SHOCK-RESISTIBILITY OF INERTIAL MICROSWITCH UNDER REVERSE SENSITIVE DIRECTIONAL ULTRA-HIGH G ACCELERATION

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ABSTRACT

The paper reports a novel inertial microswitch with multi-directional compact constraint structures for improving the shock-resistibility. Its shock-resistibility in the reverse sensitive directional ultra-high g acceleraiton (~hunderds of thousands) is simulated and analyzed. The dynamic response process indicates that in the designed inertial microswitch the proof mass weight G, the whole system stiffness k and the gap x_2 between proof mass and reverse constraint blocks have significant effect on the shock-resistibility. The fabricated inertial microswitch by surface micromachining technology has been evaluated by the dropping hammer system. The test results show that the reverse resistant threshold acceleration a_{thr} increases with the decrease of the gap x_2. The testing comparison of the microswitches with and without constraint structure indicates that the designed constraint structures can effectively improve the shock-resistibility

INTRODUCTION

Recently, MEMS inertial micro-switch has been attracting much attention due to many advantages such as lower cost, larger volume production and smaller size [1, 2]. Therefore, they are used widely in a variety of applications such as accessories, toys and remote monitoring (RMON) [3-6]. In a real world application, the microswitch will be inevitably subjected to ultra-high shocks from the reverse sensitive direction because of the complicated work environment. As a result, the large deformation of suspension spring would cause the proof mass to rebound to the stationary electrode in the sensitive direction, which would lead to a spurious trigger. However, there are few researchers paying much attention to how to improve the shock-resistibility and reduce the spurious trigger. With regards to this, a novel laterally-driven inertial microswitch with multi-directional compact constraint structures will be proposed, and the effect of the proof mass weight G, the whole system stiffness k and the gap x_2 on the shock-resistibility will be discussed when the switch is subjected to an acceleration in the reverse sensitive direction (-x direction).

DEVICE DESIGN AND SIMULATION

It can be seen from Figure 1 that the designed device mainly consists of three parts: the double stair shape cantilever beam as the movable electrode, which is attached to the proof mass suspended by four serpentine springs; one spring shape cantilever beam as the stationary electrode and the compact constraint structures consisting of constraint layer with holes and reverse constraint blocks. The introduced new constraint structures can effectively improve the shock-resistibility of the inertial microswitch and weaken the spurious trigger. The allowed maximum reverse acceleration which does not cause the switch spurious trigger is defined as the reverse resistant threshold acceleration (a_{thr}). The reverse resistant threshold acceleration a_{thr} is the critical value making the circuit spurious trigger, and the circuit will not conduct when the applied reverse acceleration is less than a_{thr}.

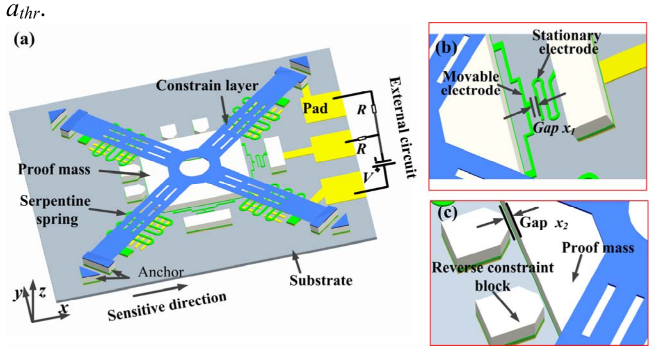

Figure 1: (a) Schematic diagram of the whole designed inertial microswitch; (b) The enlarged view of the novel movable electrode and stationary electrode; (c) Gap between proof mass and reverse constraint block.

Finite element analysis software ANSYS was used to simulate the reverse resistant threshold acceleration athr. The acceleration was applied to the microswitch in the reverse sensitive direction (-x direction). Figure 2 shows the dynamic response curves of movable electrode when the microswitch was shocked by the allowed maximum reverse resistant threshold acceleration athr. The simulated process indicates that the acceleration athr decreases with the increase of the proof mass weight G and the gap x2 between proof mass and reverse constraint blocks, but increases with the whole system stiffness k.

In order to investigate the effect of the constraint layer on the shock-resistibility, the acceleration of 45000g in the reverse sensitive direction was applied to the inertial microswitch with constraint layer and without constrain layer. Figure 3(a) shows the dynamic responses curves of movable electrode with constraint layer and without constraint layer, and spurious trigger is easier to happen if without constraint layer. That is to say, the constraint layer can improve the shock-resistibility of the inertial microswitch and eliminate the spurious trigger. The displacement-time curve of proof mass with constraint layer in the off-axis sensing z-direction is also simulated, as shown in Figure 3(b). It indicates that the proof mass collides with the constraint layer during the movement process.

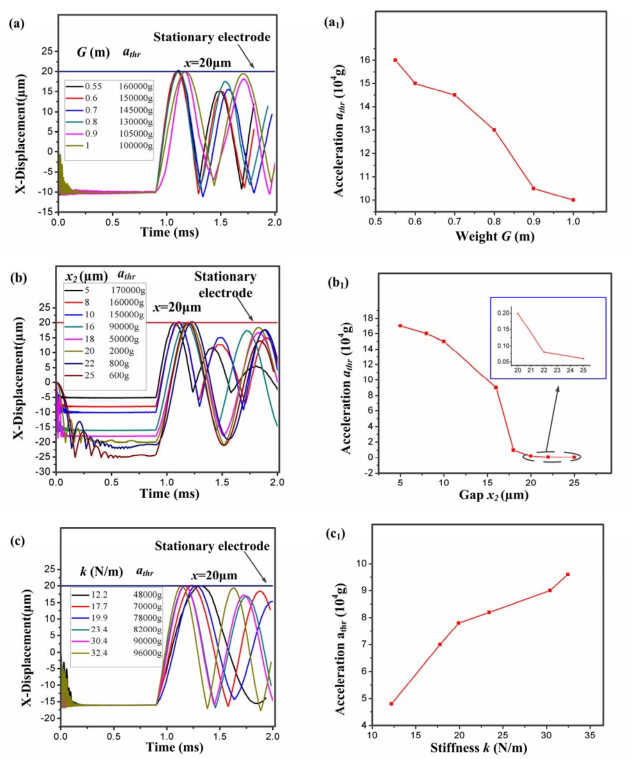

Figure 2: The dynamic response curves of movable electrode under the allowed maximum reverse resistant threshold acceleration a_{thr} when (a) different proof mass weight G; (b) different gap x_2 and (c) different system stiffness k. Dependences of a_{thr} on G (a_1); x_2 (b_1); and k (c_1).

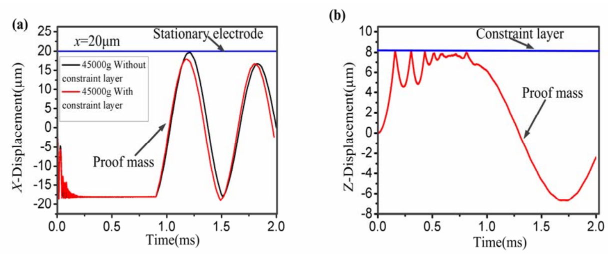

Figure 3: (a) The dynamic response curves of movable electrode with and without constraint layer under the same acceleration 45000g in the reverse sensitive direction. (b) The displacement-time curves of proof mass with constraint layer in off-axis sensing z-direction.

MICRO-FABRICATION

The designed inertial microswitch was fabricated based on surface micromachining technology on the glass substrate by a multilayer lithography and electroplating technology. In the present work, positive photoresist(AZ4903) was chosen as the mould and the sacrificial layer. Ni metal was selected as the main structure material because of its excellent mechanical property. The whole micro-fabrication process is monitored by the The stylus profiler (Dektak 6M, Veeco, USA). The main fabrication process steps of the inertial microswitch sketched in Figure 4 can be described as follows:

(i) Firstly, Cr/Cu sputtered on the quartz wafer substrate was chosen as the first seed layer. After the photoresist spin-on and patterning, then a series of raised strips, the pads and anchors were electroplated.

(ii) Next, the anchors which suspended the springs were electroplated in nickel and forming the first suspended layer.

(iii) The first suspended layer was polished and then the second Cr/Cu seed layer was sputtered on it. The spring layer and the first proof mass layer was patterned and electroplated.

(iv) The proof mass was electroplated up to the required thickness by multiple lithography and multi-layer electroplating technology.

(v) The anchors which suspended the constraint layer were electroplated and forming the second suspended layer.

(vi) The constraint layer was patterned and electroplated in nickel.

(vii) The sodium hydroxide solution was used to remove the sacrificial layer. The ammonia/peroxide solution was used to remove the chromium/copper seed layer.

The SEM image of the inertial microswitch device was shown in Figure 5(a). The upper constraint layer was removed to obtain a clear picture of the whole geometrical structure as shown in Figure 5(b).

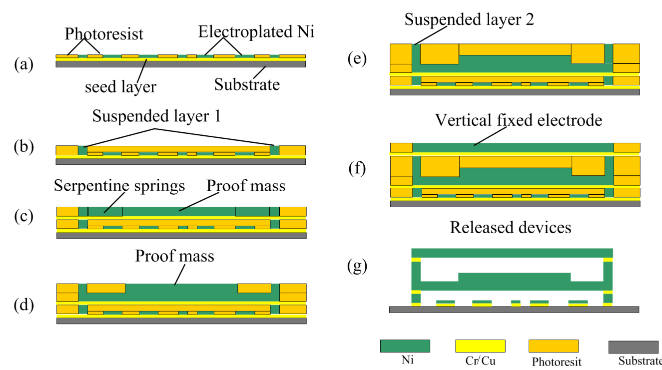

Figure 4: Main micro-fabrication process of the inertial microswitch.

CHARACTERIZATION

The fabricated inertial microswitch devices were tested by the dropping hammer system, where the test device and the standard accelerometer were fixed on the surface of steel dropping table. It can ensure that the test switch sensitive direction is vertical to the ground. Then the drop hammer was freely dropped onto the base platform from different pre-determined height H, which generates a half-sine wave acceleration with different peak value. The oscilloscope (Agilent 6000 MSO6034A) was used to detect the output signal of the accelerometer and the trigger signal. The standard accelerometer ADXL-193 with a sensitivity of 8mV/g, which was made in Analog Devices Inc, was used for calibration. Three color signal curves achieved by a multichannel oscilloscope are shown in the test results: green signal represents accelerometer signal; yellow signal is on behalf of the spurious trigger between the movable electrode and the stationary electrode in the inertial switch; the purple signal is z off-axis collision trigger signal when the proof mass collides with the upper constraint layer.

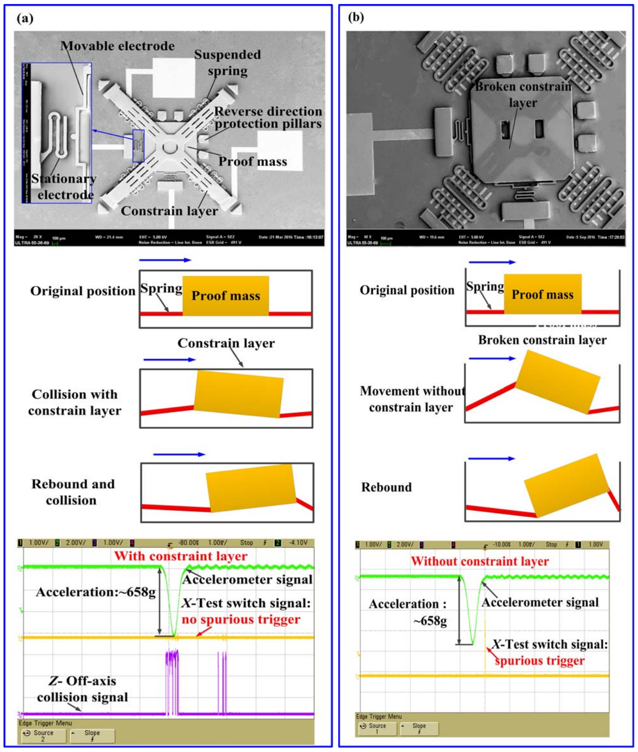

Figure 5: (a) SEM of the fabricated microswitch with constraint layer; collision process of proof mass with constraint layer in moving toward stationary electrode and corresponding test result under reverse acceleration 658g (no spurious trigger). (b) SEM, collision process and test result of the microswitch without constraint layer under the same reverse acceleration 658g (have spurious trigger).

In order to investigate the function of the constraint layer, the test inertial microswitch was shocked by the acceleration of 658g in the reverse sensitive direction (-x direction) as shown in Figure 5. Figure 5(a) shows the SEM image of the fabricated microswitch with constraint layer and the spurious trigger does not happen under the reverse sensitive acceleration 658g. When the constraint layer was broken, the spurious trigger happens under the same acceleration 658g as shown in Figure 5(b). The z-off-axis collision as shown in Figure 5(a) can be observed, which indicates that the proof mass collides with the constraint layer again and again. The whole system energy is consumed to some extent and the spurious trigger is eliminated. It can be seen from Figure 6 that spurious trigger happens until the reverse acceleration increases up to 849g (athr) in the microswitch with constraint layer. It is evident that the reverse resistant threshold acceleration athr (658g) of the microswitch without constraint layer is smaller than a_{thr} (849g) the inertial microswitch with constraint layer. Therefore, it demonstrates that the constraint layer can improve the shock-resistibility.

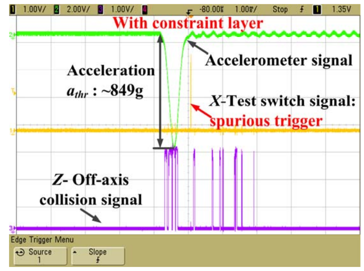

Figure 6: Spurious trigger happens until the reverse acceleration increases up to 849g (a_{thr}) in the microswitch with constraint layer in figure 4(a).

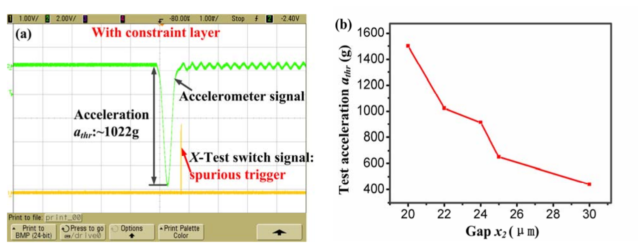

Figure 7: (a) Test result of switch with constraint layer under the high-g acceleration 1022g in the reverse sensitive direction when the gap x_2 is 22μm; (b) Dependence of test reverse resistant threshold acceleration a_{thr} on the gap x_2 between proof mass and reverse constraint block.

The fabricated microswitch has been evaluated by testing the device with different gaps x_2 When the gaps x_2 between proof mass and reverse constraint block are 22μm, the test reverse resistant threshold accelerations are 1022g as shown in Fig. 7(a). Fig. 7(b) shows an array of test reverse resistant threshold accelerations when the gap x_2 are 20μm, 22μm, 24μm, 25μm and 30μm, respectively. It indicates the test a_{thr} decreases with the increase of the gap x_2, which is in agreement with the simulated ones. It demonstrates that the inertial microswitch tends to have better shock-resistibility under smaller gap x_2.

CONCLUSION

A novel inertial microswitch with multi-directional compact constraint structure for improving the shock-resistibility has been designed, simulated and fabricated by surface micromachining technology. The simulation reveals that the reverse resistant threshold acceleration (a_{thr}) decreases with the increase the proof mass weight G and the gap x_2, while increases with the whole system stiffness k. The fabricated inertial microswitch has been evaluated by a standard drop hammer system. The test results show that a_{thr} increases with the decrease of the gap x_2, and the microswitch tends to have better shock-resistibility under smaller gap. The testing comparison of the microswitches with and without constraint structure indicates that spurious trigger is easier to happen if without constraint structure, and the designed constraint structures can effectively improve the shock-resistibility.

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