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A Novel Sensor Structure and its Fabrication Process for Integrated CMOS-MEMS Accelerometer

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1. Introduction

Motion sensors with a wide range of detectable acceleration are increasingly in demand in the medical and healthcare industries to monitor human daily activities in a variety of living environments. Moreover, further miniaturization of motion sensors would greatly benefit many of the aforementioned application fields in terms of human body attachment or embedding into clothes for continuous measurements. In the conventional MEMS (micro electro mechanical systems) accelerometer designs, however, the size and detection range are limited by the material or structure of proof mass [1]. In this paper, we report a small-sized MEMS accelerometer in an arrayed form by using the gold electroplating as a post-CMOS (complementary metal oxide semiconductor) process method, which enables us to implement metallic MEMS devices onto a sensing LSI (large-scale integrated circuits). High density of gold for proof mass has successfully enhanced the size reduction and high sensitivity for the accelerometer.

2. Accelerometer design

As schematically shown in Figure 1, we propose an ultra-compact arrayed CMOS-MEMS accelerometers that is capable of detecting a broad range of acceleration by integrating various weights of proof masses and adjusting the flexibility of the serpentine suspensions. In order to downscale the chip size of MEMS accelerometers without compromising the sensitivity, the proof mass area should be substantially reduced. Mechanical noise of a proof mass can be gauged by Brownian noise (B_N) as described in the following equation:

$$B_N = \frac{\sqrt{4k_B T b}}{m} \qquad (1)$$

where k_B, T, b, and m are the Boltzmann constant (1.38×10^{-23}J/K), the absolute temperature, the viscous damping coefficient, and the proof mass of an accelerometer, respectively. Figure 2 compares the effect of Brownian noise on the proof masses made of different materials, indicating gold as a leading candidate material for small-sized and low-noise MEMS accelerometers. Our

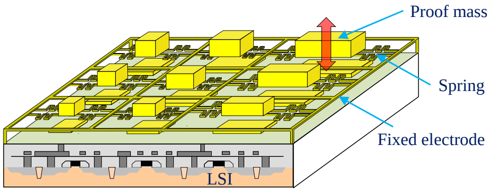

Fig. 1 Schematic image of an arrayed CMOS-MEMS accelerometer.

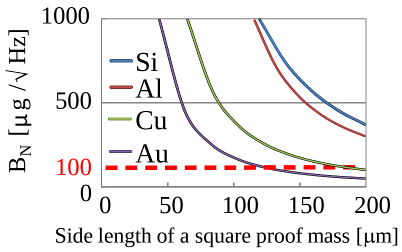

Fig. 2 Analytical modeling of Brownian noise characteristics.

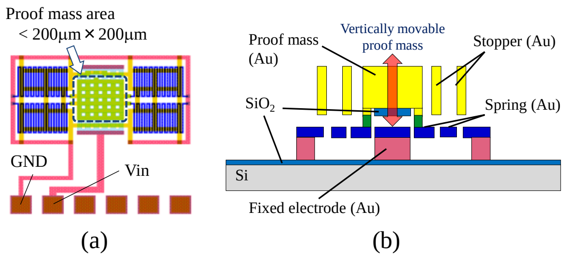

Fig. 3 A single-axis MEMS accelerometer with a gold proof mass.

target value of the B_N can be below 100 μg/√Hz to provide a sufficiently low noise floor [2]. Figure 3(a) and (b) illustrate the layout pattern and the cross-section view of the designed CMOS-MEMS accelerometer, respectively. The size of the proof mass suspended by the springs in a different gold layer is smaller than 200-μm square due to the large density of gold. The accelerometer can measure vertical motion by sensing the capacitance shift between the movable proof mass and the fixed bottom electrode; SiO_2 underneath the proof mass is formed to avoid sticking between the facing electrode surfaces, and the stoppers are used to prevent lateral over-swing of the proof mass.

3. Fabrication process

Figure 4 shows the basic process flow for the MEMS accelerometers compatible with post CMOS-LSI integration at a low process temperature below 400°C. Firstly, Ti/Au seed layers deposited by the vacuum evaporation were photolithographically defined for fixed electrodes and interconnections. Electroplating was used to add the thickness of gold [Fig. 4(a)]; this metallization method was applied in every metal layer process as follows. Photosensitive polyimide was then spin-coated and annealed at 300 °C as a 1st sacrificial layer supporting mechanical springs [Fig. 4(b)]. After depositing another sacrificial layer of photosensitive polyimide, via holes for electrical interconnections were made, and then SiO_2 was deposited by sputtering and patterned as a capacitive film for a movable electrode [Fig. 4(c)]. The proof mass and stopper structures were built on the upper surface [Fig. 4(d)]. Finally, all the sacrificial layers were removed by dry etching [Fig. 4(e)].

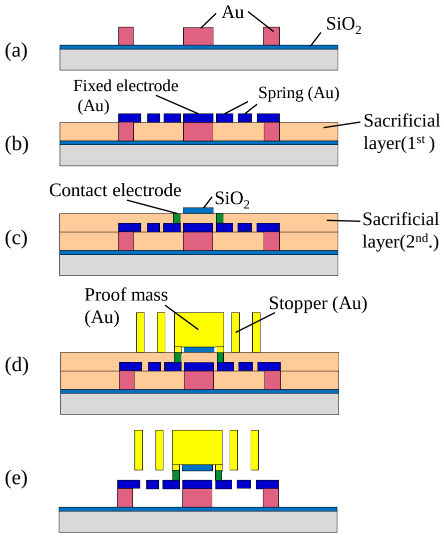

Fig. 4 Microfabrication process.

4. Experimental results

The proposed MEMS accelerometer has been successfully developed through the newly proposed microfabrication process, as shown in the SEM (scanning electron microscope) micrograph in Figure 5. By applying a direct-current voltage between the movable and fixed electrodes, as the feeding route is shown in Figure 3(a), C-V characteristics was measured as plotted in Figure 6. Pull-in operation at a voltage of 6.4 V without sticking failure was confirmed by observing the hysteresis curve on the graph that also provides the actual spring constant on the device. In table I, we have compared the design and measured parameters including the experimentally obtained mechanical resonant frequency of the accelerometer; the measured values have been in good agreement with the designed models. Furthermore, the B_N was measured to be 90.6 μg/√Hz. These experimentally obtained results have verified the feasibility of the gold electroplating for CMOS-LSI compatible process.

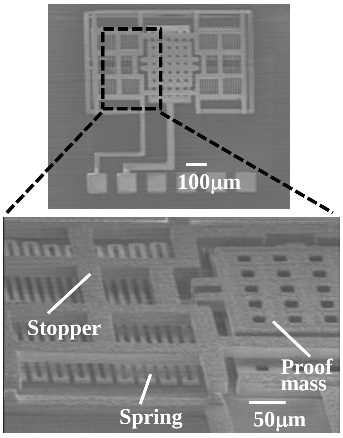

Fig. 5 SEM image of a unit of MEMS accelerometer.

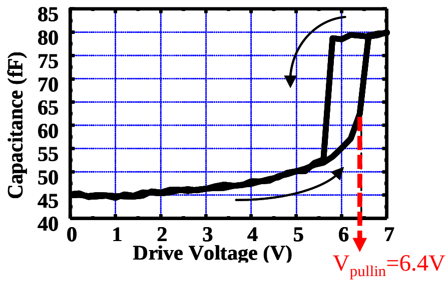

Fig. 6 Measured C-V characteristics.

5. Conclusions

We have successfully confirmed the electrostatic operation and process compatibility of the novel CMOS-MEMS accelerometer by using gold electroplating. The gold proof mass embedded into the developed MEMS accelerometer has enabled small-sized and sufficiently-low Brownian noise design in order to achieve an arrayed CMOS-MEMS accelerometer for a wide detectable range of acceleration.

Table I Comparison of device parameters

	Design	Measured	Unit
V_{pullin}	6	6.4	V
Spring constant	0.20	0.26	N/m
Mechanical resonant frequency	687	1037	Hz
Brownian noise	51.6	90.6	μg/√Hz

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