A VERTICAL DRIVEN INERTIAL MICRO-SWITCH WITH DUAL SPRING TO PROLONG HOLDING TIME

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ABSTRACT

In this paper, a new model has been proposed for the design of inertial micro-switch. Compared with the traditional model consisted by movable-fixed electrode, the electrodes are designed as two movable springs. The dynamic response processes of electrodes can be controlled via the structure parameters. The simulation results indicated that the elastic contact can effectively prolong the holding time. The fabricated prototypes were tested by drop hammer system. The test results demonstrated that the holding time of improved inertial micro-switch much longer than the traditional designed one with the same threshold acceleration.

KEYWORDS

MEMS, inertial micro-switch, holding time, dual spring, dynamic response process

INTRODUCTION

Motivation

With the development Internet of Things (IOT), the inertial micro-switch will be a potential device for many applications such as remote monitoring, handheld devices, et al. Compared with accelerometer, the inertial microswitch is both a sensor and actuator, when the applied acceleration reaches to the threshold, the movable electrode touched with the stationary electrode and a connection signal with time scale was outputted. On the off state, the consumption of the inertial switch is zero while the accelerometer always contain a constant parasitic power draw even no acceleration and impact happening. Furthermore, this kind of purely mechanical trigger is superior to accelerometer due to the electromagnetic interference. Therefore, the inertial micro-switch was widely applied in some small-scale or long life-time system where the power supply is limited [1-4].

The holding time is a key factor for inertial micro-switch. The researchers had proposed some design model to improve the holding time. However, either complex technology was required or the prototype was hard to restart in the reported references [5, 6]. Furthermore, the holding time of inertial switch was influenced by designed threshold acceleration. In our previous work [7], the designed model has been proposed to prolong the holding time. But, the work principle is disabled when the designed threshold high than a certain value (e.g. 300g). This report proposes a new model with elastic contact principle, which can prolong holding time from ~20μs to 90μs when the designed threshold acceleration is about 500g.

Concept

A vertical driven inertial micro-switch with dual spring has been proposed based on surface micro machining technology, as shown in Figure 1(a). The designed inertial switch was consisted by three parts mainly. The quarts glass was chooses as the substrate, a serious of strips were located on the substrate to eliminate the squeeze-film damping of proof mass [8]. The proof mass was suspended by four group conjoined serpentine springs. The movable electrode was designed as centrosymmetric structure, which can provide substantial benefit for off-axis performance. When the inertial switch is shocked by acceleration in the horizontal direction, the vibration of movable electrode can be weakened effectively due to the symmetric distributed spring. In order to improve the sensitivity of inertial switch, the thickness of proof mass was designed much larger than the spring. The stationary electrode was located above stationary electrode, which was supported by four blocks. In the middle of stationary electrode, the contact point was connected by springs.

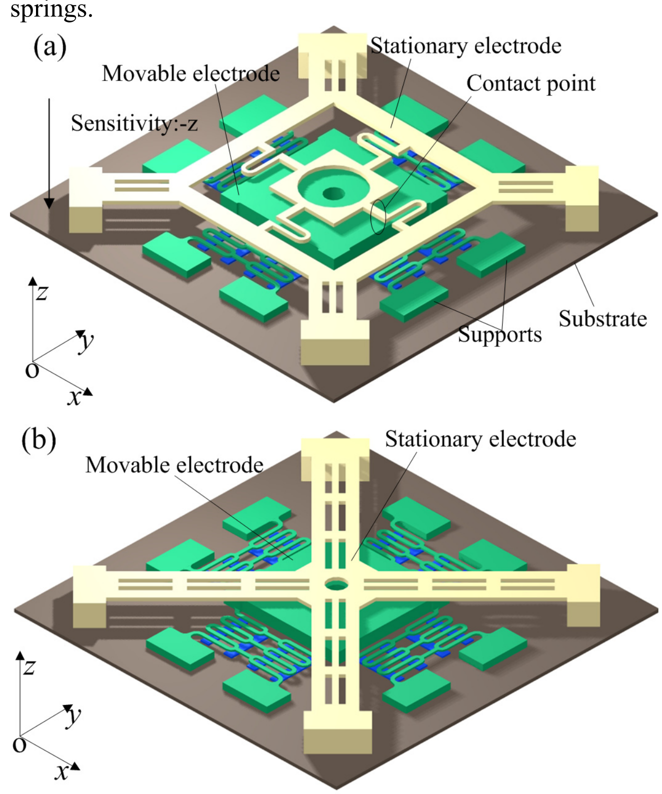

Figure 1: The schematic of designed inertial micro-switch. (a) The proposed inertial switch. (b) The previous designed model of inertial switch.

When the inertial switch was shocked by acceleration in sensitive direction, the movable electrode moves towards to the stationary electrode and touch with the contact point, the deformation of suspended spring can reduce the kinetic energy of proof mass and prolong the contact time. Compared with previous designed model shown in Figure 1(b), the stiffness of proposed stationary electrode was lower than previous model.

When the threshold acceleration of inertial switch was designed as a low-g device, the stiffness of stationary electrode shown in Figure 1(b) can meet the requirements due to the impact force of proof mass low enough. However, under the high-g shock acceleration, the holding time was influenced by the stiffness of stationary electrode to a large extent. So, the structure of stationary electrode shown in Figure 1(a) was proposed, and the stiffness was reduced effectively.

DYNAMIC SIMULATION

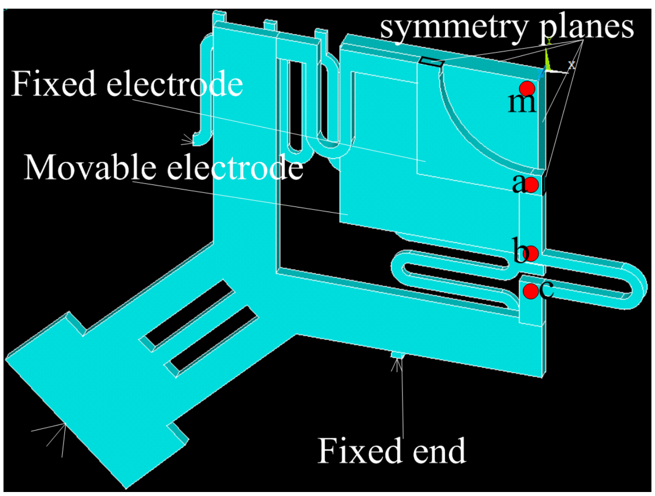

Figure 2: One quarter of simulation model.

The commercial ANSYS finite-element software was used to simulate the dynamic contact process, which can provide us a convenient and precise method to investigate the dynamic response process. In order to save calculation time, one quarter model was used to substitute for the whole model, as shown in Figure 2. In the model, the profile of movable and stationary electrode was chose as symmetry planes, the lower surface of stationary electrode and the upper surface of movable electrode were designed as contact surface. The TRAGE170 and CONTACT 174 were chosen to establish the contact pairs. The grid type SOLID Brick 185 was chosen to mesh the model with SWEEP method. The end sections of all suspended springs, fixed electrodes were constrained to be zero in all degree of freedom. Ni metal was chosen to as the structural material. From our experimental results [9], the material properties of Ni are as follows: Young's modulus is 170Gp and density is 8.96kg.m^{-3}, the Poisson's ratio is 0.3. Considering that the response process is one-time active in this simulation, the dissipation of energy is so small that you can ignore the material damping. The squeeze-film damping was selected as 0.34 for FEM simulation [10].

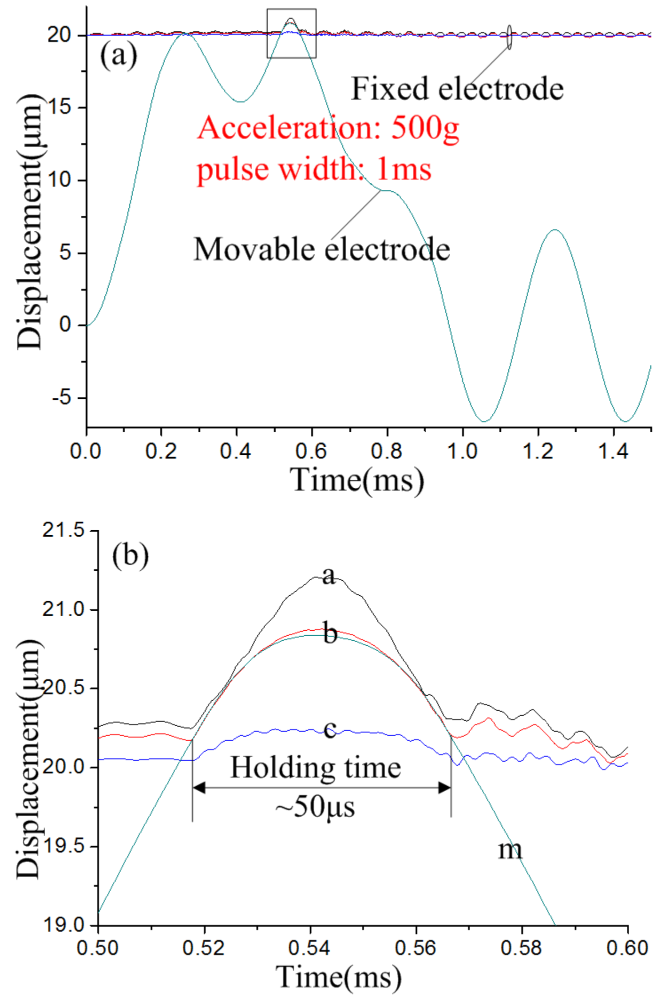

Figure 3: (a) The dynamic response curves of movable and stationary electrode. (b) The details of point a-c.

Figure 3(a) shows the dynamic response curves of proof mass and stationary electrode under the acceleration of 500g with pulse width was 1ms. Figure 3(a) indicated that the threshold acceleration of designed inertial micro-switch was about 500g. The response process of movable electrode was substituted by one selected point (*m*) on the proof mass. Three points (*a, b, c*) on the spring were selected to study the vibration of stationary electrode. Figure 3(a) indicated that that the first amplitude of proof mass reached to stationary electrode, but the contact time was very short. In the experiment, this idealize contact process was useless. The second amplitude indicated that the proof mass contact with stationary electrode and moved with it. The contact process was amplified and shown in Figure 3(b), which demonstrated the holding time was about 50μs. The curves of point *a*, *b* and *c* indicated that the point *b* moved with proof mass always attributed to the deformation of the suspended spring, which can prolong the holding time effectively.

FABRICATION

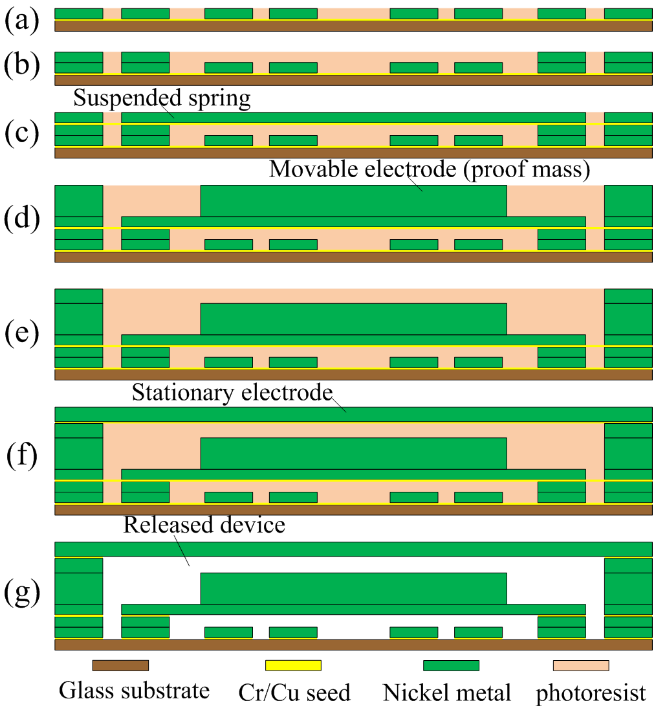

Figure 4: The schematic of fabrication process of designed inertial micro-switch.

The prototype of designed inertial micro-switch was fabricated based on surface micromachining technology. The Nickel (Ni) metal was chose as the electroplating structural material. The structure of device was electroplated orderly after the positive photoresist was patterned. The height of every layer was controlled independently by the thickness of photoresist attributed to multilayer electroplating process. The electroplating process was controlled by solution temperature (45℃), PH (4.0) and deposition rate (0.3*um/min*). The stylus profiler (Dektak 6M, Veeco, USA) was used to monitor the entire manufacturing process. The main fabrication process of the switch is illustrated in Fig. 4(a)-(g) and described as follows:

a. The quartz glass was selected as the substrate; Cr/Cu was sputtered on the surface of glass as the first seed layer, a serious of raised bars had been electroplated, which can weaken the air damping effectively.

b. The anchors were fabricated higher than raised bars, forming the gap between proof mass and raised bars.

c. The suspended spring and bottom of proof mass were electroplated on the second Cr/Cu seed layer.

d. The proof mass was electroplated higher than suspended spring, the supports of stationary electrode has been fabricated higher than the bottom of proof mass.

e. The supports were electroplated higher than proof mass, the gap between movable electrode and stationary electrode was built.

f. The third Cr/Cu seed layer was sputtered. The stationary electrode was electroplated on the Cr/Cu seed layer.

g. Acetone was used to remove the photoresist, and an ammonia/peroxide solution was used to remove the seed layer. The released inertial microswitch was obtained, as shown in Figure. 5.

Figure 5(a) was the previous designed inertial micro-switch, the stationary electrode was designed as multihole crossbeam, the holes can decrease the stiffness of the beam, but the stiffness was limited by the weight of beam. Figure 5(b) was the proposed inertial micro-switch, which indicated that the structure was intact, the suspended springs of stationary electrode were fabricated.

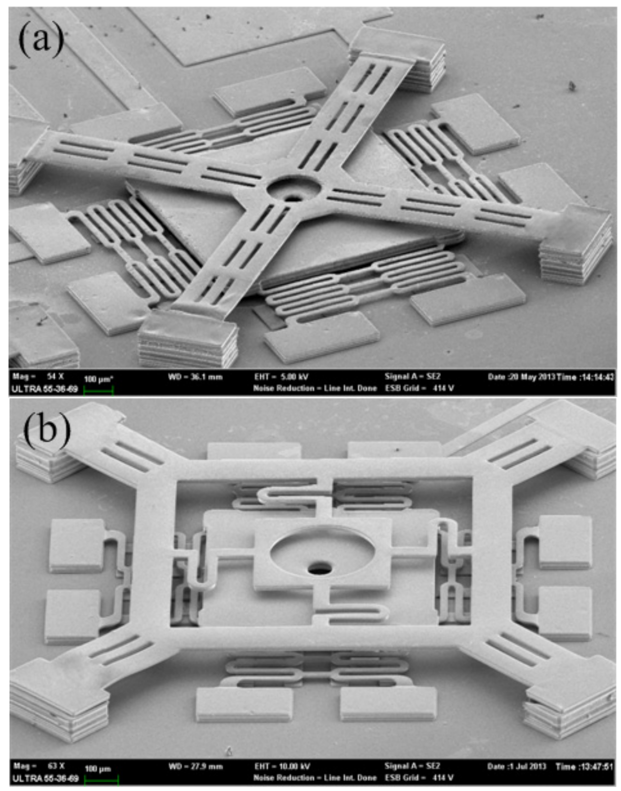

Figure 5: (a) The SEM of previous designed inertial micro-switch. (b) The SEM of proposed inertial micro-switch.

CHARACTERIZATION

The fabricated inertial witch prototype was tested by dropping hammer system. The main equipments of the this system include the dropping hammer controlled by computer, a standard accelerometer ADXL-193 from the Analog Device Inc. with sensitivity of $8mV{\cdot}g^{-1}$ and a multichannel oscilloscope (Agilent 6000 MSO6034A). The amplitude of applied half-sine shock acceleration was determined by the pre-determined height of the hammer. The pulse width of shock load was decided by the stiffness of pedestal. The tested inertial switch and standard accelerometer were connected with external circuit. In our experiment, the tested switch was connected to a power source (9*V)* with a 700Ω current-limiting resistor. The tested switch was fixed on the steel dropping table, making sure their sensitivity directions vertical to the ground. When the table was dropped freely from a pre-determined height on to the pedestal, a half-sine shock acceleration with a certain amplitude could be generated to applied to the tested switch. The output signals including the acceleration voltage and connected voltage were captured by oscilloscope when the inertial switch was switched on.

Figure. 6(a) and (b) were the tested results of corresponding fabricated inertial micro-switches shown in Figure 5(a) and (b). Figure 6(a) indicated that the holding time of previous designed inertial micro-switch was about 20μs when the designed threshold acceleration was about 500g. Figure 6(b) indicated that the holding time was about 90μs under the same shock acceleration. Compared with the test result shown in Figure 6(a) and (b), which demonstrated that the proposed inertial micro-switch with dual spring can prolong the holding time effectively attributed the flexible stationary electrode.

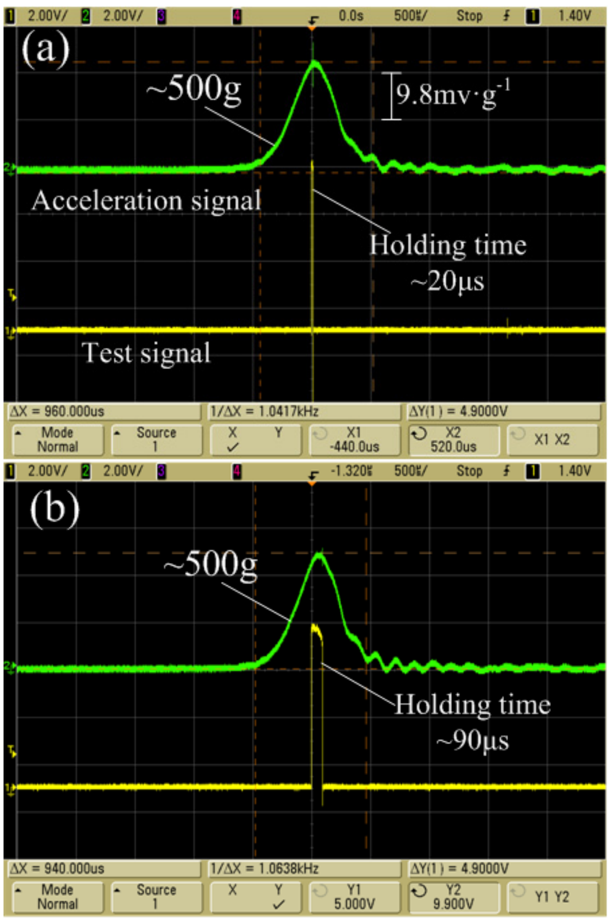

Figure 6: (a) The test result of previous designed inertial micro-switch. (b) The test result of proposed inertial micro-switch.

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