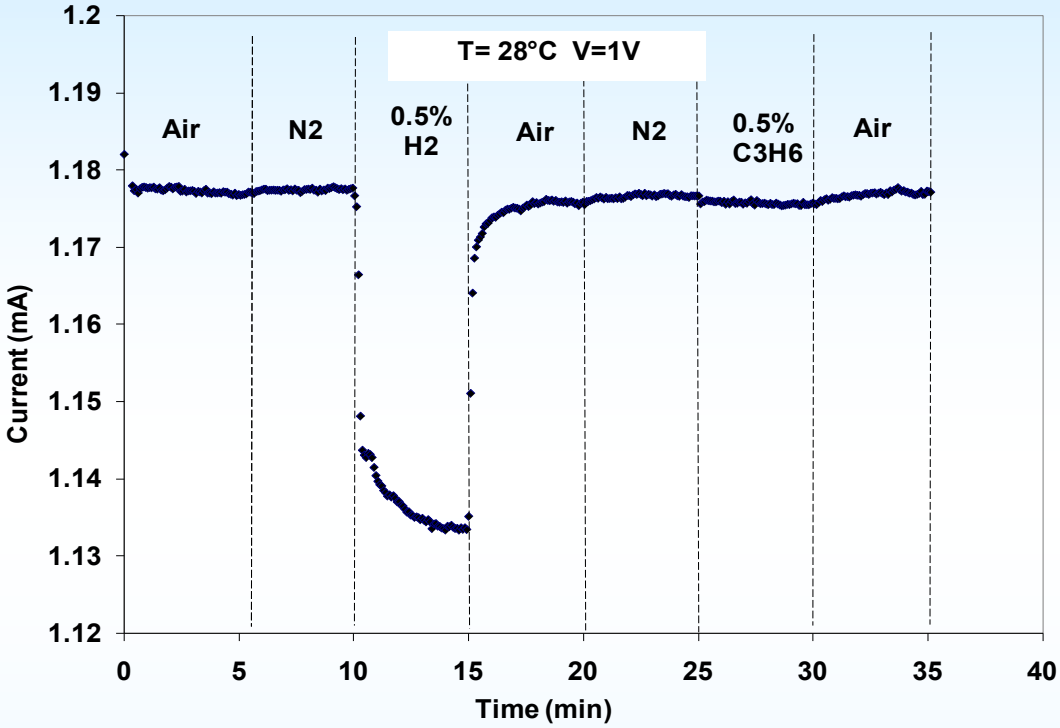


Tin Oxide Nanostuctures

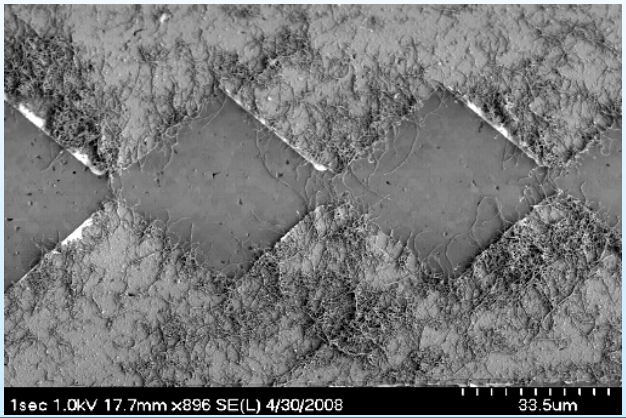


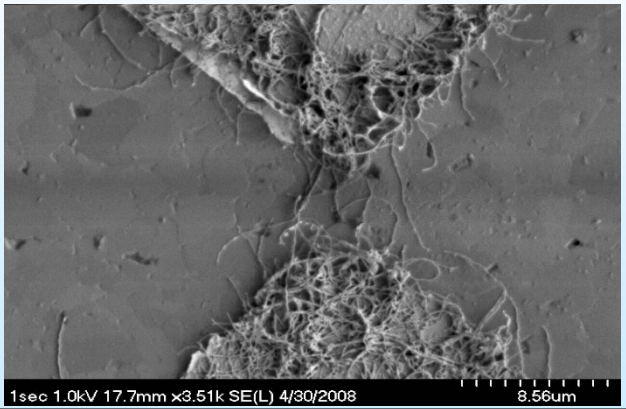


MICROFABRICATION APPLIED TO NANOTECHNOLOGY
Operational Sensors Demonstrated



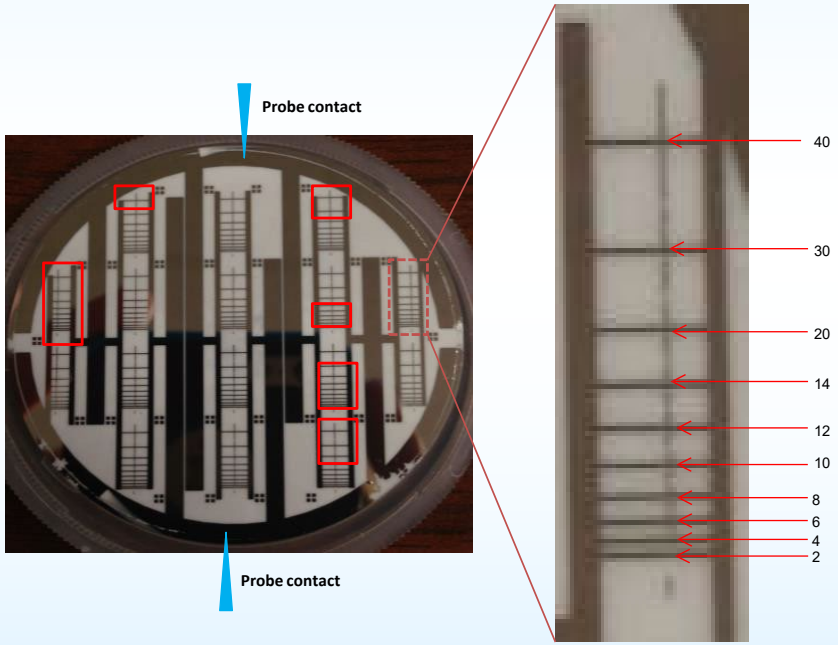
Carbon Nanotubes





MICROFABRICATION TECHNIQUES APPLIED TO NANOTECHNOLOGY
Whole Wafer Processing

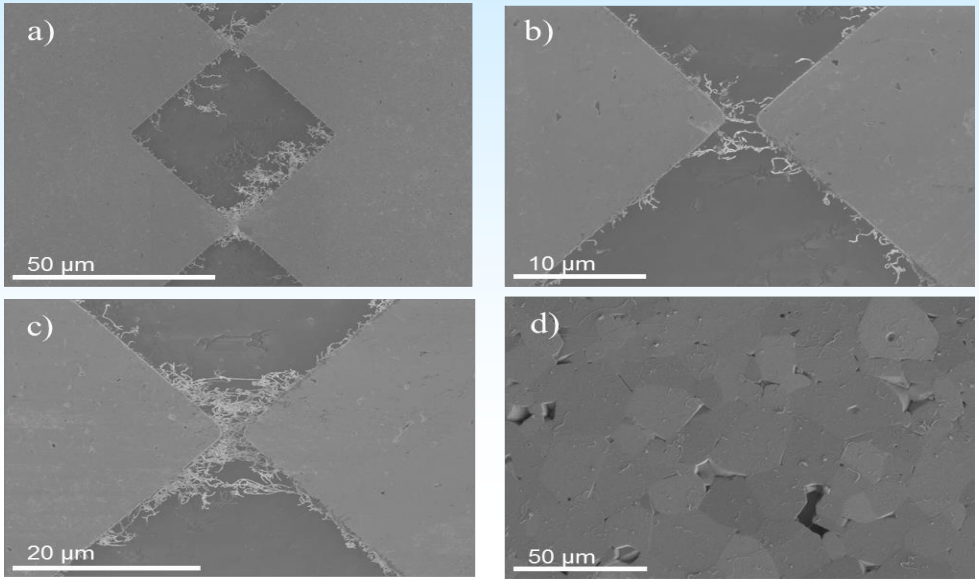
- **Applied to Full Wafer Processing**
- **Design**
  - **16 patterns, each with 146 opposing sawtooth electrodes for a total of 2336 electrodes.**
  - **Can be separated into individual sensors.**
- **High Yield Demonstrated**



Obtained alignment on 2313 of the 2336 electrodes for a 99% yield.

A. M. Biaggi-Labiosa, et al., "Whole wafer design and fabrication for the alignment of nanostructures for chemical sensor applications", 59th International Instrumentation Symposium, Cleveland, OH, August, 2013

Microfabrication Techniques Applied To Nanotechnology



a) Low magnification to show alignment on more than one sawtooth electrode.

b) Alignment of a few nanotubes between opposing electrodes.

c) Alignment of more nanotubes between opposing electrodes.

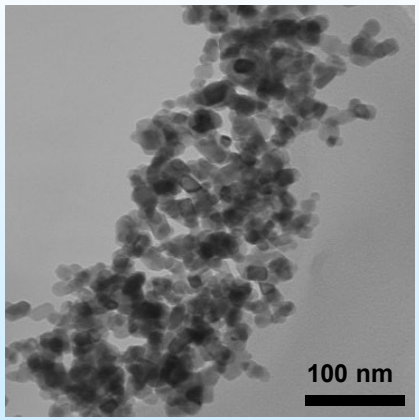
d) Image of surrounding alumina substrate showing that there are no nanotubes (or a little amount) demonstrating that the nanotubes are found between opposing electrodes.

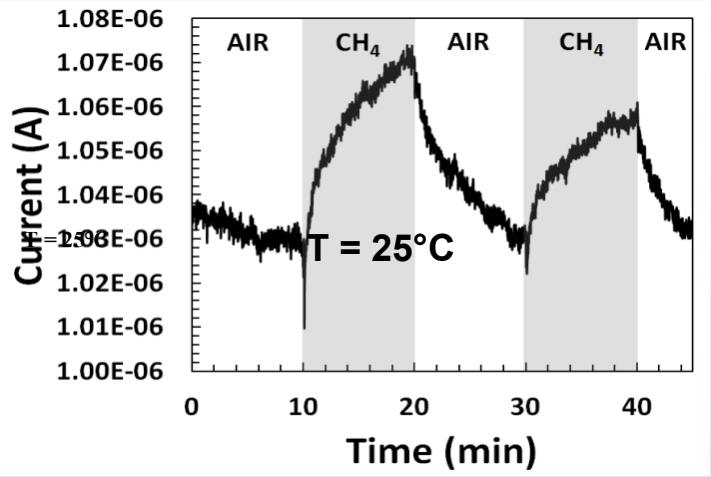
Advancements Using Microfabrication Technology

- Buried Contact Of Nanostructure With Electrodes
- Control Over Alignment of Nanostructures on Microstructure
- Inclusion Of Nanostructures Standard Device Processing

BUILDING ON THIS BASE
TEMPLATED APPROACH TO SENSOR FABRICATION

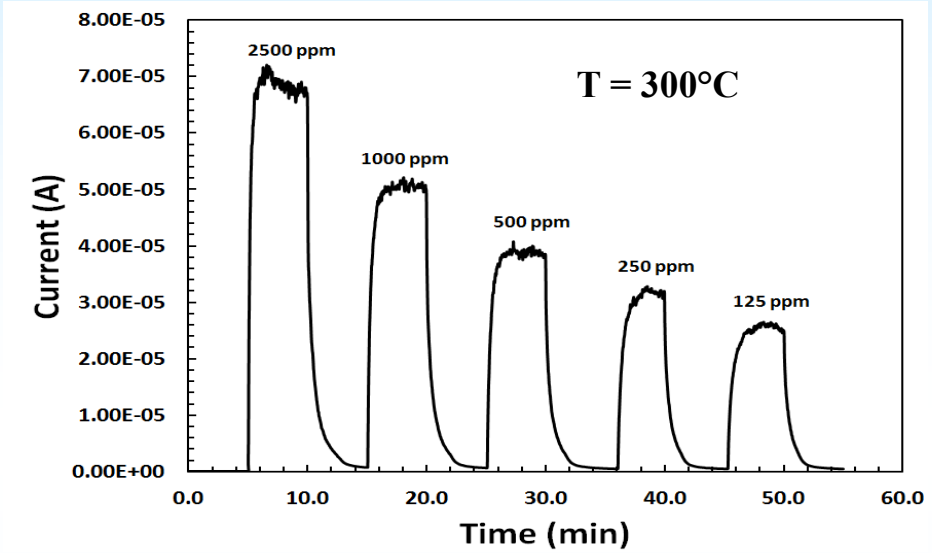
- **Template Approach**
  - **Carbon Nanotube as a Template Coated with Tin Oxide**
  - **Burn Off Carbon Leaving Only Tin Oxide**
  - **Resulting Tin Oxide Has Sensing Properties More Similar to Carbon than Tin Oxide**
- **Porous SnO_2 nanorods via templated approach**
  - **Integrated into Micro Sensor Platform Using Micro Techniques**
  - **Room temperature methane detection**





TEMPLATED APPROACH TO SENSOR FABRICATION

- Still retains properties of SnO_2 for high temperature gas detection
- High temperature methane detection (up to 500°C)
- Can Be Used for Other Templates e.g., biological materials



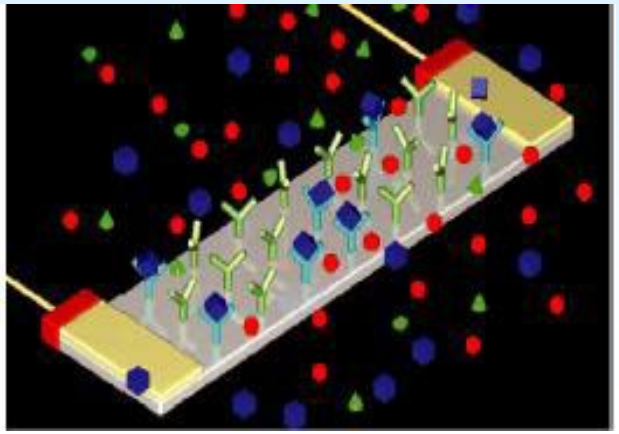
Concentration (ppm)	Temperature					
	25 (°C)	100 (°C)	200 (°C)	300 (°C)	400 (°C)	500 (°C)
2500	0.58	4.8	40	86.25	41	30
1000	-	3.6	30.3	62.5	28.3	13.5
500	-	2.8	21	47.5	25.7	14
250	-	2.2	16.3	40	22.3	13.5
125	-	1.6	11.7	32.13	20.3	12.5

- **Biaggi-Labiosa, et.al. A Novel Methane Sensor Based on Porous SnO2 Nanorods: Room Temperature to High Temperature Detection, Nanotechnology 23 (2012) 455501.**
- **Patent US10294099 B1, Templated nanostructure sensors and methods of manufacture, May 2019**

SUMMARY AND LONG-TERM VISION

- **Multiuse Micro/Nano Sensor Technology Combined With A Basic Hardware Platform (e.g., "Lick And Stick" Technology) Can Enable Smart Sensor Systems**
  - **Orthogonal, Multiparameter, Resilient Sensors Core to the Approach**
  - **Revolutionary Changes In A Range Of Applications Can Be Enabled By Smart Micro/Nano Systems**
- **Revolutionary Changes Can Be Enabled By Smart Micro/Nano Systems**
  - **A Range Of Systems Under Development**
  - **Begin With A Smart Core And Adapt To The Application**
- **Significant Development Of Nanotechnology Base Sensor Platforms Has Occurred**
  - **Baseline Work In A Range Of Nano Structure Sensing Devices**
- **Central To This Presentation Is The Use Of Microfabrication Techniques To Enable Controlled Fabrication Of Microsensors Based On Nanostructures (Patented)**
  - **Buried Contact Of Nanostructure With Electrodes**
  - **Control Over Alignment Of Nanostructures On Microstructure**
  - **Inclusion Of Nanostructures Standard Device Processing**
  - **Templated Approach Results In Tin Oxide With Sensing Properties More Similar To Carbon Than Tin Oxide**
- **Wide Range of Adaptability and Application**
  - **Microfabrication of more complex devices including nanostructures, e.g., integrated or flexible electronics**
  - **Biomaterials and sensing with Templated Nanostructures**

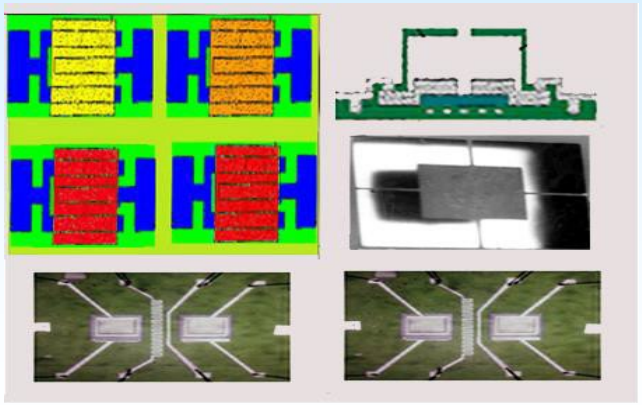
- **Objective: Demonstrate The Fundamental Ability To Assemble The Ultimate "Lock And Key" Chemical Sensor Detection System**
- **State Of The Art:**



Limited Chemical Selectivity by use "Lock and Key" Approach

Many Species, Complex Structures Lead to Limited Ability For Species Identification

NASA GRC HIGH TEMP NOSEAPPROACH



Nose Approaches necessary to attempt to understand environment but still limited in species identification: multispecies identification, closely related species, significant false positives

- **Designer Chemical Sensors: Technically Address The Fundamental Question "What Is Nano Good For?" In The Area Of Chemical Sensors:**
  - **Not: Small Nano Structures For Billion Molecule Measurements/ In Such Applications May Consider Thin Films Or Alternate Sensor Platforms**
  - **Nanostructures For Detection On Molecular Level**
- **Arrange The Chemical Sensor Structure To "Fit" The Molecule In Question**
- **Verify The Presence Of The Molecule With An Electrochemical Signature**

National Aeronautics and Space Administration

Nanoplasmonic Biosensor Project

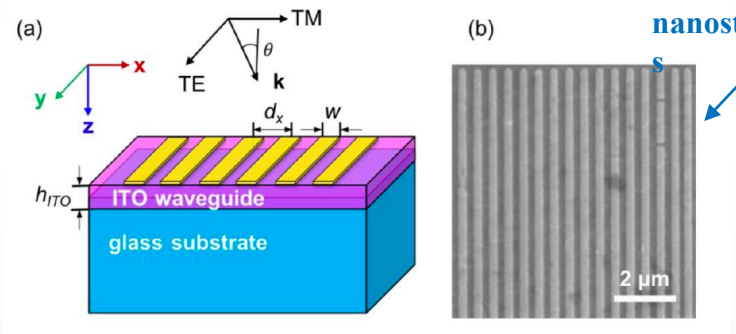
Background

Surface plasmon resonances—coupled charge-electromagnetic wave oscillations at a metal-dielectric interface—are highly sensitive to the surrounding dielectric environment. This effect may be utilized to optically detect binding events of biomolecules including RNA and DNA at the sensor surface in real time.

Our recent results

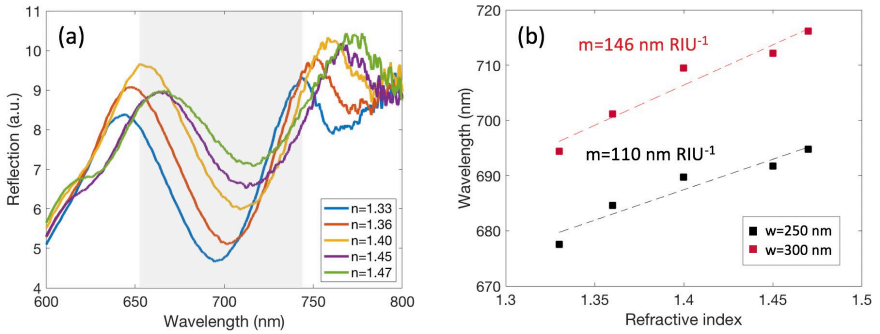
We have designed, fabricated, and tested plasmonic structures for sensitive, on-chip detection of target biomarkers. These structures consist of plasmonic gold nanoantennas coupled to a photonic waveguide. We demonstrate selective detection of target RNA sequences which is manifested as a well-defined shift in the resonance feature. We are currently working to integrate the plasmonic/photonic structures with photodetectors for on-chip field deployment.

Device design



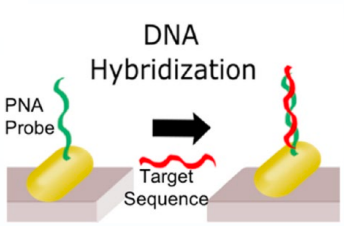
Plasmonic nanostructures

Refractive index sensitivity

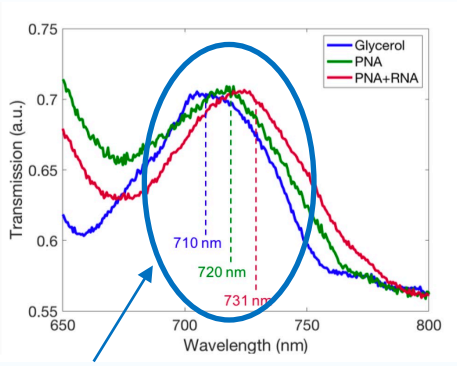


Palinski *et al*., Opt. Express, **27**, 11, 2019

DNA/RNA detection

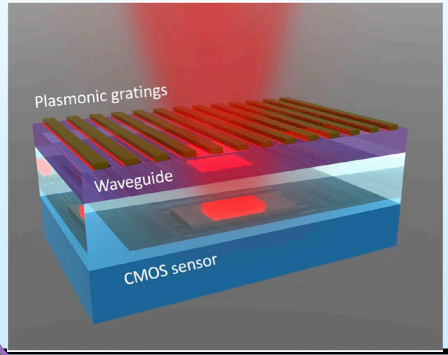


Tadimety *et al*., Biosens. Bioelectron. **130,** 236-244, 2019



Resonance shift in response to selective RNA binding (green → red)

On-chip integration



Plasmonic sensors typically rely on bulky lab equipment for signal excitation and readout (e.g., microscope, spectrometer, etc.)

Integration into portable hardware achieved

COVID-19 detection demonstrated