Multifunctional Nanowire/Film Composite-based Bimodular Sensors for In-situ, Real Time High Temperature Gas Detection

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@ DOE Sensors FOA 0000059 Kick Off Meeting

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Nanomaterials /Sensors Groups

Project Briefs

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---- Project Management Plan

Nanomaterials Science Laboratory (NSL) (http://www.engr.uconn.edu/~puxian)

- PI: Dr. Pu-Xian Gao
- 2 postdoctoral fellows, 6 graduate students, and 2 undergraduate students

➢ Research Activities @ NSL:

1) Hierarchical Nanomaterials Assembly
2) Nanowire-based Sensor and Actuator Arrays
3) Sustainable Energy & Environment Applications
4) Nano-(opto)electronics and Fire Security Applications

Sponsors: DOE, ACS-PRF, HRI, UTRC, State of CT, UConn RF

Electrochemical Sensors Laboratory (ESL) (http://www.engr.uconn.edu/~ylei)

- PI: Dr. Yu Lei
- 1 postdoctoral fellow, 4 graduate students, and 2 undergraduate students

➢ Research Activities @ ESL:

1) Explosives detection
2) Metal oxide nanomaterials and (bio)sensors
3) Conducting polymer based (bio)sensor for water quality control
4) High temperature gas sensors

Sponsors: DHS, DOE, NSF, USGS, UConn RF

Project Overview

- Funding:
  - –DOE: $795,607
  - –The University of Connecticut: $215,165
- Date: 10/01/2009 –9/31/2012
- Project Objective:
  - –To develop a unique class of multifunctional metal oxide/perovskite based composite nanosensors for in-situ and real-time industrial and combustion gas detection (HC, CO, CO_2, H_2S, NO_x, N_2,SO_x, NH_3, etc.) at high temperature (700 ^oC-1300 ^oC).

Research Team

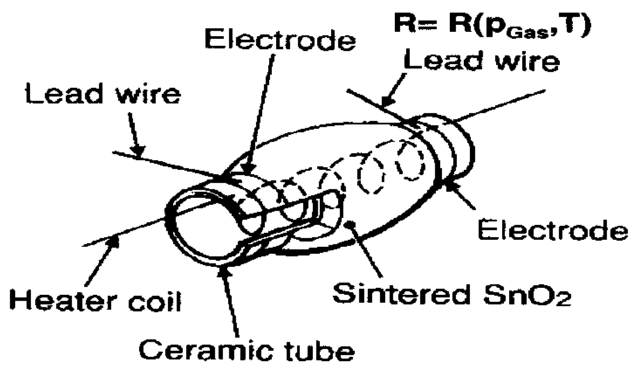
- PI: Dr. Pu-Xian Gao, manage the whole project, and lead the major effort for the design, synthesis, characterization, and resistive sensor fabrication and electrical characterization using the 3D and 2D nanowire/film composites.
- Co-PI: Dr. Yu Lei, in charge of electrospinning deposition of metal oxide nanofibrous thin film and the potentiometric sensor fabrication and characterization using the 3D and 2D nanowire/film composites.
- Postdoctoral Fellow: Dr. H. Gao; Graduate Students: H.-J. Lin, Y. Ding; Undergraduate Students: J. Leibowitz, J. Arena

Management Team

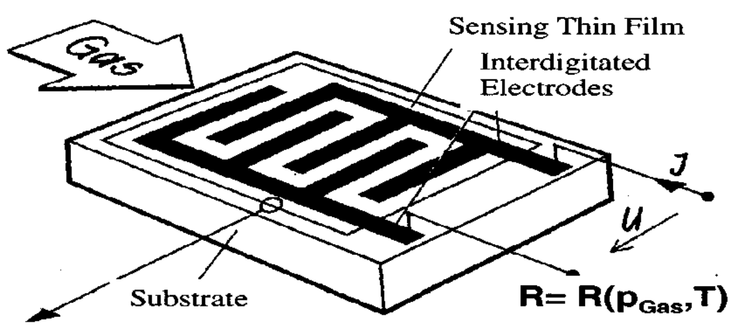
- Project Manager: Richard Read, Richard Dunst
- Contract Specialist: Jennifer Gaudlip
- Principle Investigator: Dr. Pu-Xian Gao

Resistor-type and Potentiometric Gas Sensors

a)

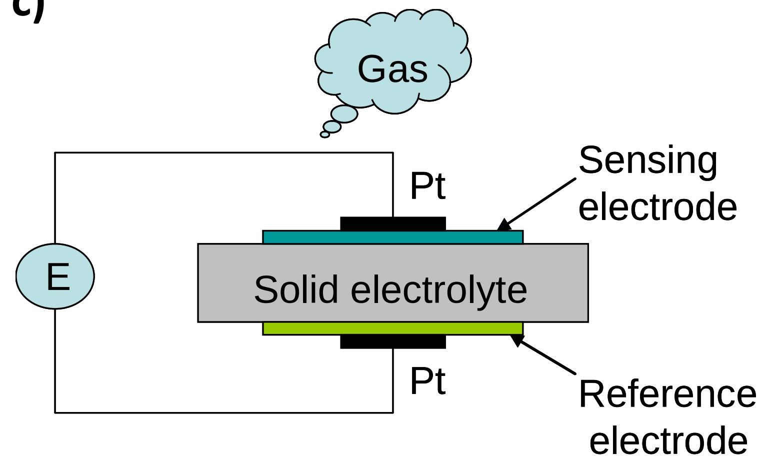


b)



Typical structures of resistor- type gas sensors: a) tubular structure; b) interdigitative electrode (IDE) chip

c)



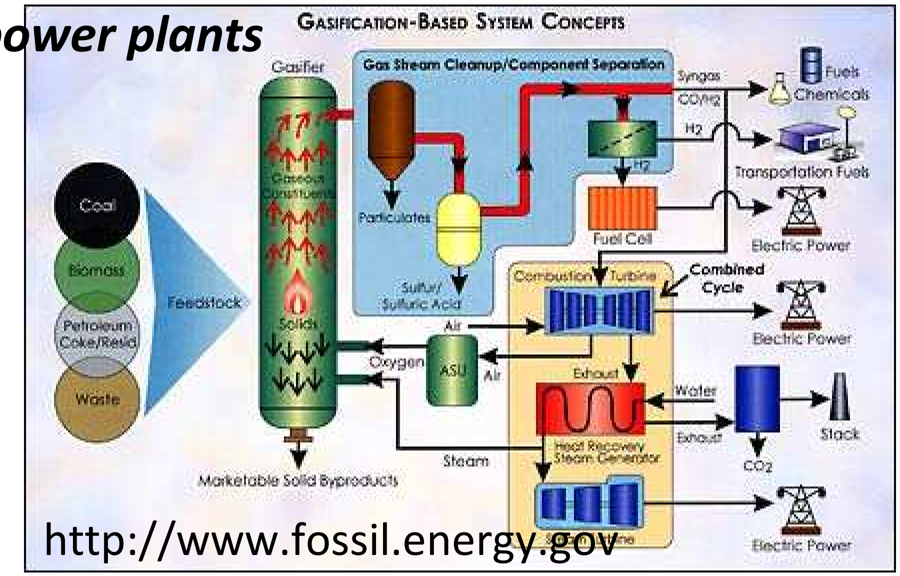
Schematic illustration of planar potentiometric gas sensor.

M. Fleischer and H. Meixner, *Sensors and Actuators B-Chemical*, **1998**.

Applications

- Industrial and Combustion monitoring (HC, CO, CO_2, H_2S, NO_x, N_2,SO_2, NH_3, etc.)

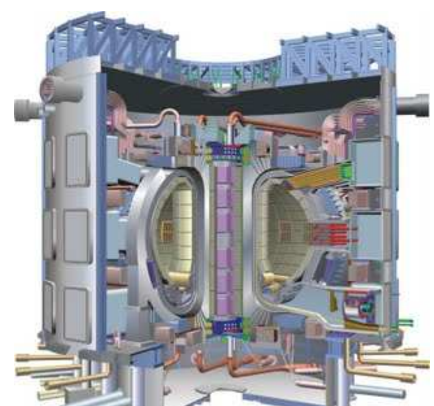
  gasification, power plants



http://www.fossil.energy.gov

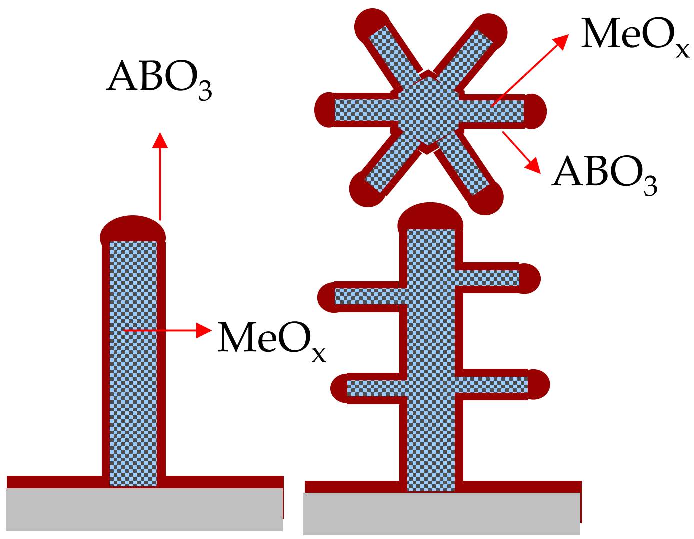
- high temperature gas sensing for

  vehicle and aircraft engines

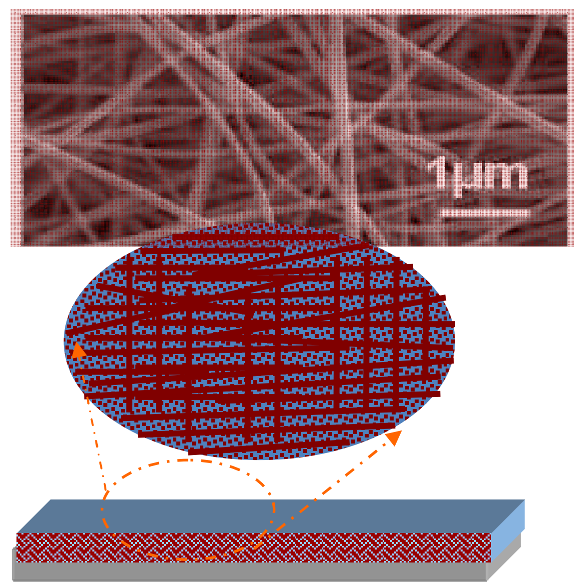


Nanowire/Nanofilm Composites

ABO_3/MeO_x composite nanowire/dendrite



ABO_3/MeO_x composite film



Materials Advantages: 1) Ultrahigh surface area; 2) High thermal stability; 3) Strong adherence; 4) Low cost; 5) High tailoring ability

P.X. Gao and Y. Lei, **2009.**

Combination of Wet chemistry and vapor phased deposition

I. MeOx nanowire/nanodendrite array growth

Vapor deposition, Wet chemical synthesis

II. MeOx nanofibrous film deposition

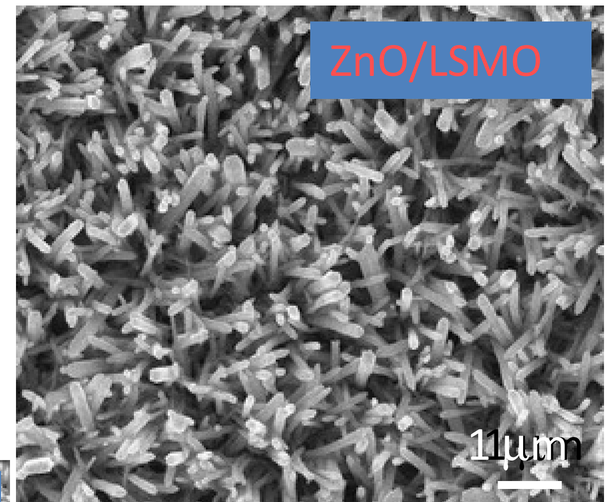
Electrospinning technique

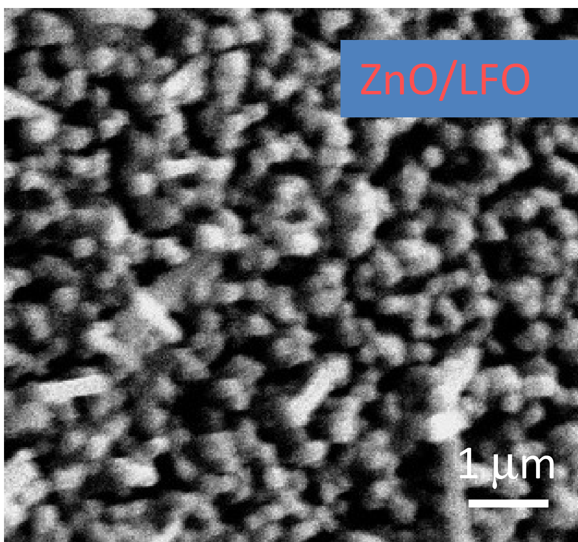
III. ABO_3 perovskite nanofilm deposition

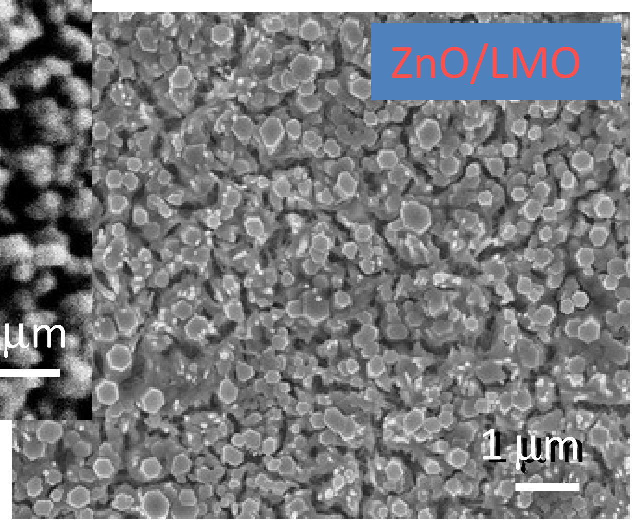
Sol-gel process, Magnetron RF-Sputtering, or Pulsed laser deposition

ZnO/ABO_3 Composite Nanowire Arrays

- A few types of ZnO/ABO_3 composite nanowire arrays have been synthesized and characterized.
  - ✓ $ZnO/LaCoO_3$ (LCO)
  - ✓ $ZnO/LaFeO_3$(LFO)
  - ✓ $ZnO/LaMnO_3$(LMO)
  - ✓ $ZnO/(La,Sr)MnO_3$(LSMO)
  - ✓ $ZnO/(La,Sr)CoO_3$(LSCO)

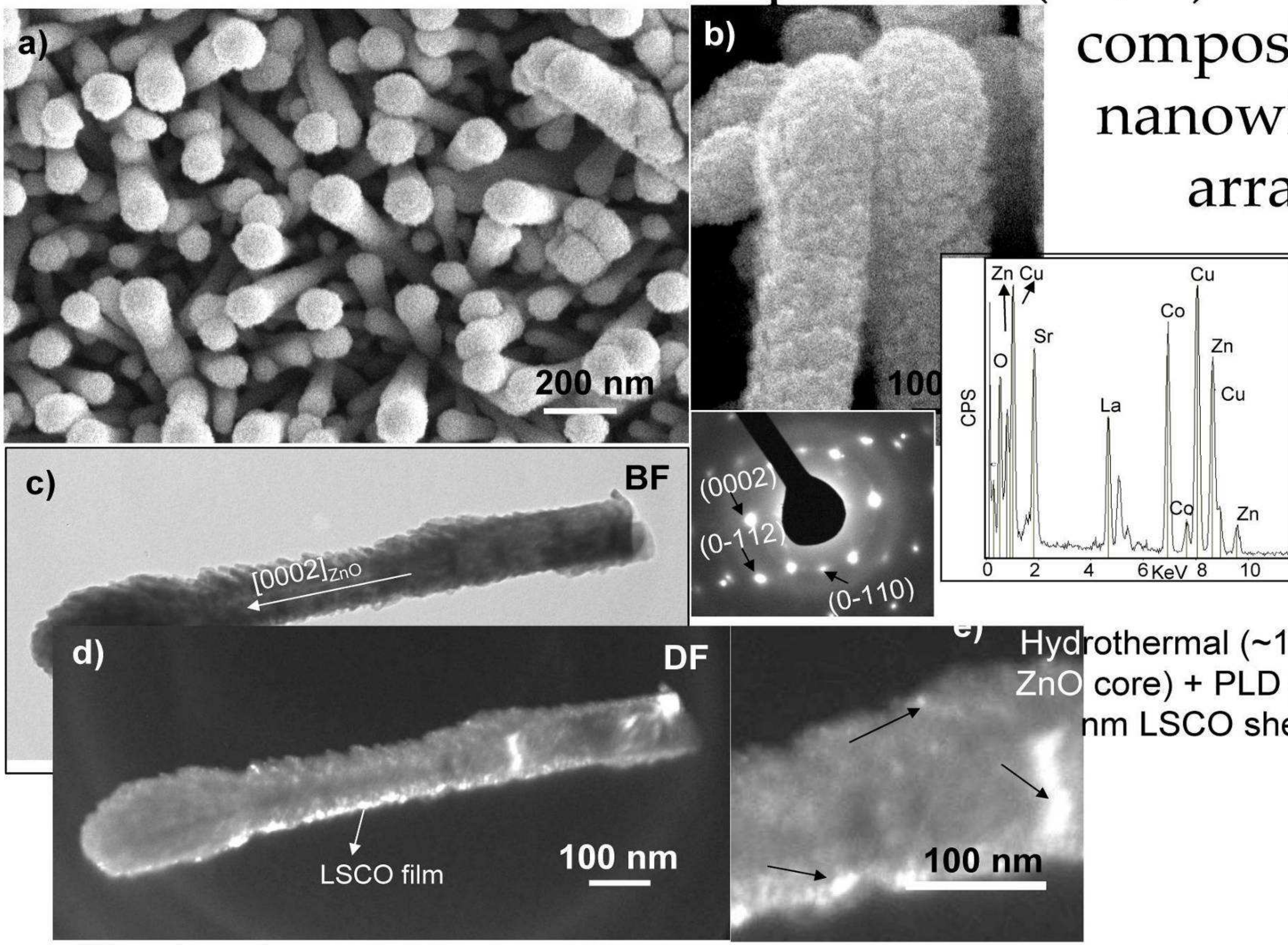






P.X. Gao et al., *unpublished,* **2009**

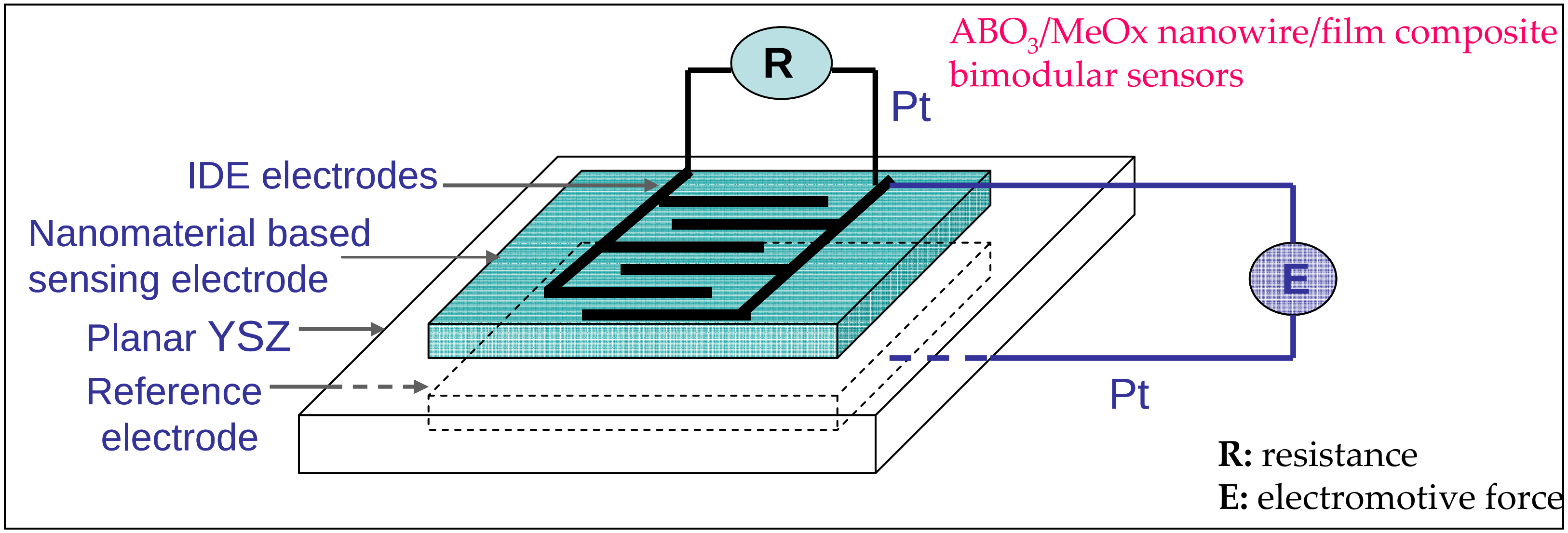
Example: ZnO/(La,Sr)CoO_3 composite nanowire arrays



Hydrothermal (~100 nm ZnO core) + PLD (10-20 nm LSCO shell)

P.X. Gao et al., *J. Mater. Chem.*, **2009.**

In-situ and Real-time Biomodular Gas Sensors



Sensors Advantages: 1) Ultrahigh surface area induced high sensitivity; 2) Catalytic filtering induced selectivity enhancement; 3) High temperature thermal stability; 4) Low cost; 5) High tailoring ability; 6) Two nearly independent measurement data sets (bi-modular); 7) In-situ and real-time measurement.

P.X. Gao and Y. Lei, **2009.**

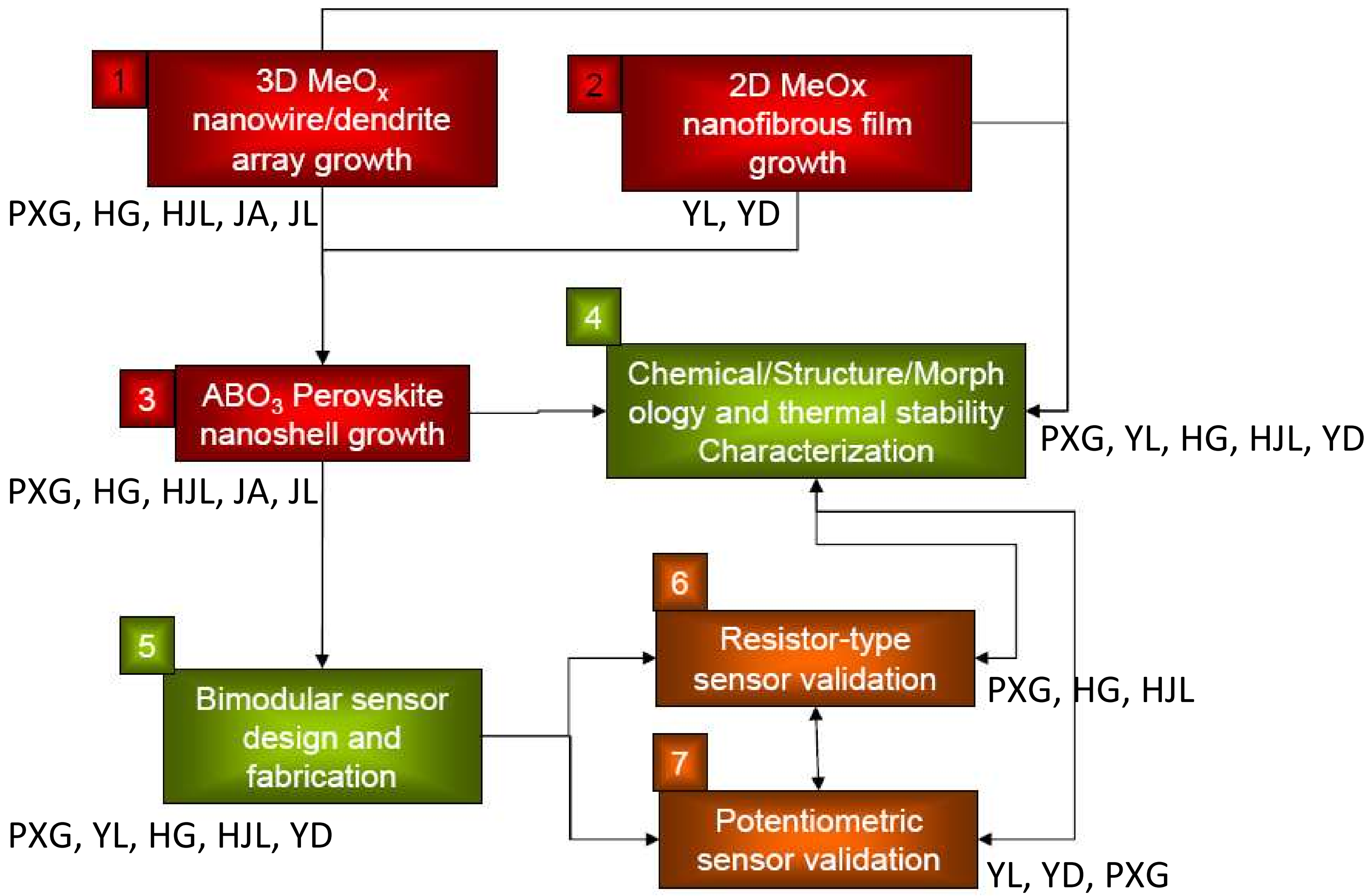
Statement of Project Objectives

- Synthesize 3D and 2D metal oxide (e.g., ZnO)-perovskite (e.g., LSCO) nanowire/nanofilm composites by vapor phase/solution phase deposition/electrospinning technique.
- Determine and optimize the synthesis parameters for Nanowire/nanofilm composite growth.
- Investigate nanowire/nanofilm composite structure, morphology, electronic structure, chemical properties, and high temperature stability using a range of microscopy and spectroscopy techniques.
- Design and fabricate the bi-modular nanosensors using the nanowire/nanofilm composites.
- Characterize the resistive detection module of the nanowire/film composite nanosensors under different high temperature gaseous environments using electrical probing techniques and establish corresponding calibration curves.
- Characterize the potentiometric detection module of the nanowire/film composite nanosensors under different high temperature gaseous environments using potentiometric testing techniques and establish corresponding calibration curves.

Scope of Work

- Utilize the PI and co-PI's experience and knowledge gained to date to apply wet chemistry, vapor phase deposition, as well as electrospining techniques to grow nanowire/film composites on desired substrates with desired dimensionality, physical and chemical structure, as well as morphology;
- Utilize the structure, chemical and morphological characterization facilities to characterize the as-grown composite nanomaterials;
- Apply photolithography defined microelectrodes such as interdigitated electrodes (IDEs) to design and fabricate prototype bi-modular nanosensors using the grown composite nanostructures;
- Apply the electrical probing and potentiometric testing techniques to characterize the composite nanostructured based resistive detection and potentiometric detection modules, respectively at high temperature.

Work Breakdown Chart



Timeline and Milestones

Task descriptions	Year 1	Year 2	Year 3
1.0: Project Management and Planning			
2.0: Synthesis of 3D metal oxide nanowire or nanodendrite arrays			
3.0: Synthesis of 2D metal oxide nanofibrous films			
4.0: Mesoporous perovskite nanoshell deposition on 3D and 2D nanowire/nanodendrite arrays and nanofibrous films			
5.0: Structure and morphology (thermal stability) characterization			
6.0: Chemical/Electronic structure characterization			
7.0: Design and fabrication of the bi-modular nanosensors			
8.0: Validation of the resistive detection module			
9.0: Validation of the potentiometric detection module			
BP1: *M10, M11, M12, M13*			
BP2: *M14, M15, M16, M17*			

M, milestone; BP, budget period