PRESSURE + *X/Z* TWO-AXIS ACCELERATION COMPOSITE SENSORS MONOLITHICALLY INTEGRATED IN NON-SOI WAFER FOR UPGRADED PRODUCTION OF *TPMS* (TIRE PRESSURE MONITORING SYSTEMS)

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ABSTRACT

The paper reports a novel low-cost batch fabrication technique for monolithically integrated pressure plus two-axis (X/Z) acceleration composite sensors for upgraded production of automobile TPMS (tire-pressure monitoring systems). The newly added X-axis accelerometer is used for automatically identifying and positioning each of the four wheels. Benefited from the single-wafer front-side fabrication technique on non-SOI wafers, the sensor has the advantages of small chip-size of 1.9mm×1.9mm, low cross-talk interference, low-cost and compatible process with IC-foundries. Testing results of the TPMS sensor meet the requirements of upgraded TPMS application.

INTRODUCTION

With the market expansion of automobile electronic industry, great technical efforts have been motivated to develop pressure plus Z-axis acceleration composite sensors for TPMS production, where the Z-axis accelerometer is used to monitor the wheel rotating for wakening up the monitoring system in due time. With this energy-saving mode, one button battery can keep working for years [1]. Recently, for further improving vehicle safety, an additional X-axis accelerometer is proposed to integrate into the composite sensor for automatic identifying and positioning each of the four wheels, even if the wheel positions are mutually exchanged in the 4S shops. When the car experiences the first turning, the different behaviors of the four wheels in X-axis acceleration will be detected and recorded in the micro-processor of the system. Now the worry lies in that the users would like to enjoy the improved function but do not want to pay more for it, thereby additional cost and increase in device size having to be avoided. Monolithic integration of the three sensors in cheap non-SOI wafers is strictly required. Besides, for compatible manufacturing in standard IC-foundries, developing a single-sided process is highly demanded. It is worthy emphasizing that, dislike the integration of X- and Y-axis accelerometers where they are both in-plane laid, integration of vertical Z- and horizontal X-axis accelerometers is quite challenging.

DESIGN

Fig.1 shows the 3-D schematic of our proposed monolithic TPMS composite-sensor structure that consists of a single-cantilever-mass X-axis accelerometer, a dual-cantilever-mass Z-axis accelerometer and a pressure-sensor located inside a PS[3] structure for packaging-stress release [2]. With optimal design, the crosstalk noise among the three sensors is hopefully eliminated [3].

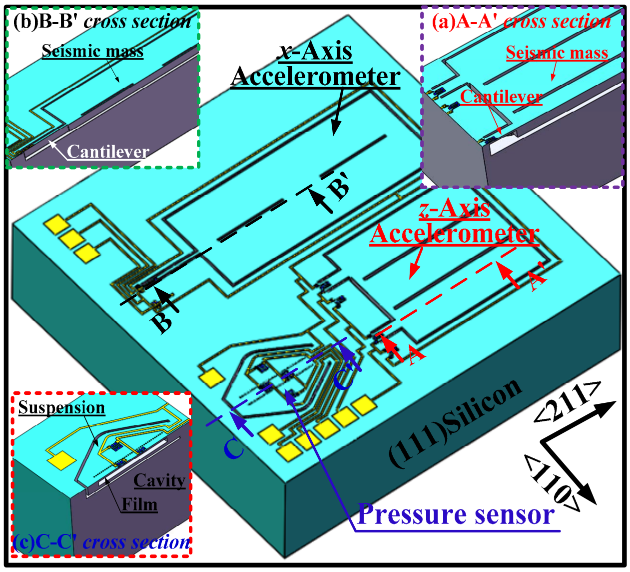


Figure 1: 3D scheme of the monolithically integrated pressure plus two-axis acceleration composite sensor, which should be fabricated from only the front-side of single (111)-wafer.

FABRICATION

Fig.2 shows the proposed TPMS composite sensor single-sided process in single (111)-wafer. With neither double-side micromachining nor expensive cavity-SOI process needed, the steps of (a)-(b) are implemented to fabricate all the piezoresistors, the pressure sensitive diaphragm and the vacuum cavity [4]. The following steps are for constructing the X- and Z-axis accelerometers.

(c): Deep-RIE trench-etching is used to define the shape of the dual-cantilever. Thereafter TEOS is deposited to coat the trench surfaces, and the TEOS at the trench-bottom is removed while the TEOS at the sidewalls is remained. Deep-RIE is used again to deepen the trench for subsequent lateral wet-etch.

(d): 25% TMAH etchant is used to laterally under-etch through the bottom area along <110> orientation to form the dual-cantilever.

(e): Even deeper trench etching is employed to define the thickness of the spring and mass of the X-axis accelerometer, as well as, the mass moving gap of the two accelerometers.

(f): The properties of anisotropic-etching in (111) silicon wafer[5] are used again to laterally under-etch to release the spring of the X-axis accelerometer and the masses of the two accelerometers.

(g): Electric contact holes are opened, and Al thin-film is sputtered, patterned, and sintered for piezoresistor interconnection. Finally, Deep-RIE is used to fully release the two accelerometers from the front-side of the silicon wafer.

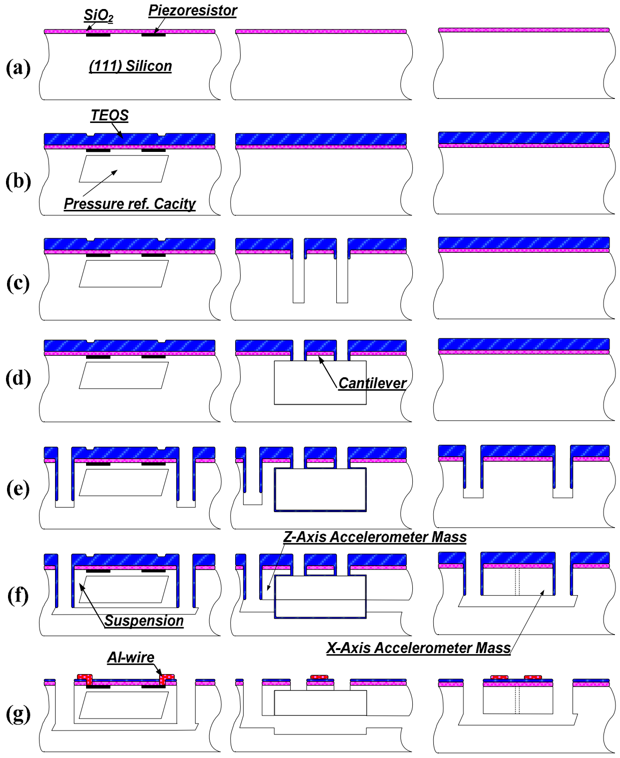
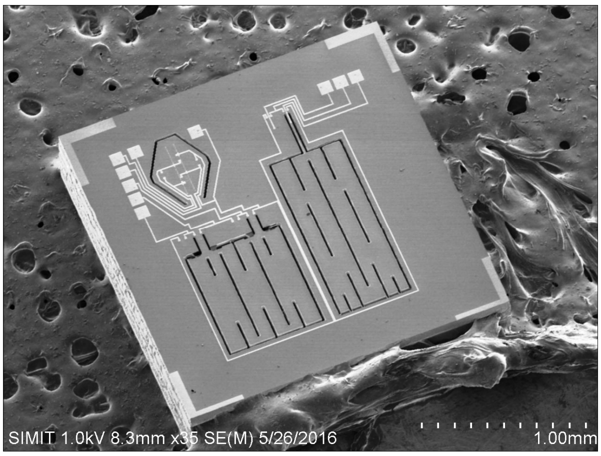
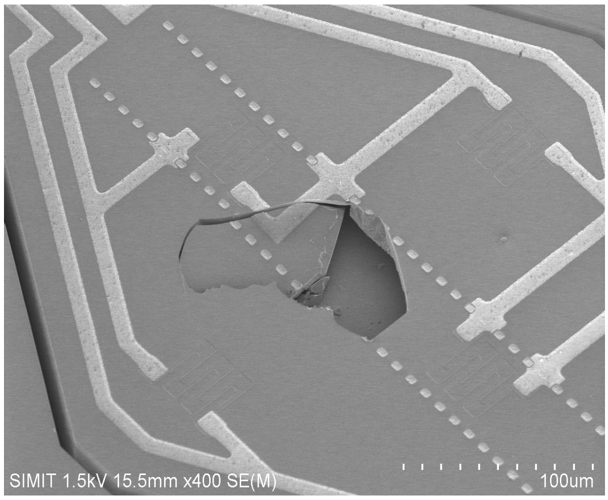


Figure 2: Single-side process steps in single (111) non-SOI wafer for on-chip integrating the three sensing units.

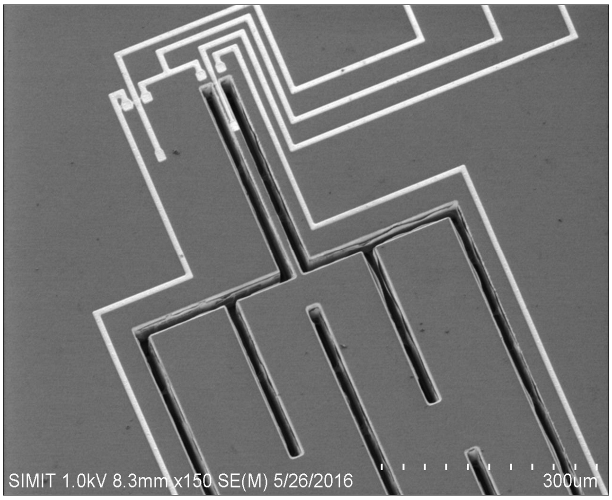
Fig.3(a) shows the fabricated TPMS composite sensor. In spite of the newly added X-axis accelerometer, the whole sensor chip dimensions are only 1.9mm×1.9mm. Surrounded with the PS^3 structure, the close-up viewed pressure-sensor in Fig.3(b) shows the sensing-diaphragm and vacuum-cavity at beneath. Figs.3(c)-(d) show the X-axis accelerometer and the backside microscope image of the Z-axis accelerometer mass as well as its dual-cantilever, respectively.



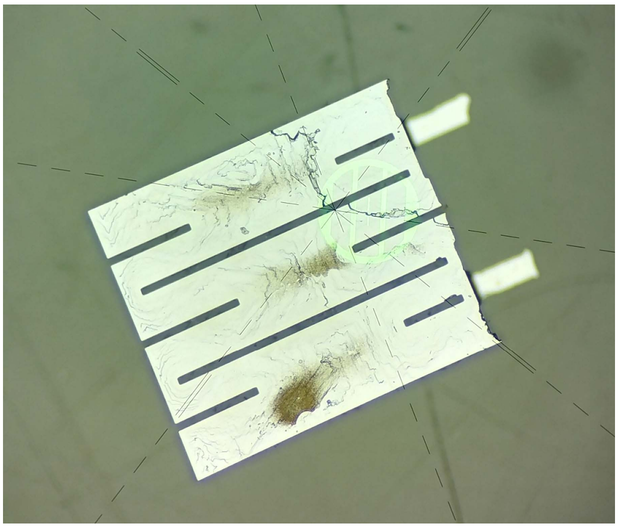
(a)



(b)



(c)



(d)

Figure 3: (a) SEM image of the monolithic TPMS composite sensor. (b) Close-up view of the pressure sensor surrounded with the PS^3 structure. (c) Close-up view of the X-axis accelerometer. (d) Backside microscope image showing the mass of the Z-axis accelerometer that is penetrated from the front-side structure.

TESTING RESULT

Supplied with DC-3.3V, the Z-axis accelerometer testing results in Fig.4 shows linear output within 120g, with sensitivity as 0.136mV/g. The Z-axis acceleration induced pressure-sensor cross-sensitivity is only 0.5μV/g.

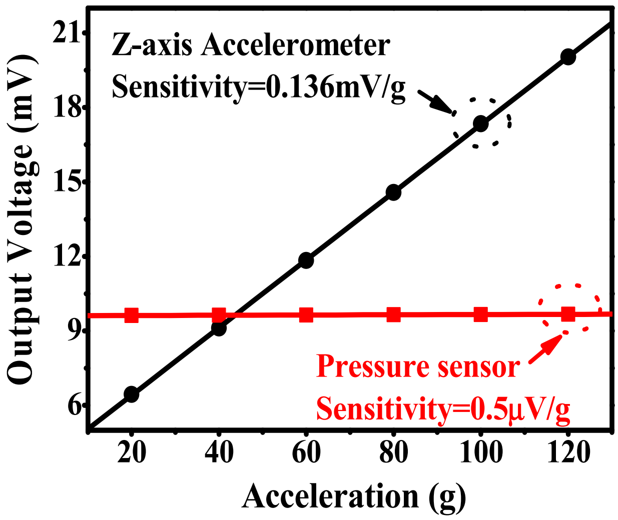


Figure 4: Z-axis accelerometer linear output and the depressed pressure-sensor output induced by the Z-axis acceleration

The pressure-sensor testing results in Fig.5 shows linear output within 700kPa, with sensitivity as 0.102mV/kPa. By simultaneously recording the output of the Z-axis accelerometer. The input-pressure induced Z-axis accelerometer crosstalk output is tested as low as 0.120μV/kPa and negligible.

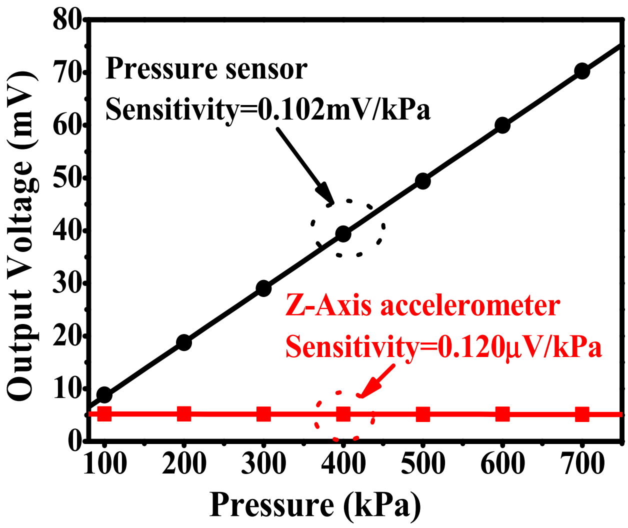


Figure 5: Pressure-sensor linear output and the pressure-induced negligible crosstalk in the Z-axis accelerometer.

Fig.6 shows the X-axis accelerometer linear output within 120g, with sensitivity as 0.132mV/g. The X-axis input-acceleration induced Z-axis accelerometer cross-sensitivity is merely 0.846μV/g. Testing results show that the developed TPMS composite sensors have high performance and meet the requirements of upgraded TPMS application.

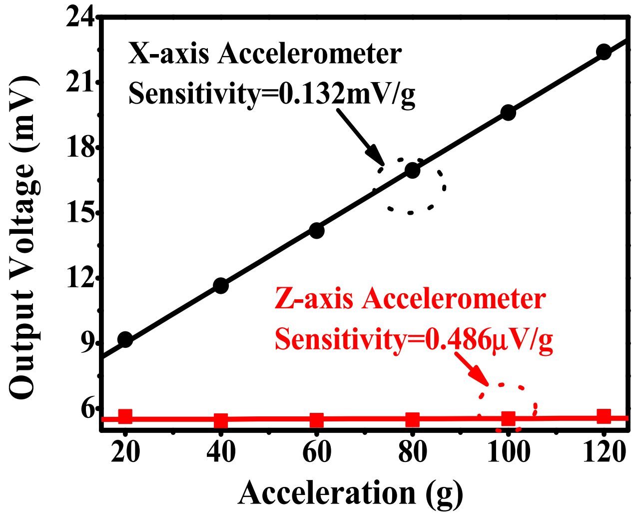


Figure 6: X-axis accelerometer linear output and the eliminated cross-sensitivity of the Z-axis accelerometer, which is caused by the x-axis acceleration.

CONCLUSIONS

In this paper, a novel monolithic integration of pressure plus two axis (X/Z) acceleration composite sensor has been proposed, designed, fabricated and characterized. Benefited from the single-wafer front-side fabrication technique on non-SOI wafers and optimum design, the composite sensor has the advantages of small sensor chip dimension of 1.9mm×1.9mm, low-cost, compatible process with IC-foundries and low cross-talk interference. Finally, testing results verified that the fabricated TPMS composite sensor has high performance and meet the requirements of upgraded TPMS application.

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