AN LTCC HYBRID PRESSURE TRANSDUCER FOR HIGH TEMPERATURE APLICATIONS

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ABSTRACT

Low Temperature Co-fired Ceramic (LTCC) and thick film technology, with their mechanical, electrical, and thermal properties make them an appropriate choice for the development of a pressure transducer. This research designs a pressure transducer using LTCC and thick film technology. We show the relation between the size of the diaphragm and resistance to pressure. We determine the best position of the piezo-resistors, which are accommodated forming a Wheatstone bridge. Two of the piezo-resistors measure the deflection on the tangential axis, and the other two measure the deflection on the radial axis. By using the Wheatstone bridge we can obtain more accuracy in the output of the transducer.

1. INTRODUCTION

This paper describes the process of making a pressure transducer with LTCC tape and thick film technology. The great qualities of this technology show a great promise to develop a transducer. This paper presents the circuit for compensation and the characterization of the piezo-resistors used in the design. The simulation of the membrane is another important part of this research. The paper provides all the steps needed to construct a pressure transducer with LTCC.

1.1 LTCC

Low Temperature Co-fired Ceramic (LTCC) has high density and reliability and a low manufacturing process cost. LTCC has a uniform structure composed 45% alumina (Al_2O_3), 40% glass, and 15% organic material. Among the properties that make LTCC useful are high strength, reliability, low Thermal Expansion Coefficient (TCE), refire stability, and an environmentally safe organic binder and solvent system.[1] LTCC is very effective in the microelectronics area because of its thermal, mechanical, and electrical properties.

For this project we use DuPont 951-AT of 114 μm thickness. During the green state this material is very soft, flexible, and easily dissolved (see Table 1.1). Figures 1.1 and 1.2 depict the firing process. The temperature raised 350°C at a rate of 10°C/min. At 350°C the organic material is dissolved. The next step is to raise the temperature to 850°C at the same rate. If this temperature is maintained for 2 minutes, the process is as *semi-sintered*. If, however, the temperature is maintained for 30 minutes, it is called a *fully-sintered* process. The difference between these processes is in the arrangement of the particles of glass. In the semi-sintered process the particles of glass surrounding the molecules of alumina; in the fully-fired process the particles of glass covers the molecules of alumina. It shrinks 12% in the x-y plane and 15% in the z plane.[1]

Once fired, the material is very strong (see Table 1.2). It is ideal for use of hybrid circuits with thick film technology.

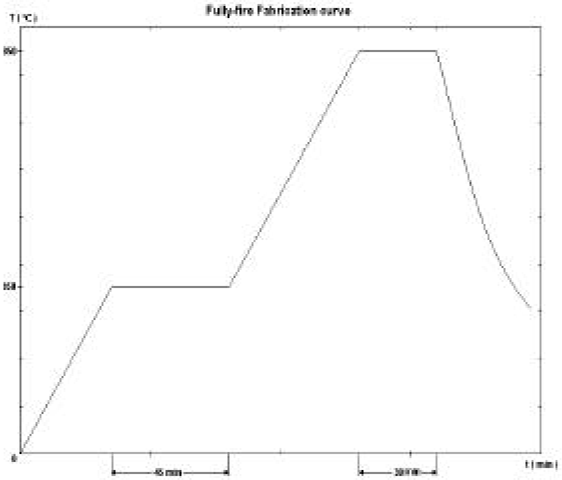

Figure 1.1: Fully–Fired Process

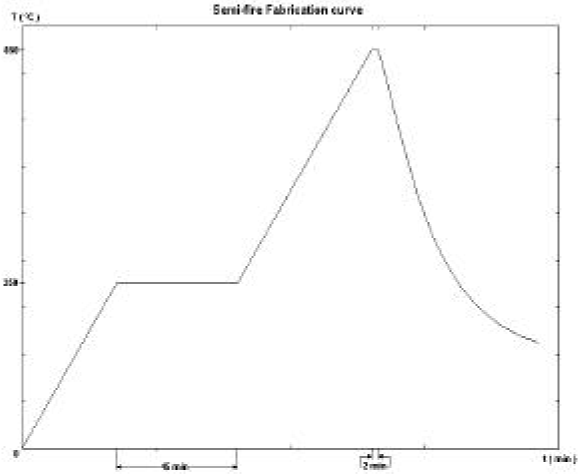

Figure 1.2: Semi-Fired Process

Table 1.1: Unfired properties

Thickness	
951-AT	114 µm ± 7% (4.5 mils)
Shrinkage	
(x,y)[a]	12.27% ± 0.3%
(z)[b]	15% ± 0.5%
Tensile Strength	1.7 MPa
Young’s Modulus	152 GPAS

[a] Typical properties are based on laboratory test using recommended processing.
[b] Eight- layer laminated structure with no metalization, using recommended processing.

Table1.2: Typical fired properties

Electrical	
Dielectric constant, κ (@ 10MHz)	7.8
Dissipation factor (@ 10 MHz)	0.15%
Insulation resistance (@100 V DC)	>10^{12} Omega
Breakdown voltage (@V/25)	>1000 V
Physical	
Thermal expansion (25°C-300°C)	5.8ppm/°C
Density	3.1 g/cm
Camber	Conforms to setter
Refire at 850°C surface	Stable
Surface smoothness	0.22 µm
Thermal conductivity	3.0 W/m-k
Flexural Strength	320MPa
System Capability	
Via Diameter Resolution	100 µm
Line/Space Resolution	100 µm / 100 µm
Maximum Layer Count	> 80 layers

1.2 PRESSURE TRANSDUCER

The main parts of a pressure transducer are the diaphragm (the sensitive element), the electrical device, and the contacts. The diaphragm is where pressure is applied. It has to be strong enough to resist pressure, and elastic to avoid a fracture when the applied pressure. The diaphragm suffers a strain or deflection, causing a change in the sensitive element. At the top of the diaphragm there is an electrical device, which coverts the strain into an electrical signal, and makes possible measure the applied pressure. The most commonly used pressure transducers are capacitive and resistive.

1.2.1 CAPACITIVE PRESSURE TRANSDUCER

Capacitive pressure transducers convert a change in the position of the electroconductive plates forming a capacitor, and a change in the properties of a dielectric between the plates into an electrical signal. Figure 1.3 shows an example of a capacitive pressure transducer.

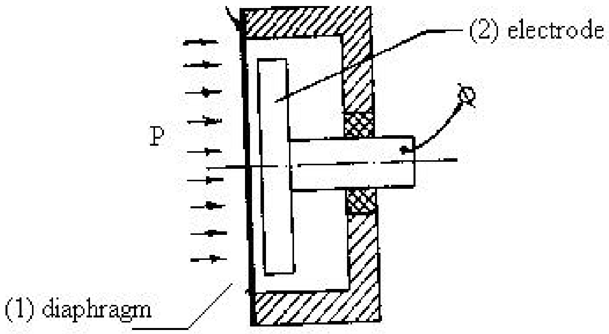

Figure 1.3: Single Capacitor pressure-sensitive element

The electroconductive diaphragm (1) affected by the pressure (P) moves towards a stationary electrode (2) positioned side along the diaphragm. The diaphragm and electrode form a capacitor sensitive to pressure.[2]

The capacitive pressure transducer has some disadvantages. There is a small change in the capacitance as a response to the mechanical signal. Accuracy is affected by wetting parts, capillary effects, some build up on electrodes, and an unpredictable change on the permittivity*[3] of the medium (for example forming gas fraction bubbles, fumes on the surface of liquid, and so on).[2] The construction and the assembly must be precise. In light of those disadvantages and the available resources, we chose to make a resistive pressure transducer.

1.2.2 RESISTIVE PRESSURE TRANSDUCERS

Resistive pressure transducers are the most common in the market. When pressure is applied to the diaphragm, it deflects proportional to the change in resistance. The change in resistance is measured by a strain gage. Because these pressure transducers are very sensitive to the deflection, their measurements are very precise.

The resistive transducer has a very simple construction, most commonly of silicon. Silicon is a high-precision, high-strength, and high-reliability material. It is very functional where miniaturized precision mechanical devices must be fabricated in large quantities.[4] High-temperature treatment, bulk imperfections, and depositions of different films on the surface of the single-crystal silicon cause a concentrate stress and cleavage on the material. Silicon is best used at low temperatures because materials deposited on the surfaces have variations in TCE and develop a nonuniform deformation under heating. For those reasons we used LTCC tape to elaborate the pressure transducer.

LTCC does not change its properties with the change in temperature and ideal for it can be sintered below 1000°C. It is very resistant to pressure and ideal for use with thick film technology. LTCC is piezoelectric, so it often is employed to convert mechanical signals into

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* The permittivity of an insulating, or dielectric, material is commonly symbolized by the Greek letter epsilon, ε; the permittivity of a vacuum, or free space, is symbolized $\varepsilon 0$; and their ratio $\varepsilon/\varepsilon 0$, called the dielectric constant, is symbolized by the Greek letter kappa, κ.

electrical signals. It is very practical for micro-technology and is low cost compared to silicon

1.3 DESCRIPTION OF THE PRESSURE TRANSDUCER

1.3.1 MEMBRANE

The membrane is the sensitive part of the transducer. Pressure on the membrane deflects it; the deflection is proportional to the pressure applied. The membrane receives more stress at the edge (see Figure 1.4). Therefore, the membrane should not be square, or it can fracture easily. A circular shape is recommended. On the top of the membrane we put the strain gages.

Figure 1.4: Stressed part of a transducer.

1.3.2 STRAIN GAGES

Strain Gages use the change in resistance of an electrical conductor as a response to the measured deformation. In our transducer we utilize bonded strain gages to measure the strain or stresses on the element of construction. The bonded strain gages have to be strong enough to withstand tensile and compressive stress. They must also have a high gage factor. The gage factor shows how sensitive is the material. Bonding strain gages have a low temperature coefficient of resistance and high resistivity, these qualities make it very sensitive. The change in the resistance is given by:

$$\frac{\Delta R}{R} = K_x \varepsilon_x + K_y \varepsilon_y \qquad (1)$$

Where: R = resistance
ΔR = change in resistance
K_x and K_y = axial and transversal gage factor, respectively;
ε_x and ε_y = strains in the direction of x and y axes, respectively.[2]

There areon the market several kinds of strain gages. Each one has different material, purposes and application.

Our strain gage consists in four piezo-resistors, forming a wheatstone bridge (see Figure 1.5). The Wheatstone bridge has four arms, all predominantly resistive.

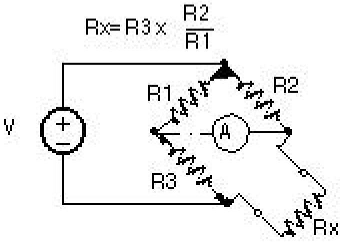


Figure 1.5: Wheatstone bridge

If a resistor has a resistivity ***r***, length *l*, width *w,* and thickness *t* (see Figure 1.6), its resistance is:

$$R=\frac{r\,l}{Wt} \qquad (3)$$

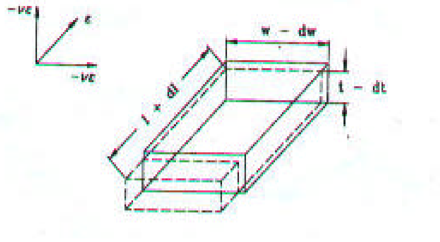


Figure 1.6: Piezo-resistor

The sensitivity of the deflection is given by the gage factor (FG). Equation shows the variation of the resistance due to some deflections.

$$FG = \frac{dR/R}{\varepsilon} \qquad (4)$$

Where: ε is the applied pressure
R is the resistance
dR is the change in resistance

If we differentiate the equation (3) and apply the Poisson ratio (v)*** we obtain:

$$\frac{dR}{R} = \frac{d\rho}{\rho} + (1+2v)\varepsilon \qquad (5)$$

2. EXPERIMENTS

2.1 EXFOLIATION

Exfoliation is a recommended technique for obtaining the diaphragm. In the exfoliation we use Hydrofluoric acid, which is known to etch glass. When a semi-sintered tape is submerged vertically in the Hydrofluoric acid during a period of time. The tape is separate in three layers. Figure 2.1 depicts the separation of the layers. We use is of 114µm. of thick tape, the thinnest available DuPont 951. When we put the layer on the hydrofluoric acid solution, the solution dissolves the layer.

This experiment proved that the thickness of the layer has to be taken into account in the exfoliation process. For this reason we decided to use a fully-fired layer for the diaphragm.

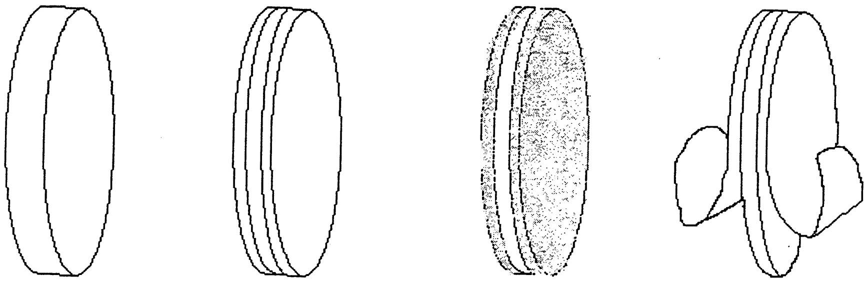


Figure2.1: Exfoliation Process

2.2 SIZE OF THE TRANSDUCERS

To make the body of the transducers we laminate eight layers of the green tape and make a perforation of .625 inch in diameter, and then fire with a fully-fired process. Once it is fired, we paste another layer on top of it but without perforation with QQ550 (a glaze used to paste ceramics). The part of this layer that is on the top of the perforation will be the diaphragm. Then it is fired, but this time by raising the temperature to 550°C at a rate of 10°C/min. Once is in 550°C stays there for 45 min. The last step is to decrease the temperature to room temperature (see figure 2.2).

The next step in the construction of this transducer is the printing of the piezo-resistors and the conductors. For the piezo-resistors we use a “strain gage paste.” This paste is not in the market, because is an experimental paste of the DuPont series. This paste is compatible with the conductors’ paste. It has a low thermal coefficient of resistance, reliability, and low noise.

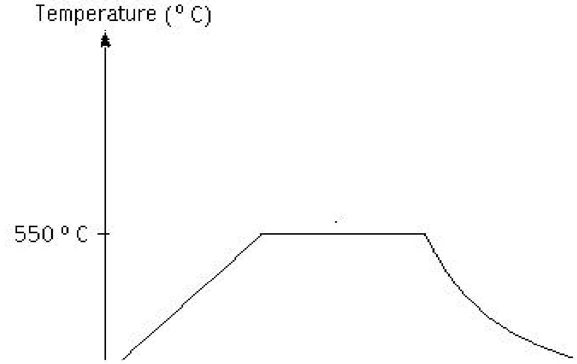


Figure 2.2: Firing process for QQ550

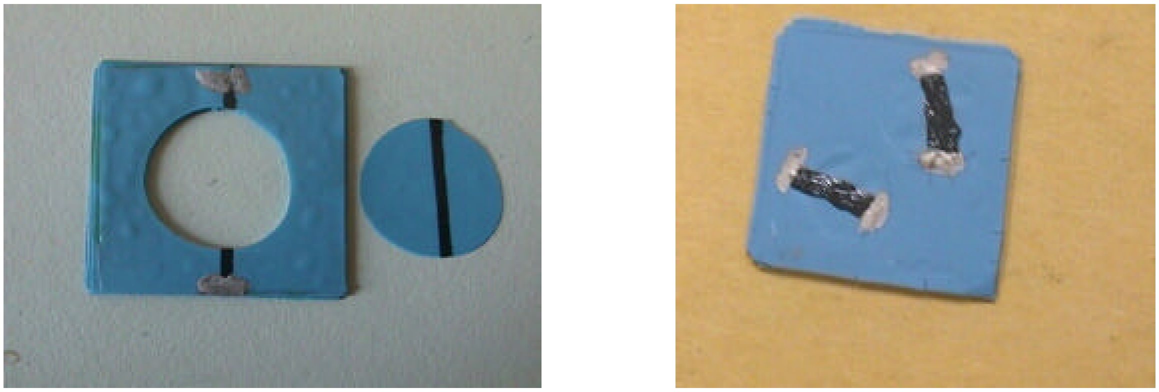
For thick film resistors the resistivity ρ in function of temperature is given by:

$$\rho = \sqrt{T}\, e^{(T_0/T)^{(1/4)}} \qquad (6)$$

Where: T_0 is the typical temperature (it depends on the structure of the material);
T is the actual temperature

We print the piezo-resistors to eliminate organic material of the paste. We fired in a hot plate at 550°C during ten minutes. The conductors are printed on the ends of the piezo-resistors. To print the contacts we use 6134 paste of the DuPont series. The main component of the paste is AgPd. The printing process is the same that we employed to print the piezo-resistors. Finally we fire transducer in a fully-fired process. This will be transducer A. We make a second transducer using same process, but changing the diameter of the diaphragm. In this occasion the diameter of the diaphragm is 0.3 inch. This will be transducer B

When we apply the same pressure to the transducers, both of them break Transducer A broke completely at the edge of the diaphragm. Transducer B cracked at the edge of the diaphragm (see Figure 2.2). This experiment proves that a transducer with a smaller diaphragm, can resist more pressure; with a bigger diaphragm resist less pressure. Both transducers receive more stress at edge of the diaphragm.



Transducer A Transducer B

Figure 2.2: Experimental Transducers

2.3 DESIGN OF THE TRANSDUCER

Using the previous results and the background of pressure transducer, LTCC and thick film technology, we design a pressure transducer. Our pressure transducer consists in16 circular diaphragms of 0.25 inch of diameter. Each diaphragm has a Wheatstone bridge with four piezo-resistors. Two piezo-resistors will measure the tangential strain; the other two will measure the radial strain. The strain is given by:

$$\sigma_t = \frac{3w}{8\pi\delta^2 m} \left[(m + 3) \frac{x^2}{R^2} - (m + 1) \right] \tag{7}$$

$$\sigma_r = \frac{3w}{8\pi\delta^2} \left[(3m + 1) \frac{x^2}{R^2} - (m + 1) \right] \tag{8}$$

Each piezo- resistor is 3/64 in and 1/64 in wide. At the ends of the piezo-resistors are the bonding pads, which are 1/64 inch length and 1/32 inch wide. With these dimensions we can approximate the offset to zero. Figure 2.3 depicts the design of the transducer

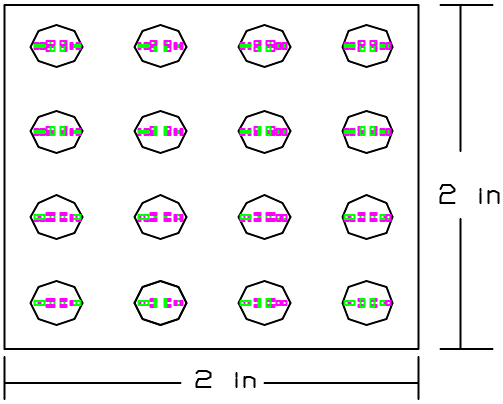


Figure 2.3 Design of the transducer

2.4 SCREEN PRINTING

We cannot do the print of the piezo-resistors and contacts by hand, because of their sizes. To make a precise print of the piezo-resistors and contacts we used a screen-printing machine. In this machine we put a screen of the Wheatstone bridge with the desired dimensions. We place the paste on the screen and the machine applies very precisely paste on top of the diaphragm.

3. CONCLUSIONS

The next step in this research is to construct the proposed transducer. Prove the functioning of the transducer is also indispensable step to complete the research. We expect that the transducer have a good response time and low noise. We expect to compare our pressure transducer with a silicon pressure transducer. The low cost and the mechanical, electrical and thermal properties of LTCC, show a great promise for microelectronics devices.

4. ACKNOWLEDGEMENTS

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