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Research Article

Microelectronic Sensors for the Aircraft and Space-Rated Equipment

[1]Kassimov A.O., [1]Khizirova M.A.
and [2]Mikhaylov P.G.

[1]Almaty University Energy and Communications Almaty, Kazakhstan,
64razak@mail.ru hizirova73@mail.ru
[2]Penza state technological university, Penza,
Russia pit_mix@mail.ru

ABSTRACT
Possibilities of microelectronic sensor usage in space rocket and aviation technology are examined. Examples of successful application of microelectronic sensors in various systems and devices are given, future trends are indicated. The designs and performance characteristics of the microelectronic sensors (MSS) for the aircraft and space-rated equipment are presented. The amplitude-frequency responses, the influence of destabilizing factors on the MSS are given. The examples of the sensor application during different tests are described.

Keywords: Sensor, Introduction, Piezoresistive, Pressure, Semiconductor, Multichannel, Microelectronic, Flat, High-Temperature, Polysilicon

INTRODUCTION
The microprocessor-based information and control systems, manufactured by up-to-date microelectronic batch-fabrication techniques, are highly developed. Nowadays they have contradicted the traditional sensors, produced individually with the use of manual operations. Large overall dimensions and weight, poor reliability and service life, bad compatibility with modern information and control systems frequently retard the creation of new products and research works. The application of the traditional sensors is complicated on orbital space stations, interplanetary devices and the aerospace equipment of new generation [1]. Microelectronic sensors feature high service life, reliability and sharp increasing of functionalities. The micromechanical sensing elements improve qualitatively the microelectronic sensor performance. By multisensitivity of semiconductor structures to different physical parameters, it is possible to design sensors for measuring some parameters at once, for example, pressure and temperature, pressure and vibration, or gas analyzers for detecting different gases [2, 3]. The microelectronic sensors are widely used in various industries, as well as for the aircraft and space-rated equipment.

Piezoresistive Acoustic Pressure Sensor PS 01
The semiconductor sensor PS 01 is intended for static, erratic and acoustic pressure -to - electric signal conversion, used in air and inert gas media. The sensor distinctive feature is measurement alongside with acoustic pressure also erratic (quick-alternating) and static pressures.

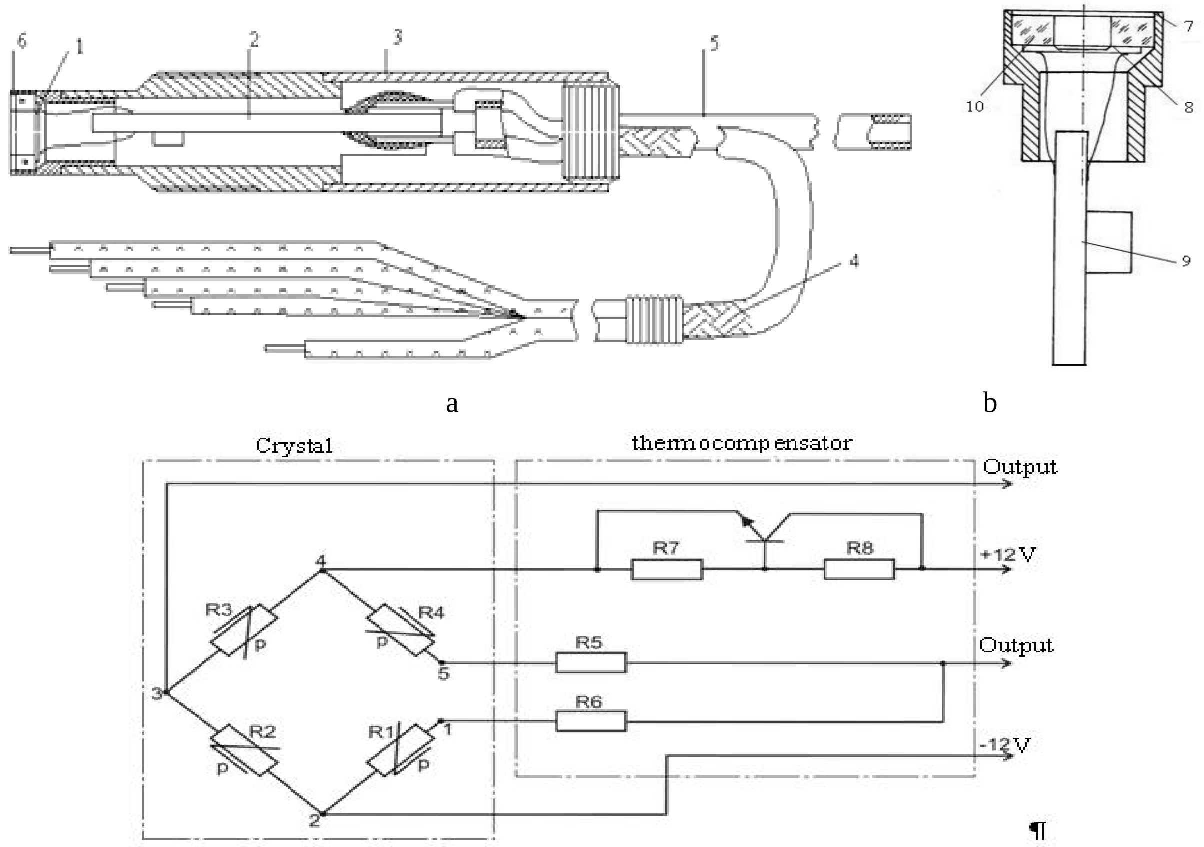
The design and the basic circuit are shown in fig. 1. The sensor (fig. 1a) consists of a semiconductor sensing element 1 (SSE), a thermo compensator/plate 2, a case 3, a cable 4, a tube 5 and a shield grid 6. The SSE incorporates the profiled resilient member (RM), made of the monocrystal silicon, in which the semiconductor piezoresistors (PR) $R1 \div R4$, connected in a bridge circuit by means of contact pads, are formed.

The SSE design is shown in fig. 1b, 1c. The thermo compensator 2 is a hybrid integrated circuit (HIC), disposed in the substrate from glass ceramics with the thin-film adjusting cermet resistors *R5 ÷ R8* and the unpackaged thermo compensative transistor *VT*1 on the substrate. The resistors *R5* and *R6* adjust U_0, the *R*7 and *R*8 compensate the sensitivity temperature drift. All the adjustments are carried out by scribing of the thin films. The principle of the sensitivity compensation depends on the voltage change in the two-pole network under the thermal change.

$$U_{АБ} = E_n - U_{ЭБ}\,(1\text{-}R8/R9), \qquad (1)$$

where $U_{АБ}$, the bridge circuit supply voltage; E_n, the sensor supply voltage; $U_{эб}$, the voltage of the emitter-to-base junction of the *VT*1.

When increasing or decreasing the temperature, $U_{ЭБ}$ compensates the sensitivity decrease, i.e. $U_{ЭБ}$ traces the temperature variations of the sensor, adjusting the output voltage. It is experimentally confirmed that the best thermo compensation is achieved by linear changing of the PR resistance from temperature. The piezoresistors, formed by implantation, have the greatest linearity. The piezoresistors, formed by thermal diffusion, possess strong nonlinearity in the range of – 20 ºC to 0 º C with the sign inversion of the resistance temperature coefficient.



a b

c

Fig 1. The design and the basic circuit are shown a - PS 01 (1 – SSE, 2 – thermocompensator, 3 – case, 4 – cable, 5 – tube, 6 - shield grid); b - (7 – housing, 8 - connection zone, 9 - transistor, 10 - steplobusa); c - Schematic diagram

The resistors of the hybrid-circuit board are trimmed by laser-induced evaporation. The resistor trimmings depend on specific electrical characteristics of the crystal: zero drift and supply current temperature drift. The supply current temperature drift, specific for each measurement module, is determined during temperature tests and analyzing load characteristics; the sensitivity drift is simulated by reference resistors, connected to the resistive voltage deliver of the two-pole network. The adjusted measurement module is housed. The outlet cable is welded to the contact pads and the sensor is hermetically sealed.

Internal mechanical stresses inside the sensors are the effect of sealing materials. The sensors undergo thermomechanical stabilization by means of temperature cycling and air pressure pulsation, equal nominal. The time drift of characteristics will stop after technological tests have been performed.

Multichannel Sensor with Electronic Channel Scanning MHS 01

The multichannel sensor MHS–1 with electronic channel scanning is developed and fabricated on the basis of the measurement module of the sensor PS 01 (fig. 2). It incorporates a cellular sensing element with 12 housed measurement modules of the sensor PS 01, a signal conditioner with analog amplifiers, a programmable shift register, a buffer amplifier and a control circuit. The sensing element is cable connected with the signal conditioner. The elements of the signal conditioner are designed according to CMOS technique. The signal conditioner is jointed with the sensing elements by a joint; the sensing element can operate off-line. It is used as with the union for all channels (measurement modules), so as with unions for each channel.

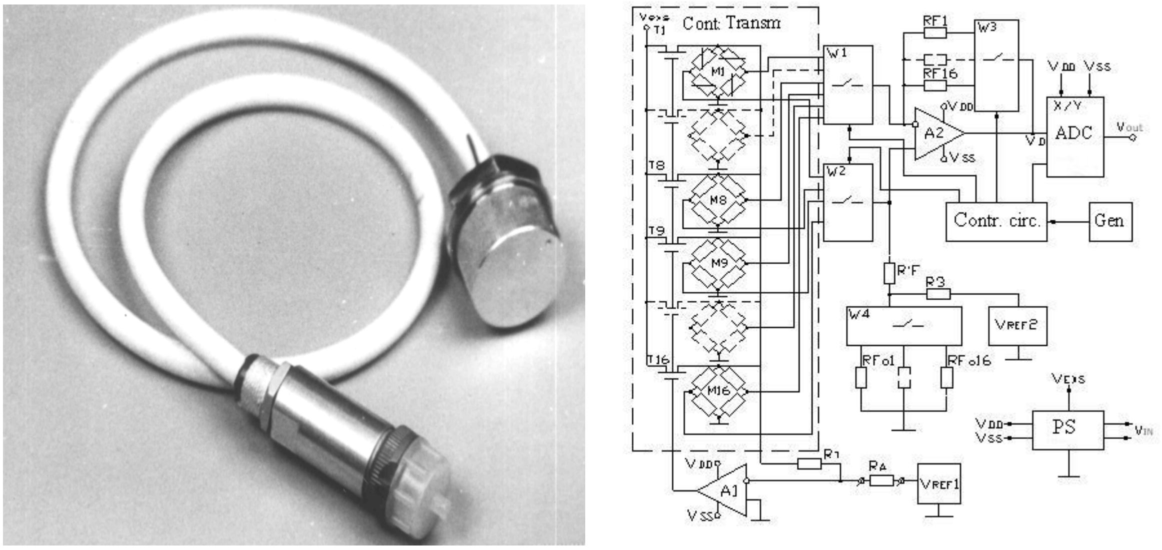


Fig. 2. Appearance and functional diagram of a multi-channel sensor MHS 01

A pressure measurement range of 0 to 0.15 MPa can be expanded up to 0.5 MPa. When expanding the pressure measurement range, nonlinearity of transformation *Px = F (Vx)* increases for not more than 30 – 40% from the allowable one; the reliability of the sensing element is not reduced, as overload capacity is rather high. The semiconductor sensing element with nominal pressure of 0.1MPa survives under maximum pressure of 1.5 MPa.

Under pressure pulsation measurement the multichannel sensor was applied on the surfaces of the scale models for the aircraft and space-rated equipment. The scale models were tested in wind tunnels in the Institute of Mechanics at Moscow State University (in Korolyov town in Moscow region).

Sensor fields of application:

- aerodynamic tests of the aircraft equipment and automobiles;
- multipoint pressure measurement in the processing equipment;
- pressure measurement in automatic control systems of technological processes;
- automatic control systems in planes, power installations, etc.;
- equipment diagnostic systems (aero-and-automobile engines, power-facilities for aircraft and space-rated equipment).

Flat Semiconductor Sensor FSS 01

The flat semiconductor sensor FSS 01 has been designed to determine the acoustical strength of elements and units for aircraft equipment. The sensor features small size and thickness. It is important for the sensor installation on the aircraft external skin at ground tests and in wind tunnels (fig. 3).

Such design of the sensor results minimum distortions in the acoustic fields, arising at a surface of the device. The sensor was used for acoustical vibration measurement of the amphibian skin at ground and flight tests (the amphibian - model"B", produced in Beriyev scientific and production association in

Taganrog town). The sensors were the parts of the airborne multichannel measuring complex. The sensors FSS 01 were mounted on the aircraft skin in the system of pressure pulsation measurement (undrainaged).
The sensor design FSS 01 incorporates the crystal and the compensating plates, designed for the sensor PS 01. The flat sensor FSS 01 consists of a case - 1, a SSE - 2, compensating plates - 3 and 4, a cover - 5, glass beads - 6, a grid - 7 and electric outlets - 8. The cover and the electric outlets are potted by the epoxide (BK-9). The case is made of fernico 29НК, the thermal expansion coefficient (TEC) of which matches the silicon TEC within an operating temperature range, to reduce thermal strains of the SSE [4, 5].

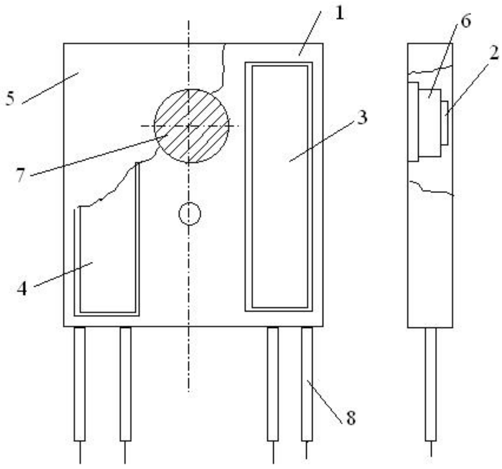


Fig. 3. Flat Semiconductor Sensor FSS 01

High-Temperature Polysilicon Pressure Sensor PPS 01
The principle of the sensors described above is based on the piezoresistance effect, arising in thermal-diffused or ion-implantation structures, isolated by the *p-n* junction from the substrate material. The maximum operating temperature in such structures is limited within a range of ~120 to 130ºC. If the temperature rises, the *p-n* junction will lose its insulating properties. To increase the maximum operating temperature of the SSE and the sensor accordingly, it is necessary to use the semiconductor structures such as « silicon-on-silicon » or polysilicon (PS) structures [6, 7].
The high-temperature sensor PPS 01 (fig. 4) consist of a SSE, a compensating plate, a case, a sleeve, a shield grid, a drainage tube and a cable. The crystal of the sensor PS 01 is used as a base crystal for the SSE. But all circuitry on the piezocrystal are based on the PS technology.

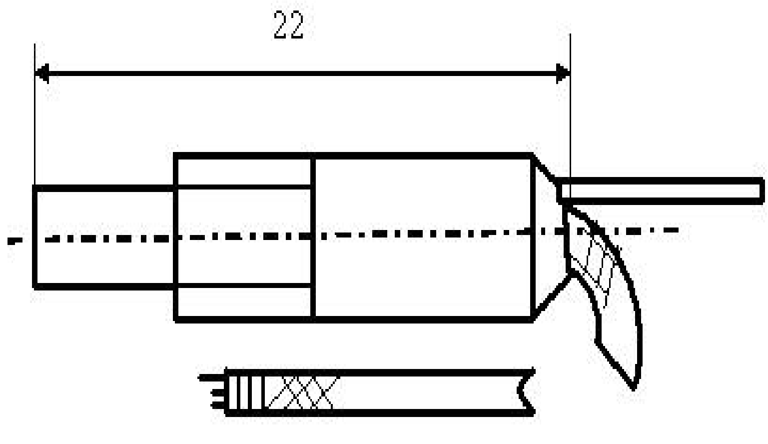


Fig. 4. High-Temperature Polysilicon Pressure Sensor PPS 01
The polysilicon film is doped by ion-implantation due to it is possible to adjust the TCR (temperature coefficient of resistance) resistors within the wide range in value from - 0.05%/ºC to +1%/ºC. Small

values of TCR are important for minimization of the sensor temperature drift. The TCR value completely depends on the dopant doze.

The main feature of the said sensor is the ceramic sleeve, on which the PS SSE and the PS compensating plates are fixed. The conductors, connecting the SSE contact pads with the compensating plate pads, are disposed in sleeve grooves and glued by high-temperature adhesives. The case cavity is encapsulated in a high-temperature compound.

The test results of the sensor PPS 01 scale models have shown that the change of the output signal from temperature is not higher than 4% or 5 %.within a temperature range of -60 to +250ºC under nominal pressure 0.15 MPa.

Model Tests of the Space-Rated and Aircraft Equipment in Gas- and-Aerodynamic Installations.

In scientific and production association (in Korolyov town in Moscow region) and in the Institute of Mechanics at Moscow State University many reseach works on aerodynamic characteristics of the space-rated and aircraft models (for the "Buran – Energia" space-rated system inclusive) were done, using the sensors PS 01 and MHS 01. About 10 sensors PS 01were installed on the models. At the model blowing in a tunnel, the sensors measured pulsation pressure levels on its surface. The multichannel sensor MHS 01 was used to investigate the static pressures in many points of the model or small-scale eddying flows. It is planning to use the sensors MHS 01 instead of pneumonic commutators, applied for investigation of units of the aircraft and space-rated equipment.

The pneumatic circuit of one pressure measurement channel at the aerodynamic experiment on the aircraft models is shown in fig. 5. Pressures are measured through drain holes and pneumatic tubes and are supplied to the pneumatic tube commutator (К) with the electromechanical drive in which the MES are installed. The abutment pressure ($P_{ОП}$) from the automated abutment pressure supplier is supplied to the reference cavity pressure sensor (PS). The abutment pressure is also supplied to position "0" of the К. And the reference pressure ($P_К$) from the reference pressure supplier is supplied to position "47".

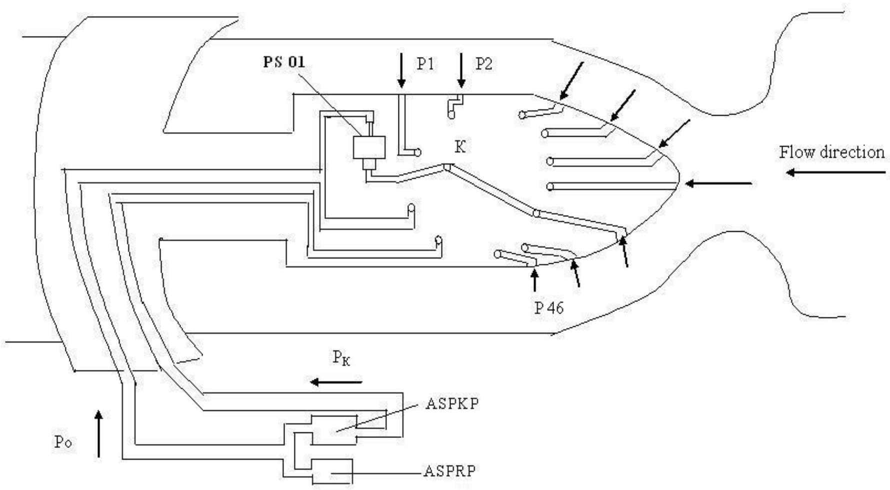


Fig. 5. Using sensor PS 01 in the study of rocket and flight models technics in wind tunnels: AZD - automatic pressure vessel: the reference (P_0), control (P_K); K - manual switch pneumatic; P1 ... P46-point removal of controlled pressure

The absolute abutment pressure is approximately equal to the measuring one. The reference pressure is relative to the abutment pressure and is approximately equal to the measurement range PS.

The sensor sensing element is unloaded in position "0". The zero level signal value of the bridge circuit is determined during measurement. The reference pressure is supplied to the measuring cavity PS in position "47", where the value of the output conversion coefficient is defined. The actual error of the abutment and reference pressures is not more than 0.1 %. Being in the position of the К from the 1^{st} up to 46^{th}, the measuring pressures (Pi) are supplied to the measuring cavity PS.

The К switching time from one position to the other is 160 ms, it results from the reference time of the K electromechanical drive (20 ms) and the equipartition time of pressure in The K channels and in measuring cavity PS (140 ms). In 184 points (4 channels) the pressure measurement time is not more than 8 s.

Such measurement circuit measures pressure in many points of the model with the limited PS number.

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