CONTAMINATION INSENSITIVE DIFFERENTIAL CAPACITIVE PRESSURE SENSORS

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ABSTRACT

In this paper, a contamination insensitive differential capacitive pressure sensor with a sealed gap is presented. This device is made of three polysilicon layers including a stationary middle plate and the top and bottom plates that are rigidly coupled together by a series of posts and hence deflect in tandem by a change in differential or gauge pressure. Because of the posts, however, the device is insensitive to common mode pressure. As the differential pressure is changed from –80kPa to 80kPa, the capacitance between the bottom and middle plates changes by 86fF, yet there is only a 2fF change in output when the common mode pressure is applied from 30kPa to 200kPa.

INTRODUCTION

A major problem with surface micromachined differential capacitive pressure sensors is sensitivity to contamination in the gap between the two sensing plates as shown in Figure 1(a) [1-7]. Typically, the micron-sized gap is small enough that it can be easily blocked by dust particles. However, this problem can be remedied if the gap is sealed. Yet, sealing the gap makes the plate deflection sensitive to changes in common mode pressure as shown in Figure 1(b). As a result, only structures that contain an isolated gap sensing absolute pressure changes have been successfully commercialized. Bay et al. [8-9] suggested that joining the external capacitor plates and the use of an intermediate electrode could eliminate absolute pressure sensitivity.

Conceptually, this device is shown in Figure 2. It has two polysilicon sensing plates A and C and a stationary middle polysilicon electrode B thus forming an isolated cavity. Plates A and C are rigidly attached to each other through a series of periodic posts. These posts stiffen the structure so that common mode pressure changes do not cause a change in capacitance output. The posts, therefore, transmit force between A and C. Thus, these two plates deflect as a single compound plate. Deflection occurs only when a pressure difference is present between plates A and C.

In this paper we present the first surface/bulk micromachined implementation of a three plate differential capacitive pressure sensor with a sealed gap that is insensitive to gap contamination and common mode pressure changes.

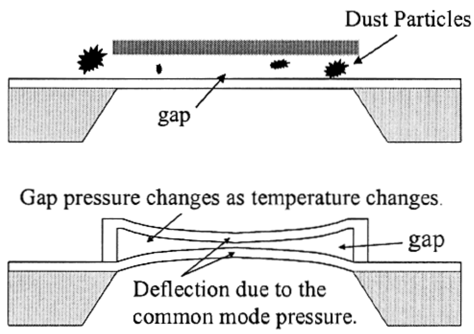

Figure 1: Major problems of differential capacitive pressure sensors: (a) Contamination of the Gap (b) Sensitivity to the common mode pressure

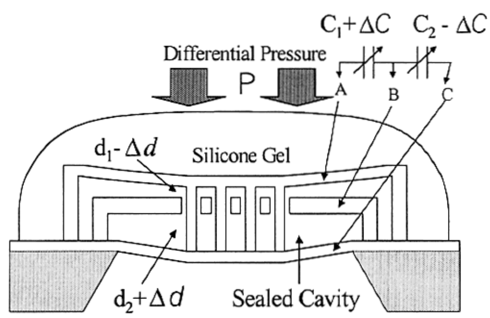

Figure 2: Device schematic structure and its equivalent circuit under pressure P.

FABRICATION PROCESS

The device is fabricated using combined surface and bulk micromachining techniques with a 16-mask process. Figure 3 shows the cross-sections at the major process steps.

The process starts by growing a layer of 0.25 µm thermal oxide on n-type (100) 100mm silicon wafers, patterning and etching it. Next, a sacrificial polysilicon layer is formed by depositing, patterning and etching 0.25 µm LPCVD low stress polysilicon. A 0.35 µm layer of low stress silicon-rich nitride then is used to form the isolation layer and to allow increased sacrificial layer distance because of its improved selectivity as compared with stoichiometric silicon nitride. The first structural layer shown in Figure 3(a), 2 µm low tensile stress polysilicon, is then deposited and phosphorus doped. The polysilicon structural layer is defined and will become the bottom capacitor plate.

A second layer of 0.35 µm low stress nitride is then deposited to form an isolation layer between the bottom and middle polysilicon layers. On top of the bottom polysilicon and low stress nitride, a 1µm thick PECVD phosphosilicate glass (PSG) layer forming a gap between the bottom and middle polysilicon plates is deposited and shown in Figure 3(b).

Next, a 2 µm low tensile stress, phosphorus-doped polysilicon layer is deposited. This polysilicon layer forms the stationary middle plate that is vacuum-sealed in the cavity and does not deflect when either differential or common mode pressure is applied. A series of square openings are etched away in order to allow the posts between the top and the bottom plates to be deposited. After the middle polysilicon layer is etched, another 0.35 µm low stress silicon nitride isolation layer, shown in Figure 3(c), is deposited, patterned, and etched.

The second 1µm PSG sacrificial layer is then deposited, patterned to form the areas for the posts and the sacrificial layer etch ports, and etched as shown in Figure 3(d). The posts are then formed with a 2.2 µm undoped polysilicon layer that is deposited as the top diaphragm. And only small holes for sacrificial etch are etched away. Thus, most of the wafer is covered and protected by the polysilicon layer during the sacrificial etch step in concentrated HF (49% by weight). After etching, the wafer is dried using the supercritical CO_2 drying process to avoid stiction [10].

The 1 µm gap is then sealed by the deposition of a PSG layer. On top of this sealing PSG, a 0.3 µm polysilicon layer is deposited, patterned, and etched. It is followed by depositing another 0.3 µm polysilicon layer shown in Figure 3 (e) to cover the interface between the sealing PSG and the top polysilicon layers to prevent pressure leakage. The 2.5 µm top polysilicon layer is doped, then, all the low stress silicon nitride and polysilicon layers on the backside are removed by RIE and Si etchant. This is followed by the deposition of 2.5 µm low temperature oxide (LTO) with very low stress, which is used as the backside hardmask. The wafers are, then, bulk micromachined using a low stress silicon nitride etch stop layer that is etched by RIE.

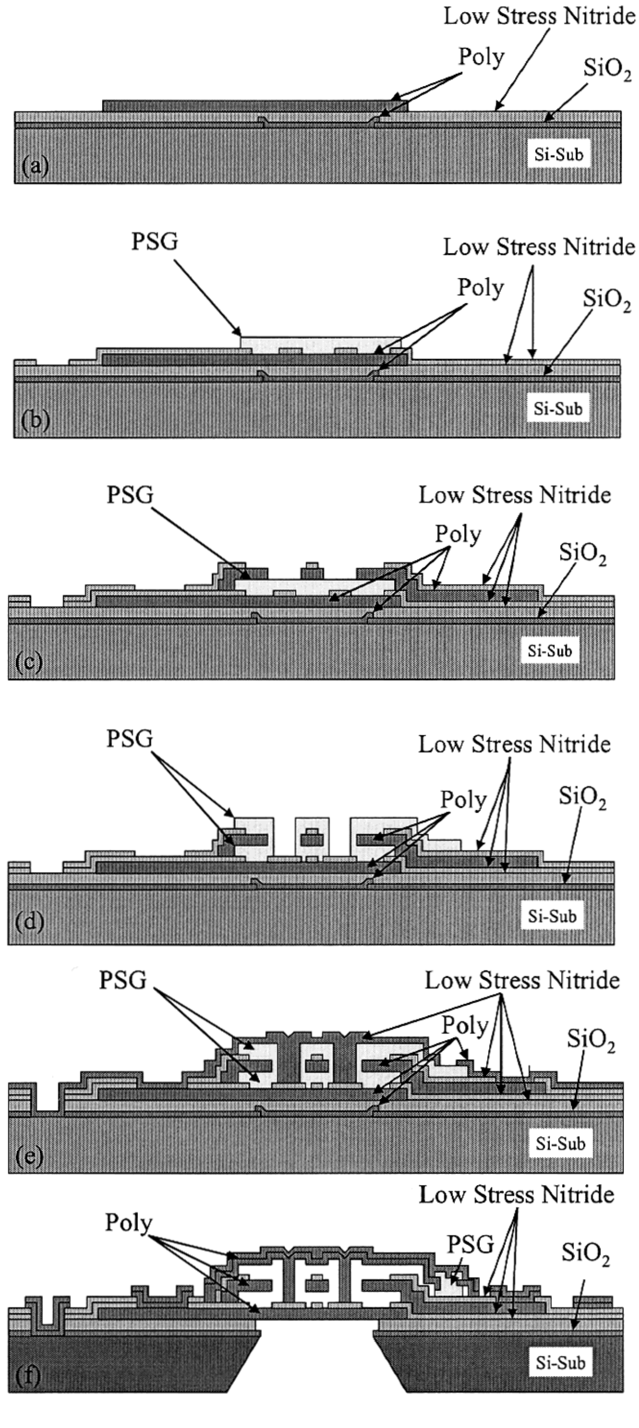

Figure 3: Device cross-sections at the major process steps

Figure 4 shows a 150x150 μm^2 device with post spacing of 40µm and sacrificial etch holes on the sides of the sealed cavity. The bottom and middle diaphragm thickness is 2 µm and the top polysilicon diaphragm is 2.5µm. The gap distance is 1 µm between each plate. The top and bottom plates are coupled with posts shown in the cross-section of Figure 5. Figure 6 and 7 show the side view and the sealing of the device, respectively. Following fabrication, the devices are diced and die attached to a pre-molded plastic package. A silicone die attach material is used to isolate package stress from the devices. After die attach, wirebonding are completed, the device shown in Figure 8 is ready for testing.

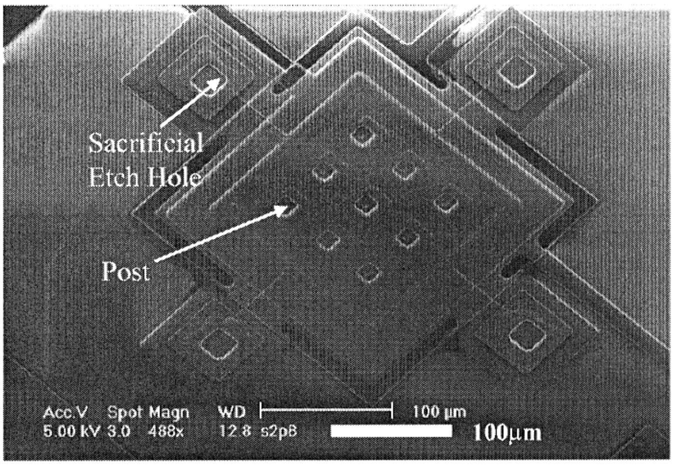

Figure 4: SEM of the capacitive differential pressure sensor.

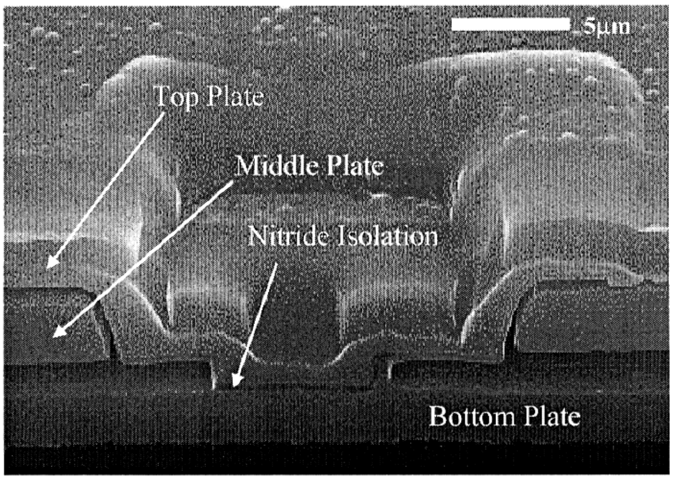

Figure 5: SEM of a post between the top and bottom diaphragms.

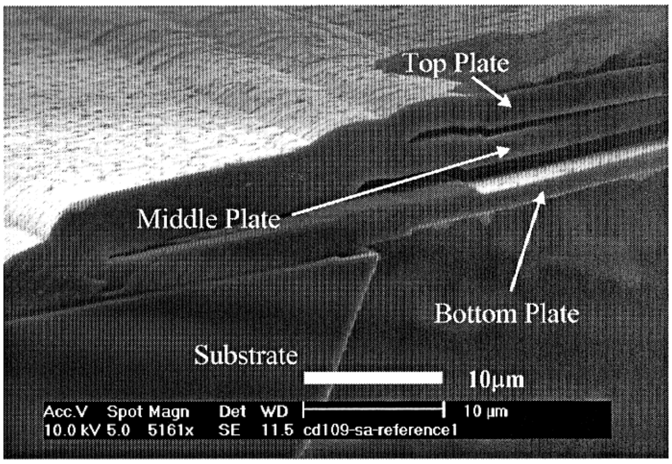

Figure 6: Side view of the capacitive differential pressure sensor.

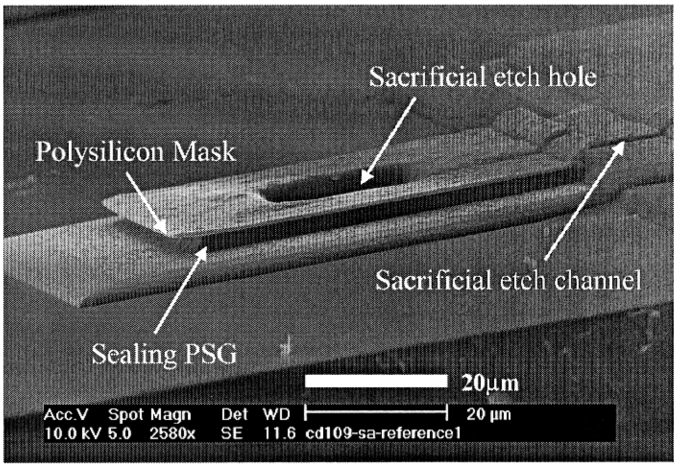

Figure 7: The cavity is sealed by PSG using polysilicon as a mask .

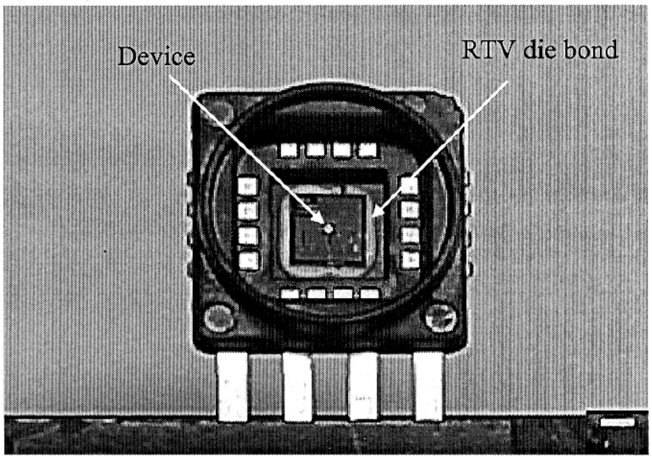

Figure 8: The device is die attached on a package.

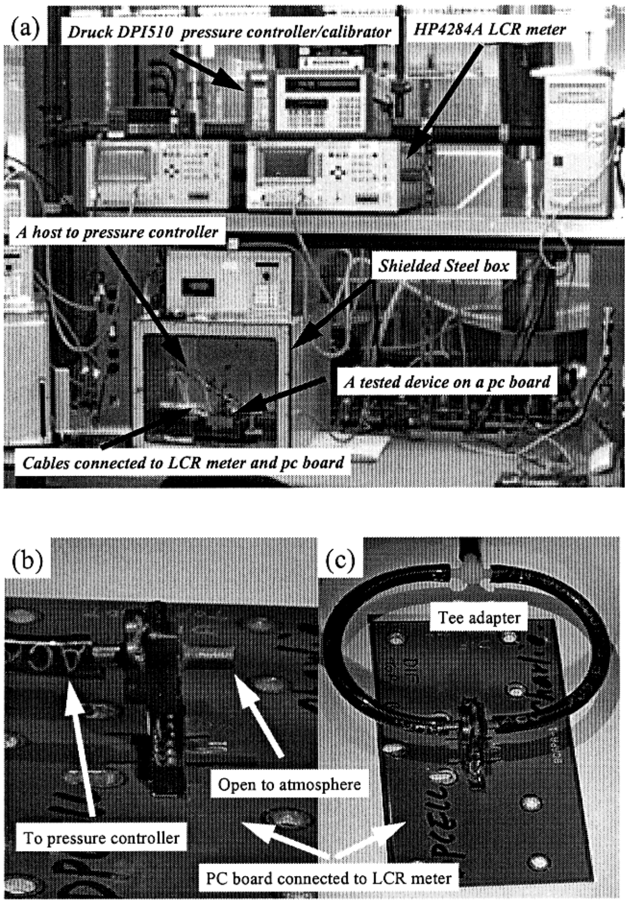

Figure 9:(a)The test setup includes a shielded steel box connected with a HP4284A LCR meter and a Druck DPI510 pressure controller/calibrator. This is setup for (b) differential (or gauge) pressure (c) common mode pressure measurements.

EXPERIMENTS

After the devices had been packaged, testing was performed in a well-shielded steel box connected with a high precision HP4284A LCR meter with a resolution of 0.001fF and a Druck DPI510 pressure controller/calibrator. With this testing setup shown in Figure 9(a), three types of measurements have been performed as follows:

Capacitance versus differential (or gauge) pressure:

The capacitance between the bottom and the middle plates (C_{BM}) is measured when the absolute pressure (30kPa to 300kPa) is applied on either front side or the backside of the device while the pressure on the other side (back or front) is kept at atmosphere (100kPa). Figure 9 (b) shows the packaged device with two ports in the gauge pressure test setup. One of the ports is connected to the pressure controller with a hose. The other port is left open to the atmosphere. Therefore, a differential (or gauge) pressure reading is recorded. The differential pressure is equivalently changed from –200 kPa when the absolute pressure is applied on the front side to 200 kPa when the pressure is applied on the backside. Because the top and bottom plates are coupled together through the posts, the measured capacitance changes are the same when applying the pressure from –70 kPa to 70 kPa on either the front side or the backside of the devices. Figure 10 shows that the capacitance versus differential (or gauge) pressure between bottom and the middle plates (C_{BM}) under the pressure difference from -80kPa to 80kPa changes by 86fF.

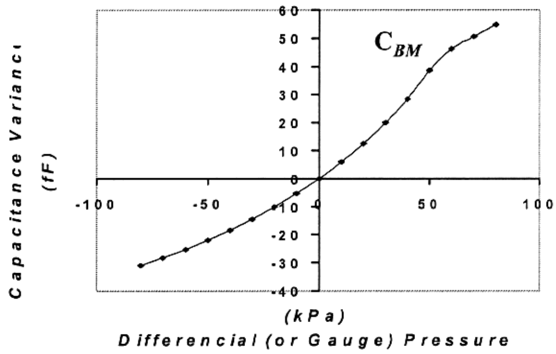

Figure 10: Capacitance variance between the bottom and middle plates C_{BM} vs differential (or gauge) pressure. Positive (negative) pressure implies that the atmospheric pressure is on the topside (backside) of the device.

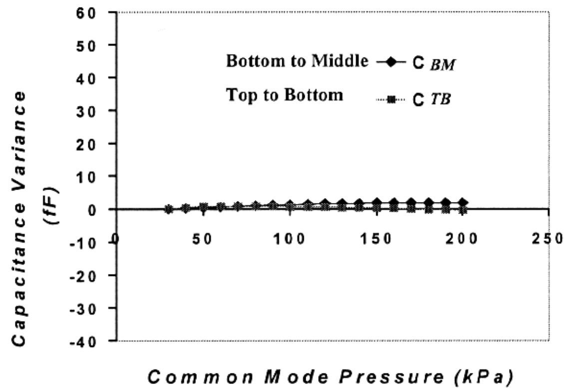

Figure 11:Capacitance variance between the top (middle) and bottom plates C_{TB} (C_{BM}) vs common mode pressure.

Capacitance versus common-mode pressure:

The common-mode pressure means that an absolute pressure is applied to both top and bottom plates of the device at the same time. It is controlled with the pressure controller using a Tee adapter and two hoses that are connected to both sides of the packaged device shown in Figure 9(c). Because the absolute pressure is applied to both top and bottom diaphragms, the deflection occurs only between the posts and is much less than the deflection caused by application of differential (or gauge) pressure. Thus, the capacitance change is very small. Figure 11 shows the capacitance versus common-mode pressure showing only a 2fF change between the bottom and middle plates (C_{BM}) and less than 1fF between the top and bottom plates (C_{TB}) when the common mode pressure is applied from 30kPa to 200kPa on both the top and bottom diaphragms.

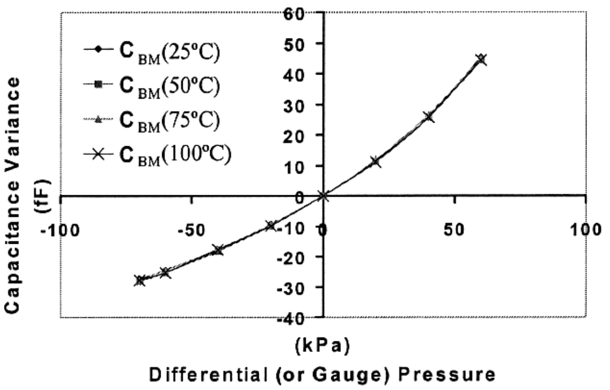

Figure 12: Capacitance variance between the bottom and middle plates C_{BM} vs differential (or gauge) pressure under different temperatures.

Capacitance versus differential (or gauge) pressure under different temperatures:

The same capacitance versus differential (or gauge) pressure measurement under different temperature from 25° C to 100° C has been performed. Figure 12 shows that the temperature change of 75° C has little effect on the capacitance change C_{BM} vs pressure. After zero offset compensation, only less than 1fF change has been observed resulting in a worst Tco of 170 ppm/° C.

SUMMARY

The design, fabrication and testing of the first surface/bulk micromachined, three-plate, contamination insensitive differential capacitive pressure sensor with sealed gap that is insensitive to common mode pressure changes has been presented. This device is made of three polysilicon layers including a stationary middle plate and the top and bottom plates that are rigidly coupled together by a series of posts and, hence, deflect together with a change in differential (or gauge) pressure. The capacitance change between the bottom and middle plates is about 86fF under a differential (or gauge) pressure change from –80kPa to 80kPa, and only 2fF when the common mode pressure is applied from 30kPa to 200kPa.

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