A Built-in Test Solution for a SMART Silicon Micromachined Resonant Pressure Sensor

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ABSTRACT

It is the nature of sensors to take a physical parameter and convert it into the electrical domain. Sensor defects that cause drift in the output cannot be distinguished from changes in the physical parameter. The use of the Integrated Diagnostic Reconfiguration (IDR) technique has been adapted to test a resonant pressure sensor demonstrating how internal sensor redundancy initially used for mixed mode and cross sensitivity rejection can be used to address problems including drift and long term stability.

1 Introduction

Advances in monolithic systems integration is stimulating new applications for single and multi-chip smart sensors. Many of these new sensors are highly complex, have limited test access and need, as with most sensors a known measurand source for calibration and test of the unit. Built-In Self-Test (BIST) techniques within these systems has hence attracted considerable interest recently to address both production and on-line test problems. The realisation of solutions is however problematic as many smart sensors are designed for harsh environments and the built-in test solution must detect problems related to cross sensitivities, drift and long term stability. In addition, on-line solutions must in most cases rely on structural testing as a calibrated measurand source is normally absent.

2 The resonant pressure sensor

The target device, an industrial micromachined resonant pressure sensor [1], is shown in figure 1.

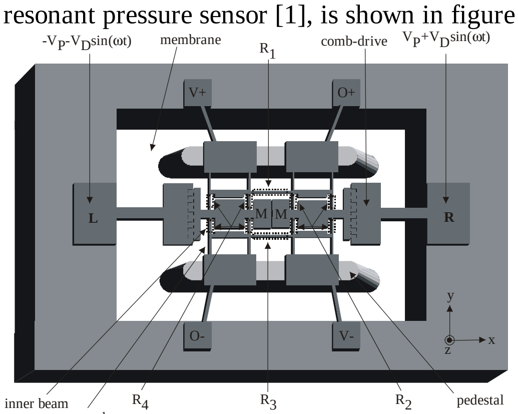

Figure 1. Pressure sensor

In the operating mode of the system, the electrostatic forces within the comb-drives cause the two movable structures to oscillate in opposite directions. The structures therefore separate and then close. Due to the stiffness of the piezoresistors connecting the two movable parts, the movement of the outer beams are negligible compared to the movement of the inner beams. The sensor is evacuated and sealed with the bottom of the substrate exposed to the external atmosphere. A change in pressure will cause the substrate to bend. The pedestals that are mounted on the substrate will therefore separate and cause a tension in the beams that form the spring. This tension causes the spring stiffness and therefore the resonant frequency of the system to change. An exaggerated drawing of the movement of the sensor is shown in figure 2.

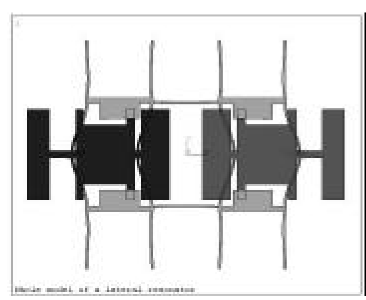

Figure 2. Movement of the pressure sensor

The piezoresistors R1 and R3 (see figure 1) change value with a frequency equal to the resonance frequency of the structure providing that one side of the resonator is moving in the inverse direction to the other. The electronics in the closed loop system maintains the amplitude of the sensor output signal at a constant level. A detailed description of the modeling and simulation of the sensor and its feedback electronics is given in [2].

3 IDR Reconfiguration Technique

The Integrated Diagnostic Reconfiguration (IDR) technique presented in [5] reduces the need for multiple redundant devices used in safety critical applications by the use of BIST and fault tolerance within a particular device. The circuit under test must have some replication in order for a comparison test to be performed. Sensors often have duplication in order to remove cross-sensitivities and unwanted modes. A circuit designed using the IDR method is composed of a number of interchangeable circuit elements. During normal operation these elements are dynamically re-arranged though the overall circuit function remains the same. When a fault occurs, one or more components cease to be equivalent to the others in the same group. When this component is interchanged with another the overall circuit function changes. The change is easily observed at the system level, thus giving early fault detection.

4 Using IDR technique as a BIST solution for a resonant sensor

The resonant sensor in figure 1 has built-in redundancy to prevent any unwanted modes of oscillation from being amplified in the feedback control. An adaptation of the IDR technique could be applied to the comb drive by firstly applying an excitation signal to one half and, during the second configuration, drive the opposite way. If one comb drive in the circuit was excited then the other half of the sensor would be coupled by the piezoresistors as a complex load.

The exact motion of the complex load does not have to be evaluated as the resulting characteristics that are extracted from the piezoresistors only have to be symmetrical to exciting one side to the other. On comparison of alternately driving the left and the right half of the circuit, the amplitude and frequency characteristics should match. Any difference in characteristics would prove that a defect on one half of the sensor was present.

5 Fault Model

A simulated break in the top right folded suspension beam would affect the resonant frequency of the device and would still provide a drifted and unstable output signal to the interfacing circuitry, see figure 3. A full FMEA has been investigated however, confidentiality prevents the referencing of results.

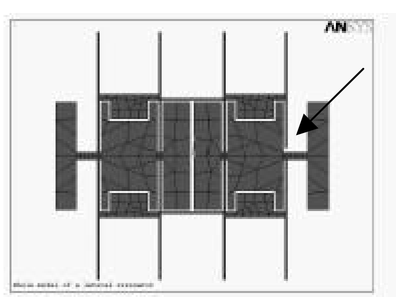

Figure 3 Fault Model of resonant Sensor

6 Simulation Results

When applying the BIST technique to a fault free model the percentage change in the piezoresistors displacements were below .5%. This means that the tolerance and fault detection level can be kept at a very low level. The results for the fault model mentioned earlier are shown below in table 1.

	Displacement nm
BIST Left Drive	
Lower Piezoresistor R3	0.1169 + 0.1037sin(ωt)
Upper Piezoresistor R1	16.27 + 15.47sin(ωt)
BIST Right Drive	
Lower Piezoresistor R3	0.1169 + 0.9125sin(ωt)
Upper Piezoresistor R1	16.27nm + 13.5sin(ωt)

Table 1 Resulting extensions of the piezoresistors

The piezoresistor values in table 1 show that in magnitude of both left and right driving modes the biasing remains the same. On comparison of the sinusoidal components the lower piezoresistor changes its value by 12% and the upper piezoresistor changes by 12.6%, which is much higher than the fault free case. The difference between the lower and upper piezoresistors is due to the rotation of the left half of the structure.

7 Conclusion

Sensor defects that cause drift in the output cannot be distinguished from changes in the physical parameter. A built-in test solution for a smart resonant pressure sensor has been shown. Problems including performance degradation, silicon overhead and implementation cost are being studied. Of great importance is the ability to model the system in the test mode. This is also currently under investigation as part of a test support methodology for microsystem devices.

References

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