Extended Abstracts of the 2017 International Conference on Solid State Devices and Materials, Sendai, 2017, pp497-498

J-7-04 (Late News)

A Tri-axis MEMS Accelerometer With a Gold Electroplated Single-proof-mass and Segmented Electrodes

Shota Otobe[1], Daisuke Yamane[1], Toshifumi Konishi[1,2], Teruaki Safu[2], Hiroyuki Ito[1], Shiro Dosho[1], Noboru Ishihara[1], Katsuyuki Machida[1] and Kazuya Masu[1]

[1] Tokyo Institute of Technology
4259 Nagatsuta-cho, Midori-ku, Yokohama, Kanagawa 226-8503, Japan
Phone: +81-45-924-5031 E-mail: yamane.d.aa@m.titech.ac.jp
[2] NTT Advanced Technology Corporation
3-1 Wakamiya, Morinosato, Atsugi, Kanagawa 243-0124, Japan

Abstract

This paper reports a novel tri-axis MEMS accelerometer with a single Au proof mass fabricated by multi-layer metal technology. We propose segmented electrodes to simplify the MEMS structure. The fabricated device shows capacitance change as a function of input acceleration in Z-, X- and Y-axis within the sensing range of 3 G. Brownian noise on each axis is evaluated to be below 300 nG/Hz$^{1/2}$ (G = 9.8 m/s^2).

1. Introduction

Microelectromechanical systems (MEMS) technology has potential to realize highly-sensitive small-sized accelerometers [1, 2]. We have developed the comb-type tri-axis accelerometer fabricated by multi-layer metal technology [3, 4]. From the viewpoints of design of MEMS devices, it is necessary to simplify the MEMS structures that utilize a single proof-mass to achieve small chip size.

In this work, we present the principle and evaluation results of a novel tri-axis single-proof-mass MEMS accelerometer fabricated by multi-layer metal technology. To simplify MEMS device structure, we propose segmented electrodes to sense tri-axes accelerations.

2. Design Concept

Fig. 1 represents a schematic image of the proposed accelerometer. An electroplated Au proof mass is suspended by folded sprigs. High-density of gold enables us to reduce Brownian noise on a small-sized proof mass and thus achieve high-resolution sensing [2]. Segmented electrodes are proposed for tri-axis acceleration sensing as shown in Fig. 2.

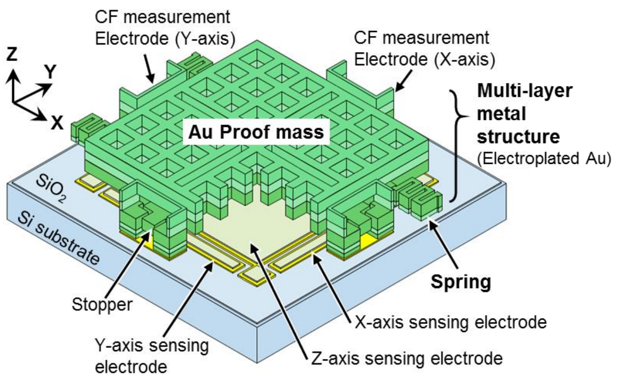

Fig. 1. Single proof-mass tri-axis segmented electrode MEMS accelerometer fabricated by multi-layer metal technology.

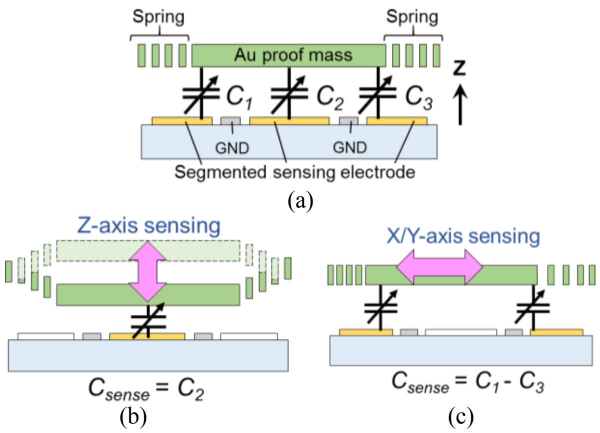

Fig. 2. (a) Cross-section view of the proposed accelerometer. (b) Z-axis, and (c) X- and Y-axis acceleration sensing.

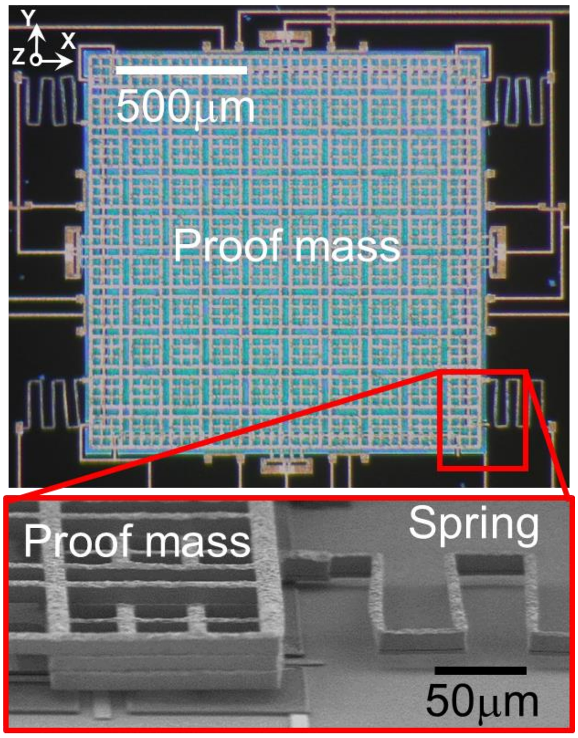

Fig. 3. Optical micrograph and SEM image of a fabricated MEMS accelerometer.

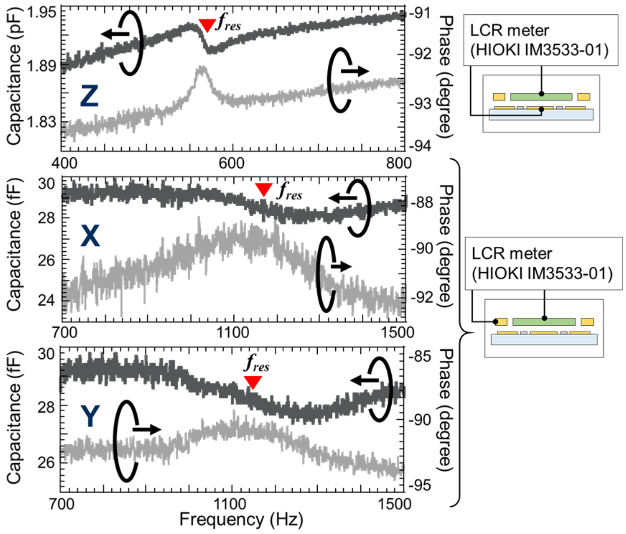

Fig. 4. Measured capacitance and phase as a function of frequency between the proof mass and fixed electrodes.

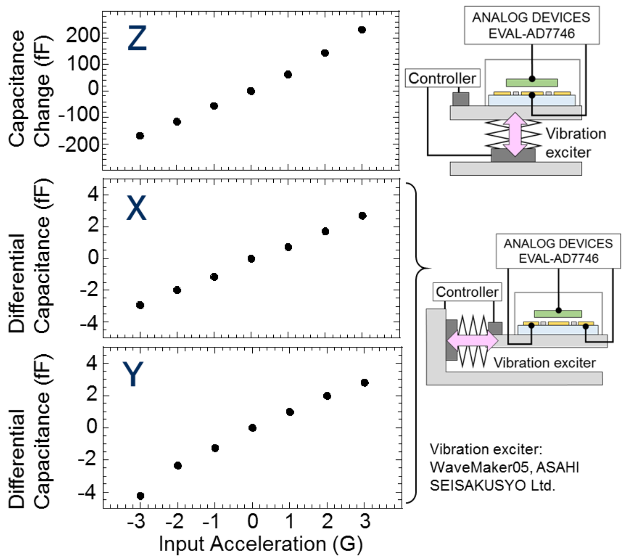

Fig. 5. Measured capacitance change/differential capacitance as a function of input acceleration between the proof mass and C_{sense}.

When sensing capacitance (C_{sense}) is C_2, Z-axis acceleration can be obtained (Fig. 2(b)). X- or Y-axis acceleration is obtained by differential sensing when C_{sense} is C_1-C_3 (Fig. 2(c)). Those segmented electrodes make it easy to design MEMS devices when compared to the previously reported tri-axis accelerometer with comb electrodes [4]. Fig. 3 shows the optical micrograph and the close-up scanning electron microscope (SEM) image of a fabricated MEMS accelerometer.

3. Evaluation Results

CF (capacitance-frequency) Measurements

Fig. 4 shows the measured capacitance and phase as a function of frequency evaluated by the LCR meter. Depending on sensing axis, we selected either Z-axis sensing electrode or C-F measurement electrode as shown in Fig. 1; we experimentally obtained resonant frequency (f_{res}) and quality factor (Q). Then, Brownian noise (B_N) was estimated by referring to [2] with the Boltzmann constant of 1.38×10^{-23} J/K at the temperature of 300 K. Measurement results and design parameters of the MEMS accelerometer are summarized in Table I. The results suggest that the actual B_N on each axis is evaluated to be below 300 nG/Hz$^{1/2}$ (G = 9.8 m/s^2), which has a potential to sense acceleration below 1 mG [5].

Table I Measured Accelerometer Characteristics

	Axis (Sensing range: ±3 G)		
	Z	X	Y
Proof mass (kg)	5.45×10^{-7} (4.95×10^{-7})*		
f_{res} (Hz)	862 (562)*	938 (1122)*	984 (1044)*
Q	25 (145)*	415 (165)*	84 (157)*
B_N (nG/√Hz)	220 (114)*	180 (114)*	83 (114)*

*Design value @RT

CG (capacitance-acceleration) Measurements

Measured capacitance change/differential capacitance as a function of input acceleration are shown in Fig. 5. The vibration exciter was used to apply input acceleration at 19.9 Hz. C_{sense} was selected according to the sensing scheme as shown in Fig. 2 and measured by the capacitance evaluation board. The results demonstrate C_{sense} change as a function of input acceleration in tri-axis within the sensing range of 3 G.

4. Conclusions

We proposed the single-proof-mass tri-axis segmented electrode MEMS accelerometer fabricated by multi-layer metal technology. The segmented electrodes was used to simplify the MEMS device structure and thus to achieve the ease of device design. The fabricated device demonstrated the capacitance change as a function of input acceleration in each axis within the sensing range. The actual B_N on each axis was evaluated to be below 300 nG/Hz$^{1/2}$. Those results confirmed that the proposed device structures would be useful for high-resolution MEMS accelerometers.

Acknowledgements

The authors would like to thank Dr. Y. Sakai, S. Iida, K. Kudo, and M. Fujinuma with NTT-AT Corp. for technical discussions. This work was supported by JST CREST Grant Number JPMJCR1433, Japan, and JSPS KAKENHI Grant Number 15K17453, Japan.

References

[1] G. Krishnan *et al.*, J. Indian Inst. Sci., **87** (2007) 333.
[2] D. Yamane *et al.*, Appl. Phys. Lett., **104** (2014) 074102.
[3] K. Machida *et al.*, IEEE Trans. Electron Dev., **48** (2001) 2273.
[4] D. Yamane *et al., Extended Abstracts of the 2014 International Conference on Solid State Devices and Materials* (2014) 974.
[5] J. Chae *et al.*, J. Microelectromech. Syst., **14** (2005) 235.