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Getter free vacuum packaging for MEMS

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ABSTRACT

Quite a few MEMS devices such as accelerators, gyroscopes, infrared sensors need to work in vacuum environment to enhance their performance. The traditional vacuum packaging methods use getters to increase vacuum maintaining lifetime. However, the getter's characteristics of high temperature activation, powder pollution, large package size limit its use in MEMS vacuum packaging. This study analyzes the factors that influence the vacuum level, and derived a relationship between the balanced vacuum level, the effective leak rate, and vacuum maintaining lifetime. A novel vacuum package design with vacuum buffer cavity was proposed, the vacuum maintaining lifetime could be increased at least 20 times as compared to the ordinary package with the same volume. Reliability experiments were conducted so as to verify that the new package design can achieve reliable vacuum packaging without getters to meet the requirements of device applications for vacuum with about 0.1 Pa in pressure level. This unique package design also provided a complementary way to work with getters to enhance the vacuum package performance and reliability of hermeticity.

1. Introduction

Quite a few MEMS devices need vacuum packaging technology to guarantee the desirable performance. One of the characteristics of these MEMS devices is that there are delicate moving parts inside a cavity. These devices include accelerators [1,2], gyroscopes [3,4], MEMS filters [5], MEMS ultrasonic sensors [6,7], which need a vacuum to decrease air damping. Some of MEMS sensors need a vacuum environment to isolate heat transfer, such as infrared detectors or bolo-meters [8–10]. The widely used absolute pressure sensors in MEMS need a vacuum cavity as a zero pressure reference [11,12]. High vacuum level can dramatically enhance the performance of these devices, but MEMS vacuum packaging faces great challenge because of its small volume, any leak or degassing will corrupt the vacuum in the device lifetime. Much research has been devoted to this field, trying to find solutions to increasing the vacuum level and enhancing the vacuum maintaining time, with most of them focusing their research on vacuum sealing processes and how to incorporate the getters into the small volume vacuum cavity of MEMS devices [13–16]. A few research groups use the patented getters to realize vacuum packaging and achieve more than 2-year vacuum maintaining lifetime [17–19]. However, the traditional getters are difficult to be incorporated into the packages because of their big volume, and their potential powder contamination on sensor chips. Recently, some new getters, marketed by SAES that are based on thin film process, can use custom patterning on glass, ceramic, silicon, and metal lids, but these getters need high temperature activation, a typical activation for SAES thin film getters requires a minimum of 15 min at 300 °C. How to coordinate the activation process with MEMS manufacturing and packaging processes is often troublesome and need careful process design. In addition, these new getters are not available in China for Chinese researchers in MEMS vacuum packaging, further evaluation experiments cannot be conducted in our lab. It is to our best knowledge that only limited long time durability testing data for the device level MEMS vacuum packages has been reported in the public literature [17–19]. In addition, MEMS vacuum packaging has been highly proprietary and has been a barrier for the commercialization of a few high performance MEMS devices and systems. Therefore, it was essential for us to come up with a getter free solution, which could be low in cost for device level MEMS packaging, so that we could achieve a long last vacuum maintaining lifetime. It is also desirable for this getter free solution to be able to be used as a complementary way to work with getters, if available, to enhance the reliability of hermeticity.

In this paper, we will quantitatively discuss gas desorption and gas permeation influence on the vacuum level for MEMS devices packaged in two separate sections. We will discuss the leak rate

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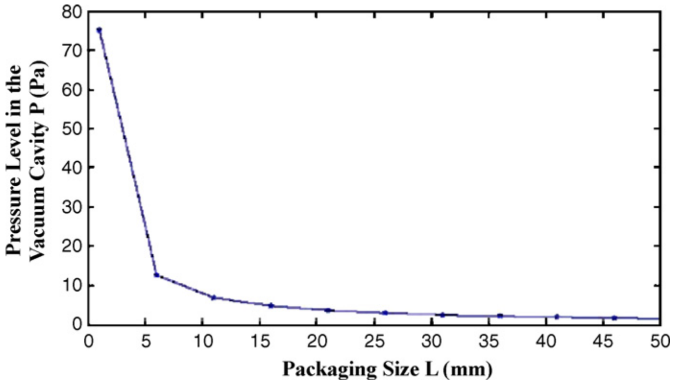

Fig. 1. The theoretical relationship between the package volume and vacuum level influenced by desorption.

Fig. 2. The metallic packages for vacuum packaging experiments.

and vacuum maintaining lifetime and will show why it is not feasible to realize a reliable vacuum packaging by only improving the sealing quality of a conventional single-cavity vacuum packaging without getters. Finally we will present our new packaging design with a buffer cavity and discuss the merits of using the buffer cavity. Experimental data will also be presented and compared with the theoretical derivations.

2. Gas desorption influence on vacuum level for MEMS devices

It is well known that all material faces will absorb specific kinds of gases except in a super high vacuum environment with a pressure level of lower than 10^{-7} Pa. In a vacuum packaging, the absorbed gases will be desorbed into package cavity and corrupt its vacuum level. The desorption influence might be of critical importance for MEMS vacuum packaging because of the small volume of the MEMS device, which has not been quantitatively addressed in the literature. Assuming the package volume is L^3, and the occupied area per absorbed molecule on surface is a, the vacuum level in the package can be calculated as the following equation when one layer of absorbed molecules will be desorbed into the cavity:

$$P = \frac{6kT}{La} \tag{1.1}$$

The relationship between the package volume and vacuum level can be evaluated as in Fig. 1 by assuming $a = 18$ Å^2, $T = 300$ K.

The package dimension of MEMS devices is generally lower than 20 mm, the base vacuum level is at least greater than 3 Pa. Therefore, the gas desorption has great influence on MEMS vacuum packaging, and the baking process under vacuum for degassing is normally required for MEMS vacuum packaging of 1 Pa vacuum level or less. As for metallic packages shown in Fig. 2, authors conducted many experiments for comparing the effect of baking process on vacuum packaging. The packages were first baked under vacuum oven at 350 °C, then sealed by resistance welding under vacuum chamber at 10^{-3} Pa, the minimum base vacuum level in the package could reach around 0.1 Pa.

3. Gas permeation influence on vacuum level for MEMS devices

The desorption of the absorbed gases in the inner faces of packages not only would corrupt the package vacuum, the gases outside the packages but also could influence the vacuum level in the package cavity by gas permeating. First, the gases will be absorbed on the outer surfaces of the package. Then, the absorbed gases will be permeating through the package wall and degassing in the package cavity.

The absorbed gases will be dissolved in the outer surface layer up to a level of dissolvability c, the following formula can describe the absorbing and dissolving processes:

$$c = k_p P_i^j \tag{1.2}$$

where k_p is the permeating coefficient, P_i is the specific gas partial pressure in the environment, and j is the dissociation coefficient related molecule dissociated into atoms.

The gas permeating process can be calculated by the following diffusion equation:

$$\frac{\partial c}{\partial t} = \frac{\partial}{\partial x}\left[D_x \frac{\partial c}{\partial x}\right] + \frac{\partial}{\partial y}\left[D_y \frac{\partial c}{\partial y}\right] + \frac{\partial}{\partial z}\left[D_z \frac{\partial c}{\partial z}\right] \tag{1.3}$$

where D_x, D_y, and D_z are the diffusing coefficients. The permeation influence on the vacuum packaging can be evaluated by the following model shown in Fig. 3.

As for the metallic package, only H_2 would be considered for permeating influence because other gases have smaller permeating coefficients and could be neglected. By taking $k_p = 2 \times 10^{-11}$(Torr L/cm^2 s $\sqrt{\text{atm}}$ mm), and H_2 content in air to be about 0.5 ppm, the permeated gases pressure can be calculated under different package wall thicknesses and package volume sizes shown in Fig. 4.

The theoretical calculations show that H_2 permeation influence on the vacuum packaging for packages greater than 1 cm^3 will result in a base vacuum level of about 10^{-6}–10^{-7} Pa, the permeation influence can be neglected for device level vacuum packaging. However, for even smaller packaging or wafer level vacuum packaging, the cavity size is about 1 mm^3, where the base vacuum level by permeation will be around 10^{-2}–10^{-3} Pa, the gas permeation influence should be carefully considered if vacuum package level

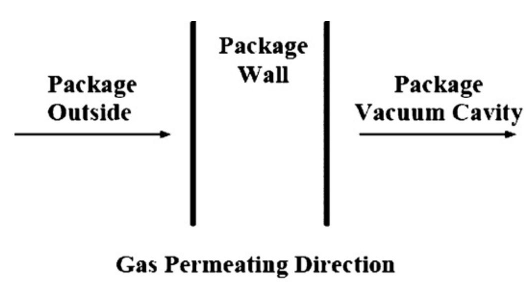

Fig. 3. Gas permeating model through package wall.