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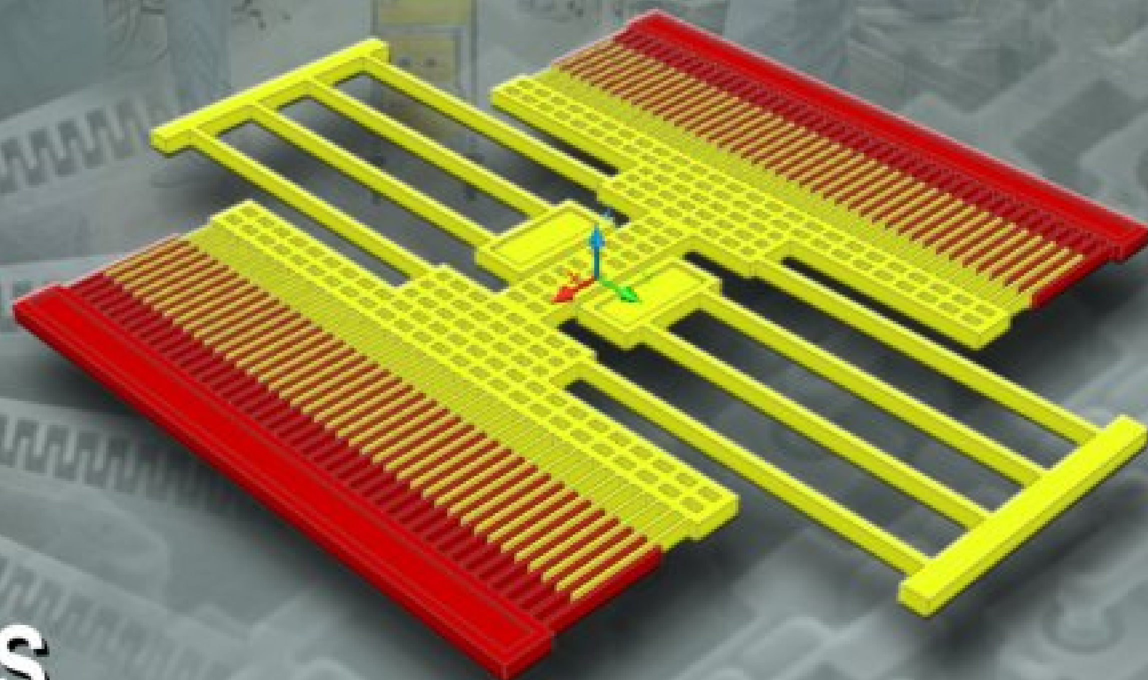

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Design of a Capacitive SOI Micromachined Accelerometer

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Abstract: A capacitive micromachined accelerometer based on the technique of silicon on insulator, is designed in this paper. The proposed microaccelerometer is designed to obtain good electrical performance and radioresistance in order to make the accelerometer integrate with the CMOS chip. The performance of the capacitive SOI microaccelerometer is calculated to determine its linear capacitance change and achieves a very linear response with input acceleration after theoretical analysis. The relationship between acceleration and output voltage is discussed. The mechanical performance of the capacitive microaccelerometer was simulated to obtain optimum design parameters and structural characteristics by the finite element method. The results show that capacitance sensitivity, range, resolution characteristic indexes and so on respectively through the simulation and theoretical analysis. Finally the fabrication process for the SOI technique suitable for batch fabrication is proposed. *Copyright © 2009 IFSA.*

Keywords: MEMS, Capacitive accelerometer, SOI, FEM

1. Introduction

Sensors and devices, based on micromachining technology, known as micro-electro-mechanical systems or MEMS, have been received increasing attention by K. E. Petersen, M. J. Madou, S. J. Sherman and so on in recent years [1~3]. MEMS inertial devices have the advantages of miniaturization, integration, intellectualization, low power, low cost, high reliability and batch production. Micromachined inertial sensors, consisting of accelerometers and gyroscopes, are one of the most important types of silicon-based sensor. It is an important and earliest commercialized micro-electro-

mechanical system. In the 1970s, the inertial measurement unit has been largely applied in navigation, guidance and stabilization for military aircrafts and ground vehicle. At the end of the Second World War, German firstly developed the integral gyro and applied in the first V-2 flying bomb in the world successfully, which was an important milestone in the history of inertial technology. At the 1980s, the rapid development of MEMS technology resulted in the appearance of micromachined inertial sensors, which was the other milestone.

Microaccelerometers alone have the second largest sales volume after pressure sensors [4]. Micro-silicon accelerometer was researched at the end of the 1960s. In 1977, the microaccelerometer on silicon using the micromachined processing was successful fabricated. The accelerometer of ADXL50 could meet the demand of performance for central gas bag of automobile, and fabrication was in 1993, whose range was ±50g. A single cantilever beam microaccelerometer was fabricated in Japan, whose range was ±11g. The demand for accelerometers is due to their automotive applications, where they are used to activate safety systems, including air bags, to control the activation of the safety airbags, S.J. Sherman, K.H.-L. Chau said [3, 5, 6] and implement vehicle stability systems and electronic suspension. Nevertheless, the application of Micromachined accelerometers covers a much broader spectrum where their small size and low cost have a larger impact. Yoshinori Matsumoto, Moritaka Iwakiri, Hidekazu Tanaka and so on could integrate with on-chip circuitry and have advantages over concerning size and productivity with a batch-fabrication process utilizing IC processes [7].

A wide range of acceleration sensors with different sensing mechanisms have been fabricated. Among them, various type of silicon microaccelerometers with both capacitive and piezoresistive principles have been developed by F. Rudolf, Y. Matsumoto, W. Yun, V.M. Mcneil and so on in recent years [8-12]. The capacitive accelerometers have higher sensitivity and lower temperature coefficients. Moreover, it's possible that self-testing and force-balancing techniques are realized by utilizing the electrostatic force. Capacitive MEMS accelerometers have been implemented using a variety of surface by L. J. Ristic, B. E. Boser, L. Hao and so on [13-15] and bulk micromachining by I. Y. Park, N. Yazdi and so on [16, 17] technologies. One type of capacitive microaccelerometer, based on bulk-micromachining technology, F. Rudolf, Y. Matsumoto used [8, 9], needs a specialized micromachining technique, such as anodic bongding and anisotropic deep etching, etc. The fabrication process required a number of steps combining surface and bulk micromachining, which makes the manufacturing process CMOS incompatible because of the high temperature steps, is often rather complex, which can cause low yield and high cost sometimes. And the effect of substrate among the apparatus is increasingly serious for the smaller size of apparatus. Another type is based on surface-micromaching technology, W. Yun used [10, 11], which carries out MEMS structures in a layer of appropriate material laid down at the top of a carrying substrate. Thus, in surface micromachined devices, the proof mass is small, causing high noise and limitations on the performance of accelerometers. Typically, the resolution of the commercial surface-micromachined accelerometers, A. Beliveau, G. T. Spencer, K. A. Thomas, and S. L. Roberson studied, is in the milligravity range [18].

Lately, thick silicon-on-insulator (SOI) substrates with small structure stress and good consistency have received a lot of attention for various MEMS applications. The SOI inertial devices could reach the high-resolution, low noises and less difficulty of processing for circuit, so as to integrate CMOS with MEMS inertial sensors based on the SOI technology recently. It reduces leakage for devices in high temperature through the SOI dielectric isolation instead of PN isolation and improves reliability [19, 20]. The 4th inertial measurement unit of ADI using SOI-MEMS processing first realized the monolithic integration between SOI-MEMS inertial devices and CMOS circuits, whose size was only 1.5 mm × 1.5 mm. Recently, high-resolution capacitive accelerometers have been developed on 40 um-thick SOI wafers, whose fabrication process is CMOS compatible and the release steps of the accelerometers are completely dry, B. V. Amini, S. Pourkamali, and F. Ayazi studied [21]. High sensitivity and low mechanical noise floor per unit area, which are important requirements to achieve μg resolution, are provided in this implementation through a thick solid proof mass with no perforation. In

this study, we describe a comb-finger accelerometer which is fabricated by using silicon direct bonding- silicon on insulator (SOI) material for CMOS production. It is adopted for the capacitive microaccelerometers in order to solve the above-mentioned problems. The technique of SOI can receive the symmetrical structure, exact thickness of film and precise coefficient of elasticity, and reduce leakage currents and parasitic capacitances. Then we described the structure of designed capacitive microaccelerometers, built the model through the ANSYS software, and the performance of microaccelerometers was calculated by the simulation and theoretical analysis.

2. Operating Principles of Capacitive Microaccelerometer

SOI (Silicon-on- insulator) is the Si on the insulating layer, whose structure contains the insulating substrate and top single crystal silicon. Also, it can take the insulating layer as the middle layer called buried layer, which was SiO_2 traditionally, in order to get the structure of three layer. The structure of accelerometer was mainly exhibited in the top single crystal silicon.

The mechanical part for accelerometer is equivalent to a second order mass-spring-damper system. The main component of the accelerometer is a spring-supported mass, usually linked with the dampers, which provide the necessary damping effect. Springs and dampers were connected to a shell. The mass will produce displacement x(t) when there is acceleration role. For inertial accelerometer, a mechanical sense element converts the initial acceleration into force, and force will be shifted into a displacement, and into a capacitor that is then detected and converted into an electrical signal. The inertia of the proof mass restrains the motion of this element in the presence of external force acting on a reference frame to which the proof mass is attached by means of a spring. The proof mass is further subject to damping from the surrounding gas ambient or from internal dissipation in the spring.

In the presence of external acceleration, the support frame of an accelerometer moves from its rest position, thus changing the capacitance between the proof mass and a fixed conductive electrode separated from it with a narrow gap. This capacitance can be measured using electronic circuitry. Some of the most widely used structures for capacitive microaccelerometers are vertical and lateral structures, the lateral comb-finger structure was shown in Fig. 1.

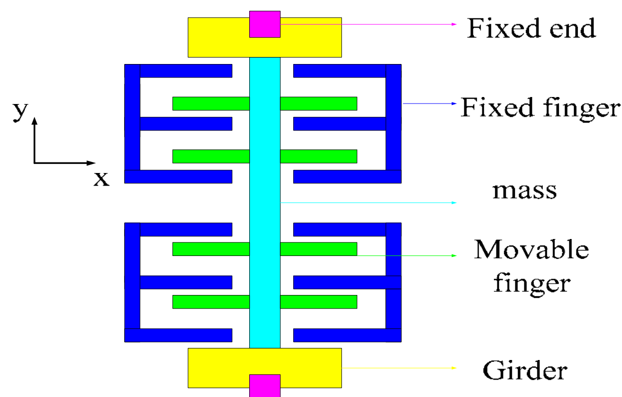

Fig. 1. Schematic diagram for structure principle.

A lateral comb-finger microaccelerometer was mainly made up of central movable fingers and several fixed fingers. A number of movable fingers are attached to the proof mass, each finger corresponding to a fixed electrode plate. Fixed electrode plates are fixed on the flat-panel of mass. The sense capacitance is formed between the movable and the fixed fingers parallel to them. Among them, and

the activities of electrode electrodes fixed constitute a differential capacitance detection. Sense organ is bilateral comb, and the sense direction in lateral comb-finger microaccelerometers is in the proof-mass plane (x-y directions). On the condition of no acceleration inputting, the testing mass is in a state of balance, capacitance C1 is equal to C2, and the voltage of output is zero. When acceleration is effecting, the movable fingers have a displacement by the action of inertial force. At the moment, the space between movable fingers and fixed plate is changed, that is, C1≠C2. The transient output signal is proportional to the size of acceleration, and the direction of movement will be reflected through the output signal.

3. Device Structure

Capacitive accelerometers using SOI wafers are highly reliable devices because they use single crystal silicon (SCS) as structural material [22]. Lateral accelerometers have been developed using comb electrodes and differentially detecting parallel electrodes to obtain linear output. The micro-structure includes a seismic mass linked to a frame by two or four flexible beams, which can move in a plane parallel to the substrate plane. The movable mass has a set of comb electrodes on each side in front of a set of fixed electrodes. The displacement of the mass, due to the acceleration, induces a capacitance variation between the two set of electrodes [23].

The structure of the biased comb-finger capacitive microaccelerometer is shown in Fig. 2. It is constructed with three layers. The bottom layer (yellow layer) is the silicon substrate which forms one side plate for the microaccelerometer capacitance. The middle layer (red layer) is silicon dioxide, the thickness of which determines the gap of the micrpaccelerometer capacitance. The thickness is precisely controlled by the silicon oxidation process.

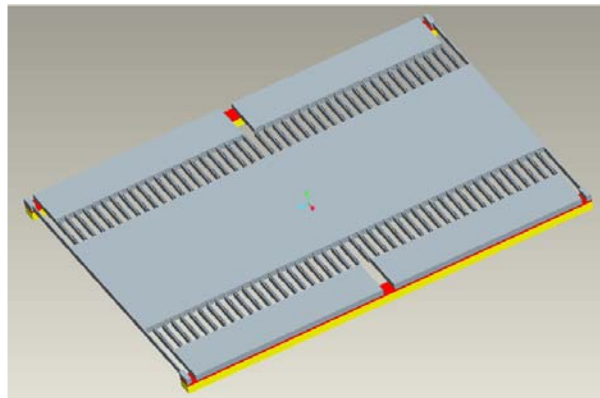

Fig. 2. Schematic diagram for the structure of biased comb-finger microaccelerometer.

This structure includes a mass, sense organ consisted of multi-group movable fingers and girders, fixed fingers and substrate. The movable fingers form a bilateral comb-finger structure with movable fingers stretching to both sides. The girders are fixed on the substrate so that the mass and movable fingers relative with the substrate are made parallel. Each of movable fingers of sense organ, interlaced with every fixed finger, is a movable electrode for variable capacitor in order to get differential capacitance. The characteristics lies in the fact that the fixed finger is the structure of multi-group unilateral comb-finger directly fixed on the substrate. The ratio of distance between every movable finger of sensor organ and adjacent fixed fingers is 1:10. Meantime, the structure of sensor organ is symmetrical by the mid-point of pivot, and the sensitive direction is z axis. The specific structure parameters of microaccelerometer are shown in Table 1.

Table 1. Structure parameters for comb-finger microaccelerometer.

Serial number	Name	Value	Serial number	Name	Value
1	Length of mass L	2530	7	Width of girder w_b	8
2	Width of mass B	1000	8	Plate distance 1 d_{f1}	4
3	Length of superposition l_{fr}	250	9	Plate distance 2 d_{f2}	40
4	Length of comb finger l_f	270	10	Ratio of plate distance η	10
5	Width of comb finger w_f	6	11	Thickness of accelerometer h	30
6	Length of girder l_b	500	12	Number of comb fingers n	88

When there is no acceleration, the mass is in equilibrium state, where the output voltage is zero. The mass will move a small displacement through the acceleration a, and the capacitance will be changed. This change is expressed as feedback voltage V_f through the process of magnification. In closed loop, V_f is in direct proportion to the acceleration a. Therefore, we can test the acceleration for accelerometer by the V_f applied to the capacitor plates.

On the condition of no acceleration inputting, static capacitance C_{01} and C_{02} are [24]:

$$C_{01} = C_{a1} = C_{b1} = n\frac{\varepsilon h l_{fr}}{d_{f1}} \tag{1}$$

$$C_{02} = C_{a2} = C_{b2} = n\frac{\varepsilon h l_{fr}}{d_{f2}}, \tag{2}$$

where Wm and h are the width and thickness of mass respectively, and w_b, l_b, w_f and l_f are the width and length of girder and fingers, respectively. The size of superposition between the movable and fixed fingers is expressed as l_{fr}. The distance between movable finger and fixed is shown as d_{f1} and d_{f2} $(d_{f1} < d_{f2})$. The number of movable fingers is expressed as n. ε is the dielectric constant.

When acceleration is acted, the mass has a displacement Δd, capacitance between fixed electrodes and movable fingers will be changed as C_{a1}, C_{a2}, C_{b1} and C_{b2}, which are corresponding to the distance d_{f1} and d_{f2} respectively.

$$C_{a1} = n\frac{\varepsilon h l_{fr}}{d_{f1} - \Delta d} \tag{3}$$

$$C_{b1} = n\frac{\varepsilon h l_{fr}}{d_{f1} + \Delta d} \tag{4}$$

$$C_{a2} = n\frac{\varepsilon h l_{fr}}{d_{f2} + \Delta d} \tag{5}$$

$$C_{b2} = n\frac{\varepsilon h l_{fr}}{d_{f2} - \Delta d} \tag{6}$$

By series expansion and ignoring the higher order items, the formula can be expressed as:

$$\Delta C_1 = C_{a1} - C_{b1} \approx 2C_{01}\left[\frac{\Delta d}{d_{f1}} + (\frac{\Delta d}{d_{f1}})^3\right]$$

$$\Delta C_2 = C_{a2} - C_{b2} \approx -2C_{01}\left[\frac{\Delta d}{d_{f2}} + (\frac{\Delta d}{d_{f2}})^3\right]$$

$$\begin{aligned}\Delta C &= \Delta C_1 + \Delta C_2 = C_{a1} - C_{b1} + C_{a2} - C_{b2} \\ &= 2\Delta d\left[C_{01}(\frac{1}{d_{f1}} + \frac{\Delta d^2}{d_{f1}^3}) - C_{02}(\frac{1}{d_{f2}} + \frac{\Delta d^2}{d_{f2}^3})\right]\end{aligned} \tag{7}$$

If the higher order items were ignored, the ΔC can be expressed as:

$$\begin{aligned}\Delta C &= \Delta C_1 + \Delta C_2 = 2C_{01}\left[\frac{\Delta d}{d_{f1}}\right] - 2C_{01}\left[\frac{\Delta d}{d_{f2}}\right] \\ &= 2\Delta d\left[C_{01}(\frac{1}{d_{f1}}) - C_{02}(\frac{1}{d_{f2}})\right]\end{aligned} \tag{8}$$

Thus, we can know the relationship between the ΔC and the Δd was linear. h is the thickness of mass, and w_b, l_b, w_f and l_f are the width and length of girder and fingers, respectively. The length of superposition between the movable and fixed fingers is expressed as lfr. The distance between movable finger and fixed is shown as d_{f1} and d_{f2} $(d_{f1} < d_{f2})$. Number of movable fingers are expressed as *n*. ε is the dielectric constant.

In a open-loop, the mass m is moved in differential capacitance ΔC as in Eq.(9) below by an applied acceleration a and displacement Δd, that is, the Eq.(9) will be got through bringing equation $ma = K\Delta d$ into Eq.(7) and ignoring the higher order items.

$$\frac{\Delta C}{a} = \frac{2m}{K}(\frac{C_{01}}{d_{f1}} - \frac{C_{02}}{d_{f2}}), \tag{9}$$

where the $K = \frac{24EJ}{l_b^3}$ [25] ($J = \frac{1}{12} h w_b^3$, E is the elastic modulus of silicon), which is the stiffness of girder, m is the mass for accelerometer.

On the assumption that the equation $d_{f2} = \eta d_{f1}$ (η>1, η=10 in this paper), the Eq.(9) is expressed as:

$$\frac{\Delta C}{a} = \frac{2mC_{01}}{Kd_a}(1 - \frac{1}{\eta^2} + \frac{\Delta d^2}{d_{f1}^2} - \frac{1}{\eta^4}\frac{\Delta d^2}{d_{f1}^2}) \tag{10}$$

Because of the small Δd and the minimal change of capacitance $\Delta C_{\min}$, the resolution can be shown as:

$$a_{\min} = \frac{Kd_{f1}\eta^2}{2mC_{01}(\eta^2 - 1)} \Delta C_{\min} \tag{11}$$

According to the Equ.8 and Eq. (11), we can know the relationship between the ΔC and the Δd was linear and the ΔC was proportional to the acceleration a. The relationship among the a, Δd and ΔC was linear.

The natural frequency of accelerometer is expressed as $f = \frac{1}{2\pi}\sqrt{\frac{K}{m}}$.

In closed loop, the force of parallel plates is shown as:

$$F = \frac{\varepsilon A V_{DC}^2}{2d^2}, \tag{12}$$

where A is the area of parallel plate, d is the distance between the parallel plates, ε is the dielectric constant, V_{DC} is the dc bias of electrode. Thus, we can get F_{a1}, F_{b1}, F_{a2}, F_{b2} four force of feedback about mass.

$$F_{a1} = \frac{n\varepsilon h l_{fr}(V_{DC} - V_f)^2}{2(d_{f1} - \Delta d)^2} \tag{13}$$

$$F_{b1} = \frac{n\varepsilon h l_{fr}(V_{DC} + V_f)^2}{2(d_{f1} + \Delta d)^2} \tag{14}$$

$$F_{a2} = \frac{n\varepsilon h l_{fr}(V_{DC} - V_f)^2}{2(d_{f2} + \Delta d)^2} \tag{15}$$

$$F_{b2} = \frac{n\varepsilon h l_{fr}(V_{DC} + V_f)^2}{2(d_{f2} - \Delta d)^2} \tag{16}$$

The total force of feedback about mass is shown as:

$$F_{fb} = -(F_{a1} - F_{b1} - F_{a2} + F_{b2})$$
$$\approx \frac{2C_{01}}{d_{f1}} V_{DC} V_f - \frac{2C_{02}}{d_{f2}} V_{DC} V_f - 2(\frac{C_{01}}{d_{f1}^2} + \frac{C_{02}}{d_{f2}^2})(V_{DC}^2 + V_f^2)\Delta d \tag{17}$$

In closed loop, the mass has force $F_{fb} = ma$, we can get Eq.(18) by ignoring the Δd .

$$a = \frac{F_{jb}}{m} = \frac{2C_0(\eta^2 - 1)}{md_{f1}\eta^2} V_{DC} V_f \tag{18}$$

When maximum feedback voltage is acting, the acceleration a is maximum that is the range of microaccelerometer.

$$a_{\max} = \frac{2C_0(\eta^2 - 1)}{md_{f1}\eta^2} V_{DC} V_{f-\max} \tag{19}$$

According the Eq.(18), the output voltage V_o can be expressed as:

$$V_o = V_f = \frac{md_{f1}\eta^2}{2C_0(\eta^2 - 1)V_{DC}} a \tag{20}$$

So the sensitivity S is shown as:

$$S = \frac{V_o}{a} = \frac{md_{f1}\eta^2}{2C_0(\eta^2 - 1)V_{DC}} \tag{21}$$

4. Simulation and Results

The microaccelerometer with girders was simulated by the ANSYS finite element analysis (FEA) method, and its properties were calculated. The mass displacement was calculated using an analytical model, in which the mass was assumed rigid and the four girders were deflected by the acceleration force at the center of the mass. The mechanical performance of structure for comb-finger capacitive microaccelerometer was simulated to obtain optimum parameters by the FEA method. The estimated parameters used in the simulations for the structure materials are given in Table 1. We use single crystal silicon as the material of microaccelerometer in the simulation.

According the known, MEMS capacitive accelerometer was a mass-spring system, the vibration was occurred on the condition of acceleration. So the significant limitation of accelerometer sensor was the narrow range for frequency response, whose main factors was the resonant frequency.

The vibration mode was evaluated using FEM method. The data results for the first 10 modes are shown in Table 2. The first model is lateral vibration, which is preferable for stable device operation. The second and third modes are torsional vibration. The frequencies of ninth and tenth modes are more than 10 times the frequencies of the original mode, which results in high stiffness of the sensing structure along the horizontal axis and can provide good cross-axis sensitivity of the device.

Table 2. The modal frequency of microaccelerometer.

Vibration mode	Modal frequency (Hz)	Vibration mode	Modal frequency (Hz)
1	2928.4	6	60324
2	8579.5	7	97575
3	16726	8	98741
4	22436	9	98871
5	40073	10	98902

As shown above, we got the frequency of the first mode for capacitive microaccelerometer was 2928 Hz, that is, the resonant frequency was 2928 Hz, which was separated from the natural frequency of interferential mode. The result of theoretical analysis was about 2.6 kHz, and the error was about 10% compared with the data of simulation, which was in the range of error for engineering.

The maximal stress of harassable axis was evaluated using static analysis of FEM method. The result for the von Mises stress distributing for 100 g and the data results of static analysis were shown in Fig. 3. The maximal stress of comb-finger microaccelerometer was on the harassable axis, whose size of structure decided the bearable capacity. When the acceleration was 137 g, the maximum stress of structure was 39.803312 MPa, which was in the range of allowable stress for the single crystal silicon, and the maximal displacement for z direction was 3.973959 µm, which was less than the 4 um.

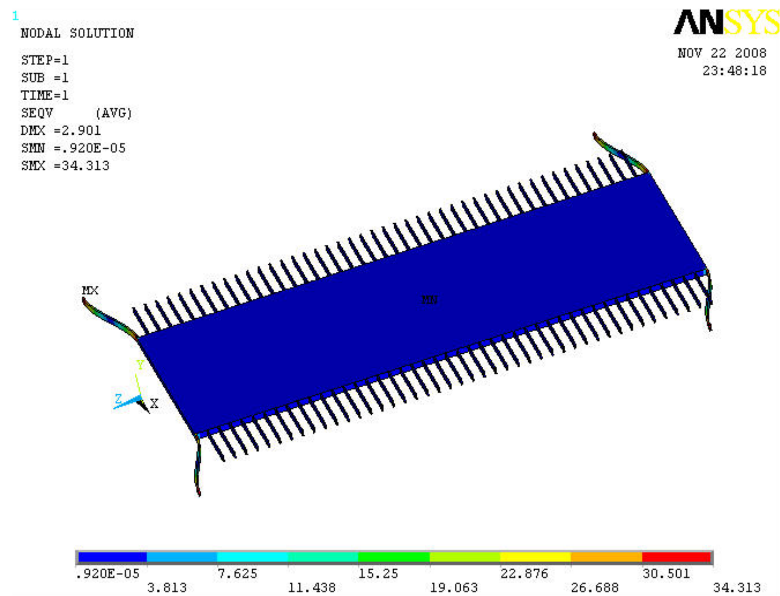

Fig. 3. The von Mises stress nephogram for 100 g.

Meantime, the microaccelerometer was linear through simulation, that is, the relationship between the acceleration a and displacement Δd of mass, which was shown in Fig. 4. The change in acceleration is proportional to the mass displacement of z direction for testing axis. This result was consistent with the conclusion of theoretical analysis, which was shown in Fig. 5. The error was in the range of permission norm for engineering.

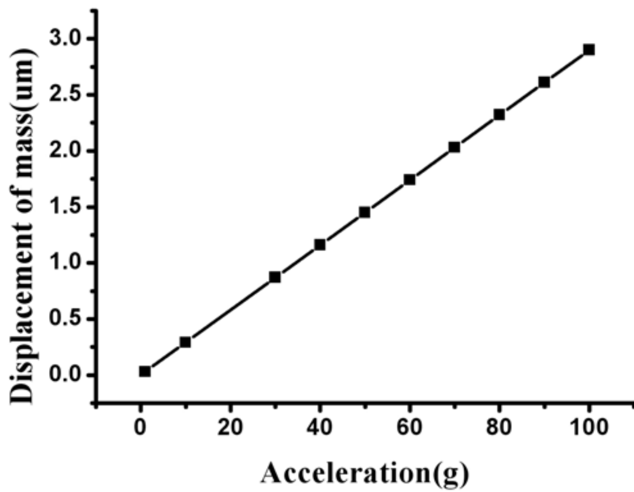

Fig. 4. Linear relationship for accelerometer through simulation.

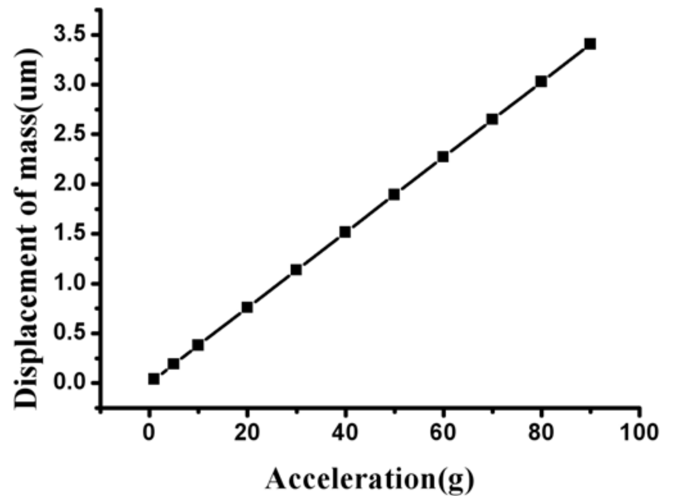

Fig. 5. Linear relationship for accelerometer through theory.

Thus, we can get the minimum resolution of the capacitive microaccelerotion was about 48 mg and the maximum scale value was about 4.9 g through the simulation and theoretical analysis. Meantime, the sensitivity of microaccelerometer was about 1.02 V, and the maximum value of shock resistance was 137 g for the microacceleromete, the displacement of z direction for testing axis for accelerometer was 3.973959 µm.

The voltage applied to the electrodes was 5 V. The output voltage was calculated by applying acceleration using a shaker able. The output voltage of the capacitive accelerometer proportional to the input acceleration is shown in Fig. 6. The data results of the output voltage are shown in Table 3.

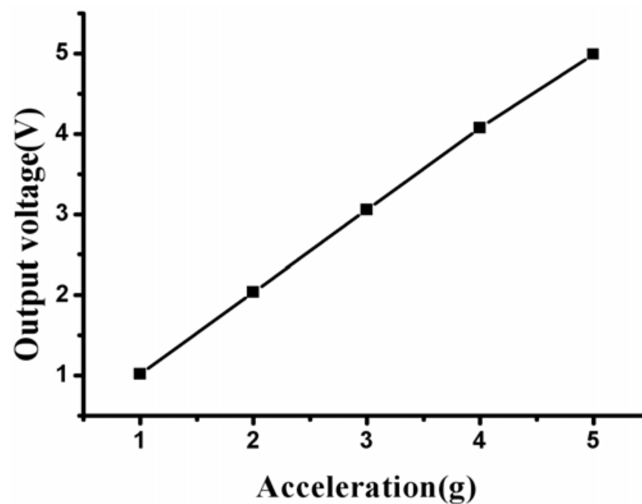

Fig. 6. The relationship between the output voltage and the acceleration

Thus, we can obtain that the relationship between the acceleration and the output voltage was linear in measurement range from the Fig. 6. We can get the linear equation fitted by the data in the two-dimensional plane, which was shown:

$$y = -4.87\times10^{-7} + 0.982x - 6.85\times10^{-7}x^2 + 1.92\times10^{-7}x^3 - 1.88\times10^{-8}x^4 \quad (22)$$

In this equation, the constant coefficient of the remaining portion except for linear term was very small, can be ignored. This showed that the curve of this equation can be regarded as the straight. This conclusion was consistent with the results in Fig. 6.

Table 3. The data results of the output voltage.

Acceleration (g)	1	2	3	4	4.9	6	10
Output voltage (V)	1.01874	2.03748	3.05622	4.07496	4.99183	6.11244	10.1874

5. Fabrication Process for SOI Devices

The process step of SOI devices was less than the traditional silicon-glass structure for MEMS inertial devices, so the process of SOI devices was concise. It mainly includes the ICP etching for back anchor, RIE etching and structure release of ICP. The ICP dry etching was the important process. Because of the different size and structure, the ICP would get the effect of undercut and notching. The undercut effect was formed in the initial stage for etching. When the lateral wall was etched by the SF_6 gas, it was easy to get the lateral etching. Finally, it formed the undercut effect. Thus, we design the process of absorption between the metal ions and the film, which was adding the sputtering in the formal flow. It overcome the effect of notching and got the good smoothness, in order to improve the quality of etching. The method obtained the good effect in the process of micro inertial devices based on silicon-glass. We adopted the process of suspension for silicon film in this paper.

When the structure of suspension for silicon film was fabricated, we adopted the SiO_2 film by thermal oxidation rather than the process of SiO_2 as barrier layer. The thermal stress and residual stress of SiO_2 was large when film was above 1μm. SiO_2 may be ruptured by stress deformation so that the process of ICP was interrupted when the plasma of gas for ICP etching was reached SiO_2. So the SiO_2 was not suitable for the adsorption layer of plasma. We use the process of absorption between the metal ions and the film.

The specific process was designed as follow: 1).Growing a thermal oxide SiO_2 layer on a main substrate (500 μm) and a SiO_2 layer on a handle substrate; 2).Bonding a handle substrate to a main substrate; 3).Oxidation of the SOI wafer to create a masking layer; 4).ICP etching the bulk silicon of mass using the photoresist as the masking layer; 5).RIE etching the SiO_2 and sputtering a metal film; 6).Lithography on silicon film, and obtaining the structure of mass by ICP; 7).Corrosion of metal film to release the structure. The deposition of an appropriate metal layer will be necessary as a final step to assure good contact surface.

The thickness of silicon film could be increased by this processing. Since accelerometers are released form the backside, no perforation in the proof mass is needed. It is the substrate-free under the mass, resulting in eliminating the parasitic, improving the sensitivity and resolution for micro inertia sensor, a higher mass per unit area and better mechanical noise specification compared to the perforated structures with same lateral dimensions that are fabricated without backside etching. The fabrication process chart of SOI devices based on substrate-free was shown in Fig. 7.

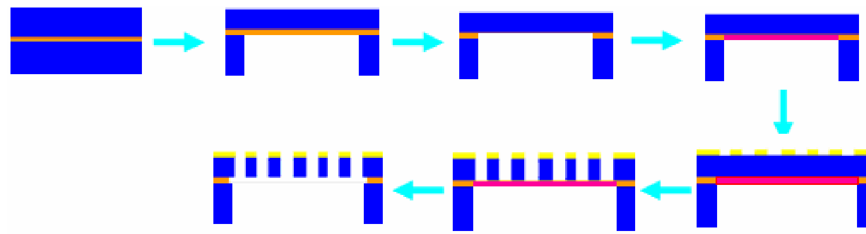

Fig. 7. The process chart of SOI based on substrate-free.

Finally, It is the process of dicing, lead wire and encapsulation. Thus, it completed the fabrication for total microaccelerometer. MEMS devices include the complex structure, such as multilayer structure, movable structure and so on, whose structure layer generally obtained by bonding the anchor with the substrate. Thus, the area of bonding was limited, which bring the difficulty for the process of dicing, lead wire and encapsulation. This is also a critical process. The metallization of the microaccelerometer bonding pads is performed simultaneously during CMOS metallization and hence no extra mask is needed for this step.

6. Conclusions

In this paper, capacitive micromachined accelerometers using the silicon on insulator structure have been described. The performance of the microaccelerometer was calculated to achieve a very linear response with input acceleration after theoretical analysis. The structure of capacitive microaccelerometer was verified correctness by the FEM simulation. The output voltage varies nearly linearly with acceleration as a result of elaborate design. The output characteristics of microaccelerometer showed that capacitance sensitivity and its resolution are 1.02 V and 28 mg respectively. The displacement of mass for z-direction is 0.029007 um on the condition of 1g acceleration. And the maximum value of shock resistance was 137 g for the microacceleromete, the displacement of z direction for testing axis for accelerometer was 3.973959 um. In addition, the SOI structure has the possibility of being integrated with circuitry, so it is considered as an attractive material for micromachined sensors. The specific process of microaccelerometer based on the SOI is presented finally in this paper.

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References

[1]. K. E. Petersen. Silicon as a mechanical material. *Proceedings IEEE,* 70, 1982, pp. 420-457.
[2]. M. J. Madou. Fundamentals of Microfabrication, *CRC Press*, Boca Raton, FL, 1997, ISBN 0-8493-9451-1, pp. 145-160, pp. 464-468.
[3]. S. J. Sherman, W. K. Tsang, T. A. Core, R. S. Payne, D. E. Quinn, K. H. -L. Chau, J. A. Farash, S. K. Baum, Surface micromachined accelerometers. *IEEE Int. Electron Device Meeting (IEDM),* 92, 501, 1992.
[4]. Navid Yazdi, Farrokh Ayazi, Khalil Najafi, Micromachined Inertial Sensors, *Proceedings of the IEEE,* Vol. 86, No. 8, August, 1998.

[5]. S. J. Sherman, W. K. Tsang, T. A. Core, R. S. Payne, D. E. Quinn, K. H. -L. Chau, J. A. Farash, S. K. Baum, Surface micromachined accelerometers, *Solid State Technology,* 36, 1993, pp. 39–47.

[6]. K. H. -L. Chau, S. R. Lewis, Y. Zhao, R. T. Howe, S. F. Bart, R. G. Marcheselli, Polysilicon surface micromachined accelerometers, *8th Int. Conf. Solid-State Sensors Actuators, Eurosensors IX*, Stockholm, Sweden, June 1995, p. 593.

[7]. Yoshinori Matsumoto, Moritaka Iwakiri, Hidekazu Tanaka and etc., A capacitive accelerometer using SDB-SOI structure, *Sensors and Actuators,* A, 53, 1996, pp. 267-272.

[8]. F. Rudolf, A. Jornod, J. Bergqvist and H. Leuthold, Precision accelerometers with mg resolution, *Sensors and Actuators,* A21-A23, 1990, pp. 297-302.

[9]. Y. Matsumoto and M. Esashi, Integrated silicon capacitive accelerometer with PLL servo technique, *Sensors and Actuators,* A, 39, 1993, pp. 209-217.

[10]. W. Yun, R. T. Howe and P. R. Gray, Surface micromachined, digitally force-balanced accelerometer with integrated CMOS detection circuitry, *Tech. Digest, IEEE Solid-State Sensors and Actuator Workshop*, Hilton Head, SC, USA, June 1992, pp. 21-25.

[11]. Airbags boom when IC accelerometer sees 50G, *Electronic Design*, 8, Aug. 1991.

[12]. V. M. Mcneil, M. J. Novack and M. A. Schmidt, Design and fabrication of thin-film microaccelerometers using wafer bonding, in *Proc. of 7th Int. Conf. Solid-State Sensors and Actustors(Transducers'93)*, Yokohama Japan, 7-10 June 1993, pp. 822-825.

[13]. L. J. Ristic, R. Gutteridge, B. Dunn, D. Mietus, and P. Bennett, Surface micromachined polysilicon accelerometer, in *Proc. of IEEE Solid-State Sensor and Actuator Workshop*, 1992, pp. 118-121.

[14]. B. E. Boser and R. T. Howe, Surface micromachined accelerometers, *IEEE J. Solid-State Circuits*, Vol. 31, Mar. 1996, pp. 366-375.

[15]. L. Hao, Z. Gang, L. R. Carley, and G. K. Fedder, A post-CMOS micromachined lateral accelerometer, *IEEE J. Microelectromech. Syst.,* Vol. 11, June 2002, pp. 188-195.

[16]. I. Y. Park, C. W. Lee, H. S. Jang, Y. S. Oh, and B. J. Ha, Capacitive sensing type surface micromachined silicon accelerometer with a stiffness tuning capability, in *Proc. of IEEE Int. Micro Electro Mechanical Syst.,* 1998, pp. 637-642.

[17]. N. Yazdi and K. Najafi, An all-silicon single-wafer micro-G accelerometer with a combined surface and bulk micromachining process, *IEEE J. Microelectromech. Syst.,* Vol. 9, Dec. 2000, pp. 544-550.

[18]. A. Beliveau, G. T. Spencer, K. A. Thomas, and S. L. Roberson, Evaluation of MEMS capacitive accelerometer, *IEEE Design Test Comput.,* Vol. 16, Oct. -Dec. 1999, pp. 48–56.

[19]. Lucheng Lin, New development of SOI technology [J], *Function material and Devices*, 7, 1, 2001.

[20]. Yugang Li, *Study on High-temperature crystal silicon pressure sensor [M],* Tianjin, 2003.

[21]. B. V. Amini, S. Pourkamali, and F. Ayazi, A high resolution, stictionless, CMOS compatible SOI accelerometer with a low noise, low power, 0. 25 _m CMOS interface, in *Proc. of IEEE Int. Micro ElectroMechanical Syst.,* 2004, pp. 572-575.

[22]. B. Diem, P. Rey, S. Renard, S. V. Bosson, H. Bono, F. Michel, M. T. Delaye, G. Delapierre, SOI 'SIMOX' from bulk to surface micromachining, a new age for silicon sensors and actuators, *Sens. Actuators* A, 46-47, 1995, pp. 8-16.

[23]. L. Zimmermann, J. PH. Ebersohl, F. Le Hung, J. P. Berry, F. Baillieu, P. Rey, B. Diem, S. Renard, P. Rey, B. Diem, S. Renard, P. Caillat, Airbag application: a microsystem including a silicon capacitive accelerometer, CMOS switched capacitor electronics and true self-test capability, *Sensors and Actuators*, A, 46-47, 1995, pp. 190-195.

[24]. Yingbin Zhen. Coupled-Field Analysis for comb finger accelerometer, *Master Degree Thesis*, China academy of engineering physics, 2002, 2, pp. 13-17.

[25]. Jun Liu, Yunbo Shi, Jie Li, *Micro-inertial technology*, Nov. 2005, pp. 98-101.

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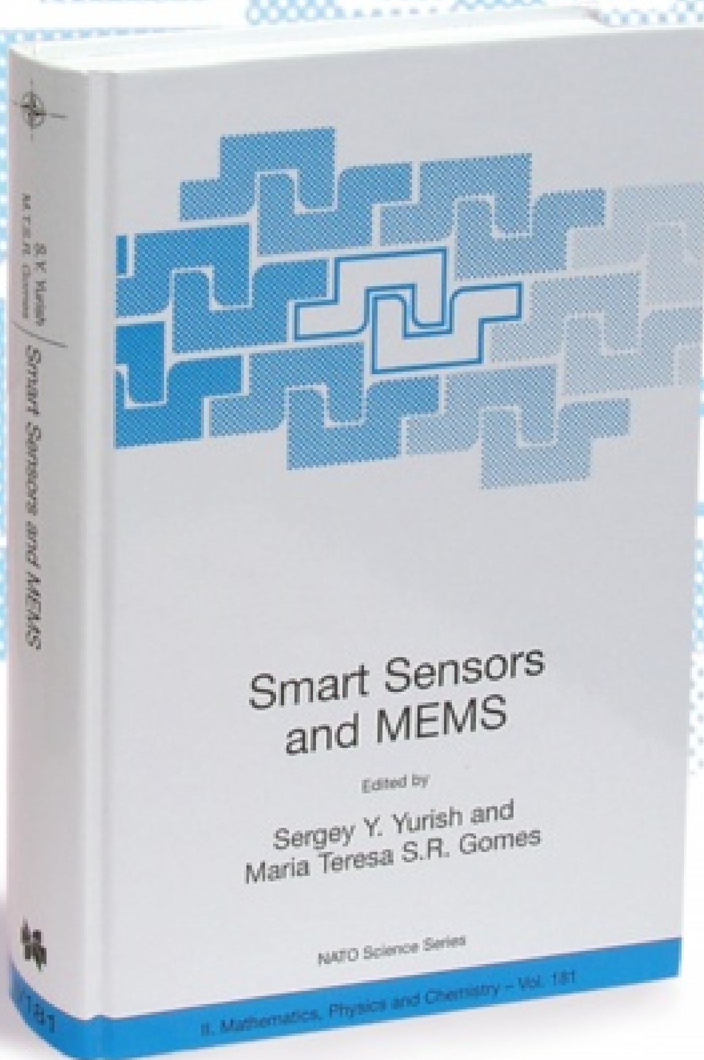

Smart Sensors and MEMS

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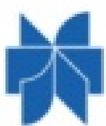

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