Gallium Nitride Integrated Gas/Temperature Sensors for Fuel Cell System

Monitoring for Carbon Monoxide and Hydrogen

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Relevance/Objective

- DOE workshop concensus on need for CO detection in hydrogen fuel at 1-100ppm(1)
- Adapt catalytic gate FET sensors for detecting 1-100ppm CO in hydrogen fuel
- Use GaN FET for increased sensitivity and faster response at higher temperature
- Improve precision and accuracy
- Field test for reliability and lifetime

- 1) Sensor Needs and Requirements for Proton-Exchange Membrane Fuel Cell Systems and Direct-Injection Engines, U. S. Department of Energy, Energy Efficiency and Renewable Energy/Office of Advanced Automotive Technologies,

  http://www.ott.doe.gov/pdfs/sensor_needs.pdf

Approach

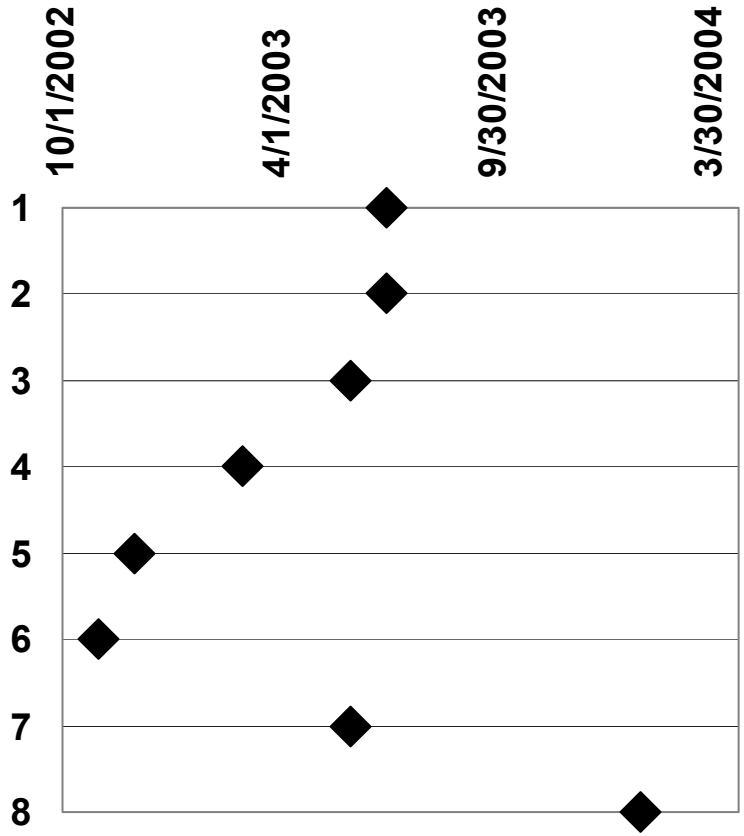
GaN based devices and circuits are an attractive option for high temperature electronic applications including gas monitoring. The effect of gas on GaN devices with metal gates has been studied and documented(1). Catalytic metals such as platinum, rhodium and palladium are good candidates for the gate metal in GaN field-effect-transistor (FET) sensors, because they form good Schottky barriers on n-GaN (necessary for FETs). The same metals are also candidates for CO detection in hydrogen, because each has shown catalytic activity in the preferential oxidation (PROX) process for oxidizing trace amounts of CO by reaction with oxygen in excess hydrogen.

1) Y. Kokubun, T. Seto and S. Nakagomi, Jpn. J. Appl. Phys., 40, L663-L665 (2001). J. Schalwig, G. Muller, M. Eickhoff, O. Ambacher and M. Stutzman, Sensors and Actuators B-Chemical, 87, 425-430 (2002), B.P. Luther, S.D. Wolter and S.E. Mohney, Sensors and Actuators B, 56,164 (1999), S.C. Pyke and L. Sadwick, DOE Report, http://www.eere.energy.gov/hydrogenandfuelcells/pdfs/32405b16.pdf, 2002, S.C. Pyke and L. Sadwick, DOE Report, http://www.eere.energy.gov/hydrogenandfuelcells/pdfs/30535ay.pdf, 2001, and S.C. Pyke, J-H. Chern, J. Hwu and L. Sadwick, DOE Report, http://www.eere.energy.gov/hydrogenandfuelcells/pdfs/28890ii.pdf , 2000.

Project Timeline

Major milestones

1- Main effect testing CO (1-100ppm) and hydrogen (30-70%) **80% Complete**
2- Determine confounding effects due to multiple components **80% Complete**
3- 2nd generation fabrication for increased yield (>50%) **Sensors expected by 6/1**
4- Low cost electronics for improved precision **Noise reduced 10X**
5- Ceramic package **Achieved**
6- Outsource fabrication **Achieved**
7- Method for resolving components using array sensors **Achieved**
8- Field test four prototypes **TBD**



Significant Interactions or Collaborations

- **Invited paper for special session: "High Band Gap Material FET Chemical Sensors", IEEE Sensors 2003, Toronto, October 21-24**
- **Three year collaboration with Larry Sadwick at the University of Utah and Innosys for GaN device design and fabrication**
- **Collaboration with Prof Ed Yu at UCSD bio-sensor proposal, GaN modeling and analysis using AFM and SCM**
- **Planned sensor joint testing with Prof Anita Lloyd-Spetz, S-SENCE and Applied Physics, Linköping University, Sweden**
- **Advanced package development subcontract pending funding: Advanced Sensors, Delphi Energy & Chassis, Flint, MI**
- **Business development discussions in process: Underground Systems Inc. and Quantum Group**

Plans, Future Milestones

- 2nd generation sensors with Pt, Rh, PdAg and Ir
  - Main effect and interference testing
- Field test sites with the following:
  - Hydrogen production process from fossil fuel
  - Process control and analysis in place for validation
  - Wet and dry hydrogen sources
- Market driven product design
  - Redesign sensor for improved precision and accuracy
  - Heater for temperature control
  - Assess cost and reliability of digital vs analog electronics
- Commercial development
  - Hydrogen safety for industrial processes to battery rooms
  - Exhaust gas analysis for NOX and combustion control

Why Use a Gallium Nitride (GaN) FET Sensor?

- GaN is a semiconductor with a 3.4eV band gap attractive for electronics operating at higher temperature than possible with Silicon at 1.11eV
- A FET (field-effect-transistor) sensor is a device made using wafer-based, high-volume, standard industry processes for low unit cost and improved consistency

  -Greater consistency in device to device quality and performance is expected with the narrow dimensional tolerances standard in foundry businesses worldwide