High-Temperature, High-Pressure Acoustic Microsensor with Diffraction-based Optical Detection

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This work is focused on the fabrication and testing of an acoustic microsensor capable of monitoring components of a gas turbine engine. The environment of the turbine requires that the sensor be able to withstand temperatures up to 800˚C and pressures up to 30ATM. Robust materials and an optical detection scheme enable the sensor to operate in this environment. The detection scheme is a phase sensitive diffraction grating on a transparent substrate covered by a compliant membrane. Figure 1 shows a schematic of the concept. Light is transmitted through the diffraction grating reflects off of the membrane and back through the grating. The intensity of the diffracted orders at fixed locations is monitored for membrane displacement measurement. It is possible to locate the electronics remotely by using optical fiber to carry the signal to and from the sensor. This eliminates the difficulties associated with shielding heat sensitive electronics.

In designing this sensor, two factors must be balanced. One of the factors is the sensitivity of the device, and the other is the survivability under adverse conditions. To strengthen the sensor, the membrane must either be made smaller or thicker. An effect of these changes would be a less sensitive device. Using the ANSYS finite element program a silicon nitride membrane built on sapphire substrate was found to have an optimum balance between sensitivity and survivability with a 50μm diameter and a 1μm thickness. Another interesting characteristic is the effect of temperature on the performance of the membrane. Because the membrane is deposited at 800˚C, the stress in the membrane is smaller at this temperature. As a result the device should be most sensitive at high temperatures.

To fabricate the sensor, a polysilicon diffraction grating was micromachined on a sapphire substrate. Different gratings were created with finger thickness ranging from 1.5-3μm and finger-to-finger gap ranging from 1-4μm. PECVD silicon oxide was used as the sacrificial layer, forming the membrane shape. Octagonal, hexagonal, and circular membranes were created with diameter ranging from 40-200μm. Low stress LPCVD silicon nitride was then deposited as the membrane layer at 800˚C. After etching the sacrificial layer, a 1.5μm air gap between the grating and membrane remained. A SEM image of one of the microsensors is shown in Figure 2.

The survivability and sensitivity of the sensor were tested. Survivability testing was done using a small furnace. The sensor was exposed to heat loads up to 600˚C at several steps and survived each test. To test the sensitivity of the sensor, a HeNe laser was focused at one of the devices and the photodetector was then aligned to measure the intensity of the first diffraction order. A small loudspeaker driven by a signal generator was used to create an acoustic pressure signal with an amplitude of 0.5Pa. Figure 3 shows the input and detected signal for one of the tests. The input consisted of 8 pulses at 20 kHz. The device detected each of these pulses. The peaks detected after the first 8 most likely represent reflections of the pulses. The sensor was able to detect pressure levels of about 1Pa with a 100dB dynamic range.

The tested device was unsealed and therefore only capable of measuring dynamic pressures. According to ANSYS results a sealed device would work as a pressure sensor under 30ATM static pressure. With addition of a top and bottom electrode, this device could be made active using capacitive forces. The devices could then be used as air-coupled transmitting transducers for active ultrasonic evaluation. The capacitive forces could also be used to tune the sensor to achieve optimum sensitivity [1].

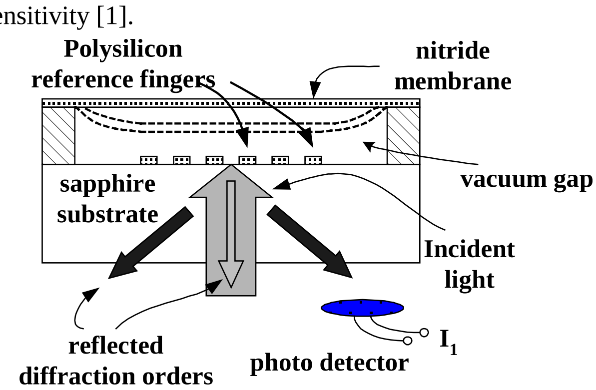

Figure 1: Schematic of high temperature acoustic microsensor with optical detection.

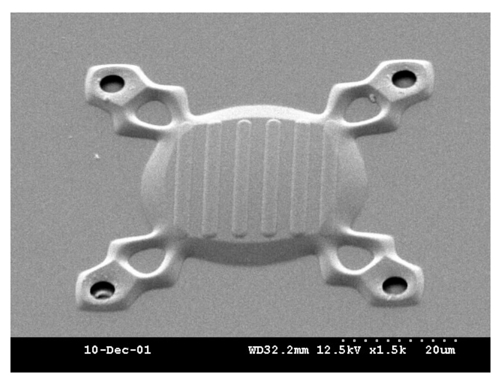

Figure 2. SEM Image of 40μm diameter microsensor membrane.

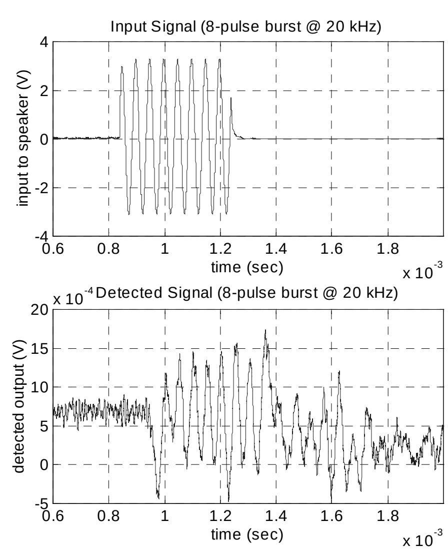

Figure 3. Input and detected optical signal for 8-pulse tone burst at 20kHz.

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References:

1. N. Hall and F.L. Degertekin, "An integrated optical detection method for capacitive micromachined ultrasonic transducers," *Proceedings of IEEE Ultrasonics Symp.*, vol. 1, pp. 951-954, 2000.