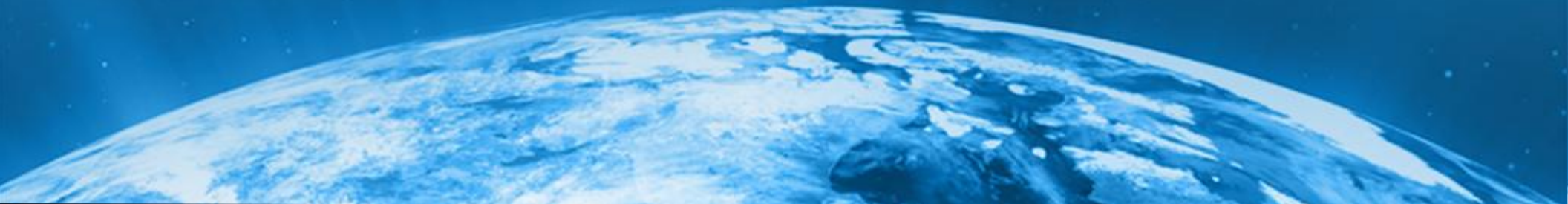




# **Printed Chem-Bio Sensor**

**March 19<sup>th</sup> , 2015**

**Dr. Judy Song, Senior Research Engineer**  
**Electro-Optical System Laboratory**  
**Georgia Tech Research Institute**



# Printed Chem-Bio Sensing Overview

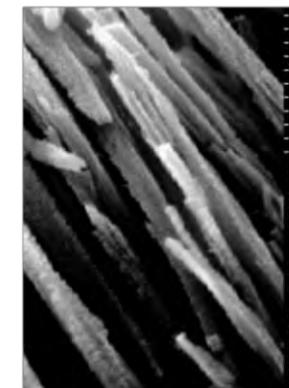
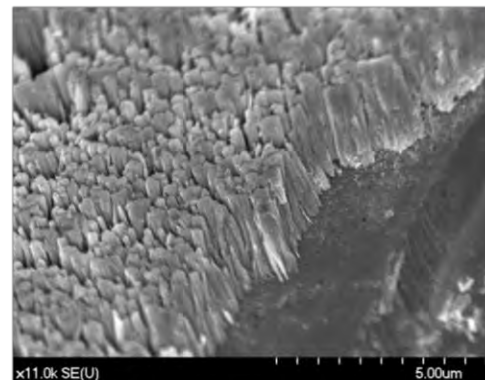
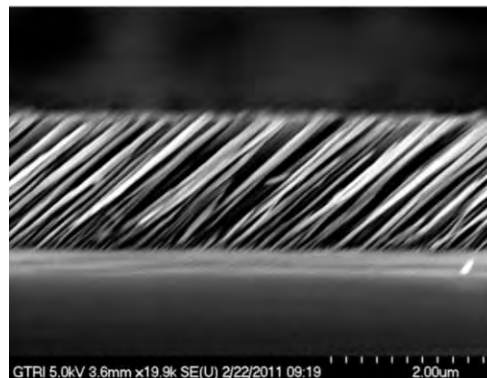
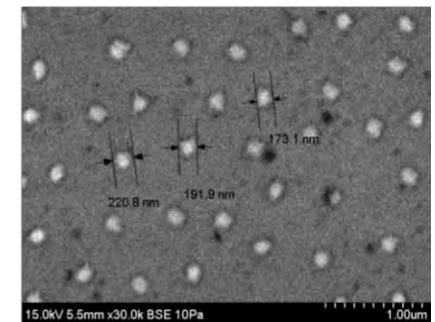
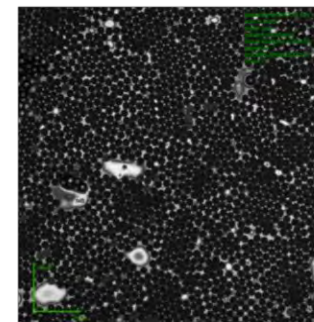
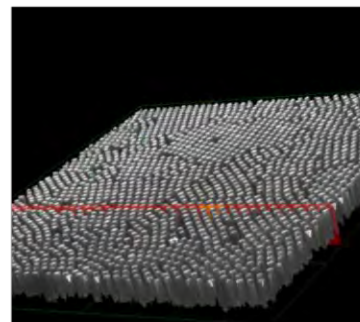
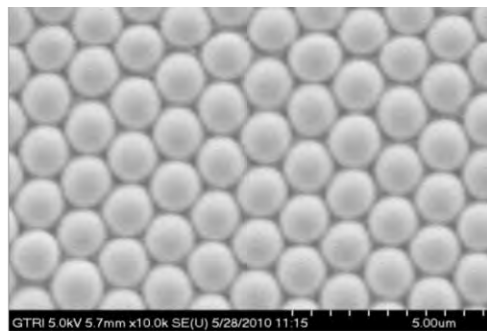
Nano-based sensing: RF, electrical and optical

Electrochemical sensing

Optical interferometric chem-bio sensing

- Long-term monitoring of chemical vapors
  - Ammonia, Hydrazine, Chemical Warfare Agents, etc.
- Standoff detection
- Low vapor pressure of explosives requires high sensitivity
  - 10 ppb for TNT, 10 ppt for Explosives (RDX, PETN)
- Deployed on buildings, vehicles, clothing, tickets
  - Low cost, small size
- Technology in need by US DHS BAA 11-03, US Army, TSA, EPA, Healthcare, etc.

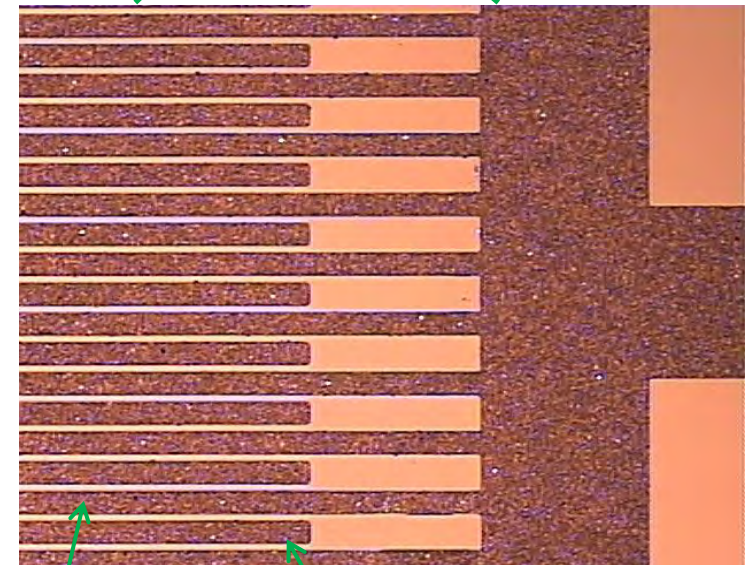
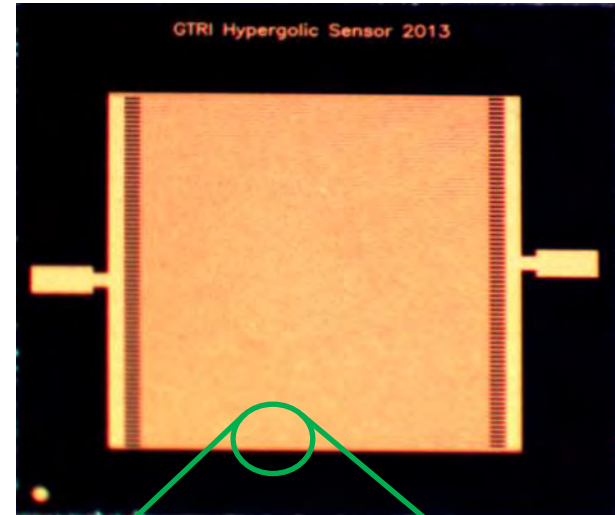
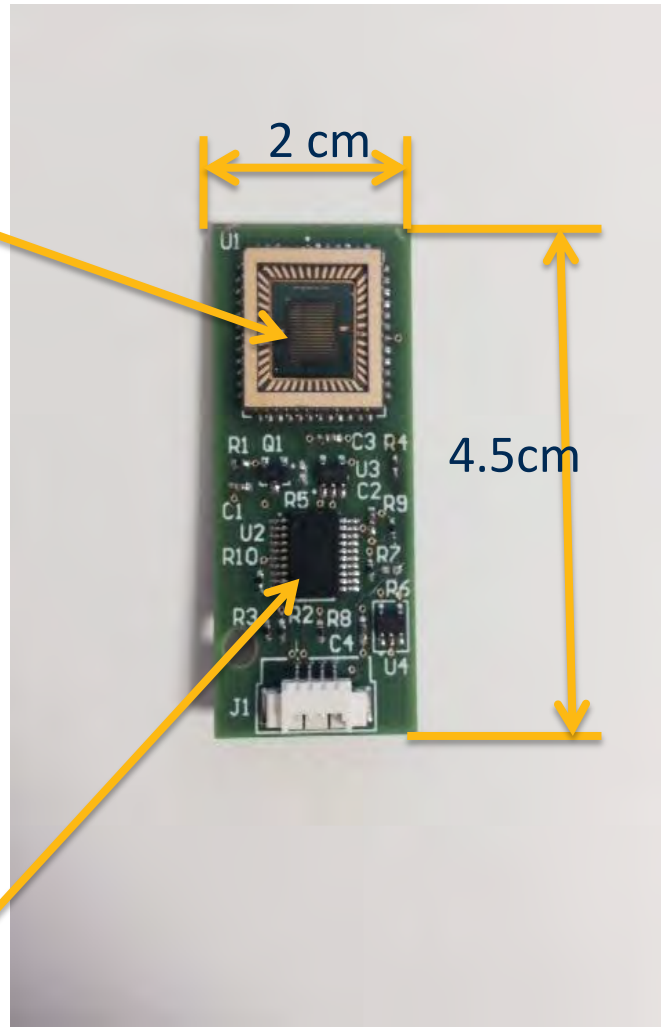
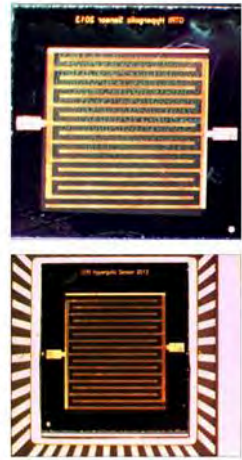
- RF: carbon nanotubes/graphene
- Impedance: CNTs/graphene
- Optical: gold/titania/silica



- Benefits of carbon nano-materials for sensing
  - Ambient temperature operation
  - Low cost fabrication
  - Specificity to particular gas (functionalization and/or sensor array )
  - Sensor reverts back once the reaction is complete
  - Easy integration with electronics (antennas, RF modules)
  - Standoff detection using wireless operation
- Passive (battery-free) sensor operation
  - Small size, low-cost, no maintenance
- Interrogation distance up to 100 m + feasible



# Gas Sensor (with 10- $\mu\text{m}$ spacing)

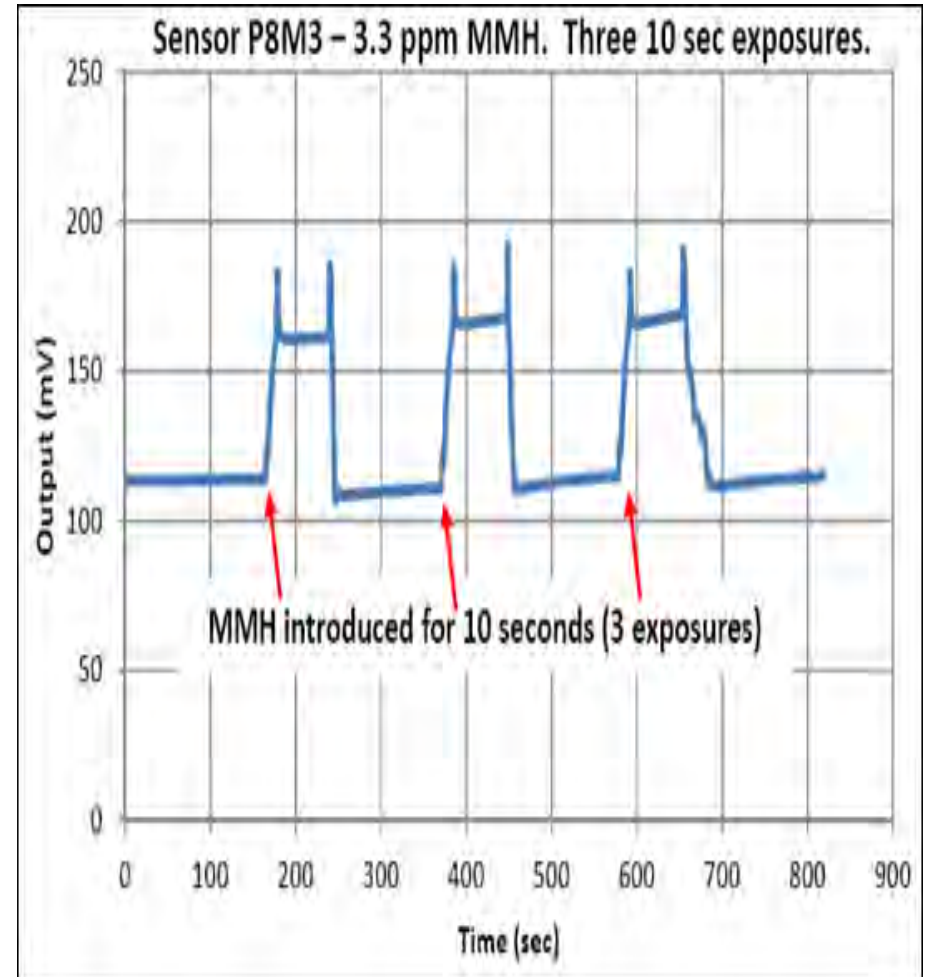
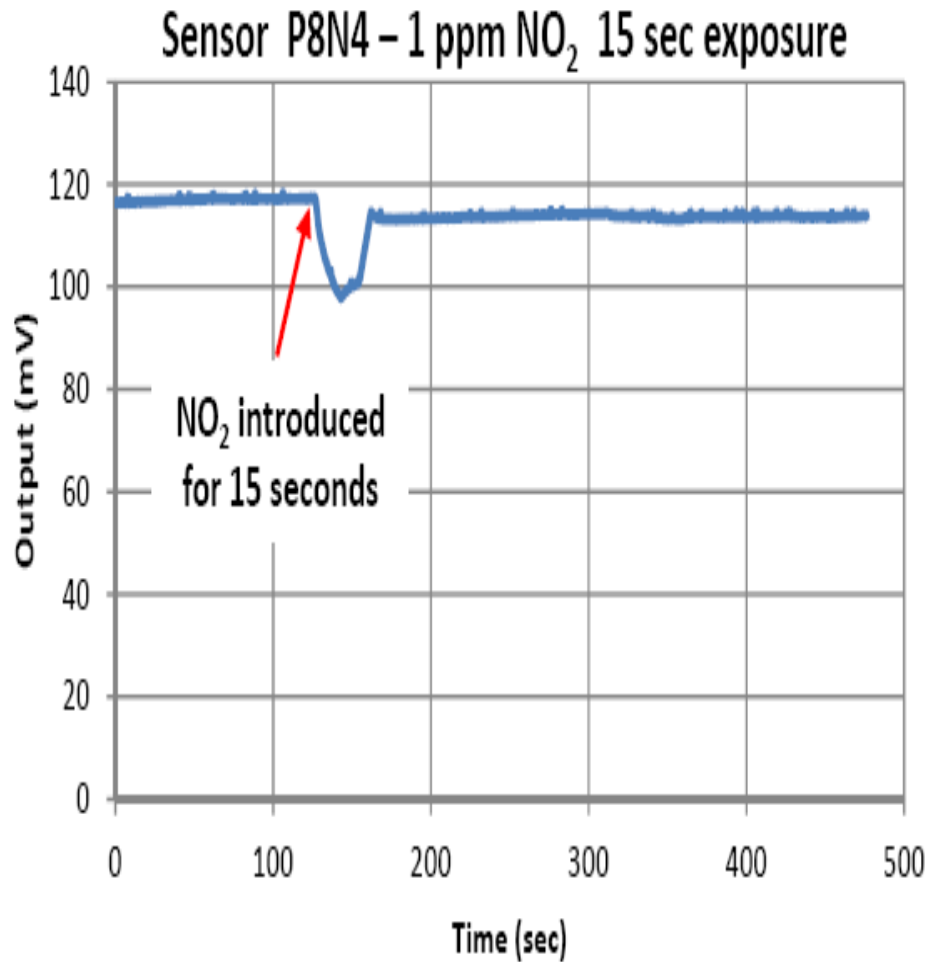


25.4- $\mu\text{m}$  width electrodes

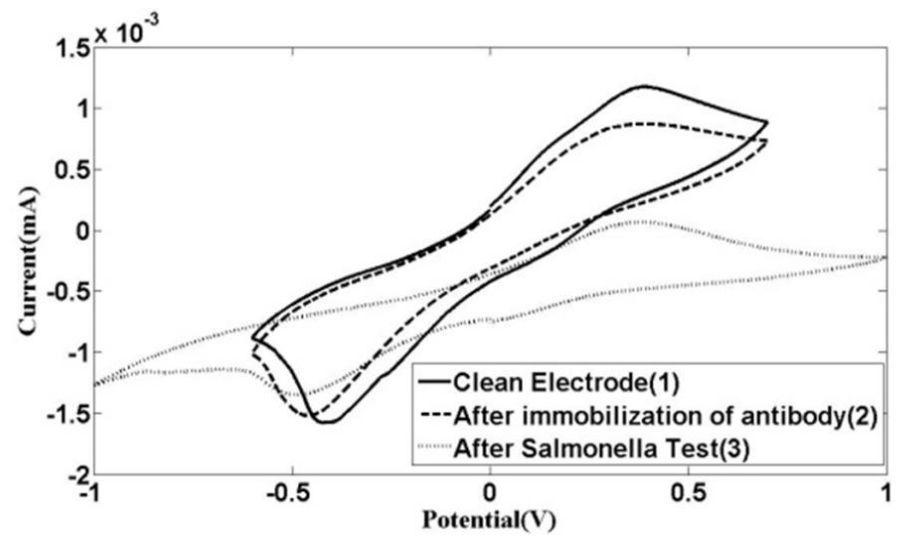
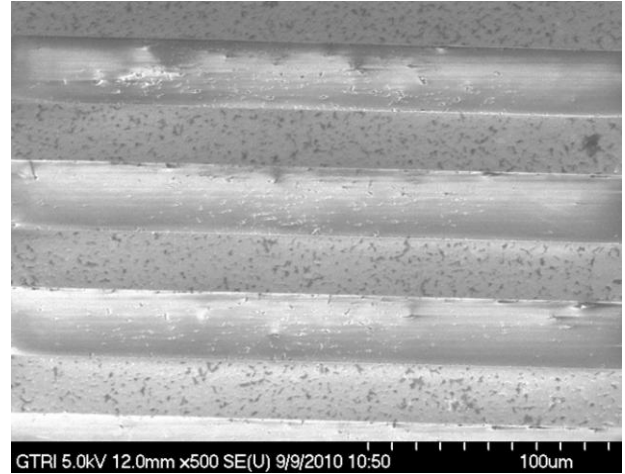
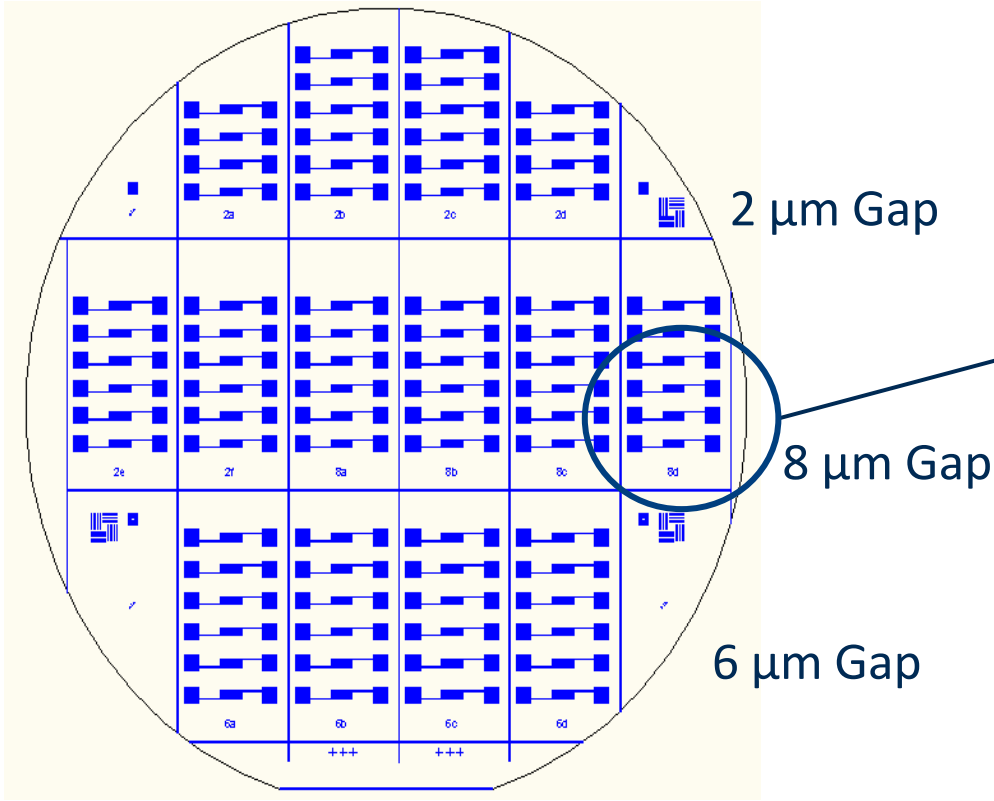
10- $\mu\text{m}$  spacing between electrodes

Aerosol jet printed CNT sensing film on pre-fabricated interdigitated electrodes (top); Wire-bonding completed sensor package (bottom).

# Chemical Vapor Sensing



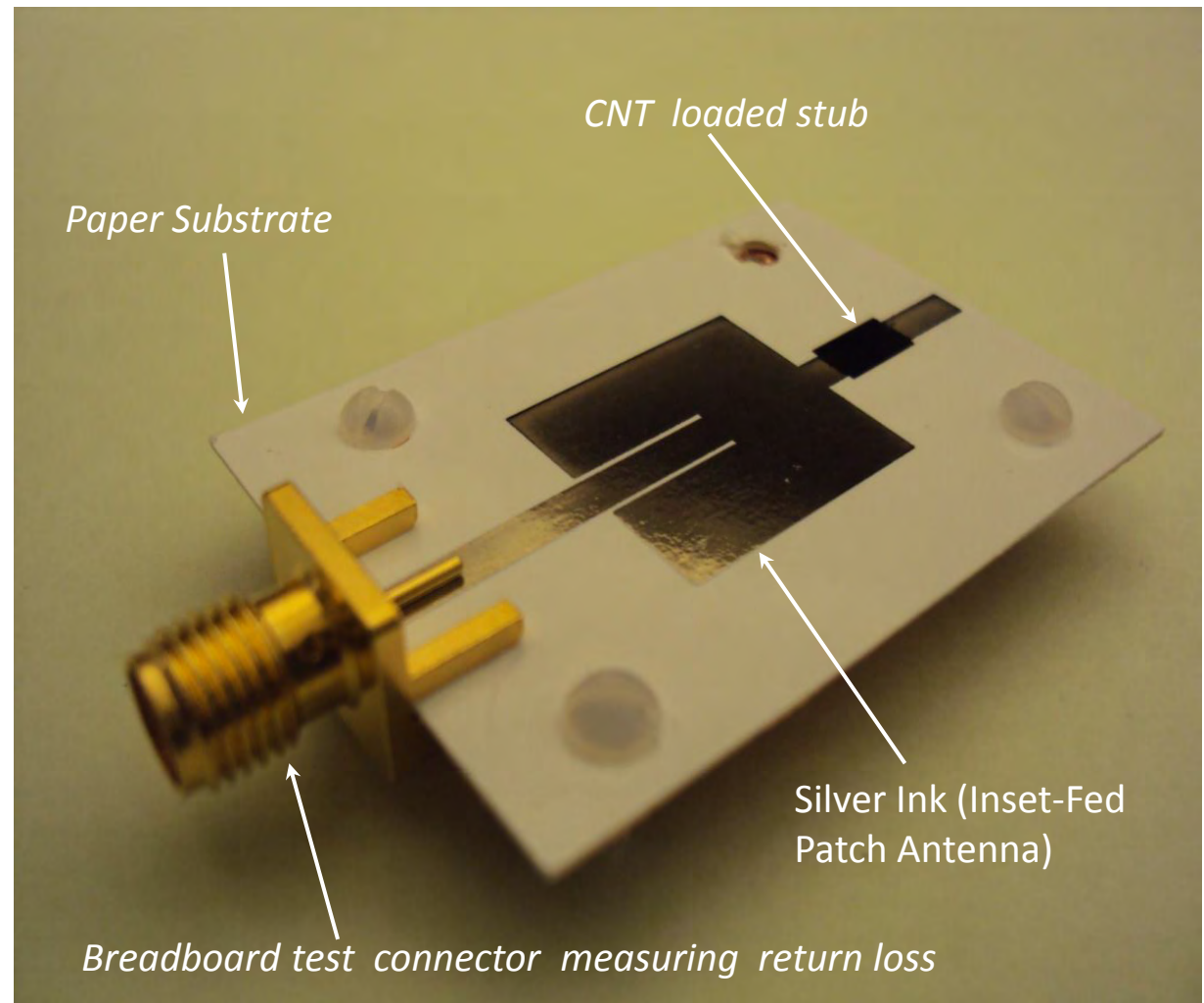
# Microelectrode Array Impedance Based Detection



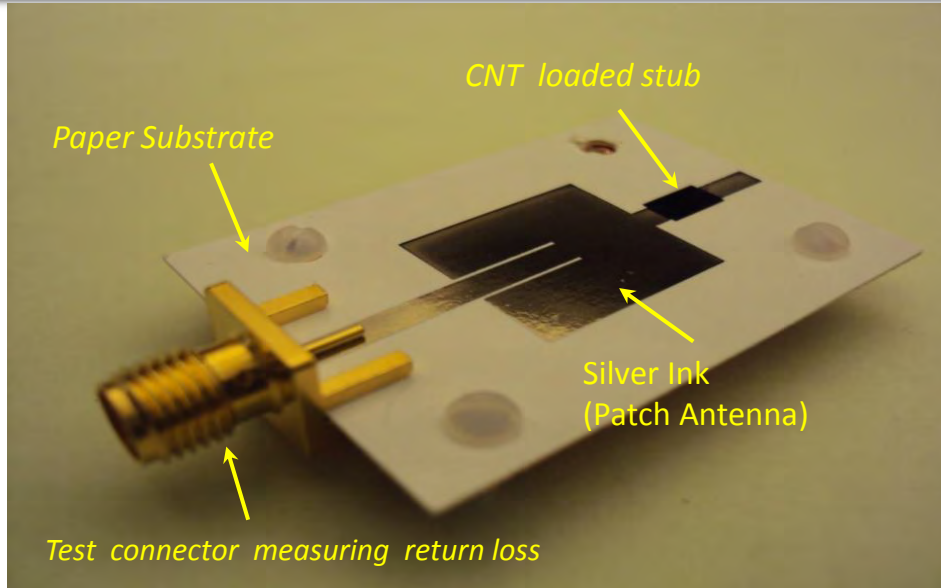


# A Novel Sensor Integrating Paper Antennas & Printed CNTs

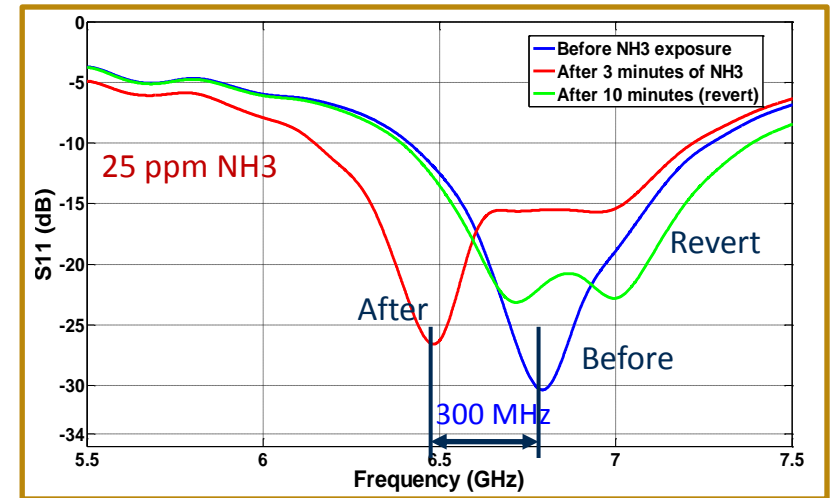
- GTRI developed an RF sensor that *integrates a CNT sensor with an antenna*
- When the CNT material is exposed to gas, *the antenna resonance shifts due to impedance change*
- Detection is a measurement of *the shift in resonance frequency*



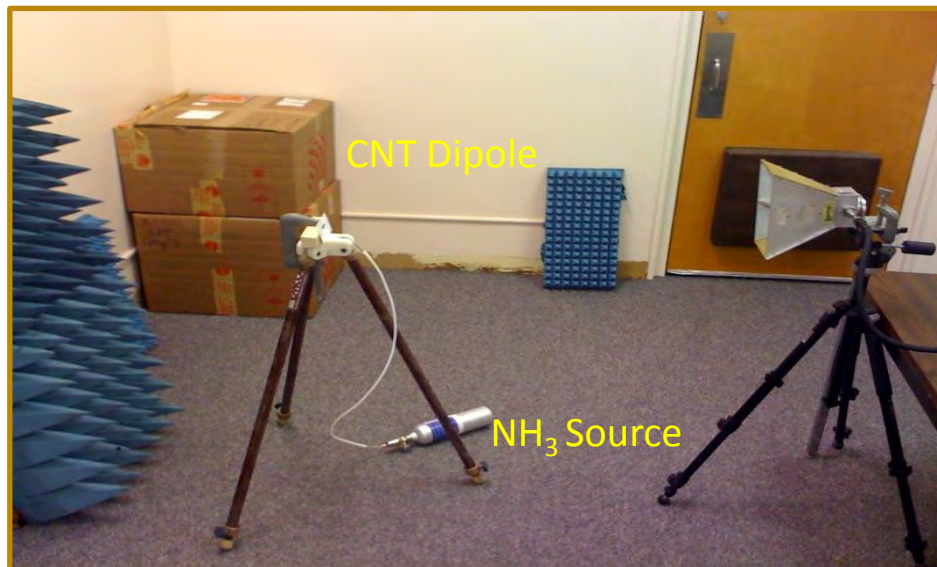
# CNT Sensor Experimental Validation



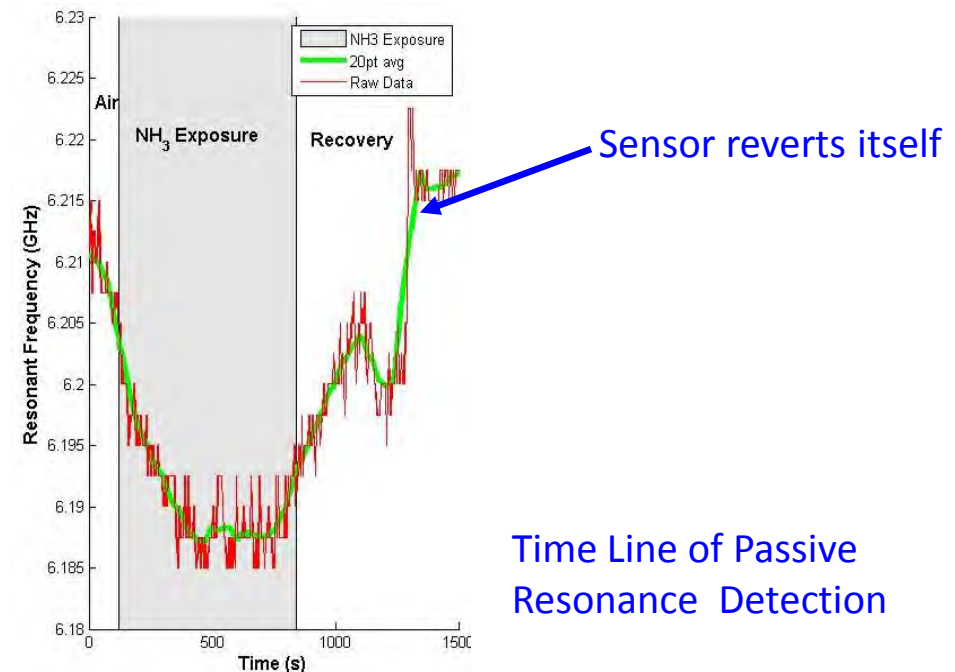
Detection of Ammonia Using Resonance Shift



Low-Power Detection Using Reflected Signal, 300 MHz resonance shift (largest reported)

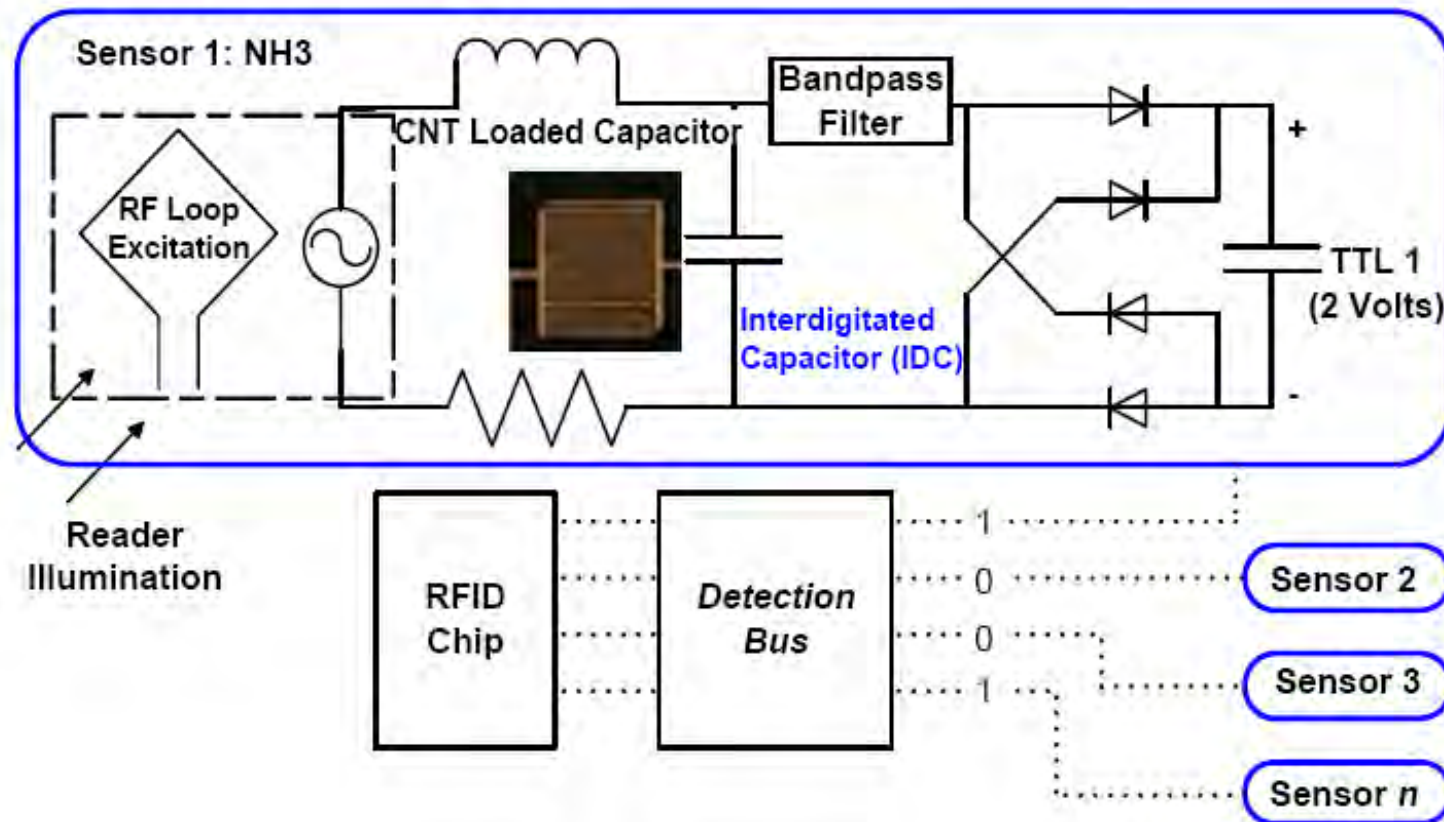


Passive Detection Using Back-scattered Signal



Time Line of Passive Resonance Detection

# Integration of CNT Detector with RFID



- IDC capacitance changes as a function of reaction and shifts the tank resonance
- The bandpass filter is tuned to the background signal and creates '1' upon rectification
- When the gas is detected, the filter is de-tuned which causes a '0' upon rectification
- Rectified signal drives an RFID chip for further processing

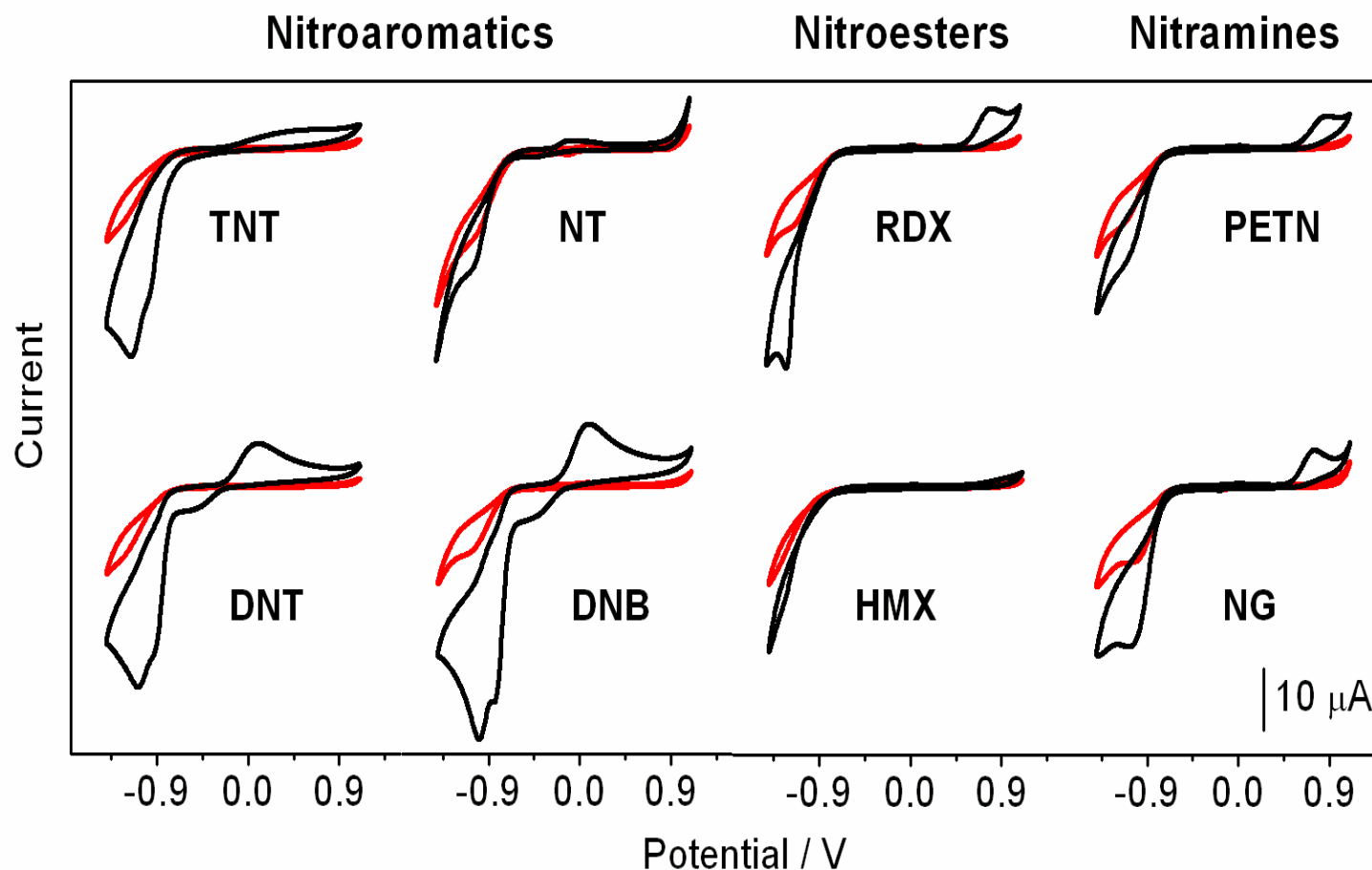


# Electrochemical Sensing

- High Sensitivity and Selectivity
- Inherent Miniaturization
- Advanced Microfabrication
- Low Cost and Power Requirements
- Rapid Detection
- Easy to Use



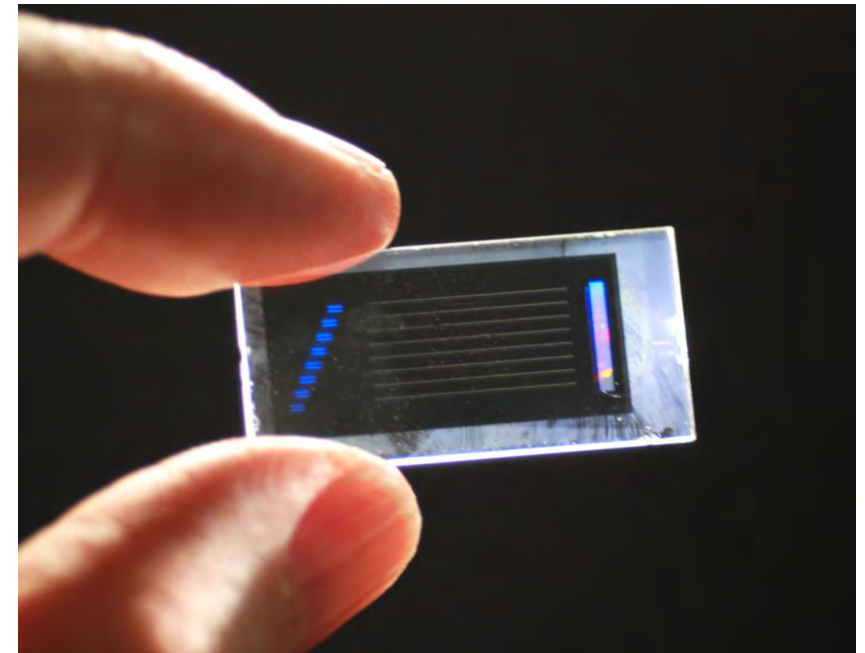
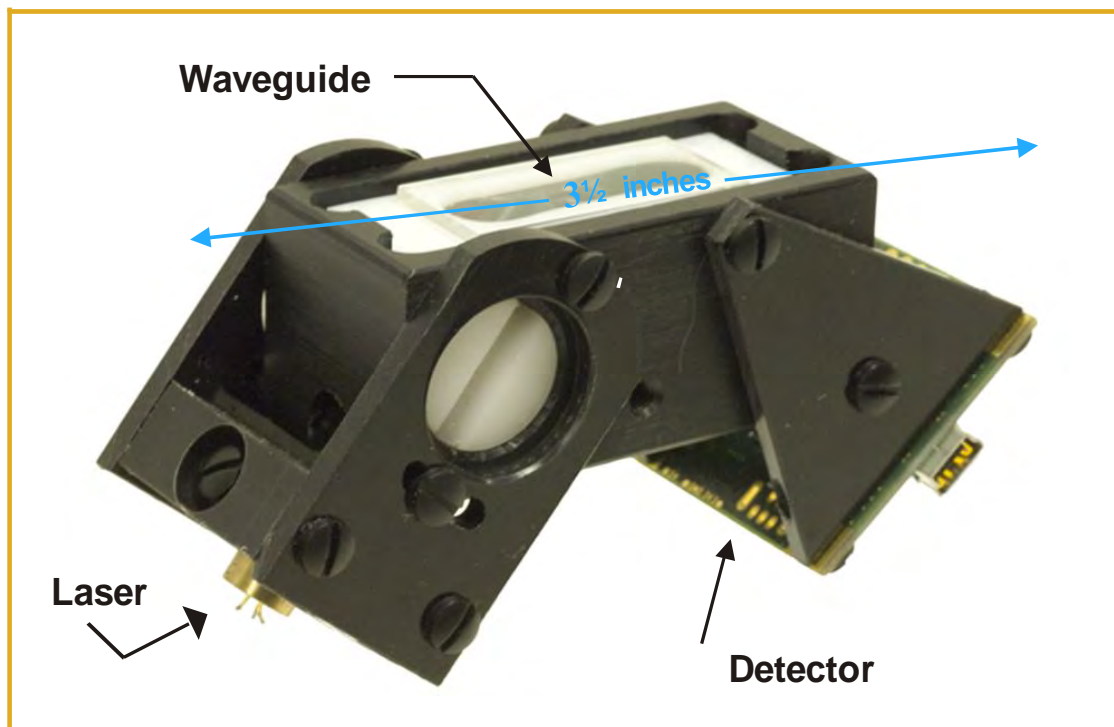
# CV Signatures for Explosives at Carbon Screen Printed Electrode



Cyclic Voltammogram Signatures for 50 ppm TNT, 2-NT, RDX, PETN, DNT, DNB, HMX and NG Solution: red line: 90 ml 0.05M PBS, pH 6.5 + 4.5 ml ACN (MetOH for HMX); black line: +50 ppm TNT, PETN, RDX, 1,3-Dinitrobenzene, nitroglycerin and HMX  
Conditions: CV:  $E_{start}$ : 1.1 V;  $E_{end}$ : -1.4 V;  $E_{step}$ : 4 mV, Scan rate: 0.1 V/s. Displayed is the 10<sup>th</sup> scan after stabilization



# Sensing Platform



Rapid prototyped sensor platform. Includes inexpensive laser diode, waveguide and USB CCD imager. Eight channel waveguide interferometer chip on right.

# Sensor Analytes Detected to Date

## Explosive Agents

TNT (vapor) Ammonium Nitrate (vapor)  
TATP (vapor) Nitro Benzene  
RDX (vapor) Urea Nitrate

## Biological Agents

*Salmonella* Avian influenza virus  
Anthrax spores Mycobacterium  
*E. Coli* *Yersinia Pestis*  
*Campylobacter* *Listeria*

## Narcotics

Methamphetamine (vap)  
Methamphetamine HCl (solid)

## Chemical Compounds

Hexane (liq, vap) Chloramine (liq)  
Acetone (liq, vap) Methylene Chloride (liq, vap)  
Chlorine (vap) Methanol (vap)  
Acetylene (in oil) Hypochlorous acid (liq)  
HCl (vap) NH<sub>3</sub> (liq, vap)  
Freon (in serum) Methane, ethane (in oil)  
Ethylene (in oil) Chloroform (liq, vap)

## Chemical Warfare Simulants

N, N-dimethyl acetamide (DMAC)  
Dimethyl methyl phosphonate (DMMP)  
Methyl salicylate  
(all vapor)

## Proteins

Avidin Ricin A Chain  
IgG, anti-IgGF1 Antigen  
IgE hCG  
CSA p24 (HIV) (all in solution)

## Other Biologicals

Biotin (co-factor) DNA Hybridization  
DNA CD4 (all in solution)

## Groundwater Contaminants

benzene (liq, vap)  
toluene (liq, vap)  
xylene (liq, vap)  
trichloroethylene (liq, vap)  
Perchloroethylene (liq, vap)  
*cis & trans* dichloroethylene (liq)  
vinyl chloride (liq)

# Thank You