SEMICONDUCTOR VIBRATIONAL FREQUENCY-RESPONSE SENSOR FOR PRESSURE MEASUREMENT

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The aim of our efforts is to design a sensor combining the advantages of both types of sensors and opportunities of the microelectronic technology as well as the properties of the oscillating string and stress diaphragm. The princinles of the oscillating string stress sensors [1] are further developed to overcome all the difficulties due to the design of these transdusers. The development of micro-electronics and micromachining makes possible to realize pressure sensor based on the semiconductor string.

The choice of semiconductor string as an active element of this sensor is determined by the following properties of monocrystal fibres:

— extremely high mechanical strength due to structure perfection of the grown fibres;

— the fibres due to their size, geometry and crystallographic orientation can be used for the manufacturing of several sensors. In this case it is necessary to make ohmic contacts and to connect the fibre with the leads;

— the doping possibility during the fibre growth allows us to obtain the crystals with required electrodynamic parameters;

— fibre sensor manufacturing technology is simple and the waste of semi-conductor material minimal.

The basic advantages of the string pressure sensors are: high sensitivity, operating stability, linear characteristics and frequency output signal.

In comparison with all other types of electromechanical resonators used for the mechanical measurements the string sensors have the highest sensitivity. The best results were obtained with the diaphragm made of the same material. Concerning the piesoresistive properties, silicon is the best material for this purpose. Using the advantages of the microelectronic technology a new type of electromechanical resonator with electrostatic excitation was developed. Its structure is shown in Fig. 1. The resonator is prepared from a monocrystal fibre (string) *1* with current terminals 2. It is firmly fixed over the elastic element *3* (a silicon diaphragm in this case). The diaphragm surface is used as an exiting electrode as well. For this reason an electric contact *4* is attached to the diaphragm. The operation of this sensor can be described as follows.

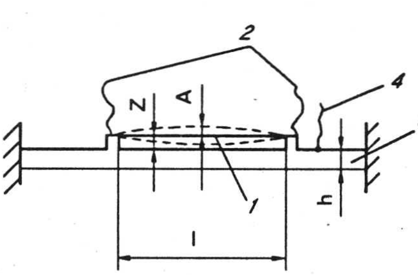


Fig. 1. Schematic diagram of the electromechanical string resonator: *1* — fibre monocrystal, *2* — current terminal, *3* — diaphragm, *4* — electric connection

When an alternating signal between the monocrystal fibre and the exciting electrode is applied, an induced electrostatic force F appears: $u = u_0 \sin \omega z$

$$F = 1/2 \frac{dC}{dz} u_0^2 \sin^2 \omega t \qquad (1)$$

where: C — string-diaphragm capacity; z — distance between the string and the diaphragm equal to the height at which the string is fixed above the diaphragm.

The harmonic exciting force generates the harmonic oscillations of the string with magnitude. These oscillations cause the strain of the string monocrystal

$$\varepsilon = \frac{\pi^2 A^2}{8l^2}(1 - \cos 2\omega t) \qquad (2)$$

where: l — oscillating length of the crystal.

As a result of the piezoresistive effect the variable component of the strain causes a generation of a variable component of the string resistance

$$\Delta R = k\varepsilon = \frac{\pi^2 k A^2}{8l^2} R_0 \cos 2\omega t \qquad (3)$$

where: k — gauge factors, R_0 — nominal string resistance.

If a direct current passes through the monocrystal fibre an alternative voltage is generated along the string. Its frequency is equal to the doubled mechanical oscillation frequency. The oscillation frequency is calculated by:

$$f = \frac{1}{2\pi l^2} \sqrt{\frac{BE_c(d_c/4)^2 + B'\sigma_c l^2}{\rho}} \qquad (4)$$

where: B and B' — numeric coefficients depending on the strain; d_c — string diameter; E_c — elasticity modulus along the string length; ρ — crystal density; σ_c — stress, acting over the string. For a round shape diaphragm sensor the expression for is

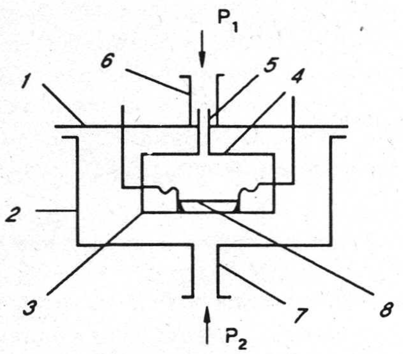
$$\sigma_c = \frac{3P(1-\mu)^2 E_c(z + h/2)}{16E_m h^3} (D^2 - l)^2 \qquad (5)$$

where: P — pressure acting over the diaphragm; μ — Poisson coefficient; D — diaphragm diameter; h — diaphragm thickness; E_m — diaphragm elasticity module.

Equation (5) is valid when the diaphragm bending is much less than the diaphragm thickness.

The elastic properties of the string are hundred times better than these of the bulk silicon [2]. The oscillations may be maintained with relatively low excitation energy as a result of the low density of silicon. Breaking strength of a string crystal is relatively high. This ensures a maximum value of intrinsic mechanical oscillation frequency for a single crystal length. Crystal deformation sensitivity is relatively high.

The structure of the pressure sensor on the base of semiconductor [3] is shown in Fig. 2. The sensitive element is mounted in the hermetical sealed package. The internal volume of the package is connected to the environment with pressure P_1 by



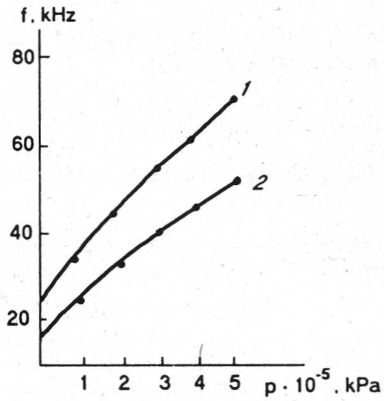


Fig. 2. Design of a string transducer: *1, 2, 4* — package parts, *3* — silicon diaphragm, *5, 6, 7* — tubes, *8* — string monocrystal

Fig. 3. Sensor sensitivity as a function of the string length: *1* — l = 2 mm, *2* — l =2.5 mm

a capillary tube. The second capillary tube connects the other side of the sensor to the measured pressure P_2. If the first tube is closed the hermetically sealed diaphragm modules may be used for absolute pressure measurements. The relative pressure changes can be measured when the diaphragm is not hermetically sealed.

When the difference between P_1 and P_2 changes a deformation of the diaphragm appears. This deformation is transformed into the variations of the output signal frequency. The sensor signal is transferred to an interface circuit. It makes the sensor module operating in the permanent autooscillation mode. The sensor structure and dimensions depend on its practical application.

The theoretical investigations and the experiments show that the geometrical dimensions of the string and the diaphragm have a significant effect on the sensor operation characteristics. As it is discussed above the intrinsic oscillation frequency of the monocrystal resonator depends on the diaphragm dimensions. Fig. 3 shows the results for the square shape diaphragm. The obtained sensitivity (output frequency as a function of the applied pressure) is in good agreement with the discussed theory and depends on the string length. The invstigations show that the transducer is thermostable.

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2. *Bogdanova N., Baizar R., Voronin V., Krasnogenov E.* Single-crystal Silicon Resistors as Sensitive Elements for Sensor. — Proc. Annual Shcol on Semiconductor and Hybrid Technology, Sozopol, 1990.
3. A.C. USSR, No.1458737.—Bull. Inventions, 1989, No. 6.