INVESTIGATION OF THE EFFECT OF Mn IMPURTTY ON HIGH-VOLTAGE p^0-n^0 HETEROJUNCTIONS BASED ON A LOW-DOPED GaAs LAYER.

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Annotation. Experiments have been carried out and the influence of Mn impurity on high-voltage p^0-n^0 heterojunctions based on a lightly doped gallium arsenide layer has been studied. The influence of Mn impurity on the position of the p^0-n^0 transition has been studied, the concentration and nature of the distribution of the main charge carriers have been determined, diffusion length of minority charge carriers, mobility of charge carriers, emergence of deep levels in a lightly doped gallium arsenide layer.

Keywords. Heterojunctions, high-voltage p^0-n^0 junctions, lightly doped GaAs layers, diffusion length, and mobility of charge carriers, deep levels, acceptor and donor levels.

Introduction. In modern microelectronics, applications of large complex semiconductor structures, which are formed when different chemical elements are used together - heterostructures. Heterojunctions, with different band gaps and varying degrees of doping, have received wide practical application in emitting and photoelectric devices (LEDs, lasers, photodiodes, etc.). Potential well formed by the peak in the energy diagram of the transition makes it possible to increase the efficiency. Light-emitting electronic devices.

It is of interest to study the influence of isovalent atoms on the process of formation of smooth p^0-n^0 transitions, since their use allows you to change the concentration level and spectrum of small impurities and deep-level traps due to interaction with background impurities in the melt and changes in intrinsic point defects in epitaxial layers.

Method. Currently, epitaxial methods for producing single-crystal layers for the manufacture of various semiconductor devices are widely used [1]. Epitaxial growth methods make it possible to combine in time the process of crystallization of a semiconductor material and the production of a device structure. Gas transport, molecular beam and liquid phase epitaxy (LPE) have become the most widespread. Ideal joining of crystal lattices into a semiconductor heterojunction is possible using LPE. This method makes it possible to produce not only two-layer but also multilayer heterostructures. One of the most promising areas in the rapidly developing field of semiconductor micro-, opto- and nanoelectronics is the development of methods for improving the perfection of gallium arsenide heterostructures and controlling the electrical parameters of semiconductor devices. Understanding the role of impurities and the resulting defects is crucial for explaining a range of phenomena from diffusion to one-way injection, or for building a theory of processes occurring in alloyed materials.

Various studies in the field of semiconductor materials science, namely, the study of the peculiarities of the processes of interaction of various impurities and defects in the structure of a semiconductor led to the need to create and produce new materials with different properties, which can be achieved through doping with various impurities.

In this regard, there is a growing need to study the processes of interaction of various impurities and the formation of defects in a lightly doped layer of gallium arsenide doped with impurities of transition metals and rare earth elements in order to develop methods for controlled stabilization of the parameters of semiconductor devices.

Despite the huge number of experimental results, the processes of formation and development of the defect structure of a gallium arsenide heterostructure doped with impurities of transition elements still remain unknown.

The purpose of this work is:

- to determine the location of the p^0-n^0 transitions;
- determine the concentrations and nature of the distribution of the main charge carriers of the lightly doped GaAs layer;
- determine the diffusion length of minority charge carriers (MCCs) in lightly doped GaAs layers;
- determine the mobility of charge carriers in lightly doped epitaxial GaAs layers;
- study the peculiarities of the behavior of Mn atoms in GaAs and determine the influence of technological doping modes on the parameters of deep centers formed by these impurities;
- study the influence of Mn atoms and the processes of thermal defect formation in lightly doped GaAs layers;
- study the processes of degradation of deep centers in lightly doped GaAs layers at high operating temperatures;
- изучить влияние дополнительно введенных примесей на процесси получения p^0-n^0 перехода в слаболегированных слоях GaAs.

Methodology. To solve the problems, the following methods were used:

After growing the epitaxial structures, the thickness of the layers, their planarity and the location of the p^0-n^0 transition were first determined.

To determine the location of the p^0-n^0 junction or space charge region (SCR), the electrooptical effect method was used [2]. The electrooptical effect manifests itself in the occurrence of double refraction in an electric field. In the case of an epitaxial structure with a p^0-n^0 junction, double beam interference should arise in the SCR due to the indication of optical anisotropy at the p^0-n^0 junction. During the studies, a MIC-5 microscope was used.

To determine the concentration and nature of the distribution of the main charge carriers, the capacitance-voltage method was used using a mercury probe with layer-by-layer etching of gallium arsenide layers. A typical distribution of charge carrier concentration in one of the resulting p^0-n^0 structures is shown in Fig. -1.

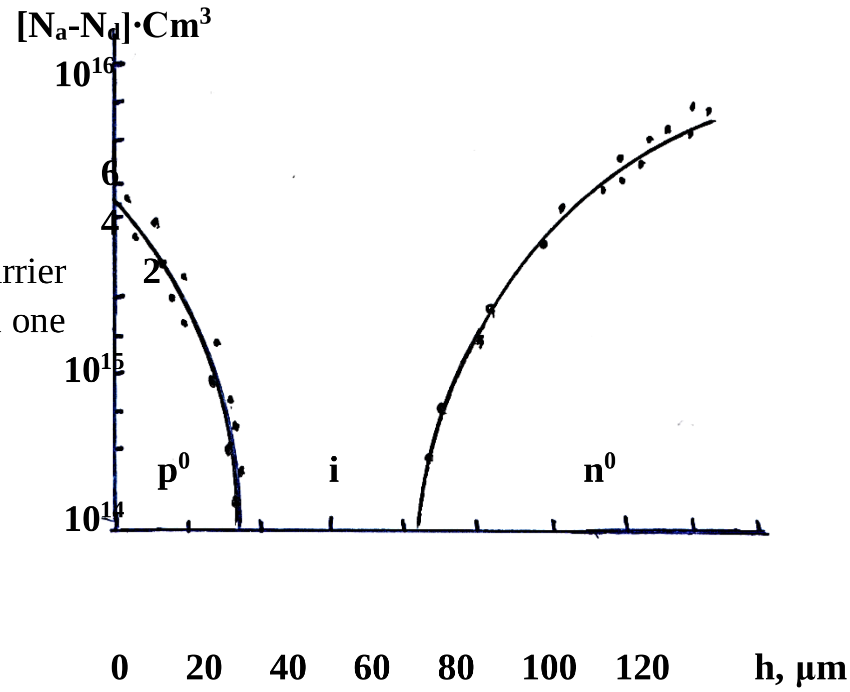


Fig. - 1. Distributions carrier concentrations charge in one p^0-n^0 structures.

The diffusion length of the NCC is the most important characteristic of any semiconductor material [5]. To determine the diffusion length of the NCC in lightly doped GaAs layers introduced with Mn impurities, a method was used to study the current distribution induced by a small diameter electron probe and is determined by the expression.

$$I = I_0 \exp\left(\frac{r_0 - x}{L_p}\right)$$

where x is the distance from the excitation area to the p^0-n^0 transition, r_0 is the radius of the excitation area.

The diffusion lengths L_d in n^0 – GaAs, determined by this method from the slope of the dependence $L_{n1} = f(x)$, reached 7÷10 μm at zero bias and increased to ≥ 90 μm at U_{arr} = 100 V. Measurements were carried out using a jXA-5A scanning electron microscope microanalyzer. In Fig. - 2.

The dependence of the diffusion length of electrons on the current in a lightly doped p^0 – GaAs layer 40 μm thick is presented. t can be seen that starting with current densities j > 50 A/Cm^2, the diffusion length L_n practically does not change and reaches values of 75÷85 μm. The increase in Ln in the region of lower currents is apparently associated with the saturation of electron capture centers.

He charge carrier mobilities were determined by measuring the Hall effect in epitaxial layers grown on semi-insulating substrates.

The measurements were carried out by the Van der Pai method on samples with six ohmic contacts obtained by melting Minddean droplets into an epitaxial layer. The values of electron mobility in n^0-GaAs layers are in the range ≈ 5000÷6000 cm^2/V·sec, and the hole mobility in p^0-n^0-GaAs layers is ≈ 3000÷5000 cm^2/V·sec.

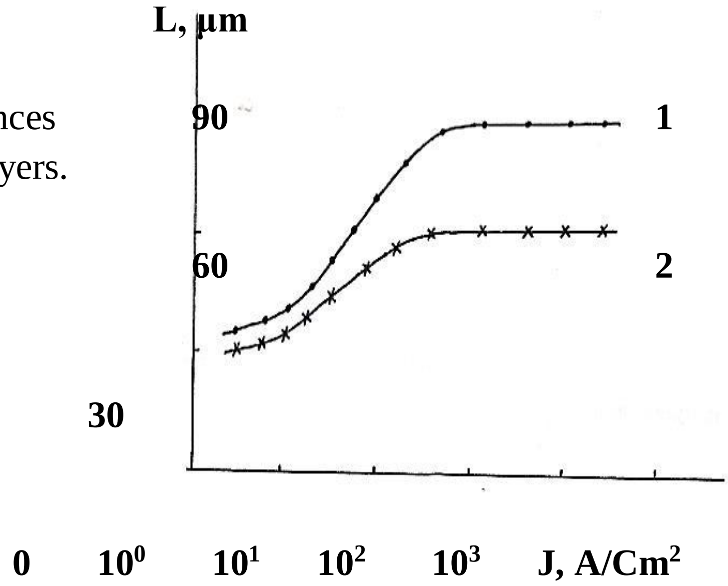


Fig. - 2. Typical dependences L_n = f(I) in p^0 = GaAs layers.
1 – p^0 - $5 \cdot 10^{15}$ cm^{-3};
2 – p^0 - $2 \cdot 10^{15}$ cm^{-3}.

The results of studies of the mobility of the main charge carriers in the n^0-regions showed that there is a high degree of compensation in the epitaxial layers Fig. - 3. As follows from the figure, the degree of compensation in the n^0 layer increases as it approaches the p^0-n^0 transition.

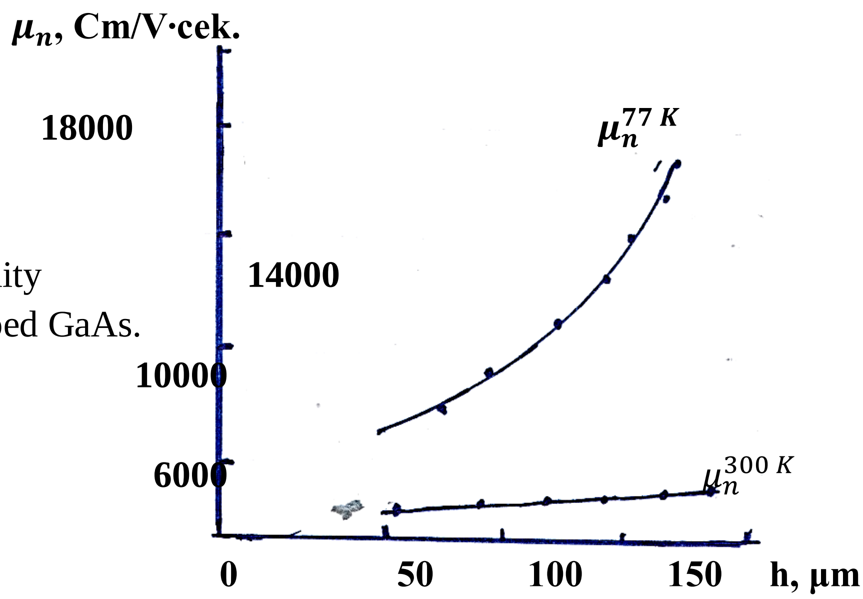


Fig. - 3. Electron mobility in a layer of lightly doped GaAs.

This nature of the dependence of mobility may indicate that the total concentration of infected centers in the layer decreases with increasing thickness of the n^0-layer and with decreasing crystallization temperature of the layer.

To determine the energy parameters of deep levels in lightly doped layers introduced with Mn impurities, the method of transient capacitive deep level spectroscopy (DLTS) and photocapacitance (PC) were used.). In all layers obtained by the LPE method, in addition to shallow acceptor and donor levels, deep levels A(E_c + 0.4 eV), B(E_c + 0.54 eV), C(E_c + 68 eV) were detected (Fig. – 4). The crosssection for capturing deep levels corresponds to the value $\sigma = 8 \cdot 10^{-17}$ cm^2, $6 \cdot 10^{13}$ cm^2, $4 \cdot 10^{-17}$ cm^2. In the literature, these levels are designated HL5, HL3, HL2 [3-4].

The recombination properties of the p^0 region are largely determined by the deep acceptor A and B centers. At the same time, the main. These centers play a role in the p – part of the p^0 region. In p^0-GaAs, they, detected by capacitance spectroscopy (LLTS) and attributed to a growth defect, are traps for holes, and their concentration decreases exponentially with decreasing growth temperature.

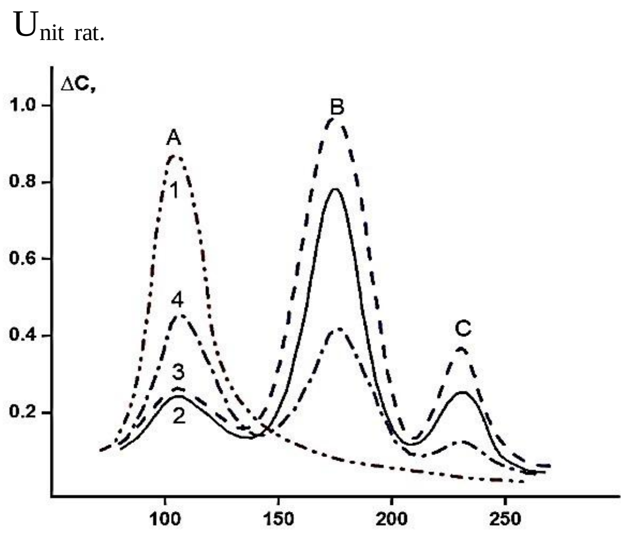
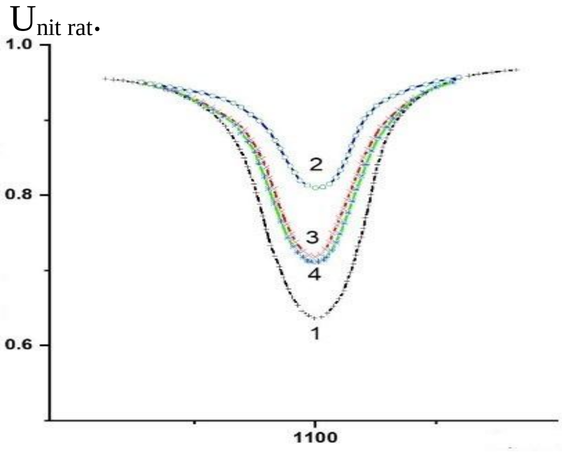


Fig.-4. DLTS spectrum one of the samples doped with Mn impurity.

The IR absorption spectrum of these samples doped with Mn impurities at temperatures from 20 ^{0}C to 200 ^{0}C are presented in Fig. - 5, and the kinetics of the influence of temperature in the range from 20 ^{0}C to 200 ^{0}C at deep levels is shown in

Fig. - 6.

Rice. - 5. IR absorption spectrum alloyed with Mn at different operating temperatures.



Along with shallow acceptors and shallow donors, deep acceptors determine the position of the p^0-n^0 junction and the size of the SCR [6]. The part of the p^0 layer adjacent to the substrate has a relatively high concentration of small acceptors, greater than the concentration of small donors and sponge acceptors.

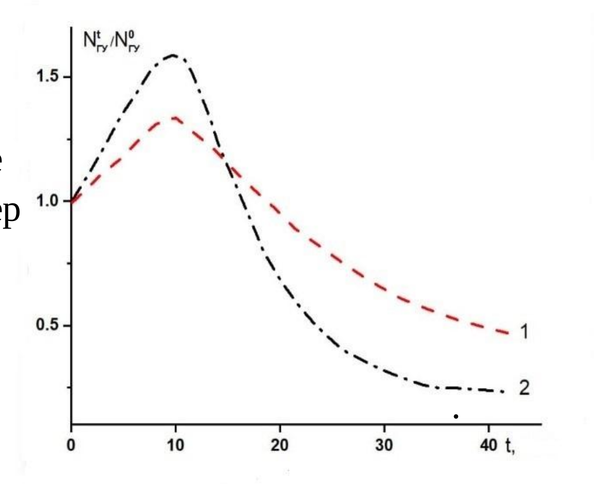
As mixing progresses from the substrate deeper into the layer, the difference $N_{d.m.} – N_{m.a.}$ decreases and then becomes equal to zero and changes sign, however, due to the presence of deep acceptors, the type of conductivity of the layer does not

change.

If $0 < N_{d.m.} – N_{m.a.} < N_{a.g.}$, then the Fermi level will be close to the position of the first deep acceptor level – A. With further displacement deeper into the layer, when $N_{a.g.} < N_{m.a.} – N_{m.a.} < N_{a.g.}$, the Fermi level will approach the position of the

second level - B and further to the third level - C.

Fig. - 6. Kinetics of influence operating temperatures at deep levels Mn-doped samples.



t, min.

Estimates show that the resistivity of the region of non-field ionization of centers with levels A, B and C at 300 K is 10^6 Ohm·cm or more. Layer coordinate, where $N_{d.m.} = N_{a.m.} + 2N_{a.g.}$ is the location of the p^0-n^0 transition. Further, in the n^0-type layer, the electron concentration will be determined by a decrease in $Nd_{d.m.}$ – $N_{a.g}$. Therefore, the p^0 region consists of two parts: a low-resistance p^0 and a high-resistance i part, and the p^0-n^0 junction is located on the border of the i and n^0 regions.

Conclusions. In conclusion, we note that

- The positions of the p^0-n^0 transition or the space charge region of the lightly doped GaAs layer doped with Mn impurities are determined. The thickness of the p^0 region is determined by the values of the transmission coefficient and the recombination properties of the resulting p^0-n^0 transitions [7,9].

– The nature and profile of the concentration distribution of the main charge carriers have been studied. The carrier concentration in the p^0- and n^0-regions ranged from $1\cdot10^{15}$ cm^{-3} to $0.1\cdot10^{15}$ cm^{-3} [7].

- The mobility of charge carriers is determined. The mobility of charge carriers was, in the n^0 layer $\mu_n \approx (5\div6)\cdot10^3$ $cm^2/V\cdot sec$, and in the p^0 layer $\mu_p \approx (400\div450)$ $cm^2/V\cdot sec$ [7,10].

- The diffusion lengths of the NCC in lightly doped GaAs layers doped with Mn impurities were determined [8,13];

- A comprehensive study of the properties of a lightly doped GaAs layer doped with Mn impurities was carried out and it was found that these impurities form deep levels with ionization energies $E_c – 0.4$ eV, $E_c – 0.54$ eV, $E_c = 0.68$ eV in n^0-GaAs <Mn >

[7,8];

- The influence of deep centers created by Mn impurities has been studied and it has been established that impurities are unstable in the gallium arsenide lattice when operating temperatures change and the kinetics of the influence of temperature on deep levels is nonlinear [11,12].

Used literature:

1. Bozorov, Kh N., O. O. Mamatkarimov, and B. T. Abdulazizov. "Electric and ionic conductivity of potassium antimony tungstate with addition of alkali metals." *«Узбекский физический журнал»* 24.2 (2022): 129-132.
2. Uktamaliyev, B. I., et al. "Determination of transport properties for polymer electrolytes containing LiTf and MgTf2 salts." *Molecular Crystals and Liquid Crystals* 763.1 (2023): 17-27.
3. Mamatkarimov, O. O., R. Khamidov, and A. Abdukarimov. "The relative current change, concentration, and carrier mobility in silicon samples doped nickel and at pulse hydrostatic pressure." *Materials Today: Proceedings* 17 (2019): 442-445.
4. Uktamaliyev, B. I., et al. "Determination of transport properties for polymer electrolytes containing LiTf and MgTf2 salts." *Molecular Crystals and Liquid Crystals* 763.1 (2023): 17-27.

5. Mamatkarimov, O., B. Uktamaliyev, and A. Abdukarimov. "Temperature dependence of active and reactive impedances of PMMA-EC-LITF2 solid polymer electrolytes." *НАУЧНЫЕ ОСНОВЫ ИСПОЛЬЗОВАНИЯ ИНФОРМАЦИОННЫХ ТЕХНОЛОГИЙ НОВОГО УРОВНЯ И СОВРЕМЕННЫЕ ПРОБЛЕМЫ АВТОМАТИЗАЦИИ* (2022): 366.
6. Manjuladevi, R., et al. "Preparation and characterization of blend polymer electrolyte film based on poly (vinyl alcohol)-poly (acrylonitrile)/MgCl 2 for energy storage devices." *Ionics* 24 (2018): 1083-1095.
7. Mamatkarimov, O., A. Abdukarimov, and B. Uktamaliev. "ABOUT THE CHARACTERISTICS OF MULTILAYER THIN-FILM STRUCTURES WITH DYES BASED ON TITANIUM DIOXIDE." *Euroasian Journal of Semiconductors Science and Engineering* 3.40 (2021): 26-29.
8. Odiljon, Mamatkarimov, Uktamaliyev Bekzod, and Abdullaziz Abdukarimov. "Determination of ionic conductivity of polymer electrolytes in li-ion batteries using electrochemical impedance spectroscopy." *ACADEMICIA: An International Multidisciplinary Research Journal* 11.7 (2021): 141-146.
9. Ikramov, R. G., et al. "Calculation of the interband absorption spectra of amorphous semiconductors using the Kubo-Greenwood formula." *Journal of Applied Science and Engineering* 25.5 (2021): 919-924.
10. Ikramov, Rustamjon G., et al. "Calculation of the Density of the Distribution of Electronic States in the Conduction Band from the Fundamental Absorption Spectra of Amorphous Semiconductors." *East European Journal of Physics* 4 (2023): 153-158.
11. Ikramov, Rustamjon G., et al. "Dangerous Bonds Individual of Hydrogenated Amorphous Silicon and Defect Absorption Spectra." *East European Journal of Physics* 4 (2023): 244-250.
12. Абдулазизов, Б. Т., et al. "Дефекты, характерные для гидрогенизированных аморф-ных полупроводников, и спектры дефектного поглощения." *«Узбекский физический журнал»* 25.3 (2023).
13. Ikramov, R. G., et al. "Kubo-greenwood Formula For The Exponential Absorption Region Of Amorphous Semiconductors And Distribution Of The Density Of Electronic States In The Tail Of The Conduction Band." *Journal of Applied Science and Engineering* 26.8 (2022): 1167-1171.
14. Абдулазизов, Б. Т., et al. "Область экспоненциального поглощения аморфных полупроводников." *«Узбекский физический журнал»* 24.2 (2022): 96-99. Икрамов, Рустамжон, et al. "СПЕКТРЫ КОЭФФИЦИЕНТА ДЕФЕКТНОГО ПОГЛОЩЕНИЯ АМОРФНЫХ ПОЛУПРОВОДНИКОВ." *Scientific Collection «InterConf»* 107 (2022): 409-420.
15. Муминов, Х. А., Б. Султонов, and О. Т. Холмирзаев. "РАСЧЕТ РАСПРЕДЕЛЕНИЕ ПЛОТНОСТИ ЭЛЕКТРОННЫХ СОСТОЯНИЙ В ВАЛЕНТНОЙ ЗОНЕ ИЗ СПЕКТРА МЕЖЗОННОГО ПОГЛОЩЕНИЯ АМОРФНЫХ ПОЛУПРОВОДНИКОВ." *EDITOR COORDINATOR* (2021): 384.

16. Икрамов, Рустамжон, et al. "СПЕКТРЫ КОЭФФИЦИЕНТА ДЕФЕКТНОГО ПОГЛОЩЕНИЯ АМОРФНЫХ ПОЛУПРОВОДНИКОВ." *Scientific Collection «InterConf»* 107 (2022): 409-420.
17. Maxmudovich, To‘xliyev Mansur. "PAST POTENSIALLI QUYOSH QURITGICHLARNI SAMARADORLIGINI OSHIRISH." *Educational Research in Universal Sciences* 1.6 (2022): 79-86.
18. Yusupov, Elmurod Kuchkarboyevich. "STUDYING PROPERTIES OF ROTATIONAL STATES 156Gd."
19. Байматов, П. Ж., et al. "ВЛИЯНИЕ ИЗМЕНЕНИЯ ХИМИЧЕСКОГО ПОТЕНЦИАЛА НА ТЕПЛОЕМКОСТЬ КВАЗИДВУМЕРНОГО ЭЛЕКТРОННОГО ГАЗА." *«Узбекский физический журнал»* 20.6 (2018).
20. Ravshanjon o’g, G‘aybullayev Dostonbek. "QUYOSH ENERGIYASI VA UNDAN FOYDALANISH." *O'ZBEKISTONDA FANLARARO INNOVATSIYALAR VA ILMIY TADQIQOTLAR JURNALI* 2.19 (2023): 1574-1576.
21. Ikramov, Rustamjon G., et al. "Calculation of the Density of the Distribution of Electronic States in the Conduction Band from the Fundamental Absorption Spectra of Amorphous Semiconductors." *East European Journal of Physics* 4 (2023): 153-158.
22. Ikramov, Rustamjon G., et al. "Dangerous Bonds Individual of Hydrogenated Amorphous Silicon and Defect Absorption Spectra." *East European Journal of Physics* 4 (2023): 244-250.
23. Ikramov, R. G., et al. "Kubo-greenwood Formula For The Exponential Absorption Region Of Amorphous Semiconductors And Distribution Of The Density Of Electronic States In The Tail Of The Conduction Band." *Journal of Applied Science and Engineering* 26.8 (2022): 1167-1171.
24. Ikramov, Rustamzhon Gulomzhonovich, Mashkhura Anvarbekovna Nuriddinova, and Xurshid Adhamjon Muminov. "A new method for determining the density distribution of electronic states on the tail of the valence band of amorphous semiconductors Se _x S _1-x." *Optics and spectroscopy* 129.11 (2021): 1382-1386.
25. Икрамов, Р. Г., М. А. Нуриддинова, and Х. А. Муминов. "Вычисление плотности электронных состояний в валентной зоне из экспериментального спектра межзонного поглощения аморфных полупроводников." *Журнал прикладной спектроскопии* 88.3 (2021): 378-382.
26. Икрамов, Рустамжон Гуломжонович, Машхура Анварбековна Нуриддинова, and Хуршид Адхамжон уғли Муминов. "Новый метод определения распределения плотности электронных состояний в хвосте валентной зоны аморфных твердых растворов Se _x S _1-x." *Оптика и спектроскопия* 129.11 (2021): 1382-1386.
27. Ikramov, Rustam, et al. "Temperature Dependence of Urbach Energy in Non-Crystalline Semiconductors." *Optics and Photonics Journal* 10.9 (2020): 211-218.
28. Абдулазизов, Б. Т., et al. "Расчет распределения плотности электронных состояний в хвосте зоны проводимости аморфных полупроводников." *«Узбекский физический журнал»* 22.6 (2020): 344-349.

29. IKRAMOV, RUSTAM GULOMJONOVICH, MASHXURA ANVARBEKOVNA NURIDDINOVA, and KHURSHID ADHAMJON UGLI MUMINOV. "Parameters defining the interzonal absorption coefficient in amorphous semiconductors." *Journal of Applied Physical Science International* 12.1 (2021): 36-40.
30. Ikramov, R. G., M. A. Nuriddinova, and R. M. Jalalov. "Density of defect states and spectra of defect absorption in a-Si: H." *Ukrainian journal of physics* 64.4 (2019): 315-315.
31. Ikramov, R. G., M. A. Nuriddinova, and A. Muminov Kh. "Spectra of the coefficient of defect absorption and the energy position of defects in amorphous hydrogenated silicon." *International Journal of Multidisplinary Trends* 1.1 (2019): 12.
32. Zaynobidinov, S., et al. "Infra-red absorption spectra of amorphous semiconductors." *Uzbekiston Fizika Zhurnali* 21.2 (2019): 88-92.
33. Ikramov, R. G., M. A. Nuriddinova, and A. Muminov Kh. "Spectra of the coefficient of defect absorption and the energy position of defects in amorphous hydrogenated silicon." *International Journal of Multidisplinary Trends* 1.1 (2019): 12.
34. ZAYNOBIDINOV, S., et al. "Spectra of interband absorption and optical gap of amorphous semiconductors; Spektry mezhzonnogo pogloshcheniya i opticheskaya shchel'amorfnykh poluprovodnikov." *Uzbekiston Fizika Zhurnali* 15 (2013).
35. Zainobidinov, S., et al. "Distribution of electron density of states in allowed bands and interband absorption in amorphous semiconductors." *Optics and spectroscopy* 110 (2011): 762-766.
36. Zajnobidinov, S., et al. "Dependence of the Urbach energy on the Fermi level in A-Si: H films; Zavisimost'ehnergii Urbakha ot urovnya Fermi v plenkakh a-Si: H." *Ukrayins' kij Fyizichnij Zhurnal (Kyiv)* 53 (2008).
37. Zajnovidinov, S., et al. "Temperature effect in absorption spectra of amorphous semiconductors; Temperaturnyj ehffekt v spektrakh pogloshcheniya amorfnykh poluprovodnikov." *Ukrayins' kij Fyizichnij Zhurnal (Kyiv)* 53 (2008).
38. Qo’chqarov, B. X., A. Nishonov, and X. O. Qochqarov. "Scientific bulletin of Namangan State University,“." *The effect of tunneling gurrent on the spedd surface generation of charge garries* 1.7 (2020): 3-6.
39. Qo’chqarov, Bekzod Xoshimjonovich, Azizbek Nishonov, and Xoshimjon Ortiqovich Qo’chqarov. "The effect of tunneling current on the speed surface generation of charge carriers." *Scientific Bulletin of Namangan State University 2019y* 1.7 (2009): 3-6.
40. Usmanov, P. N., A. I. Vdovin, and A. N. Nishonov. "Investigating the Energies and Electrical Characteristics of the Negative Parity States of the 156Gd Nucleus." *Bulletin of the Russian Academy of Sciences: Physics* 86.8 (2022): 918-923.
41. Усманов, П. Н., et al. "Энергия и структура октупольных состояний ядра 238U." *«Узбекский физический журнал»* 24.2 (2022): 90-95.
42. Arof, A. K., et al. "Investigation on morphology of composite poly (ethylene oxide)-cellulose nanofibers." *Materials Today: Proceedings* 17 (2019): 388-393.

43. Abdukarimov, Abdullaziz, et al. "Characteristics of dye-sensitized solar cells (DSSCs) using liquid and gel polymer electrolytes with tetrapropylammonium salt." *Optical and Quantum Electronics* 52 (2020): 1-15.
44. Abdukarimov, Abdullaziz, et al. "Influence of charge carrier density, mobility and diffusivity on conductivity–temperature dependence in polyethylene oxide–based gel polymer electrolytes." *High Performance Polymers* 34.2 (2022): 232-241.
45. Kuchkarov, B. H., et al. "Influence of all-round compression on formation of the mobile charge in lead-borosilicate glass structure." *American Institute of Physics Conference Series*. Vol. 2432. No. 1. 2022.
46. Uktamaliyev, B. I., et al. "Determination of transport properties for polymer electrolytes containing LiTf and MgTf2 salts." *Molecular Crystals and Liquid Crystals* 763.1 (2023): 17-27.
47. Mamatkarimov, O. O., R. Khamidov, and A. Abdukarimov. "The relative current change, concentration, and carrier mobility in silicon samples doped nickel and at pulse hydrostatic pressure." *Materials Today: Proceedings* 17 (2019): 442-445.
48. Uktamaliyev, B. I., et al. "Determination of transport properties for polymer electrolytes containing LiTf and MgTf2 salts." *Molecular Crystals and Liquid Crystals* 763.1 (2023): 17-27.
49. Abdukarimov, A. A., et al. "Dependence of the characteristics of dye-sensitized solar cells on amount tetrapropylammonium iodide." *«Узбекский физический журнал»* 22.4 (2020): 250-253.
50. Sultanov, A. M., A. A. Abdukarimov, and M. Z. Kufian. "Development of technology for creating high-voltage p0–n0 junctions based on GaAs." *Bulletin of the Karaganda University" Physics Series"* 112.4 (2023): 50-56
51. Abdukarimov, A. A., et al. "Characteristics of natural dye sensitized solar cells." *Molecular Crystals and Liquid Crystals* 767.1 (2023): 98-105.
52. Mamatkarimov, O., B. Uktamaliyev, and A. Abdukarimov. "Temperature dependence of active and reactive impedances of PMMA-EC-LITF2 solid polymer electrolytes." *НАУЧНЫЕ ОСНОВЫ ИСПОЛЬЗОВАНИЯ ИНФОРМАЦИОННЫХ ТЕХНОЛОГИЙ НОВОГО УРОВНЯ И СОВРЕМЕННЫЕ ПРОБЛЕМЫ АВТОМАТИЗАЦИИ* (2022): 366.
53. Manjuladevi, R., et al. "Preparation and characterization of blend polymer electrolyte film based on poly (vinyl alcohol)-poly (acrylonitrile)/MgCl 2 for energy storage devices." *Ionics* 24 (2018): 1083-1095.
54. Mamatkarimov, O., A. Abdukarimov, and B. Uktamaliev. "ABOUT THE CHARACTERISTICS OF MULTILAYER THIN-FILM STRUCTURES WITH DYES BASED ON TITANIUM DIOXIDE." *Euroasian Journal of Semiconductors Science and Engineering* 3.40 (2021): 26-29.
55. Yakubbaev, A. A., A. Abdukarimov, and S. H. Nazarov. "Application of pincents of spinal leaf (chlorophylle) as a natural die for paint sensitive sun element (DSSC)." *ACADEMICIA: An International Multidisciplinary Research Journal* 11.8 (2021): 185-188.
56. Odiljon, Mamatkarimov, Uktamaliyev Bekzod, and Abdullaziz Abdukarimov. "Determination of ionic conductivity of polymer electrolytes in li-ion batteries

using electrochemical impedance spectroscopy." *ACADEMICIA: An International Multidisciplinary Research Journal* 11.7 (2021): 141-146.

57. Mamatkarimov, O., and A. Abdukarimov. "ABOUT THE CHARACTERISTICS OF MULTILAYER THIN-FILM STRUCTURES WITH DYES BASED ON TITANIUM DIOXIDE." *Euroasian Journal of Semiconductors Science and Engineering* 2.3 (2020): 28.
58. Abdukarimov, A. A. "UDK: 621.315. 592 MAIN ELECTROPHYSICAL CHARACTERISTICS OF DYE-SENSITIZED SOLAR CELLS (DSSCS)." *атты V Халықаралық ғылыми-тәжірибелік конференция*.
59. Корольков, В. И., and Александр Владимирович Рожков. "Исследование стабильности переключения высоковольтных субнаносекундных фотонно-инжекционных коммутаторов." *Письма в Журнал технической физики* 18.10 (1992): 26-31.
60. Sultanov, A. M., E. K. Yusupov, and R. G. Rakhimov. "Investigation of the Influence of Technological Factors on High-Voltage p0–n0 Junctions Based on GaAs." (2024).
61. Avrutin, E. A., Korol'Kov, V. I., ORLOV, B., Rozhkov, A. V., & Sultanov, A. M. (1992). Dynamic characteristics of high-power pulses generated in GaAs/AlGaAs superluminescent diodes. *Soviet physics. Semiconductors*, *26*(4), 403-406.
62. Sultanov, A. M., & Mirzarayimov, J. Z. (2024). MAIN TECHNOLOGICAL FACTORS AFFECTING THE PROPERTIES OF LOW-DOPED LAYERS AND TRANSISTOR n+-p0–n0 STRUCTURES. *European Journal of Emerging Technology and Discoveries*, *2*(3), 41-47.
63. Султанов, А. М., and Ж. З. Мирзарайимов. "ОСОБЕННОСТИ И ПЕРСПЕКТИВЫ ИСПОЛЬЗОВАНИЯ ФОТОННОЕ–ИНЖЕКЦИОННЫХ ИМПУЛЬСНЫХ ТИРИСТОРОВ ДЛЯ МОДУЛЯЦИИ УСИЛЕНИЯ ПОЛУПРОВОДНИКОВЫХ ГЕТЕРО ЛАЗЕРОВ." *Multidisciplinary Journal of Science and Technology* 4.3 (2024): 577-583.
64. Рожков, А. В., А. М. Султанов, and Х. Бозоров. "ГЕТЕРОПЕРЕХОДЫ МИКРОЭЛЕКТРОНИКЕ." *И ПРИКЛАДНЫЕ ПРОБЛЕМЫ СОВРЕМЕННОЙ ФИЗИКИ FUNDAMENTAL AND APPLIED PROBLEMS OF MODERN PHYSICS* (2023): 115.