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Electrostatically Levitated Ball MEMS

Risaku Toda, Nobuo Takeda, Takao Murakoshi[1], Shigeru Nakamura[1] and Masayoshi Esashi[2]

Ball Semiconductor Inc. 415 Century Parkway, Allen, TX 70013
Phone: +1-972-359-2400 Fax: +1-972-359-2413 E-mail: rtoda@ballsemi.com
[1]Tokimec Inc., MRD Center 333-4 Higashi-machi, Yaita 329-2136
[2]Tohoku University, New Industry Creation Hatchery Center
01 Aramaki-Aza-Aoba, Aoba-ku, Sendai 980-8579

1. Introduction

Conventional semiconductor industry focuses on making integrated circuits and MEMS (Micro Electro Mechanical System) on flat-surface wafers. Instead of the conventional semiconductor industry, we are challenging to make integrated circuits and MEMS devices on a 1-millimeter sphere (Ball™) as an alternative technology [1]. Roundness, smallness, symmetry, closed surface topology, 3-dimensional feature, and about 3 times larger surface area than a 1-milimeter square chip are unique aspects of the spherical shape.

The fundamental concept of our fabrication process is manufacturing Balls in a continuous, enclosed tube like a chemical plant. Basically, Balls are running through the tube during the process, except the exposure process and the bumping process. To realize this technology, we are developing a spherical single crystallization technology during free-fall [2], continuous processing technologies in small diameter tubes, a lithography technology for use on spherical surfaces, a 3D layout design methodology, and a clustering technology to connect a Ball and a flat chip as well as many Balls like a molecule.

After successful development of the world first NMOS integrated circuit on the spherical surface, we are exploring Ball unique devices utilizing the unique features of the spherical shape. Benefited by highly symmetrical 3D structure, closed topology of the ball, and surface process capability to fabricate a 3D structure, 3-dimensional inertia sensor is one of the most interesting applications of the Ball technology [3].

In this paper, an electro-statically levitated 3-axis accelerometer and an omni-directional clinometer are described as unique applications of the Ball semiconductor technology.

2. Device Structure

The 3-axis accelerometer consists of an outer shell and an inner core as shown in Figure 1. There is a narrow and precise gap between the shell and the core. At least 6, typically 12 electrodes for the electrostatic actuation and the capacitive sensing are placed at the inner surface of the shell. Figure 2 shows electrodes on a 1milimeter sphere after patterning and bumping.

In the case that the core moves freely inside the shell, an omni-directional clinometer is obtained by utilizing this structure. In this case, the capacitance change tells us a tilting angle including up side down.

In the other case that the core is levitated and kept in the center by electrostatic force, the intensity of the electrostatic force tells us the acceleration. The mass of the 1-millimeter core is relatively large compared with the typical 2D surface micro-machined sensors.

In another case that the inner core will be electro-statically levitated and rotated, a gyroscope can be realized. This principle of the gyroscope is well known to have the highest sensitivity among various gyroscopes [4].

3. Fabrication process

A key process to fabricate 3-axis accelerometer is a sacrificial layer etching using xenon difluoride (XeF2), which generates the gap. A beauty of the XeF2 etching is its extremely high selectivity between the Silicon and other

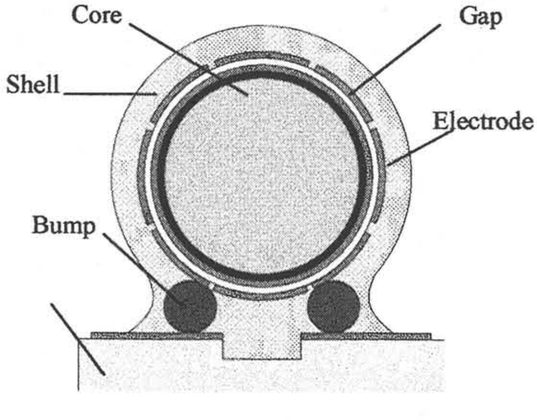


Figure 1. Cross section of 3-axis accelerometer

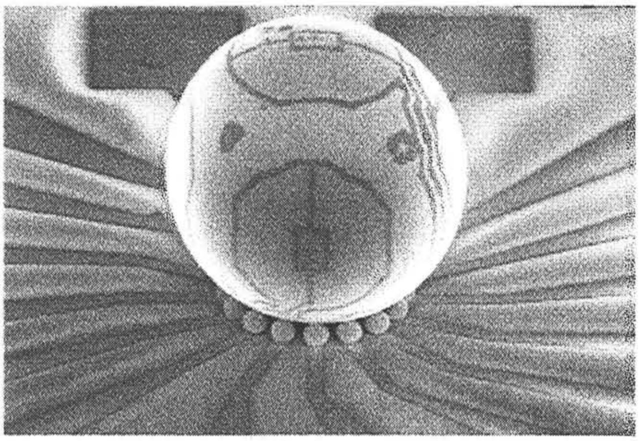
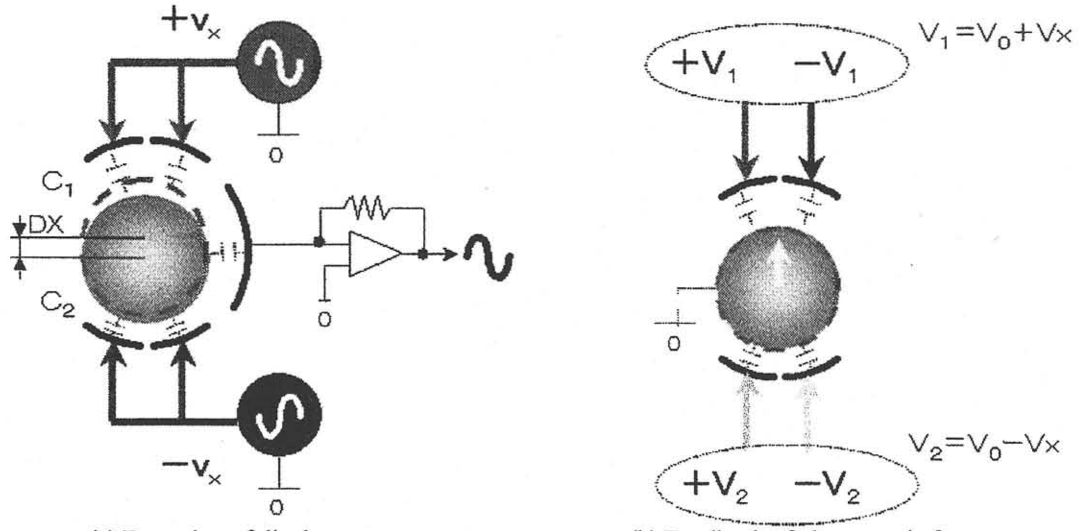


Figure 2. SEM picture of 3-axis accelerometer after patterning and micro-ball bump process



(a) Detection of displacement (b) Feedback of electrostatic force

Figure 3. Control principle of 3-axis accelerometer

materials. This etching process is performed at the final step of the process flow to avoid the damage of the shell from excessive stress of the micro-ball bump process.

The other interesting aspect is the gas permeable shell approach [5]. This shell enables to etch the sacrificial layer without any patterning on the shell. The structure can be sealed against the atmosphere easily after the sacrificial etching.

4. Electrostatical control

The position of the core is controlled by a closed-loop servo system [6]. The displacement of the core is detected by sensing the capacitance of the electrodes and electrostatic actuation is performed using the same electrodes as shown figure (a) and (b), respectively. The electrode for one direction consists of two leaves and opposite polarity voltage is applied to keep the core potential as almost zero.

Figure 4 shows a detection of a tilt angle using the 3-axis accelerometer. In this case, two axes out of three are electrostatically controlled. The accuracy of the angle detection is 0.6 degree.

5. Conclusion

We have developed an electro-statically levitated 3-axis accelerometer to utilize unique features of the sphere. A core and shell structure fabricated by a surface micro-machining method and a closed loop control system of the core position are demonstrated. The spherical shape is useful for truly three-dimensional and precise inertia sensors.

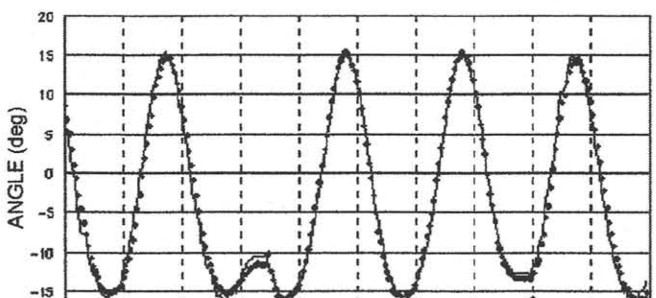


Figure 4. Detection of tilt angle using 2-axis electro-statically controlled Ball accelerometer [7].

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