CURRENT TRANSFER IN p-Si–n-$(Si_2)_{1-x}(GaN)_x$ HETEROSTRUCTURE

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Abstract: This paper presents the results of a study on the growth of substitutional solid solutions $(Si_2)_{1-x}(GaN)_x$ on single-crystal Si (111) substrates by liquid-phase epitaxy from a limited volume of a tin solution-melt in a hydrogen medium and the current-voltage characteristic (CVC) of p-Si-n-$(Si_2)_{1-x}(GaN)_x$ structures.

Keywords: solid solutions, Si_2, GaN_x, single crystal, liquid phase epitaxy from tin solution, hydrogen environment, voltage characteristics.

Introduction: The development of semiconductor instrumentation is inextricably linked with the success of the technology for obtaining traditional semiconductor materials such as Ge and Si. However, these materials do not meet modern requirements, in particular, in terms of the spectral range of electromagnetic radiation, in terms of speed and temperature range of operation of optoelectronic devices based on them. Semiconductor binary compounds III-V, II-VI and their solid solutions with elemental semiconductors have come to replace traditional materials. Among binary compounds, gallium nitride (GaN) is one of the attractive materials. Light-emitting diodes, violet injection lasers, ultraviolet detectors, and high-temperature transistors have been developed on its basis [1, 2]. However, GaN is an expensive material; large-scale use of bulk elements based on it is not cost-effective. Therefore, at present, a significant factor hindering progress in this field is the lack of an available technology for obtaining GaN films with a low (less than 10^7 cm^{-2}) dislocation density on cheap conductive substrates. In this regard, the preparation of thin GaN layers of device quality on accessible substrates, such as Si, is one of the urgent problems of modern gallium nitride micro- and optoelectronics. In this aspect, the most important and still unsolved problem is to overcome the large difference in the lattice constant and thermal expansion coefficient of single-crystal Si and GaN, in addition, the GaN lattice is hexagonal, and Si is cubic.

This paper presents the results of a study on the growth of substitutional solid solutions $(Si_2)_{1-x}(GaN)_x$ on single-crystal Si (111) substrates by liquid-phase epitaxy from a limited volume of a tin solution-melt in a hydrogen medium and the current-voltage characteristic (CVC) of p-Si-n-$(Si_2)_{1-x}(GaN)_x$ structures.

Materials and methods: Solid solutions $(Si_2)_{1-x}(GaN)x$ were grown on KDB-0.01 single-crystal Si washers with a diameter of 20 mm, a thickness of 400 μm, and crystallographic orientation (111). During growth, the parameters of the technological process of liquid-phase epitaxy were varied: the composition of the solution-melt, the temperature of the beginning and end of crystallization, the rate of forced cooling, and the thickness of the solution-melt (the distance between horizontally located Si substrates). The composition of the Sn-Si-GaN melt solution was determined based on the results of preliminary experiments and literature data [3, 4] Sn - 97.78 wt.%, Si - 0.97 wt.%, GaN - 1.25 wt.%. Under optimal conditions, the growth temperature range was 950–850^{0}C, the melt solution cooling rate was 1 deg/min, and the distance between horizontally located substrates was 1 mm. With the chosen parameters of the technological process, the entire surface of the substrate was covered with a continuous

homogeneous epitaxial film. The film surface was smooth-mirror; the thickness of the epitaxial layer was the same over the entire surface and amounted to 15 μm. Specially undoped films had an electronic type of conductivity.

To study the mechanisms of current transfer in the p-Si–n-$(Si_2)_{1-x}(GaN)x$ heterostructure, ohmic contacts were made to them, by vacuum deposition of silver - solid on the side of the substrate and quadrangular with an area of 4 mm^2 on the side of the epitaxial layer. It should be noted that during the growth of n-$(Si_2)_{1-x}(ZnSe)_x$ on a Si substrate of p-type conductivity, a diode structure is formed in the form of R_{om}-p-n-R_{0m}, where R_{0m} is a metal contact with an ohmic transition.

Results and discussion: On fig. 1 shows the dark CVC of the fabricated structure. An analysis of the direct branch of the CVC showed that in the voltage range from 0 to 0.2 V, the diffusion mode of current transfer is observed, and this segment is well approximated by an exponential dependence of the form [3]:

$$I = I_o e^{\frac{qV}{ckT}} \quad (1)$$

where q is the elementary charge; V is the electrical voltage applied to the structure; k is the Boltzmann constant; T is the absolute temperature. Dependence (1) is typical for a "long" p-n-diode, in which d/Ln > 1, here d is the base thickness, Lp is the diffusion length of minority charge carriers in the base region of the structure [3].

The value of "c" in the exponent can be calculated directly from the experimental points of the exponential section of the CVC curves using the relation:

$$c = \frac{q}{kT} \cdot \frac{V_2 - V_1}{\ln(I_2 / I_1)} \quad (2)$$

The value of the indicator calculated from relation (2) was c=3.16

Behind the exponential section in the voltage range from 0.2 to 1 V there is an ohmic dependence of the current - I =A-V, where A=1.03·10-4 A/V. The appearance of an ohmic region can be explained by modulation of the space charge by sticking centers in a high-resistance base, the role of which is played by the epitaxial layer of the n-$(Si_2)_{1-x}(GaN)_x$ solid solution. In the voltage range from 1.2 to 2.5 V, there is a power-law dependence of the current - I =A-Vα, with the power value α = 2.7.

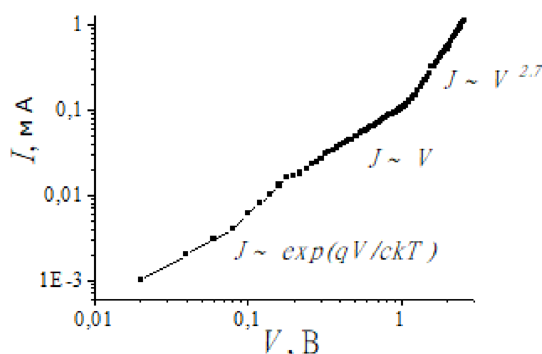

Fig.1. Direct branch of the current-voltage characteristic of the p-Si–n-$(Si_2)_{1-x}(GaN)_x$ structure in logarithmic scales.

Such a change in the dependence may be due to the fact that, at voltages above 1.2 V, the injected nonequilibrium carriers completely fill the attachment centers and, subsequently, the space charge is modulated by deep recombination centers, which are formed by defect-impurity complexes of the vacancy + impurity type in the base of the structure, and the drift mode sets in. dielectric relaxation of the space charge. Moreover, in this case it is necessary to take into account the inertia of the electron exchange within the recombination complex. In this case, a power-law dependence is observed with a degree close to the cubic law. In this case, a more complex dependence of the type [4] is observed.

$$V = A + B\sqrt{J} - \frac{D}{\sqrt{J}} \qquad (3)$$

where A, B and D are constants depending on the properties of the material. In [4] it is shown that the use of computer simulation for specific materials, expression (3) allows obtaining different degrees of α depending on $I = A\text{-}V^{\alpha}$, and the value of the α index changes with the change in the current value.

Thus, the possibility of obtaining an epitaxial layer of a substitutional solid solution $(Si_2)_{1-x}(GaN)x$ on Si substrates from the liquid phase has been shown. By studying the CVC, it was found that in the epitaxial layers of the solid solution $(Si_2)_{1-x}(GaN)_x$, apparently, defect-impurity complexes are formed, and it can be assumed that in such solid solutions the recombination rate of nonequilibrium charge carriers at low levels of excitation is determined by simple local centers, but with an increase in the excitation level, by simple local centers and defect-impurity complexes simultaneously. With a further increase in the excitation level, the contribution of impurity complexes in the recombination process can become decisive.

Conclusion: Solid solutions of the Mn1-xTmxSe (0≤x≤0.7) system with the cubic structure of the space group Fm3̅m were obtained using the solid-phase synthesis technique. The crystal structure of solid solutions of the $M_{n1-x}Tm_xSe$ system has been studied by X-ray phase analysis. An increase in the concentration of Tm cations in $M_{n1-x}Tm_xSe$ solid solutions leads to an increase in the parameter a form 0.547 nm for the $Mn_{0.975}Tm_{0.025}Se$ composition to 0.566 nm for the $Mn_{0.3}Tm_{0.7}Se$ composition.

Thin films of Thin films of $M_{n1-x}Tm_xSe$ solid solutions were synthesized using the flash method on standard substrates of optically transparent glass. It has been established that the film thicknesses are in the range of values: from 0.8 μm to 3.2 μm solid solutions were synthesized using the flash method on standard substrates of optically transparent glass. It has been established that the film thicknesses are in the range of values: from 0.8 μm to 3.2 μm.

X-ray phase analysis of thin films of Mn1-xTmxSe solid solutions was performed at room temperature in CuKα radiation. It has been established that $M_{n1-x}Tm_xSe$ (x=0.05; 0.1; 0.3) films have a cubic system of the NaCl type, space group Fm3̅m. The composition of $M_{n1-x}Tm_xSe$ thin films corresponds to the chemical composition of the initial powders.

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