Single Post Load Cell in LTCC

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***Abstract*— This paper presents the development of a force post compressive load cell, fabricated using Low Temperature Cofired Ceramics (LTCC) technology. It was implemented an LTCC mechanical load cell structure with a z-axis thick film strain gage using two different approaches. Fabrication methods and materials are explored and fabricated devices are presented. Mechanical characterization tests are still in progress, but preliminary load tests with compressive forces were found to exhibit consistent behavior, in a strain level up to 1.500 micro strain.**

I. Introduction

Micro-fabrication technologies have played a fundamental role in the development of MEMS/MST. LTCC technology is an excellent option for 3D sensors devices implementation with several advantages when compared with other micro-fabrication technologies [1].

Embedded passive components are well implemented in LTCC in order to improve MCM packaging density. Micro-volume resistors were manufactured, by filling a via hole with a proper thick film paste [2] to obtain resistors, thermistors or varistors.

In addition investigations of electrical properties of LTCC resistors were conducted [3] in order to verify compatibility of LTCC materials and pastes from different manufacturers. Recently new LTCC-MST developments were introduced allowing new fabrication techniques feasible [4,5].

Load cells are used in industry for weighing measurements. Basically a load cell is an elastic element to which an appropriate type of strain sensor is bounded. The application of a force to the elastic element cause a deformation sensed by the strain sensor providing an electrical output proportional to the applied force.

In the present work is proposed a novel structure designed for low cost compressive force sensing. Fabrication methods of different meso-scale load cell structures, implemented using LTCC technology are also presented.

Some features of this approach are: good performance to cost ratio, robust design, long-term stability and suitable for difficult environments.

The structure consists of several green tape layers machined by using a printed circuit board prototyping CNC machine accompanied by metal electrodes and posts of thick film piezoresistive paste, embedded in sacrificial materials.

II. Strain Sensors

The change in resistance of any resistor under applied stress is due to changes in the dimensions of the resistor and modifications of its material conductivity as a result of micro-structural changes.

The gage factor (GF) of a resistor is defined as the ratio of the relative change in resistance ($\Delta R/R$) and the applied strain ($\Delta l/l$)

$$GF = (\Delta R/R) / (\Delta l/l) \quad (1)$$

Metals are affected only by geometrical changes resulting in GF of 2 to 2.5. Semiconductors, thin film and thick film resistors displays higher gage factors. Besides geometrical changes because of applied strain, resistor shift is due to micro-structural modifications in material conductivity.

A sensing element based on the thick resistive films piezoresistive effect, as reported by [6] is being used in this work.

The longitudinal GF values of thick film 10K/ resistors are usually between 9 and 20, rendering an appropriate sensor for the proposed application.

Geometry of piezoresistive sensors implemented using thick film resistor materials are displayed in Fig. 1, (a) a planar structure, (b) a vertical structure, (c) a vertical structure with surrounded dielectric and in (d) the proposed novel post vertical structure suitable for z-axis force sensing.

Resistance value for vertical structures is given by:

$$R = \rho \cdot \left(\frac{z}{x \cdot y}\right) \qquad (2)$$

With ρ = film resistivity; z= thickness of resistor and x and y lateral dimensions of resistor.

Force sensors using thick film sensors have been proposed in [6, 7], using planar geometry, see figure 1(a), but planar methods are generally indirect measurements.

Z-axis sensitive devices exhibit higher GF, good thermal stability and are direct measurement technique when compared with conventional planar sensors.

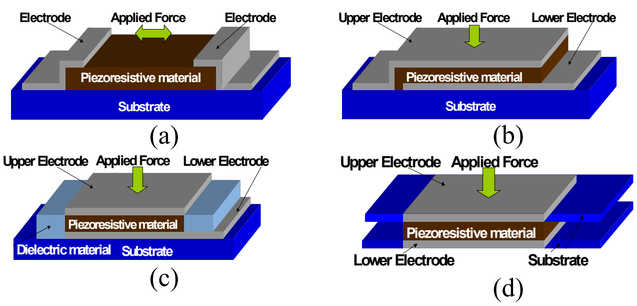

Figure 1. Thick film strain sensor geometries.

A design of z-axis piezoresistive force sensor, using geometry shown in figure 1b; obtaining high levels of strain.

Another implementation of a vertical z-axis thick-film piezoresistive resistor, surrounded with dielectric, for multipoint load sensor with sensing resistances of 2.5 KΩ and sensitivities of (ΔR/R) about 1.3% at 6 bar pressure using geometry depicted in figure 1c.

At this time we introduce a novel LTCC sensor conception for a z-axis piezoresistive sensor using geometry illustrated in figure 1d. Sensor is composed of a piezoresitive material post with upper and lower electrodes for electrical contact.

III. SENSOR OUTLINE

Operation for compressive forces offer direct force measurement and allow the use of arrays for vectorial force decomposition, without mechanical translation.
In Fig. 2 is displayed the outline of a z-axis load cell force sensor.

Force is applied through a metal sphere. Three posts at an angle of 120° to each other, connected to an upper structure, receive the decomposed force, each post sustain 1/3 of total applied force. The relation for single post configuration is 1:1, the total force is applied on to one post.

Strain (ε_z) in each one of the posts is given by:

$$\varepsilon_z = \frac{\Delta z}{z} = \frac{1}{E} \cdot \frac{4 \cdot F_z}{\pi \cdot d^2} \qquad (3)$$

With E = Young module of piezoresitive material
F_z = Force in the z direction
d = Post diameter

The expected resistor variation of each post is given by:

$$\frac{\Delta R}{R} = GF \cdot \varepsilon_z = GF \cdot \frac{1}{E} \cdot \frac{4 \cdot F_z}{\pi \cdot d^2} \qquad (4)$$

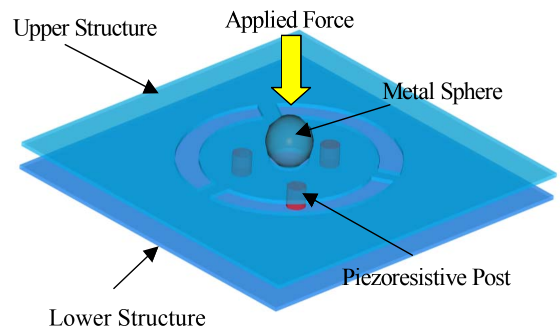

Figure 2. Load Cell Outline.

IV. FABRICATION

In order to know the behavior of each post of load cell we have decided to fabricate a single post device. The structure are fabricated whit two different sacrificial materials, high purity carbon black tape of 200 µm thickness (TCS-CARB-1) and Setter Powder Sheet™ (SPS) with thickness of 127 um both from Harmonics, Inc. With the latter we obtain best aspect ratio and form in cavities and resistor post using two of 127 um thickness.

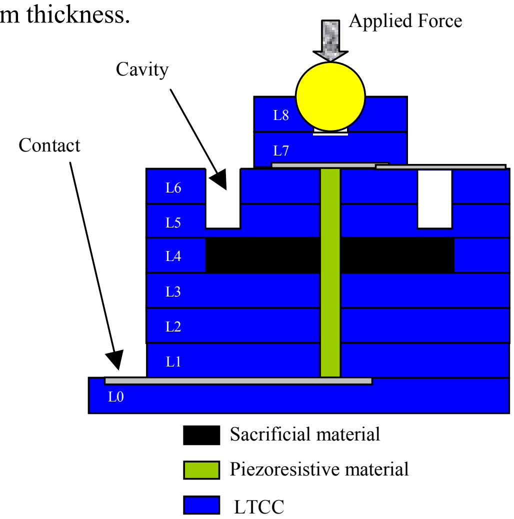

Figure 3. Single post structure.

The post has a diameter of 950 µm and a 200 µm height. Pouring method is very misleading and several steps of paste drying are needed. We decided to prepare piezoresistive material from thick film paste by removing the organic content of the paste using acetone in ultrasonic bath followed by heating up to 250 ^{o}C. Finally we use grinding to obtain a fine powder. The optimization method for former the post resistor was obtained from a pellet with this fine powder. This pellet was implanted in to L1-L6 before sintered. The rest of the manufacturing was done with the standard flow process of 951 LTCC system. Thick film 6146 paste was used for electrical contacts, both paste and ceramics are from DuPont.

The characterization system for fabricated single post device is composed of a loading structure for applying static forces to the fabricated sensor, signal conditioning electronic circuitry, data acquisition and a PC workstation for data analysis, as shown in Fig. 4.

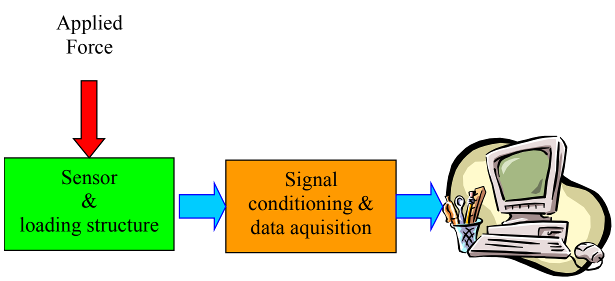

Figure 4. Instrumentation arrange for sensor characterization.

The fabrication of single post structure whit Ro = 1,3KΩ and temperature behavior of free posts (no mechanical loads) was accomplished obtaining good stability and having variations of no more than 1% of Ro. The single post structure was loaded from 0 to 15 N in a INSTRON force calibration equipment, displacement was monitored using a Laser displacement meter and resistance was measured using a Keithly 2000.

Loading results of single post force sensor are presented in Fig. 5, at this time we measured %ΔR/R and ΔL.

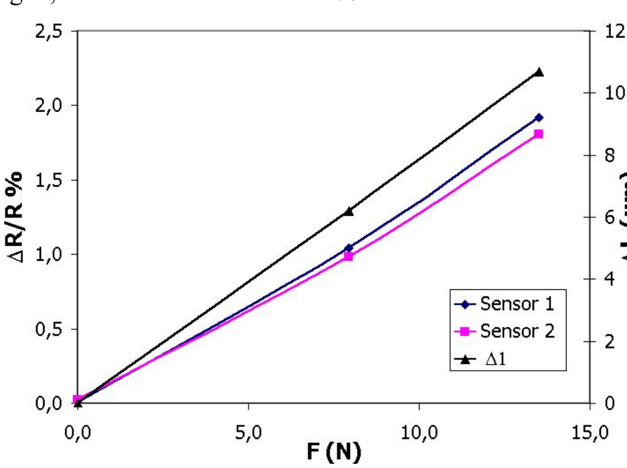

Figure 5. Single post structure loading results.

This results corresponding for two sensor fabricated, the variation of Δl are very similarly for both sensors tested, one of this are presented in a Fig. 6.

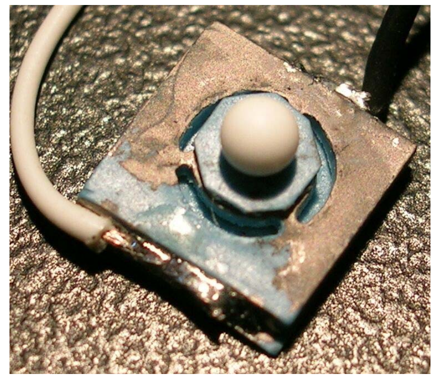

Figure 6. Fabricated and caracteritaed single post load sensor.

V. Conclusion

LTCC technology proved to produce z-axis compressive force sensor suitable for load cell applications. The fabricated sensors presents large buried cavities without sagging; buried resistive post with good aspect ratio and shape; good electrical contact after applying force several times; repeatability of fabrication process and low drift whit temperature. Further measurements for sensor characterization in higher and lower loads and temperature behavior, are in progress.

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