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PRESSURE SENSORS ON THE BASIS OF STRAIN-SENSING SEMI-CONDUCTOR ELEMENTS

Semi-conductor strain-sensing elements are analysed: strain gauges, strain-sensing diodes, strain-sensing transistors underlying pressure sensors, and also semi-conductor pressure sensors with frequency output on the basis of the given elements. Influence of pressure on the given semiconductor structure is shown.

Keywords: *sensor, pressure sensors, pressure measurement, strain-sensing element*

Introduction

Constantly growing requirements concerning automation of management systems, diagnostics and the control of various procedure have caused intensive development various behind a structure and properties of pressure sensors. Thus researches in the field of creation of such sensors are directed on improvement of their key parametres: increase of sensitivity, linearity, stability, profitability, reduction of an operating time, overall dimensions, efficiency of integration with microprocessor means of processing of the measuring information. Semi-conductor pressure sensors take the advanced places in this process [1-3].

In the given work the semi-conductor strain-sensing elements underlying different for structure and properties pressure sensors, and also semi-conductor pressure sensors with frequency output on the basis of the given elements are investigated.

1. Strain gauges

The most simple on a structure is the strain-sensing element on the basis of strain gauges [1, 2].

At the heart of tensoresistive effect change of resistance of the strain gauge, defined by change of carrier mobility of charges in the semiconductor under pressure action lays. Conductance of such semiconductor is directly proportional effective carrier mobility of charges and their concentration:

$$\sigma = qn\mu_{e\phi}, \tag{1}$$

where q - elementary charge, n - concentration of free charges carriers and $\mu_{e\phi}$ - their effective mobility.

The influence of temperature shown in change of concentration of nonbasic charges carriers, it is possible to reduce at the expense of increase in a part of the doped carriers.

Usually, a pressure sensor on the basis of strain gauges produce from a silicon sheet, a part of this sheet etch to formation of a thin membrane. An ion-implantation technique on a membrane carry out resistive elements with an interconnection wiring, forming the strain-sensing bridge from four strain gauges. At change of pressure the membrane caves in, and under the influence of tensoresistive effect there is a change of resistance of strain gauges. Sharp response of the measuring bridge is as a result reached. The thickness of a membrane and the geometrical shape of resistors is defined by area of necessary pressure. The simplified appearance of a sensor is shown in fig. 1 [4].

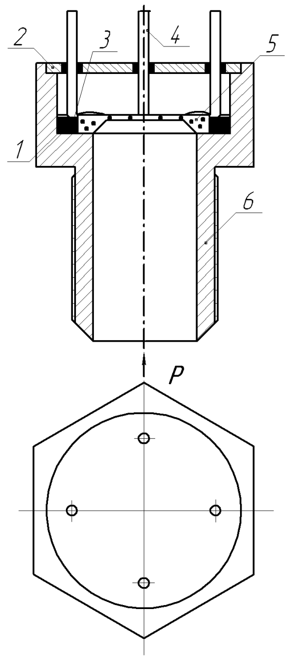

Fig. 1. The pressure sensor design: 1 - transitive ring; 2 - a cover; 3 - intermediate conductors; 4 - output wires; 5 - semi-conductor sensitive element; 6 - the case

In fig. 2 the circuitry of a silicon pressure sensor on the basis of four same strain gauges forming the strain-sensing bridge [1] is represented. Thus resistors (*R1* … *R4*) are jointed so, that at a deflection of a membrane resistance of resistors *R1* and *R3* increases, and at *R2* and *R4* - decreases. Sharp response of the measuring bridge is as a result reached. Output potential U_a answers the equation:

$$U_a = U_{cc}\frac{R_1R_3 - R_2R_4}{(R_1+R_2)(R_4+R_3)}. \qquad (2)$$

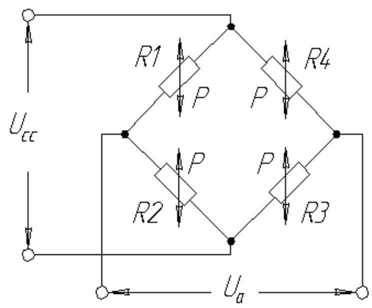

Fig. 2. The measuring bridge from four strain gauges

Advantages of these sensors the following: sharp response, linearity, small time overcurrent release, economic manufacturing techniques, small overall dimensions, stability in work and simplicity of operation. A lack, consisting in temperature sensitivity, in most cases it is possible to compensate [1].

2. Strain-sensing diodes

Let's consider the physical mechanism of pressure action on semiconductor structure. It is known [2], that pressure leads to change of distances between atoms. It causes translation of energy levels near bottom of conduction band and valence band top. As consequence, there is a redistribution of charge carriers between energy levels that influences their mobility, and also on forbidden bandwidth.

Let's consider work sharp p-n $^+$ - junction in the absence of pressure. The junction saturation current will be defined by movement of nonbasic charges carriers. As junction is nonsymmetric (n_p>> p_n), the current that holes in n-area form can be neglected. Then:

$$j_{нас0} = \frac{q n_{p0} L_{n0}}{\tau_n}, \tag{3}$$

where n_{p0}, L_{n0} - accordingly electron density in p-area and their diffusion length in the absence of pressure, τ_n - their lifetime (we will consider, that pressure does not influence lifetime of charges carriers).

Considering, that:

$$L_{n0} = \sqrt{D_{n0}\tau_n},$$

$$D_{n0} = \frac{kT}{q}\mu_{n0},$$

$$\mu_{n0} = \frac{q\tau_n}{m_{n0}^*},$$

$$n_{p0} = N_{c0}\exp\left(-\frac{E_{c0}-E_F}{kT}\right) = 2\left(\frac{2\pi kTm_{n0}^*}{h^2}\right)^{\frac{3}{2}}\exp\left(-\frac{E_{c0}-E_F}{kT}\right),$$

let's write a saturation current in a kind:

$$j_{нас0} = \frac{2q(kT)^2 m_{n0}^*}{\left(\frac{h^2}{2\pi}\right)^{\frac{3}{2}}\exp\left(\frac{E_{c0}-E_F}{kT}\right)},$$

or

$$j_{нас0} = \frac{2(qkT)^2\tau_n}{\left(\frac{h^2}{2\pi}\right)^{\frac{3}{2}}\mu_{n0}\exp\left(\frac{E_{c0}-E_F}{kT}\right)}, \tag{4}$$

where μ_{n0} - effective electron mobility in p-area and E_{c0} - energy of bottom of conduction band in the absence of pressure.

Let's define a saturation current p-n $^+$ - junction at action on it pressure. Provided that pressure causes changes μ_n and E_c p-n $^+$ - junction, we will copy (4) taking into account pressure action:

$$j_{нас} = \frac{2(qkT)^2\tau_n}{\left(\frac{h^2}{2\pi}\right)^{\frac{3}{2}}\mu_n\exp\left(\frac{E_c-E_F}{kT}\right)}, \tag{5}$$

where $\mu_n = \mu_{n0} + \Delta\mu_n$, $E_c = E_{c0} + \Delta E_c$, or:

$$j_{нас} = j_{нас0}\frac{\mu_{n0}\cdot\exp(\Delta E_{c0}/kT)}{\mu_n\cdot\exp(\Delta E_c/kT)}. \tag{6}$$

With (6) it is visible, the saturation current p-n $^+$ - junction $j_{нас}$ decreases with positive changes of effective electron mobility μ_n and energy of bottom of conduction band E_{c0} and on the contrary. It is similarly possible to define a saturation current p $^+$-n - junction.

Thus, for achievement of the maximum tensosensitivity sharp p-n $^+$ - junction, it is necessary that effective electron mobility in p-area and energy of bottom of conduction band changed in coordination at pressure action.

3. Strain-sensing transistors

Advantage of sensitive elements on the basis of transistors is the high level of a output signal in comparison with strain-sensing diodes and strain gauges.

Influence of pressure on bipolar transistor characteristics can be defined having considered pressure action on emitter and collector p-n - junctions, and also on transfer ratios of currents [2].

At work of a bipolar p-n-p-transistor on the common-base circuit the current transfer ratio is defined [2]:

$$h_{21Б} = 1 - 0{,}5(q / kT) \cdot (W^2 / \mu_p \tau_p), \tag{7}$$

under a condition, if $\gamma \bullet \gamma_K = 1$, where W - width of a transistor base, γ - efficiency of the emitter, γ_K - efficiency of a collector.

Let's estimate sensitivity of the current transfer ratio $h_{21Б}$ in relation to hole mobility μ_p using (7):

$$S_{\mu_p}^{h_{21Б}} = \frac{\partial h_{21Б}}{\partial \mu_p} = 0{,}5(q / kT) \cdot (W^2 / \mu_p^2 \tau_p), \tag{8}$$

under a condition, if: $$0 < 0{,}5(q / kT) \cdot (W^2 / \mu_p \tau_p) < 1,$$

or $$0 < 0{,}5(q / kT) \cdot (W^2 / \tau_p) < \mu_p \tag{9}$$

The sensitivity increase can be reached, increasing width of a transistor base with simultaneous reduction of hole mobility.

At bipolar transistor work on the common-emitter circuit the current transfer ratio is defined [2]:

$$h_{21E} = \frac{2kT\tau_p}{qW^2} \cdot \mu_p . \tag{10}$$

Sensitivity of the current transfer ratio h_{21E} mobility ratio of holes:

$$S_{\mu_p}^{h_{21E}} = \frac{\partial h_{21E}}{\partial \mu_p} = \frac{2kT\tau_p}{qW^2} . \tag{11}$$

As we see, in expression (11) there is no hole mobility coefficient. Hence, in the bipolar transistor hooked up on the common-emitter circuit the size of sensitivity $S_{\mu_p}^{h_{21E}}$ does not depend on pressure action, and is defined only by transistor design data thanks to what it is possible to reach considerable sensitivity concerning pressure.

Field-effect transistors have lower level of power consumption in comparison with bipolar transistors, and also less sensitive to changes of temperatures. For the conductor-insulator-semiconductor FET with the induced channel the drain current is defined [2]:

$$I_C = \frac{\mu_n C}{l^2} \cdot \left(U_3 - \frac{1}{2} U_C \right) \cdot U_C , \tag{12}$$

where C - shutter size, l - a transistor channel length, U_3 and U_C - a shutter and drain electrical pressure accordingly.

With (12) it is visible, change μ_n leads to directly proportional change of a drain current.

4. Semi-conductor pressure sensors with frequency output

Use of pressure sensors with frequency output on the basis of transistor structures with negative resistance is perspective. Thus generation of a gauged frequency signal is connected with size of the pressure enclosed to a strain-sensing element. Strain gauges, strain-sensing diodes and strain-sensing transistors can be strain-sensing elements, and strain-sensing transistors can be simultaneously a part of transistor structure with negative resistance. Change of electric parametres of a strain-sensing element causes changes of an apparent resistance of the transistor structure which wattless component has capacitor character. Interconnection in parallel with transistor structure of inductivity forms an oscillating loop which losses of energy are compensated by negative resistance of transistor structure. Thus, pressure change leads to change of a resonance frequency of a loop which exists on output of a sensor.

In fig. 3 the circuitry of a pressure sensor with frequency output [3] is presented. As a strain-sensing element bipolar transistor VT1 acts. Pressure change leads to change of a wattless component of the apparent resistance existing on a collector bipolar and a drain field transistors, and frequency respective alteration on output.

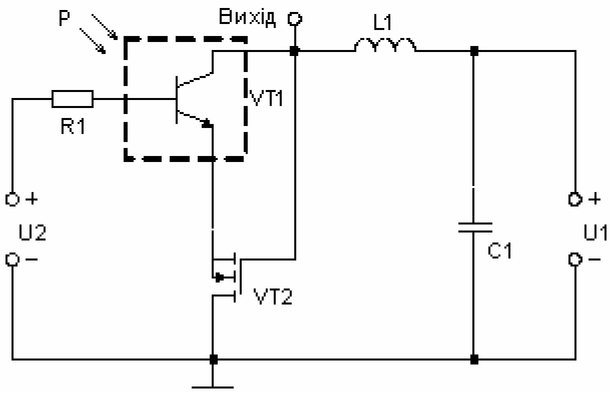

Fig. 3. The circuitry of a pressure sensor with bipolar and field transistors

Advantage of use of a frequency informative signal of a sensor over the analogue shape in the form of an electrical pressure or a current is caused by simplicity and accuracy of a frequency conversion in a digital code, high noise immunity by transfer and efficiency of commutation in multichannel measuring systems.

Conclusions

Advantages of sensitive elements on the basis of transistors is the output signal high level, and also the high tensosensitivity defined in design data of transistors. Use of pressure sensors with an output frequency signal is caused by their high noise immunity, simplicity and accuracy of transformation of a frequency signal in a digital code.

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