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A Spring Design for Tri-axis MEMS Accelerometer by Multi-layer Metal Technology

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Abstract

This paper presents a spring design for tri-axis MEMS accelerometers fabricated by multi-layer metal technology. The proposed serpentine spring with multi-layer metal structure can suspend a high-density proof mass and provide three-axis suspension functionality. Moreover, the proposed spring structure enhances the design flexibility of the spring constant in each axis. The measurement results of the fabricated device have a good agreement with the designed characteristics.

1. Introduction

The performance of micro-electro-mechanical systems (MEMS) accelerometers is required to be further improved to realize potential future applications [1], and therefore we proposed a highly-sensitive MEMS accelerometer [2] by using multi-layer metal technology [3]. Fig. 1 shows a schematic image of a tri-axis MEMS accelerometer with multi-layer metal structures. High-density metal is used to increase the proof mass and to reduce the thermo-mechanical noise [2]. Accordingly, as reported in the previous work [4], spring constant has to be sufficiently high enough to suspend the proof mass against gravitational acceleration. In this work, we present a design of a tri-axis spring for a MEMS accelerometer fabricated by multi-layer metal technology. We also show the evaluation results of a fabricated device.

2. Spring Design

Spring Constant Analysis

As presented in reference [4], the design requirements of a spring for a highly-sensitive tri-axis MEMS accelerometer implemented by multi-layer metal technology are as follows; (I) sufficiently high spring constant to support the proof mass against gravitational acceleration, (II) tri-axis suspension functionality, and (III) design flexibility of spring constant. To meet the design requirements, we calculated the spring constants of serpentine springs by using an analytical model [5]. Fig. 2 shows the spring-constant analysis results of the

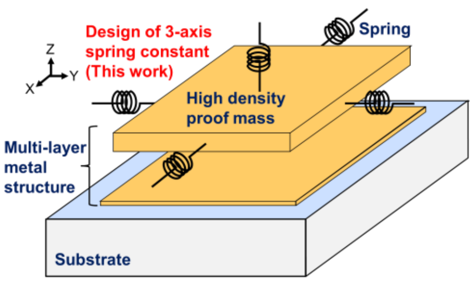
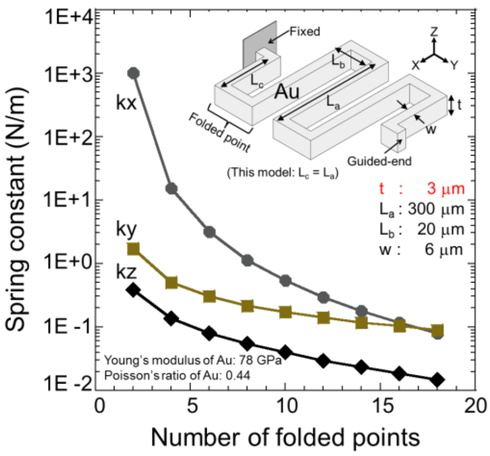
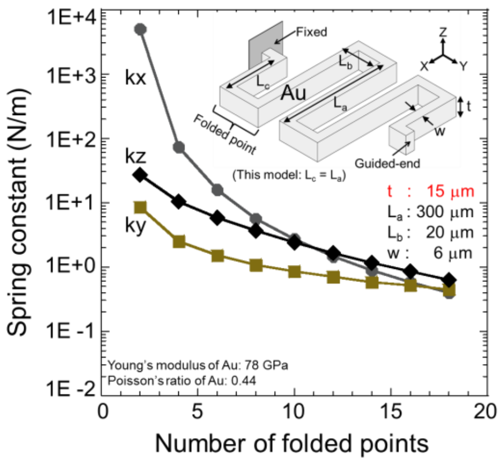


Fig. 1 Schematic image of a tri-axis MEMS accelerometer implemented by multi-layer metal technology.



(a)



(b)

Fig. 2 Analysis of serpentine spring structures. Spring thicknesses (t) are (a) 3 μm and (b) 15 μm.

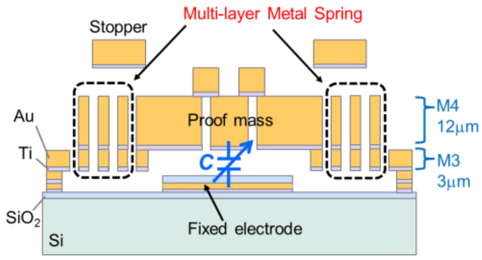


Fig. 3 Multi-layer metal spring structure integrated with a MEMS capacitive accelerometer.

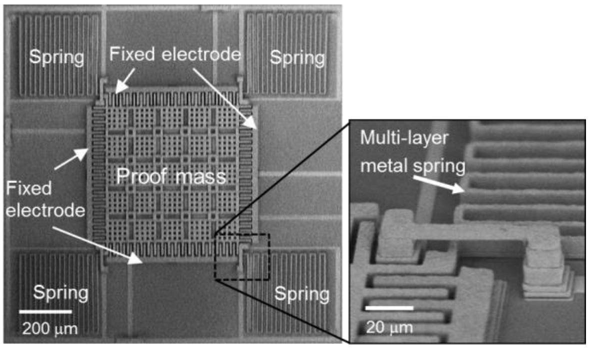


Fig. 4 SEM images of a tri-axis MEMS accelerometer with multi-layer metal serpentine springs.

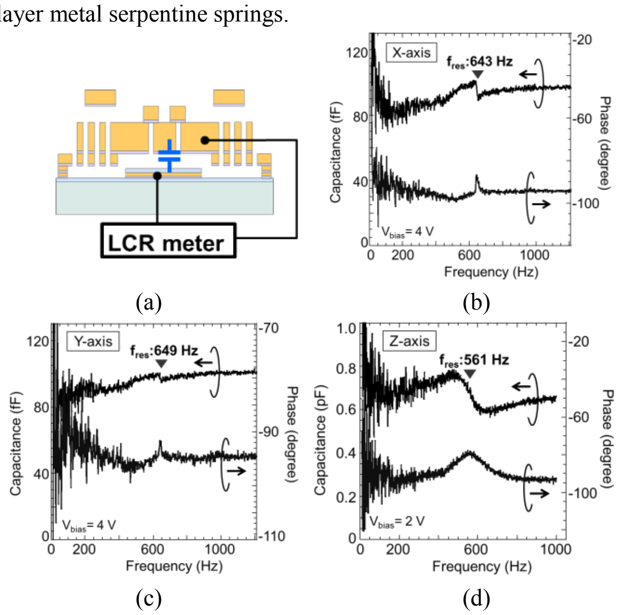


Fig. 5 Measured capacitance and phase as a function of frequency obtained by using HIOKI IM3533-01 LCR meter. (a) Experimental setup, (b) X-axis, (c) Y-axis, and (d) Z-axis characteristics.
f_{res}: Resonant frequency

spring thickness of 3 μm and 15 μm. Spring thickness of 15 μm achieves sufficient spring constants that can hold proof mass in typical multi-layer metal MEMS accelerometers [4]. Moreover, increasing the spring thickness enables us to design each spring constant in the same range, which is useful for tri-axis acceleration sensing with a single proof mass.

Spring Structure Design

Fig. 3 shows the proposed multi-layer metal spring structure. We designed serpentine spring for tri-axis sensing, and used M3 and M4 layers to achieve the spring thickness of 15 μm. To enhance the accelerometer-design flexibility and keep each layer thickness unchanged, we chose to use the combination of multiple metal layers.

Table I Measured Parameters

Axis	X	Y	Z
Range (G)	±3*	±3*	±3*
Proof mass (kg)	5.80×10^{-8} (5.27×10^{-8})*		
Resonant frequency (Hz)	643(667)*	649(668)*	561(872)*
Spring constant (N/m)	0.95(0.93)*	0.96(0.93)*	0.72(1.6)*

G: gravitational acceleration, *Design value

3. Experimental Evaluation

Fig. 4 shows the scanning electron microscope (SEM) images of a tri-axis MEMS accelerometer with multi-layer metal serpentine springs. The device was fabricated by using multi-layer metal technology [2]. The spring thickness is designed to be 15 μm as the cross-section schematic is shown in Fig. 3. We then experimentally evaluated the mechanical characteristics of the proof-of-concept device to verify the feasibility of multi-layer metal spring structure for tri-axis acceleration sensing. Fig. 5 presents the measured capacitance and phase as a function of frequency. Experimental setup is shown in Fig. 5(a), and the measurement result is shown in each axis from Fig. 5(b) to Fig. 5(d). Table I summarizes the measured and designed parameters of the developed device. The measured resonant frequencies and spring constants were consistent with the design values.

4. Conclusions

We have presented a design approach of spring structure for tri-axis MEMS accelerometers implemented by multi-layer metal technology. The proposed multi-layer metal spring with serpentine structure can suspend high-density proof mass and provide the design flexibility of the spring constant in each sensing axis. The measurement results of the fabricated device show a good agreement with the designed characteristics. Thus, we confirmed the feasibility of the multi-layer metal spring structure for tri-axis acceleration sensing.

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