Ames Research Center

NACNT

# Nanostructure Engineered Sensors for Gas Detection in Space and Terrestrial Applications

Jing Li
Center for Nanotechnology
NASA Ames Research Center

3rd NASA INAC Molecular Conductivity and Sensor Workshop
Purdue University, West Lafayette, IN
July 28, 2005

Ames Research Center

# Outline

NACNT

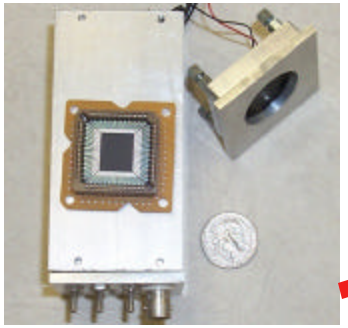
- **Requirements**
- **Product Platforms**
- **Potential Applications**
- **Nanosensing Technology**
- **Current R&D results**

# Nano Chemical Sensors for NASA Mission

Ames Research Center

NACNT

Uninhabited Aircraft

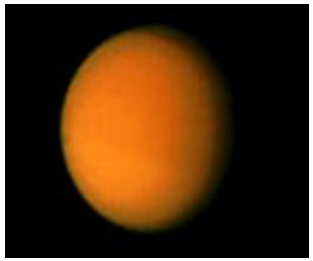


ESE nanotech gas sensors sensors

## Objectives

- Greatly increased science measurement capability - less mass and power requirements for electronics and sensors. Lightweight (Kg or so)
- Demonstrate capabilities nanotechnology can provide for composition measurements of Earth's atmosphere.
- Highly miniaturized gas detectors enabling Earth Science Enterprise Plans for in situ measurements to validate satellite observations.
- Cosmochemistry: Volatiles: $NO_2$, $H_2O$, $NH_3$, $CH_4$ , $SO_2$, $CO_2$, $H_2S$

Here: Earth

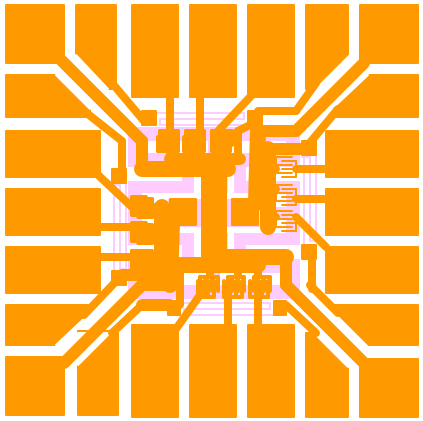


There: Space

Beyond: Outer Space

# Product Platforms

## Sensor chips

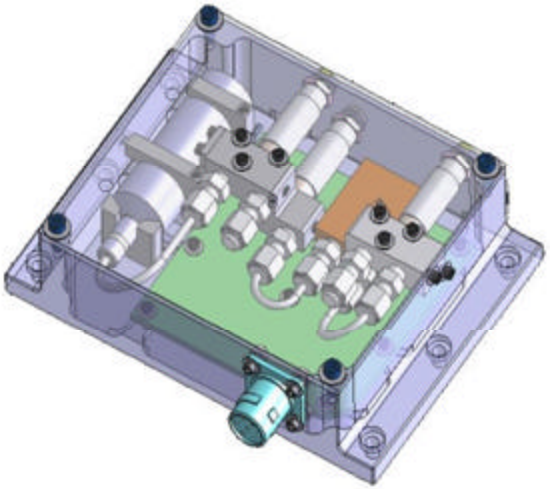


### *Array Chip*

- Sensor array
- Chip < 1 $cm^2$
- Disposable or capable of integration

## Sensing module

**Flight Demo in mid orbit In 2006**

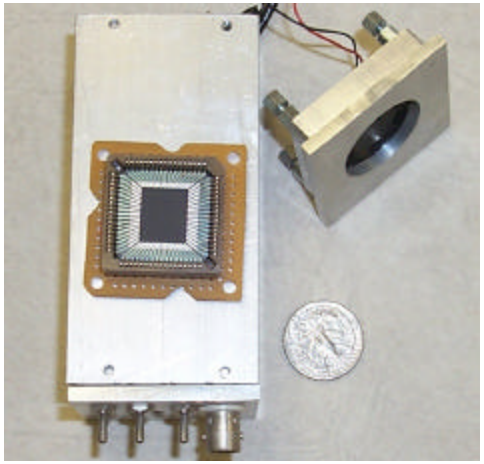


### *Sensing module*

- Collection/integration of multiple sensor input
- Sampling system
- Data storage and transmission
- RS-422 connection

## Handheld detector

**Funded by TSA/FAA**

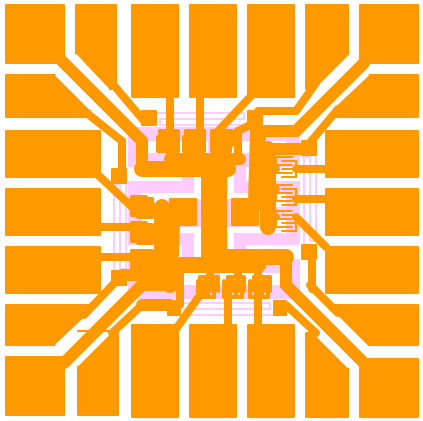


### *Handheld prototype*

- Sensor or sensor array
- < 32 ounces
- Low power & cost
- BNC, or RS-232, USB

# Potential Applications

## Sensor chips



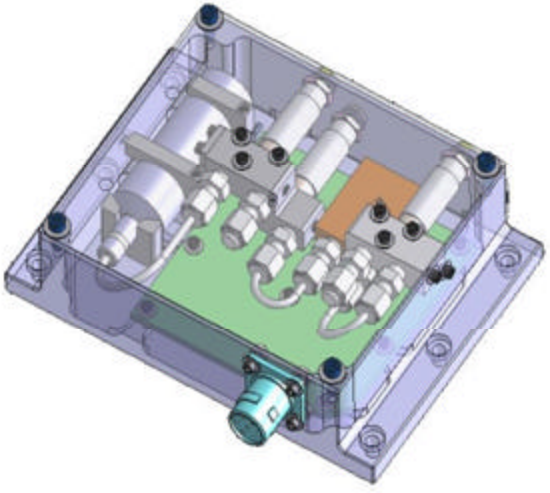
***Remote monitoring***

- Distributed monitoring in cabins, buildings, subways, stadiums
- Battlefield profiling

***Personal Detector***

- Warn personnel of CBW presence

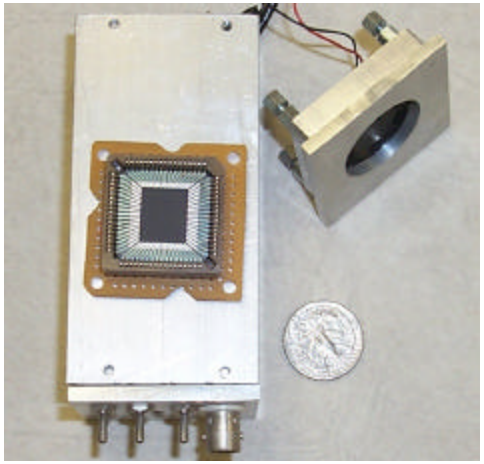
## Sensing module



***Complementary chemical measurement***

- Plug and play chemical measurement
- Process monitoring and control
- UAV surveillances

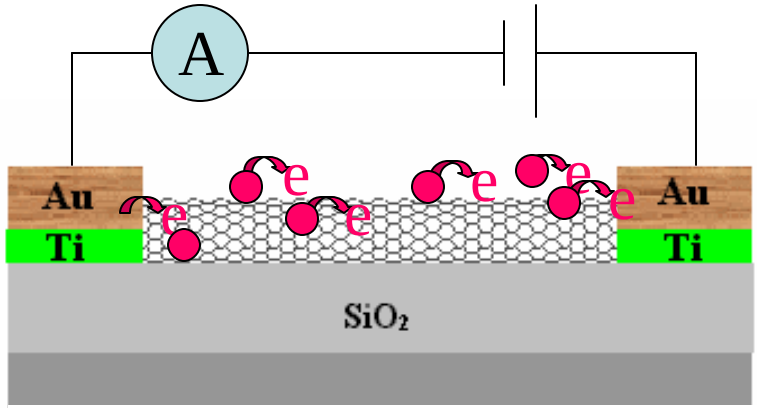
## Handheld detector

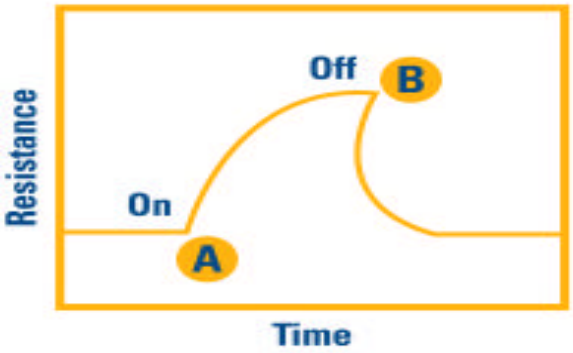


***Chemical Detector***

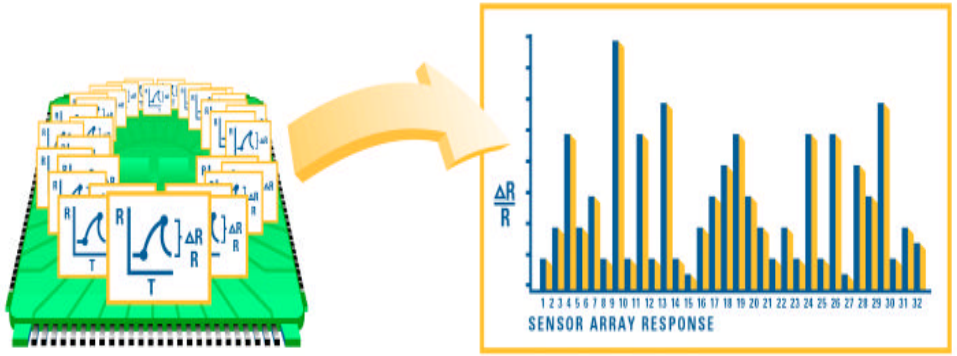
- Use by First Responders for Homeland Security
- Quick decision maker at the test point

# Nanosensing Technology




**A relative resistance or current is measured from each sensor**




**Using pattern matching algorithms, the data is converted into a unique response pattern**

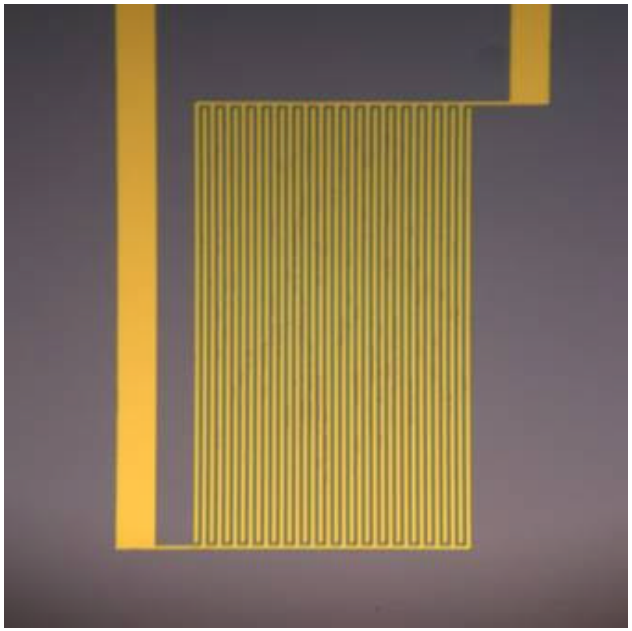
**Operation:**

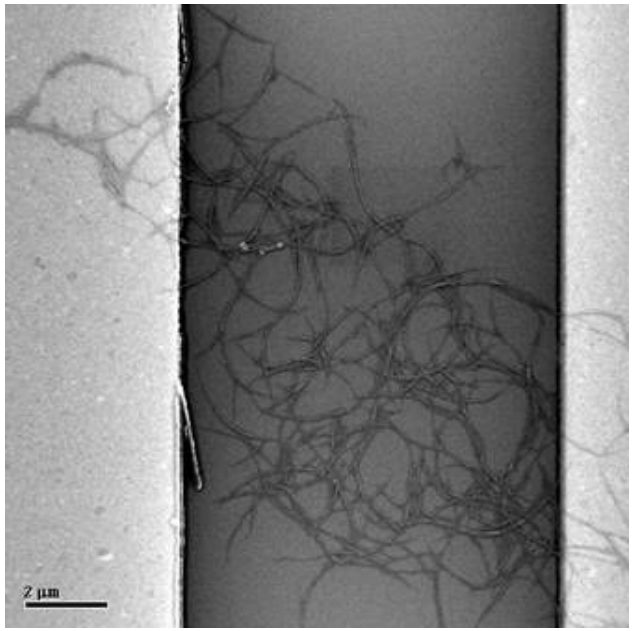
1. **The relative change of current or resistance is correlated to the concentration of analyte.**
2. **Array device "learns" the response pattern in the *training* mode.**
3. **Unknowns are then classified in the *identification* mode.**

# SWCNT Chemiresistor (single chip)

Sensor fabrication:

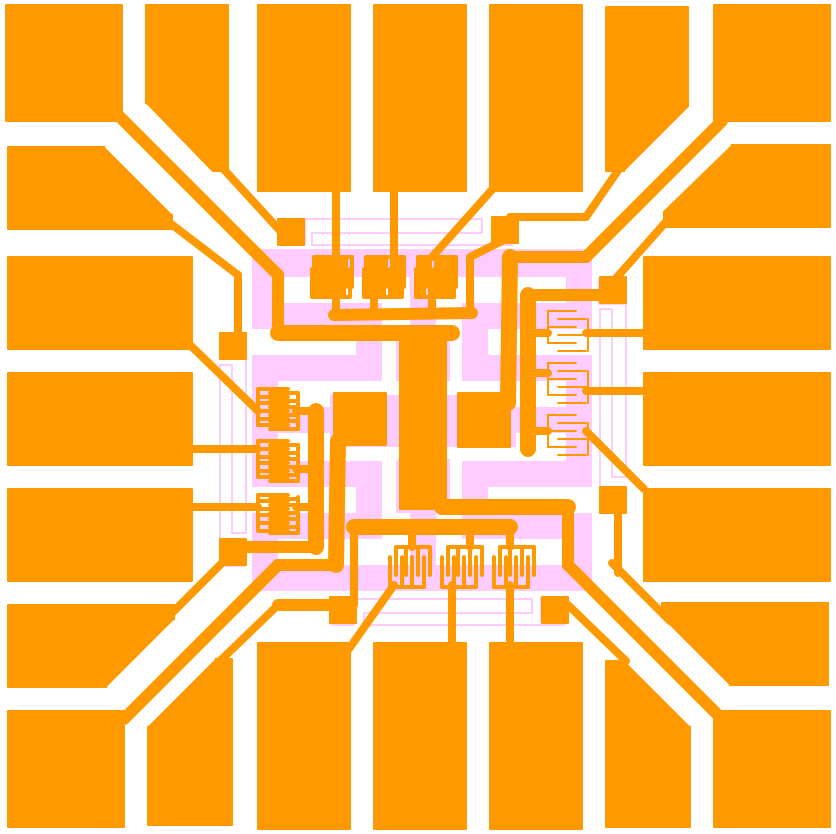
1. SWCNT dispersions--Nice dispersion of CNT in DMF/H2O
2. Device fabrication--(see the interdigitated electrodes below)
3. SWCNT deposition—Casting, or in-situ growth

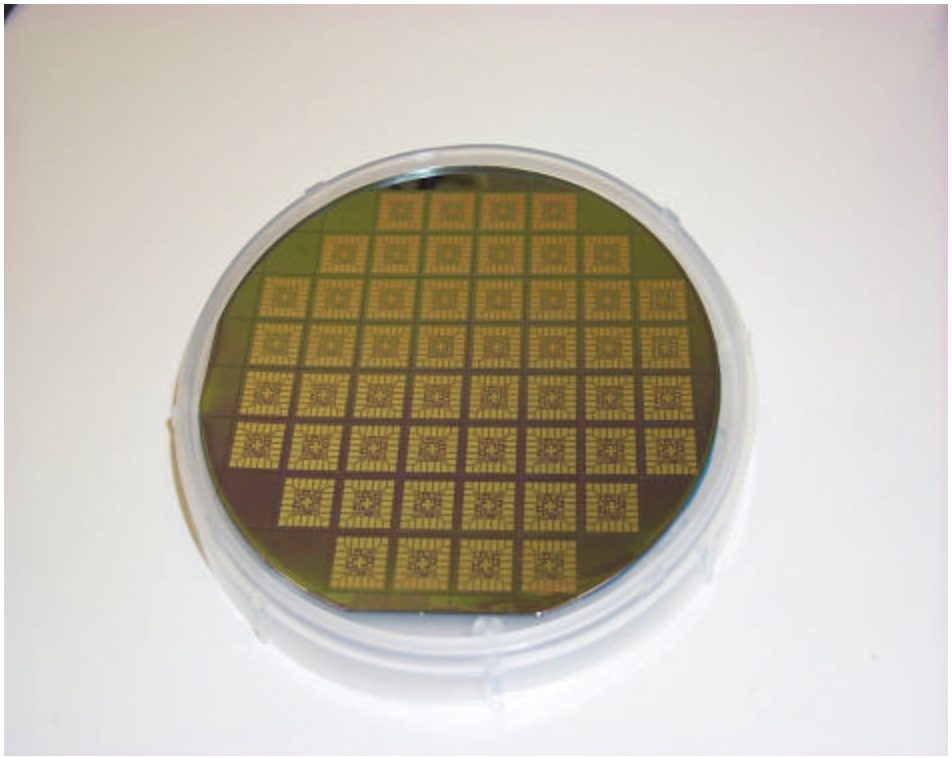





The working principle: conductivity change due to gas adsorption.

# Scalable Array Approach (multi-channel sensing chip)

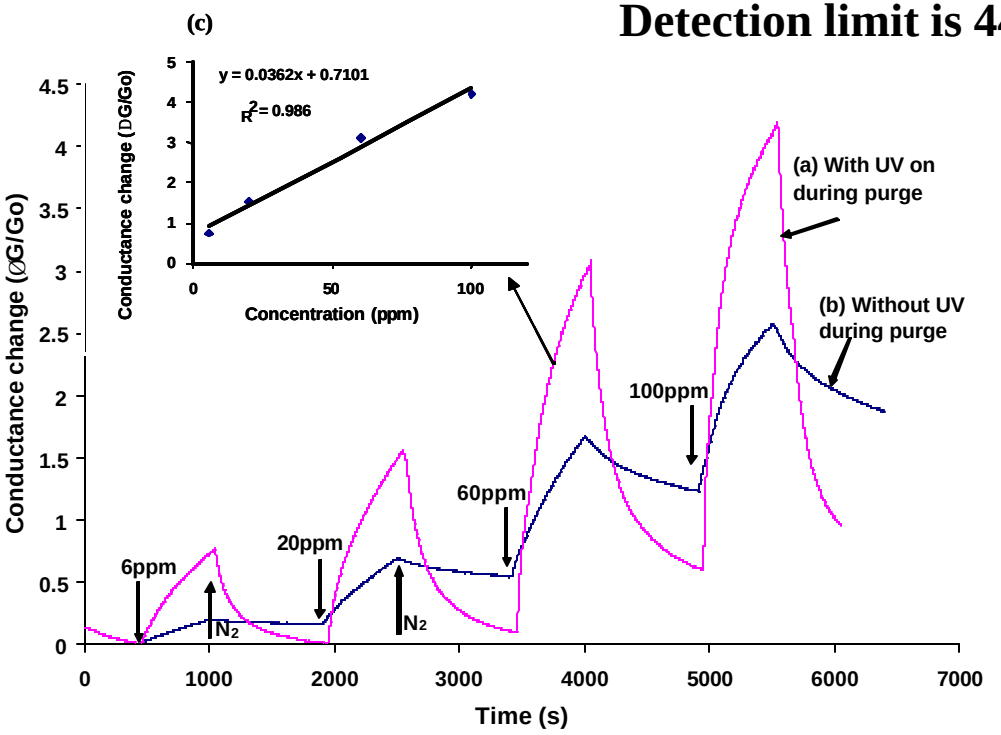




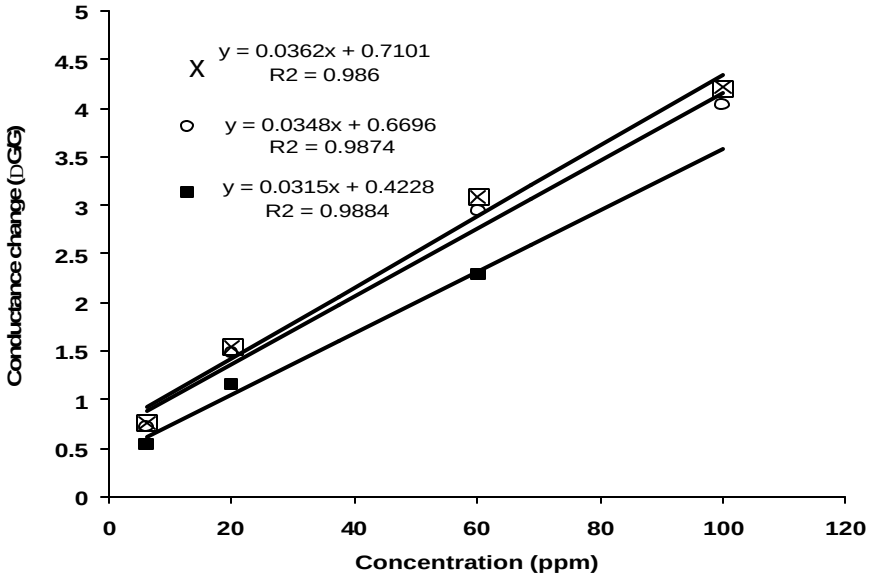
**Twelve sensing elements are on a chip (1cm x 1cm) with heaters and thermistors.**
**Number of sensing elements can be increase on a chip.**
**Number of chip can be increased on a 4” wafer.**
**Wafer size can be increase to 6”, 8”, or 12”.**

# SWNT Sensor to NO2

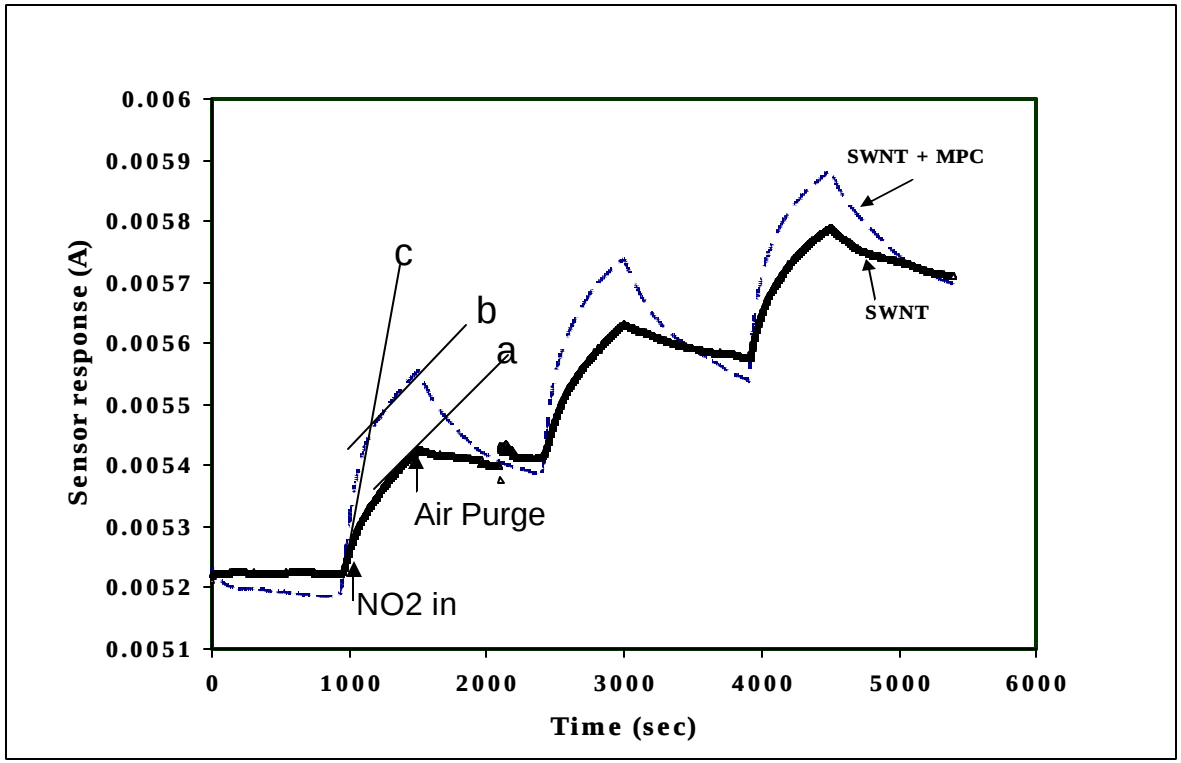
**Detection limit is 44ppb.**

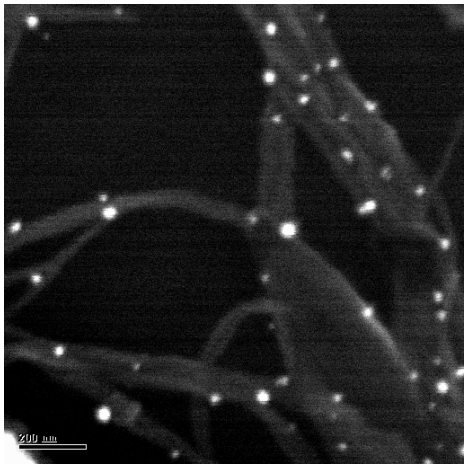


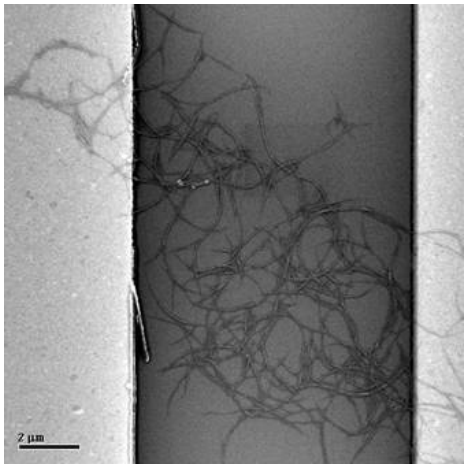

Sensitivity is the slope of the calibration curves. The average slope is 0.034±0.002 (6%).



# Improved Sensitivity from SWNT-MPC Sensor to NO2



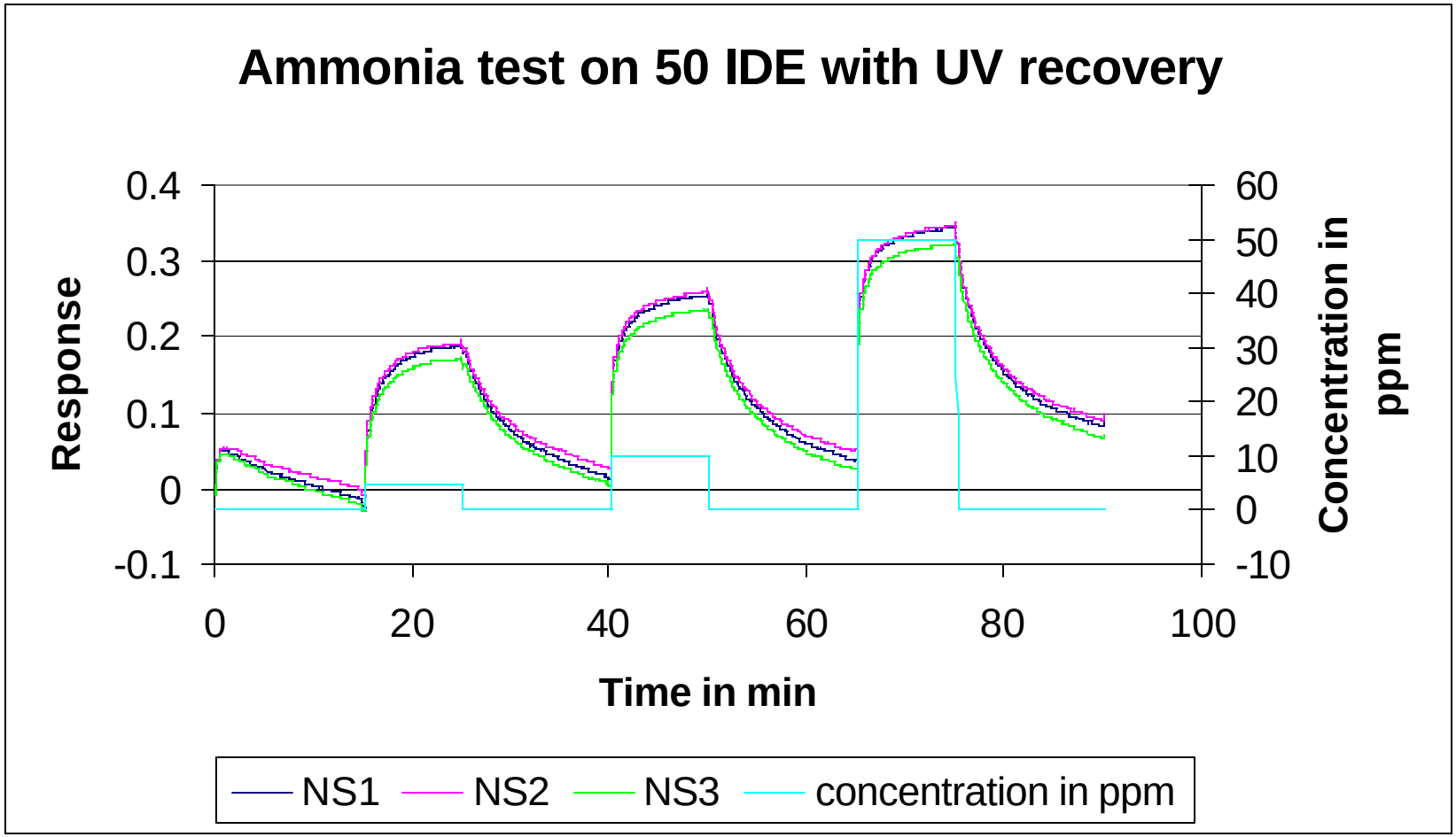


- Response is larger (**9.6-fold** from pure SWNT sensor). The detection limit is **4.6ppb** now.

- Recovery is better.

- Surface response increases.

# CNT sensors to Ammonia



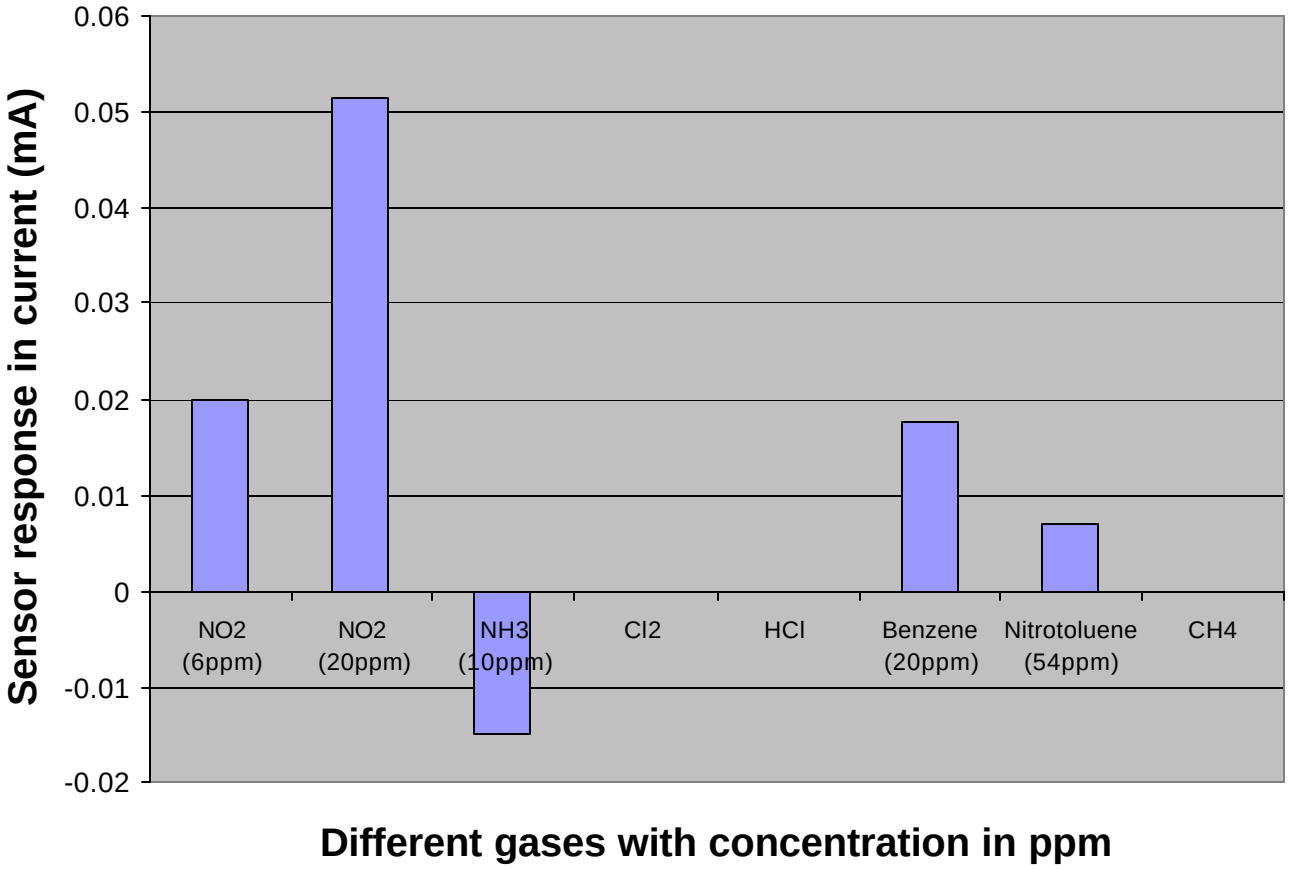
Ames Research Center

# Ways of Improving Selectivity

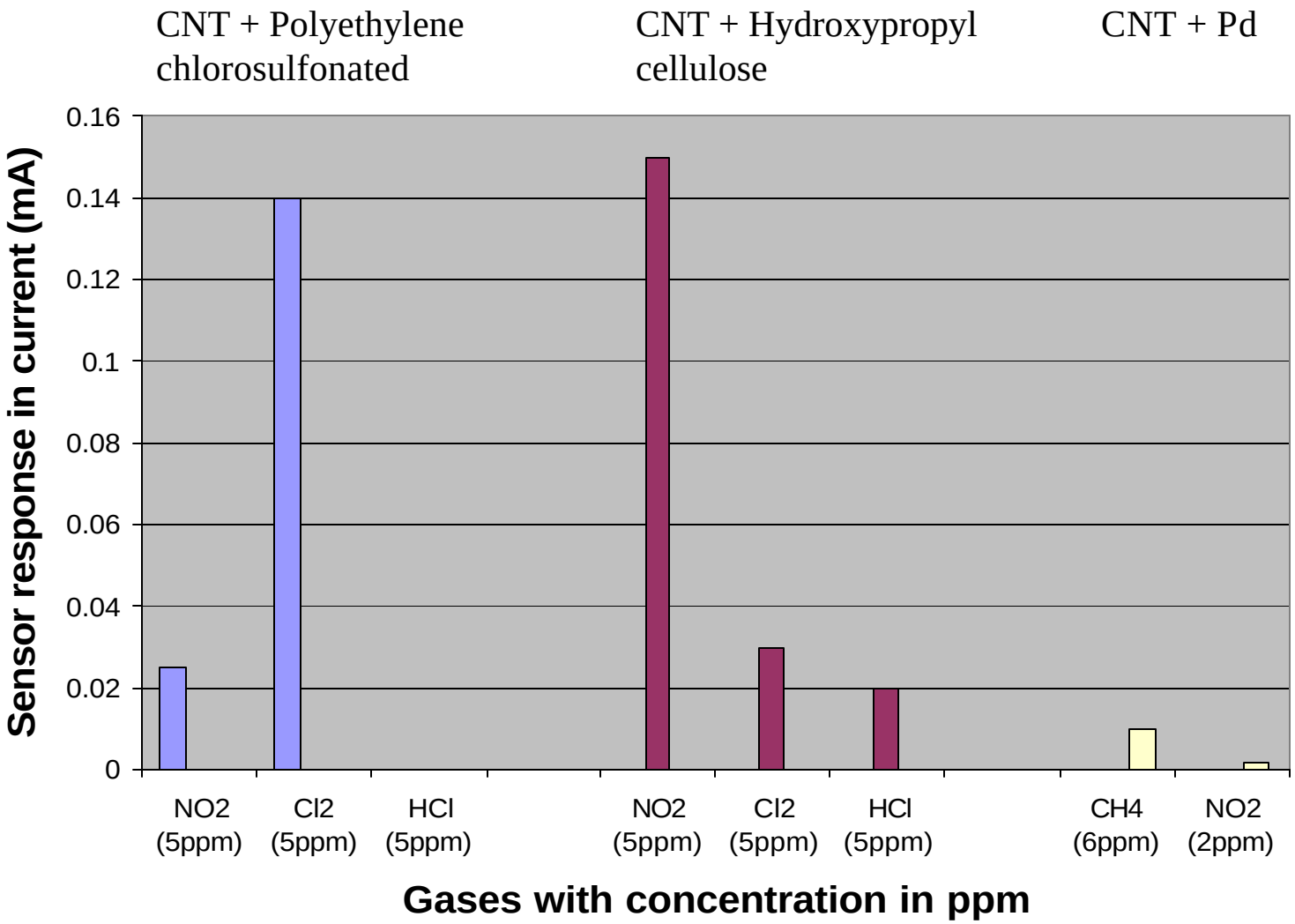

## Major approaches:

- **Functionalization of CNTs**
- **CNT + polymer composites**
- **Doping: catalytic metal clusters**
- **Field effect: gate bias for selective detection**
- **Programmed temperature control**
- **Sensor array with pattern recognition: electronic nose**

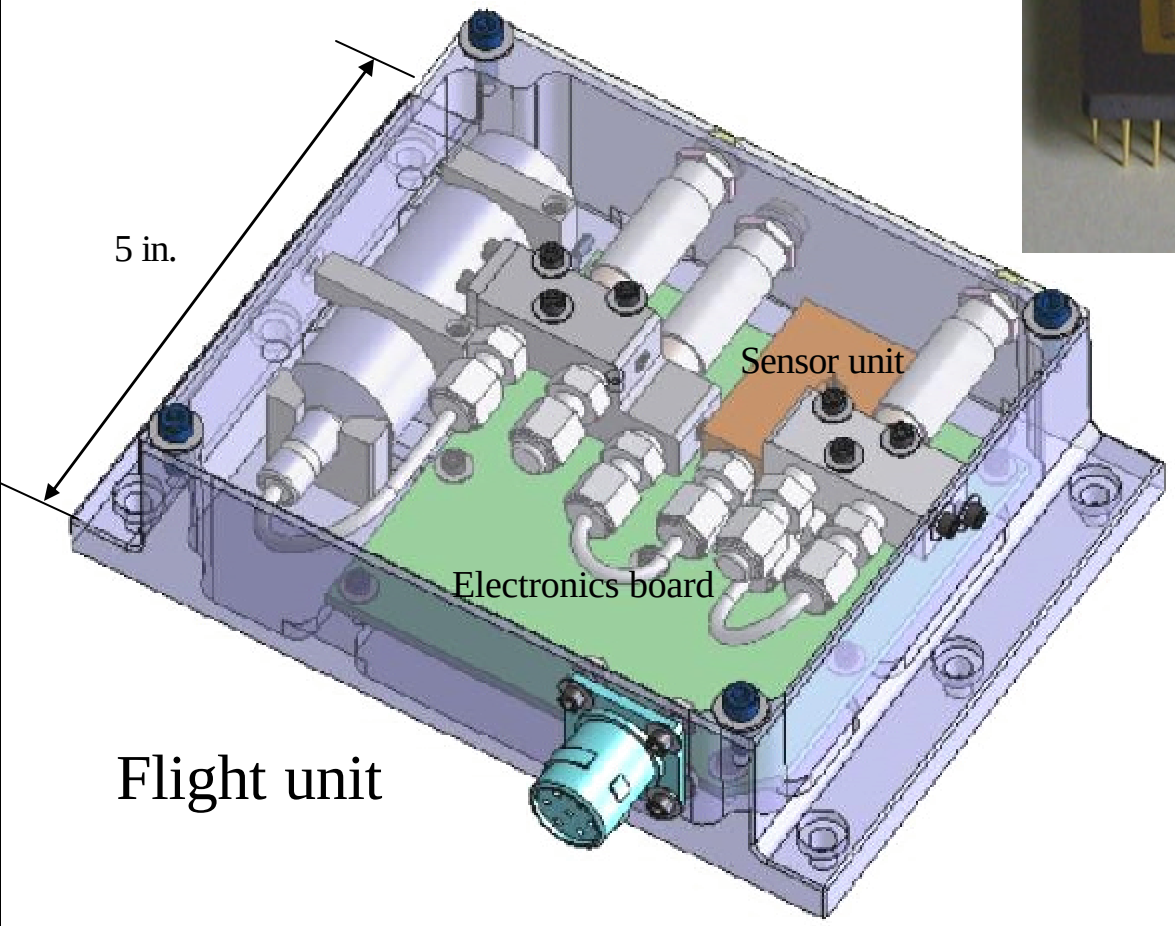
# Comparison of CNT sensors to different gases and vapors



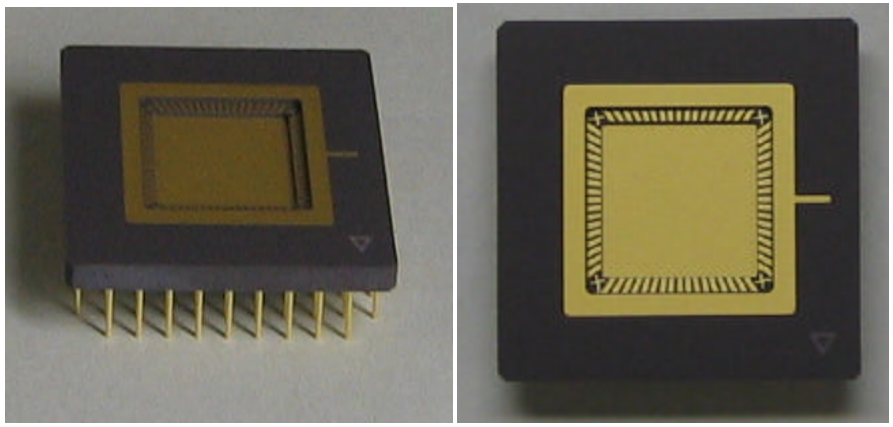
# Comparison of CNT with different mixing materials for gases



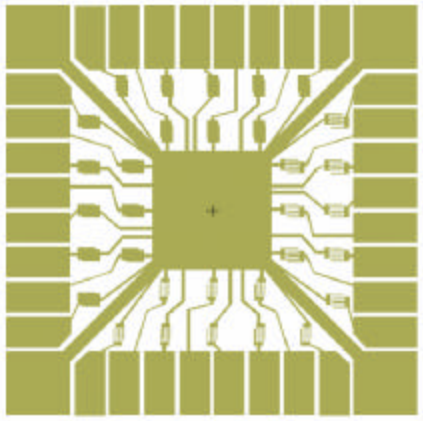
# Flight Demo Unit for Satellite




Flight unit

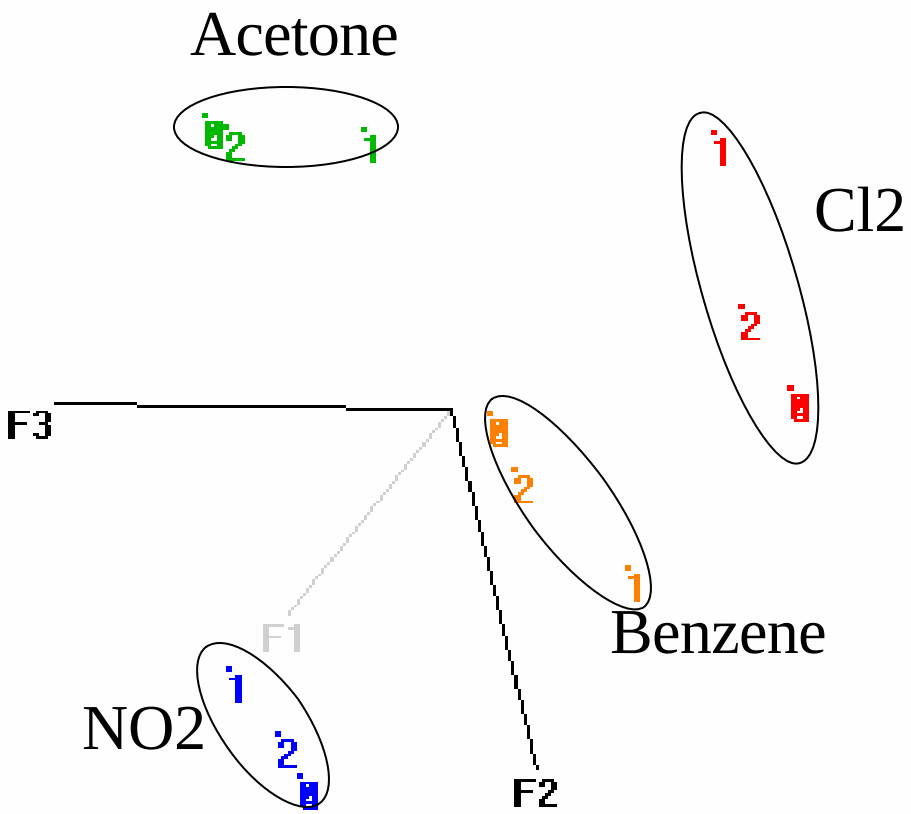


Ceramic chip carrier



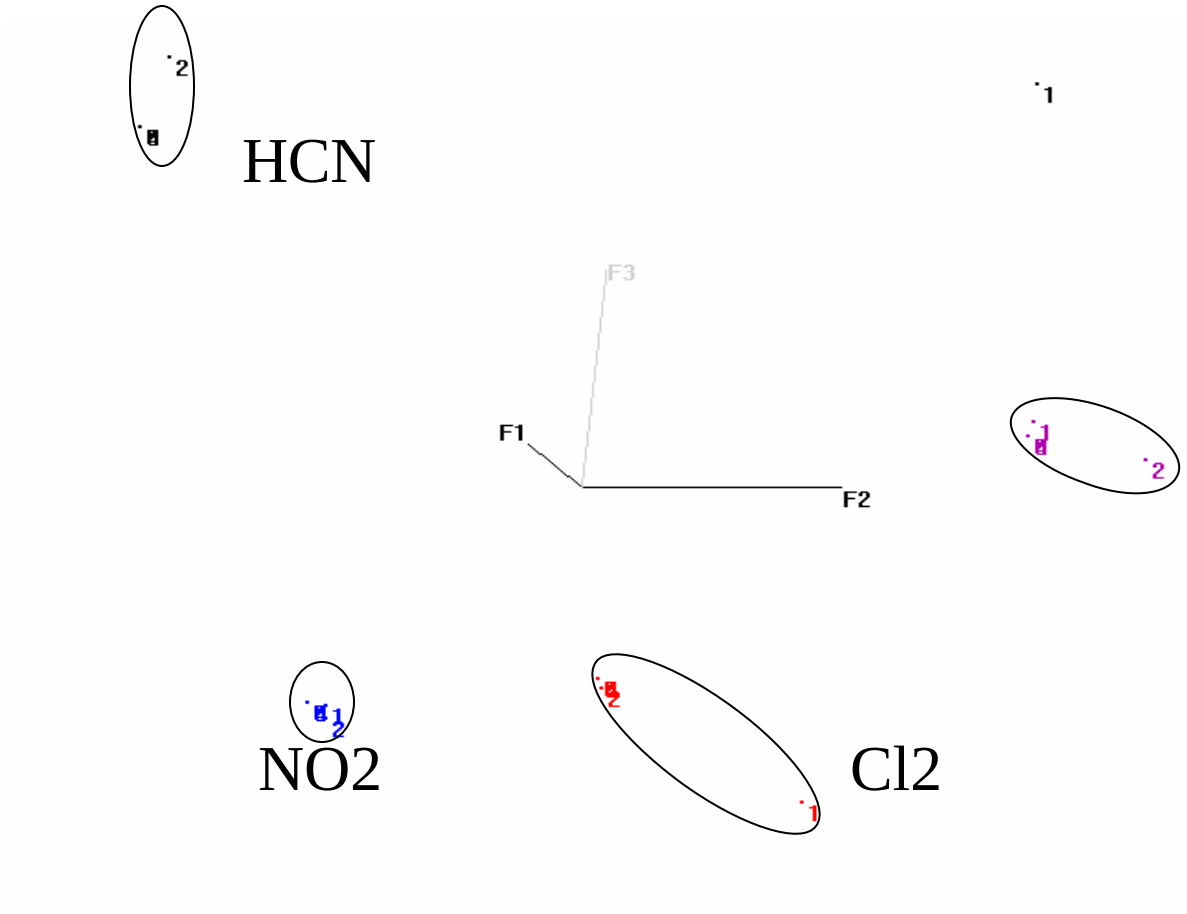
32-channel sensor chip

# Discrimination of Toxic Gases and Vapors




- Using principal component analysis
- Analytes are at ppm levels in air

# Discrimination of Toxic Gases



# Current Results vs. Target

- **Detection limit in the range of ppm to ppb**
- **Room temperature sensing**
- **Response time in 1 minute (Target for <30sec)**
- **Reproducibility of 6% from sensor to sensor**
- **Power consumption (μW to mW/sensor)**
- **Easy integration (2-terminal I/V measurement)**

Note: High sensitivity vs. polymer sensors
Low power vs. metal oxides sensors
Wider analyte spectrum vs. polymer and metal oxides sensors

# Target applications and markets

- **NASA: Cosmochemistry sensors for planetary exploration, earth observation and cabin air monitoring, and fuel leak detection.**
- **EPA: Environmental monitoring**
- **Homeland Security: Explosives detection, toxic chemicals, such as nerve gas, GB (Sarin), VX, chlorine, etc.**
- **Industry: Leak detection (civil aviation), process control in chemical, food industries, raw materials inspection.**

Ames Research Center

# Summary


•We have worked on the development of portable, low cost, low power consumption and room temperature operated, nanostructure engineered chemical sensors.

•CNT semiconductor sensors have potential of being used for NASA mission due to the unique physiochemical properties.

•This sensing platform can be utilized to the applications in homeland security, environmental monitoring, industry process control, and medical diagnostics.

•Final products will be sensor modules, handheld devices, badge type detectors, sensor chips for wireless and networking.

# Acknowledgement

This project is funded by NASA Bio-Nano program and supported by program manager, Dr. Harry Partridge, and Director of Center for Nanotechnology, Dr. Meyya Meyyappan.

| Team members are: | Summer interns: | Collaborators: |
| --- | --- | --- |
| Yijiang Lu | Christina Partridge | Jim Hanrraty |
| Philip Young | Alex Berger | Mark Mellinson |
| Jerry Jin | | |
| Lance Delzeit | | |