The Adhesion Failure Analysis of the MEMS Gyroscope with Comb Capacitor

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Abstract—The MEMS gyroscope has wide application foreground, the reliability of MEMS gyroscope is a key problem for its commercial application. With the development of the MEMS gyroscope industrialization, the reliability is underway to meet the need of market. In this paper, the adhesion failure modes of MEMS gyroscope is presented. In addition, the adhesion failure analysis is illustrated. Finally, a lateral comb capacitor structure to improve the reliability of the MEMS gyroscope is presented, the reliability of the lateral comb capacitor is discussed. The lateral comb capacitor structure is valuable for the optimize design of the other types of gyroscopes.

Keywords-MEMS gyroscope; reliability; adhesion failure; lateral comb capacitor

I. INTRODUCTION

Reliability researches about MEMS gyroscope are particularly important to break the bottle-neck of MEMS commercial applications. With the advent of MEMS gyroscope applications in application in space vehicles, automobile industry, consumer electronics etc., The MEMS gyroscope will take a more important role for their lower weight, lower capacity and higher reliability than normal gyroscopes. Moreover, electric consumers or car electronics need the products with more reliable, more stable and longer life MEMS gyroscope but low cost. To speed up the application of MEMS gyroscope in these fields, it is necessary to develop the reliability all-round [1].

The reliability problems of the MEMS gyroscope have not been discovered sufficiently and systematically. Furthermore, different samples generated different reliability issues. While the study of MEMS gyroscope reliability problems was started more than ten years ago in the world, most related researches were pursued separately in different programs. The general studies of MEMS gyroscope reliability was carried out by Sandia Laboratory of USA in the end of the last century. The groups in Sandia studied on the poly-Si structures which made by surface processes and took a series of experiments on the special micro-engine with gears and combs [2]. In China, many special reliability problems have been studied. One of the most important and almost unavoidable problems in MEMS gyroscope is adhesion failure. However, the adhesion failure research has just started and seldom issued [3]. Achievements of adhesion failure study had not been issued yet. Therefore, it is very essential to study the adhesion failure systematically.

In this paper, the adhesion failure modes of MEMS gyroscope is presented. In addition, the adhesion failure analysis is illustrated. Finally, a lateral comb capacitor structure to improve the reliability of the MEMS gyroscope is presented, the reliability of the lateral comb capacitor is discussed.

II. FAILURE INVESTIGATION

A. The measurement of MEMS gyroscope reliability system

As shown in Fig.1, The measurement of micromachine gyroscope reliability system BITMMmGR (Beijing Institute of Technology Measurement of Micromachine Gyroscope Reliability) contains an optical microscope, a high-speed camera, a gyroscope performance test circuit, a turntable, thermometer and hygrometer etc.

Figure 1. The reliability test system

B. Experimental

The relative humidity was variable in the failure investigation experiment. In the first experiment, the MEMS gyroscope was tested in a turntable, the temperature was 20°C, the relative humidity was 50%. In the second experiment, the MEMS gyroscope was placed in the turntable for 360 hours, the temperature is 20°C, the relative humidity is 85%. The adhesion failure modes of MEMS gyroscope was detected in the second experiment and shown in Fig.3.
C. The adhesion failure mechanism

Both experiments conditions are consistent except the relative humidity, the moisture is one of the main reasons of adhesion. Under 65% relative humidity condition the steam began to rally capillary. When a small amount of liquid begins to rally capillary at the small gap between two solid surfaces, a liquid-bridging phenomenon can be observed. Such a liquid-bridging phenomenon occurs in many cases. For example, an adsorbed water droplet due to humidity between the cantilever beam and the substrate of micro accelerator (or RF-MEMS) will result in a liquid-bridge, similarly many liquid-bridges between the neighbor combs of micro gyroscope will be formed when there is some water [4-6]. Adhesion caused by capillary appears to be one major problem during the assembly and/or fabrication of micro-components and the operation of system.

The liquid-bridge will cause a capillary interaction between the solid surface and the liquid. To separate these two solid surfaces, a force is needed to overcome the capillary attractive force caused by the liquid-bridge. This force is usually called as pull-off force or capillary force (or adhesion force). Such a capillary force is so insignificant for normal macro mechanical system that can be neglected. But it will play a significant role in a micro scale system. This is because surface forces become more and more important when the objects are scaled down.

The capillary adhesion was primarily due to the liquid surface tension. In the MEMS gyroscope, the liquid-bridges between the neighbor combs of micro gyroscope will be formed when there is some water. The capillary adhesion force per unit area is

$$F(l) = -\frac{\sigma(\cos \theta_1 + \cos \theta_2)}{l} b \quad (1)$$

where $b$ is the plate width, $\sigma$ is the surface tension, $\theta_1$ is the contact angle between the liquid and the top plate, $\theta_2$ is the contact angle between the liquid and the bottom plate, $l$ is the distance between the plates, $l \approx r(\cos \theta_1 + \cos \theta_2)$. The capillary force is inversely proportional to the first power of the distance, $F \propto \frac{1}{l}$.

The most important surface forces in MEMS are the capillary force, the molecular van der Waals force. The van der Waals force exists in all materials, is the weakest of all forces. However, a large number of elements involved, it can produce up to more than one long-range effect. The van der Waals force between two smooth and unlimited flat panels per unit area is

$$F(l) = \frac{A}{6\pi l^3} \quad (2)$$

where $A$ is the Hamaker constant, which depends on the nature of the surface material and media. The van der Waals force is inversely proportional to the third power of the distance, $F \propto \frac{1}{l^3}$.

As shown in Fig.4. The capillary force is larger than the van der Waals force, which is the main reason for the adhesion failure. To avoid the adhesion failure, an appropriate packing with sufficient drying vacuum is necessary.

III. LATERAL COMB CAPACITOR

In the driven system of MEMS gyroscope, the overlap area of the comb driver is much smaller than the overlap area of the comb capacitor, the impact of the surface effect to the structure of the differential drive will be greater, but at the same experimental conditions, the comb driver is no adhesion. The main reason is that the distance between the plates is not
changed when the active plate moves towards the fixed plate, the impact of the capillary force and the van der Waals force is weakened. The comb driver provides a reference to improve the reliability of the comb capacitor. The lateral comb capacitor has been innovatively presented in this paper, as shown in Fig. 5.

The opposite movement of the two parallel combs has been avoided in the lateral comb capacitor, the distance between neighbor combs do not change. The effect of capillary force and van der Waals force is limited, the detection capability of the lateral comb capacitor has been increased. The lateral comb capacitor changed linearly with the displacement of the active plate, and it is only effected by the slide air damping, the detection performance can be improved. The lateral comb capacitor structure is valuable for the optimize design of the other types of gyroscopes.

IV. CONCLUSION

In this paper, the reliability of the MEMS gyroscope has been tested using the gyroscope’s reliability testing system BITMMmGR. The adhesion failure mechanism has been researched based on the micro-mechanical theory, the results showed that the capillary force and van der Waals force play an important role to the adhesion failure. To avoid the adhesion failure, an appropriate packing with sufficient drying vacuum is necessary. Finally, a lateral comb capacitor structure to improve the reliability of the MEMS gyroscope is presented, the reliability of the lateral comb capacitor is discussed. The lateral comb capacitor structure is valuable for the optimize design of the other types of gyroscopes.

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