DESIGN AND FABRICATION OF BULK-MICROMACHINED MEMS ACCELEROMETER

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Abstract

In this project, the design and fabrication of a bulk-micromachined MEMS accelerometer device are proposed. The device has a glass-silicon-glass sandwich structure based on silicon-glass anodic bonding technique. Silicon cantilever-mass structure is used for improved sensitivity. Both top and bottom glass plates offer over-range protection for the silicon mass. The silicon movable mass constitutes differential capacitance pair with top and bottom aluminum electrodes on glass wafers. If there is any acceleration perpendicular to the device plane, the sensing mass moves toward top or bottom due to the experienced inertial force. As a result, the differential capacitance gap will be changed. By measuring the differential capacitance change, the acceleration can be measured. ANSYS simulation is used to extract the device sensitivity of the design. Based on the simulation, a set of optimized design parameters are achieved. The fabrication sequence of the MEMS accelerometer is also proposed. The proposed accelerometer can be used for automobile air-bag deployment application.

Introduction

MEMS (Microelectromechanical Systems) refer to devices and systems integrated with electrical and mechanical components in the scale of microns (1μm=10^{-6}m). Due to its small size, low cost, low power consumption and high efficiency, MEMS have been widely used in many applications, such as automobile, optical display, RF communication, biomedicine, aerospace and consumer products. MEMS and nanotechnology are believed to be the drive to trigger the next wave of technology revolution. In this poster, the design and fabrication of a silicon symmetric bulk-micromachined capacitive accelerometer are proposed. The cantilever beam is located in the middle instead of the top of the device plane. Due to this symmetrical structure design, the lateral effect is eliminated. The device has high sensitivity due to its large sensing mass. The proposed accelerometer can be used for various applications such as automobile airbag deployment system.

Accelerometer Design

The bulk-micromachined capacitive MEMS accelerometer structure is shown in Fig. 1.

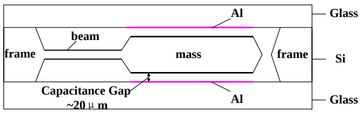

Figure 1. Structure design of symmetrical MEMS accelerometer (cross-sectional view)

The proposed accelerometer has a glass-silicon-glass sandwich structure bonded with silicon-glass anodic bonding technique. It contains three layers: top glass plate, middle silicon cantilever-mass structure and bottom glass plate. The silicon sensing mass is connected to the frame through a cantilever beams. The sensing mass constitute differential capacitance pair (C1 and C2) with the Aluminum electrodes deposited and patterned on the top and bottom glass plates. When there is no acceleration input, the capacitance gaps of C1 and C2 are equal, hence C1=C2. If there is an acceleration perpendicular to the device plane, the sensing mass moves toward top or bottom due to the inertial force. As a result, the differential capacitance gaps will be changed. By measuring the differential capacitance change, the acceleration can be measured. The 3-D view of accelerometer is shown in Figure 2. The top and bottom glass plates also offer over-range protection to the cantilever-mass structure when the deformation is too large.

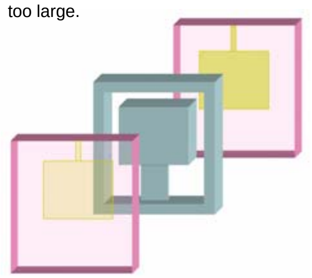

Figure 2. 3D view of the sandwich-structured MEMS accelerometer

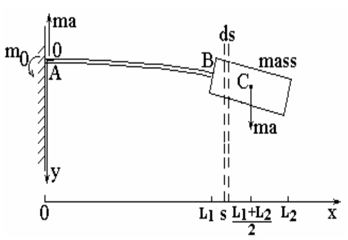

Figure 3. Schematic diagram of a cantilever-mass structure

Assume the width, length and thickness of the cantilever are W_b, L_b and t_b separately. The width, length and thickness of mass are W_m, L_m and t_m separately. The density and Young's modulus of Si material are E and ρ separately. Under the small deflection approximation, the device can be treated as a simplified spring-mass model with the equivalent spring constant of

$K_b = \frac{3EI_b}{L_b^3} = \frac{EW_b t_b^3}{4L_b^3}$, where I_b is moment of inertia of the cantilever, $I_b = \frac{1}{12} W_b t_b^3$

The mass of the sensing mass is $M_s = \rho V = \rho W_m L_m t_m$

The displacement sensitivity of the accelerometer is $S_d = \frac{F_{inertial}}{K_b} = \frac{M_s g}{K_b}$ (per g)

The intrinsic frequency of the device is $f_0 = \frac{1}{2\pi}\sqrt{\frac{K_b}{M_s}}$

Design Optimization and Simulation

Based on above analysis, we derived a set of optimized design parameters of the MEMS accelerometer, as shown in Table 1. According to the design parameters, the MEMS accelerometer has the intrinsic frequency of 405Hz and the displacement sensitivity of 0.15μm/g. ANSYS FEM simulation is used to extract the sensitivity, resonant frequency as well as the stress distribution of the device. The bending shape of the beam-mass structure under given acceleration input can also be observed. The ANSYS simulation results are in good agreement with theoretical prediction. The ANSYS models of the device is shown in Figure 5-8.

Width of beam (μm)	1400
Length of beam (μm)	2000
Thickness of beam (μm)	40
Width of mass (μm)	3600
Length of mass (μm)	3000
Thickness of mass (μm)	560
Capacitance gap (μm)	20
Static capacitance (pF)	2.16
Displacement sensitivity (μm/g)	0.15
Capacitive sensitivity (pF/g)	0.26
Intrinsic frequency (Hz)	405

Table 1. The optimized design parameters of the MEMS accelerometer

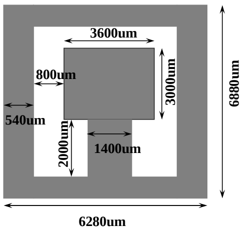

Figure 4. Dimensions of the silicon cantilever-mass structure

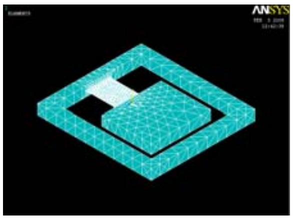

Figure 5. Undeformed shape of the MEMS accelerometer

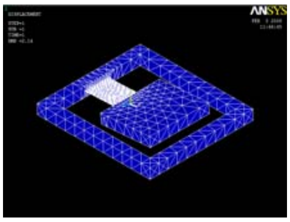

Figure 6. Deformed shape of accelerometer under acceleration input

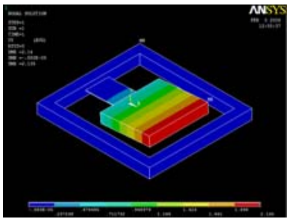

Figure 7. Sensitivity analysis when experiencing an acceleration of 1g

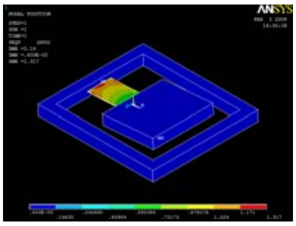

Figure 8. Stress contour plot when experiencing an acceleration of 1g

Device Fabrication

The device is to be fabricated with bulk-micromachining process. As shown in Fig. 9, the fabrication flow of the MEMS accelerometer contains five steps: (1) KOH etching for capacitance gap; (2) KOH etching for thickness difference between cantilever beam and etch-through area; (3) Maskless etching till etch-through, the beam structure is formed; (4) Deposit and pattern Aluminum electrodes on glass plates; (5) Si-Glass anodic bonding, device is fabricated. For each selective silicon etching, it has seven sub-steps: (1) Oxidation; (2) Photoresist spinning; (3) Photoresist patterning; (4) SiO_2 etching; (5) Photoresist removal; (6) Silicon etching; (7) SiO_2 removal. Due to the symmetrical structure of the device, the patterning and etching are performed in both sides of the wafer simultaneously and precise alignment is required. The symmetrical structure has the advantage that the device is insensitive to lateral acceleration input. That is, the device has no lateral effect.

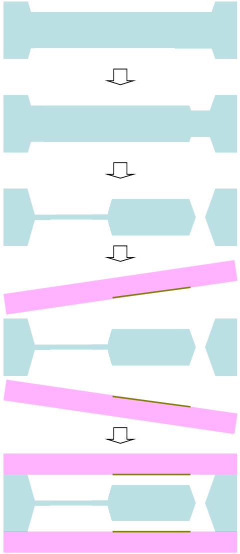

Figure 9. Process flow of fabricating the bulk-micromachined MEMS accelerometer

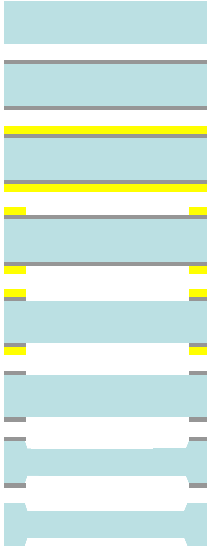

Figure 10. Sub-steps of each etching to pattern the silicon structure

Conclusions and Future Work

In this project, a symmetrical bulk-micromachined MEMS accelerometer design is proposed. The device eliminates lateral effect due to its symmetrical structure design. The device behavior is analyzed with simplified spring-mass model. The displacement sensitivity and intrinsic frequency of the device are extracted. Based on the analysis, an optimized design is suggested. ANSYS simulation is used to verify the device performance. Simulation results show that the device has a sensitivity of 0.15μm/g. The fabrication flow of the device is also proposed. In the future work, we will further improve the device performance, such as air-damping optimization.