Silicon Transducer Measuring Circuit Above +100℃

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The study was conducted in 1983-1984.

Abstract

The results of experimental studies on the characteristics of bridge measuring circuits of integrated mechanical magnitude transducers with ion alloyed and diffusion piezoresistors in the temperature range of +20°C to +180°C are reviewed. The p-n junction isolating characteristics are characterized by a branch of the inversely shifted volt-ampere (CVC) characteristic. The CVC is determined by the doping level of carriers in the bulk charge region, and the region is bounded by the diffusion length from the resistor boundary to the silicon elastic element (EE) region. It has been experimentally confirmed that the upper limit of the operating temperature range depends on the design parameters, such as the perimeter-to-area ratio of the isolier p-n junction and the number of angles in the topological structure of the p regions of the bridge circuit. The leakage currents are compared in the integrated strain-sensitive element of the mechanical transducer with low-temperature instability.

The effect of p-n junction isolating piezoresistors of integral mechanical transducers from the shunt action of the elastic element on the metrological characteristics of sensors at temperatures above 100 ° C is not adequately covered in the technical literature. Estimates of the operating temperature range vary significantly and, therefore, require clarification. This paper presents the results of experimental studies on the characteristics of bridge measuring circuits (MC) with ion-alloyed and diffusion piezoresistors in the temperature range of +20°C to +180°C.

The quality of piezoresistor isolation from the silicon elastic element (EE) is characterized by a branch of the inversely shifted p-n junction volt-ampere characteristic (CVC). The inversely shifted CVC is determined by the doping level of carriers in the bulk charge region, and the region is bounded by the diffusion length from the p-n junction boundary of resistors to the EE region. It can be considered that

$$I_{\text{rev}} = I_{0\text{gen}} + I_{\text{Sgen}} + I_d, \tag{1}$$

where $I_{0\text{gen}}$ is the carrier generation current in the p-n junction region with poor carrier density in the body of the elastic element; I_{Sgen} is the carrier generation current in the p-n junction region with poor carrier density on the surface of the elastic element; I_d is the diffusion component of the reverse current.

Using the results of [1], the temperature dependence of the inverse current density in the temperature range under study is determined by the relationship.

$$\begin{aligned} J_{\text{rev}}(T) = q\frac{W_{p-n}}{2}\left(\frac{1}{\tau_0} + K_{p-n}\cdot S_0\right) n_i e^{21.3\left(1-\frac{T_0}{T}\right)} + \\ + q\frac{L_p}{\tau_p N_p}\cdot n_i^2 e^{42.5\left(1-\frac{T_0}{T}\right)} \end{aligned} \tag{2}$$

where n_i - carrier concentrations in intrinsic semiconductors; T_0 - lower temperature limit; W_{p-n} - width of the volume charge region; τ_0, τ_p - carrier lifetime in the volume charge region and in the

[1] Kircher, C. J. (1975). Comparison of leakage currents in ion-implanted and diffused p-n junctions. Journal of Applied Physics, 46(5), 2167–2173. doi.org/10.1063/1.1729524

elastic element, respectively; S_0 - surface recombination velocity; L_p - diffusion length of minority carriers in the elastic element; N_p - impurity concentration in the elastic element; K_{p-n} - perimeter-to-area ratio of the $p-n$ junction.

When deriving the calculated dependence of the reverse current density on temperature $J_{\text{rev}}(T)$, as shown in Figure 1, the temperature dependence $\tau_p(T)$ for the silicon studied was taken into account.

For an idealized structure of an isolating junction $p-n$, it is assumed that the concentration of ionized atoms, which determine the volume charge region and the intensity of the associated electric field, is uniformly distributed in the direction of the Y axis, coincident with the metallurgical boundary of the junction. In real $p-n$ junctions, the concentration of ionized atoms in the corners of rectangular MC elements can increase, apparently leading to changes in the parameters determining the surface and volume generation components of the reverse current, and thus affects the dependence of $J_{\text{rev}}(T)$ on the number of these corners n in the topological structure.

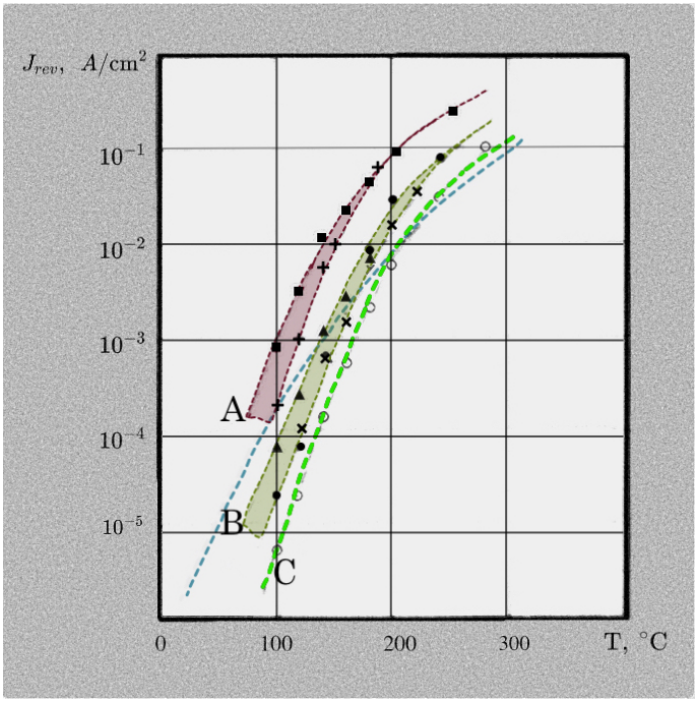


Figure 1: Temperature dependences of reverse current density of p-n junction isolating ion-alloyed and diffusion contact areas of the metasuring circui: ▬ ▬ ▬ - calculated from (3.10) ■ - #1 ; ✚ - #2; ▲ - #4 ; ● - #5; ✖ - #7 ; ❍ - #10

To investigate the characteristics, experimental samples of IPT (integrated force piezoresistive transducers with beam-shaped EE) were manufactured from n-type silicon crystals with (100) orientation, having a resistivity of $\rho_{\text{ee}} = 4.5\ \Omega\cdot$cm and a diffusion length of minority carriers $L_p = 0.01$ cm.

Beam-type IPT (force transducers) contain specially designed test MCs with different geometric parameters. Figure 2 shows the investigated topological structures of the MCs and their geometric parameters.

The topological structure of a bridge circuit is chosen, where equal square contact regions with a size of b and centered on the vertices of a square with a size of a, are connected by four single-strip piezoresistive channels of width d_{ch} for longitudinal and transverse piezoresistors. Such a scheme allows for:

- Approximating the initial transfer coefficient, $K_{mc0}(T)$, to zero and minimizing its temperature dependence.
- Reduce the total area of the isolating p-n junction to values of $A_{p-n} \leq 2 \cdot 10^{-4}\ cm^2$.

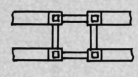
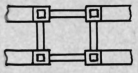
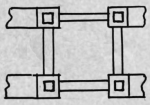
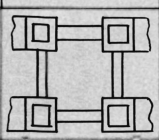
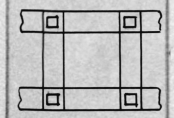
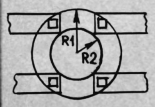
Number Structure	MC Structure	Geometric Parameters, $\times 10^{-4} cm$				The number of angles in the p–n junction structure, n	A_{p-n}, $\times 10^{-4} cm^2$	K_{p-n}
		a	b	d_{ch}	b_c			
#1		60	20	10	10	32	0,52	1400
#2		80	40	20	20	32	0.96	833
#4		120	60	20	40	32	1.92	667
#5		140	80	20	60	32	3.04	526
#7		120	40	40	20	8	1.92	500
#10		$R1 =$ $= 100$	$R2 =$ $= 60$	40	20	–	2.0	500

Figure 2: Topological structures and geometrical parameters of MC on test-IPT force transducer

Two methods of doping the piezoresistive channels (PCH) of the measurement scheme were implemented during the fabrication of the force IPTs.

1. implantation of boron ions with a doping dose of $2 \times 10^{15}\text{cm}^{-2}$ and surface resistance $R_{see} = 85\ \Omega/\square$.

2. Boron diffusion with average specific resistances of the PCH (where "autocompensation" of temperature-dependent sensitivity changes [2] [3] can be expected in the range of $(0 \div 300)°C$ when the MC is powered by a stabilized current): $0.02\ \Omega \cdot cm$, $0.03\ \Omega \cdot cm$, and $0.06\ \Omega \cdot cm$.

For all IPT variations, low-resistance contact regions were formed by diffusion of boron with surface resistances of $(10 \div 12)\ \Omega/\square$.

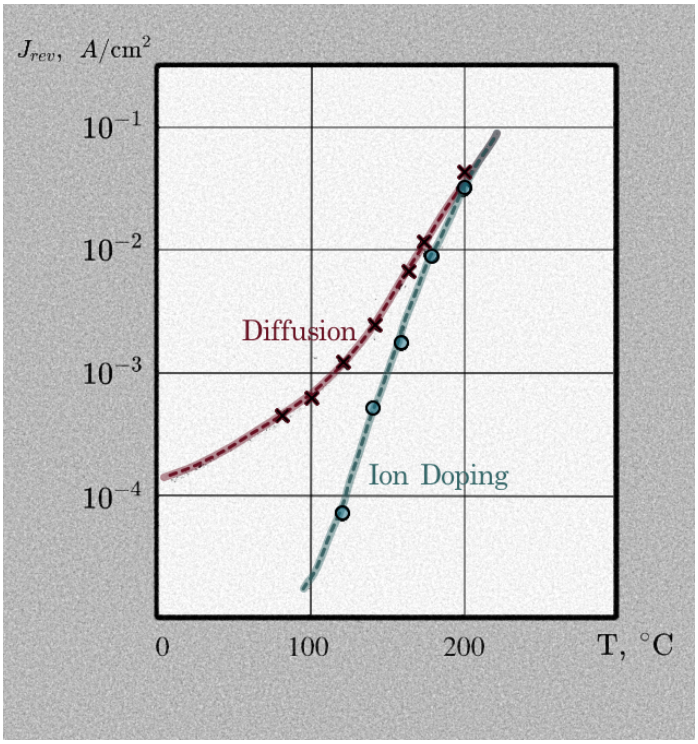


Figure 3: Dependence of insulating p-n junction reverse current density for MS #5: ✖ - with diffusion PCHs; ❍- with ion-alloyed PCHs.

Figure 3 shows the dependence of the reverse current density of isolating p-n junctions on temperature for ion-implanted and diffusion PCHs in the MC structure of test # 5 with $A_{p-n} = 3{\cdot}10^{-4}cm^2$. The noticeable difference in the change for experimental samples below +150°C can be explained by the influence of the variation in the surface recombination velocity values S_0. The temperature dependence of the diffusion component of the reverse current becomes dominant at temperatures above $+150°C$, and the dependencies for the experimental samples converge.

MC test structures with different geometric parameters were fabricated using ion implantation. The results of the study on the influence of the geometric parameters of the topological structure of the MC, K_{p-n} and n, on the isolating properties of the p-n junction are presented in Figure 1. The

[2] Vaganov, V. I. (1983). Integral nye tenzopreobrazovateli [Integral strain gauges]: p.80 (in Russian). Ehnergoatomizdat.

[3] Tikhomirov, M. Y., Spalek, Y. M., Kharenko, K. Y., Giletsky, N. P., Bogatov, P. N., Yazovtsev, V. I., Borshchev, V. N. (1977). Integrated strain-sensitive element of mechanical transducer with low temperature instability. Technology. Technology of Instrument Making: Collection of scientific-technical documents / TsNTI Poisk (in Russian), 3 (14) 19, 19 to 27. doi:10.5281/ZENODO.7261945

temperature dependences of the reverse current density for various test structures determine three regions.

(A) The high-density region of the reverse current, labeled "A," is formed by the dependencies of structures where the number of angles n is maximal ($n = 32$), and K_{p-n} is in the range of 800-1400 (#1, #2). In this case, it is unlikely that the upper limit of the operating temperature range is extended to values $T_{per} \geqslant 200°C$. The areas of the isolating p-n junctions should be $A_{p-n} \leqslant 2 \times 10^{-5}\ cm^2$, which is more than three times smaller than the previously determined limit for the total area of the four contact pads of the MC.

(B) The range of intermediate values of J_{rev} labeled "B" belongs to the dependencies of the MC structures where the number of angles n is either 32 or 8, but K_{p-n} is in the range of $(500 \div 700)\,\mathrm{cm}^{-1}$ (#4, #5, #7). Here, a realistic design for high temperatures is MC # 7 with parameters $K_{p-n} = 500\,\mathrm{cm}^{-1}$ and $n = 8$ with a junction area p-n $A_{p-n} \leq 2 \times 10^{-4}\,\mathrm{cm}^2$.

(C) The segment labeled as "C," for the ring-shaped structure MC #10 with $K_{p-n} = 500\,\mathrm{cm}^{-1}$, is characterized by a good agreement with the calculated dependence of $J_{rev}(T)$ for temperatures $T > 180°C$. The differences at temperatures $T < 180°C$ can be explained by the fact that the maximum limit value of S_0, equal to $S_0 = 1 \times 10^4\,\mathrm{cm/s}$, was chosen in the calculations for the dependence $J_{rev}(T)$. It is possible that in the actual MC, the value of S_0 may be 100 times smaller than [4].

At the current level of integrated technology, it is fundamentally possible to reduce the MC area to a value of $1 \times 10^{-4}\mathrm{cm}^2$. This corresponds to a current density of $1 \times 10^{-2}\mathrm{A/cm}^{-2}$ and $I_{rev} = 1\ \mu\mathrm{A}$.

It has been experimentally confirmed that the upper limit of the operating temperature range depends on the design parameters, such as the perimeter-to-area ratio of the isolating p-n junction, K_{p-n}, and the number of angles in the topological structure of the p-regions of the MC, n_{p-n}. Assuming that $A_{p-n} < 2 \times 10^{-4}\ \mathrm{cm}^2$, $K_{p-n} = 500 \div 700$, and $n_{p-n} \leq 8$, the upper limit of the operating temperature range for IPT with an isolating p-n junction corresponds to values above +200°C.

[4] Stepanenko, I. P. (1980). Osnovy mikroehlektroniki [Fundamentals of microelectronics]: (in Russian). Sovetskoe radio