ELECTRONIC AND CRYSTAL STRUCTURE OF GAP (111) SURFACE IN IMPLANTATION OF AL^{+} IONS

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Abstract. GaAlP films and Nano crystal phases were obtained by method implantation of Al^{+} with E_0 = 1 keV ions at different doses on the surface of a GaP (111) single crystal, their electronic and crystal structure was researched. It was shown that the type and parameters of the three-component nanostructure lattice well coincide with those of the substrate. The relationship between the width of the band gap E_g and the size of nanocrystalline phases is researched. It was found that in the case of the surface dimensions of phases d less than 35-40 nm (thickness 3.5-4 nm), in the nanocrystalline phases $Ga_{0.6}Al_{0.4}P$ quantum-sized effect are conducted.

Keywords: surface, single crystal, ion implantation, nanocrystalline phase, band gap width, quantum-sized effect, solar cells.

1.Introduction

Binary semiconductors A^3B^5, A^2B^6 and multi-component heterostructures based on them are widely used in the creation of various instruments of opto-, micro- and nanoelectronics. In particular, multilayer structures with GaP, GaInP, AlGaInP layers are used and have prospects for manufacturing laser diodes, solar cells, photovoltaic and optoelectronic devices. Particular interest is presented obtaining of triple solid solutions of the type $Ga_{1-x}Al_xAs$, $Ga_xIn_{1-x}P$ with regulated width of the band gap. Therefore, the composition, structure, electronic and optical properties of multicomponent and multilayer heterostructures based on A^3B^5 semiconductors have been well researched so far. [1-9]. Obtaining such structures, the methods of molecular-beam and solid phase epitaxy are widely used. Researches, conducted in recent years [10-12] have shown that the method of low-energy ion implantation is an effective means of creating nanosized phases and layers on the surface and in the near-surface area of materials of various natures.

This work is devoted to obtaining by the ion implantation method three-component nanophases and $Ga_{1-x}Al_xP$ nanofilms on the GaP surface and researching their composition, electronic and crystal structure.

2.Experimental methods

Single crystal samples of GaP (111) were chosen as the objects of investigation. Before ion implantation GaP (111) was degassed under conditions of ultra-high vacuum ($P = 10^{-7}$ Pa) at T = 900 K for ~ 4 hours. Researches were carried out with use of methods: Auger electron spectroscopy (AES), Reflection high-energy electron diffraction (RHEED), Ultraviolet photoelectron spectroscopy (UPS) and removal of energy and angular dependencies of the coefficients of secondary emission (CSE). To determine the profile of atom distribution by depth, a layer-by-layer Auger analysis was performed by spraying the sample surface with Ar^{+} ions at 3 keV at a drop angle of 80-85 relative to normal, the etching rate was (5±1) Å/min. Ultraviolet photo electronic spectra were recorded at photon energies $h\nu \approx 10.8$ eV. The source of photons was a standard hydrogen gas-discharge lamp. The technique and methodology of the experiments are described in detail in [13].

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3. Experimental results

Implantation of Al^+ ions with E_0=1 keV at a dose D = 10^{17} cm^{-2}, as in the case of GaAs [20], led to a homogeneous implementation of Al atoms in the middle part of the irradiated surface GaP. At the same time, the Al concentration on the surface was ~30-35 at. % and the entire irradiated surface were strongly disordered. After heating at T = 900 K, a three-component compound with an approximate composition of $Ga_{0.6}Al_{0.4}P$ was formed on the surface. Fig.1 indicates the initial state of GaP and GaP Auger spectra with $Ga_{0.6}Al_{0.4}P$ surface film. It is seen that, when a new connection is formed, the positions of peaks Ga (E = 54 and 79 eV) are slightly shifted and their intensity significantly decreases, the intensity and position of peak P (E = 121 eV) does not change significantly.

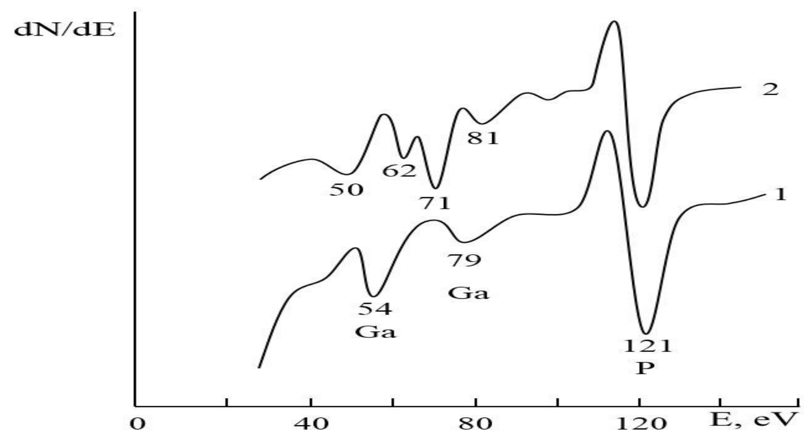

Fig.1. Initial state of Auger spectra: 1- Single crystal GaP (111), 2-Film $Ga_{0.6}Al_{0.4}P$/GaP (111).

New peaks with energies 71 and 81 eV are appearing, typical for Al and its connection with GaP. The intensities of these peaks practically do not change to a depth h ≈ 30-35 Å. Analysis of the full Auger electron spectroscopy indicated that after ion implantation and annealing a heterostructured film $Ga_{0.6}Al_{0.4}P$ with thickness 30-35 Å is formed, and a transition layer 50-60 Å is formed between the film and the substrate (Fig.2).

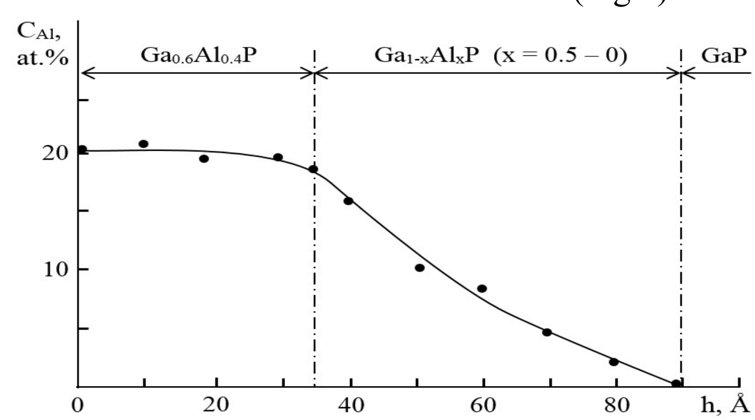

Fig.2. Dependence of concentration of Al atoms measured after heating at T=900 K GaP implanted with Al^+ ions with E_0=1 keV at dose D = 10^{17} cm^{-2}

Figure 3 indicates the angular dependence of inelastic reflected electrons η for pure GaP and GaP with $Ga_{0.6}Al_{0.4}P$ film, measured at E_p = 2000 eV. It can be seen that the curves η(φ) of these samples have non-monotone character and the position of the main peaks practically coincides with each other, i.e. it can be assumed that GaP and GaAlP have the same crystal structure with close lattice parameters. Researches carried out using the RHEED method indicated that $Ga_{0.6}Al_{0.4}P$ film crystallizes into a cubic lattice with a constant lattice a = 5.45 Å.

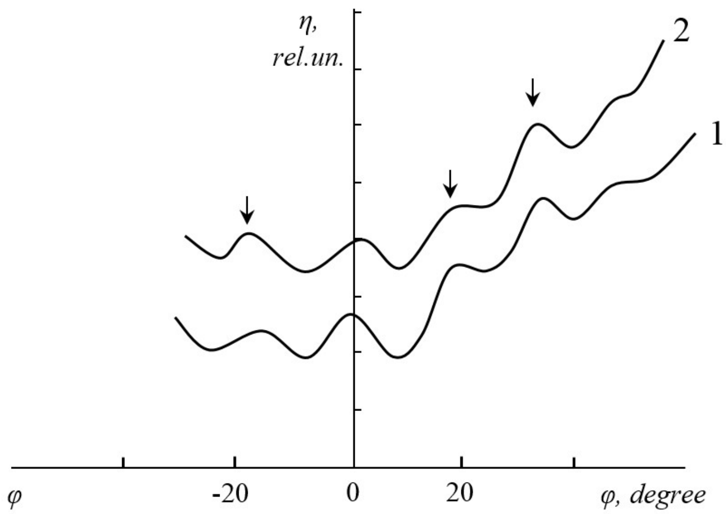

Fig.3. Dependence of η on the angle of incidence φ beam of primary electrons for: 1 - Single crystal GaP (111), 2 - GaP (111), with $Ga_{0.6}Al_{0.4}P$ film 35-40 Å thickness.

It should be noted that at D <10^{14} cm^{-2} nanocrystalline phases of $Ga_{0.6}Al_{0.4}P$ were not clearly distinguished, and at D ≥ 10^{16} cm^{-2} the boundaries of individual phases were overlapping and solid film formation.

Conclusion

Implantation of Al^+ ions with E_0 = 1 keV in GaP in combination with annealing, nanocrystalline phases (in D interval = $5\cdot10^{14}$ - $8\cdot10^{15}$ cm^{-2}) and nanofilms (at D = $4\cdot10^{16}$ cm^{-2}) $Ga_{0.6}Al_{0.4}P$ with thickness h = 35-40 Å were obtained. It is shown that these phases and films crystallize into a cubic lattice and the parameters of this lattice approximately coincide with those of the GaP lattice (a = 5.45 Å). The width of the band gap of $Ga_{0.6}Al_{0.4}P$ nanocrystalline phases, depending on size, increases from 2.4 eV (at d = 30-35 nm) to 3.1 eV (at d = 10-12 nm). Such structures have prospects in the creation of solar energy devices.

References

1. Zavaritskaya T N , A V Kvit, Mel'nik N N and Karavanskii V A . 1998 The structure of porous gallium phosphide // Semiconductors, volume 32, pp.213–217doi.org/10.1134/1.1187548
2. Agekyan V F, Ivanov-Omskii V I, Knyazevskii V N, Rud V Yu and Rud Yu.V. 1998 Optoelectronic phenomena in GaAs and GaP layers prepared by nitrogen treatment // Semiconductors volume 32, pp. 1075–1076, doi.org/10.1134/1.1187570

3. Seredin P V, Domashevskaya E P, Arsentyev I N, Vinokurov D A, Stankevich A L and Prutskij T. 2013 Superstructured ordering in $Al_xGa_{1-x}As$ and $Ga_xIn_{1-x}P$ alloys // Semiconductors volume 47, pp. 1–6, https://doi.org/10.1134/S106378261301020X
4. Wei Su-Huai, Zunger A. 1994 Optical properties of zinc-blende semiconductor alloys: Effects of epitaxial strain and atomic ordering // Phys.Rev. B, 49, 14337 doi.org/10.1103/PhysRevB.49.14337.
5. Ryumantsev O I, Brunkov P N, Pirogov E V and Egorov A Yu. 2010 Study of defects in heterostructures with GaPAsN and GaPN quantum wells in the GaP matrix // Semiconductors volume 44, pp. 893-897, doi.org/10.1134/S1063782610070110
6. Kent P R C and Zunger A 2001 Theory of electronic structure evolution in GaAsN and GaPN alloys // Phys.Rev. B, Phys.Rev.B 64, 115208 , doi.org/10.1103/PhysRevB.64.115208
7. Putyato M A , Valisheva N A , Petrushkov M O , Preobrazhenskii V V , Chistokhin I B , Semyagin B R , Emel'yanov E A , Vasev A V , Skachkov A F , Yurko G I and Nesterenko I I 2019 A Lightweight Flexible Solar Cell Based on a Heteroepitaxial InGaP/GaAs Structure // Technical Physics volume 64, pp. 1010–1016(2019), doi.org/10.1134/S106378421907020X
8. Green M A, Emery K, Hishikaw Y a, Warta W, Dunlop E D, Levi D H and Ho-Baillie A W Y 2016// Prog. Photovolt.: Res. Appl. Vol.25.N 1.P.3-13. DOI: 10.1002/pip.2855
9. 11. Dyadenchuk A F and Kidalov V V. 2015 The use of porous A3B5 compounds for supercapacitor plates // Journal of Nano- and Electronic Physics, Volume 7, No. 1, 01021 (4cc) (in Russian).
10. Umirzakov B E, Pugacheva T S, Tashatov A T and Tashmukhamedova D A. 2000 Electronic structure and optical properties of CaF {sub 2} films under low energy Ba {sup+} ion-implantation combined with annealing // Nuclear Instruments and Methods in Physics Research. Section B, Beam Interactions with Materials and Atoms; Journal Volume: 166-167; Journal Issue: 1-4, DOI: 10.1016/S0168-583X(99)01151-9.
11. Isakhanov Z A , Mukhtarov Z E , Umirzakov B E and Ruzibaeva M K 2011 Optimum ion implantation and annealing conditions for stimulating secondary negative ion emission. Tech. Phys 56: 546, doi.org/10.1134/S1063784211040177
12. Donaev S B, Djurabekova F, Tashmukhamedova D A and Umirzakov B E. Formation of nanodimensional structures on surfaces of GaAs and Si by means of ion implantation. Physica status solidi (c) 12 (1-2), 89-93, doi.org/10.1002/pssc.201400156.
13. Umirzakov B.E., Normuradov M.T., Tashmukhamedova D.A., Tashatov A.K. Nanomaterials and prospects for their application. - Tashkent: MERIYUS, 2008 .- 256 p. (in Russian).
14. Boltaev Kh Kh ,Tashmukhamedova D A 2014 Umirzakov B E .2014 Structure and electronic properties of nanoscale phases and nanofilms of metal silicides produced by ion implantation in combination with annealing // Journal of Surface Investigation. X-ray, Synchrotron and Neutron Techniques volume 8, pages 326–331, doi.org/10.1134/S1027451014010108