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THERMAL BEHAVIOR OF SILICON CAPACITIVE PRESSURE SENSORS USING ELECTROSTATIC PRESSURE

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Abstract

This paper presents two methods to characterize the thermal coefficient of pressure sensitivity without hydrostatic pressure measurements. These methods are then easier to implement because they only use electrostatic pressure. One model uses the thermal coefficient of capacity and the thermal coefficient of electrostatic pressure sensitivity. The second one is based on the thermal coefficient of capacity and on the thermal coefficient of fundamental resonance frequency. These two models have been validated between -20°C $+150^{\circ}\text{C}$ for circular silicon membrane manufactured with silicon/pyrex technology.

Keywords : Capacitive sensors, Temperature sensitivity, Temperature coefficient, Silicon membrane, modelling, micro-technologies, static and dynamic behaviour.

I- Introduction

Thanks to micro-technology, the price of pressure microsensors is very low and then a big part of this price is related to packaging and qualification tests. On wafers tests are often realized before packaging in order to select only good sensing cell before packaging.

For pressure sensors the on wafer tests are difficult to do, related to pressure application which requires hermetic set up.

We present two methods to overcome this difficulty using electrostatic pressure instead of hydrostatic pressure. This electrostatic pressure can be use as static pressure to simulated real pressure or as dynamic pressure to monitor the resonant frequency of the membrane.

The pressure sensor studied here is fabricated with silicon/pyrex technology.

II- Sensor Description

A simple model of the capacitive pressure sensor fabricated for this study is shown in fig. 1. It consists of: (a) a rigid and insulating pyrex substrate (b) a conductive silicon membrane bonded to the substrate with anodic bonding and (c) an aluminum metal plate deposited inside a cavity.

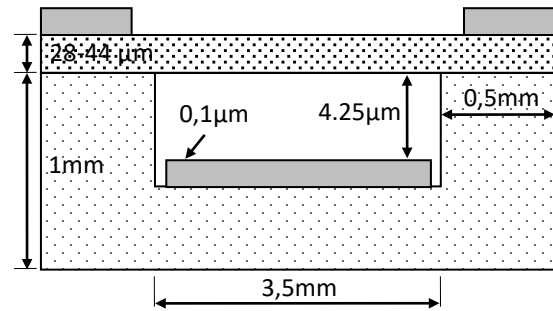


Figure 1 : Basic structure and dimensions of a sensing cell under study.

In the linear field, the sensor is characterized by the offset C_0 for zero differential pressure and the pressure sensitivity S_p .

At rest, the membrane and the fixed plate form a planar capacitor whose capacitance is equal to C_0 . If fringe electric fields remain negligible, the relation of C_0 can be written as:

$$C_0 = \epsilon_0 \frac{A}{d} \quad (1)$$

Where A and d are, respectively, the area of the fixed plate and the distance between the membrane and the fixed plate. The thermal coefficient is characterized by its relative partial derivative:

$$TC[C_0(T)] = \frac{1}{C_0(T)} \frac{\delta C_0(T)}{\delta T} \quad (2)$$

The sensitivity to pressure (P) is defined by the following expression:

$$S_p = \frac{\Delta C}{\Delta P} \quad (3)$$

And their thermal coefficient is given by:

$$TC[Sp(T)] = \frac{1}{Sp(P)} \frac{\delta Sp(T)}{\delta T} \quad (4)$$

III- Characterization of thermal coefficients

A) Thermal coefficient of offset C_0

An example of thermal variations of C_0 and their thermal coefficient are shown respectively in fig. 2 and fig. 3.

The figure 3 shows that the variations of the thermal coefficient of C_0 can be fitted by a linear model in the range $-20^\circ\text{C} +150^\circ\text{C}$.

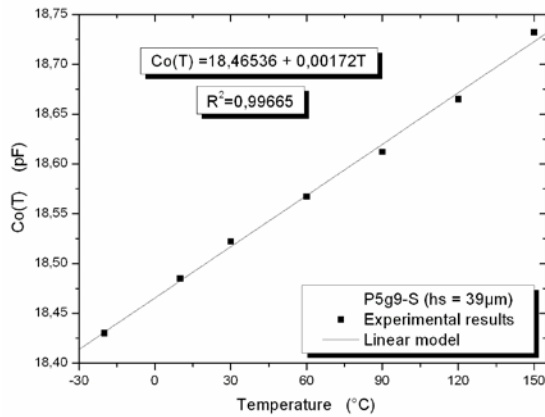


Figure 2 : Thermal drift of C_0 .

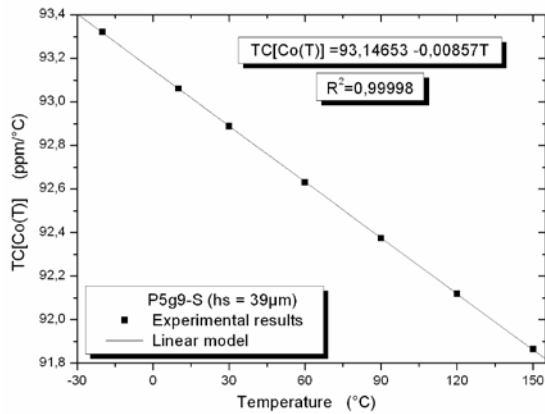


Figure 3 : Thermal coefficient of C_0 .

B) Thermal coefficient of voltage sensitivity

A continuous potential difference V is applied between the silicon membrane and the metal electrode inside the cavity which creates an attraction force bending the membrane and causes a variation ΔC of the capacity [1-2].

The sensitivity of capacity to applied voltage is defined by:

$$S_v = \frac{C(V) - C_0}{V^2} \quad (7)$$

The figure 4 shows an example of variations of the capacity as a function of the square of applied potential at a constant temperature $T=30^\circ\text{C}$. We show that the variations of the capacity are proportional to the square of tension.

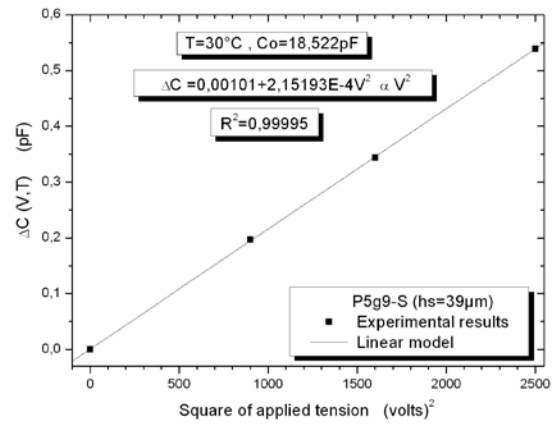


Figure 4 : Capacitance variation versus square of applied potential at $T=30^\circ\text{C}$.

For this example and according to the expression (7), the thermal variations of the tension sensitivity and their thermal coefficient are shown respectively in fig. 5 and fig. 6.

The figure 6 shows that the variations of the thermal coefficient of the tension sensitivity can be fitted by a linear model in the range $-20^\circ\text{C} +150^\circ\text{C}$.

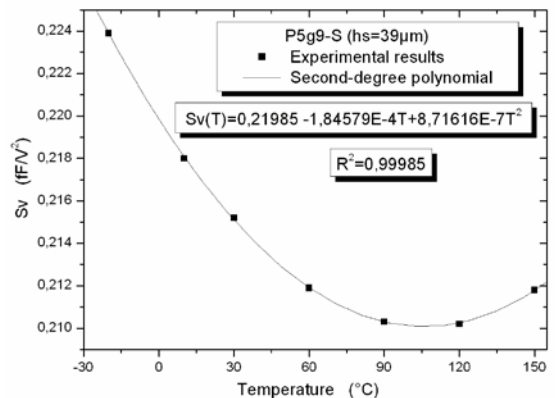


Figure 5 : Voltage sensitivity versus temperature.

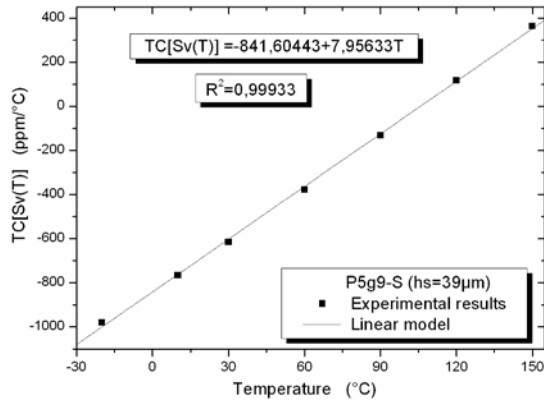


Figure 6 : Thermal coefficient of voltage sensitivity versus temperature.

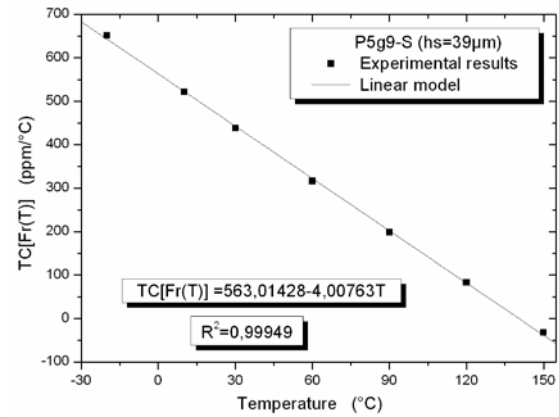


Figure 8 : Thermal coefficient of fundamental resonance frequency versus temperature.

C) Thermal coefficient of resonance frequency

In order to measure the fundamental resonance frequency F_r , a sinusoidal electrostatic pressure is applied between the silicon membrane and the electrode inside the cavity. The sinusoidal signal amplitude is 1V added to 1V constant voltage. These constant value was chosen enough small not to force the membrane and large enough to obtain visible resonance frequency. The figure 7 and figure 8 precise, respectively, the aspect of the thermal variations of the fundamental resonance frequency and their thermal coefficient.

Figure 8 shows that the variations of the thermal coefficient of fundamental resonance frequency can be fitted by a linear model in the range -20°C $+150^\circ\text{C}$.

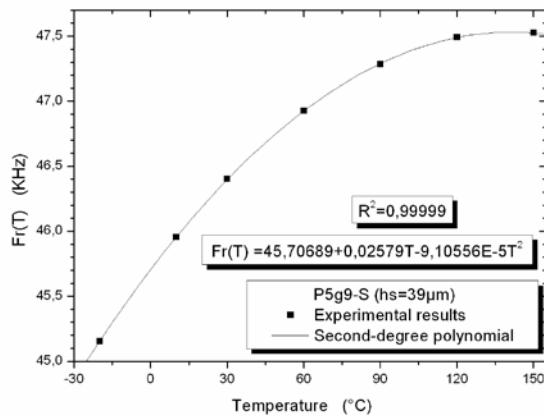


Figure 7 : Fundamental resonance frequency versus temperature.

IV- Thermal coefficient pressure sensitivity

A) By means of the voltage sensitivity

For small values of voltage V , the distance between the fixed plate and the membrane is small. Each element of the membrane is then subjected to an almost constant electrostatic pressure P_v :

$$P_v \approx \frac{\epsilon_0 V^2}{2 d^2} \quad (5)$$

In these conditions, the pressure sensitivity of the sensor is approximately equal to:

$$Sp_v \approx \frac{\Delta C}{P_v} \approx \frac{2\epsilon_0 A^2}{Co^2} S_v \quad (6)$$

The first model of the thermal coefficient of the pressure sensitivity according to the relation (6) is given by:

$$TC[Sp_v(T)] \approx TC[S_v(T)] - 2 TC[Co(T)] \quad (7)$$

B) By means of the fundamental resonance frequency

The pressure sensitivity of the sensors can be evaluated by means of the measurement of the fundamental resonance frequency [3] :

$$Sp_{Fr} \approx \frac{Co^2}{\epsilon_0 m (2\pi Fr)^2} \quad (8)$$

Where m represents the mass of the membrane.

The second model of the thermal coefficient of the pressure sensitivity according to the relation (8) is defined by the following expression:

$$TC[Sp_{Fr}(T)] \approx 2TC[Co(T)] - 2TC[Fr(T)] \quad (9)$$

C) Results

The figure 9 shows, for an example, a comparison between the two models calculated according to the expressions (7) and (9). We can notice that the two models give almost the same results and that the thermal coefficient of pressure sensitivity can be fitted by a linear law :

$$TC [Sp(T)] = A + BT$$

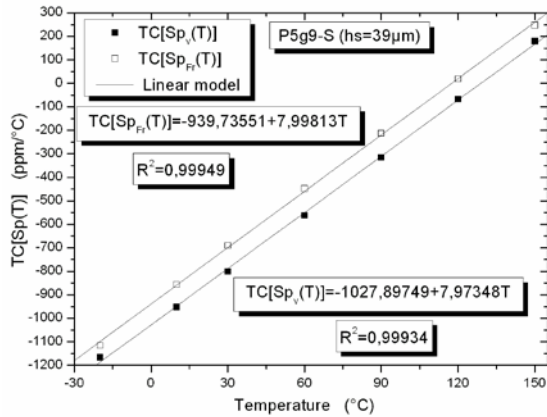


Figure 9 : Comparison between the two models of thermal coefficient of the pressure sensitivity.

Table 1 gives these two coefficients for 15 sensors with different silicon membrane thickness. We can see that the two models give similar results with an average shift lower than ± 15 % for A coefficient and ± 5 % for B coefficient.

V- Conclusion

Pressure sensitivity thermal coefficient of capacitive pressure sensors has been evaluated replacing hydrostatic pressure by electrostatic pressure. A comparison was carried out between two models using static and dynamic electrostatic pressure. The two models give similar results for temperature range between -20°C +150°C. and for silicon membrane between 28µm and 44µm.

This makes it possible to be freed from hydrostatic pressure measurements and then to realize more simple on-wafer tests.

Table 1 : Comparison of the two models for different silicon membrane thickness

Silicon thickness µm	- Av ppm/°C	A _{Fr} ppm/°C	B _v ppm/°C	B _{Fr} ppm/°C
28	2537	2581	19,1	18.8
31	1814	1803	14	13.3
35	1235	1354	10,1	10.2
37	1054	1099	8,7	8.5
37	1062	1092	8,8	8.4
39	940	1028	8	8
39	936	1021	8	7.9
39	925	1001	7,8	7.9
39	912	1014	7,7	7.8
40	838	953	7,1	7.3
40	858	976	7,3	7.6
41	774	863	6,7	6.7
43	660	744	5,8	5.8
44	609	697	5,5	5.7
44	621	716	5,6	5.8

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