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Sandia National Laboratories

High Temperature Acoustic Wave Gas Sensors

For automotive exhaust and industrial stack monitoring

Overview

A new area of research and development at Sandia National Laboratories is exploring the utility of acoustic wave-based microsensors for high temperature gas monitoring. Robust coatings on surface acoustic wave (SAW) and bulk wave resonant devices allow sensitive measurement of gas species concentration at temperatures above 250°C. The small size, low cost, and simple implementation of these sensors make them excellent candidates for monitoring vehicle exhaust streams and industrial combustion processes.

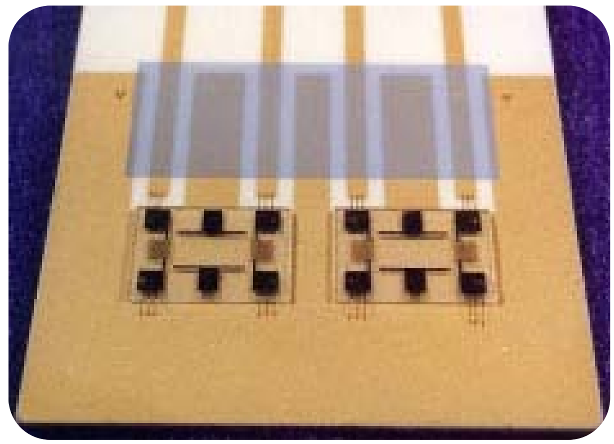

Figure 1. Surface acoustic wave (SAW) sensors wire-bonded to a ceramic substrate in preparation for high temperature testing.

Technical Approach

Acoustic wave sensors are constructed on two basic platforms: surface acoustic wave (SAW) devices used as delay lines or resonators and thickness shear mode (TSM) bulk wave resonators (see Figure 1). Other acoustic platforms, such as flexural plate wave (FPW) or beam resonators, can also be utilized. Quartz is commonly used as a piezoelectric substrate for the SAW devices and TSM resonators for operation at temperatures up to 500° C. Above this temperature, higher Curie point piezoelectrics, such as lithium niobate or lithium tantalate, are implemented. Chemical sensing layers consist of pure or mixed noble metal catalytic thin films, binary metal oxide thin films (e.g., TiO2, ZrO2, SnO2) with and without metal ion doping, and metal ion activated surfactant-templated mesoporous metal oxide films (a Sandia-patented technology).

The acoustic sensor functions as the control element in an oscillator electronic loop. Since the sensor chemical films are very rigid, concentration of gas species is directly indicated by changes in the oscillator operating frequency during exposure (see Figure 2). Several interaction mechanisms can create a frequency shift: (1) mass changes produced by sorption of gas molecules, chemical combination with film ions/atoms, or stripping of atoms from the film matrix; (2) temperature changes produced by exothermic/endothermic chemical reactions; (3) surface stress changes created by atomic or molecular substitutions at crystal or grain boundary sites; and (4) conductivity changes produced by ion interaction or chemical reaction. Thin film coating materials are tailored to utilize one or more of the interaction mechanisms to sense and discriminate particular gas species. Target gases of interest include H2, CO, CO2, NO, NO2, SO2, H2O (water vapor), and HCs (residual hydrocarbons found in combustion exhaust streams, especially the non-methane organic gases).

Applications

This technology is being developed for potential use in the following applications:

- On-vehicle monitoring of exhaust gas species to:
    1. Determine efficiency and function of the catalytic converter,
    2. Document compliance with emission regulations, and
    3. Operate in an engine control loop to optimize performance.
- Monitoring of gas constituents in industrial exhaust stacks to determine compliance.
- *In situ* monitoring of industrial combustion processes for control and optimization.

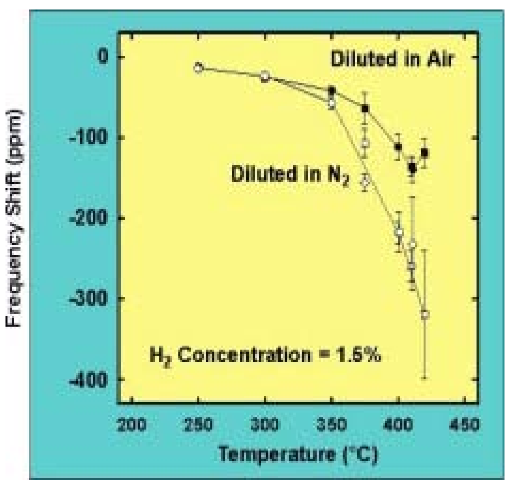

Figure 2. Measured frequency shift of a zirconia-coated quartz SAW device when exposed to hydrogen gas at different temperatures.

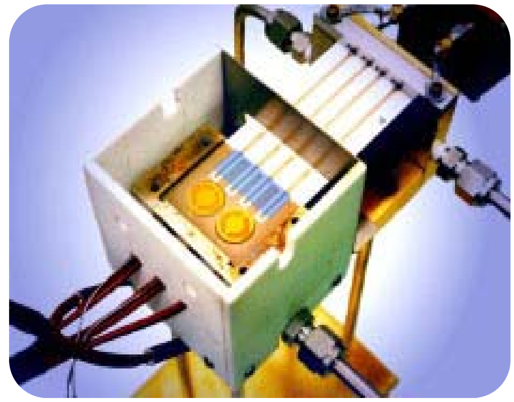

Figure 3. The high temperature test cell used for measuring acoustic sensor response to gas species.

Resources

- A high temperature gas test system for SAW devices, TSM resonators, and other sensor components. The system consists of a multiple gas mixing and flow station, a temperature-controlled test cell (up to 500° C), and complete control and data acquisition instrumentation. (See Figure 3.)
- Facilities for fabrication of quartz and LiNbO3 SAW devices and bulk wave resonators, including substrate polishing, photolithographic patterning, metal electrode deposition, and wire-bonding of devices.
- Facilities for depositing and modifying thin film
- sensor coatings: spin-coaters for sol-gel depositions, RF sputtering chambers, high-temperature curing ovens.
- Techniques for thin film coating inspection and characterization: X-ray diffraction, ellipsometry, optical microscopy, N2 sorption using the BET method, AFM, SEM, FTIR spectroscopy, and profilometry.
- Network and impedance analyzers for electrical characterization of devices and models for extracting sensor properties from device response.

For additional information or questions, please email us at MGA@sandia.gov.

Sandia National Laboratories is a multi-mission laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND NO. 2009-1553 W