

Liquid phase epitaxy, structural, and electrical properties of $(\text{Si}_2)_{1-x}(\text{GaP})_x$ solid solutions on Si(111) substrates

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The paper presents the production of a heteroepitaxial GaP layer on a Si(111) substrate using a buffer, continuous epitaxial layer $(\text{Si}_2)_{1-x}(\text{GaP})_x$ $0 \leq x \leq 1$ from a tin solution-melt. The generalized moments of the components of the solid solution $(\text{Si}_2)_{1-x}(\text{GaP})_x$ were calculated and it was shown that the formation of epitaxial layers is more probable: $m^{**}_{\text{GaP}} = 3.96856 \cdot 10^{-9}$ C/m and $m^{**}_{\text{Si}_2} = 2.55856 \cdot 10^{-9}$ C/m. The single crystallinities of the grown epitaxial layers are investigated. The triangles formed at the beginning of growth on the surface of the Si substrate show that the $(\text{Si}_2)_{1-x}(\text{GaP})_x$ layers began to grow in the direction with the orientation (111). Structural study showed an increase in the lattice period of the film $a_{(\text{Si}_2)_{1-x}(\text{GaP})_x} = 0.54619 \pm 0.00004$ nm relative to Si ($a_{\text{Si}} = 0.54307 \pm 0.00004$ nm) and GaP ($a_{\text{GaP}} = 0.54451 \pm 0.00004$ nm), which is explained by the arising compressive stresses along the plane of the epitaxial layers. SEM analyses confirmed the presence of Si, Ga, P components in the $(\text{Si}_2)_{1-x}(\text{GaP})_x$ film. Using CoreAFM, nanosized height nanoscale islands with a size of 50-60 nm and nano-pits with a depth of 8 nm on the surface of the $(\text{Si}_2)_{1-x}(\text{GaP})_x$ film were detected. The films had n-type conductivity with a concentration of $n = 5 \cdot 10^{18} \text{ cm}^{-3}$ and a mobility of $\mu = 80 \text{ cm}^2 \cdot \text{V}^{-1} \cdot \text{sec}^{-1}$ of charge carriers at 300 K. The film thicknesses varied within 15-30 μm depending on the growth conditions. The photosensitivity of the $\text{pSi-n}(\text{Si}_2)_{1-x}(\text{GaP})_x$ structure covered the spectral range of 1.1-2.58 eV.

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1. Introduction

At present, in the field of semiconductor instrumentation, the demand for high-speed, highly efficient and inexpensive semiconductors and structures (manufactured on their basis) is growing [1]. Accordingly, obtaining semiconductor materials with high electrophysical, photoelectric parameters with a crystalline perfect structure is an urgent task of micro and nanoelectronics.

Well-known semiconductor materials such as GaAs, GaP, GaSb, GaN, InSb, InP, InAs, ZnSe have high photoelectric parameters and are used as active elements in the development of optoelectronic and other devices, but their capabilities are also limited due to some electrophysical parameters. Therefore, growing solid solutions synthesized from several semiconductors is of undoubted interest for the development of modern semiconductor materials science, since it will combine the advantages of each of the components. On the other hand, the reserves of these components in the earth's crust are very small and the synthesis of high-quality crystals of binary compounds is a technologically difficult task and are expensive materials. Therefore, the possibility of obtaining epitaxial films of solid solutions of binary compounds based on relatively cheap Si and

heterojunctions on Si substrates makes them promising materials [2-4]. Heterojunctions based on wide-bandgap $\text{A}^{\text{III}}\text{B}^{\text{V}}$ compounds are one of the most important methods for implementing injection of minority current carriers into materials with monopolar conductivity. A heterojunction, in contrast to a homojunction, significantly increases the region of maximum spectral sensitivity, and therefore the efficiency of photoconversion and other values of the optical parameters of the structure [5,6]. However, high-quality growth of (III-V), (II-VI) compounds on Si is difficult due to the mismatch in the lattice constant and thermal expansion coefficient [7,8].

In terms of integrating Si technology with III-V compounds, one of the promising materials is GaP. The synthesis of solid solutions consisting of Si and GaP components combines the photosensitive regions of Si and GaP and has a wider sensitivity spectrum range than Si and GaP. And this solid solution with continuous variable chemical compositions along the growth direction serves as an intermediate epitaxial buffer layer between Si (substrate) and GaP (film) [9]. Since expanding the sensitivity region of the device is important for creating more efficient devices, such as solar cells and photo sensors [10-12]. In [13], a GaP/Si heterojunction interface was studied using X-ray photoelectron spectroscopy (XPS). The GaP film was obtained on a Si substrate using

metal-organic chemical vapor deposition for use in silicon heterojunction solar cells. Because the heterostructures obtained based on the GaP/Si heterojunction exhibited low open-circuit voltages in all cases, the authors attributed this to the interface state of the substrate.

When growing GaP epitaxial layers on Si(100) substrates using metal-organic chemical vapor deposition, a high defect density is observed. These defects are associated with antiphase domains formed in the GaP film during growth. This degraded the photovoltaic parameters of the structure [14].

Incompatibility of intrinsic properties of materials such as lattice mismatch, interfacial heterovalence, thermal expansion mismatch creates crystal defects including threading dislocations (TD) and stacking fault pyramids (SFP) and microtwins (MT), as well as dislocations [15-18].

As is known, the properties of heterojunctions, including Si-GaP, are mainly determined by the quality of the substrate-film interface. One solution to this problem is to grow a film with a buffer layer between the film and the substrate [19,20]. Continuous variable chemical composition of the solid solution from the substrate to the surface serves as a smooth smoothing factor to overcome the difference in structural quantities between the substrate and the film. With this technological method, it is possible to reduce the dislocation density and emerging microcracks at the heterointerface of the structure [21]. In some works [22,23], theoretical calculations were performed to predict the probability of their formation before the experiment to obtain complex solid solutions. The values of the generalized moments of the component and the potential of multielectron atoms were successfully used.

This reduces the number of unnecessary preliminary experiments, material consumption and time. The lattice parameter values of GaP and Si are matched satisfactorily ($a_{\text{Si}} = 0.54307$ nm, $a_{\text{GaP}} = 0.54451$ nm). The lattice constant mismatch is 0,26% at 300 K, but the thermal expansion coefficients of GaP $\alpha_{\text{GaP}} = 4,7 \cdot 10^{-6} \text{K}^{-1}$ and Si $\alpha_{\text{Si}} = 2,3 \cdot 10^{-6} \text{K}^{-1}$ differ by more than 2 times. Therefore, to obtain a crystalline perfect film, it is advisable to grow GaP epitaxial layers on Si substrates through a $(\text{Si}_2)_{1-x}(\text{GaP})_x$ buffer layer, which smooths out the discrepancies in thermal parameters between the substrate and the epitaxial film.

In this work, we present the preparation of Si-GaP heterostructures using a buffer continuous solid solution $(\text{Si}_2)_{1-x}(\text{GaP})_x$ ($0 \leq x \leq 1$). To grow GaP epitaxial films on Si substrates, the liquid-phase epitaxy method from a limited volume of the melt solution was chosen. The LPE method allows growing layers of the solid solution $(\text{Si}_2)_{1-x}(\text{GaP})_x$ ($0 \leq x \leq 1$) with a smoothly and monotonously changing composition from Si to GaP along the growth direction. Forced program and sufficiently low cooling rate of the melt solution contributes to obtaining a solid solution $(\text{Si}_2)_{1-x}(\text{GaP})_x$ from the conditions of an equilibrated thermodynamic state of the liquid phase. This contributes to the growth of an epitaxial film with a perfect crystalline structure.

2. Materials and methods

Epitaxial structures were obtained in a setup for growing films from a limited volume of a melt solution. A vertical quartz vessel filled with purified hydrogen was used as a reactor. The substrates were placed horizontally in a graphite cassette parallel to each other. The distance between the substrates varied within 0.5 mm - 2.5 mm.

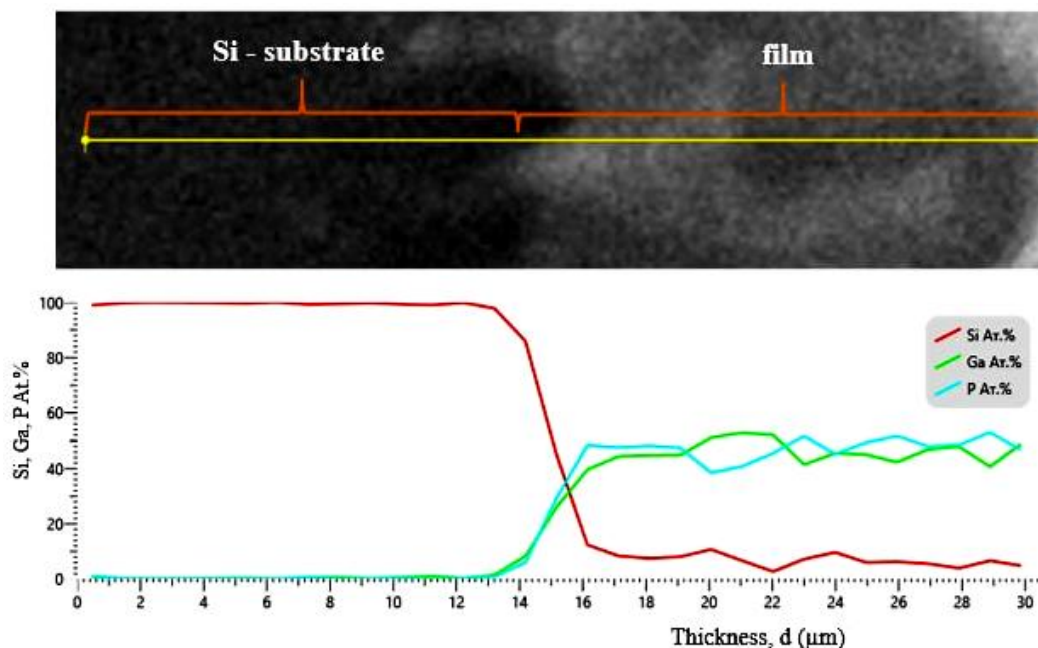


Fig. 1. Raster image of a cross-section (a) and the distribution profile of Ga, P, Si atoms (b) across the thickness of the epitaxial layer of the $\text{Si}-(\text{Si}_2)_{1-x}(\text{GaP})_x$ solid solution (colour online)

Chemically pure (99.999%) Si (111) single-crystal wafers with a diameter of 20 mm and a thickness of 350–400 μm were used as substrates. Silicon and gallium phosphide powders were used to obtain a tin-based melt solution.

The thickness of the epitaxial films was measured with a LIZ thickness meter with an accuracy of $\pm 1 \mu\text{m}$. Scanning electron microscope images scaled to film thickness were also used (Fig. 1).

The surface morphology of the grown films was studied using scanning electron microscopy (SEM EVO MA 10 (Zeiss), JEOL JSM-IT510) and atomic force microscopy (CoreAFM). Structural phase studies were performed on high-resolution diffractometers D2 PHASER/Bruker (GID and GONIO modes using HR-XRD, Panalytical/Empryan).

The specific resistance, conductivity type, concentration and mobility of charge carriers in epitaxial layers of the $(\text{Si}_2)_{1-x}(\text{GaP})_x$ solid solution were investigated by the Hall method using an automated measuring complex HMS-7000 (ECOPIA, South Korea) at 300K.

To ensure efficient current collection, ohmic contacts were formed on the epitaxial layers using thermal evaporation of metals in a vacuum at a pressure of 10^{-5} Torr and a substrate temperature of 460°C . First, a high-purity silver (Ag) layer was deposited on the surface of the epitaxial layers, providing low contact resistance. A nickel (Ni) layer was then deposited, serving as a protective coating and diffusion barrier (specifically, preventing oxidation). After depositing the Ag/Ni metal layers and evacuating the chamber to 10^{-5} Torr , the samples were thermally annealed. Annealing was performed at the same temperature of 460°C for 3 minutes in a vacuum, which ensured metal diffusion and the formation of a reliable ohmic contact.

Four ohmic contacts were applied to the surface of the samples, located at the edges closer to the vertices of the quadrangle, as shown in Figure 2. The smaller the d_c/L_c ratio, where d_c is the average contact diameter and L_c is the distance between contacts, the smaller the measurement error. Therefore, the contact areas were chosen to be as small as possible. The measurement error for resistivity, Hall mobility, and charge carrier concentration was $\sim 2\%$.

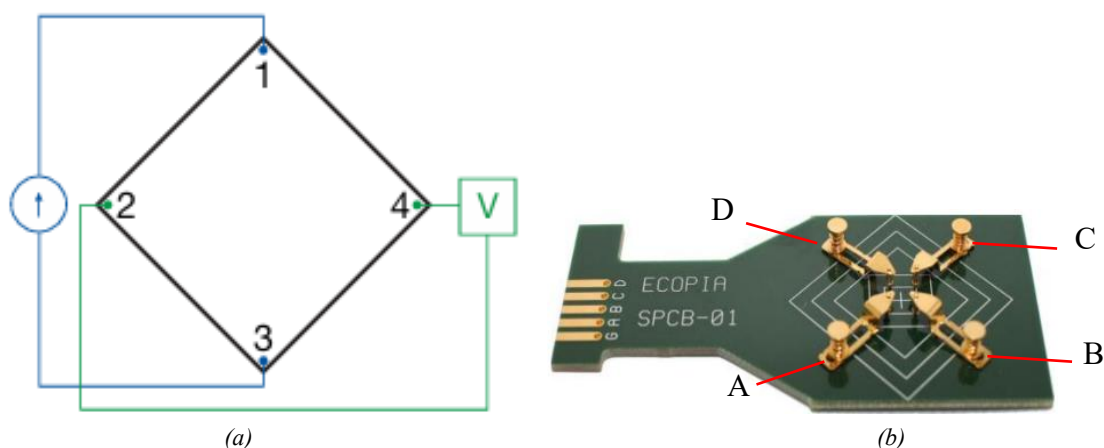


Fig. 2. Configuration of current-collecting contacts (1, 2, 3 and 4) applied to the surface of the epitaxial film $(\text{Si}_2)_{1-x}(\text{GaP})_x$ for measuring electrophysical parameters using the Hall method (a), external view of the sample holder (b) (colour online)

Spectral characteristics of the samples were measured using a monochromator with a slit diameter of 0.2 mm. An MDR-23 (or similar) device with a diffraction grating and an adjustable entrance slit was used as a monochromator. A DKsSh-150 xenon lamp (continuous spectrum) was used as a radiation source. Photocurrent was recorded using a Keithley 6485 picoammeter.

3. Results and discussion

3.1. Theoretical part

To grow a solid solution of $(\text{Si}_2)_{1-x}(\text{GaP})_x$, the possibility of forming a solid solution between silicon and gallium phosphide was first theoretically investigated.

Developing the theory of the generalized moment introduced by V. K. Semenchenko [24] to characterize the force field of ions and molecules, it is possible to determine the mutual solubility of different elements with a high probability. This substantiated the conditions for the formation of solid solutions of substitution of elementary semiconductors and semiconductor compounds [25].

However, in these works, the electronic structure, characterized by the physicochemical properties of elements and compounds, is not taken into account for the generalized moment of an ion or atom. One of these quantities is the electronegativity of elements.

Electronegativity is a fundamental characteristic of an atom and quantitatively describes its ability to shift electron density toward itself in a chemical bond, thus determining the degree of bond polarization. In molecular

and crystalline systems, this manifests itself in changes in the effective charge of atoms, local electric fields, and potential relief parameters.

In binary and multicomponent compounds, the difference in atomic electronegativity significantly influences the nature of interatomic interactions, determining the ratio of the covalent and ionic components of the chemical bond. In particular, for binary compounds of the III-V type, an increase in the difference in electronegativity between atoms of groups III and V ($\Delta\chi = |\chi_{III} - \chi_V|$) leads to a strengthening of the ionic component of the bond. This is accompanied by an increase in the effective charge transfer between sublattices, an increase in the Coulomb contribution to the interaction energy, and, consequently, an increase in the bond energy and the rigidity of the crystal lattice [24].

Taking these factors into account, the generalized moments of gallium phosphide molecules were calculated. The calculations were based on V.K. Semenchko's formula, taking into account the characteristics of the electronic structure and electronegativity of gallium and phosphorus atoms. Tabulated values of the covalent radii and electronegativity differences of these elements according to the L. Pauling scale were used [26,27]:

$$m_{Ga}^{**} = \frac{(N_{Ga} - \gamma_{Ga} + N_P - \gamma_P - 0.35) \cdot e \cdot (1 + [\chi_{Ga} - \chi_P])}{r_{Ga} + r_P} \quad (1)$$

where N_{Ga} , N_P - the atomic numbers of gallium and phosphorus atoms in the periodic table of chemical elements; γ_{Ga} , γ_P - the shielding coefficients of the corresponding atoms; r_{Ga} , r_P - their covalent radii; e is the elementary charge.

From relation (1), it follows that the potential of a heteropolar bond exceeds that of a homopolar bond, due to the more pronounced transfer of electron density and the enhanced Coulomb interaction between partially charged atoms. Therefore, it can be expected that the value of m_{GaP}^{**} reflects the individual electrophysical characteristics of GaP molecules and makes a significant contribution to intermolecular interactions in multicomponent systems.

The calculations performed show that the formation of a solid solution $(Si_2)_{1-x}(GaP)_x$ is probable, which is confirmed by the close orders of magnitude of the generalized moments: $m_{GaP}^{**} = 3.96856 \cdot 10^{-9}$ C/m and $m_{Si_2}^{**} = 2.55856 \cdot 10^{-9}$ C/m. This ratio indicates the comparability of interatomic interactions in the components of the system and promotes the formation of a homogeneous solid solution.

Thus, along with geometric factors, effective charges, and types of electron shells, taking into account the electronegativity of atoms allows for a more correct description of the physical, especially energy properties of semiconductors based on the primary fundamental parameters of atoms of chemical elements, which will

contribute to the development of the molecular-statistical theory of solutions.

3.2. Growth of solid solutions $(Si_2)_{1-x}(GaP)_x$ from solution-melt on Si substrates

The production of solid solutions $(Si_2)_{1-x}(GaP)_x$ was carried out from a limited Sn-Si-GaP melt solution in a single technological cycle in different temperature modes in the range of 1000 °C - 800 °C. The cooling rate was 0.5-2 °C /min. Before loading the silicon wafers into the liquid-phase epitaxy reactor, they were boiled in alcohol. They were then immersed in hydrofluoric acid (HF) for 2 minutes. Afterward, the wafers were rinsed with deionized water and purged with a dry stream of nitrogen. A detailed description of the technique used is presented in [28].

When grown from the liquid phase, the components of the epitaxial film dissolve in the tin solvent to saturation. After contact with the substrate, the saturated Sn+Si+GaP solution-melt system cools at a rate of 1 °C/min, and the supersaturated components of the dissolved material begin to crystallize on the substrate surface in the form of an epitaxial film. The chemical composition of the Sn+Si+GaP solution-melt was determined from the state diagram of the components [29,30].

The main condition for the crystallization of the $(Si_2)_{1-x}(GaP)_x$ solid solution is high supersaturation of the melt solution for both components (Si and GaP) at the crystallization front of the epitaxial layers. This condition corresponds to the growth temperature range from 1000-800 °C, selected from the phase diagram of the multicomponent system (Sn-Si-GaP). The composition of the melt solution corresponding to this temperature range: Sn - 79.8 g. (96.9 wt.%), Si - 0.49 g. (0.59 wt.%), GaP - 1.89 g. (2.29 wt.%), which corresponds to Sn - 92.39 mol.%, Si - 2.39 mol.% and GaP - 5.19 mol.%, provides the necessary supersaturation of the melt solution for both components of the solid solution.

In the melt solution, the silicon and gallium phosphide components will be in molecular or nanocluster form [31]. During the formation of epitaxial layers of $(Si_2)_{1-x}(GaP)_x$ from the liquid phase, the chemical composition of the film varies along the growth direction, i.e. silicon molecules are replaced by gallium phosphide molecules. Molecules migrating along the surface will crystallize precisely in those places where the energy of elastic distortion of the crystal lattice is minimal. This facilitates the growth of an epitaxial film with a perfect crystalline structure.

Distributions of solution-forming components over the thickness of the epitaxial layer of the obtained $(Si_2)_{1-x}(GaP)_x$ structures indicate their perfection. Note that inclusions of other phases were absent. Elemental maps of the $(Si_2)_{1-x}(GaP)_x$ film surface indicated the presence of Si, Ga, and P elements in the film composition. Quantitative analysis of the film surface composition is shown in Fig. 3.

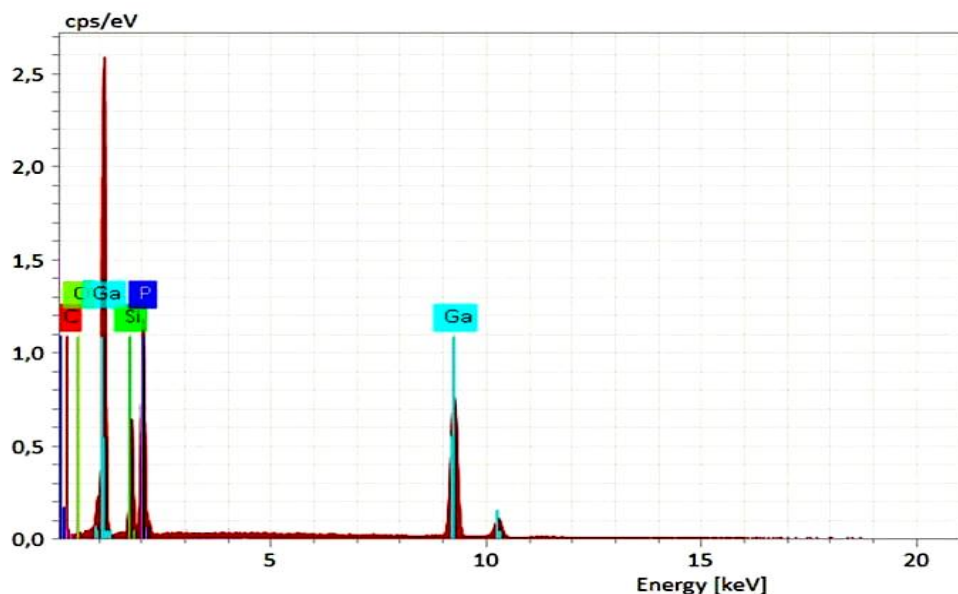


Fig. 3. EDS spectra of the surface of epitaxial layers $(\text{Si}_2)_{1-x}(\text{GaP})_x$ (colour online)

Quantitative analysis of the chemical composition of the film surface obtained using SEM (Fig. 3) indirectly showed that $(\text{Si}_2)_{1-x}(\text{GaP})_x$ films with a solid solution structure with different final surface compositions were indeed grown on the silicon substrate. In this case, the final chemical composition of the film surface depended on the growth temperature range, although the crystallization onset temperature was the same.

We simultaneously studied changes in the chemical composition of the $(\text{Si}_2)_{1-x}(\text{GaP})_x$ solid solution along the growth direction. Fig. 1 shows that at a thickness of $h = 20.6 \mu\text{m}$, the chemical composition of the $(\text{Si}_2)_{1-x}(\text{GaP})_x$ film reaches a value of $x = 1$ (Fig. 1). In the $\text{Si}-(\text{Si}_2)_{1-x}(\text{GaP})_x$ structure, a homojunction can be expected at the substrate-film interface, which begins in the region where

the silicon film-substrate growth begins. This enables us to grow epitaxial layers with minimized stresses between the film and the substrate.

To study the single crystallinity of the grown epitaxial layer $(\text{Si}_2)_{1-x}(\text{GaP})_x$ on the Si(111) substrate, the film growth process was interrupted and the samples were examined using a microscope. Surface images showed $(\text{Si}_2)_{1-x}(\text{GaP})_x$ nuclei, the formation of which occurs along the selected substrate directions. The triangles formed at the beginning of growth on the surface of the Si substrate show that the epitaxial layers began to grow in the direction of the Si substrate with the orientation (111) (Fig. 4). This allows us to expect that further growth will ensure the formation of single crystal layers epitaxially continuing the crystalline structure of the substrate.



Fig. 4. Formation of embryos on the Si (111) substrate in the initial stage of epitaxy of the solid solution $(\text{Si}_2)_{1-x}(\text{GaP})_x$ (colour online)

After the complete completion of the growth process of the epitaxial layers $(\text{Si}_2)_{1-x}(\text{GaP})_x$ on the substrate, the film monocristallinity was studied using the XRD method. The grown $(\text{Si}_2)_{1-x}(\text{GaP})_x$ solid solutions were single crystals and had cubic structures of the sphalerite type with the orientation (111) (Fig. 5a,b). The surface of the Si substrate was also examined as a control, its X-ray diffraction pattern is shown in Fig. 6a, b. The analysis showed that the substrate surface corresponds to the crystallographic plane (111).

The diffraction patterns showed a maximum (111), which corresponded to reflection from the lattice of almost only the grown phase. The maximum was shifted compared to reflection from the lattice of the Si substrate toward smaller Bragg angles.

A significant broadening of the diffraction maximum indirectly confirms the suggestion of the presence of fairly strong azimuthal surface stresses.

The shift of the maxima to the region of smaller Bragg angles indicated an increase in the lattice period of the grown solid solution ($a_{(\text{Si}_2)_{1-x}(\text{GaP})_x} = 0.54619 \pm 0.00004$ nm), since the lattice periods of the phases Si ($a_{\text{Si}} = 0.54307 \pm 0.00004$ nm) and GaP ($a_{\text{GaP}} = 0.54451 \pm 0.00004$ nm) have smaller values. The reason for such an increase in the lattice period of the grown phase can only be compressive stresses arising on the surface (in the surface plane), tending to increase the layer thickness, and thus causing an increase in the lattice period of the grown phase. The observed lattice parameter ($a_{(\text{Si}_2)_{1-x}(\text{GaP})_x} = 0.54619 \pm 0.00004$ nm) is the deformed parameter of the solid solution in a stressed state.

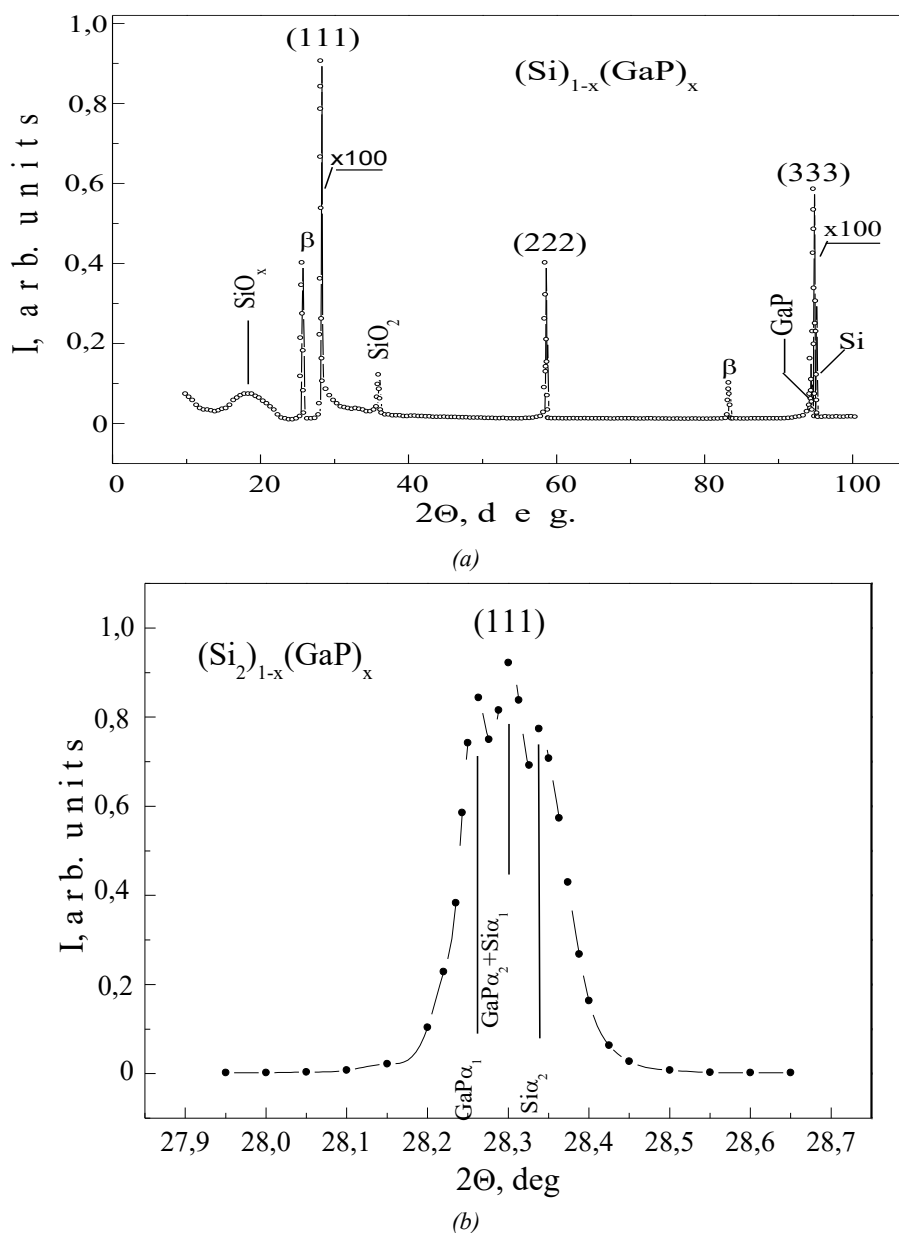


Fig. 5. (a) X-ray diffraction pattern of a film solid solution $(\text{Si}_2)_{1-x}(\text{GaP})_x$; (b) Section of the diffractogram from the surface of the $(\text{Si}_2)_{1-x}(\text{GaP})_x$ film

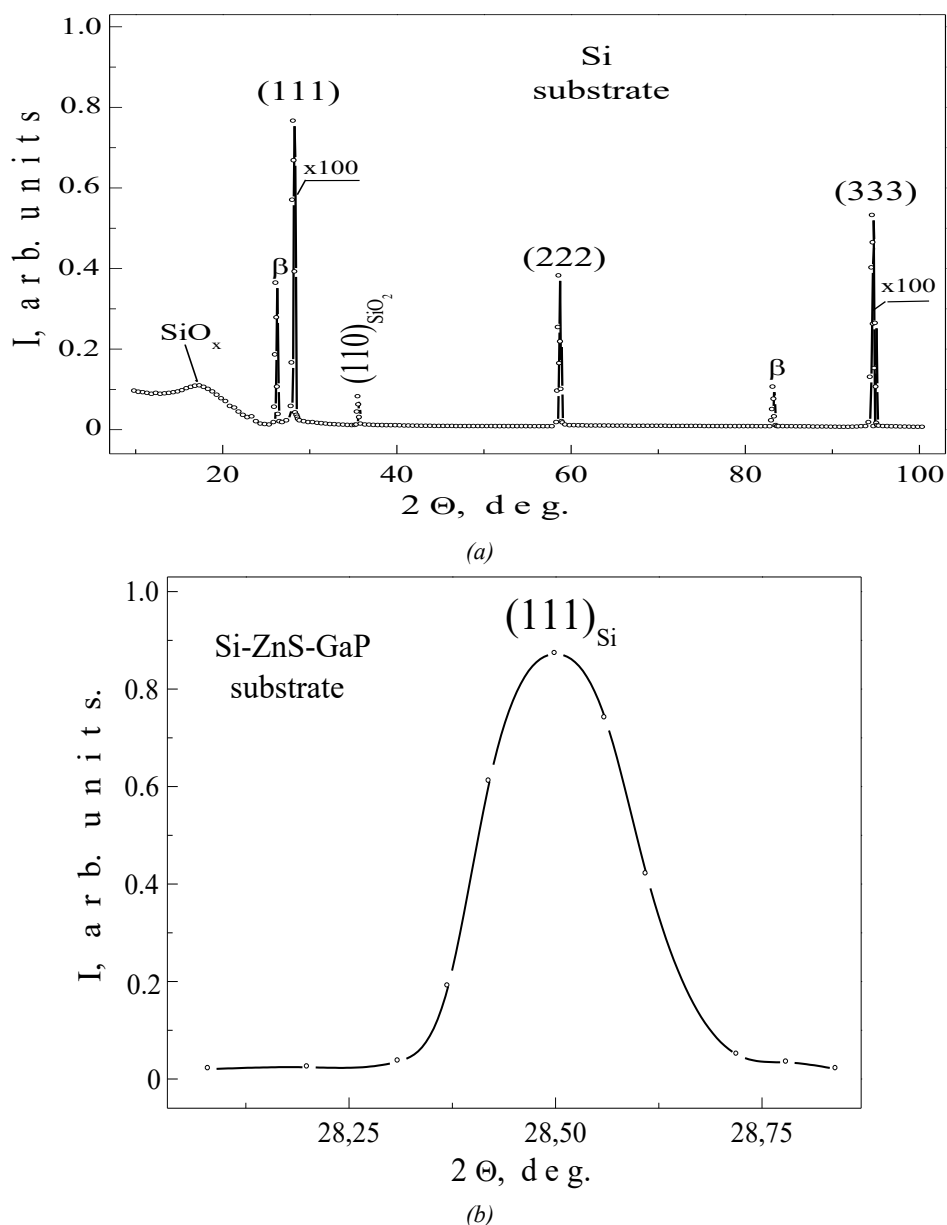


Fig. 6. (a) X-ray diffraction pattern of Si substrate; (b) Section of the diffraction pattern from the surface of the Si substrate

Using CoreAFM, the surface morphology of the grown $(\text{Si}_2)_{1-x}(\text{GaP})_x$ films was studied. Nanosized crystals were found on a plane with an image size of $1.5 \times 1.5 \mu\text{m}^2$: the height of nanoscale islands is 50–60 nm and the width

is 40–50 nm (Fig. 7). Such nanosized crystals contribute to the expansion of the spectral sensitivity region of silicon. Nano-pits with a depth of 8 nm and a width of 42.4 nm were simultaneously observed (Fig. 8).

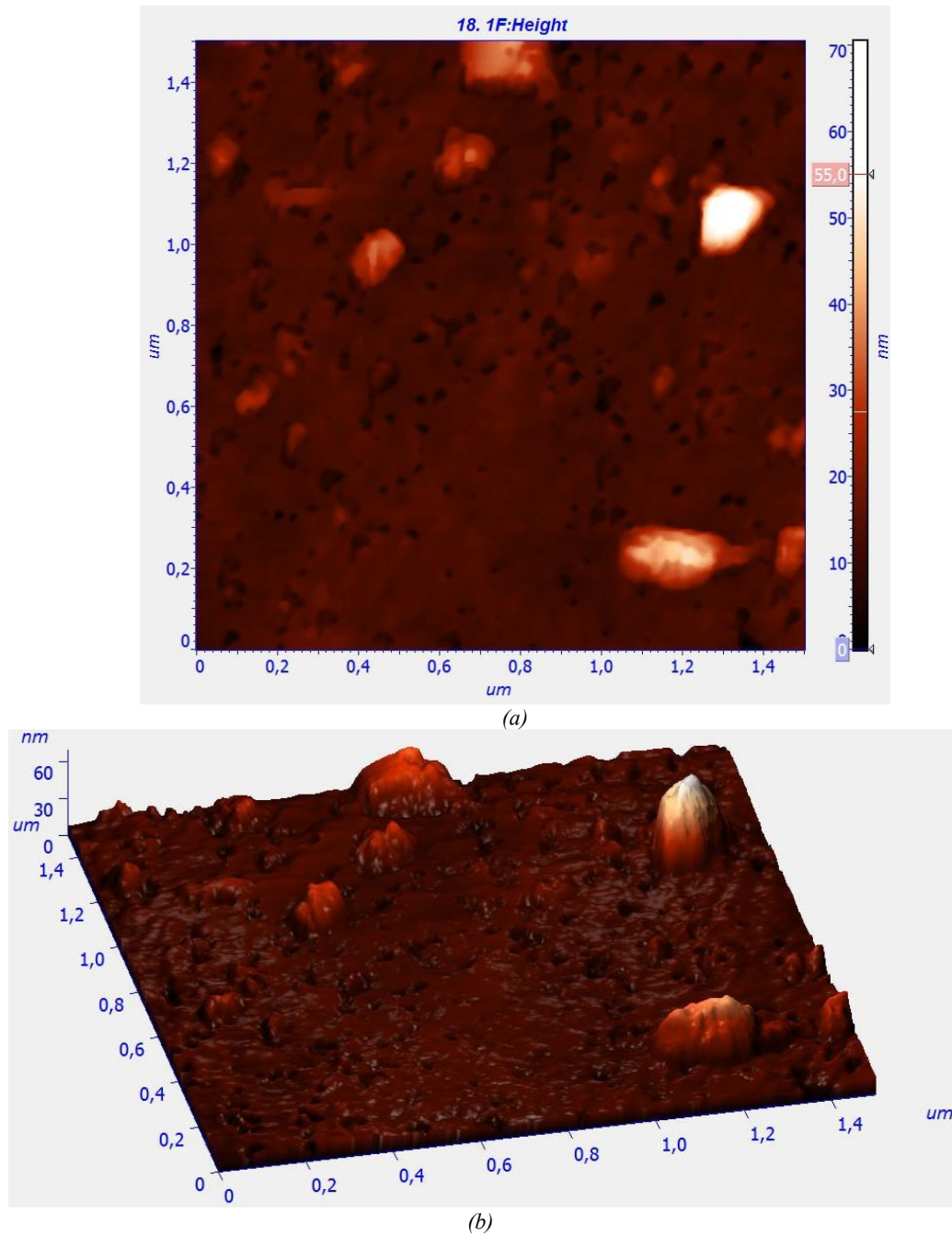
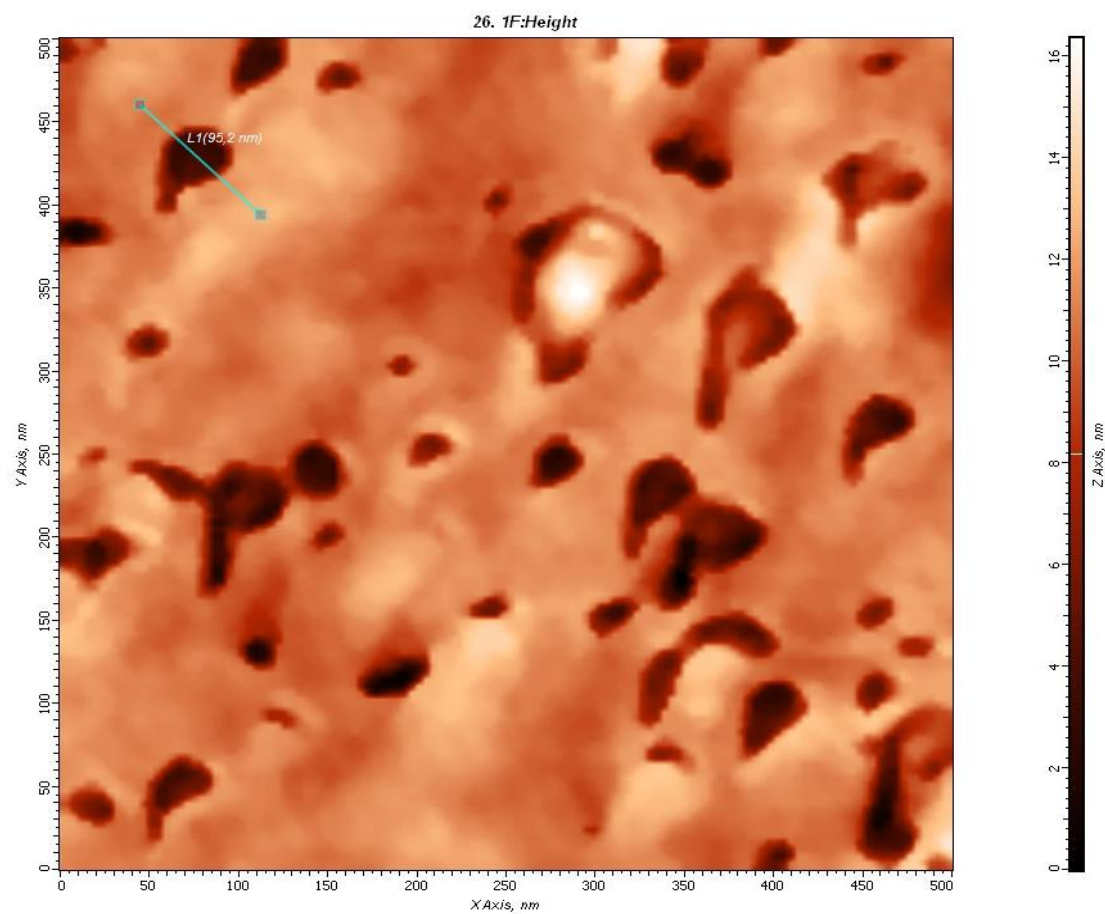
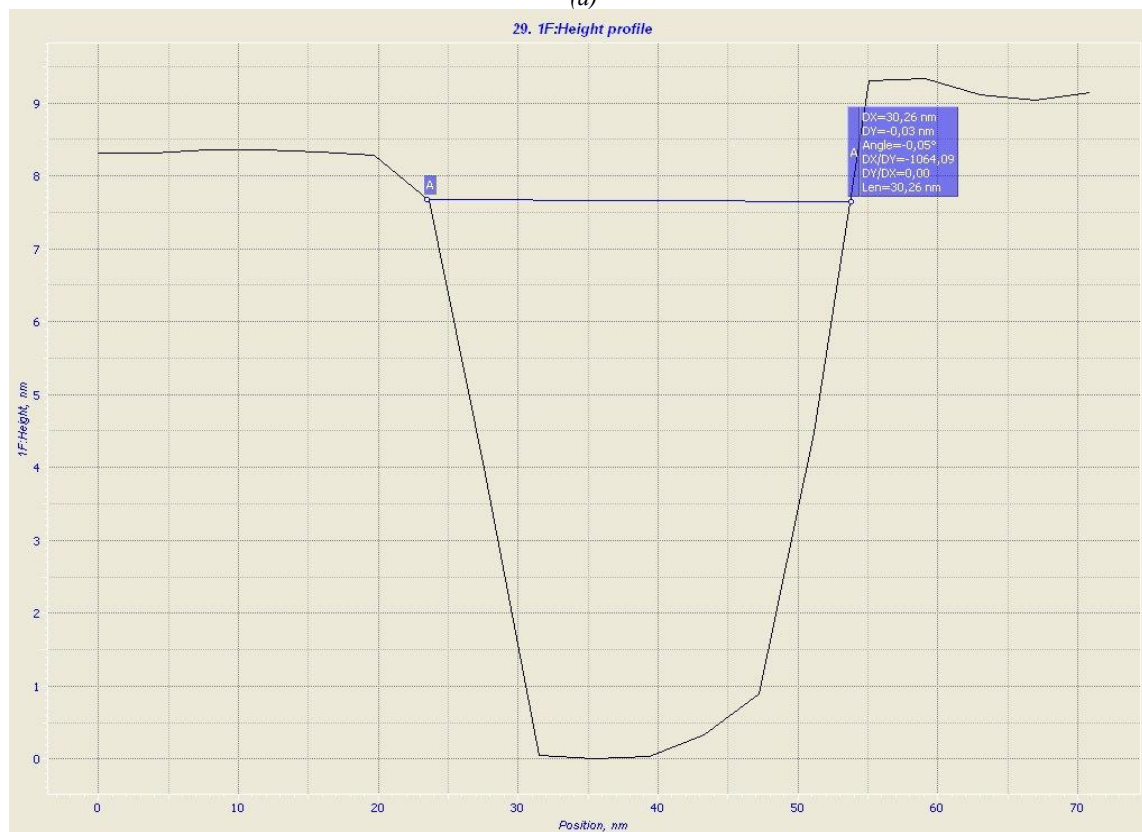


Fig. 7. Two-dimensional (a) and three-dimensional (b) images of the surface of the epitaxial film $(\text{Si}_2)_{1-x}(\text{GaP})_x$. The image size is $1.5 \times 1.5 \mu\text{m}^2$, the height of the nanoscale islands is 50-60 nm and the width is 40-50 nm on the substrate (colour online)



(a)



(b)

Fig. 8. Two-dimensional image of the surface of the epitaxial film $(\text{Si}_2)_{1-x}(\text{GaP})_x$ (a) and the dot depth profile (b) The image size is $1.5 \times 1.5 \mu\text{m}^2$, the nano-pits depth is 8 nm, the width is 42.4 nm (colour online)

As a semiconductor material, the electrophysical properties of the solid solution $(\text{Si}_2)_{1-x}(\text{GaP})_x$ were investigated. The grown epitaxial layers of solid solutions $(\text{Si}_2)_{1-x}(\text{GaP})_x$ had n-type conductivity with $n=5 \cdot 10^{18} \text{ cm}^{-3}$ concentration and $\mu=80 \text{ cm}^2 \cdot \text{V}^{-1} \cdot \text{sec}^{-1}$ charge carrier mobility at 300 K. The film thickness varied within 15–30 μm depending on the growth conditions.

It should be noted that the films were synthesized from a tin-based melt solution of the Sn–Si–GaP system. Therefore, the presence of tin atoms as an impurity in the solid solution cannot be ruled out. This can be considered self-doping, related to the growth conditions and the composition of the melt solution. The presence of tin likely influences the formation of electronic conductivity and may contribute to the observed high charge carrier concentration.

The photosensitivity of the $p\text{Si}-n(\text{Si}_2)_{1-x}(\text{GaP})_x$ structure was measured in the photodiode mode at a temperature of 300 K and is shown in Fig. 9. As can be seen from the figure, the photosensitivity was recorded in the spectral range of 1.1–2.58 eV, which indicates the formation of a Si donor energy level of intraband photogeneration of electron-hole pairs in the p-n junction layer.

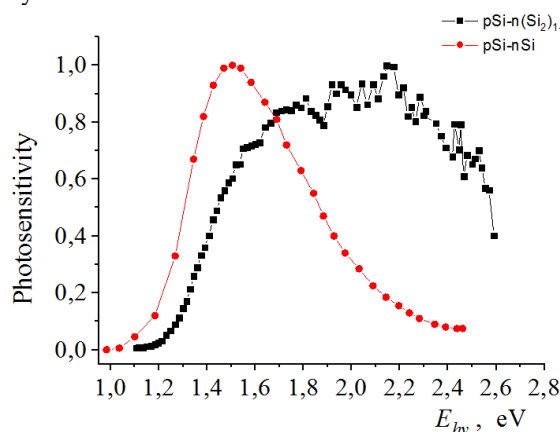


Fig. 9. Spectral sensitivity of $p\text{Si}-n\text{Si}$ and $p\text{Si}-n(\text{Si}_2)_{1-x}(\text{GaP})_x$ structures measured in photodiode mode (colour online)

On the other hand, the band gap of the solid solution, starting from the substrate-film heterointerface, expands to its surface due to the change in the chemical composition of the film. Due to the variability of the $(\text{Si}_2)_{1-x}(\text{GaP})_x$ solid solution, the photosensitive region of the spectrum of $p\text{Si}-n(\text{Si}_2)_{1-x}(\text{GaP})_x$ structures expands along the growth direction. The surface layer of the film serves as a "window", passing incident quanta of the spectrum. The generated electron-hole pairs inside the film, reaching the p-n junction, participate in current flow. Comparative experimental results show that the spectral sensitivity region of the $p\text{Si}-n(\text{Si}_2)_{1-x}(\text{GaP})_x$ ($0 \leq x \leq 1$) heterostructure is significantly wider than that of the well-known $p\text{Si}-n\text{Si}$ classical structures (Fig. 9).

4. Conclusion

In the present work, theoretical calculations were performed and the values of the generalized moments of the crystal-forming components Si, GaP for the formation of a solid solution $(\text{Si}_2)_{1-x}(\text{GaP})_x$ were determined: $m_{\text{GaP}}^{**}=3.96856 \cdot 10^{-9} \text{ C/m}$ и $m_{\text{Si}_2}^{**}=2.55856 \cdot 10^{-9} \text{ C/m}$.

Using a buffer layer, epitaxial layers of GaP and $(\text{Si}_2)_{1-x}(\text{GaP})_x$ were grown from a tin solution-melt on a Si(111) substrate. This allows smoothing out the difference in the coefficient of thermal expansion and lattice parameters between the substrate and the film along the growth direction.

With the interruption of the growth process, the initial stages of growth were studied and the formation of triangular islands on the surface of the Si(111) substrate, continuing the orientation of the substrate, was observed. X-ray diffractometry showed the single crystallinity of the grown films. The increase in the lattice period of the film $a_{(\text{Si}_2)_{1-x}(\text{GaP})_x}=0.54619 \pm 0.00004 \text{ nm}$ relative to Si and GaP is explained by the occurrence of compressive stresses along the plane of the film due to minor discrepancies in the lattice parameters and CTE between the substrate and the film. Consequently, nanosized nanoscale islands and nanopits were formed on the surface of the film. As a semiconductor material, the solid solution had n-type conductivity with a concentration of $n=5 \cdot 10^{18} \text{ cm}^{-3}$ and a mobility of $\mu=80 \text{ cm}^2 \cdot \text{V}^{-1} \cdot \text{sec}^{-1}$ of charge carriers at 300 K. The photosensitivity of the obtained $p\text{Si}-n(\text{Si}_2)_{1-x}(\text{GaP})_x$ structures cover a wide spectral range of 1.1–2.58 eV than that of Si and GaP. Therefore, such structures can be used to expand the spectral sensitivity region of silicon photodetectors and solar cells.

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