SEMICONDUCTOR VIBRATIONAL FREQUENCY-RESPONSE SENSOR FOR PRESSURE MEASUREMENT

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The representing electromechanical resonator on elastic vibrations of monocrystals strings from semiconductor materials rather simple in manufacturing of string in tenzoconverter on the basis of monocrystals is described. The examples of such class of converters using in concrete designs of devices for measurement of various physical parameters are reported.

The aim of our efforts is to design a sensor combining the advantages of two types of sensors and opportunities of the microelectronic technology as well as the properties of the oscillating string and stress diaphragm. The principles of the oscillating string stress sensors [1] are further developed to overcome all the difficulties arose when one tries to design these transducers. The development of microelectronics makes it possible to realize a pressure sensor based on a semiconductor string.

The choice of a 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 semiconductor material is minimal.

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

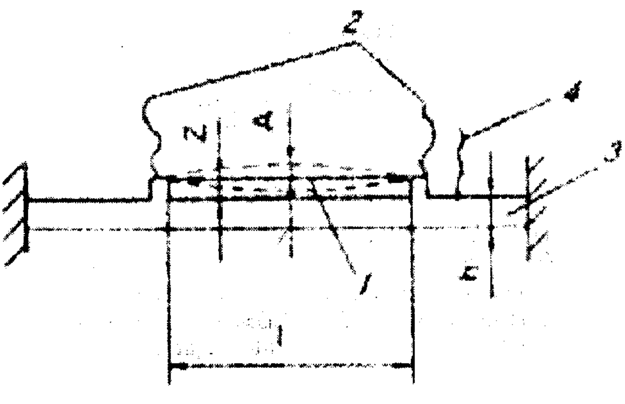

Fig.1. Schematic diagram of the electromechanical string resonator: 1 – fibre monocrystal, 2 – current terminal, 3 – diaphragm, 4 – electric connection

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 piezoresistive 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.

When an alternating signal between the monocrystal fibre and the exciting electrode is applied, an induced electrostatic force F appears:

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

where: C is a string-diaphragm capacity; z is a 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 is an 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 is a gauge factor, R_0 is a 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' are numeric coefficients depending on the strain; d_c – string diameter; E_c is an elasticity modulus along the string length; ρ is a crystal density; σ_c is stress, acting over the string. For a round shape diaphragm sensor the expression for stress is

$$\sigma_c = \frac{3P(1-\mu)^2 Ec(z+h/2)}{16E_m h^3}\left(D^2-1\right)^2 \quad (5)$$

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

Equation (5) is valid when the diaphragm bending is 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 strenght of a string crystal is relatively high. This ensures a maximum value of intrinsic mechanical oscillation frequency for a single crystal lenght. Crystal deformation sensitivity is relatively high.

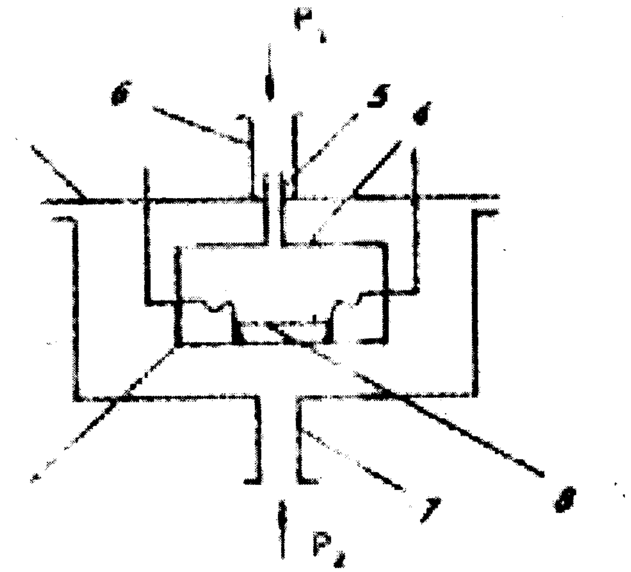

Fig.2. Design of a string transducer: 1,2,4 – package parts, 3 – silicon diaphragm, 5,6,7 – tubes, 8 – string monocrystal

The structure of the pressure sensor on the base of a 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 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.

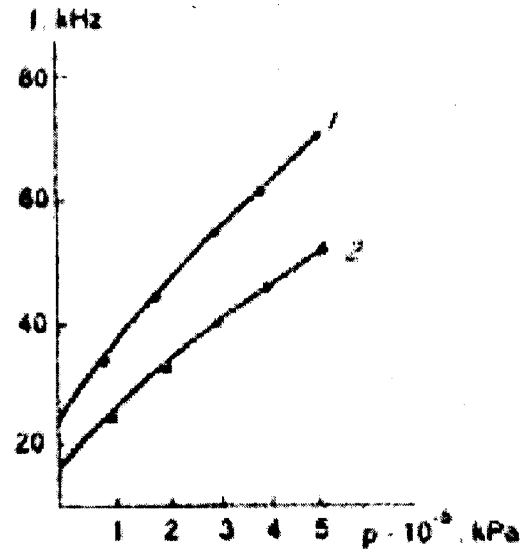

Fig.3. Sensor sensivity as a function of the string length: 1 - l=2mm, 2 – l =2.5 mm

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 interface circuit. It makes the sensor module operating in the permanent autoscillation 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 a good agreement with the discussed theory and depends on the string length. The investigations show that the transducer is thermostable.

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YARIMKEÇİRİCİLƏR ƏSASINDA SIMLİ TƏZYİQ ÇEVİRİCİLƏRİ

Konstruksiyasına və hazırlanmasına görə sadə olan simli yarımkeçirici monokristallardan hazırlanmış, elastik rəqslər əsasında işləyən elektromexaniki rezonatordan ibarət olan təzyiq tenzo çevirici təsvir edilmişdir. Müxtəlif fiziki parametrlərin ölçülməsi üçün konkret konstruksiyada bu cür təzyiq çevirilmələrindən istifadə edilməsinə dair misal gətirilir.

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ПОЛУПРОВОДНИКОВЫЙ ВИБРАЧАСТОТНЫЙ ТЕНЗОПРЕОБРАЗОВАТЕЛЬ ДАТЧИК ДАВЛЕНИЯ

Описан сравнительно простой по конструкции и в изготовлении струнный тензопреоброзователь, представляющий собой электромеханический резонатор на упругих колебаниях монокристаллических струн из полупроводниковых материалов. Приводятся примеры использования тонкого класса преобразователей в конкретных конструкциях устройств для измерения давления.

Received: 30.09.01