DESIGN AND CONSTRUCTION TECHNIQUES FOR PLANAR POLYSILICON PRESSURE TRANSDUCERS
WITH PIEZORESISTIVE READ-OUT

H. Guckel, D. W. Burns and C. R. Rutigliano
Wisconsin Center for Applied Microelectronics
Department of Electrical and Computer Engineering
1415 Johnson Drive
Madison, WI 53706

We have previously reported on experimental construction techniques for planar, vacuum sealed piezoresistive pressure transducers which are fabricated from polysilicon.¹ Fabrication methods have now been finalized and involve a polysilicon diaphragm which is reactive-sealed using a low strain LPCVD silicon nitride layer.² The nitride is also used for dielectric isolation of polysilicon strain sensors which are formed from a second polysilicon film. A stable, high yield processing sequence has been achieved.

In order to make this work useful a design method is needed which converts pressure transducer specifications to device structure. The design algorithm must predict plate stresses, strains and deflections. This is complicated by the non-zero, but reproducible built-in strain field which has a first order effect on thin film plates. Virtual displacement techniques and a double trigonometric series are used to produce the necessary mechanical data for rectangular plates. The differential equation describing plate deflections w as a function applied pressure q and stresses due to the built-in strain field N_x, N_y , and N_{xy} is³

$$\frac{\partial^4 w}{\partial x^4} + 2 \frac{\partial^4 w}{\partial x^2 \partial y^2} + \frac{\partial^4 w}{\partial y^4} = \frac{1}{D} (q + N_x \frac{\partial^2 w}{\partial x^2} + N_y \frac{\partial^2 w}{\partial y^2} + N_{xy} \frac{\partial^2 w}{\partial x \partial y})$$

If the deflection profile is known, the bending and twisting moments, and shear forces can be calculated. The boundary conditions are for the case of clamped edges. A solution of the form

$$w(x, y) = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} b_{mn} (1 - (-1)^m \cos 2 \frac{m\pi x}{a}) (1 - (-1)^n \cos 2 \frac{n\pi y}{a})$$

where the coefficients b_{mn} are given by

$$b_{mn} = \frac{3q(1-\nu^2) a^4}{\pi^4 E h^3 (3m^4 + 2m^2 n^2 + 3n^4) (1 + \frac{9(1-\nu^2)(m^2 + n^2) \epsilon_0 a^2}{\pi^2 (3m^4 + 2m^2 n^2 + 3n^4) h^2})}$$

satisfies the boundary conditions and converges to the deflected surface. The origin is located at the center of the plate. The formulation also predicts a critical built-in strain value, ϵ_0 , that will cause a plate of a given length to thickness ratio (a/h) to buckle. The algorithm produces plate dimensions to give the maximum strain sensitivity within the limits set by processing considerations. These limits include plate size due to buckling for compressive films, minimum and maximum thickness for the plate which is set by mechanical and patterning constraints, and maximum stresses before fracturing.

The built-in strain field modifies the deflections and strain sensitivity appreciably. The built-in strain is dependent on processing procedures. It can be determined and monitored during device fabrication by buckling of cofabricated doubly supported beams.⁴

The plate behavior is monitored by using polysilicon strain-sensitive resistors.⁵ The mechanical and electrical response of these devices have been studied using cantilever beam techniques. The temperature behavior, gage factor and noise figure for the resistors have been measured. The ability to produce p- and n-doped structures with opposite gage factors is of particular interest.

Resistor data and mechanical data are combined to determine resistor placement. At least two design constraints occur: a fully active bridge configuration and the need to minimize the influence of optical alignment tolerances. The design algorithm accounts for both problems. Fully active bridges are realized using n- and p- resistors on the plate. The alignment problem is reduced considerably by extending the piezoresistors slightly beyond the plate edge and with turn-around points located at the zero-strain points on the plate. Calculation of strain sensitivities must include the variation of strain with position on the piezoresistive element as well as effects of geometrical changes during loading. The algorithm has been used to design absolute pressure transducers for 15 psi, 100 psi and 500 psi. The designs are based on built-in strains of -0.05% with 2 micron polysilicon thickness. Plate dimensions of 147, 100 and 73.8 micron, respectively, have been calculated and are currently being tested in fabricated transducers. Test results for the 1 atm gages show full-scale resistance changes of 1.2% for resistor values of 47-49k Ω .

Fig. 1. An SEM of a bonded 100 psi transducer shows the serpentine piezoresistor configuration which minimizes placement error.

References

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