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LLNL-TR-409294

A Micro-Opto-Mechanical Photoacoustic Spectrometer

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December 9, 2008

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Auspices Statement

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. This work was funded by the Laboratory Directed Research and Development Program at LLNL under project tracking code 08-FS-010.

FY08 LDRD Feasibility Final Report
A Micro-Opto-Mechanical Photoacoustic Spectrometer
LDRD Project Tracking Code: 08-FS-010
Jack Kotovsky, Principal Investigator

- Project Overview

This report describes progress achieved in a one-year LDRD feasibility study of a Photo Acoustic Spectrometer (PAS). Specifically, this team sought to create an all-optical and very small PhotoAcoustic Spectrometer Sensing system (PASS system). The PASS system includes all the hardware needed within a gas environment to analyze the presence of a large variety of molecules. The all-optical PASS system requires only two optical-fibers to communicate with the opto-electronic power and readout systems that exist outside of the gas environment. These systems can be at any distance from the PASS system as signal loss through the optical fibers is very small.

The PASS system is intended to be placed in a small space where gases need to be measured and thus must be very small. The size and all-optical constraints placed on the PASS system demand a new design. The PASS system design includes a novel acoustic chamber, optical sensor, power fiber coupling and sensing fiber coupling.

- Project Goals

Our collaborators at the Atomic Weapons Establishment (AWE) have proven the capabilities of a complete photoacoustic spectrometer that uses a macro-scale PASS system (first 2 references). It was our goal to miniaturize the PASS system and turn it into an all-optical system to allow for its use in confined spaces that prohibit electrical devices. This goal demanded the study of all the system components, selection of an appropriate optical readout system and the design and integration of the optical sensor to the PASS system. A stretch goal was to fabricate a completed PASS system prototype.

- Relevance to LLNL Mission

Future surveillance of the nuclear weapons stockpile demands specialized sensors for systems monitoring. This need includes broad-specie gas monitoring. A variety of commercial gas monitoring tools is available but none of these tools come close to meeting the stringent requirements for stockpile implementation. Specifically, material, size, power, safety and security requirements eliminate the use of commercial devices. For this reason, novel instrumentation must be developed. This effort is part of an ongoing LLNL Microsensors Program that creates these novel sensing systems.

- FY08 Accomplishments and Results

During the year, the demand for a miniature, all-optical PASS system evolved from a problem statement to an array of working prototypes. The following sections present chamber design, sensor design, fiber coupling design and system integration.

Chamber Design

The PAS system depends on the measurement of pressure pulses if a gas of interest is present. The sensitivity of this measurement depends on the magnitude of pressure fluctuation around ambient. Although an open-air system is possible, the magnitude is enhanced by an enclosure that constrains the gas volume. Modeling work performed by AWE suggests a cylindrical acoustic chamber with no significant openings provides excellent pressure response. Modular cylindrical prototypes were designed and fabricated to allow system characterization under varied chamber dimensions. Several chamber lengths and diameters were created.

Sensor Design

A sensor design that shows excellent sensitivity and durability is desired. The material choice must meet the stringent constraints of weapon systems and survive very long deployments. A variety of optical films were created in the LLNL microfabrication facility. These include combinations of silicon nitride, silicon oxide and metallic coatings. Ultimately, a circular diaphragm was created that includes a multi-layer material stack for stress-tuning (see Figures 1 and 2). Optical measurements show that an excellent optical return is achieved with a pre-buckled diaphragm. The buckled diaphragm is designed to give enhanced sensitivity by reducing the diaphragm stiffness.

Choice of a specialized optical interferometer readout system allows for very robust diaphragm movement detection. Fiber alignment and positioning of the readout system is not critical, making the overall PASS system very robust. The power and sensing systems were designed to be insensitive to position variation enhancing the system's long term survivability and simplicity.

Fiber Coupling Design

For this study, both single and dual fiber designs were considered but only the dual fiber design was pursued to simplify initial testing and to help isolate any difficulties that may occur in testing. For PAS operation, laser power is coupled to the acoustic chamber in either time or modulation-frequency division multiplexing via the power fiber. A single fiber carries the stimulating laser light to the acoustic chamber. The interferometric readout system also uses a single fiber to detect diaphragm motion. This fiber is coupled to the opposite end of the acoustic chamber (see Figure 3). Both coupling ferrules are modular and similar in form to allow efficient testing of varied diaphragm sensors.

○ Project Summary

This one-year feasibility study proved the design and fabrication of a novel, miniature photoacoustic spectrometer sensor system can be achieved. The system was conceived,

preliminary studies performed and ultimately, several prototypes were built that will be tested by collaborators at AWE. Follow-on work is anticipated to advance the technology beyond this study.

○ Related References

Parkes, A.M., Keen, K.A., McNaghten, E.D., “Trace gas detection using a novel cantilever-based photoacoustic spectrometer with multiplexed optical fiber-coupled diode lasers and fiber-amplification,” *Fibre Optic Sensors and Applications V*, Proc. SPIE, Vol. 67701C, Ed. Eric Udd, 2007.

Lindley, R.E., Parkes, A.M., Keen, K.A., McNaghten, E.D., Orr-Ewing, A.J., “A sensitivity comparison of three photoacoustic cells containing a single microphone, a differential dual microphone or a cantilever pressure sensor,” *Applied Phys. B., Lasers and Optics*, 2006.

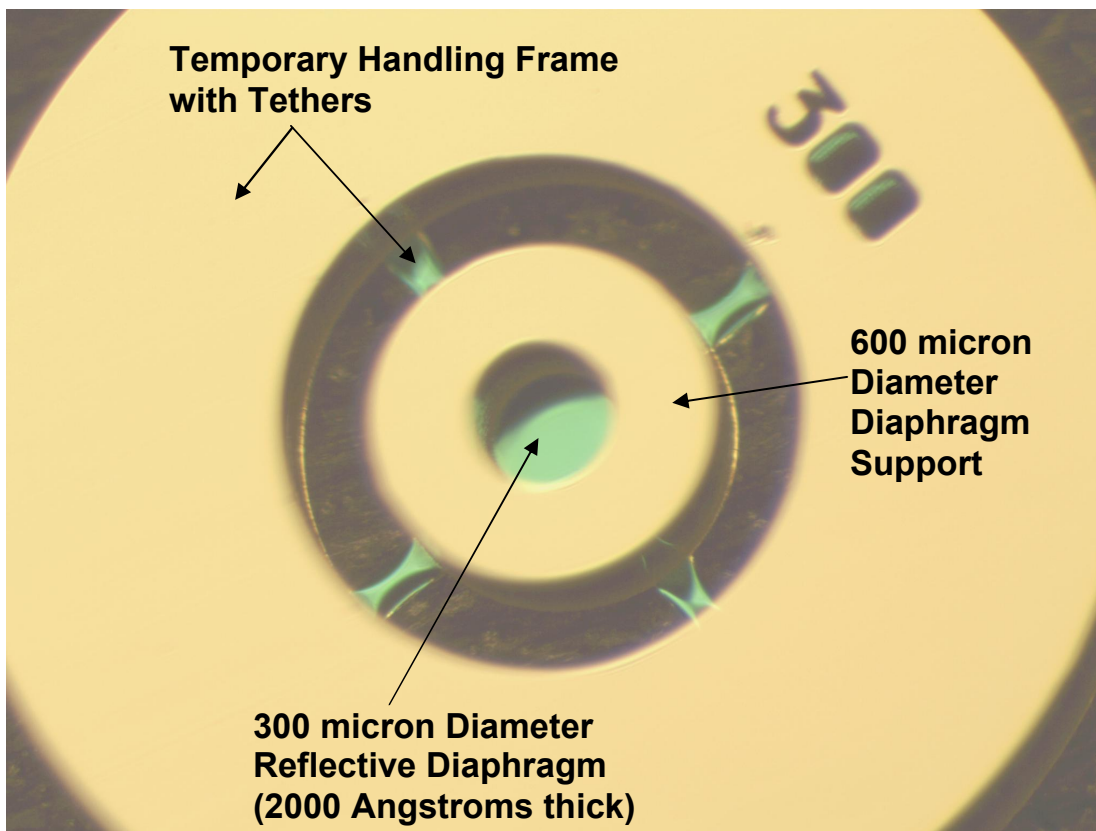


Figure 1. Backside view of the MOMS diaphragm sensor

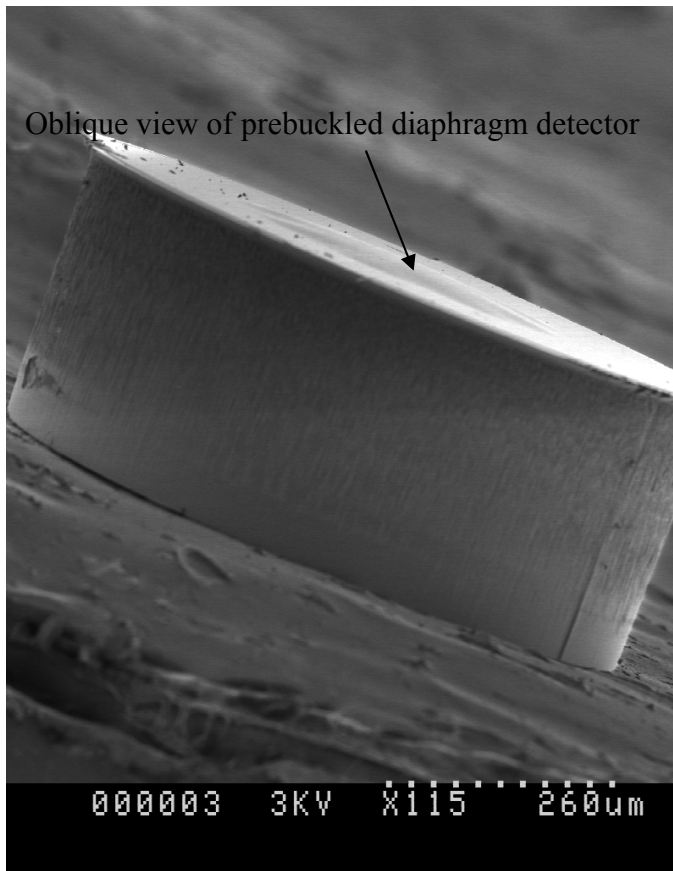


Figure 2. Electron micrograph of a MOMS diaphragm sensor

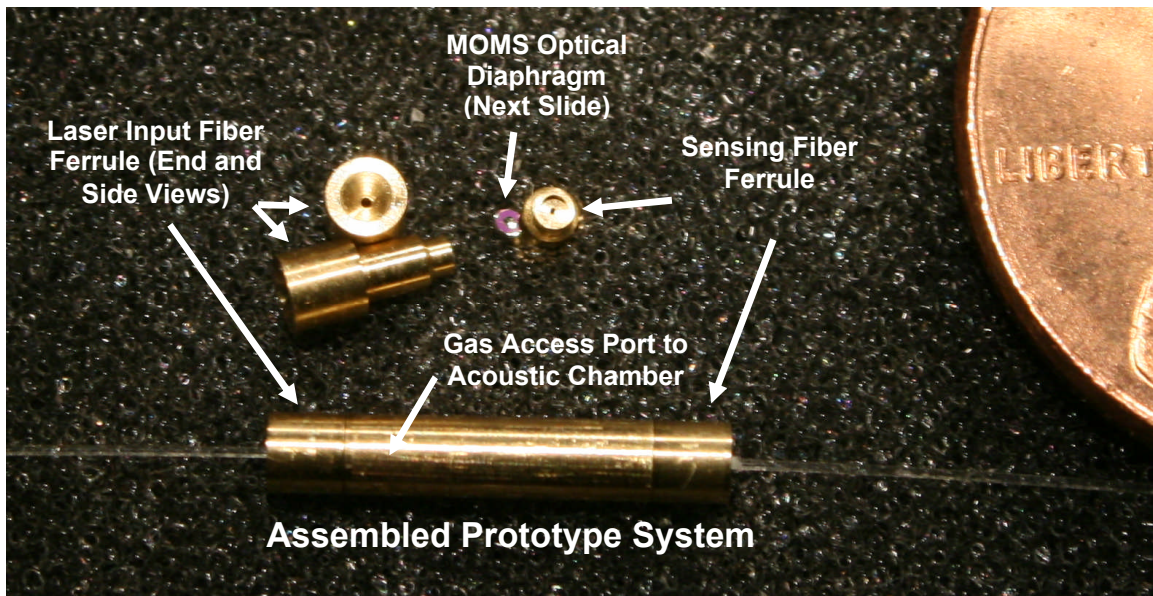


Figure 3. Components of the photoacoustic spectrometer system (PASS) and a complete PASS prototype.