Extended Abstracts of the 22nd (1990 International) Conference on Solid State Devices and Materials, Sendai, 1990, pp. 701-704

A Miniature Integrated Capacitive Pressure Sensor

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A miniature integrated silicon capacitive pressure sensor has been fabricated. The pressure sensor consists of a Pyrex glass and a silicon chip. a silicon diaphragm and a CMOS capacitance to frequency converter are integrated on the same silicon chip. The silicon chip is hermetically sealed by the Pyrex glass using anodic bonding in wafer process. The sensor capacitor is formed by the silicon diaphragm and a counter metal electrode on the Pyrex glass. The output frequency is detected by the current change in power line. The pressure sensor has higher sensitivity, lower temperature drift and lower power consumption than the conventional piezoresistive pressure sensor.

1. INTRODUCTION

Small size, high performance pressure sensors are required for industrial, automotive and biomedical fields. Silicon piezoresistive pressure sensors have been developed and used. However, the piezoresistive devices have high temperature coefficients and suffer packaging stress, so that individual compensation circuits are needed in spite of their added costs.

Since the capacitive pressure sensor have higher sensitivity than the piezoresistive devices, the capacitive sensors have significant advantages concerning the above-mentioned problems. The capacitance measurement circuit has to be integrated on the sensor chip, because the small sensor capacitance is affected by the relatively large stray capacitance of the lead wires[1]. This paper describes the integrated capacitive pressure sensor fabricated with CMOS and micromachining technology.

2. STRUCTURE

The structure of the integrated capacitive absolute pressure sensor are shown in

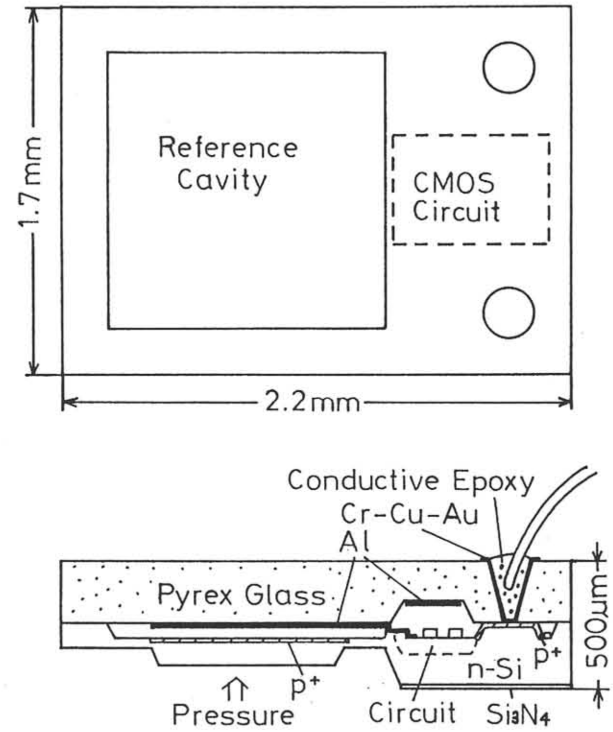

Fig.1 Structure of the integrated capacitive pressure sensor.

Fig.1. The pressure sensor consists of a Pyrex glass and a silicon chip. The sensor capacitor is formed by a metal electrode on the Pyrex glass and a silicon diaphragm which has a mesa structure at the center. A

CMOS capacitance to frequency converter (C-F converter) is integrated on the same silicon chip. The sensor needs no package case, because the sensor and circuit are hermetically sealed by the Pyrex glass. The electrical feedthrough from the circuit are made with the feedthrough structure through the glass holes[2]. The metal film above the circuit is a light shield to reduce photoelectric leakage current.

The sensor size is 2.2mm×1.7mm and 500 μm in thickness. The gap between the metal electrode and the silicon diaphragm is 1.75 μm. The diaphragm size is 1.2mm×1.2mm and 15μm in thickness. The mesa size is 740μm ×740μm and 45μm in thickness.

3. FABRICATION

The integrated capacitive pressure sensor is fabricated with CMOS and micromachining technology. Fig.2 shows the fabrication process of the pressure sensor. (a) The top surface of a (100) oriented 200μm thick n^--type silicon wafer is etched to the depth of 2μm by anisotropic etching in 35wt% KOH solution. The etching depth determines the gap between the silicon diaphragm and the metal electrode on the glass. The mesa structure is etched at the back side of the silicon wafer. (b) A CMOS C-F converter and P^+ diffused layers are fabricated into the shallow well. P^+ diffused layers are used for the sensor capacitor electrode and the feedthrough structure. Silicon nitride mask is formed at the back side of the silicon wafer. (c) Small holes of about 120μm in diameter are engraved through a 300μm thick Pyrex glass using electrochemical discharge machining in NaOH solution[3]. (d) The glass is etched to the depth of about 10μm by HF solution using Cr-Au-resist mask[3]. 250nm thick aluminum is evaporated on the glass and patterned to make the capacitor electrode and a light shield above the circuit.

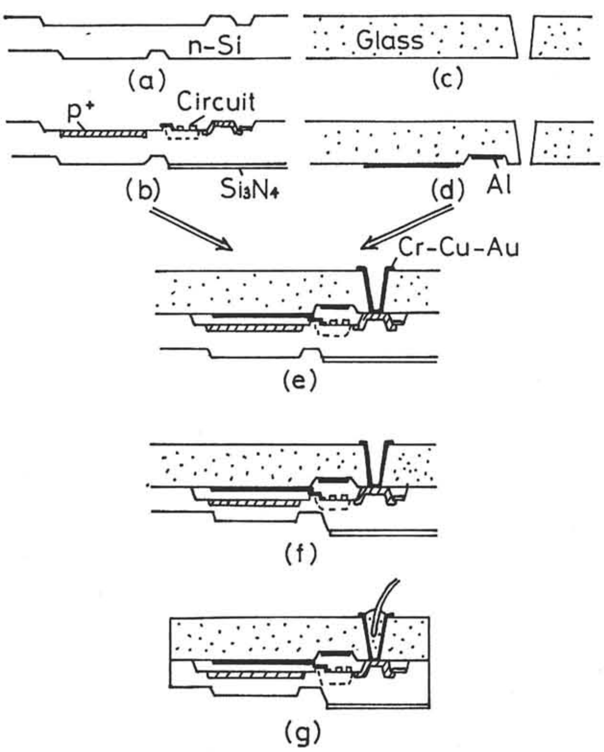

Fig.2 Fabrication process of the pressure sensor.

(e) The glass cover is hermetically sealed to the silicon wafer using anodic bonding at 390℃, 600V. The aluminum electrode on the glass is made contact with the aluminum pad on the silicon wafer. Cr-Cu-Au is evaporated at the glass holes using metal mask. (f) The silicon diaphragm is formed by etching the back side of the silicon wafer to the depth 153μm in KOH solution using silicon nitride mask. The silicon-glass wafer is diced into individual sensor chips. (g) Lead wires are attached to the holes with conductive epoxy or tin solder.

The silicon chip and Pyrex glass are hermetically sealed by silicon-glass anodic bonding in wafer process. The fabrication process gives small and low-cost sensor. Fig.3 shows the fabricated pressure sensor at process flow (f).

4. SENSOR DESIGN

The sensor characteristics are calculated as follows. The deflection of the mesa W_m due to applied pressure P is given by

$$W_m = KP \quad (1)$$

where K is constant related to the dimension of the diaphragm. K is inversely proportional to the third power of diaphragm thickness. The control of diaphragm thickness is important for the sensitivity control of the sensor. The area of sensor capacitor is S, and the gap is d. The sensor capacitance C_x is expressed as

$$C_x = \varepsilon S/(d-W_m) \quad (2)$$

where ε is the dielectric constant. The sensor base capacitance C_0 is expressed as

$$C_0 = \varepsilon S/d \quad (3)$$

Because the base capacitance must be large enough to neglect the stray capacitance C_s, the gap d must be as small as possible to obtain large base capacitance.

When the maximum pressure is applied to the sensor, the deflection W_m is equal to the gap d, and the sensor capacitance will be infinite from equation (2). Substituting W_m=d to equation (1), the maximum applied pressure P_m is defined by next equation.

$$P_m = d/K \quad (4)$$

The schmitt trigger oscillator circuit shown in Fig.4 is used for capacitance detection. The frequency f_x is given by

$$f_x = I_0/(2C_xV_h) = I_0(1-P/P_m)/(2C_0V_h) \quad (5)$$

where I_0 is charge or discharge current for the sensor capacitor and V_h is hysteresis of the schmitt trigger circuit. The current I_0 must be large enough to neglect the leakage current I_L. From equation (5), the frequency f_x is proportional to the applied pressure P, and falls to zero at the maximum pressure P_m.

Output frequency is detected by monitoring the supply current change in the power line. Therefore, only two lead wires are connected to the sensor.

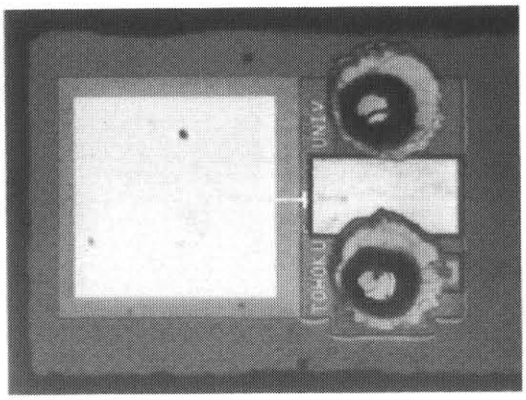

Fig.3 Photograph of the integrated capacitive pressure sensor.

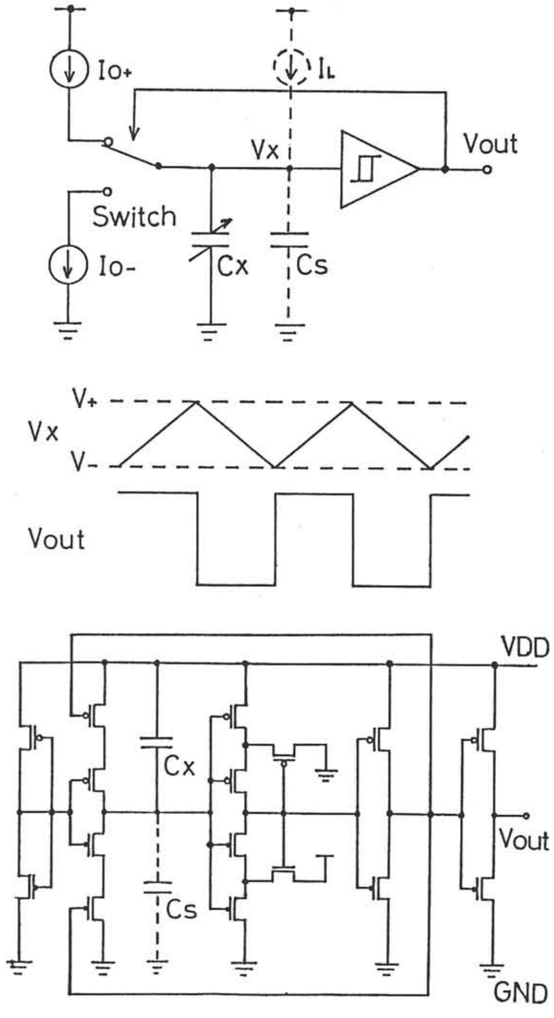

Fig.4 Circuit diagram of C-F converter.

5. CHARACTERISTICS

The thermal zero shift of the sensor is caused by the thermal change of the sensor capacitance and of the circuit parameter. The thermal zero shift depends on supply voltage, and was minimized at a appropriate supply voltage (3.95V) at which the the thermal change of the sensor capacitance and of the circuit parameter were canceled out[4].

Fig.5 shows the measured pressure characteristics of the sensor at the supply voltage of 3.95V. The base frequency at the pressure of 760mmHg was 65.4KHz. The frequency varied from 72.5kHz to 54.5kHz increasing the pressure from 500mmHg to 1100mmHg. The non-linearity from 500mmHg to 1100mmHg was 4.0%F.S. The sensitivity was reduced above 1100mmHg.

The reduction of the sensitivity was probably caused by the hillock of the aluminum electrode on the Pyrex glass, because the diaphragm deflection is hindered by the hillock. The hillock was produced during anodic bonding process.

The characteristics of the pressure sensor are as follows. The full span was 600mmHg. The sensitivity was -30Hz/mmHg. The thermal zero shift was 0.046%F.S./℃ and the thermal sensitivity shift was 0.088%F.S./℃. The power dissipation was 86.5μW. The long term drift was ±2mmHg/Week. These value are superior to conventional piezoresitive devices.

6. CONCLUSION AND FURTHERWORK

An integrated silicon capacitive absolute pressure sensor has been designed and fabricated. The feedthrough structure and the batch fabrication process gives small, reliable and low-cost sensor. The output frequency is detected by two wires detection, and is easily converted to digital signal.

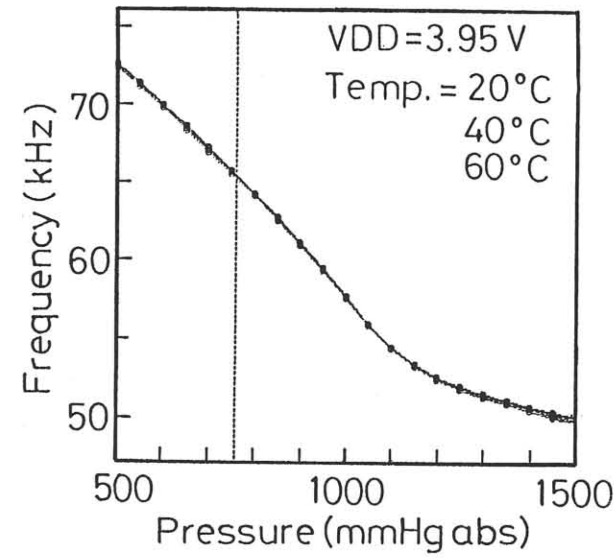

Fig.5 The relation between output frequency and applied pressure.

The sensitivity of the integrated capacitive pressure sensor can be furthermore improved using a Ti/Pt metal electorode[5]. The thermal shift of the sensor can be also improved using vacuum or relative pressure reference cavity[6].

ACKNOWLEDGMENTS

This work was supported by Japanese Ministry of Education Science and Culture under a Grand-in-Aid No.63850084.

REFERENCE

1) W.H.Ko, Sensors and Actuators, 10,pp.303-320 (1986).
2) M.Esashi, Y.Matsumoto and S.Shoji, Sensor and Actuators, A,pp.1048-1052 (1990).
3) S.Shoji and M.Esashi, Technical Digest of the 9th Sensor Symposium,pp.27-30 (1990).
4) Y.Matsumoto, S.Shoji and M.Esashi, techinical Digest of the 9th Sensor Symposuim,pp.43-46.
5) B.Puers et.al, Sensor and Actuator, A,pp.108-114 (1990).
6) Y.S.Lee and K.D.Wise, IEEE Trans. Electron Devices, ED-29, No.1, pp.42-48 (1982).