LTCC Post Load Cell

Mário R. Gongora-Rubio [1*], M. Roberti [3], Z M. da Rocha [2], L Fraigi [3]
[1*] Institute for Technological Research of São Paulo State (IPT)
Av. Prof Almeida Prado No 532, Cidade Universitária,
CEP 05508-901 - São Paulo/SP, Brazil, e-mail: gongoram@ipt.br
[2] Laboratório de Sistemas Integráveis (LSI), University of São Paulo, São Paulo, Brazil
[3] National Institute of Industrial Technology (INTI), Argentina

Abstract

This paper presents the development of a force post compressive load cell, fabricated using Low Temperature Cofired Ceramics (LTCC) technology. It was implemented as an LTCC mechanical load cell structure with a z-axis thick film strain gage using two different approaches. Fabrication methods and materials are explored in this work and fabricated devices are presented. This paper will also present the results of initial electromechanical sensitivity to load force and temperature tests. Compressive force behavior is consistent, in a strain level up to 1.500 micro-strain.

Keywords

LTCC, Micromechanical devices, Piezoresistive Sensors, Force sensors

Introduction

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

Embedded passive components are easily implemented in LTCC in order to improve MCM packaging density. Micro-volume resistors have been 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, have been conducted [3] in order to verify compatibility of LTCC materials and pastes from different manufacturers. Recently new LTCC-MST developments were introduced making 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 causes a deformation sensed by the strain sensor providing an electrical output proportional to the applied force.

In the present work, a novel structure designed for low cost compressive force sensing is proposed. 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 suitability for difficult environments. The structure consists of several green tape layers machined by using a printed circuit board prototyping CNC router accompanied by metal electrodes and posts of thick film piezoresistive paste, embedded in sacrificial materials.

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 (ΔR/R) and the applied strain (Δl/l)

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

Downloaded from http://meridian.allenpress.com/jmep/article-pdf/3/4/169/2247212/1551-4897-3_4_169.pdf by guest on 01 November 2022

Metals are affected only by geometrical changes resulting in GF of 2 to 2.5. Semiconductors as well as thin film and thick film resistors display higher gage factors. Besides geometrical changes because of applied strain, resistor shift is due to micro-structural modifications in the 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 10 KΩ/□ resistors are usually between 9 and 20, as pointed out in the literature [8], rendering an appropriate sensor for the proposed application.

The geometry of piezoresistive sensors implemented using thick film resistor materials are illustrated in Figure 1. Part (a) is a planar structure, (b) a vertical structure, (c) a vertical structure with surrounded dielectric and (d) the proposed novel post vertical structure suitable for z-axis force sensing. The resistance value for the 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 are the lateral dimensions of the resistor.

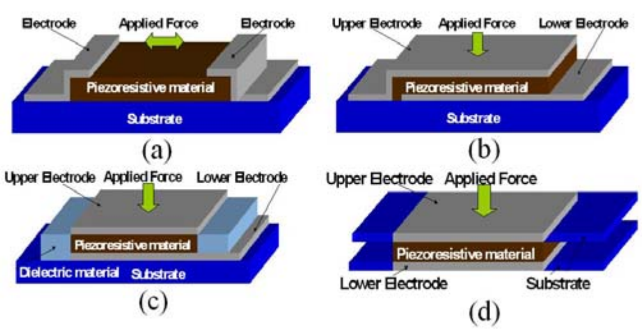

Figure 1. Thick film strain sensor geometries.

Force sensors using thick film resistors have been proposed in [6, 7], using the planar geometry, see Figure 1(a), but planar methods are generally indirect measurements. Z-axis sensitive devices exhibit higher GF, good thermal stability and use direct measurement techniques when compared with conventional planar sensors, as observed in [9, 10].

A design of a z-axis piezoresistive force sensor, using the geometry shown in Figure 1b, was previously introduced to obtain high levels of strain [11, 12].

Another implementation of a vertical z-axis thick-film piezoresistive resistor, surrounded with dielectric, was proposed in [13], using geometry depicted in Figure 1c. This design is intended for multipoint load sensors with sensing resistances of 2.5 KΩ and sensitivities of (ΔR/R) approximately 1.3% at 6 bar of pressure.

The authors have developed a novel LTCC sensor conception for a z-axis piezoresistive sensor using the geometry illustrated in Figure 1d. The sensor is composed of a piezoresitive material post with upper and lower electrodes for electrical contact.

Materials

For load cell sensor implementation the authors utilize Low Temperature Co-fired Ceramics materials to implement structural substrates for these devices. Ceramic tape layers provide an easy, inexpensive, and rapid platform for the integration of passives, electronics and microfluidics.

The mechanical properties of the fired Dupont 951 LTCC system used in this work include a Young's modulus of 152 GPa, a Poisson's ratio of 0.17, and a material density of 3.1 g/cm^3.

The processing of the green ceramic tape layers is usually done in three basic steps:

- Patterning of individual layers with via holes, resistors, conductors, dielectric pastes, depending on the application;
- Collation and lamination of the tape layers under pressure and temperature;
- Co-firing of the entire part to sinter the material.

LTCC composites are susceptible to plastic deformation upon lamination or under the stress of body forces once the glass transition temperature of the glass binder is reached during processing. Hence sagging of a suspended cavity during lamination and sintering must be prevented [14].

Lamination using organic fluids [15] is a technique that consists of the deposition of a thin layer of an organic fluid upon green ceramic tape surface to obtain a temporary bond until the sintering process is complete.

Advantages of lamination using organic fluids comprise excellent adhesion, easy tape alignment at room temperature, low temperature and pressure and no pressure gradients, easy deposition that can be realized by dipping, screen-printing or dispensing techniques.

Piezoresistive effects on thick film resistor materials are well established [8], providing evidence that thick film

Downloaded from http://meridian.allenpress.com/jmep/article-pdf/3/4/169/2247212/1551-4897-3_4_169.pdf by guest on 01 November 2022

resistor can be used as strain gages. In this work the authors used available Dupont thick film resistor pastes from the QS product family and compatible silver materials.

Recently a sacrificial volume technique for preserving a enclosed unfilled volume was introduced by Peterson et al. [5]. They used an insert of a sacrificial material that dissociates during the firing step and leaves no material residue after burnout. Figure 2 illustrates a TGA analysis for a carbon tape material using a typical LTCC firing profile. A consistent weight loss near 600 ^{o}C is clearly visible from this data.

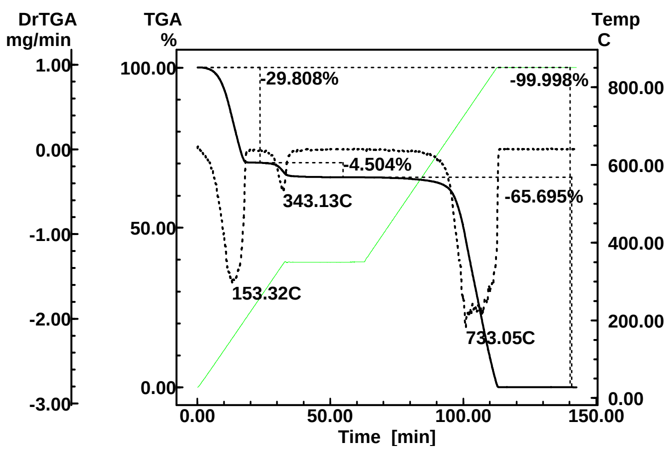

Figure 2 TGA analysis for Carbon tape material.

Sacrificial material that uses a carbon tape in solid form [15] and is commercially available has been used in this work. We also modified the LTCC temperature sintering profile, and changed the furnace atmosphere by controlling the air/nitrogen ratio. The modified sintering profile is illustrated in Figure 3.

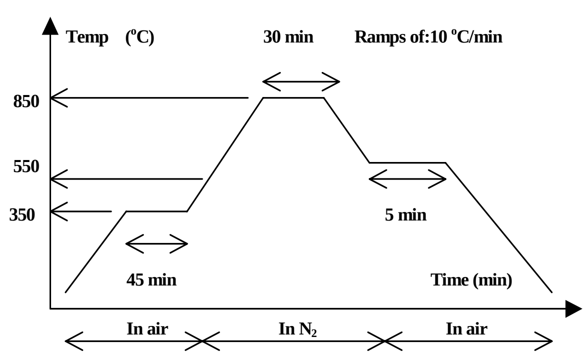

Figure 3. Modified sintering temperature profile for use with sacrificial materials.

As previously described [5], setter powder sheets and ceramic powder liners with uniform ZrO_2 or Al_2O_3 particle size materials and an organic binder are formed into paper-thin sheets. These sheets can eliminate adhesion between the parts and the setter and reduce stresses on difficult to fire devices. Therefore, the authors have used these materials for the fabrication of load cell sensors [15].

Sensor Outline

Operation of a resistor sensor with compressive forces offer direct force measurement and allow the use of arrays for vectorial force decomposition without mechanical translation.

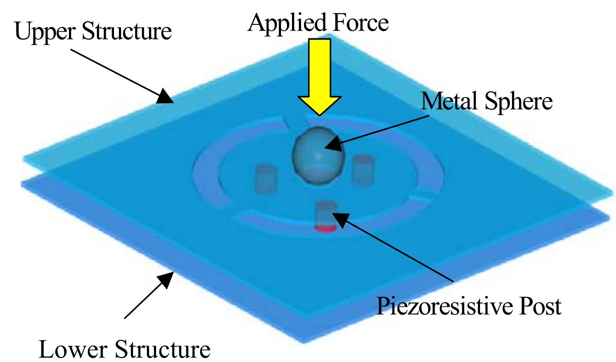

Figure 4. Load cell outline.

Figure 4 illustrates the outline of a z-axis load cell force sensor. The force is applied through a metal or ceramic sphere connected to a mechanical fixture. Three posts are used at an angle of 120^{o} to each other, and connected to an upper structure. Each post sustains 1/3 of the total applied force. The 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
Δz = change in the z direction

The expected resistance change of each post is given by:

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

Downloaded from http://meridian.allenpress.com/jmep/article-pdf/3/4/169/2247212/1551-4897-3_4_169.pdf by guest on 01 November 2022

Post Load Cell Fabrication

Fabrication of devices uses two approaches for electrode positioning: from inside and outside the sensor cavity respectively.

The first implementation of the proposed device is presented in Figure 5, and is formed of six LTCC layers (DuPont 951-AX). Three layers (L1- L3) were laminated with their corresponding electrodes facing up, one layer with a circular cavity (L4), filled with sacrificial material, and finally two layers (L5-L6) laminated with electrodes downwards. Inside the cavity a sacrificial material with three via holes is assembled. These via holes are filled with piezoresistive paste.

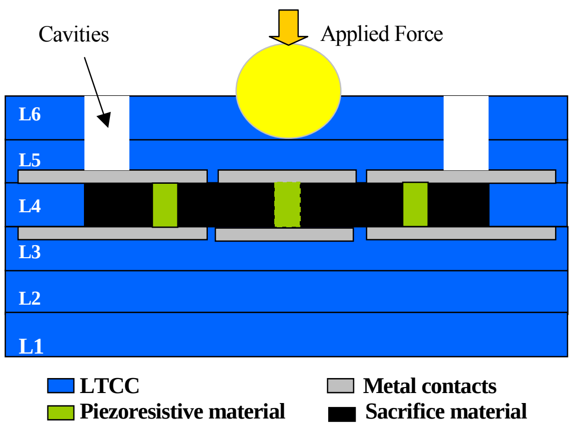

Figure 5. Internal sensor electrode implementation.

In order to avoid vias and simplify the connections 1mm contacts we machined out of the structure in layers (L3, L5). Several devices were made simultaneously, which reduced considerably the fabrication times and cost. Green tapes were laminated at 100 ºC under a pressure of 170 kgf/cm^2 for 10 minutes.

Tapes were micromachined using a numerically controlled (CNC) milling machine, with tools of 250 µm, 500 µm and 1 mm in diameter. The AUTOCAD™ software tool was used to design structures for each layer.

Figure 6a illustrates sacrificial tapes after machining and Figure 6b illustrates the final assembly of the device, before sintering.

The device has dimensions of 11 mm x 11 mm including the contacts. Electrodes were obtained by a silver paste (DuPont 6146) applied on the green tapes surfaces by means of screen printing, resulting in a total thickness of 50 micrometers.

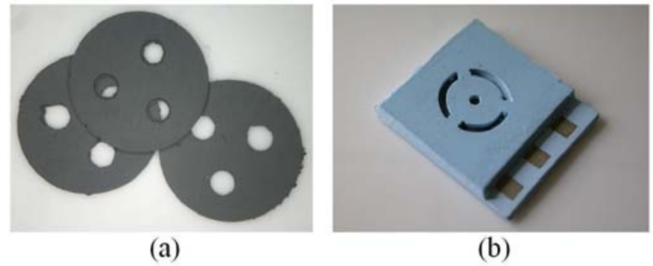

Figure 6. (a) Machined carbon sacrificial tape layers, and (b) final assembled device prior to sintering.

In order to locate thick film piezo-resistive posts, a commercially available fugitive material, was used. Three 1mm diameter cavities were filled with a high purity carbon black tape 200 µm in thickness (TCS-CARB-1 from Harmonics, Inc.) that is used as a sacrificial material. Some cavities in layers (L5, L6) were machined in order to ease the gas flow (CO_2) produced during sintering. Piezoresistances were obtained by printing paste into the via orifices.

Dupont thick film commercial pastes of 1KΩ/ □, 10KΩ/ □ and 100KΩ/□ from the QS family were used. Finally, all the layers were stacked and laminated together at 100 ºC under a pressure of 85 kgf/cm^2 for 20 minutes. After lamination, the device was sintered using a modified LTCC temperature profile.

A second implementation of a z-axis force sensor formed from six LTCC layers (DuPont 951-AX), is presented in Figure 7. Three layers (L1- L3) were laminated with their corresponding electrodes on the lower surface, one layer with a circular cavity (L4), for sacrificial materials, and finally two layers (L5-L6) were laminated with electrodes on the upper surfaces.

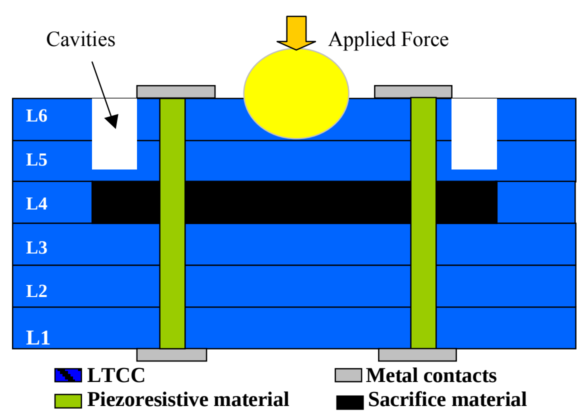

Figure 7. External sensor electrode implementation.

Downloaded from http://meridian.allenpress.com/jmep/article-pdf/3/4/169/2247212/1551-4897-3_4_169.pdf by guest on 01 November 2022

Inside the cavity a sacrificial material with three via holes was assembled. In these via holes piezoresistive paste was printed.

In order to locate thick film piezo-resistive posts a Setter Powder Sheet™ (SPS) or Ceramic Powder Liner ™ (CPL) with a thickness of 0.001 in from Harmonics, Inc. was used as a sacrificial material. The remaining materials and processes are similar to those used in the previous sensor.

Experimental Results

Concerning the first approach: Figure 8 displays a top view of Layers (L1-L4) with carbon tape and a bottom view of layers (L5 and L6) before final lamination. Figure 8a shows a detailed view of eight of the fabricated devices, while Figure 8b illustrates a single laminated sensor prior to firing. Figure 9a is a photograph of fabricated sensor, as well as, a cross section along the dotted line A-A displaying the internal piezoresistive posts (see Figure. 9b).

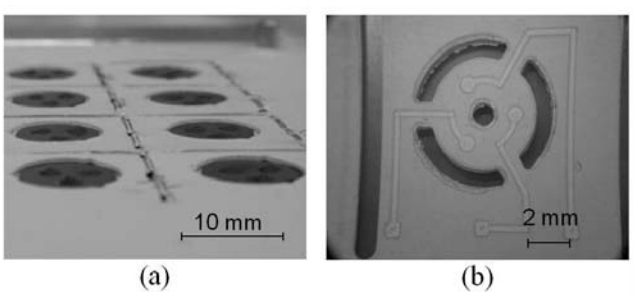

Figure 8. Top and bottom view of fabricated sensor.

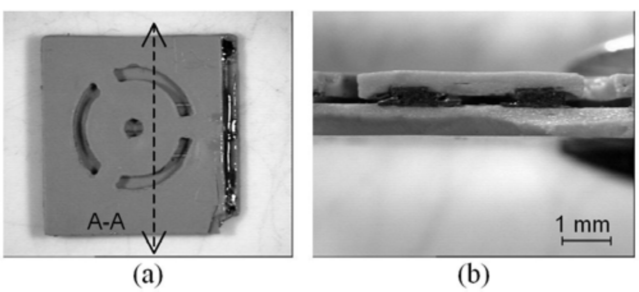

Figure 9. Post load cell with detail of post piezoresistance.

Several challenges appeared during the fabrication steps, including a sagging problem due to the devices large size, the piezoresistive thick film insertion method, paste slipping during sintering and short circuits between internal electrodes.

Using modified sintering profile the sagging problem was improved, but still is a problem to be resolved. In Figure 10 a sintered device is shown, revealing undesirable sagging in the upper structure.

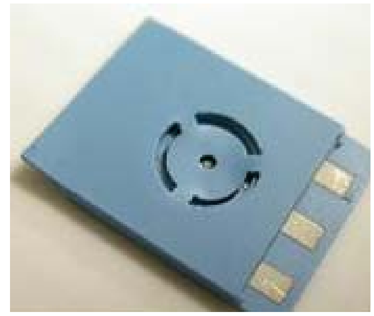

Figure 10. Sintered sensor displaying sagging.

Each post within the structure has a diameter of 950 µm and a 200 µm height. The insertion method is very difficult to control 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 °C, finally we used a grinding process to obtain a fine powder, before we executed the powder insertion.

Measurement of post resistance indicated that the post insertion method should be improved, so we developed a method of generating a pellet out of piezoresitive material powder by controlling the volume and compression force before insertion into the post openings.

In Figure 11 a detail of a test post created using powder of piezoresistive materials is illustrated. Al_2O_3 setter powder sheets were used as sacrificial material in this process. Note some Al_2O_3 residue is clearly visible after sintering.

Figure 11. Test post detail.

In addition, some posts were short-circuits. These results are the consequence of the hole dimensions in the carbon tape and slipping of paste during sintering. We found that the 100KΩ/ □ paste was not useful for post forming purposes, but that the 10KΩ/ □ paste was practical. After several improvements we could fabricate internal electrodes load cell sensors with a yield of 80%, so we resolved to implement the second approach using external electrodes.
The second approach used to implement sensor post utilizes powder piezoresistive material and Al_2O_3 setter powder

Downloaded from http://meridian.allenpress.com/jmep/article-pdf/3/4/169/2247212/1551-4897-3_4_169.pdf by guest on 01 November 2022

sheets as sacrificial materials. As a result Figure 12 shows a laminated sensor (structural layers and sacrificial material) ready to accommodate the piezoresistive material. After the powder placement in the sensor orifices, a standard firing profile was used to sinter parts, rendering the sensors as shown in Figure 13.

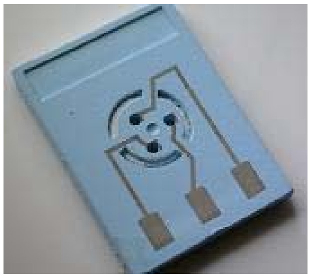

Figure 12. External electrode sensor in green (unfired) state.

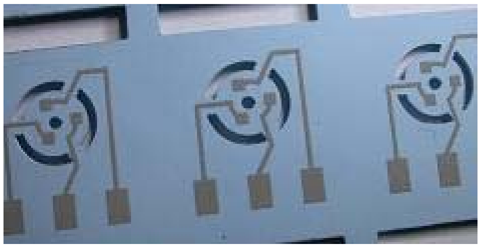

Figure 13. Fabricate external electrode sensors.

Figure 14. Sensor post visualitation.

In order to verify post morphology we fractured the upper sensor structure as displayed in Figure 14.

The characterization system for the fabricated 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. Before we proceed with fabricated sensor calibration it was decided to test the post behavior, so we implemented a single post device, see Figure 15, with the same fabrication steps mentioned in latter sections except the piezoresistive post. In this case we used a piezoresistive pellet as test post. The fine resistive powder was compacted with a cylindrical pellet molds and implanted on the hole between L1-L6.

In this single post device a Setter Powder Sheet (two SPS thickness 0.001 in) was used for the sacrificial material. This material was added to L0 and L7 to form good external electrical contacts. In L8 it is added to the center applied force area and to protect the electrical contacts. This device presents good post shape, no sagging after sintering, good resistance repeatability and better electrical contacts. The resistance post value (Ro) @ 25°C and without load was 1.3KΩ.

Temperature behavior of free posts (no mechanical loads) showed good stability (better than 1%) in a range of 25-85°C.

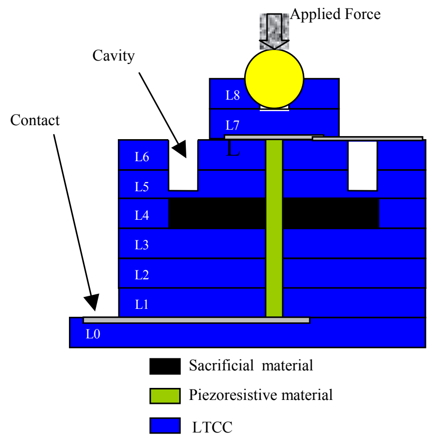

Fig. 15. Post test structure.

The test structure was loaded from 0 to 15 N using an INSTRON force calibration instrument. Displacement was monitored using a Laser displacement meter, and resistance was measured using a Keithly 2000. Loading results of 3D force sensor are presented in Figure 16, at this time we measured %ΔR/R and ΔL.

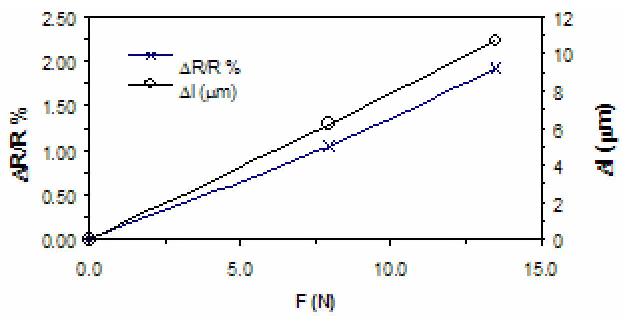

Fig. 16. Post test structure loading results.

Downloaded from http://meridian.allenpress.com/jmep/article-pdf/3/4/169/2247212/1551-4897-3_4_169.pdf by guest on 01 November 2022

Conclusions

LTCC technology proved to produce z-axis compressive force sensors suitable for load cell applications. Several sensor fabrication methods were presented as well as the development and optimization of a method to obtain piezoresistive posts.

The fabricated sensors present: large cavities without sagging; posts with good aspect ratio and shape; good electrical contact after applying force several times; repeatability of fabrication process and low drift with temperature.

Further measurements for sensor characterization at higher loads and temperature dependent behavior, are in progress.

Acknowledgment

We would like to acknowledge Magnetti Marelli of Brasil for the resistor pastes and Harmonics Inc. for the Carbon black samples.

The authors would also like to acknowledge the CNPq PROSUL program and CAPES for their financial support.

References

[1] M. R.Gongora-Rubio, P. Espinoza-Vallejos, L. Sola-Laguna and J. J. Santiago-Aviles; ''Overview of Low Temperature Co-Fired Ceramics Tape Technology for Meso-System Technology''; *Sensors & Actuators A, Physical;* v. 89, 2001, pp. 222 - 241.

[2] L.J. Golonka, K.-J.Wolter, A.Dziedzic, J. Kita & L.Rebenklau; Embedded passive components for MCM; *24Th International Spring Seminar on Electronics Technology*, Calimanesti-Caciulata, Romania, May 5-9, 2001, pp. 73-77.

[3] A.Dziedzic, L.J. Golonka, J. Kita, H Thust, K-H Drue, R Bauer, L.Rebenklau & K-J Wolter; Electric and stability properties and ultrasonic microscope characterization of Low temperature co-fired ceramics resistors; Microelectronics Reliability 41, pp 669-676, 2001.

[4] Peterson K.A., Rohde S. D. Walker C.A., Patel K.D., Tuner T.S. and Norquist C.D., Microsystem integration with new techniques in LTCC, Proc. of Ceram. Intercon. Tech. Conf., IMAPS, Denver (2004) 19-26

[5] Peterson K. A., Patel K. D., Ho C. K., Rohde S. B., Nordquist C. D., Walker C. A., Wroblewski B. D. and Okandan M.; Novel Microsystem Applications with New Techniques in Low-Temperature Co-Fired Ceramics; International Journal of Applied Ceramic Technology, 2 [5] 345–363 (2005)

[6] M. Prudenziati (Ed.) *Handbook of sensors and actuators 1: Thick film sensors*, Elsevier 1994.

[7] White N. M. and Brignell J. E.; A Planar Thick-film Load Cell; Sensors and Actuators A, 25-27(1991) 313-319

[8] Hrovat M., Belavic D., Samardzija Z.; Characterisation of thick film resistor series for strain sensors; Journal of the European Ceramic Society 21 (2001) 2001–2004

[9] Puers B., Sansen W. & Paszczynski S.; Assesment of thick film fabrication methods for force (pressure) sensors; *Sensors and Actuators,* Volume 12, Issue 1, July 1987, pp 57-76.

[10] Puers, B., Sansen, W, Paszczynski, S and Leuven, K. U., Miniature highly sensitive pressure- force sensor using hybrid technology. In Proceedings 6th European Microelectronics Conference, ed. B. Turnbill. ISHM Europe, London, 1987, pp. 416–420.

[11] Zheng Y., Atkinson J. & Sion R.; On the zero offset stability of thick film strain gauges; Microelectronics International, 19/ 3 [2002] 24–29.

[12] Zheng Y., Atkinson J., Zhang Z. & Sion R.; An evaluation of materials and processes employed in the construction of novel thick film force sensors; Microelectronics International 20/ 1 [2003] 31–33.

[13] Belavic D., Hrovat M., Pavlin M. Vertical thick-film resistors as load sensors; Journal of the European Ceramic Society 21 (2001) p.1989–1992

[14] Espinoza-Vallejos P., Zhong J., Gongora-Rubio M. R., Sola-Laguna L. And Santiago-Aviles J.J., The measurement and control of sagging in meso electromechanical LTCC Structures and Systems" in: MRS Conference Proceedings Vol 518, (1998).

[15] Rocha, Z. M.; Ibañez Garcia N.; Oliveira, N. A.; Matos, J. Do Rosário & Gongora-Rubio, M. R., Low Temperature and Pressure Lamination of LTCC Tapes For Meso-Systems, In: IMAPS Conference And Exhibition On Ceramic Interconnect Technology, 2004, Denver.

[16] Harmonics Inc. Website: http://www.harmonicsmaterials.com/

Downloaded from http://meridian.allenpress.com/jmep/article-pdf/3/4/169/2247212/1551-4897-3_4_169.pdf by guest on 01 November 2022

Biographies

Mario Ricardo Gongora-Rubio. He received his B.S. in Electronics Engineering at Catholic University Javeriana 1974, Bogota, Colombia. His M.Sc. was in Electrical Engineering at Polytechnic School of São Paulo University in 1990 and Ph.D. in Electrical Engineering in 1999, also at Polytechnic School of São Paulo University.

He is currently a senior researcher of the Institute for Technological Research of São Paulo State, São Paulo, Brazil. His research interests include Nano and Microtechnology, Microfluidics, LTCC technology applications on microsystems for analytical chemistry, chemical process, environmental and biomedical fields.

Mariano Roberti. He received his B.S. at National Technological University in Buenos Aires, Argentina. Currently is at the INTI, National National Institute of Industrial Technology (INTI), Argentina. His research interests are focused on LTCC technology for Microsystems.

Zaira Mendes da Rocha. She received B.S. in Material, Process and Electronics components Technology at FATEC Technology School, São Paulo, Brazil, in 2002 finished her M.Sc. in Electrical Engineering at Polytechnic School of São Paulo University in 2005 and currently is a Ph.D. student at Polytechnic School at University of São Paulo. Current research interests are in LTCC processing technology for applications in analytical chemistry.

Liliana B. Fraigi. She received B.S. in Electronics Engineering at National University of Argentina in Buenos Aires, her Ph.D. was in Electrical Engineering at National University in 2006. She is head of Microsystem Technology group at National National Institute of Industrial Technology (INTI), Argentina. Research interests include silicon and LTCC technologies for Microsystems.

Downloaded from http://meridian.allenpress.com/jmep/article-pdf/3/4/169/2247212/1551-4897-3_4_169.pdf by guest on 01 November 2022