Design and Development of LTCC based package for 3-axis packaging of MEMS sensors

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Abstract— **There is a wide range of applications for Micro Electro Mechanical Systems (MEMS) based devices which are used in automotives, aerospace, mobile communication etc. Sensor fabrication and its packaging are very closely connected for reliable functioning of the module. Packaging for MEMS based devices should necessarily provide mechanical support, environmental protection and of course the electrical interconnections to the device. Low temperature co-fired ceramic (LTCC) technology is widely used for packaging of MEMS devices and sensors. Being machinable at green stage LTCC offers the flexibility of structuring for customized package design.**

This paper attempts to develop LTCC based package for 3-axis packaging of MEMS based sensors. For sensors like accelerometer where 3-axis measurement is required in many applications either the device needs to be fabricated in such a manner that it can detect acceleration in 3-axis or the single axis sensitive device may be packaged in such a way so that the packaged module may detect acceleration in 3-axis. These devices involve the movement of the proof mass, therefore special packages with a built-in cavity are also fabricated. The dedicated cavity provides required space for the movement of the proof mass without any hindrance. Thick film alumina based packages have also been developed.

***Keywords-** Micro Electro Mechanical Systems (MEMS), Low Temperature Co-fired Ceramics (LTCC); 3-axis packaging; Accelerometer*

1. Introduction

Testing and characterization of various MEMS based sensors require special packaging techniques. LTCC technology offers reliable multilayer packaging for silicon based MEMS devices [1]. The advantages of LTCC technology include an excellent match of coefficient of thermal expansion (CTE) to silicon which minimizes the stresses due to packaging [2, 3]. LTCC tapes can be easily structured in the green state which allows the possibility to make cavities and windows for active components into the structure [4-6].

MEMS based piezoresistive accelerometer devices in which the movement of proof mass on the application of acceleration produces a change in resistance gives a direct relation to the applied acceleration. These sensors are very useful in the aerospace application and mobile phones [5, 7]. LTCC technology offers a reliable packaging of these sensors. Design and fabrication of package for 1-axis sensitive MEMS device to make it functional in 3-axis by virtue of its packaging is demonstrated. LTCC based package for packaging individual device is fabricated. Three such LTCC packaged devices are placed orthogonally to each other over a cube so that acceleration may be sensed in all the three directions. In this case, a cube of Perspex with volume 1 cubic inch is formed since the density of Perspex is low so the weight of the entire module remains low.

A simple cost effective thick film alumina based package is also designed and fabricated. These packages can be used for testing 1-axis sensitive MEMS based sensors which do not require a dedicated cavity for sensing. Sensors which can be tested using these packages shows a limitation in contrast to LTCC based packages which offers formation of cavity and other dimensional changes at green stage.

2. LTCC based packages

2.1 Process Evolution

The design strategy for the fabrication of LTCC based package for 3-axis packaging is conceptualized. It is followed by layout designing using Graffy HYDE software. The design layout for eight pin configuration is shown in Fig. 1.

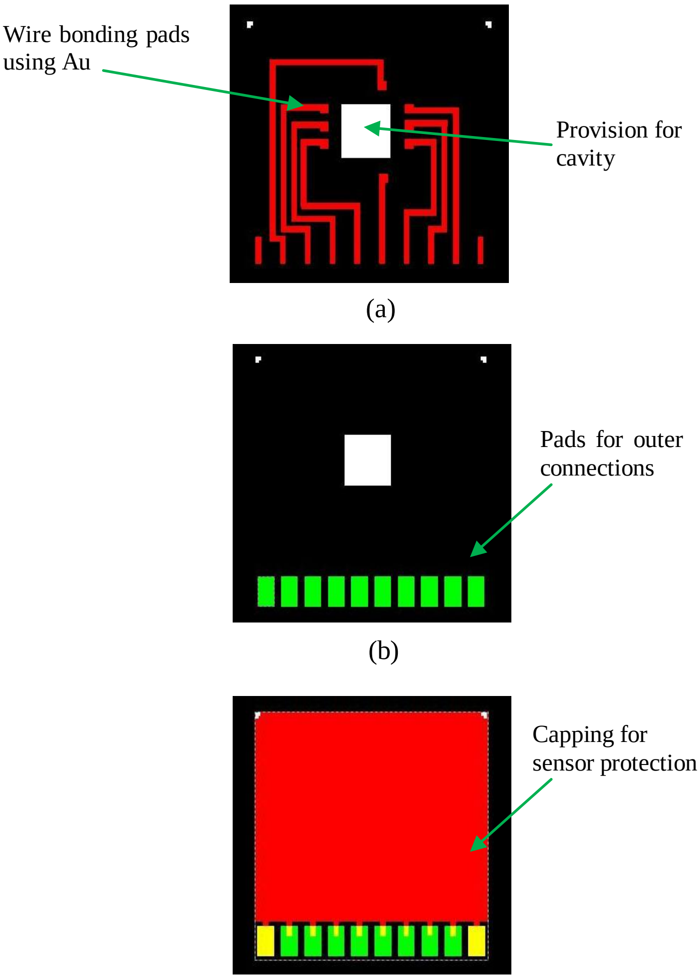

Fig. 1: Layout for eight pin configuration

The line width for Au printing is 0.5 mm and the wire bonding pad size is 0.8 mm x 0.8 mm. PdAg pads have a dimension of 1.75 mm x 3 mm. The planar dimension of the package is 25.4 mm x 25.4 mm after firing. The accelerometer device being fabricated at CEERI is of dimension 6 mm x 6 mm with a suspended proof mass, therefore, dimension of cavity in LTCC is kept 4 mm x 4 mm as per the design layout. The total no. of useful pins in the layout is eight while two other pins are NC (not connected). For mechanical and environmental protection the package may be capped using a metal frame or a LTCC lid as shown in Fig. 1(c). These packages can be customized in size according to the sensor to be incorporated. Provision of cavity is required only for the devices which require displacement of the proof mass. Fabrication process flowchart for LTCC based package is illustrated in Fig. 2.

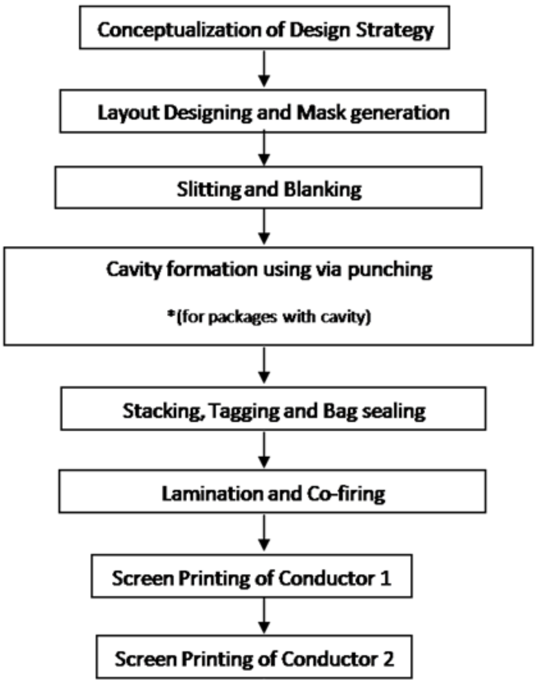

Fig. 2: Fabrication Process Flowchart

2.2 Fabrication Process Steps

The fabrication process involves substrate preparation over which screen printing has been performed. The structure consists of three layers of DuPont 951 PX tape (thickness 762 μm before firing). This is followed by isostatic lamination process (70 ^{o}C, 3000 Psi for 10 minutes). In consideration to the shrinkage parameters, cutting of tape in required package size is done after lamination. The packages are co-fired at a peak temperature of 850 °C.

Fired substrates are screen printed as per the mask layout. DuPont 5715 Au paste is used for printing wire bonding pads and electrical interconnecting lines. DuPont 6146 PdAg pads are printed for providing connections from the device to the outside world. Firing is done after each printing step at a peak temperature of 850 °C. The fabricated packages are shown in Fig. 3.

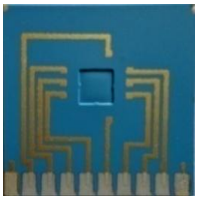

Fig. 3: Fabricated LTCC packages with inbuilt cavity

2.2.1 Cavity formation:

Via-punching is used for preparing packages with in-built cavity. The cavity part is created on a 10 mil tape which is tagged and bag sealed with the other two tapes without a cavity. The packages with in-built cavity are fabricated for the proper displacement of the proof mass of MEMS based accelerometer devices on the application of external force. The cavity part is shown in Fig. 4.

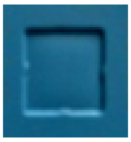

Fig. 4: Cavity generation in LTCC

2.2.2 External interconnections and mounting:

Lead interconnections are provided using reflow soldering process at a temperature of 250 °C. Three individually packaged devices using the LTCC package are mounted over the cube so that the 3-axis sensing could be done using 1-axis sensitive devices. A representation of the entire module (without device) after mounting over the cube is shown in Fig. 5.

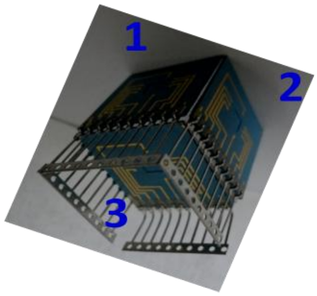

Fig. 5: Mounting of LTCC packages over the cube

3. Packages Based On Alumina Technology

3.1 Fabrication process for alumina based package

A similar approach was followed for developing alumina based packages. These packages can be used for the devices which do not require a cavity for their functioning. Layout designing for Alumina based packages is done using Graffy HYDE software.

Standard alumina substrates of 1" x 1" are used for the fabrication process. Wire bonding pads and electrical interconnecting lines are printed using DuPont 5715 Au paste. The outer pads are printed using DuPont 9061J PdAg paste. Firing is done after each printing step at a peak temperature of 850 °C. Alumina based packages have been developed as shown in Fig. 6. Lead interconnections are provided using reflow soldering process. The planar dimension of a single package is 25.4 mm x 25.4 mm. The module after mounting of three such packages over a cube is shown in Fig. 7.

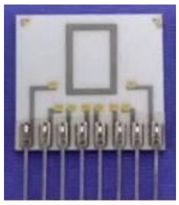

Fig.6: Alumina based package

Fig.7: Alumina based module

4. Conclusions

In this paper, development of packages for testing and characterization of 1-axis sensitive MEMS based sensors to make it functional in 3-axis is presented. Mounting of the individual package over a cube makes the 1-axis device orthogonal to each other thus offering a method to sense in all 3-axis. LTCC technology is used for the fabrication of such packages. Special packages with in-built cavity are fabricated for sensors with proof mass. The height of cavity after shrinkage is around 200 µm which is sufficient for the movement of proof mass. Fabrication of alumina based packages (without cavity) is also presented. These packages are low cost solution as compared to LTCC based package but have the limitation of structuring. The type of package viz. with a cavity or without cavity, which will be used for packaging, depends on the sensor to be packaged. For sensors which do not have a proof mass can be packaged in non-cavity packages but for sensors having displacement of proof mass require special cavity packages. The possibility of cavity formation in LTCC technology allows the testing and characterization for most of the MEMS based sensors which is not feasible with alumina based packages. A comparison of both the types of packages is shown in Table 1.

Parameter	LTCC based package	Alumina based package
Possibility for cavity formation	Yes	No
Mechanical structuring	Possible	Not possible
Overall cost for fabrication	High	Low
Testing and characterization possibility	For most of the MEMS based sensors	Restricted to few sensors

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REFERENCES

[1] Pentti Karioja, Kari Kautio, Jyrki Ollila, Kimmo Keränen, Mikko Karppinen, Veli Heikkinen, Tuomo Jaakola, and Markku Lahti, “MEMS, MOEMS, RF-MEMS and photonics packaging based on LTCC technology”, Electronics System-Integration Technology Conference (ESTC), 2014.

[2] J. Kita, et. al., Properties of laser cut LTCC heaters, Microelectron. Reliab. 40, 2000, p. 1005–1010.

[3] Dheeraj Kharbanda, et. al., Design Simalation and modelling of LTCC based microhotplate for gas sensor applications, IEEE conference publications, ISPTS, 2012, p. 257-260.

[4] Darko Belavic, et. al., The application of thick-film technology in C-MEMS, J Electroceram 19, 2007, p. 353-368.

[5] M. Kraft, et. al., MEMS for Automotive and Aerospace Applications, Woodhead Publishing Series in Electronic and Optical Materials, 2013.

[6] Hua Gan, et. al., A Novel LTCC capacitive accelerometer Embedded in LTCC Packaging Substrate, Proceedings of 6th IEEE Inetrnational Conference on Nano/Micro Engineered and Molecular Systems, 2011

[7] H.A.C. Tilmans, J. De Coster, P. Helin, V. Cherman, A. Jourdain, P. De Moor, B. Vandevelde, N.P. Pham, J. Zekry, A. Witvrouw , I. De Wolf ,”MEMS packaging and reliability: An undividable couple”, Microelectronics Reliability 52 (2228–2234), 2012