

Integrated Strain-Sensitive Element of Mechanical Transducer with Low Temperature Instability

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Abstract

This paper deals with the creation of an integral sensing element for a mechanical transducer with high conversion linearity and temperature stability in the range $(-60div + 80)circC$. The formation of a stable output signal in the temperature range is realized by a known method, by introducing into the corresponding half-bridge a thin film nichrome resistor R_c with a thermal resistance coefficient (TCR) of an order of magnitude smaller than that of diffusion piezoresistors. The effect of temperature on the output signal can also be reduced by using a stabilized current supply (DCC).

To create semiconductor integrated transducers, it is necessary to solve two main problems:

- to reduce the dependence of the output signal of the measuring bridge circuit on the temperature;
- to exclude the influence of the clamp on the parameters of the sensing element when assembling a strain-gauge converter.

In this article a possible solution of the first one is proposed, ensuring high stability of measurements in a wide temperature range.

The main factors that determine the instability of the output signal are the strong temperature dependence of the strain sensitivity of the resistors and the scatter of values of the thermal resistance coefficient (TCR) of the resistor.

This paper considers the creation of an integrated sensing element for mechanical transducers with high conversion linearity and temperature stability in the range of $(-60 \div +80)^\circ\text{C}$. Fig. 1 shows a topological drawing of such a transducer in the form of a cantilever beam of n-type silicon, in which are formed: Wheatston measuring bridge with p-type diffusion resistors $R_1 - R_4$; balance resistors R_b ; compensation resistors R_c .

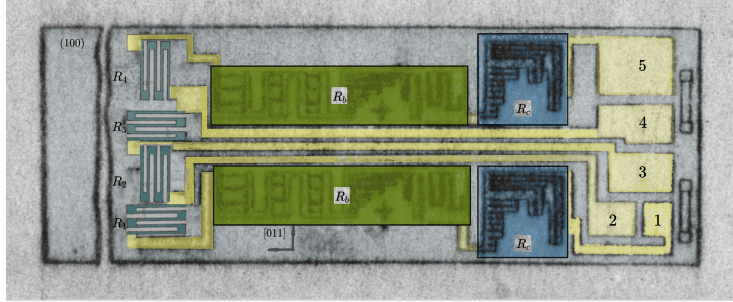


Figure 1: Topological drawing of the sensitive element of the strain gauge transducer

The dependence of the output signal V_{out} on the load is practically linear, since changes in the resistance values of neighboring piezoresistors in a bridge circuit are equal in magnitude and opposite in sign (for a full bridge), for which they are placed in mutually perpendicular crystallographic directions [011]. Compensation of the initial output signal in the temperature range is carried out by a well-known method, introduction into the corresponding half-bridge of the nichrome thin-film resistor R_c with a TCR of an order of magnitude smaller than that of diffusion piezoresistors.

In this case, the output signal arising from the connection of R_c and technological variation in the values of nominal resistance of piezoresistors is brought to zero by the introduction of diffusion-balancing resistors R_b .

The main factor determining the dependence of strain sensitivity on temperature is the level of doping of the diffusion layers, that is, resistivity ρ . For p-type silicon, it is known that, if we consider the effect of piezoresistance in the crystallographic direction [011], the main factor is the shear piezoresistance coefficient π_{44} , which is inversely proportional to temperature¹. If we consider the case of the bridge circuit power supply from a DC voltage generator, the smallest temperature dependence of the output signal should be observed at the lowest possible ρ , but this reduces the value of π_{44} , which determines the strain sensitivity. The influence of temperature on the output signal can also be reduced at higher ρ values²³ by using stabilized current for the power supply (DCC). In this case, the output signal is independent of temperature if the temperature coefficients of resistance and sensitivity are equal in value and opposite in sign.

However, the TCR and TCS values are determined primarily by the alloy-

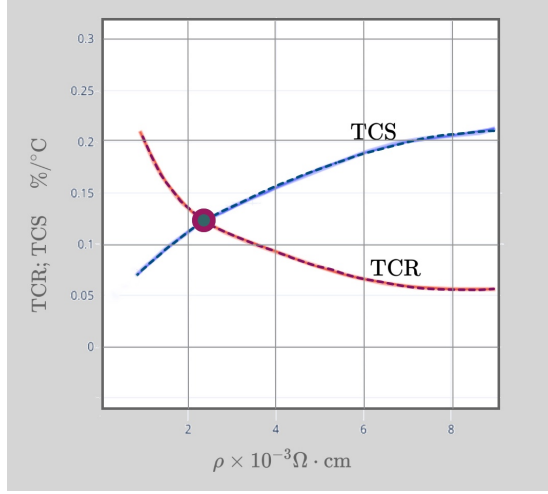


Figure 2: Temperature dependence of strain-sensitivity coefficients (TCS) and resistance (TCR) of p-type diffusion silicon layers on resistivity.

ing level. To meet the thermal compensation conditions, a careful selection of diffusion layers is required in the range $\rho \left(1 \cdot 10^{-3} \div 1 \cdot 10^{-2}\right) \Omega \cdot cm$. This is evidenced by our experimentally obtained dependences shown in Fig. 2.

In determining the required level of doping for the DCV and DCC cases, the effect of the resistivity of the diffusion resistors on the converter characteristics was investigated. For this purpose, test sensing elements (SE) were fabricated, the main steps of their fabrication are illustrated by the scheme shown in Fig. 3.

When measurements were made, it was necessary to exclude the influence of clamping on the magnitude and temperature dependence of the output signal of the sample studied. For this purpose, the specimens were fixed in a "simulator beaker". The calculated epure of mechanical stresses within the *SE* console coincided with the epure of the clamp console. The pinch point was located from the piezoresistors at a distance sufficient to ensure that the pinch effect did not exceed 0.5% of the nominal output signal, equal to 100 mV. Measurements were taken over a temperature range of $(-60 \div +80)^{\circ}C$ in increments of $T = 20^{\circ}C$. When taking the calibration characteristics, the loading was carried out discretely ($\Delta P = 20 g$).

Let us analyze the characteristics obtained as a result of measurements. Fig. 4 shows the comparative calibration characteristics of piezoresistor samples $(1.4 \cdot 10^{-3} \div 5.6 \cdot 10^{-3}) \Omega \cdot cm$. The dependences are characterized by the absence of non-linearity, which can be easily explained by the high level of doping of p-type diffusion layers and a fairly accurate alignment of SE.

The relationship between the transfer coefficient K_{tr} , that is, the ratio of the output signal to the supply voltage, and the shear piezoresistance coefficient, is

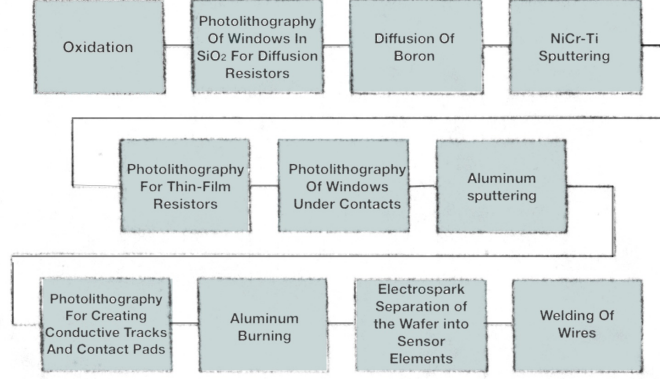


Figure 3: The main stages of creating a sensing element of a strain-gauge transducer.

described by the following equation ⁴:

$$K_{tr} = \frac{V_{out}}{V_{in0}} = \frac{1}{(2 + 2 \cdot \gamma)} \cdot \pi_{44} \cdot E \cdot \varepsilon_x, \quad (1)$$

where ε_x is the relative strain in the piezoresistor location area; E is the Young modulus; γ is the Poisson's ratio.

The increase in sensitivity with increasing ρ is explained by the increase in the piezoresistance coefficient π_{44} with decreasing impurity concentration.

The graphs in Fig. 5 and Fig. 6 show the temperature curves of the relative change in the output signal of the bridge circuits. The load at the end of the console is selected so that the output signal under normal conditions is equal to 1% of the supply voltage, that is, 100mV.

The effect of temperature on the output signal when powered by DCV can be analytically described by the equation obtained by differentiating expression (1):

$$\frac{1}{V_{out0}} \frac{dV_{out}}{dT} = \frac{1}{\pi_{44}} \frac{d\pi_{44}}{dT} \quad (2)$$

where $\frac{1}{\pi_{44}} \frac{d\pi_{44}}{dT}$ is the TCS value.

Thus, the drift of the output signal in the operating temperature range depends on the temperature coefficient of the piezoresistance π_{44} . In other words, the smaller the TCS, the more stable the characteristics of the SE. In Fig. 5 the highest stability corresponds to $\rho = 1.4 \cdot 10^{-3} \Omega \cdot cm$.

Let us estimate the influence of temperature on the signal of the measuring circuits of the bridge powered from DCC. Let us differentiate expression (1) for the case of constant supply current I_{in0} ($V_{in}(T) = R_{in}(T) \cdot I_{in0}$):

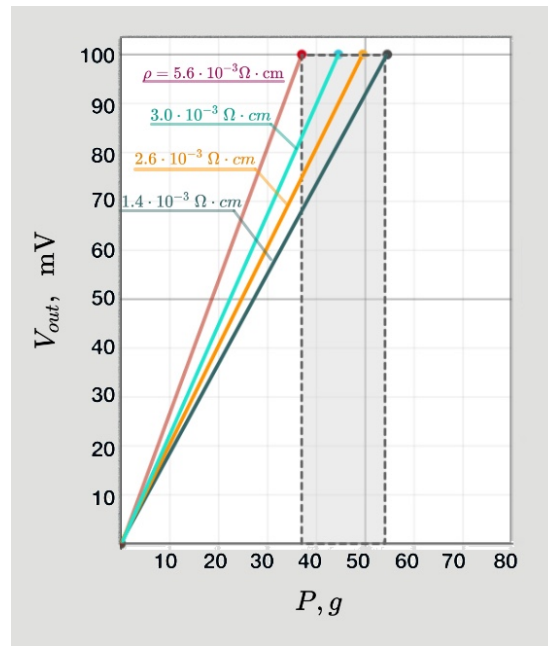


Figure 4: Graduation characteristics of the sensitive element for different values of resistivity.

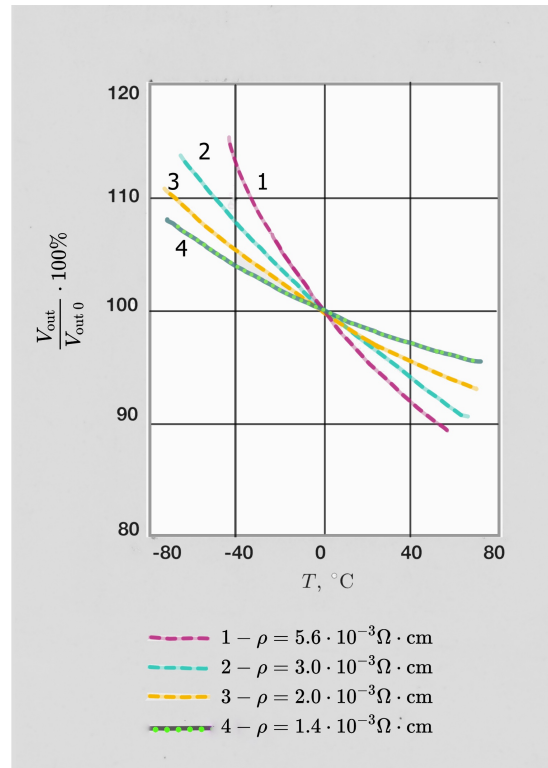


Figure 5: Dependencies of the relative change of output voltage on temperature for the case of DCV power supply.

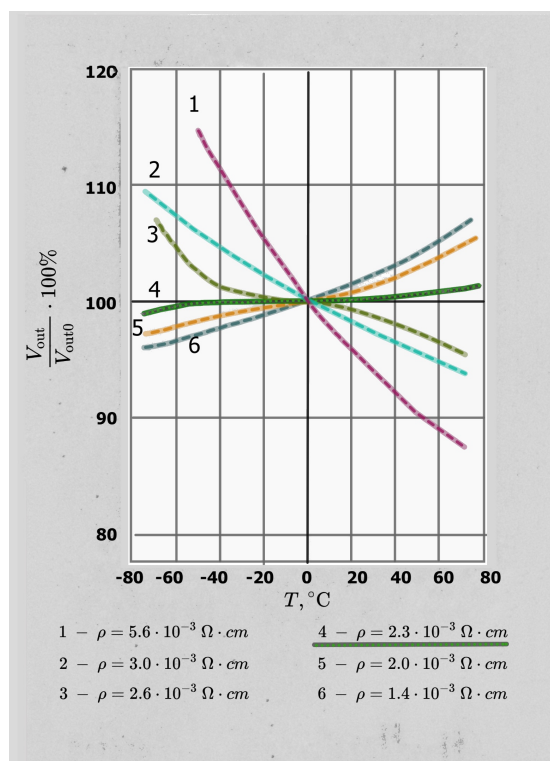


Figure 6: Dependences of the relative change of output voltage on temperature for the case of DCC power supply.

$$\frac{1}{V_{out0}} \frac{dV_{out}}{dT} = \left(\frac{1}{R_{in}} \frac{dR_{in}}{dT} + \frac{1}{\pi_{44}} \frac{d\pi_{44}}{dT} \right) \quad (3)$$

where $\frac{1}{R_{in}} \frac{dR_{in}}{dT}$ is the TCR value.

Here, the course of the temperature dependence of the output signal is determined by the relations TCR and TCS. Consider the dependences shown in Fig. 2. For $\rho > 2.3 \cdot 10^{-3} \Omega \cdot cm$ the negative TCS is greater than the positive TCR (modulo), which means that the law of variation V_{out} must obey the law of variation π_{44} in the temperature range, which is confirmed by curves for $\rho = 5.6 \cdot 10^{-3} \Omega \cdot cm$ and $\rho = 3 \cdot 10^{-3} \Omega \cdot cm$. For $\rho < 2.3 \cdot 10^{-3} \Omega \cdot cm$ the TCR value is greater than the TCS (modulo), and the temperature travel of the resistance is of paramount importance. It is visually (see Figs Fig.5 and 6 Fig.6), that at application of direct current (DCC), for measuring circuits consisting of diffusion silicon p-type piezoresistors with resistivity $(2.1 \cdot 10^{-3} \div 2.4 \cdot 10^{-3}) \Omega \cdot cm$ there is a sharp decrease in the temperature dependence of the output signal. For example, compare the case of the lowest output instability $\frac{V_{out}}{V_{out0}} \cdot 100\%$:

- for DCC at $\rho = 2.3 \cdot 10^{-3} \Omega \cdot cm$;
- for DCV at $\rho = 1.4 \cdot 10^{-3} \Omega \cdot cm$.

Thus, we can consider the problem of creating integrated strain gauge transducers that in the range $(-60 \div +80)^\circ C$ have the temperature instability of the output signal $\pm 0.014 \text{ } \%/^\circ C$.

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