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Current Status and Topics of MEMS Sensors

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1. Introduction

Nowadays, MEMS (Micro Electro Mechanical Systems) technology is in the limelight and many MEMS devices, especially sensors, are widely available on the market. At the beginning, the MEMS technology was derived from integrated circuit (IC) technology[1], however the MEMS technology progressed different way from IC technology. For example, in IC technology, extreme miniaturization, increasing wafer size, and reducing defects are the main issues, whereas fast and deep etching, wafer level packaging, and fusion with functional materials such as PZT and polymer are attracting attention in the MEMS technology[2]. However, in recent years it seems that these technologies meet again in current sensing devices as cooperation of MEMS device with latest LSI in a package level. In this paper, current status and topics of such MEMS sensors will be discussed.

2. MEMS sensors

MEMS sensors in fashion

Many MEMS sensors are in the market now, e.g. pressure sensors, temperature/humidity sensors, flow sensors, microphones, acceleration sensors, gyroscopes, and various bio sensors. The most noteworthy sensors are inertial sensors (i.e. acceleration sensor and gyroscope)[3,4], which have a movable structure and peripheral circuitry in one small package. They are already incorporated into many popular products, such as video and still cameras, handy phones, laptop computers, automobiles, pedometers, and so on. They are low-cost, mass producible, small and light weight, and low-power consumption, which are major merits of MEMS technology. In the following, current status of some MEMS sensors, as inertial sensors in the beginning, will be described.

Acceleration sensors

The MEMS acceleration sensors are very well developed since they have been used for airbag control of automobiles, and are widely used for many products. Today, acceleration sensors are incorporated even into video game such as Nintendo's Wii[5].

The trends of MEMS acceleration sensor development are further miniaturization, cost reduction, 3-axis sensing, and digital processing in one package. Almost all acceleration sensors have an integrated circuitry in one chip, in which the sensing structure is monolithically integrated together with integrated circuitry or hybrid integration with a LSI chip. The monolithic integration is thought to be ultimate or complete style, but it seems that the hybrid integration is more practical and effective because one can perform optimum design for both sensor structure and circuitry, individually.

Inertial sensors generally have a movable structure that travels with the applied inertia. In order to secure the movement of the structure, the early devices used a can or ceramic package that has a cavity or free space in the package. This is a simple solution but the cost reduction and miniaturization are greatly limited. Moreover, for dicing of the wafer, special attention is required because the movable structure may be exposed to cooling water or cutting chips. Currently, these problem can be solved by the use of wafer level packaging or bonding technology as shown in Fig. 1. In this scheme, the sensor structure is hermetically and electrically sealed by silicon cap structure using soldering, eutectic bonding and so on in a wafer level[6]. Thus the wafer can be easily diced and molded as usual integrated circuits and extreme miniaturization and low cost can be achieved. Thus the packaging technology is a key factor for success in business. Currently, the size and price of the three dimensional acceleration sensor in MEMS technology are around 3x3x1.5 mm^3 and less than 3 dollars for mass production, respectively. Power consumption is also small, around 0.2 mA for 2 V operation.

Gyroscopes

Gyroscopes in MEMS technology are in the limelight now. It can be used for vibration reduction of cameras, navigation, suspension control for automobiles and so on. Some silicon MEMS gyroscopes have been marketed in these several years. However, the MEMS gyroscopes are still under developing and there is large room for growth. Many developers are continuously studying for reducing the size and cost and improving their characteristics. Actually, the characteristics of the MEMS gyroscopes are not good, especially about zero point accuracy and stability. Current MEMS gyroscopes have a resolution of around 0.1 deg/s

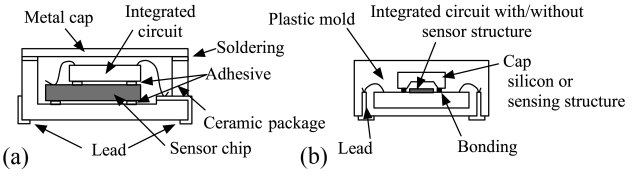

Fig. 1 Conventional packaging (a) and modern packaging (b) . In (a), electrical connection is performed by bonding wires and ceramic package with cavity is used. For (b), electrical connection and hermetically sealing are by bonding technique. Low cost plastic-mold can be used.

for usual band width with zero point accuracy of 10~100 deg/s. Power consumption is not so small compared with the acceleration sensors, 10~100 times lager. Two dimensional gyroscopes in one chip are available now, but design of 3 dimensional gyroscope is difficult and it is not in the market now. Similarly to the acceleration sensors, all MEMS gyroscopes have peripheral circuits in the same package.

Other MEMS sensors

Many other MEMS sensors available in the market. Figure 2 shows examples of such devices. It includes a pressure sensors, temperature/humidity sensor, microphone, together with an acceleration sensors and gyroscopes. These devices have both a sensor element and peripheral circuitry in one package. Some of them have an A/D converter and digital circuitry in the chip, and digital interfacing and digital control can be achieved. This enables easy connection to a microprocessor. When the device is mounted on a printed circuit board with a microprocessor, one cannot distinguish the sensor device and usual electrical parts. The MEMS sensor is no longer special device but one of usual electrical parts.

3. MEMS Technology

There are some key technologies for MEMS devices, such as deep-RIE (Reactive Ion Etching), bonding, and surface micro machining. In the following, these technologies will be briefly described.

Deep-RIE

Deep-RIE is a highly anisotropic etching process for realizing deep, steep-sided holes or trenches in silicon wafers, with high aspect ratios of several tens in magnitude. After several studies were conducted to realize deep and high-aspect trench holes, the Bosch process[7] was successful in producing a very high aspect ratio with high etching selectivity to oxide and photo resist. Recently, an etching rate exceeding 25 μm/min with selectivity of several hundreds to photo resist was obtained by a commercial machine. This etching rate is more than ten times larger than that of conventional anisotropic wet etching[1]. This technology achieved various 3-dimensional structures and further miniaturization of the device.

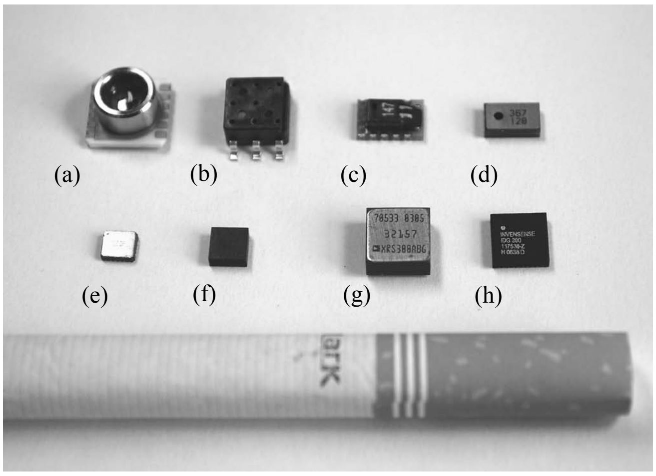

Fig. 2 Various MEMS sensors. (a) and (b) Pressure sensors from Intersema(MS5534) and Fujikura(FAM-15PA), (c) Humidity with temperature sensor, Sensirion(SHT11), (d) Microphone, Knowles Electronics(SP0103), (e) and (f) 3-dimensional acceleration sensor, Hitachii Metals(H34C) and Analog Devices(ADXL330), (g) and (h) 1 D and 2D gyroscopes, Analog Devices(ADXRS300) and Invensence(IDG300).

Bonding

The famous and long established bonding technologies are anodic bonding (Glass - Silicon) and silicon direct bonding (Silicon - Silicon)[1]. For example, the former has been used for packaging and the latter is for obtaining an SOI (Silicon On Insulator) wafer which is useful for starting material of MEMS devices. Recently, from packaging requirements as described above, many other bonding techniques that combine latest LSI with sensing structure have been developed[6]. The details will be shown in the conference.

Surface micromachining

Surface micromachining is based on the deposition and etching of structural layers on top of the substrate. Development of the full-scale surface micromachining process began in 1987 using poly silicon layers as a movable structure[8]. Several effective structures such as comb actuators and displacement detectors were proposed. The first monolithically integrated acceleration sensor that includes sensor structure and peripheral circuitry has been developed using this technology[9].

As of today, poly silicon film is not the only material used in the fabrication of a movable structure; single-crystal silicon layer is also used widely. For this purpose, an SOI wafer is very useful as a starting material. Although the maximum thickness of polysilicon film is limited to about 10 μm due to deposition technology, unrestricted thickness can be obtained using an SOI wafer.

4. Conclusions

Some MEMS sensors and MEMS technologies were briefly introduced. Only a few types of devices and technologies were presented here, but various types of MEMS devices are being developed and delivered. The MEMS technology should be worthwhile for future development of all microelectronics.

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