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Physical Sensors in MEMS Technology

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1. Introduction

MEMS technology has attracted interest recently. It is expected that this technology allows the development of smart products and the computational ability for micro sensor and actuator systems. It can expand possible applications with large volume and low cost.

This paper includes a brief survey of physical sensors in MEMS technology and introduction of some physical sensing systems developed by our laboratory.

2. History of MEMS and Its Current Status

As well known, MEMS, Micro Electro-Mechanical Systems, can be defined as a highly functional combination of microelectronics and micromechanics. Actually, this concept of MEMS for sensing devices is not so novel and it can retrospect to 1980's. At that time, this concept was called as "Intelligent sensors", "Smart sensors" and "Integrated sensors." These words, including MEMS, have almost the same meaning. In 1980's, some famous person defined such words as "the device with signal conditioner, compensator, exception process and flexible algorithm in one small chip[1,2]." A microprocessor based system with sensors and A/D converters was commonly assumed for this system. However, in actual practice, such microcomputer based implementation was not realised because it heavily reduced fabrication yield and increased the device size and cost by the production technology at that time. Nevertheless, some researches for simple integration of interface circuitry into the sensor chip have begun. In almost cases, bipolar analog circuitry was incorporated with the sensor elements. Examples include integrated magnetic sensors[3], pressure sensors[4] and acceleration sensors[5], in which amplifiers, switching circuitry and simple temperature compensators were integrated together with sensing elements. Though some researches have progressed, a few practical devices were available in the market at that time.

Now, the technical-level has been drastically improved in this 20 years. Todays, "True" intelligent and "Large scale" integrated sensors can be realized in MEMS technology. Figure 1 shows examples of such modern and highly functional MEMS sensors in the market. All devices have an complete peripheral circuitry for stable operation and easy use such as an amplifier, signal compensator, complex driving circuitry, trimming or adjustment circuitry, analog to digital converter, and digital interface circuitry as well. For usual operation, they require only power supply (or in some cases, decoupling capacitors) and provide several voltage order output signal or even digital output. Now, we are completely ready to realize an old days dream, microprocessor based intelligent sensors.

3. Examples of physical sensors in MEMS technology

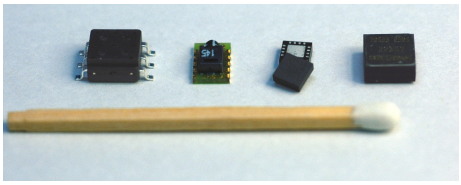

Fig. 1 Modern sensors in MEMS technology. From left to right : Pressure sensor (Fujikura Ltd.), humidity with temperature sensor (Sensirion Inc.), 2-axis acceleration sensor (Analog devices Inc.), and gyroscope(Analog devices Inc.).

In the following, some physical MEMS sensors from our laboratory will be briefly introduced.

2-Dimensional Gyroscope

Figure 2 shows a 2-dimensional gyroscope which includes rotational disk with support beams[6]. The sensing structure is vacuum sealed by Pyrex glasses. The reference vibration (rotational vibration) is excited by electrostatic force generated using comb actuators at fringe of the disk. The Coriolis force by applied angular velocity makes a torque around x or y axis according to the direction of the applied angular velocity resulting in the differential capacitance change between the silicon disk and fixed electrodes on the glass substrate. Because this structure has symmetry of 4-fold rotation, the orthogonal components of the angular velocity can be detected simultaneously. Figure 3 shows an example of measured characteristics of this device.

Vibratory Beam Accelerometer

In most cases, during the design of MEMS devices, the production cost and mass-producibility are matters of primary concern rather than the resolution or absolute stability. However, there are many applications that require high resolution and high stability such as vehicular navigation without

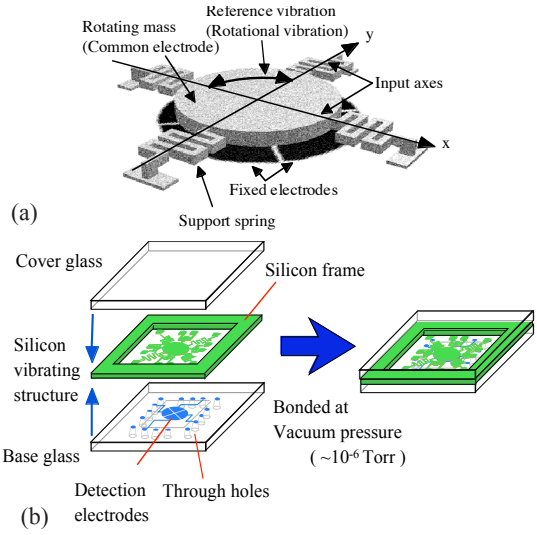

Fig. 2 Basic concept (a) and wafer level assembly (b) of 2-dimensional gyroscope.

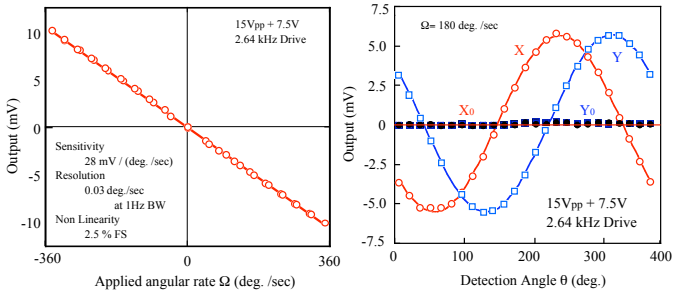

Fig. 3 Measured characteristic of 2-dimensional gyroscope.

GPS, space application, detection of preliminary tremors of an earthquake and so on. We are studying vibratory beam accelerometers and their control circuitry for such applications. The vibratory beam accelerometer, which is one of resonant-type sensors, essentially has both high resolution and high stability. Figure 4 shows the device photograph[7]. The device has a proof mass suspended by 2 support beams and 2 detection beams. On each detection beams, a driving wiring and detection wiring are formed. In the magnetic field, AC current through the driving wiring excites the vibration to the beam and detection wiring generates electric motive force according to the vibration of the beam. By feed back circuit, the beams can be vibrated at their own resonance frequency. Applied acceleration to the detection axis generates expansion and compression force to the detection beams resulting in the differential change of resonance frequencies of the beams. This change in resonance frequency is an output of the device. In order to realize accurate measurement of resonance frequency, the design of driving circuitry is important. We apply analog/digital mixed circuit for this purpose. The

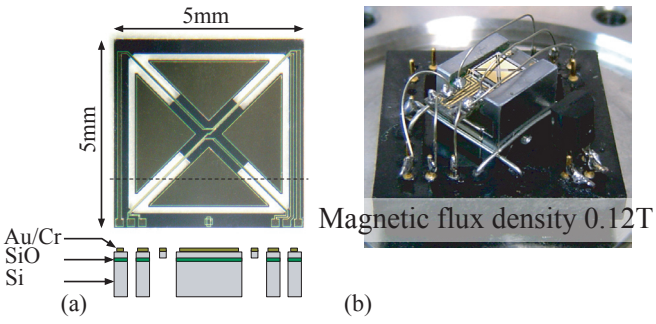

Fig. 4 Vibrating beam accelerometer: silicon structure (a) and chip with magnetic circuit (b).

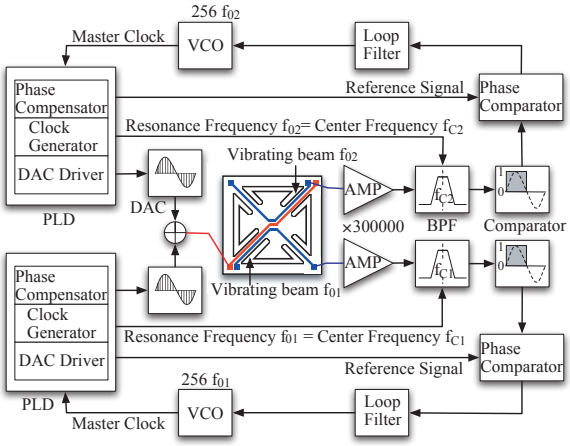

Fig. 5 Interface electronics for vibrating beam accelerometer.

details are omitted here but block diagram of the system is shown in Fig. 5. Figure 6 is the sensing characteristics of the system.

Multi Environmental Sensing System

Miniaturized and multi environmental sensing system is useful for many application, for example, monitoring of environmental circumstances during transportation, remote monitoring of activities of children and patients, monitoring of day to day physical load and condition of a man for health care, and so on. We designed and fabricated the device with such capability[8]. The device shown in Fig. 7 includes a 3-dimensional acceleration(or shock) sensor, (atmospheric) pressure sensor, humidity sensor, temperature sensor and peripheral circuitry for individual sensors on a 10 x 15 mm^2 single chip. It also has power-down circuitry for battery operation. When a logging or wireless communication function is integrated with this chip, many applications mentioned above will be available. Now we are trying to integrate a logging and communication capability with this chip. And more, assuming to attach this system to the human body for health care and monitoring, we are developing sensing elements for body temperature and pulse.

4. Conclusions

Brief history and current status of MEMS, and a part of our activity were presented. Now, the MEMS technology has become to be an essential technology of the microelectronics, and it has been advancing year after year, following Moore's Law. I believe an MEMS may hold great promise for the future.

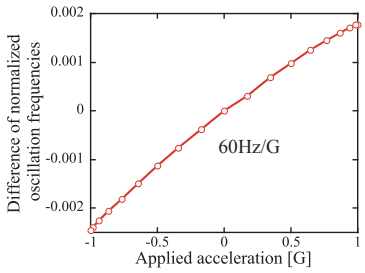

Fig. 6 Measured characteristic of VBA; Some non-linearity due to out-of-axis sensitivity can be seen in this device.

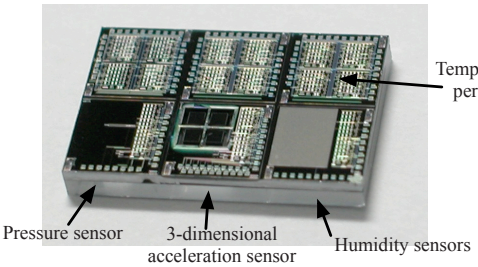

Fig. 7 Multi-environmental sensing system. Size: 15 x 10 x 1 mm^3.

References

[1]S.Middelhoek et. al., Transducers'85, (1985)2.
[2]R.A.Breckenridge et. al., Proc. AIAA/NASA Conf. on Smart Sesnors, (1978),1.
[3]T. Nakamura et. al., Sensors and Actuators, A21-A23 (1990)762.
[4]K. Yamada et. al, Sensors and Actuators, 4 (1983)63.
[5]H. Muro et. al., Proc. Micro System Technologies'92 (1992)233.
[6]T. Fujita et. al., Sensors and Actuators, A97/98 (2002)527.
[7]Y. Miki.et. al. APCOT 2006, MPS-A0497(2006).
[8]T. Fujita et. al., Sensors and Actuators,A97/98, (2002)527.