THE USING OF PHYSICAL PROPERTIES OF SEMICONDUCTOR MATERIALS IN ADVANCED ENGINEERING

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Abstract. *This article examines the development prospects of the semiconductor, radioelectronic and optoelectronic industries. Semiconductor materials and the use of devices made from them are analyzed. It is also noted that the use of semiconductor materials has a positive effect on the development of the industry.*

Keywords: *pulse diodes, low-frequency diodes, diodes, varicaps, zener diodes, tunnel diodes, integrated circuits.*

INTRODUCTION

Semiconductor physics is the most important part of modern physics; on the basis of its achievements, the fields of instrument engineering, radio engineering and microelectronics have developed. Based on the study of the electrophysical properties of semiconductor materials, it is possible to create new physical devices. In particular, on the basis of materials studied in the physics of semiconductors, a section of solid state physics, physical instruments and devices are created that meet the requirements of the present time. By studying the properties of silicon and germanium, which are elementary semiconductors, as well as the properties of semiconductors of complex structure and observing the change in their properties under external influence, it is possible to create devices with the necessary properties. The creation of such objects in silicon crystals, which is considered the main material of modern electronic technology, is a very promising task. The amount of impurities introduced into a silicon crystal is limited by their solubility in silicon.

MATERIALS AND METHODS

Nowadays, scientific and technological progress cannot be imagined without electronics. The creation of the fifth perfect generation of modern electronics involves the creation of a new type of semiconductor electronic devices and integrated circuits and their use in computer technology, automation, radio engineering, measuring technology, television, solar cells and holographic recording and other areas. If we look back in history, semiconductor devices in the form of point diodes or crystal detectors were used much earlier. For example, the properties that correct the contact of sulfite compounds with metals were determined in 1874. It observed the glow of silicon carbide when current passed through a point contact, and also generated and amplified high-frequency electromagnetic oscillations. During the Second World War, germanium and silicon point diodes with high and ultra-high repeatability were developed, and semiconductor thermoelectric generators were prepared that directly convert thermal energy into electrical energy. In 1948, American scientists J. Bardeen, V. Brattain and V. Shockley created point-point transistors. V. Shockley's theory of the pn junction marked the beginning of a new stage in the development of semiconductor electronics. In the 1950s, bipolar transistors, thyristors, high-power rectifier diodes, photodiodes, phototransistors, photocells, tunnel diodes, and other early electronic components began to be created.

By the 1960s, integrated circuit production began. In 1967, under the leadership of J.I.Alferov, hybrids with properties close to perfection were created, and on the basis of them we can say that mobile communication devices, etc. are currently used in everyday life. Lasers were created based on these heterojunctions. Due to the superiority of their properties and breadth of application, semiconductor materials, including the technology of creating semiconductors with piezoelectric (volume changes caused by light) properties and the physical study of their properties, are one of the pressing problems of our time. Although these data indicate a wide range of applications for semiconductor devices, the prospects for their use are still very broad.

RESULTS AND DISCUSSION

Elements of modern electronics are the main raw materials of the fifth generation electronics industry. The main electronic elements of this generation of electronics are semiconductors with certain properties. Semiconductor manufacturing technology is developing very quickly. To understand the amazing physical properties of various semiconductor devices and master the principles of their design, you need to know the methods of technological preparation and methods of obtaining semiconductor structures.

Diodes are classified according to their purpose and use in electronic devices. Semiconductor diodes have replaced vacuum and gas-filled diodes and are now widely used in electronic devices. They are used as the main element of power supplies for devices to rectify alternating current and protect electronic devices from surges in mains voltage. All semiconductor diodes can be divided into two groups: rectifiers and special-purpose diodes. Rectifier diodes are used to convert alternating current to direct current. Depending on the shape and frequency of direct current, they are divided into low-frequency, high-frequency and pulse diodes. The basic element of the structure of most semiconductor devices is the electrical junction, which consists of a transition layer and a metal-semiconductor contact formed in two regions of the semiconductor with different resistivities and different conductivity regions, including the resulting junctions. If one of the two regions of a semiconductor is n-type and the other is p-type, the junction is called an electron-hole junction or p-n junction. The properties of most common devices are determined by processes occurring in pn junctions. For example, if the concentration of inputs in the n-type field and the p-type field is very high, then the type of current-voltage characteristic of the p-n junction is radically different from that of a conventional p-n junction, and the characteristic in the form of N will be Diodes made from such p-n junctions, called tunnel diodes.

Low Frequency Rectifier Diodes - These diodes are typically used to rectify AC power at power frequency (50 GHz). They can operate at even higher frequencies. These diodes are divided into three types depending on the maximum permissible direct current: low power diodes with constant current up to 0.3 A, medium power diodes (direct current from 0.3 A to 10 A), high power diodes (constant current power higher 10 A). Currently, rectifier diodes are made from silicon. Later, such diodes began to be manufactured based on gallium arsenide.

Pulse diode is a semiconductor diode with short transients, capable of operating in pulse mode. Point pulse diodes were initially developed. Later, planar technology began to produce pulsed diodes of incomparable quality. The main substance is silicon; sometimes gallium arsenide is also used. In the manufacture of planar pulsed diodes, radiation diffusion occurs through windows in the silicon oxide layer. The surface of the p-n junction of such diodes can be made quite small, therefore the electrical capacitance of the p-n junction is small [1]. Schottky diodes are based on a metal-semiconductor rectifying contact. Based on the rectifying metal-semiconductor contact, rectifying, pulsed semiconductor diodes operating at very high frequencies are manufactured. They differ from pn junction diodes in that they can operate at higher frequencies. The recharging time of the metal-semiconductor contact capacitance has a major influence on the frequency properties of Schottky diodes. Recharge time also depends on the base resistance. Therefore, it is desirable to create a Schottky contact in a semiconductor crystal with p-type conductivity, since the mobility of electrons in this crystal is greater than the mobility of holes. For a sample of Schottky diodes, the permissible direct current is 10 A, the corresponding direct voltage does not exceed 0.6 V, the permissible voltage is 20 V. Diodes for very high frequency - with the help of such diodes (HF), the signal is changed and processed. They are used in various electronic devices and measuring equipment at frequencies above 300 MHz. It allows you to create (generate) and amplify electromagnetic oscillations in the field of thought, increase frequency, modulate signals, control and limit tasks. Types of IOC diodes: tunnel and freewheel diodes, varicps, avalanche-volatile diodes, Gunn generators, pulse diodes, mixing diodes, detectors, reconnection diodes.

A semiconductor zener diode is a diode that serves to stabilize voltage, in which the voltage is very weakly related to the reverse current, that is, the current changes, but the voltage remains practically unchanged. Electrical drilling is avalanche or tunneling drilling. The main parameter of a zener diode is the stabilization (stabilization) voltage, which depends on the width of the pn junction or the relative resistance of the diode base. Therefore, when obtaining n, methods of melting and diffusion of p-n junctions are used. At the same time, if the input is inserted on both sides of the silicon crystal, then when a voltage is applied between these sides, two p-n junctions are formed, connected to each other. Such zener diodes are called dual-anode zener diodes. They are used to stabilize voltages of different polarities.

Tunnel diodes - these diodes are made on the basis of a p–n junction formed in a semiconductor with a fairly high density of ligation inputs. Due to the high conductivity of the electron and hole fields, the width of the pn junction is small (about 0.01 μm), that is, two orders of magnitude (~100 times) thinner than other diodes. Charge carriers can tunnel through such a thin layer of potential barrier. The structure of tunnel diodes is almost the same as that of other diodes, but semiconductors (GaAs or Ge) with an input concentration of 1020 cm-3 are used to form the junction. Gallium arsenide is a more promising material; in the production of tunnel diodes the following are used: donors - tin, sulfur, tellurium, lead, selenium and acceptors - cadmium and zinc.

Varicaps act as electrically controlled capacitors. The principle of their operation is based on the dependence of the barrier capacitance of the pn junction on the reverse bias voltage. Varicaps are semiconductor devices whose operation is based on a change in the barrier capacitance of the p-n junction when the reverse voltage changes. Varicaps are used as electrically controlled capacitive elements in electronic circuits to regulate and change the frequency of an oscillatory circuit. Normal operation of a varicap occurs under reverse bias, that is, when a reverse voltage is applied, the height of the potential barrier of the pn junction increases. Varicaps are mainly used to adjust the frequency of oscillating circuits. Parametric diodes based on capacitive control are used to amplify and condition very high frequency signals, as well as multiplier diodes.

- used in frequency multipliers with a wide frequency range.

Integrated circuit – combining a large number of transistors, diodes, capacitors, resistors and conductors, connecting them into a single structure (constructive integration); performing complex information changes in the circuit (circuit and technical integration); in a single technological cycle reflects the creation of electrical radio elements of the circuit, simultaneously making connections and simultaneously creating a large number of identical integrated circuits using a group method (technological integration). Microcircuits, the elements of which are formed in a layer close to the surface of the semiconductor base, are semiconductor integrated circuits. The semiconductor industry begins with the production of monocrystalline silicon ingots, which are the main material for manufacturing integrated circuits. Semiconductor chip - all elements and interconnections are made in a single semiconductor crystal (for example, silicon, germanium, gallium arsenide) [2]. The physics of semiconductors and dielectrics is the main part of modern physics; on the basis of its achievements, the fields of instrument engineering, radio engineering and microelectronics are developing. Semiconductors belong to the group of substances between metals and dielectrics in terms of electrical conductivity, and at $T = 0$ their valence band is occupied by electrons, and the band gap is small (~1eV). An atom consists of a nucleus surrounded by a cloud of electrons.

Semiconductors include materials whose resistivity at room temperature ranges from $10^{-5}$to 10^{10} Om cm. (in semiconductor technology it is customary to measure the resistance of 1 cm^3 of material). Semiconductors outnumber metals and dielectrics, and in most cases semiconductor materials such as silicon, gallium arsenide, selenium, germanium, tellurium, and various oxides, sulfides, and carbides are used.

Based on the study of the electrophysical properties of semiconductor materials, it is possible to create new physical devices. In particular, on the basis of materials studying part of solid state physics and semiconductor physics, physical devices and instruments are created that meet the requirements of the present time.

By studying the properties of silicon and germanium, which are elementary semiconductors, as well as the properties of semiconductors of complex structure, observing the change in their properties under external influence, it is possible to create devices with the necessary properties.

In particular, silicon crystal is widely used in instrument making and microelectronics. That is why it is important to study the electrophysical, mechanical, optical and other properties of this element. External influence: studying changes in the properties of silicon under the influence of radiation, pressure, deformation and other influences is an urgent problem [3].

There are several ways to measure the concentration (p,r) and mobility (Mr,Mp) of free charge carriers (electrons and holes) in semiconductor silicon. The use of a particular method depends on their metrological description, information content for explaining the measured quantities, the physical basis of measurement methods, the electrical properties of the sample, its geometric shape and dimensions. All this is a method based on the Hall effect. With this method, in addition to measuring the pmp of a silicon sample, the electrical conductivity can also be determined.

Silicon Si (silicymine) is an element of group IV of the periodic system of Mendeleev, atomic number 14, atomic mass 28.0856, belongs to the group of non-metals. Consequently, its single atom has 14 electrons, 10 of which fill 5 levels in the inner shell of the solid, the remaining 4 of which are two natural stable isotopes of silicon 3 $^{28}{}_{14}$ Si (92,28 %), ^{29} Si (4,67 %), ^{30} Si (3,05%) and consists of two radioactive isotopes ^{27} $_{14}$ Si (β^{+}, 4,9s), ^{31} $_{14}$ Si(β^{-}, 170 min).

The crystal chemical radius of the Si silicon atom is 0.134 nm, and the radius of the Si^{+4} ion is 0.039 nm. Silicon crystallizes in the form of a face-centered cubic lattice Si, the lattice constant of this cube is λ=0,54304 nm. The density of silicon is -2,328 g/sm^3, the melting point is 1415^{0}C, the heat capacity is 20.1 kJ/mol·K, the heat of fusion is 49.8 J/m·Mole, the heat of evaporation is -355 kJ/mol [5].

Let's take a look at some important techniques used to grow semiconductor silicon crystals.

First, pure silicon must be separated from its compounds. There are several ways to do this. By reducing silicon tetrachloride SiCI4 Zn at high temperature, pure silicon Si can be extracted from it:

$$SiCI(gas)|+2Zn(gas) \rightarrow Si(solid)+ 2ZnCI_2(gas)$$

Reduction of silicon tetrachloride SiCl4 with hydrogen produces purer silicon than the previous method. The reaction takes place at a temperature of 10500–11000 C.

$$SiCI_4+2N2 \rightarrow Si +3NCI$$

Semiconductor materials are divided into 5 groups based on their composition.

1. Elementary semiconductors;
2. semiconductor compounds A^{III} B^{V};
3. Semiconductor connections A^{II} B^{VI};
4. Semiconductor materials A^{IV} B^{IV};
5. Complex semiconductor materials.

Almost all elementary semiconductors and most A^{III} B^{V} and $A^{II}B^{VI}$, semiconductor compounds, as well as complex semiconductor materials, have a crystalline structure of the diamond or zinc oxide type, belonging to the tetrahedral phase, where each atom is surrounded by four equidistant neighbors located at the height of the tetrahedron. The bond between two neighboring atoms is carried out by electrons with opposite spin. Therefore, in elementary semiconductors the chemical bond is 100% covalent, and in A^{III} B^{V} compounds the bond is ionic-covalent [8].

In A^{III} B^{V} compounds, the proportion of ionic bonds increases. The main fundamental parameter of semiconductors is the band gap Ye_d. Ye_d is the energy required to release the valence electron involved in the chemical bonding of the crystal lattice, which is involved in the conductivity of the material. In semiconductors, the size of Ye_d is determined mainly by the state of the valence electrons of the atoms forming the crystal lattice.

table 1.

Element	Electronic	E_g, eV
C	$1s^2 2s^2 2p^2$	5,48
Si	$1s^2 2s^2 2p^6 3s^2 3p^2$	1,17

+Ge	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^2$	0,74
Sn	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^2$	0,082

Although all of these elements form a diamond-like crystal lattice with covalent bonds, the arrangement of valence electrons in the electronic structure of their atoms, the energetic coupling in the lattice, and the band gap Ye_d can vary greatly. This law is relevant for semiconductor compounds $A^{III}B^{V}$, $A^{II}B^{VI}$ and complex materials. Therefore, by combining elements in compounds (that is, different energy states of valence electrons in an atom), a controllable semiconductor material can be obtained. This material is very close to diamond in its physical dimensions.

The band gap of gallium arsenide is 1.43 eV, and the electron mobility is higher than that of Ge and Si. The mobility of holes in gallium arsenide is close to the mobility of holes in Si. Zinc and ancient copper are used as acceptors of this material, and S, selenium, tellurium and elements of group VI of the periodic table are used as donors.

Indium antimonide. In addition to high electron mobility, the band gap (0.18 eV) is relatively small. The photoconductivity of this material covers a large region (up to 8 microns) of the infrared part of the spectrum. In this case, the highest value of photoconductivity corresponds to a wavelength of 6.2 μm. Indium antimonide is used for the manufacture of highly sensitive photovoltaic cells, optical filters, thermoelectric generators and refrigerators.

Gallium phosphide: differs in band gap (2.3 eV). Red or green LEDs are made from it. In addition, LEDs are also made from compounds of boron, aluminum and gallium nitride. Sulfides of compounds AIII-VI (PbS, Bi2S3, CdSe, CdS) are used in the manufacture of photoresistors. They are also used as luminophores [9].

Table 2

Semiconductor materials

Material	Element and connection	Name	Crystal structure	Lattice constant at 300 K (Å).
Element	C	Carbon	D	3,56683
	Ge	Germany	D	5,64613
	Si	Silicon	D	5,43095
	Sn	Fire	D	6,48920
IV-IV	SiS	Silicon carbide	W	a=3,086; s=15,117
III-V	AlAs	Aluminum arsenide	Z	5,6605
	AlP	Aluminum phosphide	Z	5,4510
	AlSb	Aluminum antimonide	Z	6,1355
	BN	Boron nitride	Z	3,6150
	BP	Boron phosphide	Z	4,5380
	GaAs	gallium arsenide	Z	5,6533
	GaN	Gallium nitride	W	a=3,189; s=5,185
	GaP	Gallium phosphide	Z	5,4512

CONCLUSION

Semiconductor devices have a number of useful properties, such as the ability to conduct current more easily than other elements, exhibit variable resistance, and sensitivity to light or heat, and the electrical properties of the semiconductor material can be controlled through doping or the application of electric fields or light. can be modified by switching, semiconductor devices can easily perform tasks such as amplification, switching and energy conversion. Therefore, devices created on the basis of semiconductors are one of the main factors determining the future of radio electronics, electronics, laser industry and information technology.

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