Contributions to the design and fabrication of piezoresistive transducers on membranes with MEMSCAP MetalMUMPs process.

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Abstract— **This paper presents the work carried out in relation to the design and optimization of piezoresistive transducers on membranes to enhance the sensitivity and built using MetalMUMPs process of MEMSCAP.**

Piezoresistive transducer, membrane, sensitivity, MetalMUMPs

I. Introduction

First discovered by Lord Kelvin in 1856, the piezoresistive effect is a widely used sensor principle. To put it simply, an electrical resistor may change its resistance when it experiences a strain and deformation. This effect provides an easy and direct energy/signal transduction mechanism between the mechanical and the electrical domains. Today, it is used in the MEMS field for a wide variety of sensing applications [1], such as, pressure sensors and accelerometers.

The piezoresistive effect in silicon makes it a good candidate to use as a transducer. However, the ability of polysilicon to be deposited on a wide range of substrates has received the attention of the MEMS research community and industry, since this means that free-standing structures could be fabricated [2].

Nevertheless, the sensitivity of polysilicon piezoresistive transducer is lower compared to single crystalline piezoresistive sensor [3]. For this reason, enhancing the sensitivity has also been a main issue in the research of micro pressure sensors.

This paper discusses the design considerations and implementation of piezoresistive transducers based on membrane in order to improve their performance when they are fabricated with MetalMUMPs technology of MEMSCAP.

II. Piezoresistors optimization on Wheatstone bridge configuration

A. Study of stress profile

The stress profile of the diaphragm for an operating pressure of 25 KPa has been studied for the effective placement of the piezoresistors. Using MemMech Solver, a software tool of CoventorWare which applies finite element method, it is possible to simulate mechanical behavior of the membrane in terms of displacement and stress.

For a square shaped polysilicon membrane encapsulated by two nitride layers (MetalMUMPs process), the stress distribution along X-X’ and Y-Y’ are depicted in Figs. 1 y 2. From Figs. 8 and 9 it is evident that for a square diaphragm the stress profile along X–X' and Y-Y' axes are similar and also that there is a concentration of stress at the edges, hence the resistors are placed in these areas.

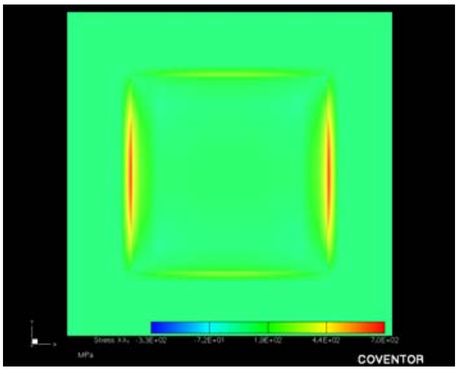

Figure 1: ***Longitudinal stress profile along X-X'***

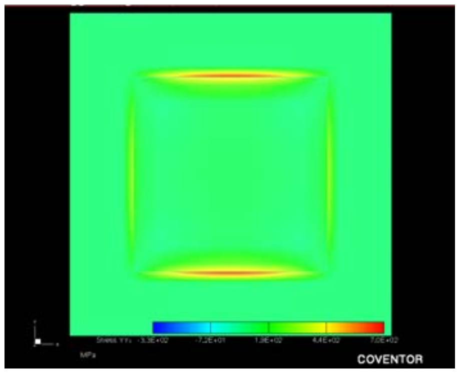

Figure 2: ***Longitudinal stress profile along Y-Y'***

B. Sensing optimization

Taking into account the previews results, using Wheatstone bridge configuration, illustrated in Fig. 3, and varying the offset of the piezoresistors along both *x* and *y* axis from the diaphragm edge to center, it is possible to detect the position where resistance values experience the maximum change without this affects to sensor linearity, which means the maximum sensitivity.

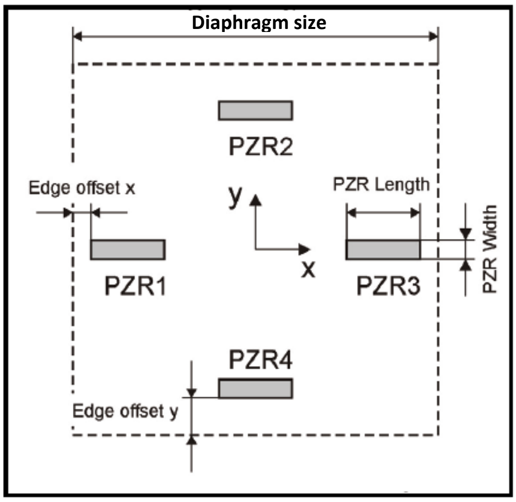

Figure 3: Piezoresistors in Wheatstone bridge configuration.

The piezoresistors PZR1 and PZR3 placed perpendicular to the edge of the diaphragm experience an increase in resistance due to the longitudinal and transverse tensile stresses, whereas PZR2 and PZR4 placed parallel to the edge of the diaphragm experience a decrease in resistance. It is in the first case in which the slope is bigger. Therefore, with this distribution sensibility of PZR1 and PZR3 piezoresistors is better than sensibility of PZR2 and PZR4.

The configuration shown in Fig. 4 has been implemented to obtain similar slope and behaviors from each set of piezoresistor. Both PZR1 and PZR3 have been replaced by sets of two piezoresistors linked by another one. On the other hand, new piezoresistors have been added to PZR2 and PZR4, in order to work as external connectors. With these new elements external measurements are possible. However, adding piezoresistors increase the resistance, therefore every piezoresistor have to be dimensioned to keep the same resistive value.

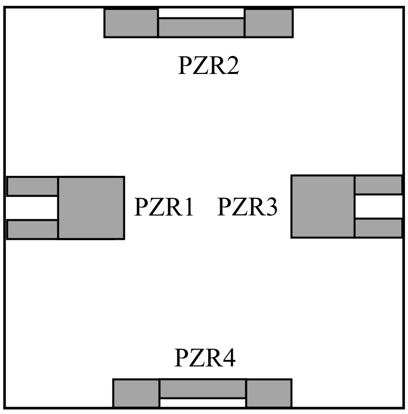

Figure 4: Piezoresistors distribution optimized

The resistive value of a piezoresistor depends on its dimensions –length, width and thickness-. In this case, the thickness is fixed to 0.7 μm which is the polysilicon layer thickness. On the other hand, length and width can be experimentally set up to obtain the desired resistive value.

With the new configuration, change in resistance is 8.20% for lateral piezoresistors, PZR1 y PZR3, whereas for PZR2 and PZR4 is 8.41%.

III. Integration with a Variable Capacitor

The previews design has been integrated to a capacitive sensor (varactor) made with MetalMUMPs process, which is an electroplated nickel micromachining process on a single silicon wafer [4] and where polysilicon (Poly) layer has been used as both capacitive and piezoresistive sensor. For this reasons, dimensions and location of piezoresistors have been limited.

Though piezoresistors have been isolated from the rest of the Poly, they also suffer strain due to the fact that upper and lower nitride layers experiment deflection when a pressure is applied on the central diaphragm.

Fig. 5 illustrates the chips that are going to be fabricated. As it is shown, the final design has been implemented for different sizes in order to check experimentally the relationship among performance, chip dimensions and die's dispersion.

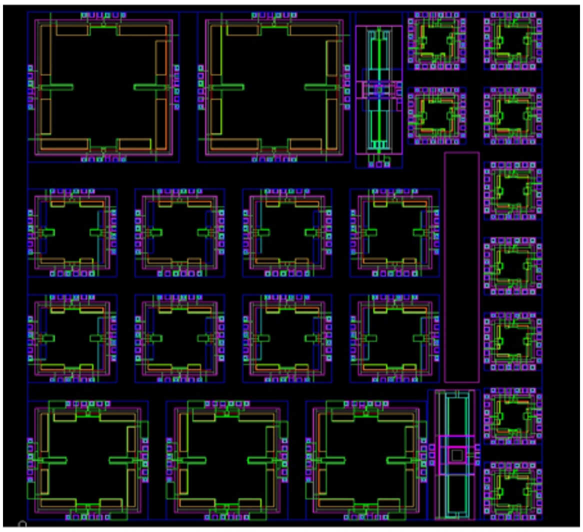

Figure 5: Fabrication layout

IV. Conclusions

The simulations have proved that it can be obtain suitable results of sensitivity for piezoresistors placed next and perpendicular to the edge of diaphragm. On the other hand, connectors to external pads are needed but they add high values of resistance to the original design. Finally, fabrication considerations have shown that micro-perforations on the piezoresistors make them change the expected performance for the transducer.

Acknowledgment

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