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NONLINEARITY OF THE PIEZORESISTIVE EFFECT OF p-TYPE SILICON DIFFUSED LAYERS WITH HIGH SURFACE CONCENTRACION

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ABSTRACT

In this work we present results of measurement of piezoresistivity coefficients of <100> oriented silicon with high boron dopant concentrations. An nonlinear approximative exspression has been derivated, that can treat piezoresistance effect quantitavely .

The results of this work where used to discuss the nonlinearity of integrated piezoresistive bridge pressure sensors, in which the piezoresistors where obtained by diffusion of boron into silicon diaphragm.

1. INTRODUCTION

The change of electrical resistivity as a function of mechanical stress (piezoresistive effect) is in general case given by equation:

$$[\Delta\rho/\rho] = \Sigma\, \Pi_{ijkl}\, \sigma_{kl} \qquad (1)$$

in which $\Delta\rho/\rho$ is a relative change of resistivity, σ_{kl} stress tensor and Π piezoresistive coefficient. Silicon has cubic lattice of diamond type, and therefore the number of indepedent variables is reduced from 81 to 3. If the piezoresitors are placed along crystalogaphic axes, which is usual for semiconductor devices where this effect is used, the expression for resistivity change becomes:

$$\Delta R/R = \Pi_l \sigma_l + \Pi_T \sigma_T$$

Π_l denotes piezoresistive coefficient of longitudinal resistor, formed along <110>, where electrical current and mechanical stess have the same direction. Π_t is piezoresistive coefficient of transversal resistor, also formed along <110>, where the direction of current and mechanical stess are perpendicular one to each other. Piezoresistive coefficients may be regarded as linear only in the first approximation, and for small stress value. Ref. /1/ and /2/ report investigation for nonlinearity of piezoresistive effect of diffused resistor with dopant concentration range $1x10^{24}m^{-3}$ to $1.5x10^{25}m^{-3}$. We did not find data in literature about concentrations of approx. $2x10^{26}m^{-3}$ althought they have hight practical importance.

2. EXPERIMENTAL

It is well known that <100> oriented silicon is widely used for pressure sensors and accelerometars. The mentioned orientation enables us to etch sample accurately along <111> plane using orientation-depend etching techniques and thus to form diaphragms or cantelivers. Samples with following parametars where used in measurements: silicon orientation <100>, n-type, resistivity 5 ohm-cm, with diffused resistor with surface concentracion of approx. $2x10^{26}m^{-3}$. The surface concentracion of resistor was determined via known data for piezoresistance temperature coeffiecienat /4/. The resistor were formed in open-tube boron diffusion from Boron+ source. Diffused layers was 700 um in length and 15 um in width, placed parallel along <110> axes. Eight samples were canteliver-cuted, with various length and width. Mechanical stress along clamped canteliver with force applied at the end is given by expression /3/:

$$\sigma_x = (F\ L)/z\ \{[1 - (1/15)\ u^2] - L_o\ /L\} \qquad (3)$$

where

$$u \simeq (12\ F\ L^2)/Y\ b \qquad z \simeq b\ L^2/3$$

and L is canteliver length; Lo is the distance between resistor and the attachment place; Y is Young's ellasticity module, b is the width and h the thickness of the canteliver. Mechanical load was delivered using known weight attached on the end of the canteliver. The extension is denoted with +, and the compression with -. It was neceessary to hold the specimen in a dark place and at constant temperature. A temperature variation less than 0.1 °C during measurement, would cause a significant error.

3. RESULTS

The measured values of piezoresistive coefficient Π_{44}, which were found to be 27 - 30 $10^{-5}\,MPa^{-1}$, agree well with the results given in /4/. It confirms, together with the measured temperature coefficient of piezoresistor of 0.14 %/ °C, that resistor dopant concentration of $2x10^{26}$ m^{-3} was succesfully acheived. The resistivity of longitudinal and transversal resistor versus mechanical stress is shown in Fig 1. This dependance can be approximated with high degree of accurasy, if the second order polynomial is used:

$$(\Delta R/R)_{l,t} = C_{1l,t}\,\sigma + C_{2l,t}\,\sigma^2 \qquad (4)$$

The coefficients of polynomial are:

C_{1l} = 2.78 10^{-4} MPa^{-1} $\quad$ C_{2l} = 6.57 $10^{-8} MPa^{-2}$

C_{1t} =-1.48 10^{-4} MPa^{-1} $\quad$ C_{2t} = 8.76 $10^{-8} MPa^{-2}$

and is extracted by metod of least squares.

Nonlinearity of piezoresistive coefficients was calculated in the usual way, according to the expression:

$$NL\ (\sigma) = \frac{R(\sigma) - [\{R(\sigma_m)-R(\sigma_o)\}\ L/L_m + R(0)]}{R(\sigma_m) - R_o} \qquad (5)$$

were $R(\sigma)$ is the resistance value under stress σ and σ_m is maximum stress. Its meaning is illustrated by Fig. 2.

4. CONCLUSION

Nonlinearity characteristics of piezoresistive coeficient of diffused p-type resistor on <100> silicon with high surface concentration were analyzed, using a

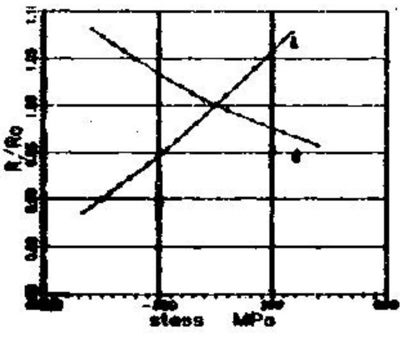

Fig 1 Relative change of resistivity vs. mechanical stress

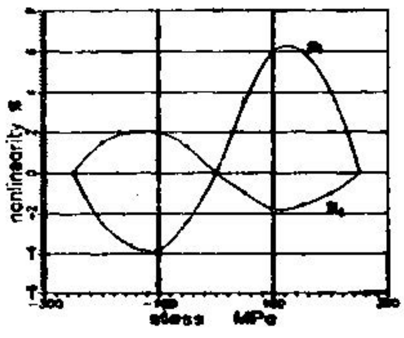

Fig. 2. Nonlinearity change vs. mechanical stress

canteliver-cuted samples. Following conclusions have been reached;

- piezoresistive coefficient can be approximated with order polinomial with sufficient accuracy.
- transversal resistor nonlinearity is higher than longitudinal one.
- nonlinearities of transversal piezoresistor for stress strain have opposite signs and approximatiely the same intensity. It is therefore possible to compensate these nonlinearities with piezoresistors connected in a Wheatstone's bridge.

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