Extended Abstracts of the 2015 International Conference on Solid State Devices and Materials, Sapporo, 2015, pp786-787

Robustness of Integrated Stoppers for MEMS Accelerometer Fabricated by Multi-layered Metal Technology

Daisuke Yamane[1,4], Toshifumi Konishi[2], Motohiro Takayasu[1,4], Teruaki Safu[2], Hiroshi Toshiyoshi[3,4], Masato Sone[1,4], Kazuya Masu[1,4] and Katsuyuki Machida[1,2,4]

[1] Tokyo Institute of Technology
4259 Nagatsuta, 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
[3] Research Center for Advanced Science and Technology, The University of Tokyo
4-6-1 Komaba, Meguro-ku, Tokyo 153-8904, Japan
[4] Japan Science and Technology Agency CREST
4-1-8 Honcho, Kawaguchi, Saitama, 332-0012, Japan

Abstract

This paper presents micromechanical tolerance to the excess acceleration of integrated stoppers used in a MEMS accelerometer fabricated by multi-layered metal technology. To investigate the robustness, we have proposed a stopper model for multi-physics simulation. By employing the actual physical parameters, comparison of the simulation and the experimental results of the MEMS accelerometer suggests that the model is validated. The proposed multi-physics simulation can handle analysis of non-linear phenomena of the stopper behavior. The stopper has a potential robustness against acceleration of over 100 G (1 G = 9.8 m/s^2).

1. Introduction

There is an increasing demand of MEMS (microelectromechanical systems) accelerometers with wide sensing range and high resolution [1]. Thus, we have proposed an integrated MEMS accelerometers as shown in Fig. 1 [2]; we also have confirmed that the MEMS devices fabricated by multi-layered metal technology has capability of 20 G (1 G = 9.8 m/s^2) detection without stopper's mechanical failure [3]. In practical use, we have to investigate the robustness of the integrated stoppers for the MEMS accelerometer exposed to high-G acceleration. To analyze non-linear behavior of the stopper for integrated MEMS accelerometers, we have proposed an equivalent circuit model of the stopper implemented on an electrical circuit simulator. Multi-physics simulation was carried out to show the electrical capacitance change of the device as a function of input acceleration [4].

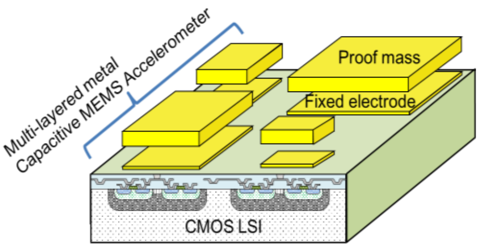

Fig. 1 Schematic image of integrated MEMS accelerometer.

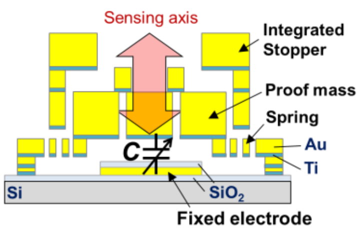

Fig. 2 Design concept of the MEMS capacitive inertial sensor.

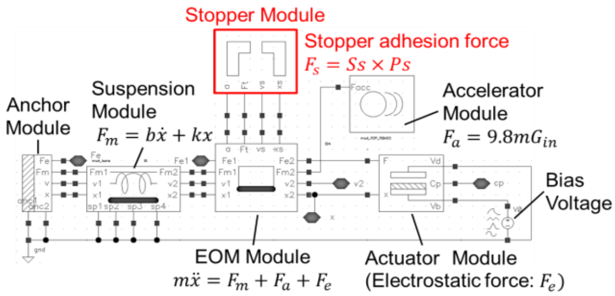

Fig. 3 Equivalent circuits of MEMS accelerometer with stopper.

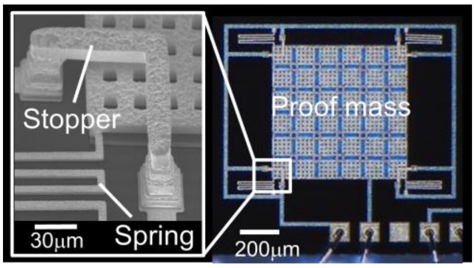

Fig. 4 SEM images of stoppers in a MEMS accelerometer (detection range < 3G) fabricated by multi-layered metal technology.

2. Stopper Model for Multi-physics Simulation

Fig. 2 shows the design concept of the MEMS capacitive inertial sensor. Input acceleration is detected by the capacitance change between the proof mass and the fixed electrode. The proof mass motion is limited by the stoppers at excess acceleration. To analyze the stopper effectivity, we have proposed a stopper model of multi-physics simulation as shown in Fig. 3. The stopper model includes stopper's adhesion force. Integrated stoppers for a MEMS

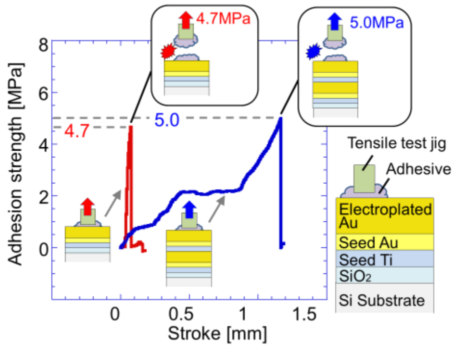

Fig. 5 Measured adhesion strength obtained by AG-X (Shimadzu, Corp.) with multi-layered metal samples fabricated by electroplating process used for integrated MEMS accelerometers.

accelerometer is shown in Fig. 4. The stopper adhesion force (*Fs*) is calculated by using the stopper anchor area (*Ss*) and the adhesion strength (*Ps*), which was experimentally evaluated by tensile test as shown in Fig. 5; the samples were fabricated by the same MEMS process [3] as used for multi-layered metal stoppers. From this test, the actual *Ps* was estimated to be more than 4.7 MPa.

3. Results and Discussions

Experimental evaluation

Fig. 6 shows the measured and simulation results of C-G (capacitance change as a function of input acceleration) characteristics. Stopper parameters of *Ss* and *Ps* were 18.1×10^{-10} m^2 and 4.7 MPa, respectively. Other simulation parameters of the MEMS accelerometer were extracted from ref.[2]. We confirmed that the stopper model for the multi-physics simulation could show the stopper effectivity when input acceleration was out of detection range.

Transient analysis

Fig. 7 shows the transient analysis results of the MEMS accelerometer by the multi-physics simulation. The results present the capacitance change associated with input acceleration, and predict the stopper break at the input acceleration of 11 kG.

Stopper robustness estimation

To estimate stopper robustness, we analyzed different values of *Ss* (*S1*, *S2* and *S3*) for the multi-physics simulation. The C-G simulation results indicate that the stopper could tolerate over 100 G.

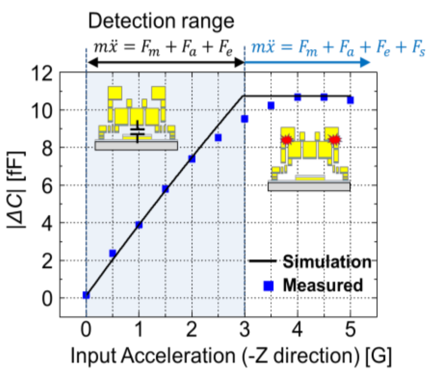

Fig. 6 Measured and multi-physics simulation results of C-G characteristics of the MEMS accelerometer.

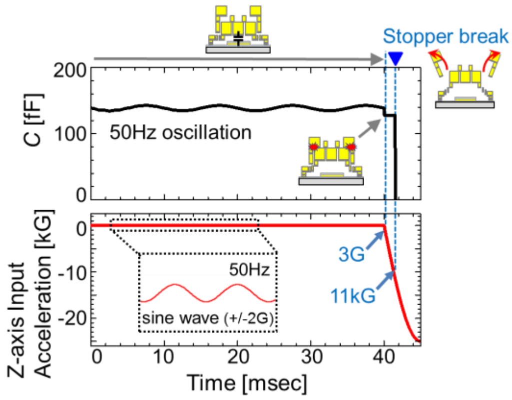

Fig. 7 Transient analysis of the MEMS accelerometer using the multi-physics simulation with the stopper module.

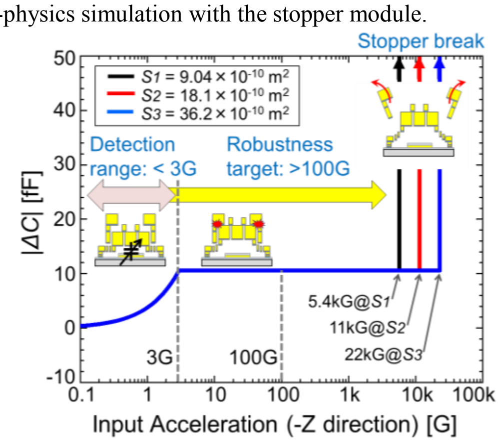

Fig. 8 Multi-physics simulation for the estimation of stopper robustness.

4. Conclusions

We have proposed the stopper model for multi-physics simulation. The stopper model describes the integrated stoppers for MEMS accelerometers fabricated by multi-layered metal technology. The multi-physics simulation with the stopper model was consistent with the experimental results. The transient and C-G analyses at the input of high-G acceleration have been successfully demonstrated to show the non-linear behavior of the stopper. These results suggest that our multi-physics simulation can predict the stopper robustness of the MEMS accelerometer. From the simulation results, it is confirmed that the stopper has the potential of the robustness at the acceleration of over 100 G.

Acknowledgements

The authors would like to thank Dr. T. Maruno, Dr. Y. Akatsu, M. Yano, K. Kudo, T. Matsushima, and M. Fujinuma with NTT-AT Corp. for technical discussions. This work was supported by JSPS KAKENHI Grant Number 15K17453.

References

[1] G. Krishnan *et al.*, *J. Indian Inst. Sci.*, **87** (2007) 333.
[2] D. Yamane *et al.*, *Jpn. J. Appl. Phys.*, **54** (2015) 087202.
[3] K. Machida *et al.*, *ECS Trans.*, **61** (2014) 21.
[4] T. Konishi *et al.*, *J. Microelectromech. Syst.*, **22** (2013) 755.
[5] R. Abdolvand *et al.*, *J. Microelectromech. Syst.*, **16** (2007) 1036.