ANNOTATION

of dissertation for the Philosophy Doctor (PhD) degree in specialty "6D071900 – Radioengineering, electronics and telecommunications" by Khaniyev Bakyt on the topic **"The electrical characteristics of semiconductor gas sensors in the presence of photon exposure"**

The dissertation work is devoted to the study of the electrical characteristics of highly sensitive electronic gas sensors of polar and non-polar gases, which are solid-state electronics devices based on nanostructured porous silicon (PS) and heterostructural materials obtained as a result of growing metal-oxide semiconductors (MOS) on the PS surface by magnetron sputtering and nickel metal layer deposited by chemical method. The results of the study of their electrical characteristics in the presence of photon exposure are also presented.

Relevance of the dissertation theme.

Currently, the development of industrial technologies and automation of processes, increasing requirements for human health and environmental protection have led to a significant increase in demand for gas sensors. The control and monitoring systems used to analyze the composition of air in the environment and accurately determine the concentration of a certain type of gas mainly consist of a gas sensor, an analog-to-digital converter, a microprocessor used for digital processing of information about the composition of air, and information output devices. In addition, if necessary, such systems can be equipped with wireless communication systems for remote control and monitoring. The main areas of application of these devices include industrial enterprises, factories, mines, industrial safety services and places of mass gathering of people.

The sensing element is the main measuring component of the electronic gas sensor. In most cases, metal-oxide semiconductors (MOS) such as ZnO, SnO_2, TiO_2, In_2O_3, WO_3 and MoS_2 are used as the main sensing element of gas sensors. In addition, many papers have been published on the study of the possibilities of gas sensors based on organic compounds, optical sensors, materials based on carbon nanotubes (CNTs) and conductive nanostructures as various gas sensors. However, the most common in practice gas sensors based on MOSs in most cases operate at high temperatures from 150 to 300 °C, which, accordingly, requires more energy consumption and as well as has lower selectivity and sensitivity to certain types of gas. In addition, they have poor compatibility with modern silicon-based electronic devices and complex manufacturing technology. Thus, monitoring harmful gases with the help of gas sensors based on MOSs at room temperature can be considered a difficult task.

The large surface area due to the fractal structure of the material, the chemical activity of the material surface, the simplicity of the obtaining technology, as well as the presence of unique optical, electrical and structural properties make the PS material a promising material for use as a sensitive element in gas sensor technology. In addition, another advantage of using silicon nanostructures as gas sensors is their

compatibility with modern electronics. Although the PS is very sensitive to certain types of gases, its stability is low due to the fairly rapid oxidation of its surface. Consequently, for industrial applications of solid-state electronics, it is possible to increase the sensitivity and selectivity of electronic gas sensors to hard-to-detect types of gases by using a heterostructural material consisting of PS and MOS. The results of the experimental study showed that the obtained samples can detect harmful gases at room temperature up to a concentration of 0.1 ppm. These results indicate the possibility of creating highly sensitive and economical electronic sensors of various harmful and dangerous gases. High-tech equipment and electronics processes were used to obtain sensitive elements and study their electrical, morphological and optical characteristics.

Thus, the study of electrical, optical and morphological properties of nanoscale semiconductor materials, as well as increasing the sensitivity and selectivity of electronic gas sensors based on the studied materials to polar and non-polar gases is an urgent task of great practical importance in electronics.

The purpose of the research

Investigation of electrical, optical, morphological characteristics of nanostructured porous silicon and surface-modified porous silicon, on the surface of which a metal-oxide semiconductor and a metal layer are deposited, as well as the development of a highly sensitive and selective electronic gas sensor based on them for polar and non-polar types of gases.

The object of the research.

Nanoscale porous silicon, CuO/PS, WO_3/PS, Ni/PS;

The subject of the research.

Changes in the electrical conductivity of porous silicon, nanoscale semiconductor heterostructures under the action of light, the effect of metal oxide semiconductors and metal particles on the gas-sensitive properties of porous silicon.

Research methods.

Electrochemical etching method for obtaining porous silicon, magnetron sputtering method for deposition metal-oxide semiconductors on the surface of porous silicon, chemical method for growing a metal layer, experimental and analytical methods.

In order to achieve the above stated goal, it is necessary to carry out the following tasks:

1 Using electronic devices and high-tech processes obtaining porous silicon samples by electrochemical etching, depositing a metal-oxide semiconductor layer on the porous silicon surface by magnetron sputtering method, as well as growing a nickel layer on the porous silicon surface by chemical method;

2 Investigation of morphological, optical, electrical properties of the samples and study of the effect of photons of light on the electrical properties of the samples;

3 Investigation of the sensitive characteristics of semiconductor nanostructures to ammonia, ethanol, toluene, chloroform vapors and creation of an electronic gas sensor based on the obtained sensitive materials.

Scientific novelty of the dissertation results.

The novelty and originality of the work are as follows:

1. It has been found that there are optimal effective parameters for electrochemical etching of porous silicon, at which the sensitivity of the electronic gas sensor based on it is the highest;

2. It has been experimentally demonstrated that the sensitivity and selectivity of gas sensors to polar and non-polar gases increases when depositing on the surface of porous silicon a metal layer and metal-oxide semiconductors;

3. A quantitative analysis of the nonlinear hysteresis structure in the current-voltage characteristics of semiconductor materials PS, CuO/PS, WO_3/PS in room conditions and under the influence of photons has been carried out;

The main provisions for the defense.

1. Nanostructured p-type porous silicon obtained by electrochemical etching at parameters j = 5 mA/cm^2, U = 30 V, t = 40 min (72% porosity) is the most efficient NH_3 gas sensor at a concentration of 0.1 ppm in the porosity range of 59–83%;

2. The sensitivity of the gas sensor based on the CuO/PC heterostructure to toluene and chloroform vapors up to 0.1 ppm concentration at a voltage value of U = 2 V reaches from <1% to 33.9% and 27.6%, respectively, compared with the original PS;

3. The areas of nonlinear hysteresis in the current-voltage characteristics of porous silicon and CuO/PS, WO_3/PS heterostructures, measured in the voltage range of 0–2 V when exposed to photons of a xenon lamp with an intensity of 0.1 W/cm^2, increase by 10.6, 2.1, and 3.7 times, respectively, compared with room conditions.

Practical and theoretical importance of the dissertation.

The results of the dissertation make it possible to manufacture inexpensive small-sized gas sensors with high sensitivity and selectivity to ammonia, ethanol, toluene, chloroform vapors based on semiconductor nanostructures.

The reliability and validity of the results

The reliability of the results achieved in the dissertation work is confirmed by the presence of publications in local journals recommended by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan, in foreign journals included in the Web of Science (Clarivate Analytics, USA) and Scopus (Elsevier, Netherlands) databases, and in the proceedings of international conferences, as well as consistency with the results of other authors.

The personal contribution of the author

The author participated in the research work at all stages of the dissertation work. The work on obtaining semiconductor nanostructures, studying the influence of gas and light particles on their electrical characteristics, as well as processing and analyzing the results of the study of optical, morphological and electrical characteristics of samples was carried out by the author. Approval of the tasks and work plan, discussion of the results were carried out jointly with the supervisor

Publications

10 publications have been published on the topic of the dissertation, including 5 papers in the materials of international conferences, 3 papers in scientific publications recommended by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Science and Higher Education of the Republic of

Kazakhstan for the degree of Doctor of Philosophy (RhD), 2 articles in journals included in the international information resources Web of Science (Clarivate Analytics, USA) and Scopus (Elsevier, Netherlands).

Approbation of the dissertation. The results obtained in the dissertation were presented and discussed:

– at the International Conference of Students and Young Scientists "FARABI ALEMI" (2019, 2021, 2022, Al-Farabi Kazakh National University, Almaty);

– at the 11th International Scientific Conference “Chaos and Structures in Nonlinear Systems. Theory and Experiment” (2019, Karaganda, Kazakhstan);

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Ханиев Б.А., Ибраимов М.К., Жанабаев З.Ж., Сагидолда Е., Диханбаев К.К., Тілеу А.О. Высокочувствительный аммиачный сенсор на основе пористого кремния // Авторское свидетельство, 2022. №24953.

The scope and structure of the thesis.

The thesis consists of an introduction, 3 sections, conclusion and list of references from 121 titles, contains 103 pages of basic computer text, including 82 figures, 52 formulas and 7 tables.