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Development of A Novel Silicon Membrane MEMS Capacitive Pressure Sensor for Biological Applications†

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Abstract: MEMS capacitive pressure sensors have proven to be more reliable in terms of temperature drift and long-term stability when compared to MEMS piezoresistive pressure sensors. In this work, MEMS capacitive pressure sensor using micromachined technology has been designed and fabricated in this study. As the movable electrode, a silicon membrane is used, while the fixed electrode is a gold metal film on a glass substrate. There is no deformation of the silicon membrane when the pressure is equal on both sides. As a result of the pressure of 0 kPa applied to the silicon membrane, a capacitance exists between it and the metal electrode. Differences in pressures on both sides of the silicon membrane will cause the membrane to deform. Silicon membranes deform due to pressure differences, which affect the capacitance between metal electrodes and silicon membranes. MEMS capacitive pressure sensors benefit from the super mechanical properties of silicon material compared to metal-based sensors. Capacitive MEMS sensors are more desirable for applications requiring high performance and stability as compared to metal pressure sensors. This device is suited to measuring blood pressure with a measurement range of 0-45kPa. When applied pressure was 0 kPa, the measurement capacitance was 3.61 pF, and when 45 kPa was applied, it was 7.19 pF.

Keywords: Silicon membranes; MEMS; Pressure sensor; Capacitive sensor

1. Introduction

There are two electrodes in a MEMS capacitive pressure sensor, one of which is movable, and one which is fixed. A silicon membrane is used to make a movable electrode, and a metal film is used to make a fixed electrode. To create silicon membrane structures, silicon micromachining processes are used. As pressure is applied to a silicon membrane structure, the structure is deformed to determine the outside pressure. In terms of mechanical properties, silicone materials are excellent, as they have high yield strength, no plastic delay, and mechanical hysteresis characteristics. As a result of silicon's superior mechanical properties, MEMS capacitive pressure sensors perform far better than metal sensors. MEMS capacitive pressure sensors are better suited to high-performance and high-stability applications than metal pressure sensors.

MEMS capacitive pressure sensors have a higher level of performance when compared with MEMS piezoresistive pressure sensors, particularly in terms of temperature drift, long-term stability, and others. MEMS piezoelectric capacitive sensor for underwater application has been reported [1, 2]. MEMS capacitive pressure sensors are developed and produced by many companies and research centres. A MEMS capacitive pressure sensor serves as the core-sensitive component of the sensors used by the VTI barometric pressure sensor and altimeter, as well as the Fuji gauge pressure sensor [3, 4]. A High sensitivity MEMS pressure sensor chip for different ranges (1 to 60 kPa) utilizing the novel electrical circuit of piezo sensitive differential amplifier with negative feed-

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back loop (PDA-NFL) is developed. This sensor has a sensitivity of 44.9 mV/kPa/V and nonlinearity error of 0.26 (for 0.5 kPa). It has Zero pressure output signal (Offset) of 14 mV [5]. The experimental results of pressure sensor showed that a sensitivity of 4.72 mV/kPa/V and a non-linearity error of 0.18 %FSO at 20 °C, was achieved in the pressure range of 0–3 kPa. It has zero-point offset voltage of 5.78 (mV) [6]. In accordance with the FEM results, the experimental results showed that the fabricated pressure sensors using bossed diaphragms combined with side edge and diagonal directional positioned peninsula-islands had sensitivities of 0.065 mV/V/Pa and 0.060 mV/V/Pa, respectively, and nonlinearity errors of 0.33% FS and 0.30% FS, respectively, within the pressure range of 0–500 Pa [7].

In this paper, a silicon-glass capacitive pressure sensor is described. MEMS micromachining was used to fabricate the silicon membrane, and silicon-glass anodic bonding enabled sensitive devices to be achieved. Silicon membranes are used as movable electrodes, while gold metal films on glass substrates are used as fixed electrodes.

2. Fabrication Process

In Figure 1, MEMS capacitive pressure sensors are shown in their structure and working principle. Several materials are used in the design of MEMS capacitive pressure sensors, including silicon membranes as movable electrodes, gold metal films as fixed electrodes, and glass substrates as support. The fixed electrode needs to maintain a consistent electrical connection for accurate capacitance measurements. Therefore, gold is an excellent electricity conductor, essential for creating a reliable capacitive sensing element. Gold exhibits low contact resistance, forming good electrical connections with other materials and surfaces. This is crucial for minimizing signal loss and maintaining accurate measurements. In our current work, MEMS (Micro-Electro-Mechanical Systems) capacitive pressure sensors absolute pressure is used as sensing mechanisms. The sensors measure the pressure by detecting the change in capacitance between two conductive plates or electrodes because of the applied pressure. When pressure is applied, the distance between the plate's changes, causing a variation in the capacitance, which can then be converted into an electrical signal proportional to the applied pressure. There is a pressure difference between the two sides of the silicon membrane, and the capacitance between the silicon membrane and the metal electrode is the result of this pressure difference between the two sides [8, 9].

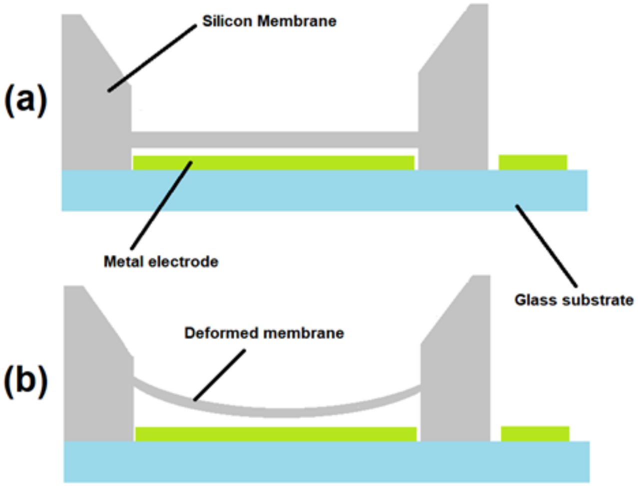

Figure 1. Mechanism of MEMS capacitive pressure sensors; (a). When there is no pressure; (b). Deformation of the silicon membrane in response to pressure.

Figure 2 shows the fabrication process of the MEMS capacitive pressure sensor. The process consists of two parts. The silicon substrate process is one part of the process. To fabricate the silicon membrane, silicon etching techniques were used. Another part is the glass substrate process. To achieve a fixed metal electrode, metallization and patterning techniques were used. The silicon and glass wafers were bonded using silicon-glass anodic bonding technology. Anodic bonding has been the most widely used bonding method for MEMS because it is easy, reliable, and highly yield. In principle, anodic bonding can be done between electron-conductive materials and ion-conductive materials. The most typical combination is Si and borosilicate glass, which shows ion conductivity at 300 °C or higher. Other semiconductors and metals except Ag can also be anodically bonded with glass, but different kinds of glass for Si must be used to match the coefficient of thermal expansion. The merit, which is not found in other bonding methods, is that an electrostatic attractive force of about 20 kgf/cm2 works between wafers, and thus bonding uniformity, i.e. yield, is excellent without special cares such as uniform loading. In addition, the reliability of bonding strength and hermeticity has been proved in a long history of MEMS applications. Typical bond strength is between 10 and 20 MPa according to pull tests, higher than the fracture strength of glass [10]. Chips were separated and sensor dies were created through dicing. The developed MEMS capacitive pressure sensor chip is shown in Figure 2.

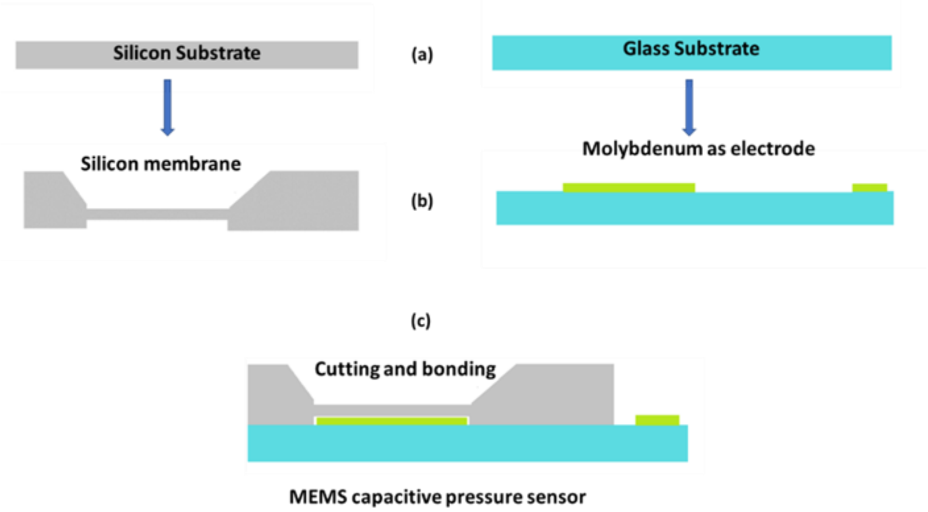

Figure 2. Process for fabricating MEMS capacitive pressure sensors.

3. Results and Discussion

Gas pressure was applied using a GE Sensing PACE5000 precision pressure controller. This pressure measurement range is suitable to measure blood pressure from 0 to 45kPa. A pressure of 0 kPa resulted in a measurement capacitance of 3.61 pF, while a pressure of 45 kPa resulted in a measurement capacitance of 7.19 pF. Figure 3 shows the results of the capacitance-pressure curve and elastance-pressure curve measurement. As expected, with the increase of pressure, the capacitance of silicon membrane increases while elastance decreases.

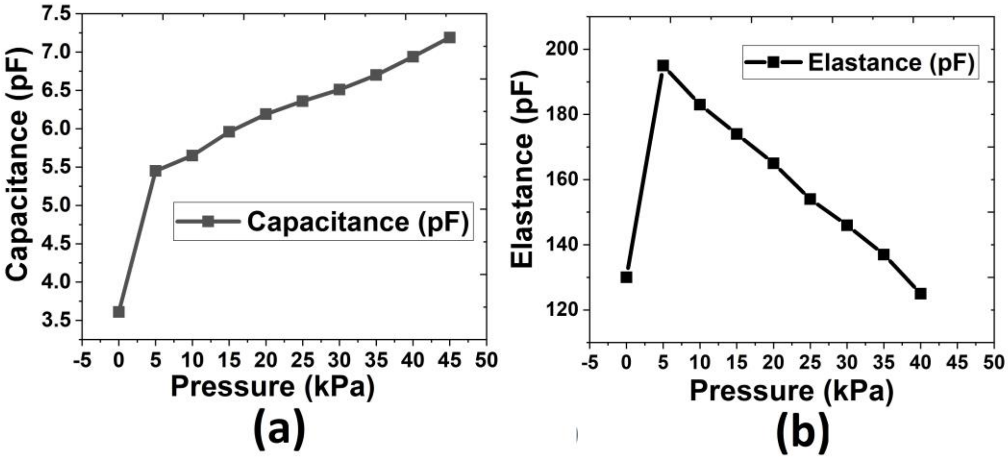

Figure 3. Measurement curves for capacitive pressure sensors using MEMS technology. (a). Graph of capacitance Vs. pressure; (b). Graph of elastance Vs. pressure.

4. Conclusion

This work represents the design and fabrication of a MEMS capacitive pressure sensor. Anodic bonding of silicon-glass was used to fabricate the sensor using micromachined technology. A silicon membrane is used as a movable electrode, and a gold metal film on a glass substrate is used as a fixed electrode. With an applied pressure of 0kPa, the measurement capacitance is 3.61 pF, and with a full operating range of 45 kPa, it is 7.19 pF. Capacitance increases with the increase of pressure while elastance decreases. This type of measurement is suitable for the application of blood pressure measurements because the operating pressure used from 0kPa to 45 kPa.

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