



the **ENERGY** lab

**PROJECT FACTS**  
**Advanced Research**

# Development of Nanocrystalline Doped Ceramic Enabled Fiber Sensors for High Temperature In Situ Monitoring of Fossil Fuel Gases

## Description

The United States Department of Energy's (DOE) National Energy Technology Laboratory (NETL) has a mission to develop affordable and clean energy from coal and other fossil fuels to secure a sustainable energy economy. To further this mission, NETL funds research and development of novel sensor technologies that can function under the extreme operating conditions often found in advanced power systems, particularly gasification-based systems. Reliable and robust sensors are essential to the development of high-efficiency, clean energy technologies such as low-emission power systems that use coal or other fossil fuels.

In a project sponsored by the DOE's Advanced Research program, the New Mexico Institute of Mining and Technology is leading electrochemical engineering researchers at the University of Missouri Science and Technology and the University of Cincinnati to develop a new type of sensor suitable for in situ and fast gas monitoring in advanced fossil-energy systems. This sensor is formed by coating silica-based optical fibers with nanocrystalline-doped ceramic materials. The nanocrystalline structures not only allow formation of functional dense films under temperatures tolerable to the fiber (<750 °C), but also make the films more chemically sensitive than traditional materials in bulk form.

## Goals

The goal of this project is to develop sensors for high-temperature in situ monitoring of gases in advanced power systems using fossil fuels, in particular synthesis gas (syngas) derived from coal. The specific technical objectives of this research include (1) identifying sensor materials with the chemical, structural, and optical properties needed to detect coal-derived synthesis gases (syngas);

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## PARTICIPANTS

Missouri University of Science and Technology

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## PERIOD OF PERFORMANCE

6/21/2005 - 06/30/2011

## COST

### Total Project Value

\$1,064,621

### DOE/Non-DOE Share

\$797,942 / \$266,679

## NATIONAL ENERGY TECHNOLOGY LABORATORY

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(2) synthesizing nanocrystalline ceramic films and protective silicalite layers on structured optical fibers; (3) designing and fabricating structured fiber devices for enhanced sensor performance; and (4) testing the developed sensors in simulated high-temperature and high-pressure syngas environments.

## Technological Approach

The project will leverage interdependent research efforts in the areas of material, chemical, and electrical/optical engineering to arrive at a novel multiplexed fiber optic-based gas sensor that can be used in high-temperature and high-pressure environments. The research will include selection of coating materials, fabrication processes, and sensor design to develop silica fiber-based gas sensors for detection of coal-derived syngas of varying compositions. Design of special optical fiber structures, performance testing of sensor devices in simulated application environments, and improvement of the selectivity, sensitivity, reversibility, and stability of the sensor devices will allow for a thorough understanding of this new type of gas sensing technology. The work will be accomplished in two phases. Phase 1 will focus on identifying highly selective doped ceramic

materials and optimize the thickness and microstructure of the nanocrystalline ceramic films. The films will be required to detect hydrogen ( $H_2$ ), carbon monoxide (CO), carbon dioxide ( $CO_2$ ), and/or hydrogen sulfide ( $H_2S$ ) in the concentrations and conditions found in the production and treatment of syngas. Qualification of materials and sensor designs will target those that can sense at least two gases. During Phase 2, components of the sensor will be integrated and extensively tested to characterize and optimize overall performance. Sensor integration will include the development and use of a suitable data acquisition system and sensor packaging, both of which are needed to conduct laboratory performance testing. The prototype sensors will be tested under a variety of conditions including temperatures up to 500 °C, pressures up to 200 pounds per square inch (psi), and multi-component gas mixtures. Phase 2 is expected to result in at least one sensor with acceptable selectivity, sensitivity, and overall ability to accurately detect the target samples as well as reasonable long-term survivability/stability of the assembled prototype. The primary technological product expected from this work is an operational prototype (see Figure 1) that demonstrates the commercial viability of multiplexed fiber optic-based micro-sensors for distributed gas detection.

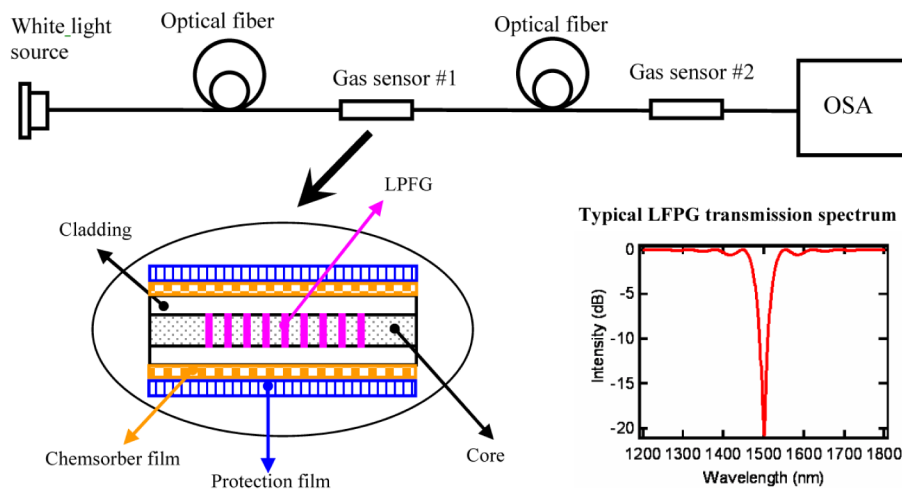


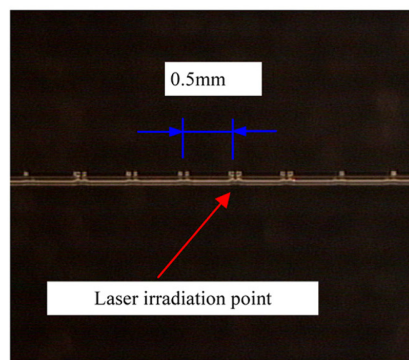
Figure 1. Schematic illustration of nanomaterial-coated thermal long-period fiber grating (TLPG)-based high-temperature gas sensors

## Accomplishments

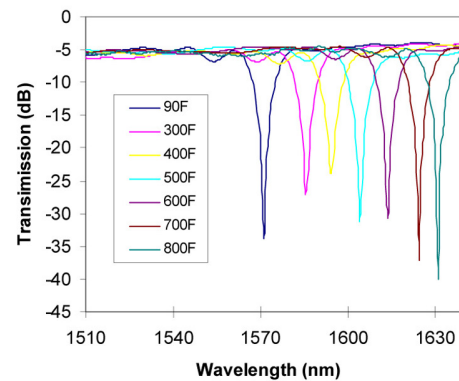
The long period fiber grating (LPFG) based sensor platform has been designed, fabricated and characterized. Various doped ceramic materials have been investigated and identified for selective detection of target gases at high temperatures. Doped-ceramics thin films have been successfully synthesized on LPFGs to fabricate high-performance gas sensors. The performance of the integrated sensors was tested and verified in laboratory simulated gas mixtures at high temperatures ( $>500\text{ }^{\circ}\text{C}$ ), mainly focused on  $\text{H}_2$  and  $\text{CO}$  sensors.

## Benefits

The sensors being developed in this project will help produce affordable and clean energy from coal and other fossil fuels in an effort to secure a sustainable energy economy, supporting the DOE's goals to increase the availability of power from domestic fuels and decrease the negative environmental effects of power production. Advanced process controls facilitated by robust sensors will contribute to high efficiency, high reliability, and outstanding environmental performance of existing and future advanced power and fuel systems. Specifically, this device is expected to fill a need for a low-cost, reliable, miniaturized gas sensor that will be capable of fast, accurate, in situ monitoring of gas composition in hot syngas streams in the harsh environments characteristic of advanced power generation systems. These new types of sensors, depending on the nanomaterial coatings, are expected to have uses in many critical areas, including emission control, environmental pollutant monitoring, food and water quality assurance, biological and medical analysis, and even in homeland security, to detect explosives.



(a)



(b)

Figure 2. Thermal long-period fiber grating (TLPG) fabricated by  $\text{CO}_2$  laser irradiations: (a) microimage of a TLPG, (b) TLPG transmission spectrum at various temperatures

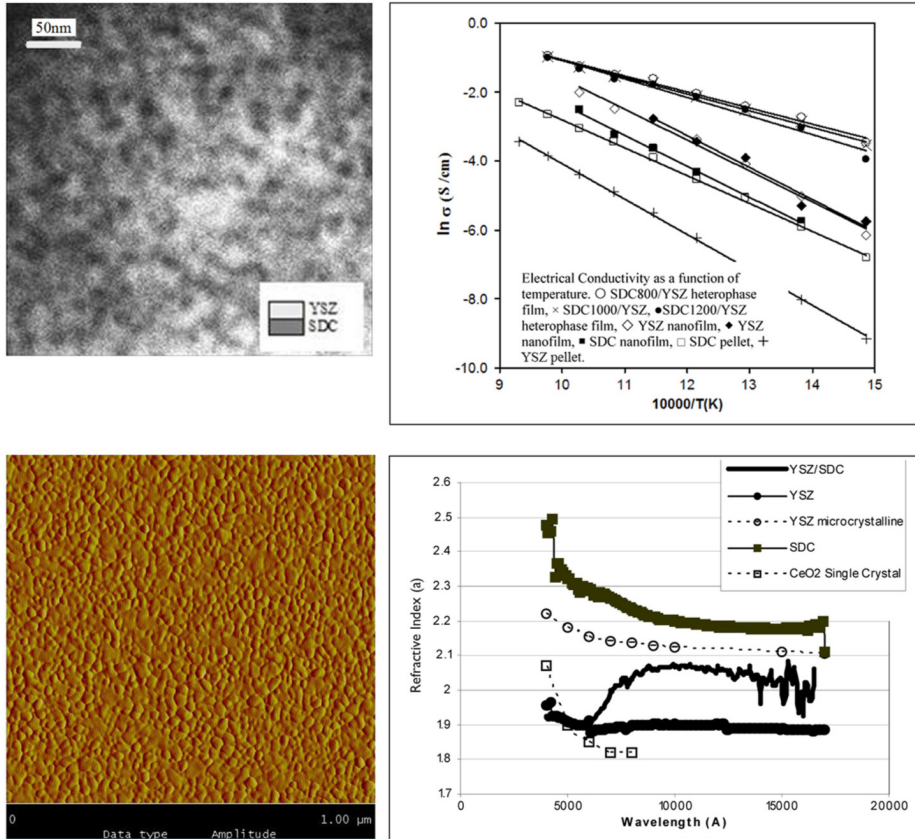


Figure 3. Microstructure of YSZ/SDC heterophase nanocrystalline thin films and their electrical and optical properties suitable for the proposed optical gas sensors

