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A surface-micromachining-based inertial micro-switch with compliant cantilever beam as movable electrode for enduring high shock and prolonging contact time

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ABSTRACT

A novel laterally-driven inertial micro-switch with two L-shaped elastic cantilever beams as the movable electrode, which is attached to the proof mass, is proposed in this paper. The advantage of this design is that the contact time of the inertial micro-switch can be prolonged. Meanwhile, the micro-switch can withstand a higher shock than the traditional designs whose cantilever beams are attached to the fixed electrode. The designed inertial micro-switch was simulated and optimized with ANSYS software and fabricated on a quartz substrate by surface micromachining technology. The simulated result demonstrates that the threshold acceleration (a_{ths}) under stable switch-on state is about 288 g and the contact time is about 198 μs when the pulse width of acceleration loads is 1 ms. At the same time, it indicates that the threshold acceleration, the response time and the contact time of designed micro-switch all increase with the pulse width of acceleration loads. The simulation of impact process in non-sensitive direction shows that the introduced constraint sleeve structure in the novel inertial micro-switch can lower the off-axis sensitivity. The fabricated micro-switch prototype has been tested by a standard dropping hammer system under shock accelerations with various amplitudes and pulse widths. The experimental measurements show that the contact time is about 150 μs when the threshold acceleration is about 288 g. It also indicates that the response time and the contact time both increase with the pulse width, which is consistent with the simulation ones.

1. Introduction

Recently, many researchers have paid more attention to the inertial micro-switch based on surface micromachining technology because of the advantages of lower cost, smaller size and large volume production. This device has been also widely used in a variety of commercial applications, such as handheld devices, industrial transportation, automobiles safety and so on [1–5]. It is well known that the accelerometer needs a constant supply power when it is working. However, on some small-scale or long-lifetime systems where the supply power is very limited, it is evident that the accelerometer doesn't meet these requirements. The micro-electro-mechanical systems (MEMS) inertial micro-switch as a kind of passive device doesn't consume electricity until an acceleration event occurs. Therefore, it can be used in some long-lifetime systems such as the internet of things in spite of the limited power [6–9].

Various types of laterally-driven inertial switches have been designed and proposed in our previous works [3,10–13]. Generally, for most of them the elastic cantilever beam as the stationary electrode is used to prolong to the contact time. The maximal stress of the L-shaped cantilever beam under applied acceleration 280 g is 245 MPa [11]. Although it is smaller than the yield strength (317 MPa) of the metal nickel, the optimization could be still carried out for improving the anti-shock capacity of the inertial micro-switch in the practical application. Based on our previous design, how to decrease the maximum stress of the cantilever beam is effective and feasible. With regards to this, in this paper, we design a novel micro-switch with the L-shaped cantilever beam used as the movable electrode, which is attached to the proof mass rather than

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the stationary electrode. The advantages of this design are that the stress is smaller and the cantilever beam is not easy to be broken when the device is shocked by a large acceleration.

In some practical application environments, the contact time of the inertial micro-switch is also a key factor which influences the signal identification performance of external circuit. For example, the short contact time will increase the difficulties of signal-processing and need very high signal identification performance of external circuit. In this paper, an inertial micro-switch with an elastic cantilever beam, which is attached to the proof mass, is designed and fabricated. The L-shaped cantilever beam in the designed micro-switch could effectively prolong the contact time by itself elastic deformation. And considering that the contact time is affected by the pulse width and the peak value of applied acceleration loads, the related simulation analysis, characterization and test will be also carried out in the present work. In addition, a compact constraint sleeve structure is also introduced in the designed inertial micro-switch to limit the random vibration of the proof mass and lower the off-axis sensitivity. Finally, the designed inertial micro-switch is fabricated on a quartz wafer by low-cost convenient multi-layer electroplating technology. And a dropping hammer system is used to test and evaluate the fabricated micro-switch.

2. Device design and simulation

2.1. Device design

A laterally-driven micro-switch with single horizontal sensitive direction is designed on an insulated quartz substrate. A compliant cantilever beam attached to the proof mass is proposed in this design, which can effectively prolong the contact time and endure a high shock. As shown in Fig. 1, the inertial switch mainly is made up of three parts. The first part is two L-shaped cantilever beams as the movable electrode, which is supported by the suspended proof mass with four serpentine springs. The second part is one block located in front of the proof mass as the stationary electrode. The third part is a barrier system which consists of two pillars at the back of the proof mass as the reverse direction protection pillars, eight fixed columns at the edge of the proof mass as the laterally limitation block and a sleeve with holes suspended by the eight lat-

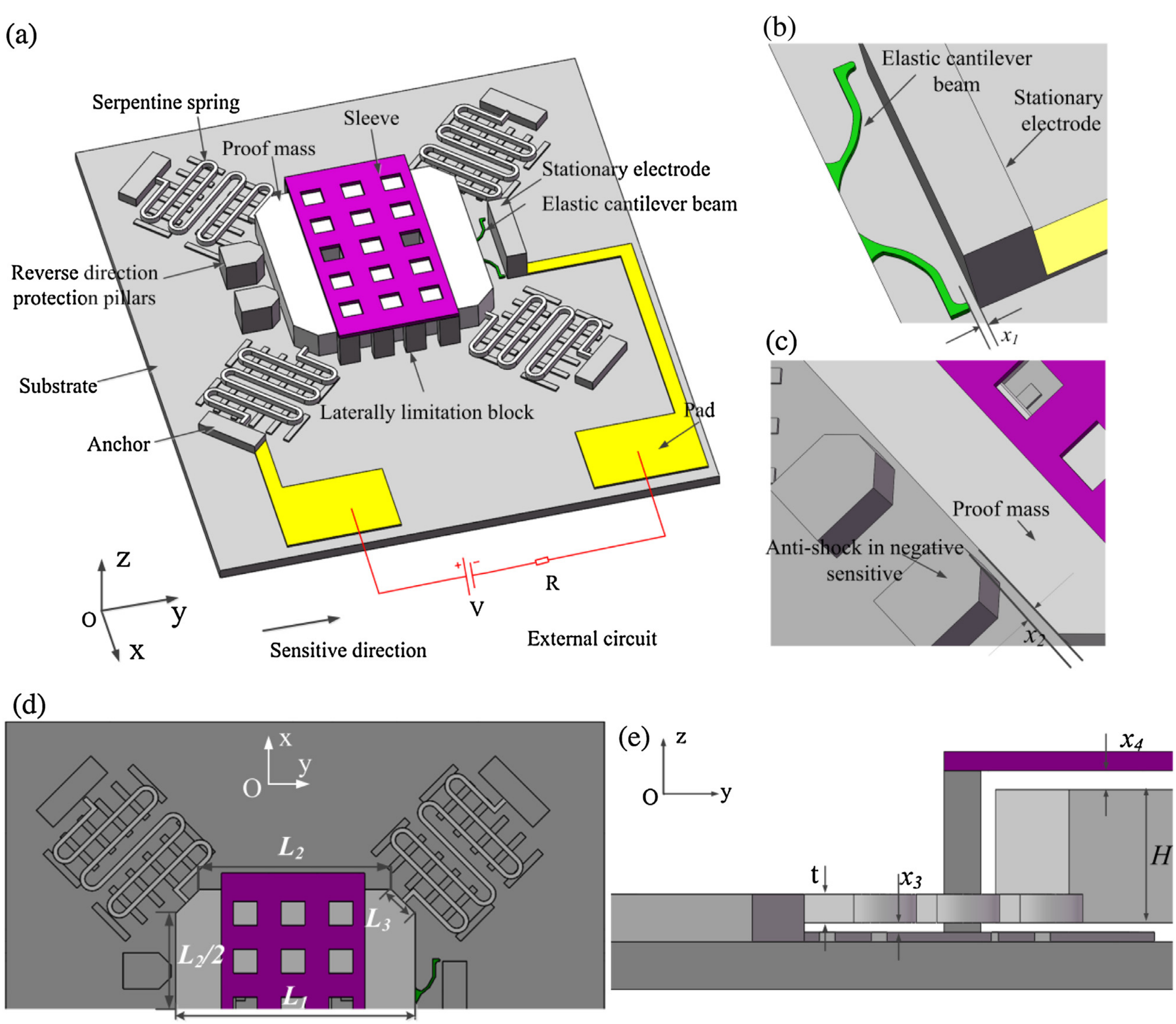

Fig. 1. The schematic diagram and structure parameters of the designed inertial micro-switch. (a) 3D sketch of the micro-switch; (b) The enlarged view of the novel shape elastic cantilever attached to the proof mass; (c)The gap between the proof mass and the shock resistance anchor; (d)Top view of one half of the laterally-driven inertial micro-switch device; (e) The side view of one-half structure.