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Short Communication

Laser probing of micromachined capacitive pressure sensor silicon membrane[†]

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Abstract

The paper reports the study of vibrations occurring in a thin silicon membrane of a conventional capacity pressure sensor. The 20 μ-thick silicon membrane has an area of 6x6 mm. Vibrations induced on the membrane with the help of electrical excitation were studied using a heterodyne laser probe. The probe output gives a measure of the amplitude of vibration of the membrane. Using this technique spatial response of the capacitive pressure sensor diaphragm has been carried out. The resonant frequency peaks of the membrane were measured and the effect of air pressure loading observed.

Keywords: Heterodyne laser probe, displacement measurement silicon membrane, micromachining, capacitive pressure sensor.

1. Introduction

Devices that sense pressure by converting mechanical deflection into an electrical signal are generally of two types: capacitive or piezoresistive. While the capacitive pressure sensor is based on the vibration of capacitance with pressure, in the piezoresistive sensor it is the resistance that varies.

Capacitive structures, widely used in traditional pressure sensors, feature high sensitivity, high stability and low temperature drift. Silicon-based capacitive pressure sensors have the advantages of miniaturization, batch fabrication and onchip compensation.[1, 2]

A heterodyne probe is basically an optical laser probe that allows a time-resolved measurement of very low amplitude mechanical displacement. It uses single-frequency He-Ne laser source for fast, localised and contactless detection; thus it is a nondestructive testing tool. Phase lock-loop-based heterodyne interferometer eliminates troublesome parasitic vibrations. Its signal processing system delivers a calibrated response, directly proportional to the object, displacement.[3]

2. Sensor structure and fabrication

The fabricated silicon sensor is as shown in Fig. 1 with a diaphragm of about 20 μm thick and an area of 6 × 6 mm. A thin coating of nickel is done on the front side to get an electrical contact. It also serves as a polished surface for the probe laser to reflect back from. The device was intended to function as a capacitive pressure sensor, so that there is a hole (pressure conduit) on one of the

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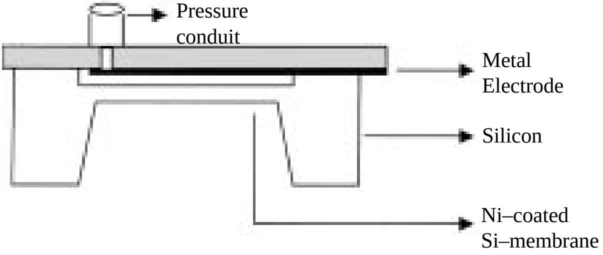

FIG. 1. Schematic of the pressure sensor device.

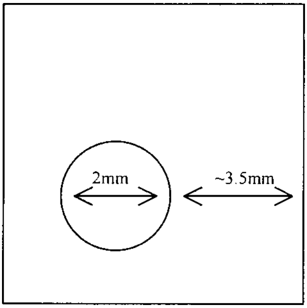

FIG. 2 Top view of diaphragm showing position of hole on other electrode.

electrodes (aluminum on glass) of the capacitor. The introduction of this hole in the present context could be seen as a loading factor.

The relative position of the hole on the diaphragm can be seen from Fig. 2. The pressure conduit on the glass has a diameter of 2 mm and is at one of the corners of the electrode. It is positioned so as to increase the sensitivity of the capacitive pressure sensor.

3. Heterodyne laser probe

A compact off-centred asymmetrical heterodyne laser probe was used for probing and measuring the component of very low amplitude periodic mechanical displacements normal to the membrane surface.[3] A general layout of the optical components of the probe is presented in Fig. 3. The inside components of the interferometer are shown in Fig. 4.

Light source

a) Helium-neon laser g) Deflecting mirrors.

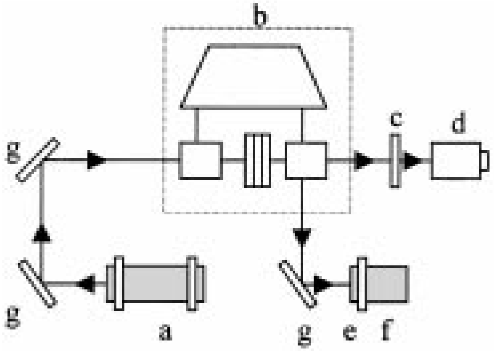

FIG. 3. Complete optical configuration.

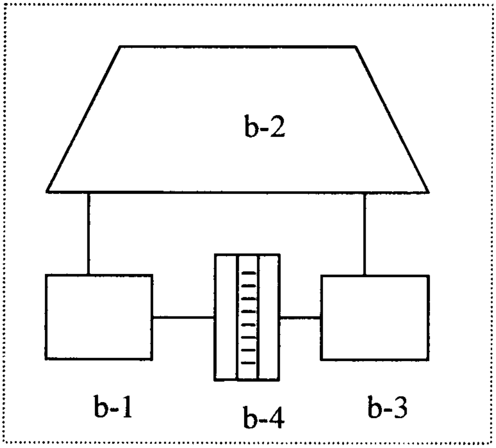

FIG. 4. The interferometer.

Interferometer

b) Mach-Zehnder interferometer (Fig. 4), b-1) Beamsplitter, b-2) Dove prism, b-3) Polarizing beamsplitter and b-4) Bragg cell.

Detection

g) Deflecting mirror, e) Analyzer and f) Photodetector.

The linearly polarized laser beam delivered by the source (a) is split into two paths by the beam splitter b-1. After propagating through the Dove prism b-2 and polarizing beam splitter b-3, the reference beam reaches the photodetector (f). The probe beam is transmitted by the beamsplitter b-1. Its frequency is shifted by the Bragg cell b-4. The mechanical displacement of the object's surface generates a modulation of the phase of the probe beam, upon its reflection on the sample to be tested. The double pass in the quarterwave plate (c) rotates the polarization of the beam by 90°. It is therefore reflected by the polarizing beamsplitter and directed towards the photodetector (f). The analyzer (e) is rotated such that it allows the two incident, orthogonally polarized, vibrations to interfere.

The photodetector (f) delivers a beat signal at the frequency of the Bragg cell, phase-modulated by mechanical displacement of the object. The photodetector consists of a photodiode and low-noise preamplifier. The intensity of the signal from it depends on the amount of light reflected by the tested sample.

The final electrical signal is therefore directly proportional to the displacement of the object. The detectivity of the probe is of the order of 10^{-5}nm/(Hz).$^{1/2}$

4. Measurement set-up

The measurements on the diaphragm were carried out as shown in Fig. 5. A sinusoidal signal was given to the capacitor structure formed by diaphragm and the metal coated on the glass, separated by a small gap ($\sim 4\,\mu$m). The amplitude of the vibration of the diaphragm is obtained from the reading of the heterodyne laser probe.

5. Results and discussion

The frequency response of one of the devices (Fig. 6) indicates that the resonant frequency of the device is about 300 kHz with harmonics at 600 and 900 kHz. On application of external pressure

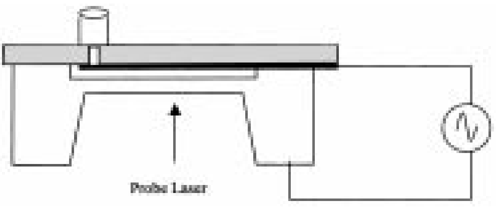

FIG. 5. Arrangement to study the diaphragm.

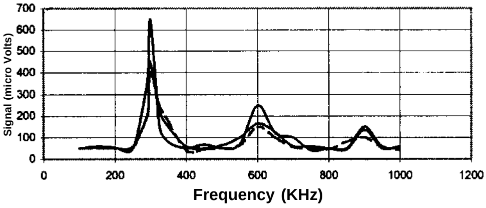

FIG. 6. Frequency response of capacitive pressure sensor with pressure variation.

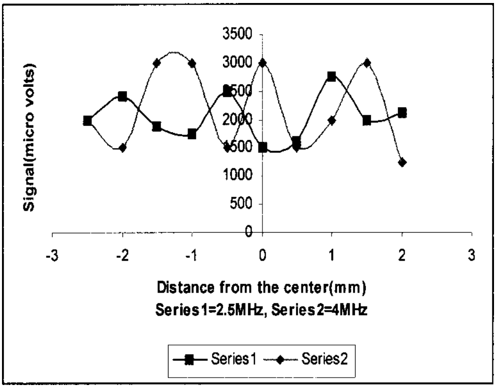

FIG. 7. One-dimensional spatial response at 2.5 and 4 MHz.

(through conduit), the amplitude of the displacement of vibration came down at all frequencies. The pressure exerted from the hole has a loading effect, due to which the amplitude of the signal measured decreases. The spatial response of the vibrating membrane (Fig. 7) also indicates the presence of pressure conduit on the metal electrode. As can be seen, the maximum deflection, which had to occur at the middle of the diaphragm, has shifted towards right. The frequency response of another sample indicated that the resonance in the diaphragm occurs at the frequencies 250 kHz, 500 kHz, 750 kHz, 2.5 MHz and 4 MHz. The energy at the harmonics at higher frequency is much higher as compared to the fundamental resonant frequency at lower frequency. An one-dimensional scan of spatial variations at these two frequencies (2.5 MHz and 4 MHz) (Fig. 7) shows that there is a shift in the phase of 180° in the vibration mode.

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