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Розробка світлодіодів на основі гетеропереходів типу Шотткі Графіт/n-GaP

Дипломна робота

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Анотація

У даній роботі створено новий гетероперехід типу Шотткі Графіт/n-GaP методом осадження тонкої графітизованої вуглецевої плівки на підготовлену підкладку n-GaP в універсальній вакуумній установці Leybold-Heraeus L560 шляхом випаровування електронним пучком чистого масивного полікристалічного графіту.

Визначена висота потенціального бар'єру для досліджуваної структури при кімнатній температурі рівна $\varphi_0 = eV_{bi} = 1.69$ еВ;

Аналіз прямих гілок ВАХ гетеропереходу типу Шотткі Графіт/n-GaP, побудованих в напівлогарифмічному масштабі показав, що значення показника неідеальності (n) в області напруг $3kT/e < V <$ 0,7 В дорівнює 5. Це свідчить про те, що домінуючим механізмом струмопереносу є багатоступінчаті тунельно-рекомбінаційні процеси за участю поверхневих станів на межі поділу Графіт/n-GaP. При аналізі проходження носіїв заряду крізь енергетичний бар'єр при більших прямих зміщеннях ($V> 0,7$ В) показує, що величина коефіцієнта неідеальності n=12. За даних умов домінуючим механізмом струмопереносу можна вважати тунелювання, яке описується формулою Нюмена.

Проведений аналіз механізмів струмопереносу через досліджувані гетеропереходи типу Шотткі Графіт/n-GaP при зворотному зміщенні показав, що тунелювання є домінуючим механізмом струмопереносу в даній структурі.

Проаналізувавши вольт-фарадні характеристики гетеропереходу типу Шотткі Графіт/n-GaP, встановлено, що величина вбудованого потенціалу, визначена з вольт-фарадних характеристик і ВАХ досліджуваного гетеропереходу при кімнатній температурі, не співпадає. Ця відмінність зумовлена впливом поверхневих станів на межі поділу Графіт/n-GaP.

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INTRODUCTION

They are the most visible type of diodes, which emit a rather small frequency range of visible light of different color wavelengths, invisible infrared light for remote controls or laser light when a current passe through them.

A 'light-emitting diode' or LED as it is always known by that name, is basically just a specialized type of diode since they have very similar electrical properties to a PN diode. This means that the LED will pass current in its forward direction but prevent current flow in the reverse direction.

Light-emitting diodes are made from a very thin layer of doping semiconductor material largely depending on the semiconductor material used and the amount of doping, when the forward LED emits colored light at a specific spectral wavelength.

Graphite, is a crystalline form of the element carbon with its atoms arranged in a hexagonal structure. It occurs naturally in this form and is the most stable form of carbon under standard conditions. Under high pressures and temperatures it converts to diamond. Graphite is used in pencils and lubricants. It is a good conductor of heat and electricity. Its high conductivity makes it useful in electronic products such as electrodes, batteries, and solar panels.

CHAPTER 1. Theoretical part

1.1. Physical properties of the thin films graphite and crystals GaP

1.1.1. The structure of graphite. The giant covalent structure of graphite

Graphite has a layer structure which is quite difficult to draw convincingly in three dimensions. The diagram below shows the arrangement of the atoms in each layer, and the way the layers are spaced.

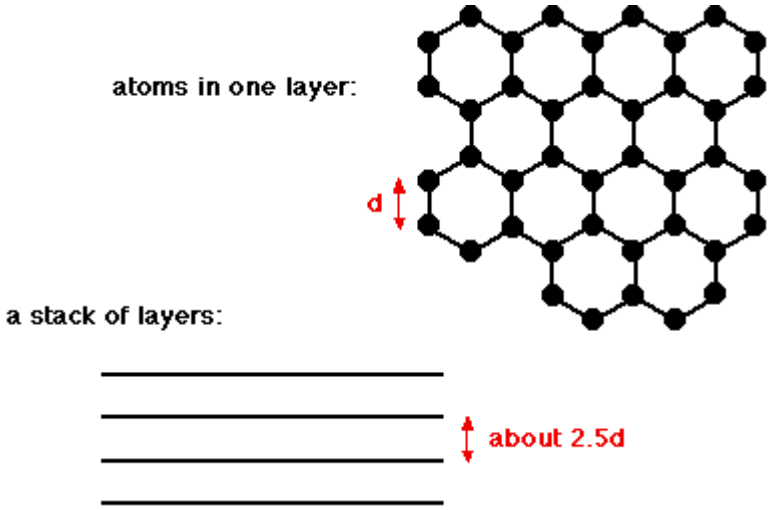

Fig. 1.1. Structure the layers of graphite

Notice that you can't really draw the side view of the layers to the same scale as the atoms in the layer without one or other part of the diagram being either very spread out or very squashed.

In that case, it is important to give some idea of the distances involved. The distance between the layers is about 2.5 times the distance between the atoms within each layer.

The layers, of course, extend over huge numbers of atoms - not just the few shown above.

You might argue that carbon has to form 4 bonds because of its 4 unpaired electrons, whereas in this diagram it only seems to be forming 3 bonds to the

neighbouring carbons. This diagram is something of a simplification, and shows the arrangement of atoms rather than the bonding.

Graphite

- has a high melting point, similar to that of diamond. In order to melt graphite, it isn't enough to loosen one sheet from another. You have to break the covalent bonding throughout the whole structure.
- has a soft, slippery feel, and is used in pencils and as a dry lubricant for things like locks. You can think of graphite rather like a pack of cards - each card is strong, but the cards will slide over each other, or even fall off the pack altogether. When you use a pencil, sheets are rubbed off and stick to the paper.
- has a lower density than diamond. This is because of the relatively large amount of space that is "wasted" between the sheets.
- is insoluble in water and organic solvents - for the same reason that diamond is insoluble. Attractions between solvent molecules and carbon atoms will never be strong enough to overcome the strong covalent bonds in graphite.
- conducts electricity. The delocalised electrons are free to move throughout the sheets. If a piece of graphite is connected into a circuit, electrons can fall off one end of the sheet and be replaced with new ones at the other end.
- Graphite is an electrical conductor, hence useful in such applications as arc lamp electrodes. It can conduct electricity due to the vast electron delocalization within the carbon layers (a phenomenon called aromaticity). These valence electrons are free to move, so are able to conduct electricity. However, the electricity is primarily conducted within the plane of the layers. The conductive properties of powdered graphite allow its use as pressure sensor in carbon microphones.

Noteworthy

The logic of this is that a piece of graphite ought only to conduct electricity in 2-dimensions because electrons can only move around in the sheets - and not from one sheet to its neighbours.

In practice, a real piece of graphite isn't a perfect crystal, but a host of small crystals stuck together at all sorts of angles. Electrons will be able to find a route through the large piece of graphite in all directions by moving from one small crystal to the next.

A crystal or crystalline solid is a solid material whose constituents (such as atoms, molecules, or ions) are arranged in a highly ordered microscopic structure, forming a crystal lattice that extends in all directions. In addition, macroscopic single crystals are usually identifiable by their geometrical shape, consisting of flat faces with specific, characteristic orientations. The scientific study of crystals and crystal formation is known as crystallography. The process of crystal formation via mechanisms of crystal growth is called crystallization or solidification.

The word crystal derives from the Ancient Greek word (krustallos), meaning both "ice" and "rock crystal", from (kruos), "icy cold, frost".

Examples of large crystals include snowflakes, diamonds, and table salt. Most inorganic solids are not crystals but polycrystals, . many microscopic crystals fused together into a single solid. Examples of polycrystals include most metals, rocks, ceramics, and ice. A third category of solids is amorphous solids, where the atoms have no periodic structure whatsoever. Examples of amorphous solids include glass, wax, and many plastics.

Despite the name, lead crystal, crystal glass, and related products are not crystals, but rather types of glass, amorphous solids.

Crystals are often used in pseudoscientific practices such as crystal therapy, and, along with gemstones, are sometimes associated with spellwork in Wiccan beliefs and related religious movements.

Crystals differ in physical properties, ., in hardness, cleavage, optical properties, heat conductivity, and electrical conductivity. These properties are important since they sometimes determine the use to which the crystals are put in industry. For example, crystalline substances that have special electrical properties are much used in communications equipment. These include quartz and Rochelle salt, which supply voltage on the application of mechanical force (see piezoelectric effect), and germanium, silicon, galena, and silicon carbide, which carry current unequally in different crystallographic directions, as semiconductor rectifiers.

Graphene is a two-dimensional carbon allotrope. It is composed of carbon atoms positioned in a hexagonal design, which can be said to resemble a chicken wire.

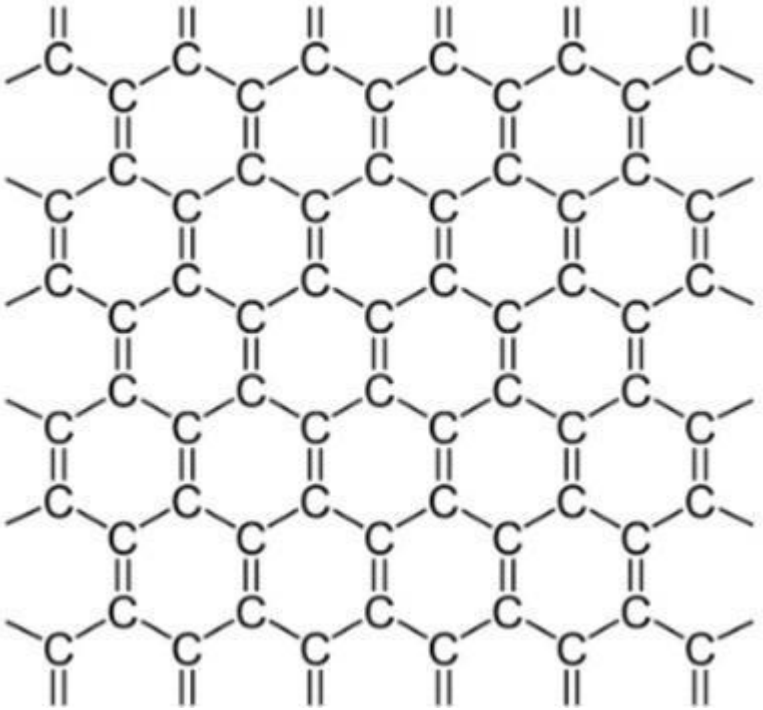

Fig.1.2. Graphene is a two-dimensional carbon allotrope. It is composed of carbon atoms positioned in a hexagonal design, which can be said to resemble a chicken wire.

A single layer of carbon atoms arranged in such a honeycomb structure forms a single graphene sheet. Several sheets stacked one on top of the other are regarded as multi-layer graphene, up to the point where the material becomes

graphite (usually over about 30 layers, although clear standardization is severely lacking at the moment). Graphite, a 3D crystal composed of weakly coupled graphene layers, is a relatively common material - used in pencil tips, batteries and more.

In graphene, each carbon atom is covalently bonded to three other carbon atoms. Thanks to the the strength of the covalent bonds between carbon atoms, graphene boasts great stability and a very high tensile strength (the force in which you can stretch something before it breaks). Since graphene is flat, every atom is on the surface and is accessible from both sides, so there is more interaction with surrounding molecules. Also, the carbon atoms are bonded to only three other atoms, although they have the capability to bond to a fourth atom. This capability, combined with the aforementioned tensile strength and high surface area to volume ratio of graphene may make it appealing for use in composite materials. Graphene also enjoys electron mobility that is higher than any known material and researchers are developing methods to use this property in electronics.

Using graphene, it should someday be possible to make transistors and other electronic devices that are much thinner than devices made of traditional materials, and this is only one example of graphene's potential in the electronics field. Since graphene is electrically conductive, transparent, strong, and flexible, it may also be an attractive material for use in touch screens. Graphene also has very high thermal conductivity and so, could be used to dissipate heat from electronic circuits.

Graphene can be a parent form for many carbon structures (fig. 1.3), like the above-mentioned graphite, carbon nanotubes (which can been viewed as rolled-up sheets of graphene formed into tubes) and buckyballs (spherical structures with a cage-like structure made from graphene only with some hexagonal rings replaced by pentagonal rings).

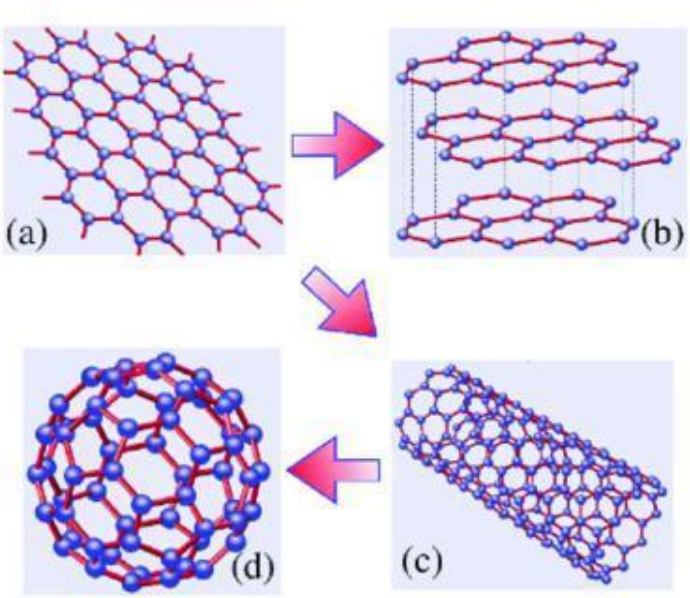

Fig. 1.3. Graphine Structure

Graphene is one of the first and most famous examples of a 2D crystal. Two-dimensional materials and systems are fundamentally different from three-dimensional ones in many ways. Graphene can be used as a model system for studying two-dimensional physics and chemistry in general, and so has been attracting much academic interest since its isolation in 2004. It is also considered to have tremendous potential for a myriad of applications, like next-gen batteries, sensors, solar cells and more - thanks to a wide array of properties, some of which have been already mentioned in this article, like excellent electrical and thermal conductivity, mechanical strength, unique optical properties and more.

Carbon Allotropes and Related Materials

Carbon was one of the first elements known to humans, and is one of the most remarkable of all chemical elements. The use of carbon materials for a multitude of applications derives from the materials' unique diversity of structures and properties that extend from chemical bonding between carbon atoms to nanostructures, crystallite alignment, and microstructures. Diamond and graphite are both three-dimensional (3D) crystalline forms of the element carbon. Graphite consists purely of sp^2 hybridized bonds, whereas diamond consists purely

of sp^3 hybridized bonds. The carbon atoms in diamond are arranged in a lattice, which is a variation of the face-centered cubic (fcc) crystal structure . It has superlative physical qualities, most of which originate from the strong covalent bonding between its atoms (sp^3 hybridization). Unlike diamond, graphite in particular is described as consisting of a lamellar (layered, planar) structure . In each layer, the carbon atoms are arranged in a hexagonal lattice with separation of 0.142 nm (sp^2 hybridization), and the distance between planes (layers) is 0.335 nm. The two known forms of graphite, α (hexagonal) and β (rhombohedral), have very similar physical properties. The lamellar structures have much stronger forces within the lateral planes than between the planes.

Graphitic carbon nanomaterials can be regarded as members of the same group because they consist primarily of sp^2 carbon atoms arranged in a hexagonal network. This common structure means that they all have some common properties, although they also have significant differences due to their different sizes and shapes. Graphene is the basic structural element of other allotropes, including graphite, fullerene (e.g., C_{60}) , carbon nanotube (CNT) , graphyne , and other related materials (e.g., carbon fiber (CF), amorphous carbon (AC), charcoal (fig. 1.4). It can also be considered as an indefinitely large aromatic molecule, the limiting case of the family of flat polycyclic aromatic hydrocarbons.

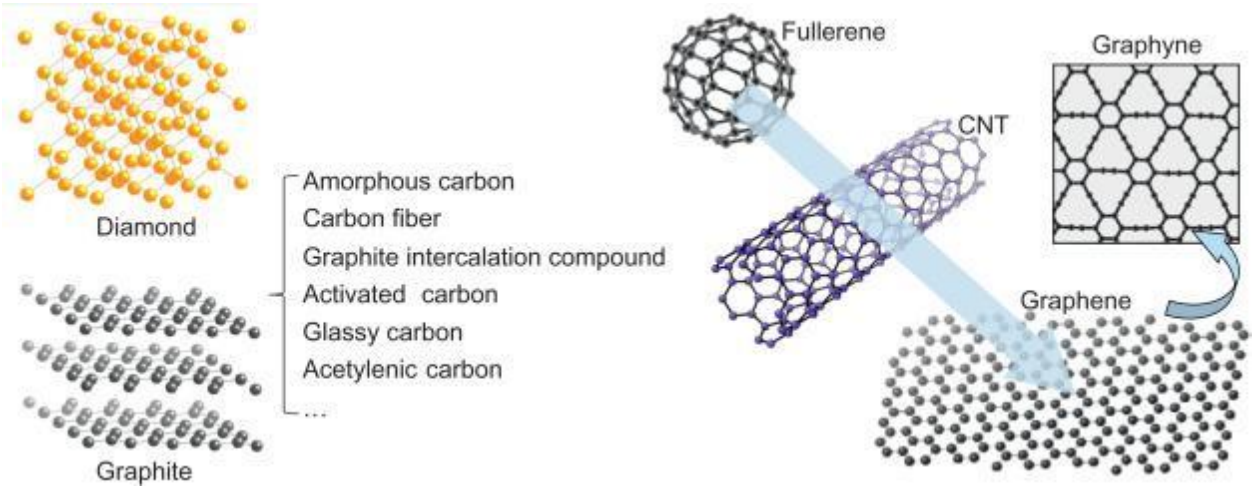

Fig. 1.4. Carbon allotropes and related materials. CNT, carbon nanotube

Fullerenes (also called buckyballs) are molecules of varying sizes composed entirely of carbon that take on the form of hollow spheres or ellipsoids. Fullerenes were the subject of intense research in the 1990s, both because of their unique chemistry and for their technological applications, especially in materials science, electronics, and nanotechnology.

A CNT is considered as a cylinder formed by rolling up a graphene sheet with caps which are similar to parts of the fullerenes, and exhibits extraordinary strength and unique electrical properties and is an efficient conductor of heat. Diameters of single-walled carbon nanotubes (SWNTs) and multiwalled carbon nanotubes (MWNTs) are typically 0.8^{-2} nm and 5^{-20} nm, respectively, although MWNT diameters can exceed 100 nm. Individual CNT walls can be metallic or semiconducting depending on the orientation of the lattice with respect to the tube axis, which is called chirality.

CFs are a long, thin strand of materials about 5^{-10} μm in diameter, and composed mostly of carbon atoms that are bonded together in microscopic crystals aligned parallel to the long axis of the fiber . The crystal alignment makes the fiber incredibly strong for its size. Several thousand CFs are twisted together to form a yarn, which may be used by itself or woven into a fabric. The yarn or fabric is combined with epoxy and wound or molded into shape to form various composite materials. CFs-reinforced composite materials are used in many areas, including spacecraft parts, racing car bodies, golf club shafts, bicycle frames, fishing rods, automobile springs, sailboat masts, and other components where light weight and high strength are needed.

Graphite intercalation compounds (GICs) are complex materials having a formula CX_m where the ion X^{n+} or X^{n-} is inserted (intercalated) between the oppositely charged carbon layers. Typically m is much less than 1. These materials are deeply colored solids that exhibit a range of electrical and redox properties of potential applications. Expanded graphite (EG) is made by immersing natural flake graphite in a bath of chromic acid, then concentrated sulfuric acid, which forces the crystal lattice planes apart, thus expanding the graphite.

AC refers to carbon that does not have a crystalline structure. The properties of AC depend on the ratio of sp^2 to sp^3 hybridized bonds present in the material. Materials that are high in sp^3 hybridized bonds are referred to as tetrahedral AC (owing to the tetrahedral shape formed by sp^3 hybridized bonds), or diamond-like carbon (owing to the similarity of many of its physical properties to those of diamond). AC materials may be stabilized by terminating dangling-π bonds with hydrogen. Activated carbon, also called activated charcoal (usually derived from charcoal), is a form of carbon processed to have small, low-volume pores that increase the surface area available for adsorption or chemical reactions.

Graphyne is a one-atom-thick planar sheet of sp- and sp^2-bonded carbon atoms arranged in a crystal lattice . It can be seen as a lattice of benzene rings connected by acetylene bonds. Graphyne has been a theorized allotrope of carbon for a long time and attracted great attention after the discovery of graphene.

Other carbon-based materials include glassy (or vitreous) carbon, a class of carbon widely used as an electrode material in electrochemistry as well as in prosthetic devices and high-temperature crucibles; pure atomic and diatomic carbon; and linear acetylenic carbon, a one-dimensional carbon polymer with the structure $_(C{=}C)_n$.

Graphene possesses many outstanding properties in terms of optical transparency, electric conductivity, mechanical strength, and thermal conductivity.

Graphene is a super light material with a planar density of 0.77 mg/m^2. As shown in Fig , the unit structure of graphene is a hexagonal carbon ring with an area of 0.052 nm^2. Such a ring only consists of two carbon atoms since each atom at vertex is shared by three unit rings. Graphene only consists of one atomic layer of carbon atoms which also contributes to its advantages of being superthin and ultralight.

Benefiting from one atomic thickness, graphene has a very high transparency of 97.7% , it only absorbs 2.3% of visible light . As shown in Fig., the difference in transparency between a substrate and single layer graphene as well as a single layer and bilayer graphene are both 2.3%. Because of this, the transparency of

graphene becomes an effective indication of the numbers of graphene layer, which is confirmed by simulations using noninteracting.

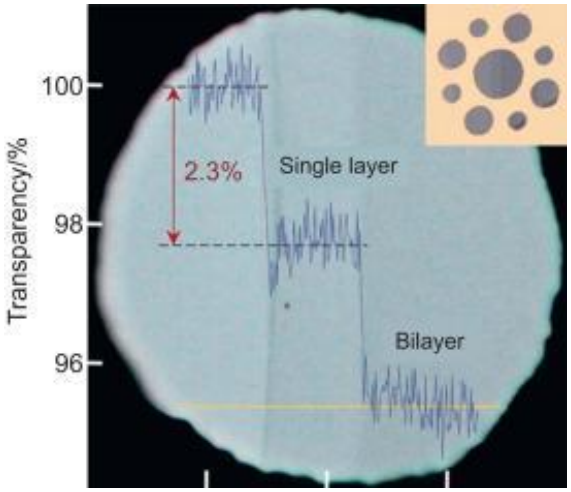

Fig. 1.5. Transparency of graphene.

1.1.2. Electrical and thermal properties of graphene thin films

Graphene thin films formed from interlocking and overlapping platelets of graphene or GO have electrical, optical, and thermal properties that diverge from those of single-layer graphene. A single layer of graphene has optical transparency of approximately 98%, which decreases as the number of layers increases. The electrical conductivity of few-layer graphene is typically lower than a multilayer, providing a trade-off of increased conductivity for lower transparency. Multilayer graphene laminates, therefore, have lower optical transparency compared to single-layer graphene, but can have much lower resistivity approaching 100–1000 Ω/square.

Graphene and graphene-based thin films, however, are superior to ITO for thermal management applications since the thermal conductivity of ITO is relatively low (5.9 W $m^{-1} K^{-1}$) compared to graphene laminate films (~10^2 W $m^{-1} K^{-1}$) . Interestingly, the excellent thermal properties of single-layer graphene are also retained to a large extent in thin graphite multilayers and graphene laminate films. In ITO, the thermal properties at room temperature conditions are determined primarily by the electronic band structure. By contrast, thermal

characteristics in graphene-based materials require a more complex interpretation due to important effects from lattice vibrations. The thermal and electrical conductivity of graphene-based thin films strongly depend on the average number of graphene layers forming the platelets, their lateral size, and density of the flakes including voids between neighboring domains.

Electrical conductivity of graphene-based films is greatly affected by both the preparation method and the post-treatments. Graphene-based films produced using RNA as a surfactant reveal a trend of decreasing sheet resistance with annealing temperature from Sharifi et al. shown in fig 1.6. The decrease in sheet resistance as a function of the annealing temperature demonstrates that annealing is effective in improving the conductivity of RNA-surfactant-based films without altering transparency. RNA is insulating and tends to decompose above room temperature; the amount of RNA aggregates intercalating the graphene flakes decreases dramatically upon annealing at high temperature (510 °C), leading to better conduction between flakes and improved overall conductivity. The effect of thermal annealing is compared to functionalization where the sheet resistance decreased after initial exposure to a nitric acid (HNO_3) bath, followed by a further decrease after soaking in thionyl chloride ($SOCl_2$) without a decrease in transparency. This combination of treatments leads to thin films with sheet resistance of 200 Ω/square at 50% transmittance, or 2.3 MΩ/square at 85% transmittance. Although this performance is inferior to graphene materials epitaxially grown on copper, it is comparable to other classes of graphene-based thin films such as SDBS-based graphene dispersions.

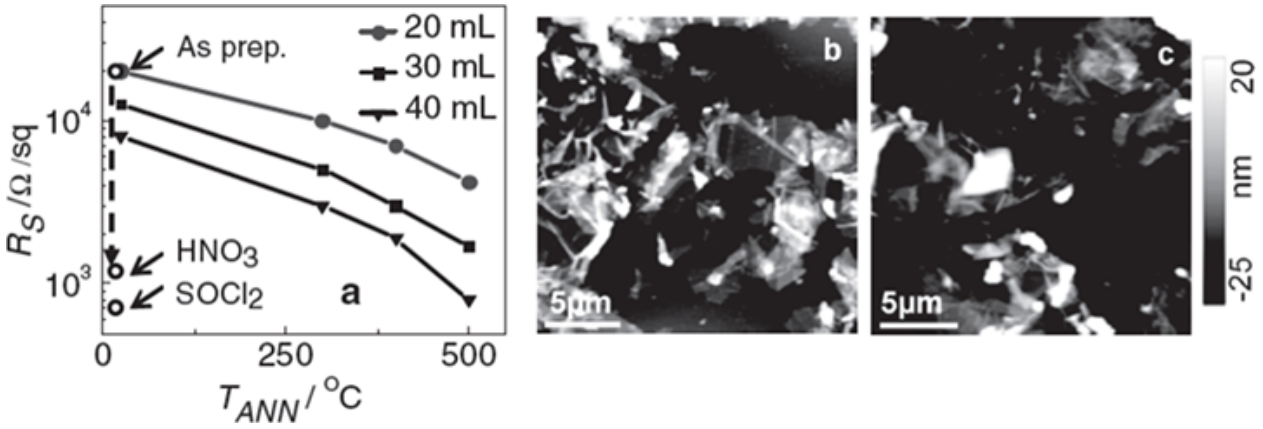

Fig. 1.6. (a) Sheet resistance as a function of annealing temperature for graphene-RNA VI films at different filtration volumes. (b) AFM image before annealing. (c) AFM image of the same sample after annealing.

1.1.3. Optical properties of thin films graphite

Optical properties are the most direct and the simplest way to obtain information on the energy gap of semiconductors. These properties are useful in determining energy band structures as well as design and analysis of opto-electric devices . The energy gap in semiconductors can be modified by the effects of temperature as well as the magnetic field. However, the temperature dependence of energy gap is a basic property of semiconductor materials and the knowledge on such dependence is of great importance for applications in opto-electric devices .

Carbon can exist in a number of allotropic forms including diamond, graphite, graphene, fullerenes, and carbon nanotubes (CNT) that also have a great deal of variability. The carbonaceous materials are recently attracting ever growing attention of the research community due to their strong potential in electronics, optics, medicine, etc. However, among planar carbon materials with sp^2 hybridization of electron orbitals, the researchers were mainly focused on highly ordered pyrolytic graphite (HOPG) and graphene. HOPG is a highly ordered synthetic bulk material, which is characterized by strong anisotropy of optical, electronic, and elastic properties . Graphene is a two-dimensional carbon material comprising a one-atom thick layer of graphite. Optical and electronic properties of graphene are determined by zero bandgap and linear dependence of the electron energy on momentum in the vicinity of K-point of Brillouin zone. This in particular results in the nearly featureless visible absorption spectrum of graphene, which absorbs 2.3 % of incident radiation in the wavelength region of 350– 800 nm.

Much less attention was paid to the electronic and optical properties of nanometrically thick pyrolytic carbon (PyC) films consisting of disordered and intertwined graphene flakes with the linear size of several nanometers. Biocompatibility, durability, wear resistance, and robustness make this carbon

material attractive for bio- and medical applications. However, the optical and electronic properties of these films may be influenced by the synthesis conditions . That is why a comparative study of the graphene-based materials with short-range (e.g., PyC) and long-range (e.g., graphene) crystalline ordering may provide deeper insight on the synthesis and physical mechanisms responsible for the properties of carbon materials with dominating sp^2 hybridization of electron orbitals. Such a study should include a detailed analysis of the strong absorption band near 240–300 nm (Fig. 1.7), which originates from the π–π∗ electron transition and is observed in single- and multilayer graphene, carbon nanotubes, and HOPG.

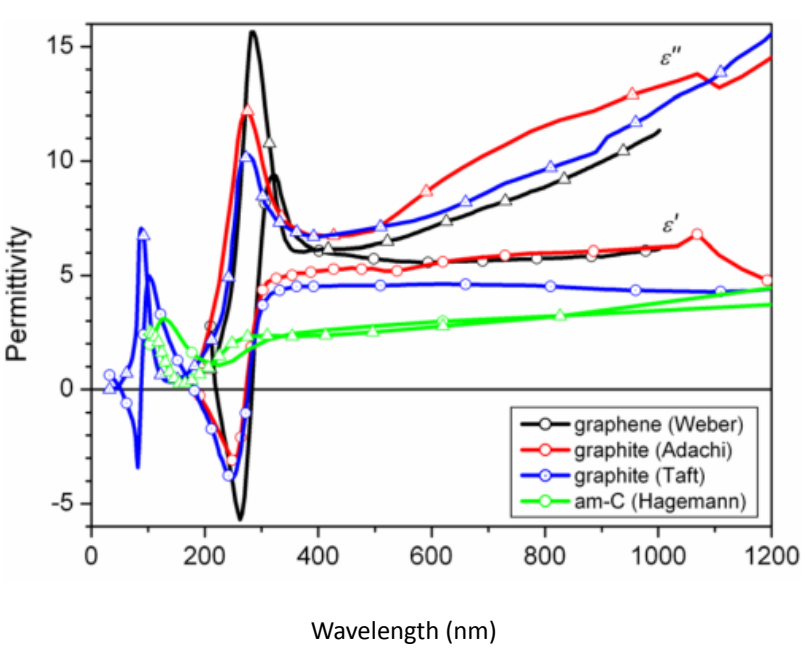

Fig. 1.7. Real (circles) and imaginary (triangles) parts of complex dielectric permittivity of graphite and graphene according to and amorphous carbon.

This band is of special interest because of recent results on the application of carbon films for surface-enhanced Raman scattering (SERS), surface-enhanced infrared absorption (SEIRA), and surface-enhanced coherent anti-stokes Raman spectroscopy (CARS). It was surprising that PyC and HOPG substrates do not provide enhancement in SERS, while a single-walled CNT substrate does. At the same time, graphene and CNT substrates provide a strong enhancement for

surface-enhanced CARS. These experimental findings are still not fully understood and require a comprehensive and comparative analysis of optical and electronic properties of these sp^2 materials. In this paper, we compare optical properties of ultrathin PyC films, few graphene layer thick films, and HOPG. The paper is organized as follows. Experimental details and samples fabrication methods are discussed in the “Methods” section. The “Results and Discussion” section describes experimental data and results of comparative analysis of dielectric properties along with the modeling of PyC film optical properties. The conclusions are outlined in the “Conclusions” section.

The optical properties of pyrolytic carbonb films in the visible spectral range have been studied with reflectance/transmittance spectroscopy. We have shown that dielectric permittivity of the PyC films deposited on silica substrate are quite similar to those obtained for graphite and graphene. Thus, the real part of PyC permittivity, is positive, and the ratio of the real and imaginary part of dielectric permittivity for PyC in the visible spectral range is less than 1, being a condition of absence of electromagnetic enhancement in SERS for molecules absorbed on PyC films exited by visible light. We demonstrate that the Lorentz-Drude model describes well the general features of the optical properties of PyC from 360 to 1100 nm. However, atomic force and transmission electron microscopy investigations have shown that films possess a granular morphology and rough surface that should be taken into account in future experiments

1.1.4. Physical properties of crystals GaP

The GaP sample used in this work was a 6.344 mm × 3.081 mm × 0.716 mm in dimension which cut from a wafer of 1 mm thick. The wafer was originally cut from a large single crystal having a diameter of about 5 cm. Since the optical properties of semiconductor materials vary with the wave length, measurements

are usually made with a different monochromatic radiation. For this case, a monochromator type was used to obtain radiation spectrum produced by a 1000 W tungsten lamp. The output beam from the monocromator was focused on the polished GaP sample through a light focusing unit. This unit which consisted of two convex lenses was used to steer the light beam on the sample through the first lens and collected the light to focus it on the detector through the second lens. The detection unit was a spectrometer type with a solid state detector. The detector produces an output signal with an amplitude proportional to the intensity of the light. For photoconductivity measurements in semiconductors, an Ohmic contact is needed. By the method of direct thermal evaporation, Au is used on n-type GaP single crystal whose the details are given in reference . The coating system type was used for evaporation. Photoconductivity measurements consist of varying wavelength (λ) of the incident monochromator light produced by the system mentioned earlier.

The corresponding values of the samples resistance (R) were measured by using the RCL meter type (FLUKE PM 6306). For the temperature dependence of measurements mentioned above, the sample was mounted on a low temperature optical cryostat . The optical cryostat was fixed between two poles of a home made d-c electromagnet, which was capable to produce a stable magnetic field up to 2.2 Tesla. The sample temperature was controlled by using an electric heater made from 0.4 mm diameter copper wire. The temperature was measured by using a copper-constantan thermocouple. The sample thickness was measured using optical interference technique in an air wedge method. Details for these measuring systems are given in reference.

If the incident light intensity, which is coupled into the sample, is denoted by Io, then the transmitted intensity I that leaves a sample of thickness d is given by:

$$I = I_0 \frac{(1-R^2)exp(-ad)}{1-R^2 exp(-2ad)}$$

where R is the reflectivity and α is the absorption coefficient which is defined as the attenuation of the incident light per unit length of the path traversed in the sample. Near the absorption edge:

$$I - R^2 exp(-2ad) \approx 1$$

that is, R^2 exp(-2αd) is much less than unity. Equ. 1 can now be reduced to:

$$I = I_0 \left(1 - R^2\right) \exp exp\,(-ad)\,,$$

which is valid near the absorption edge for normal incidence, and providing that R is very low for a high quality polished surface sample, Equ. 3 can be rewritten as :

$$I = I_0 \exp exp\,(-ad)\,,$$

from which α can be deduced as:

$$\propto = \left(\frac{1}{d}\right) In\left(\frac{I}{I_0}\right),$$

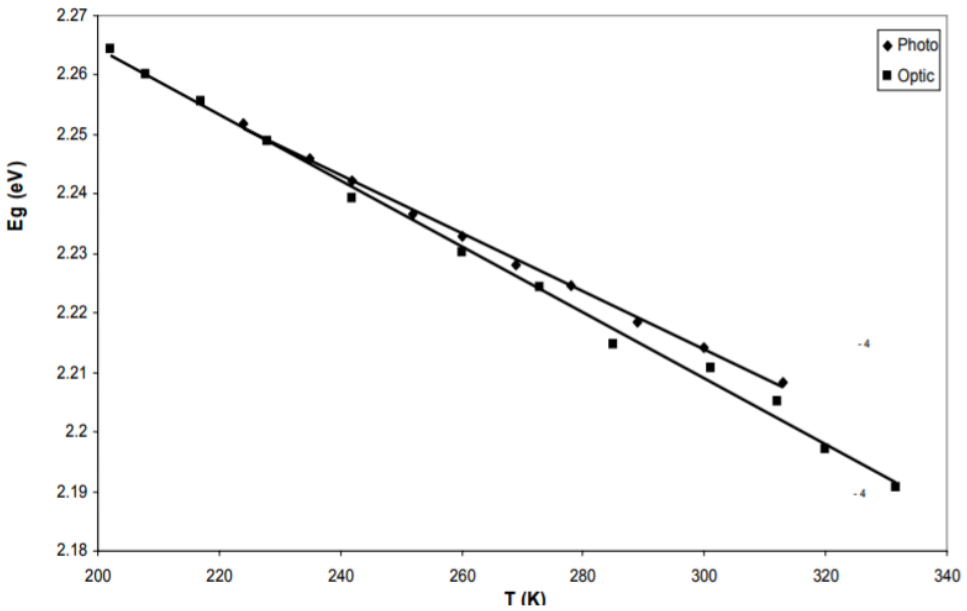

Fig 1.8. Temperature dependence of the energy gap from optical measurements.

The variation of the absorption coefficient α with photon energy hν for indirect band to band allowed transition is of the from

$$\propto (hn) = A(hn - Eg)^2$$

where A is an energy independent constant. The optical energy gap Eg was obtained by extrapolating the straight line portion of the $[\alpha(h\nu)]^{1/2}$ drawn versus hν curve to a zero absorption. This process was repeated for temperatures from 202 K to 332 K. The obtained values of E_g were plotted versus their corresponding temperatures as shown in Figure 1.8. The least square best fit to this curve gives the temperature dependence of E_g as $Eg = -5,48\times10^{-4}T + 2.375eV$

This dependence is in good agreement with those results reported by others for the same above temperature range. The magnetic field effect on the energy gap was also investigated through measuring its effect on the optical absorption process mentioned above. The shift of the energy gap due to the effects of magnetic field $(\Delta E_g)_B$ for all investigated temperatures is shown in Figure 1.9. From this figure the change of energy gap by the magnetic field $(\Delta E_g)_B$ as a function of temperature is obtained.

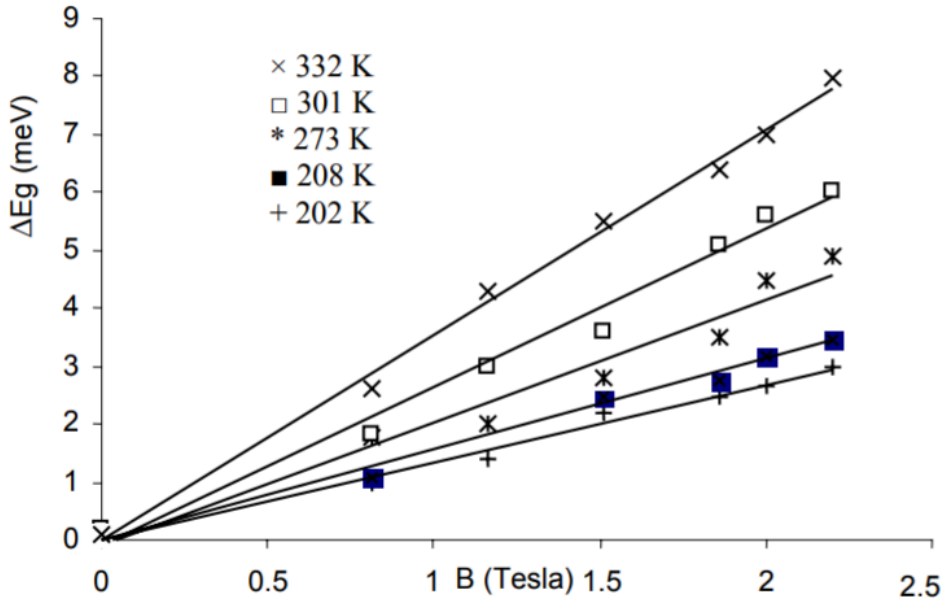

Fig 1.9. Energy gap shift (ΔE_g) versus magnetic field (B) for various Temperature.

Figure 1.10 indicates that, the effect of applied magnetic field on energy gap in GaP is more sensitive at the higher temperatures than at lower ones. The effect may be due to the reduction of ionization impurity scattering mechanism, since impurity activation energy levels inside the band gap is inversely proportional to the temperature and that consequently increase the effects of the magnetic field on the energy gap.

The reduced effective mass M_r^* of carriers in semiconductors was calculated by using the relation.

$$\Delta = \frac{ehB}{2m_r^*}$$

The temperature dependence of calculated values of m_r^* is shown in Figure 4. There are two expected reasons for this dependence: first, the existence of ionized impurity states below the conduction band vales (n-type) of semiconductor materials.

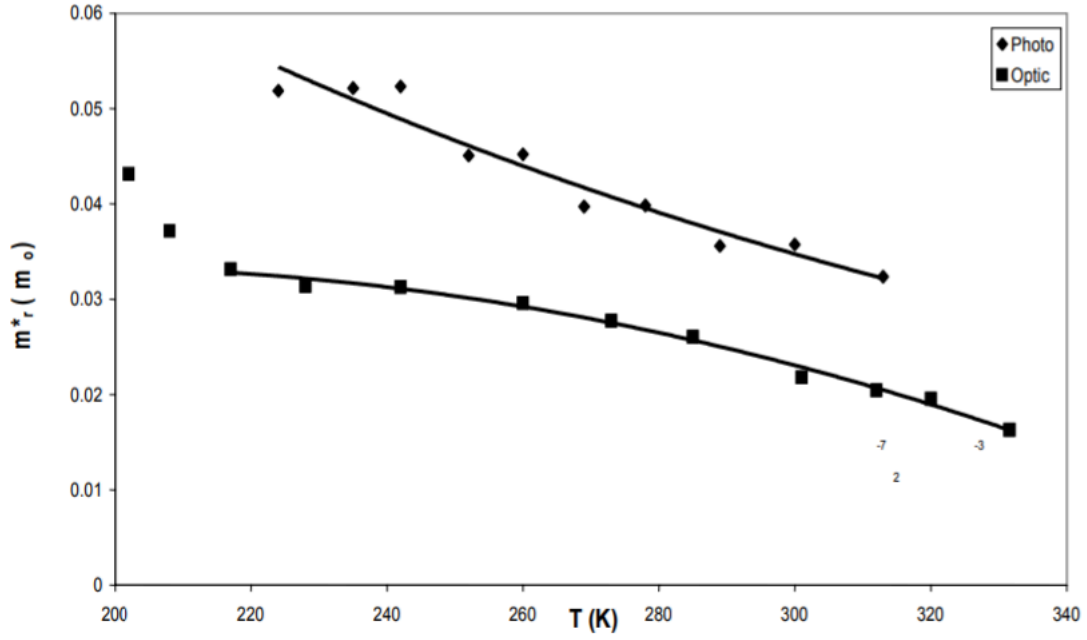

Fig 1.10. Temperature dependence of the average reduced effective mass measured from both optical absorption and photoconductivity

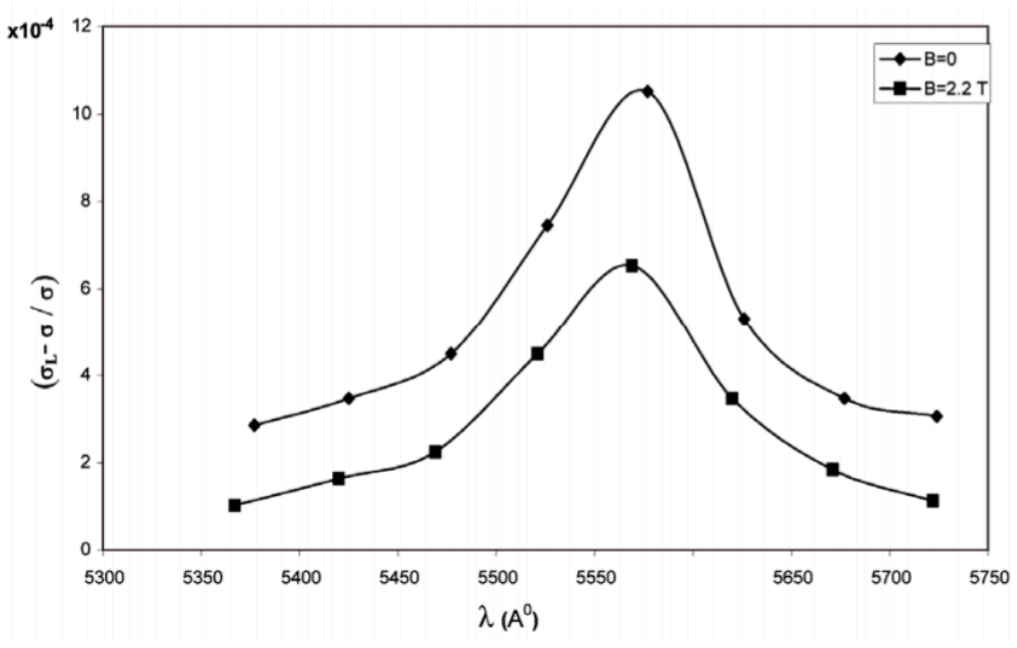

Fig 1.11. Variation of photosensitivity and magnetophotosensitivity with the wavelength at 278 K

These types of carriers will cause an ionized impurity scattering mechanism for the transition of electrons between the two energy bands. By increasing temperature such impurities will excite to conduction band states, leaving ionized state levels empty, then less electron scattering would be expected and that consequently gives smaller reduced effective masses . The second expected reason is the temperature dependence of the conduction band structure valleys. The conduction band structure for GaP has an indirect energy transition at the point X , while its direct transition is at Γ . The temperature increase lowers the X -valley relative to that of Γ -valley. Since the electron-phonon scattering at X -valley has dominant contribution to the effective mass, the lowering of the X -valley as a result of temperature increase stimulates more impurity ionization, thereby reducing the carriers scattering. The latter effect leads to the smaller effective mass

1.2. Using of thin films graphite

Thin graphite films attract significant interest due to their unique physical properties and potential applications. Chemical vapor deposition in the presence of metal catalysts is one of the most promising and widely used techniques to produce these films. There are many experimental works devoted to the material synthesis; however, the results are usually obtained by the trial-and-error method without a proper understanding of the processes behind the experiment. We theoretically analyze the carbon diffusion processes inside a metal substrate during the deposition. The theory allows interconnection of the deposition parameters with the thickness of produced graphite films. Numerically solving the diffusion equations for the real systems, we obtained a good correlation between simulations and experimental data. Based on our simulations, we made some conclusions about the formation of graphite films by the precipitation process. The numerical simulations were mostly done for the popular nickel substrates, but we also made some calculations for iron, showing that it also could be used to form thin graphite films under certain conditions.

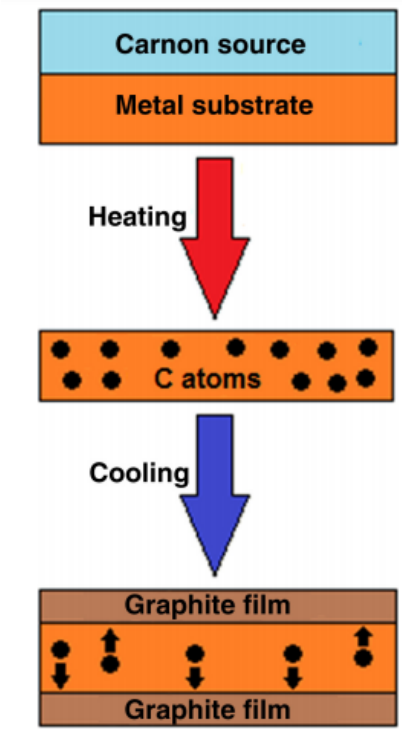

Fig. 1.12. The graphite film formation by precipitation

Some metals (including Ni) have significant carbon solubility at elevated temperatures, making it possible to form graphite films by the precipitation mechanism. The scheme of this process is given in Fig. 1.12. In the first step, the metal substrate is heated in the presence of a carbon source [it could be either a carbon-containing gas like methane or a solid carbon-containing material like the Poly (methyl methacrylate) film]. Carbon atoms dissolve in a substrate at high temperature, and the longer we keep the system heated, the more atoms can diffuse into the depth of the metal. In the second step, the system is cooled down, the carbon solubility drops, and carbon atoms start to diffuse to the surfaces, where they go out from the metal and form a graphite film. In the present study, we build a theoretical model describing the precipitation process. The solution of diffusion equations allows us to determine the thickness of a graphite film formed in a process with known parameters. The comparison between theoretical predictions and the real experimental data shows the good agreement between the results. In addition, we discuss some important aspects of the precipitation mechanism.

These applications could be found., in medicine, ultra-fast electronics, energy harvesting , and telecommunications.

CHAPTER 2. Experimental part

2.1. Electron-beam evaporation

E-beam (electron beam) evaporation is a thermal evaporation process, and, along with with sputtering, is one of the two most common types of physical vapor deposition (PVD). E-beam evaporation provides for the direct transfer of a larger amount of energy into the source material, enabling the evaporation of metal and dielectric materials with very high melting temperatures, such as gold and silicon dioxide, respectively. Therefore, it is possible to deposit materials that cannot be evaporated with standard resistive thermal evaporation. An additional benefit of e-beam evaporation is higher deposition rates than possible with either sputtering or resistive evaporation.

In e-beam evaporation, the evaporation material can be placed directly in a water-cooled copper hearth or into a crucible and heated by a focused electron beam. The heat from the electron beam vaporizes the material, which then deposits on the substrate to form the required thin film.

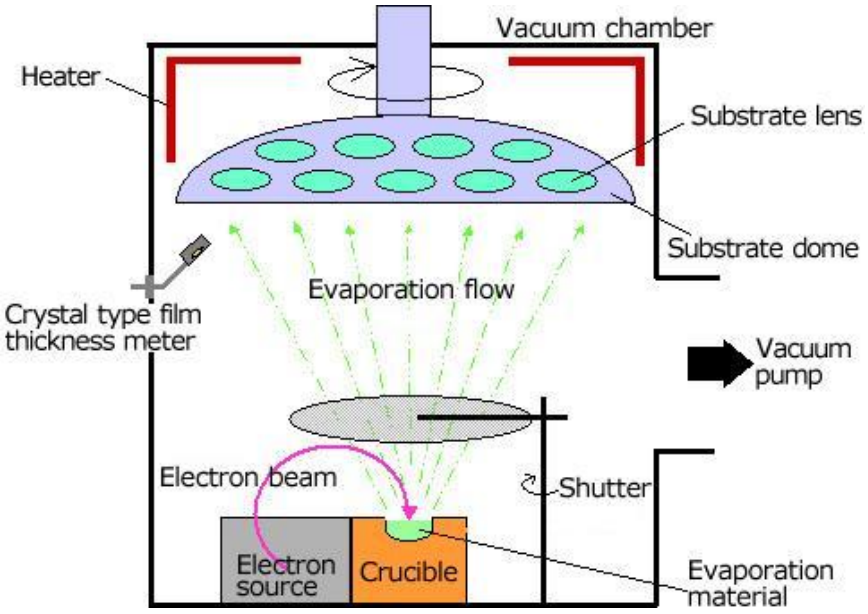

Fig. 2.1. The following figure shows an image of structure of an electron beam evaporation device.

In electron beam evaporation, the source material can be evaporated using high energy electrons in the form of an intense beam. A hot filament causes the thermionic emission of electrons, which can, after acceleration, provide sufficient energy for evaporating any material. In a typical case involving 1 A of emission accelerated through a 10 kV voltage drop, 10 kW is delivered upon impact. To avoid melting the filament in the arriving evaporant, the filament is located out of sight of the evaporant as shown in Fig. 2.1 and the electron beam is pulled around to the surface by a magnetic field, B, the point shows the direction in this figure. The combined force, F, on an electron in electric (E) and magnetic field is known as Lorentz force.

This device consists of two main sections (fig. 2.2): an electron source, which is housed in the vacuum evaporation device, and generates electrons, accelerates them as an electron beam, and deflects them; and a crucible (hearth) section that holds the evaporant material. The electron source is also called an E-source, EB-source, or E type electron gun.

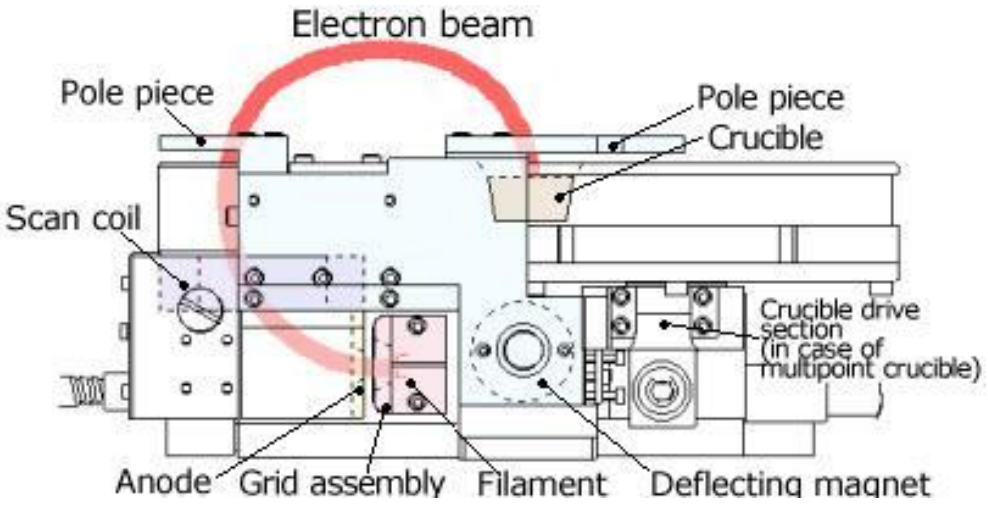

Fig. 2.2. Electron source structure

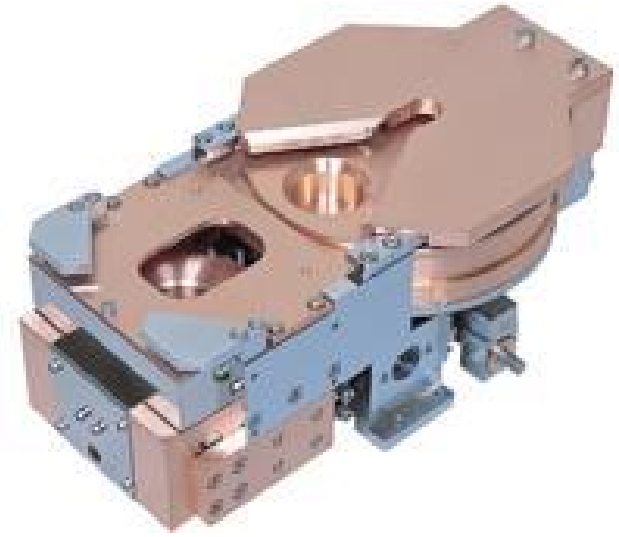

Fig. 2.3. Foto electron source

Electricity is applied to the filament to heat it, and induce the emission of thermal electrons.

As negative high voltage (normally -4 to -10kV) is applied to the filament, this accelerates the thermal electrons due to the voltage difference between anodes.

The ejected electrons are deflected by a magnetic field (permanent magnet or electromagnet) and irradiated onto the evaporant material in the crucible.

As necessary, electricity is supplied to the scan coil to scan the beam and make the irradiation area larger.

2.2. Fabrication of Graphite/n-GaP Schottky-type heterojunction

In this work we investigate the electrical properties of a new, not studied earlier, light emitting of graphite/n-GaP Schottky-type heterojunction, prepared by the deposition of transparent graphitic carbon thin films onto the single crystal substrate of gallium phosphide with the donor impurity concentration Nd = $3 \cdot 10^{14}$ $см^{-3}$ by the electron-beam evaporation of pure graphite target. GaP single crystals with n-type of conductivity, used for the fabrication of the light emitting of

graphitic carbon/n-GaP Schottky-type heterojunction. Gallium phosphide (GaP), a phosphide of gallium, is a compound semiconductor material with an indirect band gap of 2.24 eV at room temperature. Gallium phosphide has been used in the manufacture of low-cost red, orange, and green light-emitting diodes (LEDs).

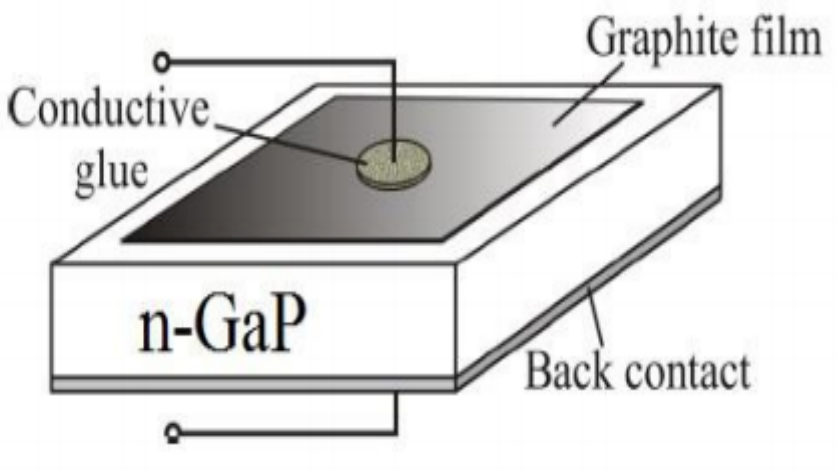

Fig. 2.4. The schematic representation of the graphite/n-GaP Schottky-type heterojunction

On figure showed the schematic representation of the graphite/n-GaP Schottky-type heterojunction. The fabrication of the light emitting of graphite/n-GaP Schottky-type heterojunction were carried out by the deposition of the graphitic carbon thin films onto the cleaved n-GaP substrates (area of the heterojunctions S = 0.2 cm^2) in a universal coating system Leybold–Heraeus L560 by the electron-beam evaporation of pure bulk polycrystalline graphite. The electron beam intensity, deposition rate and the films thickness were controlled by means of an INFICON XTC deposition controller. During the deposition process, the residual pressure in the vacuum chamber was equal to 5 × 10^{-5} mbar. The deposition process lasted for 90 s with the average deposition rate 0.27 nm/s (the resultant thickness of the films was about 25 nm) at the substrate temperature of 723 K. The electric contact to the graphite film was formed by the conductive glue. In the case of gallium phosphide, the ohmic contacts resulted from indium

baking (back contact). Current–voltage (I–V) characteristics were measured on the basis of a computer-controlled voltmeter, ammeter and power supply. The program for controlling all these units during the I-V characteristic measurement was created in the LabView software environment.

2.3. Methods of research of I –V characteristics of Graphite/n-GaP Schottky-type heterojunction

The volt-ampere study was based on a computer-controlled ammeter, voltmeter, and power supply. The program that controls all these blocks during the measurement of I – V characteristics was created using the LabView program.

In general, there are two possible electrical circuits for the study of I – V characteristics - with a common voltmeter (Figure 2.6 (a)) and with a common ammeter (Figure 2.5 (b)).

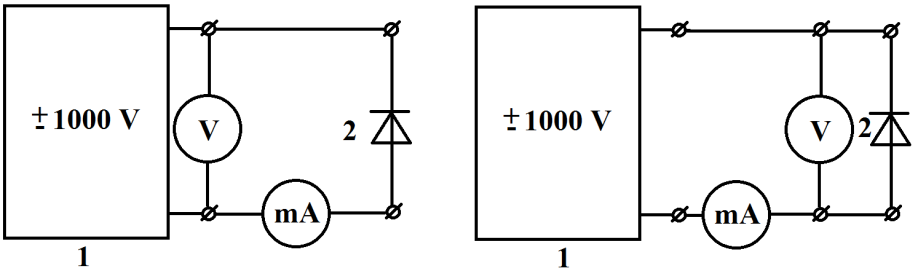

Fig. 2.5.Wiring diagrams of the sample for the study of I – V characteristics: a) - with a common voltmeter; b) - with a common ammeter; 1 - power supply; 2 - the studied heterostructure.

The choice of the study scheme, both for direct and reverse inclusion depends on the electrical resistance of the sample. The problem that arises when choosing a circuit is that the resistance of the ammeter is usually low and close to zero, but modern electronic ammeters are many ranges, but the resistance of the ammeter in the range of 1-10 A and above (not often used for I – V)) will be 10-100 mΟ, and for the ranges 1 ÷ 100 mA, the resistance is already 1-10 Om, in the case of 10^{-6} ÷ 10^{-9} and less, the resistance of the ammeter reaches 1 kΟm and will correspond to the input resistance of the amplifier. The next problem when choosing a circuit is that the resistance of the voltmeter at different ranges will

also range from 10-100 mм. From Figure 2.5 (a) the circuit with a common voltmeter excludes the voltmeter in the measured current, and with the common ammeter will accordingly exclude the voltage drop across the ammeter from the measured voltage. Taking into account these aspects when choosing and applying the scheme of I – V research it is necessary to proceed from the following provisions:

a) with a structure resistance of 10^4 ohms and above in the forward direction (fully open barrier) it is possible to use only a circuit with a common voltmeter, as a voltmeter that has only two orders of magnitude greater resistance can take a significant part of the current (percentage), and an ammeter that has 3-4 orders of magnitude less resistance has a voltage drop of less than 0.1% which can be neglected.

b) with a resistance of 10^2 Ohms and below in the forward direction, you can only use a circuit with a common ammeter, as a voltmeter with 4 orders of magnitude greater resistance, takes a fairly small current (about 0.01%) which can be neglected, and the ammeter which has 1 ÷ 2 orders of magnitude less resistance, will have a voltage drop of up to 10%, which is unacceptable.

c) in the intermediate case (resistance of the structure 10^2-10^4 Ohms) the situation will be more complicated. In this case, it is necessary to consider the resistance of the structure both in the forward (with an open barrier, the resistance will correspond to the series) and in the opposite direction (with a closed barrier, the resistance will correspond to the shunt) and find a compromise solution. During the R & D, depending on the studied structure, both inclusion schemes were used.

To automate the measurement process, as well as store data on a PC, all devices were connected to a computer using a USB bus. Devices were controlled using a program written in LabView. The block diagram of this program is shown in Figure 2.6.

The set of tools of the program allows:

1. Set the number of points to be investigated, and accordingly the step of voltage change when measuring the I – V characteristics;

2. Set the maximum current that can withstand the structure that protects it from damage;

3. Set the voltage of forward and reverse bias;

4. Allows you to select the mode of changing ranges or the range of current and voltage measurement, respectively, for an ammeter or voltmeter (automatic change of ranges is not recommended - the device can select the range at which there will be a significant contribution to measuring parameters and steps will appear on the I – V curve);

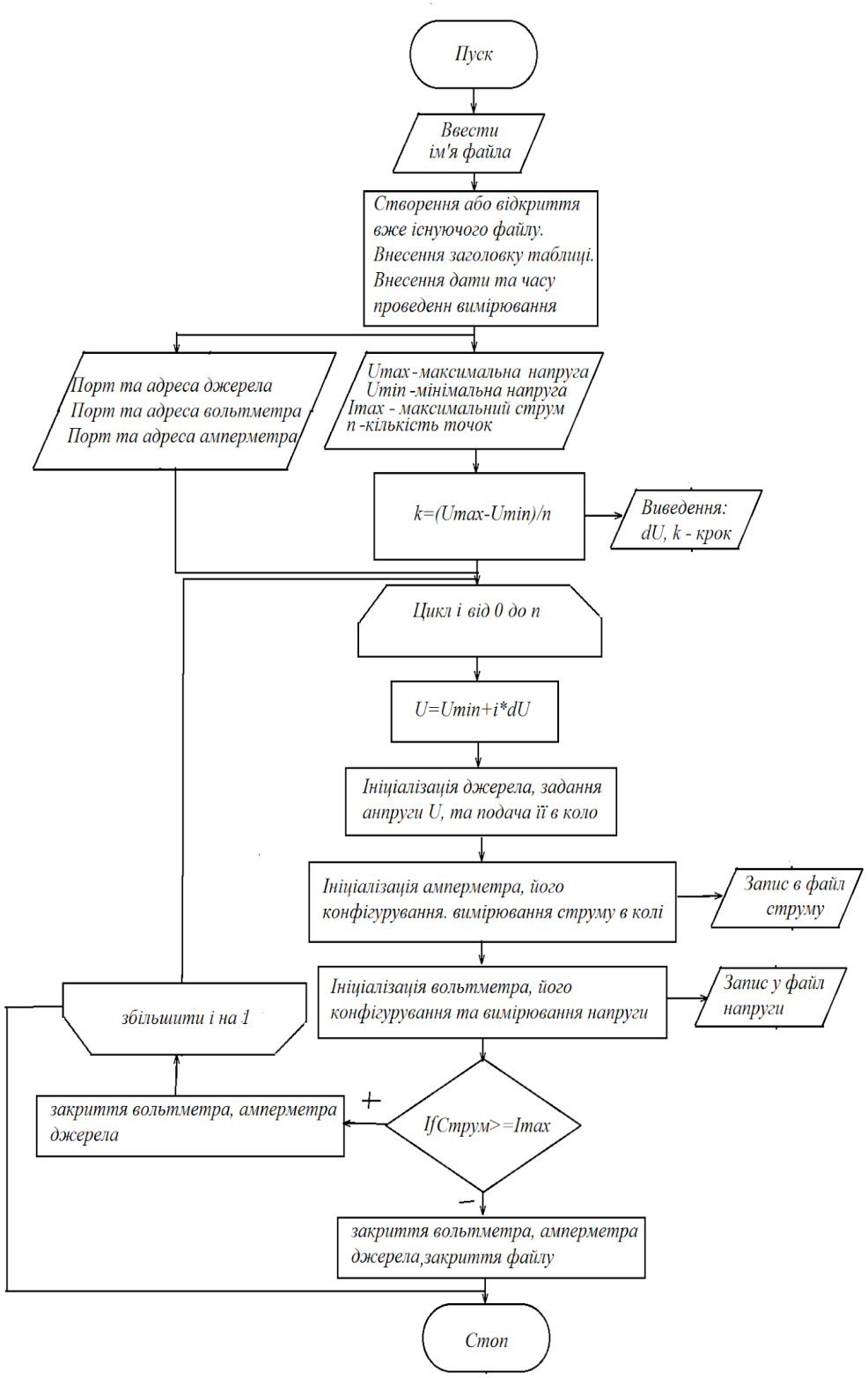

Fig. 2.6. Block diagram of the program

5. Before measurements, set the exposure time after switching (this is necessary for those structures that have long transients of current, such as structures with

traps for charge carriers - when changing the current traps can both provide additional charge carriers and take them, and this leads according to the change in current value);

6. Ability to save measurement results in a file that is suitable for data processing in programs such as MS Excel and Origin;

7. Displays all the results that were obtained after the measurements (Figure 2.7);

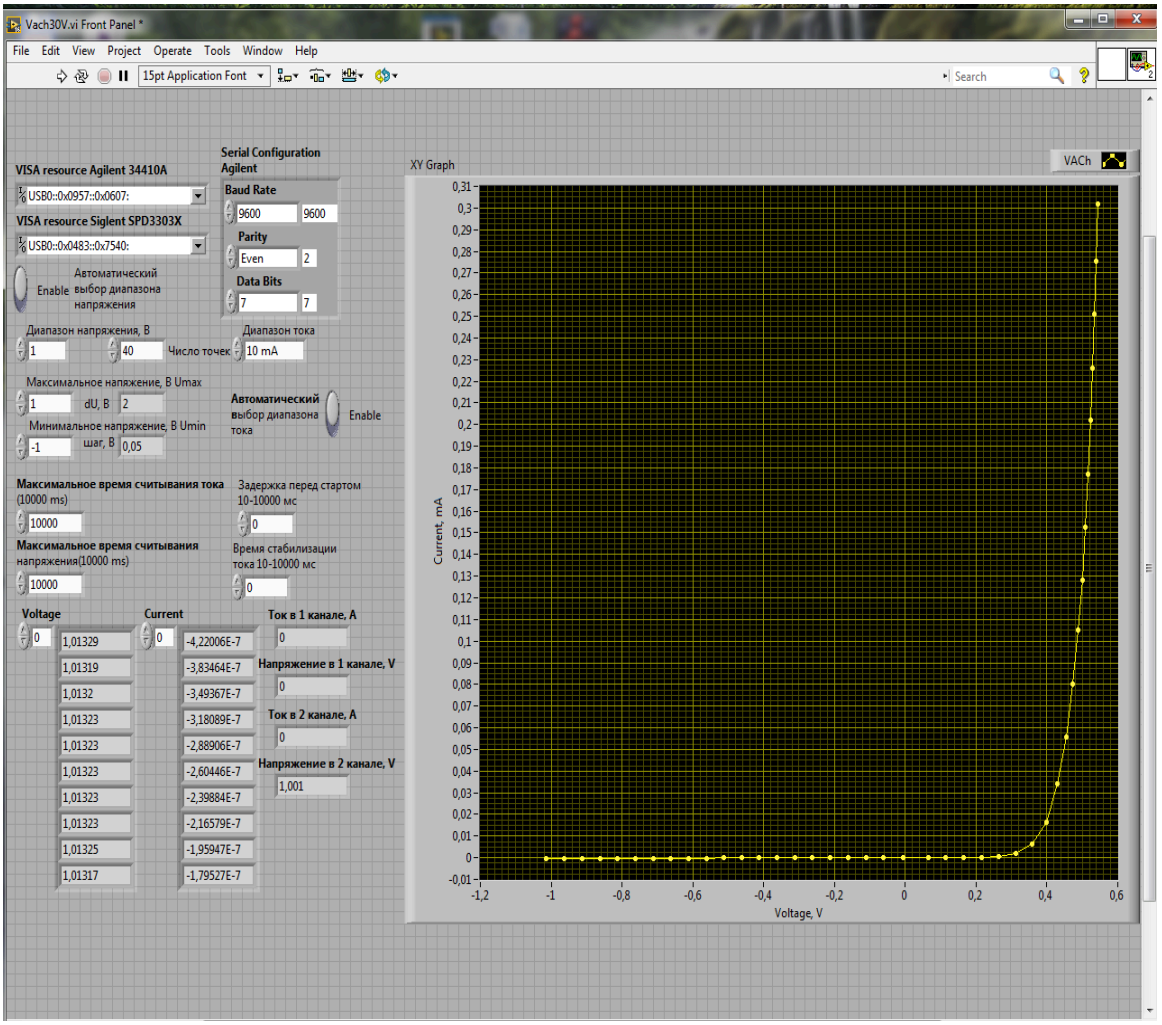

Fig. 2.7. Program window for I – V research

The measured values of voltage and current for each point (measurements of each parameter at the point are performed 10 times, after which the arithmetic mean is displayed, which is stored as the studied parameter, which allows to significantly reduce the error).

CHAPTER 3. Results and discussions

3.1. I –V characteristics of the Graphite/n-GaP Schottky-type heterojunction

3.1.1. Electrical properties of the Graphite/n-GaP Schottky-type heterojunction

In fig. 3.1 presents the volt-ampere characteristics of a Schottky Graphite / n-GaP type heterojunction measured at room temperature. By extrapolating the linear sections of the I – V characteristics to the intersection with the stress axis, the value of the height of the potential barrier for this structure, which is 1.69 eV, was determined.

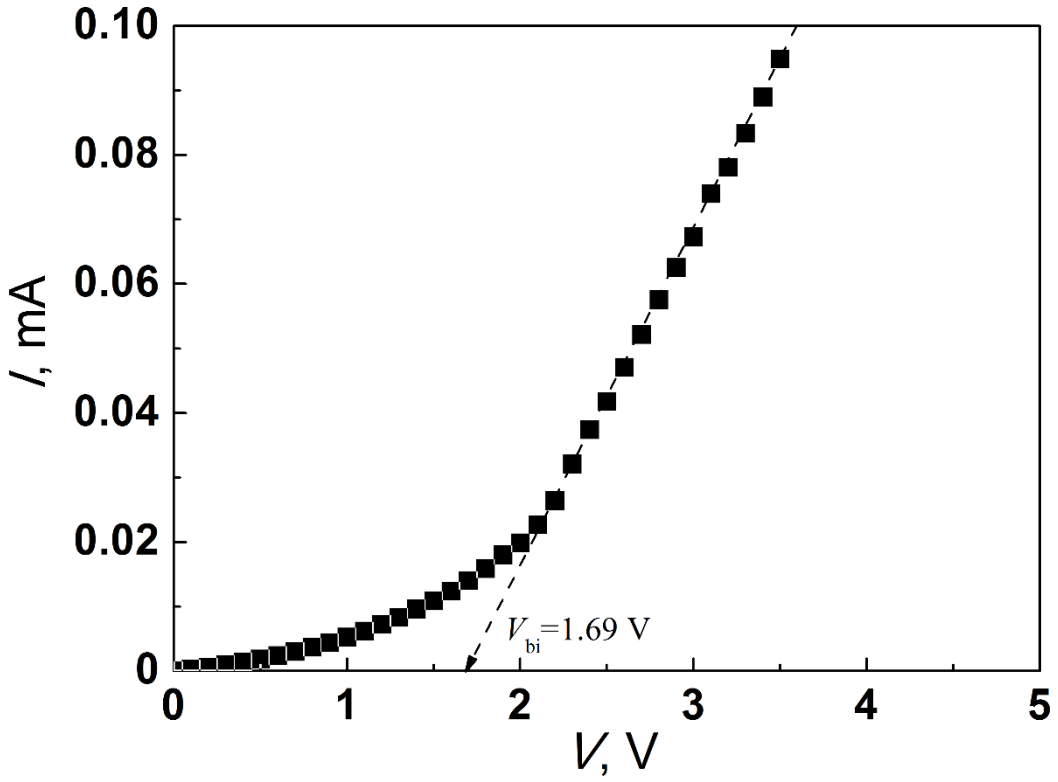

Fig. 3.1. Volt-ampere characteristics of a Schottky graphite / n-GaP type heterojunction

The value of the series resistance R_s of a Schottky-type graphite/n-GaP heterojunction can be determined from the dependence of its differential resistance R_{dif} on the voltage (Fig. 3.2).

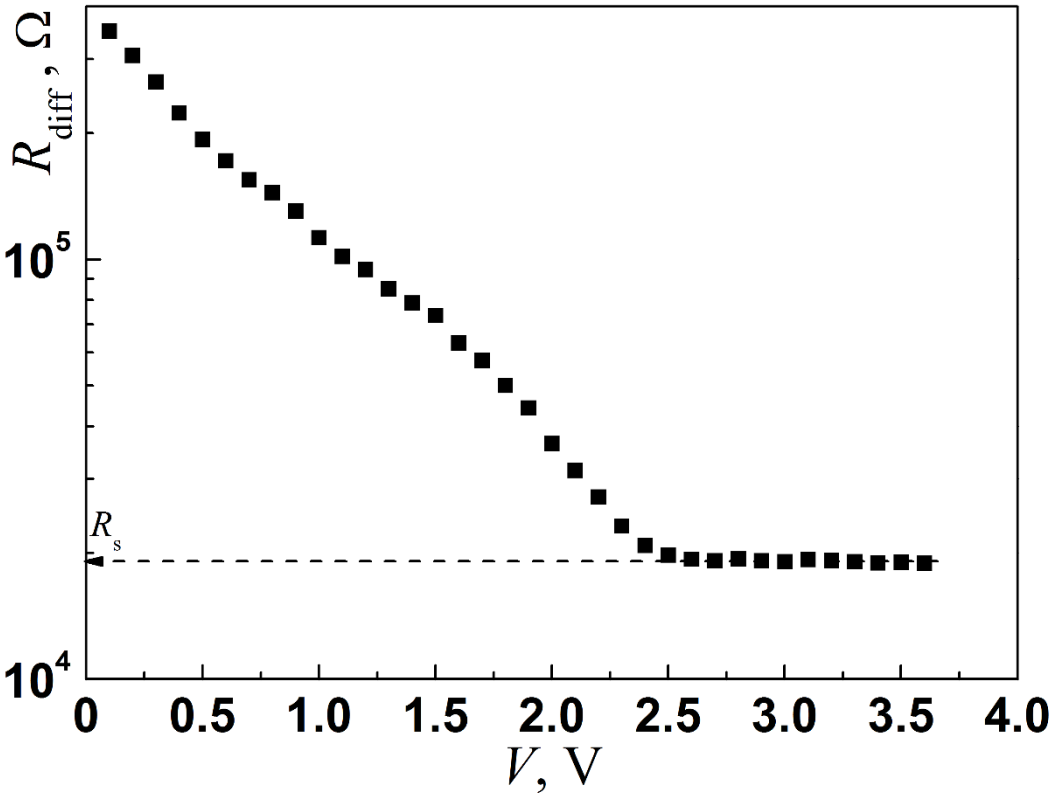

Fig. 3.2. Dependence of the differential resistance of a Schottky graphite / n-GaP type heterojunction

It is seen that the curves R_{dif} (V) reach saturation at direct displacement $V > V_{bi}$. This indicates that the voltage drop in the region of the spatial charge becomes constant, that is, the barrier of the Schottky-type graphite / n-GaP heterojunction opens and the current through the heterojunction is limited only by its series resistance. The value of the series resistance (R_s) can be easily determined by extrapolating the saturation region to the intersection with the axis of resistance.

3.1.2. Mechanisms of current transport at forward bias of the Graphite/n-GaP Schottky-type heterojunction

In fig. 3.3 presents the volt-ampere characteristics of a Schottky-type graphite / n-GaP heterojunction on a semi-logarithmic scale. As can be seen from the figure, in the region of direct displacements V> 3kT / e rectilinear sections are observed, which indicates the exponential dependence of current on voltage.

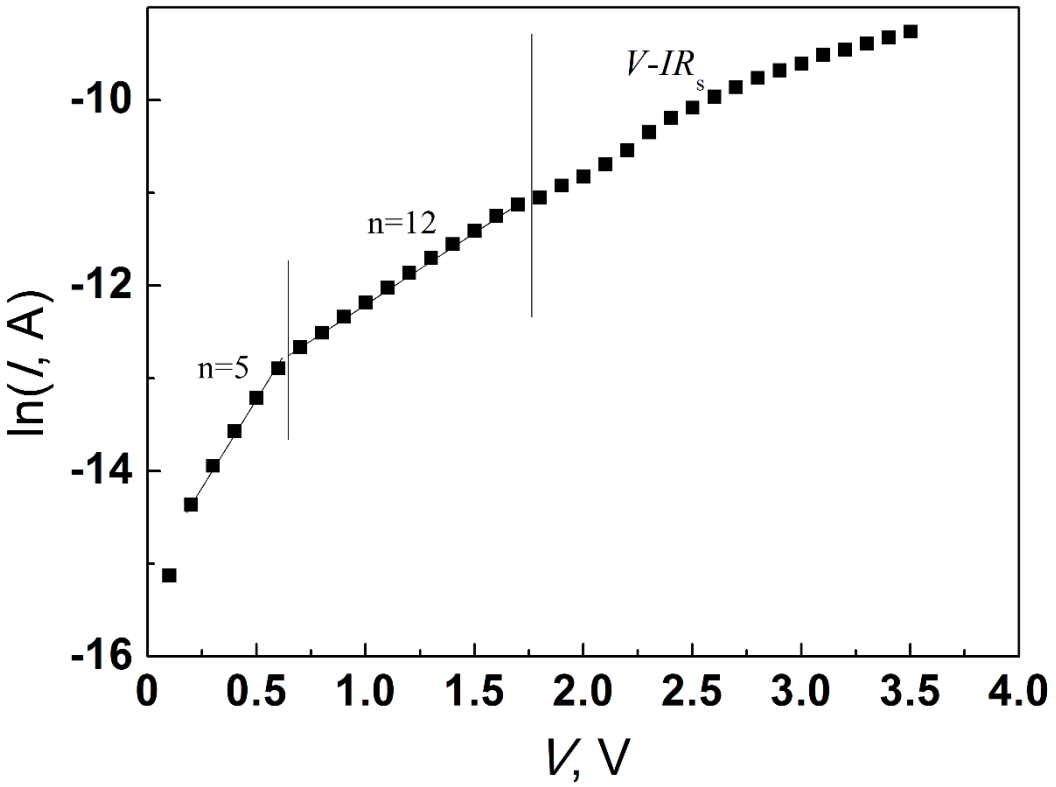

Fig. 3.3. Volt-ampere characteristics of a Schottky-type graphite / n-GaP heterojunction on a semi-logarithmic scale

The coefficient of nonideality n is equal to 5 in the voltage region (3kT/e <V <0.7 B), which is evidence of the tunneling nature of the current transfer mechanism. At small displacements, the region of the spatial charge is not yet thin enough for direct tunneling, which is described by Newman's formula. Therefore, given the high concentration of N_s mismatch dislocations, multistage tunneling-recombination processes involving surface states at the graphite/n-GaP interface can be considered the only mechanism of current transfer. The current at direct bias is defined by the following expression:

$$I = B\exp\left(-\alpha\left(\varphi_0(T) - eV\right)\right), \tag{3.1}$$

where B - is a value that is weakly dependent on temperature and voltage, φ_0 is the height of the potential barrier.

In the voltage range V> 0.7 V (Fig. 3.3), the dependence I (V) is well described by Newman's formula for tunnel current:

$$I = I_t^0 \exp(\beta T)\exp(\gamma V) = I_t \exp(\gamma V), \tag{3.2}$$

Where $I_0 = I_t^0 \exp\, exp\, (\beta T)$ – cut-off current . Y. β - constants

3.1.3. Mechanisms of current transport at reverse bias of the Graphite/n-GaP Schottky-type heterojunction

It can be assumed that the current transfer mechanisms installed during direct bias will be dominant when the polarity of the external voltage changes.

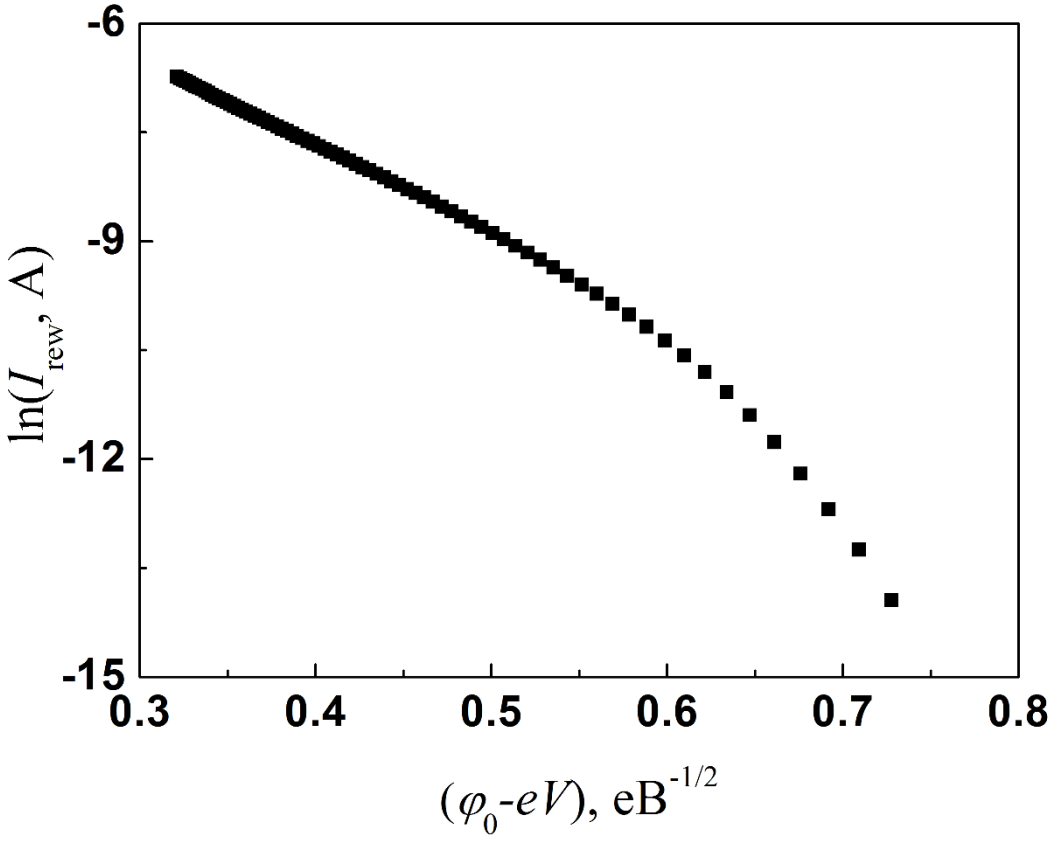

Fig. 3.4. Reverse branches of the I – V characteristics of a Schottky graphite / n-GaP heterojunction on a semi-logarithmic scale

When the reverse bias in the case of a sharp transition, the expression for the tunnel current has the form [4]:

$$I_{зв} \approx a_0 \exp\left(\frac{b_0}{\sqrt{\varphi_0(T) - eV}}\right), \qquad (3.3)$$

where a_0 and b_0 are voltage-independent parameters.

The fact that the reverse branches of the I – V characteristics in Fig. 3.4 are straight lines in the coordinates ln (Izv) = f (φ0-eV) -1/2, according to equation (3.3), confirms the dominance of the tunneling mechanism of current transfer in th region of inverse displacements | V | > 3kT / e.

3.2. C –V characteristics of the Graphite/n-GaP Schottky-type heterojunction

On the insert to fig. 3.5 shows the C-V characteristics of a Schottky-type graphite / n-GaP heterojunction measured at room temperature and an alternating signal frequency of 1 MHz. The rectilinear section indicates a uniform distribution of uncompensated donors in the respective areas of the base material

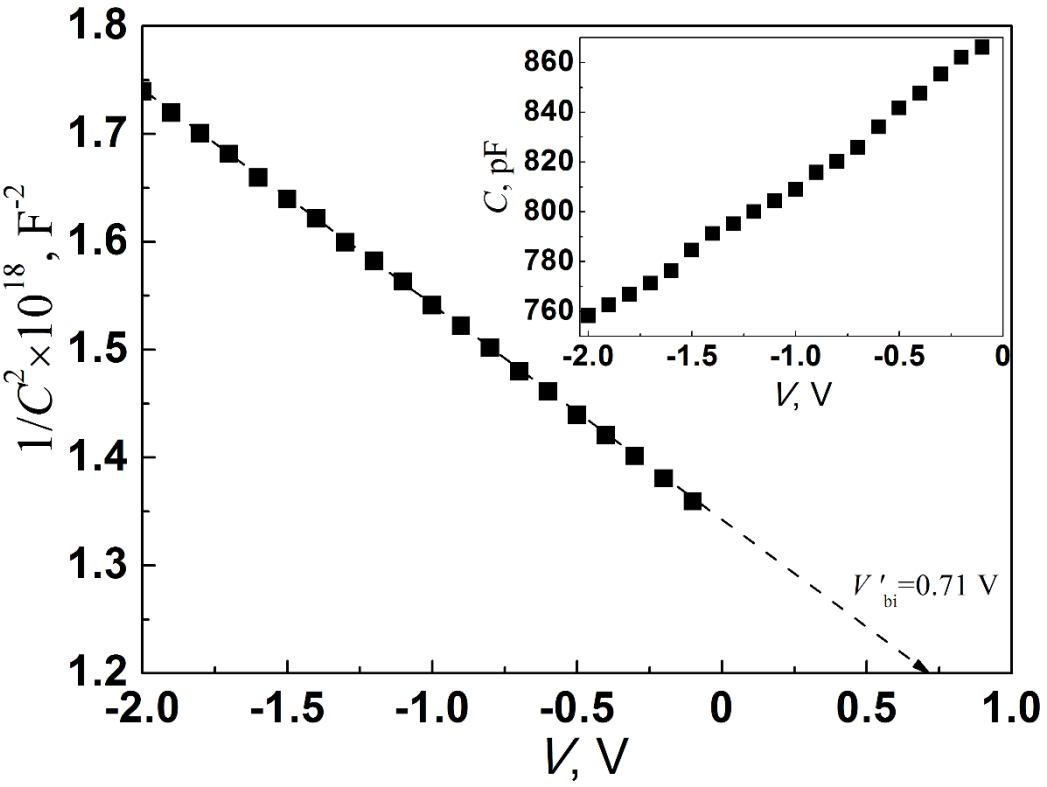

Fig. 3.5. Volt-farad characteristics of a Schottky-type graphite / n-GaP heterojunction measured at a frequency of a variable signal of 1 MHz and T = 300 K

By extrapolating the linear section to the intersection with the voltage axis, determine the value of the built-in potential V_{bi}' = 0,71 eB [7], which is less than the value of the built-in potential determined from the I – V characteristics of the studied heterojunction at room temperature V_{bi} = 1,69 eV This difference is due to the influence of electrically charged surface traps on the graphite / n-GaP heterointerface. It is known that the presence of an electric charge captured at the interface of the heterojunction affects the width of the space charge region and, consequently, the barrier capacitance.

The barrier capacitance of a sharp asymmetric electric transition with a charged interface Cb can be calculated by the following formula:

$$C_b = S\sqrt{\frac{q\varepsilon_0\varepsilon_{InP}N}{2\left(V_{bi}\pm\frac{Q_{SS}^2}{2\varepsilon_0\varepsilon_{InP}qN}-V\right)}}, \qquad (3.4)$$

where Q_{ss} - the electric charge is captured at the junction. The sign "+" is used in equation (3.4), when the electric charge captured at the transition boundary has the opposite sign, to the space charge in the depletion region (the width of the space charge region W is greater, and therefore the barrier capacity C_b is less).

From equation (3.4) it is seen that the extrapolation of the linear dependence $(1/C)^2$ V to the intersection with the voltage axis gives us $V_{bi}' = V_{bi} \pm Q_{ss}^2/2\varepsilon\varepsilon_0 qN$ instead of the actual value of the built-in potential V_{bi}.

Conclusions

Heterojunctions of the Schottky Graphite / n-GaP type were obtained by electron beam evaporation. The determined height of the potential barrier for the studied structure at room temperature is equal $\varphi_0 = eV_{bi} = 1.69$ eV;

Analysis of the direct branches of the I – V characteristics of the Schottky-type graphite / n-GaP heterojunction constructed on a semi-logarithmic scale showed that the value of the nonideality index (n) in the voltage range 3kT / e <V <0.7 V is 5. This indicates that the dominant mechanism current transfer is a multi-stage tunneling-recombination processes involving surface states at the graphite / n-GaP interface. When analyzing the passage of charge carriers through the energy barrier at large direct displacements (V> 0.7 V) shows that the value of the coefficient of imperfection n = 12. Under these conditions, the dominant mechanism of current transfer can be considered tunneling, which is described by Newman's formula.

The analysis of current transfer mechanisms through the studied Schottky-type graphite / n-GaP heterojunctions with reverse displacement showed that tunneling is the dominant current transfer mechanism in this structure.

After analyzing the C-V characteristics of the Schottky Graphite / n-GaP type heterojunction, it was found that the value of the built-in potential determined from the volt-farad characteristics and the I – V characteristics of the studied heterojunction at room temperature do not match. This difference is due to the influence of surface states on the graphite / n-GaP interface.

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ADDITION. Occupational health and safety in emergencies

Before starting work it is necessary:

- To study the basic and assembly schemes of the equipment which is subject to regulation;
- Get the necessary measuring equipment, make sure it is working;
- Check the condition of the workplace;
- Remove from the workplace unnecessary items that interfere with work;
- Position the lamp so that the work area is well lit and the light does not blind the eyes;
- Make sure the availability and serviceability of protective equipment;
- To be convinced of serviceability of isolation of wires, connecting blocks, plug sockets and plugs;
- To check up serviceability of protective grounding of the repaired and measuring devices;
- To be convinced of serviceability of starting, blocking and signaling devices;
- Make sure that all toggle switches, switches and circuit breakers are in the "off" position.

Work safety requirements:

- Maintain cleanliness and order in the workplace;
- Perform only the work assigned by the teacher;
- When working without de-energizing it is necessary to use a tool with insulated handles;

When working with the voltage on, work on the included equipment is allowed only with one hand, avoiding contact with the other hand (and exposed body parts) of equipment, chassis, metal housings, as well as measuring instruments in metal housings;

- Connection of the measuring equipment is necessary for carrying out at the de-energized block;

- It is allowed to measure voltage up to 1000 V on the switched on equipment by touching the high-voltage probe or voltage divider included in the measuring instrument, the point, the potential of which must be set. During such measurements, the safety measures provided for in the operating instructions of the measuring instrument must be taken;

- When replacing parts, the equipment should be disconnected from the mains;

- At short breaks in work the soldering irons which are in a working condition, it is necessary to place on a special support. During long breaks, the soldering iron must be disconnected from the mains;

- When leaving the workplace, repaired equipment and measuring instruments should be turned off.

Safety requirements after work:

- Put switches, toggle switches, switches in the "off" position;

- Disconnect the testing equipment and measuring instruments from the network;

- Clean the workplace, tools, devices and protective equipment;

- Present the work done to the teacher.

Safety precautions when working with high voltage

- It is necessary to carry out various electrical work only when the entire network is de-energized. This axiom must be followed, even when performing the simplest procedure to replace a blown light bulb at home.

- When servicing or repairing high voltage equipment, it is necessary to use tools covered with insulating material. An experienced specialist should pay attention to the calculation of cable power and network differences.

- Work should be done only with dry hands. It is necessary to exclude water getting into the installation area.

- When replacing fuses, never insert metal objects into the socket to avoid electric shock or severe burns.

- In the event of an emergency, the fire must not be extinguished with water. First of all the device should be disconnected from current, and then already to liquidate.

Fire safety

General fire safety requirements:

- Everyone should know the rules of conduct in case of fire, evacuation routes, be able to use primary means of firefighting, know their location;

- Flammable and combustible liquids must be stored in specially designated areas separately from other materials.

Rules of conduct for people in case of fire:

- In case of fire, it is necessary to call a specialized fire department by phone 101 and notify neighbors, company management, colleagues and immediately begin to eliminate the fire by all available means;

- Take the necessary measures to extinguish the fire on their own;

- Evacuate people and property. First of all, the most valuable and flammable materials are evacuated;

- If it is impossible to extinguish the fire on their own, you need to leave the room as soon as possible through the main and emergency exits;

- Leaving the room where the fire broke out, close the door tightly to reduce the flow of oxygen to the room.

Evacuation of people in case of fire

An indicator of the effectiveness of the evacuation process is the period of time during which people can, if necessary, leave individual rooms and the house in general.

Evacuation safety is achieved when the duration of evacuation of people from individual rooms and the house as a whole is less than the critical duration of a fire that poses a danger to humans.

The critical duration of a fire is the time to reach dangerous human temperatures and reduce the oxygen content in the air.

The main danger that kills people in a fire is smoke and hot air, so in a smoky room you need to breathe only through a wet dense fabric, remembering that the concentration of smoke is lowest near the floor.

Primary fire extinguishers are placed on special boards. Shields are installed so that the farthest building is not more than 100 m, and from storage facilities with flammable materials - not more than 50 m, or at the rate of - one shield per 5000 m2.

Fire extinguishers are painted in signal red, and the inscriptions on them and on the shields are made in contrasting white.

Basic measures when working with chemicals

Working with chemical reagents is a dangerous type of work, as chemicals can actively affect people and technology. Therefore, compliance with safety rules is the most important condition for the work.

When dealing with chemicals, keep in mind the following:

Service personnel who have contact with chemical reagents must undergo preliminary (at the time of entry into employment) and periodic medical examinations (once a year);

- Admission to work with chemicals of pregnant women, adolescents under 18 years, patients with organic skin lesions, chronic diseases of internal organs, central nervous system, upper respiratory tract, visual organs is prohibited;

- Persons who have been specially instructed on safety measures when working with flammable and toxic substances are allowed to work with reagents;

- The room in which the work with the chemical reagent is carried out, must be equipped with general exchange supply and exhaust ventilation, local exhausts in places of possible accumulation of vapors;

- It is forbidden to pour the product near heat sources, sparks, open flames;

- Wet cleaning of working premises should be carried out regularly.

- Chemicals must be stored in closed containers in warehouses, semi-closed type;

- In rooms for storage and use of chemical reagents it is forbidden to use open fire, and also to use the tools giving at blow by a spark;

- When working with the product, observe fire safety measures, safety precautions, use personal protective equipment. Overalls must withstand the effects of chemical reagents;

- Use safety goggles such as GR, rubber gloves, waterproof gloves, special shoes, use a BKF filter gas mask;

- The workplace is equipped with a first aid kit containing neutralizers for the solution with which you have to work, and a supply of fresh water;

- When using methyl alcohol and products that contain methyl alcohol, take special precautions;

When dosing or draining chemical solutions, staff must be on the windward side;

- Symptoms of poisoning: headache, dizziness, vomiting, abdominal pain, general weakness, irritation of the mucous membranes, flickering in the eyes;

- Acids are the most dangerous substances: they destroy the surface layer of tissue, cause burns to the point of charring the skin, affect the eyes, affect the respiratory system;

- Alkalis cause saponification of the fatty layer of the skin, dehydration of tissues, dissolution of proteins.