Nitric Oxide Microsensors for Engine Emissions, Environmental, and Human Health Monitoring Applications

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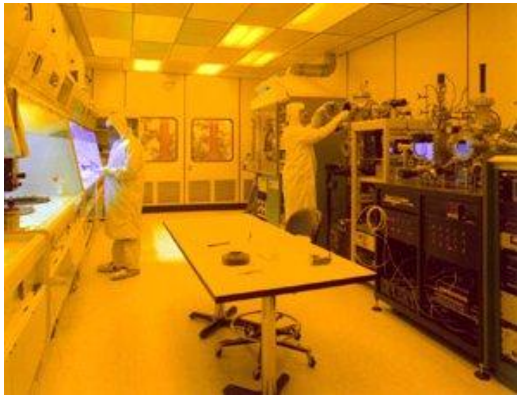
Outline

- **Background of Chemical Sensors at NASA GRC**
- **Development of Nitric Oxide (NO) Microsensors**
  - ♦ Harsh environment engine emission and environmental monitoring
  - ♦ Human health monitoring
- **Summary**

NASA Glenn Research Center

Chemical Sensor Development at NASA GRC

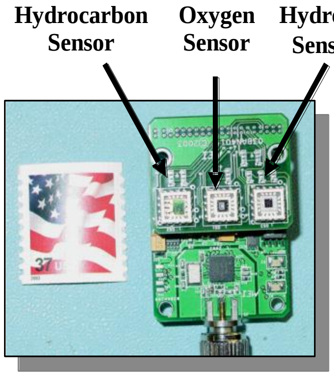
- **Microsensors and platforms**
  - H_2, CH_4, C_2H_4, C_3H_6, CO_2, CO, O_2, NOx, and N_2H_4
  - Orthogonal technology: different sensing mechanism
  - Schottky diodes, resistors, and electrochemical cells



NASA GRC Sensors and Electronics Branch cleanroom

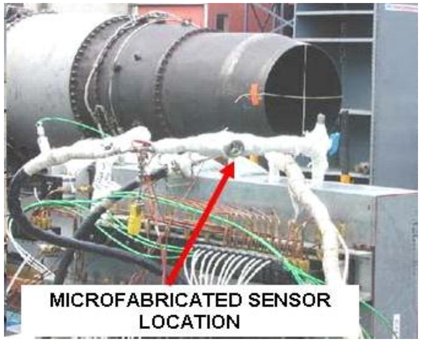
- **Applications**
  - Propulsion system, fuel depot leak detection
  - Low false alarm fire detection.
  - Harsh environment engine emissions and environmental monitoring
  - Human health monitoring and potential astronaut health evaluation

- **Approaches**
  - Smart sensor system: sensor arrays, signal processing and conditioning components, power and telemetry
  - "Lick and Stick" for full-field view of environment
  - Nanotechnology and batch microfabrication
  - Small size, low weight, cost, and power consumption

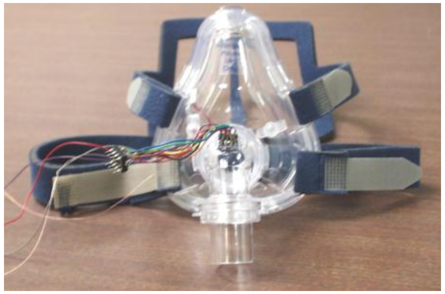


Example of smart sensor system

Development of Nitric Oxide Microsensors

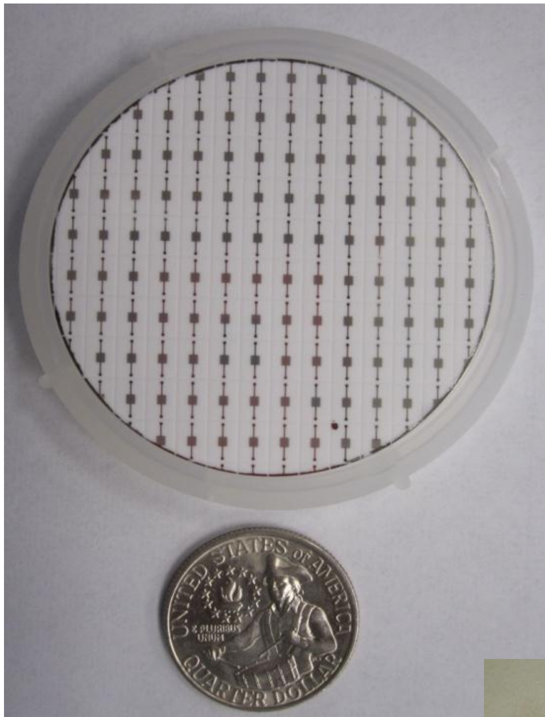


- **Harsh environment engine emission and environmental monitoring**
  - * Detection limit required: ppm level
- **Human health monitoring application**
  - * Detection limit required: 10 ppb; e.g. Asthma patient.

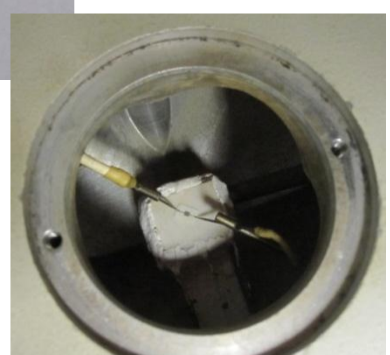


- **Parallel Approaches**
  - * Electrochemical cells
  - * SiC based sensors
  - * Resistor based sensors
    - ♦ N-type semiconductor Indium Tin Oxides (ITO): sensitive materials for reducing gases
    - ♦ Two types of films investigated : sputter deposition and polymer precursor

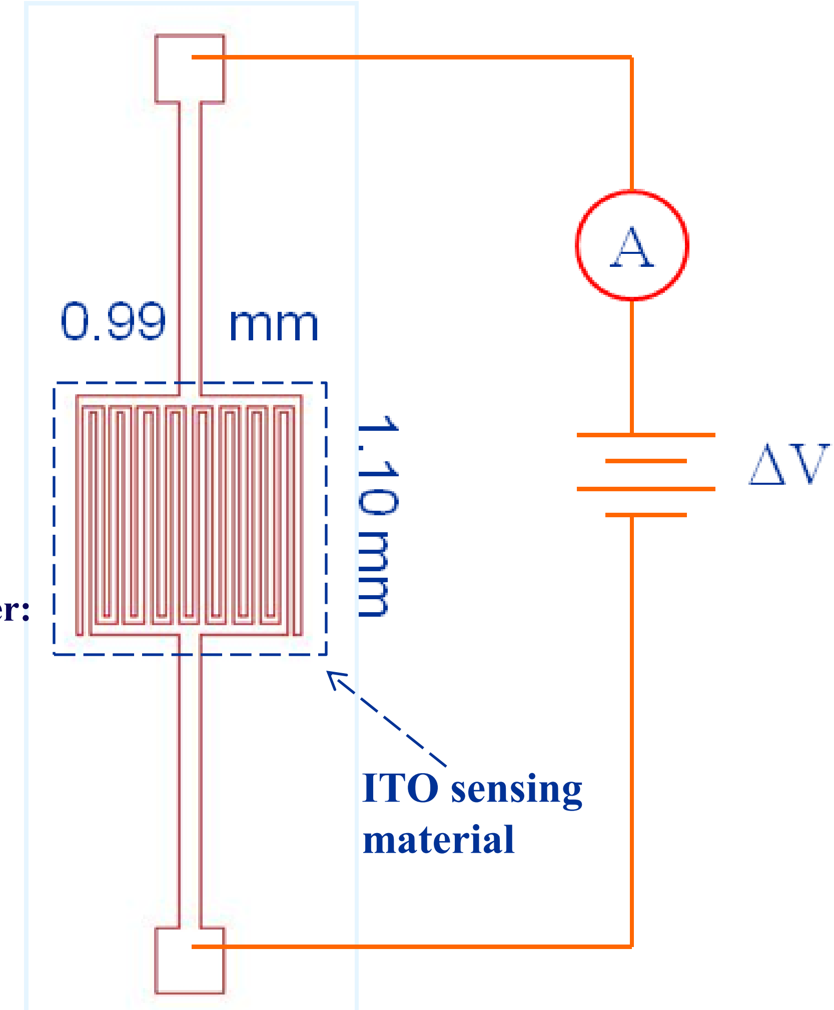
Pt interdigitated electrodes fabricated on a 2-inch alumina wafer



Gas testing chamber:
Probe contact



Electrode structure and schematic of gas testing setup



Two Approaches to Deposit ITO Sensing Materials

- **Sputter Deposition**
  - ∗ ITO Sputter Target: 90% In_2O_3 and 10% SnO_2 (by weight)
  - ∗ 1200 Å ITO
- **ITO organic precursors**
  - ∗ Mixture of 2-ethylhexenoic acid modified indium isoproxide and tin isoproxide
  - ∗ Drop deposit on the interdigitated electrode, heat treat

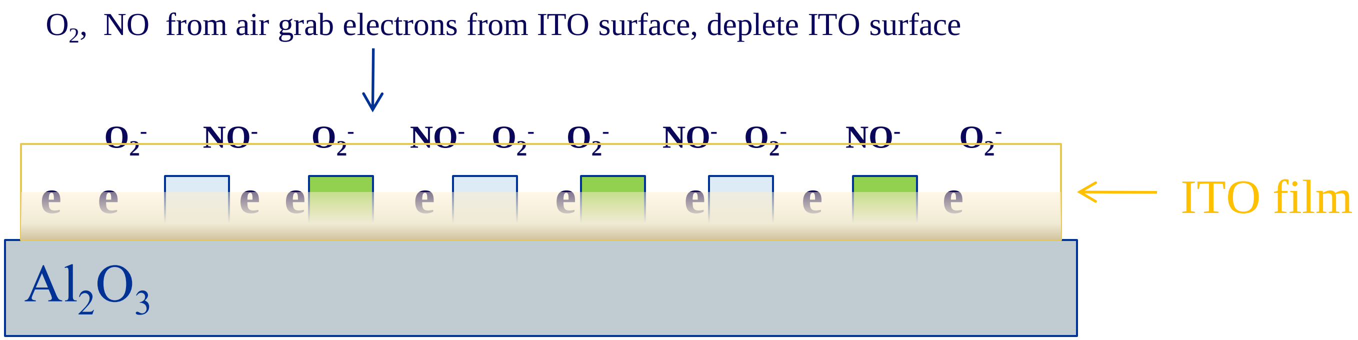
$$In(OC_3H_7^i)(C_7H_{15}COO)_2 + Sn(OC_3H_7^i)_2(C_7H_{15}COO)_2 \xrightarrow[\text{Oven}]{550°C,\ 2\ hr}$$

ITO [90% In_2O_3 and 10% SnO_2 (by weight)]+ CO_2 + H_2O

  - ∗ Thickness in the micro range

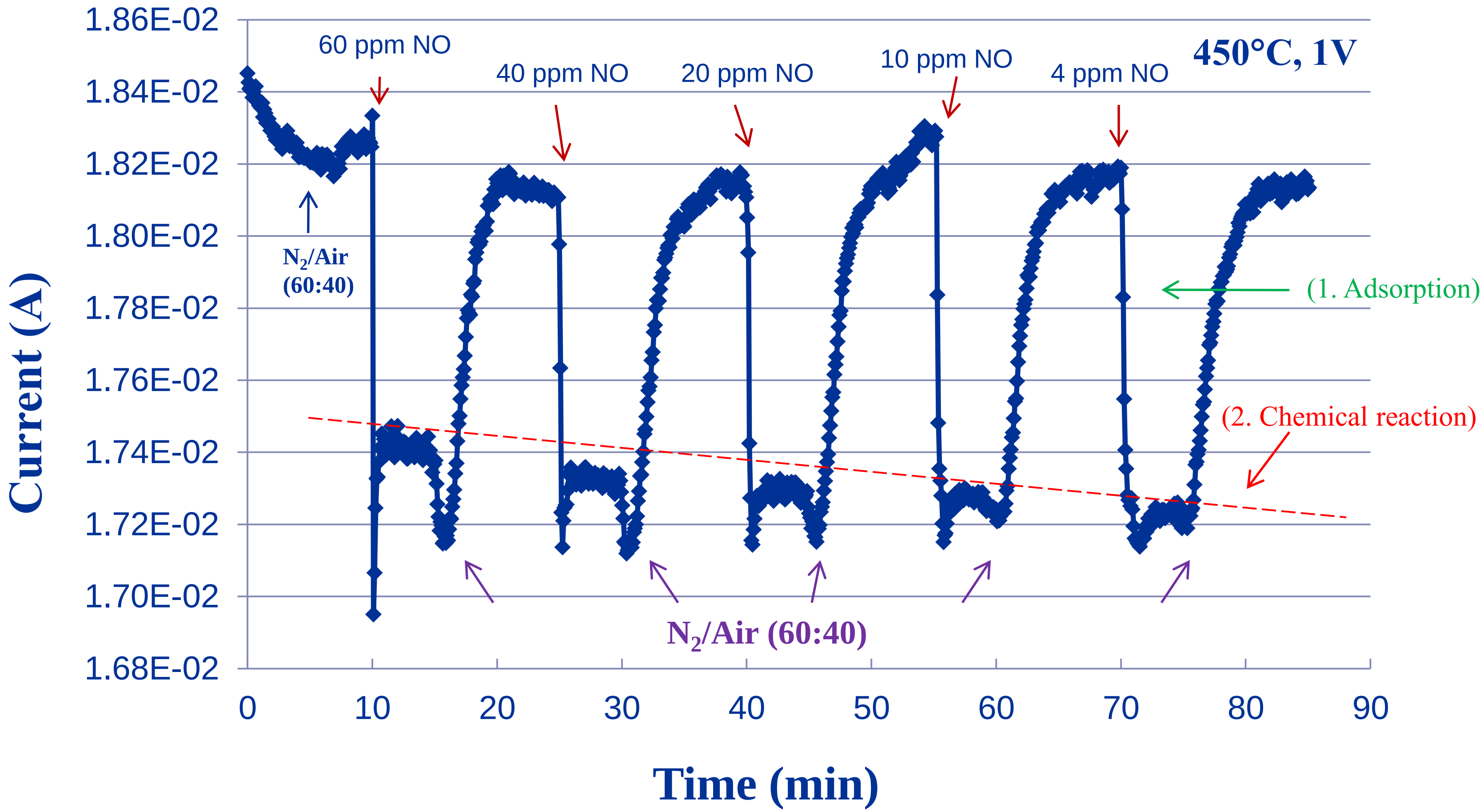
Sensing Mechanism

- **Sputter ITO Thin film: at 450°C, 1V, NO sensing involves two processes:**
  - ∗ Low concentration (ppb to low ppm): adsorption
  - ∗ High concentration (ppm): adsorption and NO oxidation reaction:



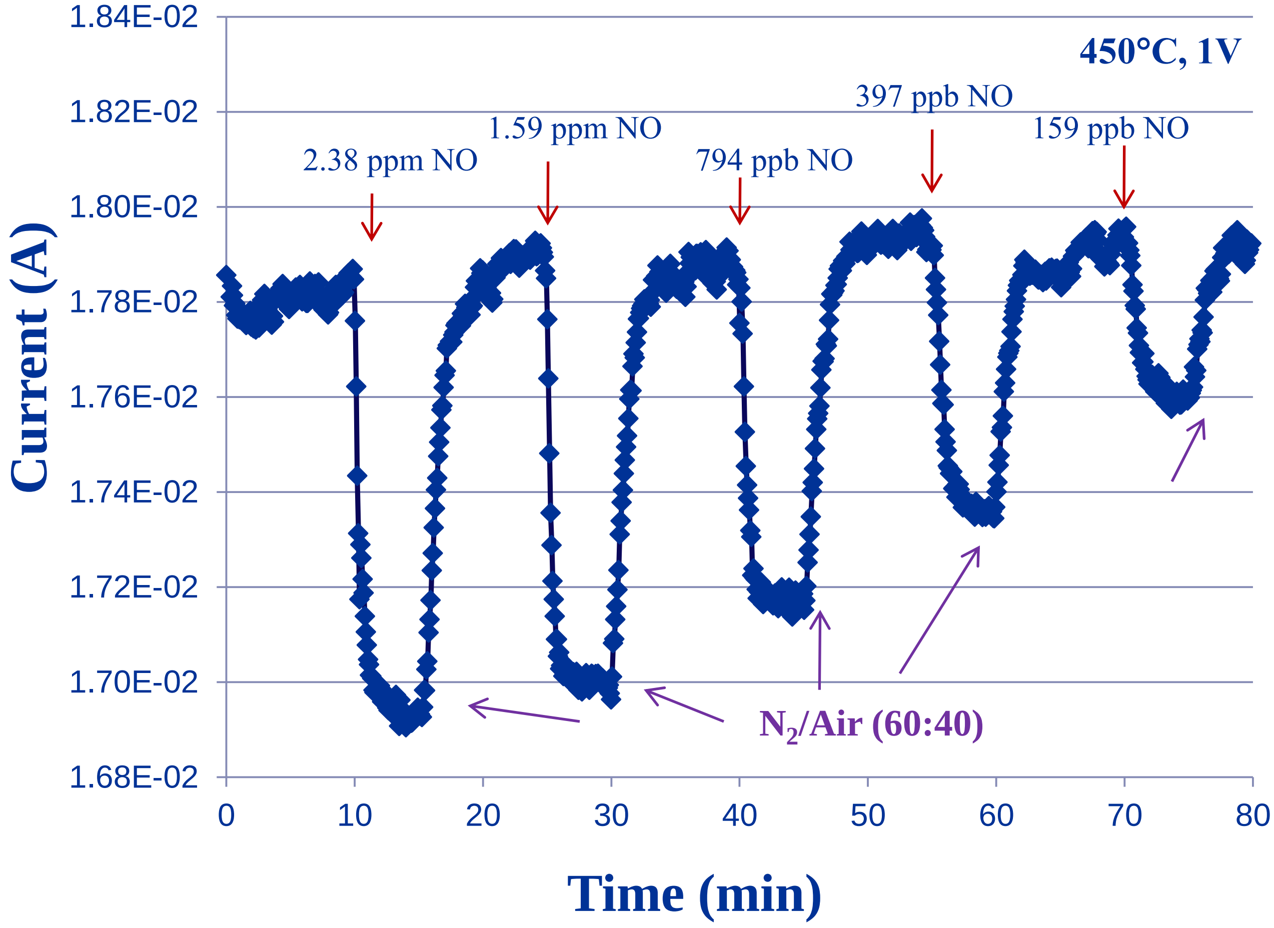
- ♦ Adsorption: O_2 and NO adsorbed on the ITO surface, deplete surface electrons, increase film resistance: $O_2 + e \rightarrow O_2^-$; $NO + e \rightarrow NO^-$
- ♦ Reaction: NO react with O_2^-, release electrons back to ITO, decrease resistance: $NO + O_2^- \rightarrow NOx\ (NO_2 + N_2O_3 + N_2O_5 \ldots) + ne$

Sputtered ITO Microsensor Response to Nitric Oxide Gas (ppm)



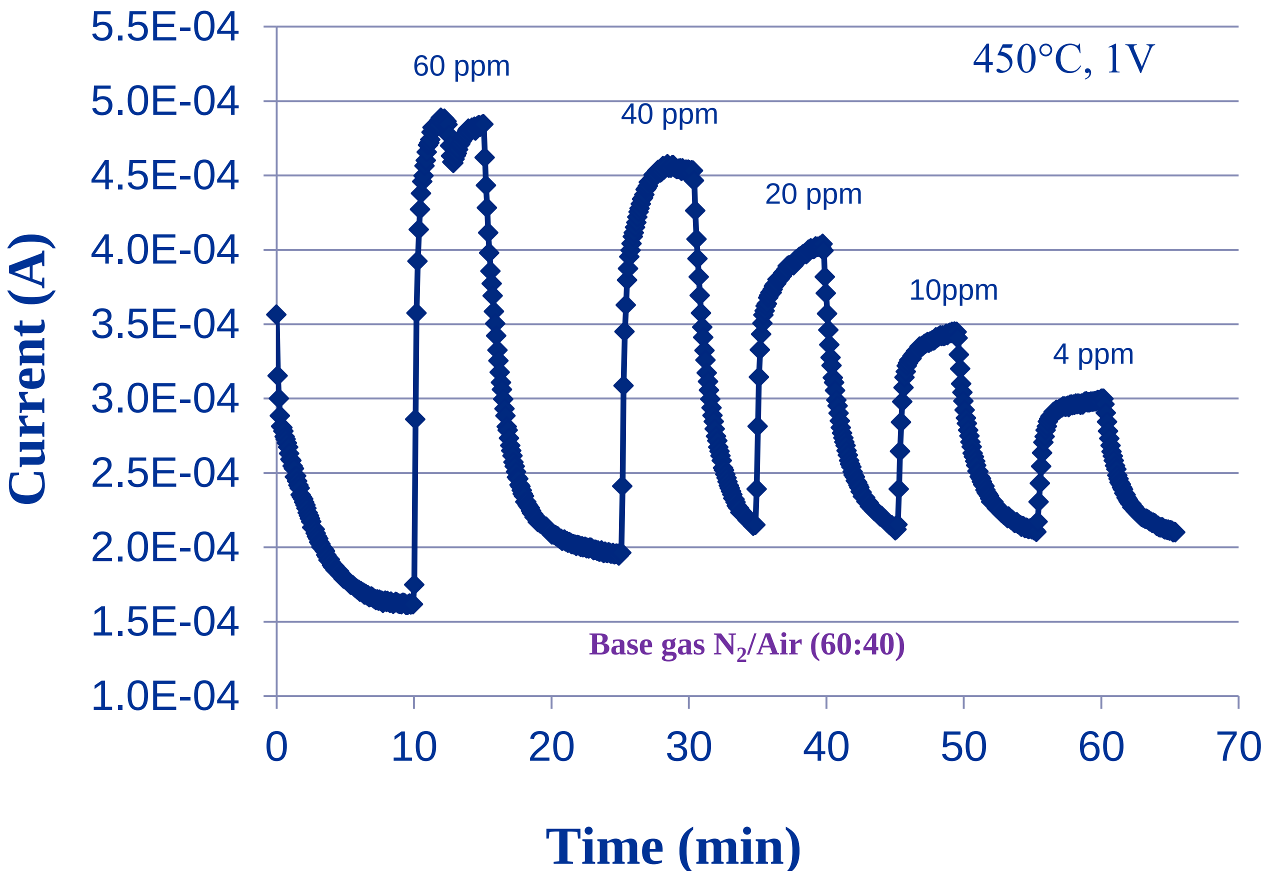
Note: 1200 A ITO thin film deposited in sputter system.
NO concentration: 100 ppm NO in N_2 gas. The NO was diluted with N_2 and Air to match base gas N_2 and Air ratio (60 : 40). Total flow is 2500 sccm.

Sputter Deposited Nitric Oxide Microsensor Response to Nitric Oxide Gas (ppb-ppm)



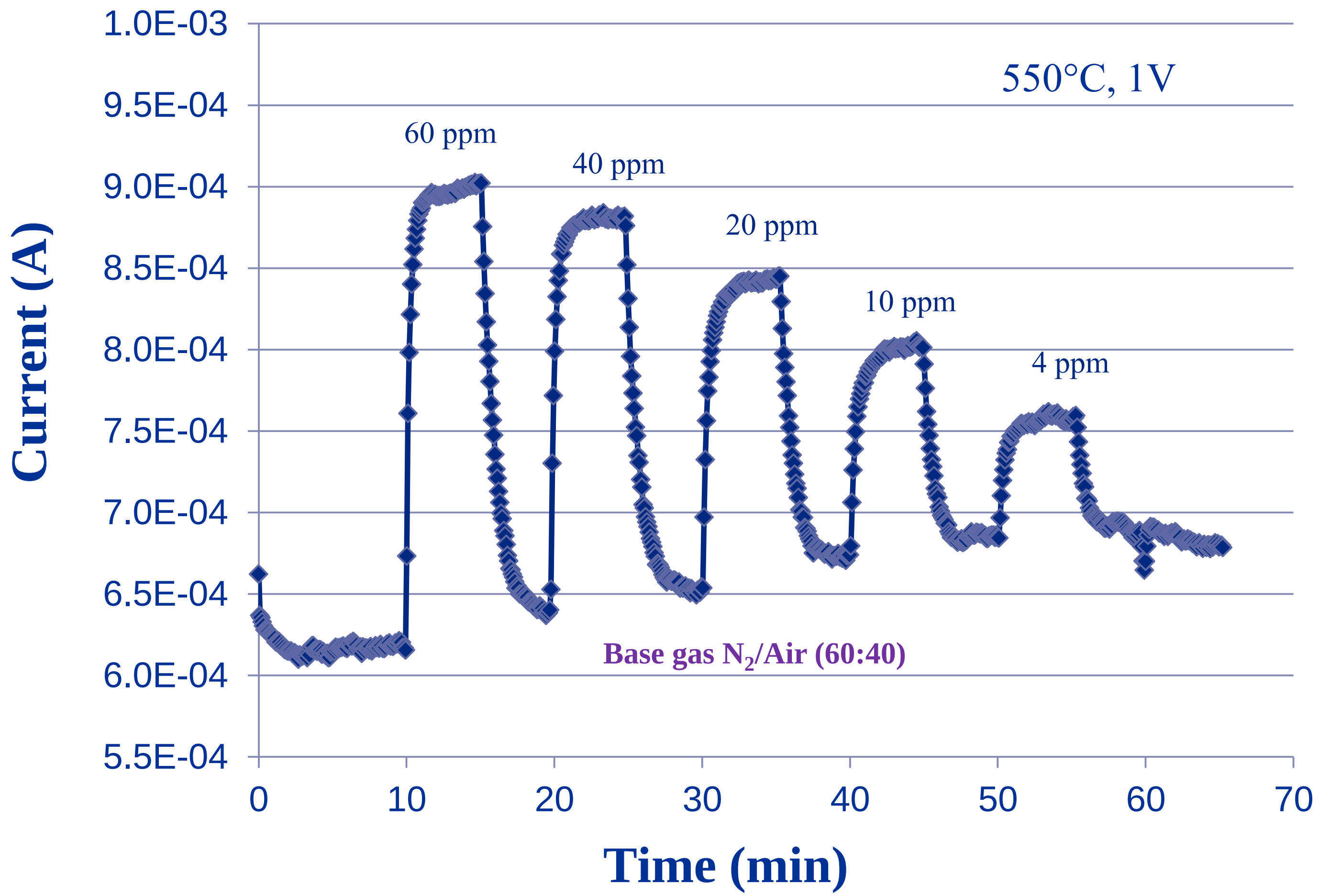
Note: Original NO concentration: 3.97 ppm NO in N_2 gas. The NO was diluted with N_2 and Air to match base gas: N_2 and Air ratio (60 : 40). Total flow is 2500 sccm.

Nitric Oxide Microsensor (ITO from polymer precursor) Response to Nitric Oxide Gas (ppm)



Note: ITO sensing material from ITO polymer precursor, heat-treated at 550°C for 2 hr
NO concentration: 100 ppm NO in N_2 gas. The NO was diluted with N_2 and Air to match baseline N_2 and Air ratio (60 : 40). Total flow is 2500 sccm.

Nitric Oxide Microsensor (ITO from polymer precursor) Response to Nitric Oxide Gas (ppm)



Note: ITO sensing material from ITO polymer precursor, heat-treated at 550°C for 2 hr
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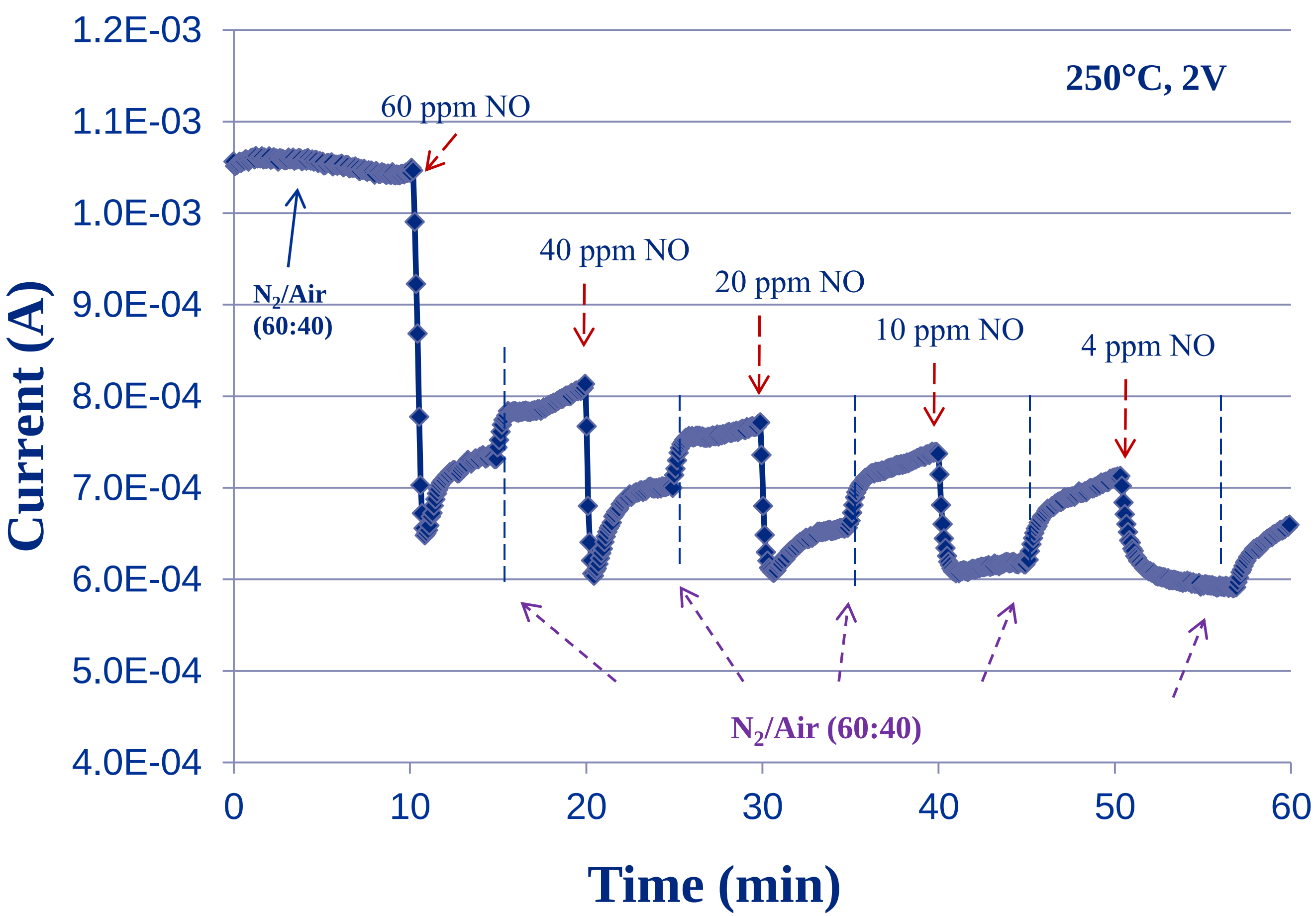
Nitric Oxide Microsensor (ITO from polymer precursor) Response to Nitric Oxide Gas (ppm)



Note: ITO sensing material from ITO polymer precursor, heat-treated at 550°C for 2 hr
NO concentration: 100 ppm NO in N_2 gas. The NO was diluted with N_2 and Air to match base gas N_2 and Air ratio (60 : 40). Total flow is 2500 sccm.

Sensing Mechanism

(with ITO from organic precursor)

- **High temperatures, 450°C to 550°C, involve one process:**

  NO oxidation reaction: $NO + O_2^- \rightarrow NOx\ (NO_2 + N_2O_3 + N_2O_5 \ldots) + ne$

- **Low temperature: 250°C, 2V, involves two processes (like sputtered film in ppb level NO gases):**

  NO adsorption and NO oxidation reactions

♦ **Next: Film surface morphology analysis to understand different NO sensing behavior**

Summary

- Resistor based nitric oxide microsensor being developed for aerospace applications: engine emission and health monitoring
- Two approaches used for the ITO sensing materials exploration. Preliminary data showed NO detection from ppm to ppb achieved. Improvement in detection limit needed
- Two sensing mechanisms involved: adsorption and chemical reaction. ITO films from different processes have different behaviors. More investigation needed to develop practical NO sensors
- Extensive testing and surface morphology studies to be conducted
- Provide potential simple and sensitive NO sensors: low cost, small size, batch fabrication, high yield, and easy use
- Provide quick information for selecting NO sensing materials for nano-structure NO sensor development.

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Thank You!

Please visit:

http://www.grc.nasa.gov/WWW/sensors/