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Research on the Key Technology of LTCC Pressure Sensor

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Abstract: This article introduces the fabrication technology processes of the capacitive pressure sensor based on the low temperature co-fired ceramic (LTCC) material. Filling the cavity with different materials as a sacrificial layer is mainly discussed, and two different materials are chosen in the fabrication. It is found that the cavity filled with polyimide expands largely during sintering, while carbon ESL49000 material filled is more preferable to keep the cavity flat. Finally, the structure leaving without an air evacuation channel is designed and tested in a built-up pressure environment, the frequency measured decreases approximately linearly with the pressure applied, which proves the design leaving no air evacuation channel advisable.

Keywords: LTCC, sacrifice layer, capacitive cavity, passive wireless, wireless detection

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1. Introduction

As a new material, low temperature co-fired ceramic (LTCC) is widely used in applications like fabricating radio freqency (RF) devices, microwave circuits, and package. LTCC devices have a relatively simple structure and technology process [1, 2]. But they seldom have been used to fabricate pressure sensors [3]. A passive wireless pressure sensor is proposed based on LTCC in this paper. The quality of the device depends largely on the performance of the fabrication technology especially the key technological steps in the fabrication of micro structures [4]. Although LTCC device has a standard technological process and a relatively mature technological fabrication line, its degree of development and technological maturity is far below the semiconductor technology especially the key technologies still need to be improved when devising micro-electromechanical systems (MEMS) structures [5, 6]. However, as to achieving the excellent performance of the capacitive pressure sensor based on LTCC device, the strict requirements, precise control, and groundbreaking improvements of the technological process should be followed.

This article introduces the fabrication technological processes of the capacitive pressure sensor based on the LTCC material firstly. The step of filling the cavity with different materials is emphasized on, and two filler materials are chosen in the experiment. It is found that the polyimide material makes the sensitive film expand largely and

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even crack, while the ESL49000 material used can keep good flatness of the pressure-sensitive film. Finally, the structure leaving no air evacuation channel is designed and tested in a built-up pressure environment, and the frequency measured decreases approximately linearly with the pressure applied, which proves the design leaving no air evacuation channel advisable.

2. Model of sensors

As shown in Fig. 1, the sensor is made of four layers of the LTCC green ceramic tape. Firstly, the silver paste is screen printed on a corresponding layer, and the sacrificial layer is filled into the cavity; then, the four green ceramic tapes are stacked together; after that, the green ceramic tapes are sintered in the furnace, during which the sacrificial layer will be evaporated into the air; finally, the evacuation channel is sealed with the sealant in the furnace but at relative low temperature. It is seen that the fabricated sensor is composed of a spiral inductor connected with two plates. The resonant frequency can be expressed as follows [7]:

$$f_0 = \frac{1}{2\pi\sqrt{L_S C_S}} \tag{1}$$

where L_S is the inductance of the sensor, and C_S denotes the plate capacitance, respectively.

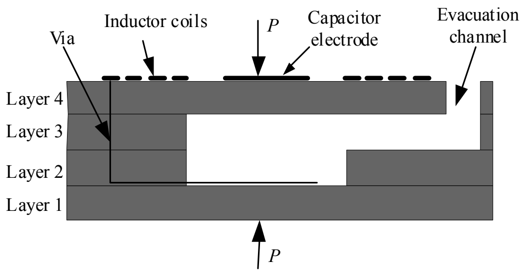

Fig. 1 Structure of the LTCC pressure sensor.

The pressure applied outside of the sensor deforms the plate, thus changing the resonant frequency of the sensor which can be obtained using an external test circuit by wireless coupling of the antenna, thereby, the value of exerted pressure can be deduced by the frequency measured.

The critical part of the sensor in the pressure test, as known, is the sensitive film, which includes the first and fourth green ceramic tapes in Fig. 1, because the quality of the sensitive film will have a very big impact on the performance of the sensor. Firstly, the uneven sensitive film will lead to the irregular shape and abnormal distance of electrodes between capacitors, thus affecting the theoretical frequency calculation. Secondly, the collapse of the sensitive film will make it very difficult to fabricate the capacitive cavity and may even cause the sensor inoperative when the top sensitive film contacts with the bottom directly. Thirdly, if the deformation of the sensitive film exceeds the material elastic range, the sensor will be unworkable. Therefore, the quality of the sensitive film is strictly required in fabrication.

The design aims to make a high sensitive sensor within a small range of pressure test, therefore, the sensitive film should be fabricated as thin as possible, and the good mechanical characteristic and flatness are required in technological processes. Firstly, the LTCC shows a characteristic of the ceramic material completely after sintering which is actually a composite material with poor tenacity especially after being made thinner, and the additional stress of the technological process may easily cause crack even fragment. Secondly, multilayer green tapes forming the sensor need to be laminated and sintered to become a dense solid ceramic body. If there is nothing to support the sensitive film in the hollow capacitive cavity during lamination, the enormous pressure and sintering process will cause the sensitive film, in most cases, deformed inward greatly. Therefore, the filler as the sacrificial layer in the cavity is of importance during fabrication, and strict rules are required in choosing the filler material.

3. Filling of cavity

The technology of using the filler as the sacrifice layer is introduced in the fabrication of the pressure sensor which serves as a protection of the pressure-sensitive film during lamination and can evaporate totally after sintering, thus ensuring good flatness of the film.

3.1 Principles of selecting the filler material

The selection of the filler material should consider factors as follows [8–11]:

(1) Poor infiltration is needed between the materials of the sacrifice layer and LTCC green ceramic tape to protect the filler material from being infiltrated into the green ceramic tapes.

(2) The material of the sacrifice layer needs to have a certain resistance to pressure so that it can support the sensitive film from being deformed during lamination.

(3) The melting point of the filler material should be less than the highest sintering temperature of the LTCC green ceramic tape (900 ℃) to ensure that it has no residual after sintering.

(4) The coefficient of thermal expansion (CTE) of the sacrifice layer should match to that of the LTCC green ceramic tape as large difference in CTE will cause the sensitive film deformed inward or outward.

3.2 Polyimide as sacrifice layer

The Dupont Kapton HN polyimide as the filler material is chosen in the experiment, because it is more in line with our requirements in various aspects except CTE (20 ppm/℃) is a little higher than Dupont 951 (5.8 ppm/℃) material, thus after calculation the polyimide filler with about 90-μm thickness which is lower than the height of a layer of the green ceramic tape (114 μm) and smaller than the area of the cavity is chosen. The polyimide material as the filler can be seen in Fig. 2.

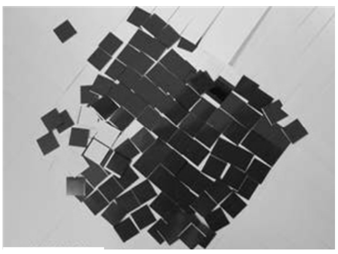

Fig. 2 Polyimide material as the sacrifice layer.

A very large bulge even rupture is found in the sensitive film of the sensor filled with polyimide as the sacrifice layer after sintering, as shown in Fig. 3. To find out the main reasons causing expansion, the sensitive film is removed, and a small amount of residual polyimide material is found in the cavity.

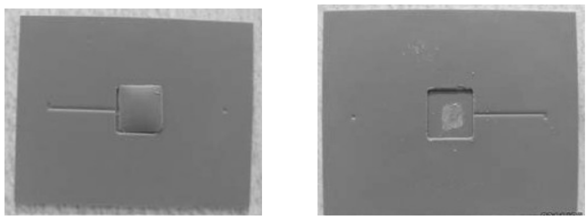

Fig. 3 Sample after sintering.

Since the size of the polyimide material has been calculated to exclude the impact of the CTE mismatch on the sensitive film, the poor volatile of the polyimide material during sintering is inferred to be the reason causing the sensitive film expanded. It is found that the temperature to remove organics such as the binder is concentrated on 400℃ to 500 ℃, after that, the porous ceramic structure becomes dense, while the melting point of the polyimide material is about 600 ℃. It is deduced that when the polyimide material begins to volatilize in 600℃, the gas molecule can hardly pass through the dense ceramic tape. Although the air channel connecting the capacitive cavity to outside is designed, the experiments show that most of gas still go through the ceramic layer. Because much evaporated gas fails to penetrate through the dense ceramic tape, elevated gas pressure in the cavity will squeeze the sensitive film, in addition the ceramic tape becomes softened under high temperature, which both cause the sensitive film expanded outward. The residual polyimide material left in the cavity in Fig. 3 is a forceful proof to the speculation before.

3.3 ESL49000 material as the sacrifice layer

Based on the prior experience, the carbon ESL49000 material, shown in Fig. 4, is then chosen as the sacrifice layer whose thickness is about 110 μm and quite close to the height of a layer of the green ceramic tape, thus it can serve as a perfect support to the sensitive film in lamination. The material begins to evaporate by chemical reaction with external oxygen from about 450 ℃, which is shown in Fig. 5, thus showing a good performance in protection in about 400℃ and the temperature of unstable state of green ceramic tapes, and most of carbon can be drained away before LTCC ceramic tapes become dense, hence having no effect on the sensitive film; furthermore, it can be completely evaporated between 600 ℃ and 700 ℃, so there will be no volatile residue left in the cavity. The sensor is shown in Fig. 6.

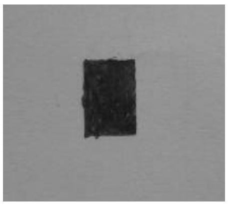

Fig. 4 ESL49000 material as the sacrifice layer.

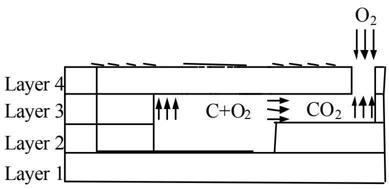

Fig. 5 Model of the filling of the capacitive cavity.

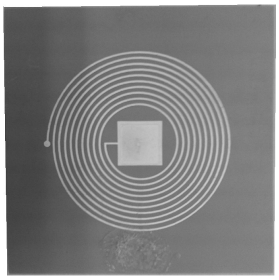

Fig. 6 Photo of the sensor.

4. Sensor without the air evacuation channel

In our previous designs, the air evacuation channel is left for gas exhaust when carbon has chemical reaction with external oxygen, but the design brings the problem of sealing air evacuation channel after sintering meanwhile. Similar to choosing the sacrifice layer material above, there are also strict rules in choosing sealing material and different materials such as high-temperature adhesive, glass caps are used for sealing, but it is found that any deviation in the sealing process will cause the sensor leaked when placed in pressure environment using a mass spectroscope. Because of the problem brought by sealing air evacuation channel, the rate of the final product is actually very low.

It is found that during 400 ℃ to 500 ℃ in sintering the dupont951 ceramic exhibits porous state, at which the oxygen can penetrate through the cavity to have chemical reaction with the carbon tape filled and then the carbon dioxide generated ejects outside, therefore the sensor leaving no air evacuation channel is tried in the design, as shown in Fig. 7. After several trials, it is found that when the time in sintering is controlled reasonably, the sensor fabricated shows the equal test effect in the pressure environment. As shown in Fig. 8, a good flatness of the cavity is found without the air evacuation channel.

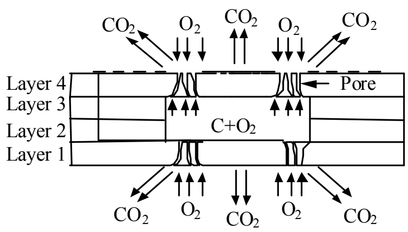

Fig. 7 Model of the filling of the capacitive cavity.

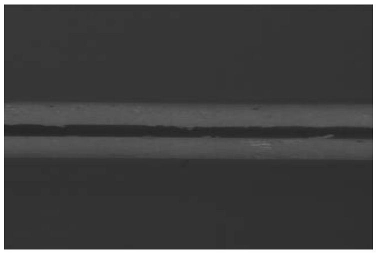

Fig. 8 SEM image of the capacitive cavity.

The sensor without the air channel is measured inside a pressure tank by the antenna connected to the network analyzer, and among gas pressure ranging within 1.2 bar the relation between the frequency measured and exerted pressure is shown in Fig. 9. It is found that the frequency measured decreases approximately linearly with the pressure applied and the response sensitivity derived is nearly 1.384 kHz/Pa, which proves that the design leaving no air evacuation channel is advisable.

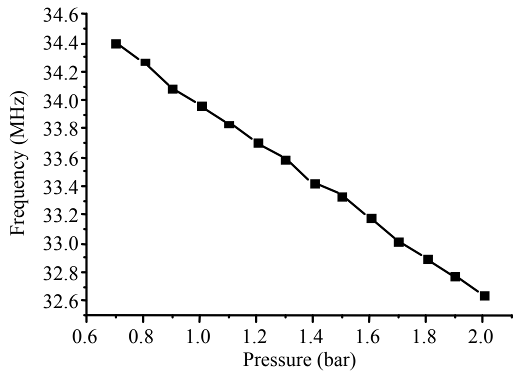

Fig. 9 Frequency measured versus pressure from 0.7 bar to 2 bar.

5. Conclusions

This paper introduces the research on the fabrication technological processes of the capacitive pressure sensor based on LTCC. The polyimide material and ESL49000 material are chosen as the sacrifice layer in the experiment. The structure leaving no air evacuation channel is tested in a built-up pressure environment. The test results show that the resonance frequency of the sensor decreases with an increase in the applied pressure, which proves the design leaving no air evacuation channel advisable.

This research is about the wireless passive pressure sensor based on LTCC, due to the realization on passive and wireless device, it will be expected to be applied to the field of non-contact pressure test, etc. The LTCC material can work in the environment of high temperature more than 400 ℃ subsequently, and the pressure test about the sensor will be conducted in the environment of high temperature (above 400 ℃). If the test is passed, the sensor will be expected to be applied to the field of the non-contact pressure test, etc. in the high temperature environment.

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