SHOCK MITIGATED MICRO-ELECTROMECHANICAL SYSTEMS STRUCTURE

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ABSTRACT

We report a simple, yet effective, MEMS structure to mitigate the external mechanical perturbation, such as shock. A conventional single membrane can travel beyond allowed distance to be damaged upon an external shock. The excessive travel can be reduced by having an additional electrode to attract the membrane electrostatically. The added elements, in conjunction with fine control algorithm, mitigate the impact of shock. The dual membrane structure effectively reduces the travel distance by 37 %, upon deploying merely 0.5 V. The dynamic implementation of shock mitigation method, using an on-board accelerometer together, delivered successful *in-situ* mitigation of shock on a dual-membrane MEMS microphone.

INTRODUCTION

Despite many successful MEMS sensors/actuators penetrating in the market, several challenges still exist, including protecting the MEMS devices from the external perturbation. Many theoretical and experimental studies on the response to shock impacts have been explored, yet a small number of prior studies demonstrated the methods of mitigating the external shock impact. One group reported hard shock stops [1], which, tends to generate secondary impacts and causes undesirable device oscillations. Nonlinear springs and soft coatings were suggested by a group in order to improve shock mitigation skills [2]. Another group presented adaptive control to reduce vibration-induced bias errors in inertial sensors [3]. Those were either ineffective or required sophisticated structures and algorithms. In this work, we attempt to mitigate the impact of external shock by adding an electrode to control the excessive movement of a membrane via electrostatic stimuli and restoration force in a dynamic behavior upon the shock.

RESULTS

In a conventional structure, the movable membrane travels beyond allowed distance to be damaged (Figure 1(b&d)) upon an external shock (Figure 1(a)). By adding an additional electrode on top of the membrane to attract the movable membrane, the excessive movement can be effectively reduced, as shown in Figure 1(c&e).

Figure 1: Schematics; (a) Shock load profile; (b) Single movable membrane device; (c) Dual membranes (a movable membrane and an electrode) device; (d) Single membrane device upon shock; (e) Dual membranes device in presence of shock.

We fabricated a fully CMOS-compatible device, using n-doped polysilicon as structural layers and SiO_2 as sacrificial layers, as illustrated in Figure 2.

Figure 2: Process flow of shock-mitigated dual-membrane structure. (a) Deposit Si_3N_4 ; (b) Define substrate contact; (c) Deposit and pattern the 1st sacrificial layer; (d) Deposit Si_3N_4 /Polysilicon/ Si_3N_4 ; (e) Etch 1st membrane (Si_3N_4 /Polysilicon/ Si_3N_4); (f) Deposit and pattern 2nd membrane sacrificial layer; (g) Deposit 2nd membrane (Si_3N_4 /Polysilicon); (h) Etch 2nd membrane (Polysilicon/ Si_3N_4); (i) Define and deposit metal pad; (j) Remove sacrificial layers.

Unlike prior studies that demand incorporating sophisticated structures, we added one additional layer to mitigate the shock effect. The top view of the device is shown in Figure 3.

Figure 3: Top view of fabricated dual membranes device.

First we validated our method by theoretical modeling. The electrostatic attraction between the additional electrode and the movable membrane subdues the excessive travel distance of the movable membrane by 37%, using merely 0.5 V. We performed the drop tests from 15 cm high, corresponding to ~40g calibrated by a commercial accelerometer, as shown in Figure 4.

Figure 4: Experiment Setup: MEMS devices along with readout interface sit on a drop test platform. The platform folds to let the board drop vertically. The outputs of DUT were recorded through DAQ.

The drop tests show that the shock-mitigated scheme reduces the excessive movement of the membrane by different voltages between the electrode and membrane. The travel distance of the conventional structure without shock-mitigated electrostatic force was compared as a control to demonstrate the effectiveness of the shock-mitigation. The dual membrane shock-mitigated structure dramatically reduced the membrane travel distance (Figure 5).

Figure 5: Experimental results: response upon a shock of $\sim 40g$. (a) Shock response of single membrane device. (b) Shock response of dual membrane device reduced 37% by using merely 0.5 V between electrode and membrane.

We also imposed acoustic excitation of 96 dB SPL using a speaker along with the shock, 22 cm height, corresponding to $\sim 100g$, to emulate realistic setting of MEMS microphones in operation. The experimental results have good correspondence with the theoretical calculations, having a discrepancy of less than 25%, in Figure 6.

Figure 6: Trend line of shock response with acoustic excitation under different potential differences (0 V, 1 V, 1.5 V). g_m is the travel distance of membrane, g_0 is the nominal gap distance. V_A is the voltage between electrode and membrane. V_B is the voltage between membrane and substrate.

Finally, the shock mitigation method was demonstrated as dynamic *in-situ* implementation using a commercial accelerometer, MMA1200KEG from Freescale Inc., to trigger the on-board micro-controller, Arduino Zero from Arduino Inc., to control the electrostatic force between electrode and membrane. Upon the external shock, the accelerometer triggers the micro-controller to control the electrostatic force within 200 μs before the membrane reaches its maximum displacement (Figure 7(a)).

Figure 7: Dynamic *in-situ* control of shock-mitigation: (a) The accelerometer triggers the micro-controller, at threshold voltage of $> 1.16 V$, to control the electrostatic force between electrode and membrane within 200 μs . (b) Shock response without any mitigation. (c) Shock response with mitigation of the dynamic control reduced the membrane travel distance by 50% using 1.56 V.

CONCLUSIONS

A dual-membrane MEMS structure was presented to effectively mitigate the external perturbation, including shock. We elaborately demonstrated the validity of the approaches based on theoretical and experimental results. A smart shock mitigation system consists of an accelerometer and controller; the dual-membrane structure showed that it automatically senses the shock, controls the electrostatic force to mitigate the shock response, and make compensation to restoration force in order to reduce the excessive movement of membrane.

ACKNOWLEDGEMENTS

The authors appreciate the support from National Science Foundation (EPDT-1101797).

REFERENCES

- [1]. L. B. Wilner, "A high performance, variable capacitance accelerometer," Instrumentation and Measurement Technology Conference, 1988. IMTC-88. Conference Record., 5th IEEE
- [2]. S. W. Yoon, N. Yazdi, N. C. Perkins, and Khalil Najafi, "Micromachined integrated shock protection for MEMS," Sensors and Actuators A, vol. 130-131, pp. 166-175, 2006.
- [3]. M. W. Weber, "Adaptive circuits and methods for reducing vibration or shock induced errors in inertial sensors," U.S. Patent No. 7,401,515. 22 Jul. 2008

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