EXPERIMENTAL TECHNIQUE AND DEVICES

Conference materials
UDC 544.478-03
DOI: https://doi.org/10.18721/JPM.173.231

Sensor of fast-variable and static pressure

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Abstract. A new design and technological solution has been developed for the sensing element of a static and rapid-change pressure sensor based on the integration of strain-resistant and piezoelectric films of nanometer size, which made it possible to create a multifunctional sensor element with small pressure deviations from the actual values.

Keywords: sensing element, pressure sensor, strain gauge, piezoelectric thin films, static pressure, dynamic pressure

Citation: Agafonov D.V., Novichkov M.D., Shepeleva A.E., Gurin S.A., Ryzhov A.A., Volkov V.S., Sensor of fast-variable and static pressure, St. Petersburg State Polytechnical University Journal. Physics and Mathematics. 17 (3.2) (2024) 157–160. DOI: https://doi.org/10.18721/JPM.173.231

Материалы конференции
УДК 544.478-03
DOI: https://doi.org/10.18721/JPM.173.231

Датчик быстропеременного и статического давления

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Аннотация. Разработано новое конструктивно-технологическое решение для чувствительного элемента датчика статического и быстропеременного давления на основе интеграции тензорезистивных и пьезоэлектрических пленок нанометрового размера, что позволило создать многофункциональный чувствительный элемент с малыми отклонениями давления от действительных значений.

Ключевые слова: чувствительный элемент, датчик давления, тензорезистор, пьезоэлектрические тонкие пленки, статическое давление, динамическое давление

Ссылка при цитировании: Агафонов Д.В., Новичков М.Д., Шепелева А.Э., Гурин С.А., Рыжов А.А., Волков В.С. Датчик быстропеременного и статического давления // Научно-технические ведомости СПбГПУ. Физико-математические науки. 2024. Т. 17. № 3.2. С. 157–160. DOI: https://doi.org/10.18721/JPM.173.231

Introduction

The current stage of development for the management of new generation special equipment is characterized by increased accuracy, stability and performance in such areas as automotive, aircraft, mining and nuclear energy, where static and dynamic pressure is the most important parameter for measurement and control, with the help of which it is possible to prevent the possibility of emergency situations, thereby avoiding spending on expensive equipment repairs and at the same time saving human lives, that is why the number of pressure sensors is inevitably increasing every day [1]. Currently, pressure sensors are based on different physical principles: strain-resistive and piezoelectric sensors are used to measure static and pulse pressures, respectively. Sensor designs capable of measuring both pressures simultaneously and with a given technique do not currently exist. This is why users have to use two different sensors, which can burden the system, take up a lot of space and be expensive [2]. The goal of the work was to develop and study a new design of the sensor, which will significantly expand its functionality, in particular, to use the sensor to measure pressure in various frequency ranges.

Materials and Methods

The sensing element of the rapid-change and static pressure sensor (Fig. 1), which converts the energy of mechanical deformation into an electric charge and a change in resistance, is built on the basis of a round silicon membrane with a rigid center. The substrate surface is oxidized to form a dielectric layer with a thickness that provides reliable electrical insulation. Piezoelectric capacitive structures of a bending type made of ZnO, as well as four strain gages made of alloy nichrome, are applied to it.

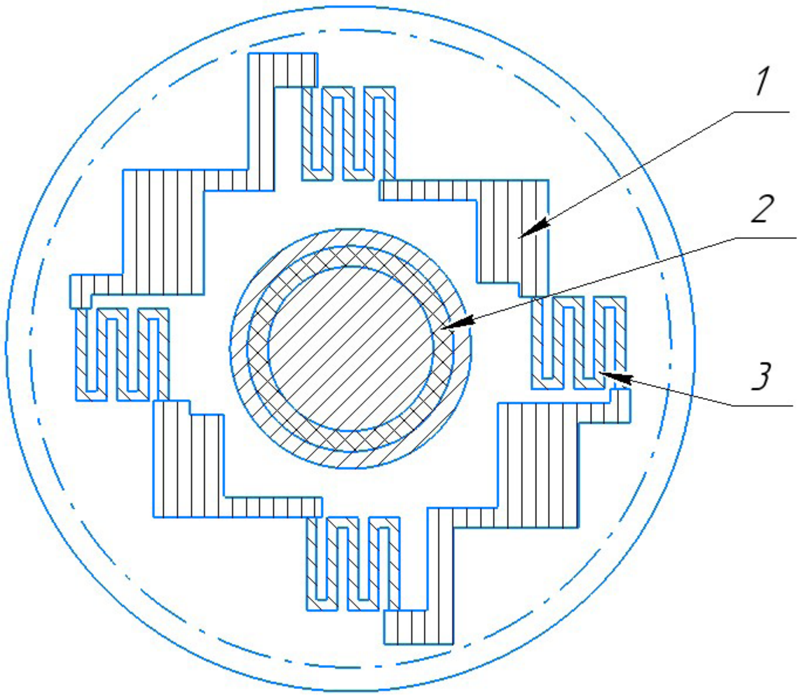

Fig. 1. Topology of the sensing element:
contact pads *1*, piezoelectric thin films *2*, strain gages *3*

Piezoelectric structures are formed in the center of the silicon wafer using the free mask method. The technology for producing ZnO thin films with piezoelectric properties is implemented at the Caroline D12A vacuum plasma spraying installation using the magnetron sputtering method. The essence of this method is the bombardment of the target surface, made of zinc oxide ZnO, with ions of the working gas.

To obtain piezoelectric structures on a sensitive element, the technological mode presented in Table 1 is proposed.

Table 1

Mode of production of piezoelectric films from ZnO

Spray parameters of mixers	Working gas	Working gas pressure, Pa	Power, kW	Membrane temperature, °C
ZnO	Argon	5	0.8	350

Compression and tension strain gauges are located at the places of the greatest inflection of the membrane. The formation of resistive films is carried out by thermal spraying of the alloy nichrome from a tungsten evaporator [3]. The current through the evaporator with a nichrome resistive material attachment smoothly increases to 260—270 A until the attachment melts. Then, simultaneously with the opening of the flap, the current is instantly increased by about 15%. Spraying is carried out until the required resistance value of the control witness sample is reached within 60 seconds, while the substrate temperature reaches 350 °C.

To obtain strain-resistant structures on a sensitive element, the technological mode presented in Table 2 is proposed.

Table 2

Spraying mode of nichrome layer

Vaporizer	Evaporator current, A	Initial residual pressure in chamber, mmHg	Final residual pressure in chamber, mmHg	Substrate temperature, °C	Control sample resistance, kOm/□	Spraying time, s
Nichrome	280–350	$2\cdot10^{-5}$	$3.5\cdot10^{-5}$	350	1,050–1,080	60

Gold with an adhesive sublayer of vanadium is used as a conductive material in the formation of interconnections and contact pads of strain gages and piezoelectric transducer plates [4]. The deposition of V-Au layers is carried out by the resistive method at a substrate temperature of 250 °C, followed by exposure for 30 minutes.

Results and Discussion

A technology has been developed for the manufacture of sensors sensitive elements for rapidly alternating and static pressures based on the integration of nanoscale piezoelectric and strain gauge films, which provide the following parameters for thin-film strain gages, presented in Table 3.

Table 3

Parameters of thin-film resistors

Parameter	Value
Thickness *d* of strain-resistant film, nm	80–100
Temperature coefficient of resistance TCS, 1/°C	2.0–3.6
TCS spread of strain gauges in strain gauge, 1/°C	$5\cdot10^{-6}$
Strain sensitivity coefficient	$2\cdot10^{-7}$

The parameters for piezoelectric films are presented in Table 4.

Table 4

Parameters of piezoelectric thin films

Parameter	Value
Layer thickness, nm	60–100
Frequency range, Hz	10^{-2}–10^{6}
Operating temperature range, °C	-100–+250
Voltage sensitivity d_{33}, pC/N	500
Sensitivity to relative influences with minimum output signal of 5 mV	10^{-9}

Conclusion

The topology of the pressure sensor sensing element, as well as the technology for manufacturing highly sensitive and thermally stable strain gages made of alloy nichrome and piezoelectric thin films made of ZnO deposited on an elastic silicon membrane by magnetron sputtering has been developed [5]. All this made it possible to obtain the desired properties of thin films and enhanced heat dissipation at increased electrical loads. This type of sensor is capable of analyzing the results and transmitting pressure information over a wider frequency range than sensors currently manufactured.

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Received 25.07.2024. Approved after reviewing 12.08.2024. Accepted 28.08.2024.