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GaN Low-dimensional Structures

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The GaN low-dimensional structures obtained by nitridation of GaAs porous layers were investigated for the first time. The process of GaN quantum dots formation on the GaAs surface was considered. This process was a result of electrochemical etching of GaAs followed by treatment in atomic nitrogen environment. Nitrogen atoms, which were deposited on the GaAs surface, replace arsenic ones that leads to the formation of a thin GaN layer on the GaAs surface. The photoluminescence and surface morphology of the structures obtained were studied by scanning electron spectroscopy.

Keywords: Nitridation method, Quantum dots.

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1. INTRODUCTION

Investigation of the properties of porous silicon gave an impetus to the study of porous layers in other semiconductors. Increasingly, the researches try to find a universal method for obtaining low-dimensional semiconductor materials. Recently, the scientists try to create porous layers on the binary and more complex materials by means of their electrochemical etching [1-5]. Many reports about GaP, SiGe, SiC, GaAs, etc. compounds have been already appeared in the literature.

The main problem of modern optoelectronics is the search of materials for the ultraviolet spectral region. Nitride-gallium epitaxial films play an important role in the formation of short-wave electronics devices. Semiconductor compound GaN is a promising material for light-emitting diodes and lasers operating in this range (GaN 3.4eV (360 nm)).

However, to obtain radiation in the far ultraviolet region, one can use GaN quantum dots. As known, shift of the main photoluminescence band to the ultraviolet spectral region occurs in this case. Therefore, the aim of our work is to obtain GaN quantum dots on porous GaAs semiconductors as a result of nitridation accompanied by the conversion of new GaAs layers to GaN. Such structures can find application in the production of sensors, effective radiation sources, high-efficiency solar batteries, light-emitting and photodiodes, photodetectors and even single-electron transistors.

2. EXPERIMENTAL RESULTS AND DISCUSSION

Porous GaAs was produced by electrochemical treatment of monocrystalline GaAs (001) which is the anode. Mixtures of hydrofluoric, hydrochloric, and nitric acids were used as the electrolyte. For the experiments, the *n*-type GaAs samples with polished the surface were used as the anode and platinum – as the cathode, which are placed parallel to each other. The etching process was carried out in electrochemical environment. Such parameters as operating time, initial current strength, concentration of acids were changed in the experiments.

The pore-formation in GaAs occurred at etching in an aqueous solution of hydrofluoric acid during the time interval from 10 to 30 min for the specified compositions and concentrations of the electrolytes components; the current densities were varied in the range from 8 to 400 mA/cm^2. The experiment was carried out at room temperature.

The etching process was implemented in several stages:

1. polishing of the surface, its degreasing;
2. directly the process of electrochemical etching;
3. cleaning of the surface from the etching products.

Nitridation of porous GaAs was performed using the following parameters: annealing time from 40 to 60 min, annealing temperature 820-1020 K, working pressure in reactor – 10^{-2}-10^{-1} bar.

The nitridation process (to obtain thin GaN layers) was carried out in N_2+H_2 (2 % H_2) discharge. Hydrogen binds arsenic in AsH_3, and the latter is adsorbed from the surface according to the reaction

$$\mathrm{GaAs} + \mathrm{N} + 3\mathrm{H} \rightarrow \mathrm{GaN} + \mathrm{AsH}_3 .$$

Study of the photoluminescence was performed at the temperature of 77 K, for which we have used the nitrogen laser ILGI-503 with the wavelength of 337.1 nm and pulse length of 10 ns. Using the monochromator MDR-12, we have analyzed the obtained spectra.

Substitution of As atoms by N atoms, which leads to the formation of a thin GaN layer on the GaAs surface, is one of the most important problems in the deposition on the GaAs surface. Decomposition of the GaN layer to quantum dots begins after GaN deposition.

Study of the morphology was carried out using the scanning electron microscope. In Fig. 1 we illustrate the morphology of GaN quantum dots on the surface of porous GaAs layers (111) obtained after annealing in atomic nitrogen. On the inset we show the chemical composition of quantum dots obtained by the EDAX method, according to which Ga and N atoms are present on the surface of the obtained samples.

Reformation of GaN nanoparticles, accompanied by the change in their stoichiometry and size leading to the shift of the band maximum in the photoluminescence (PL) spectra, can be the result of the ion migration.

In Fig. 2 we illustrate the PL spectrum of the obtained structure. As seen from this figure, the shift of the main PL band takes place. PL spectrum of the obtained structures represents a symmetrical band with the maximum at 337 nm. Shift of the main PL band occurs to the short-wave spectral region that can be explained by the quantum-size effect (electronic and optical properties of quantum-dimensional structures depend on the crystal size in the direction, along which the charge carrier motion is restricted). Spectrum of the obtained structure compared with the PL spectrum of GaN is substantially extended, the maximum of its radiation band is shifted to the side, the peak of the PL band is placed near the energy of 3.6 eV (345 nm).

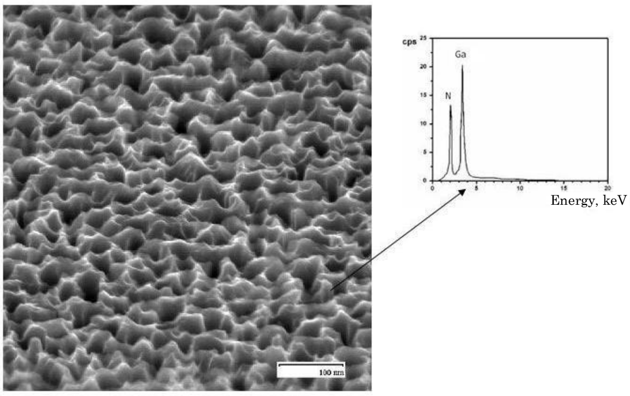

Fig. 1 – SEM-images of the GaN quantum dots on the surface of porous GaAs layers (111) obtained after annealing in atomic nitrogen (the inset: chemical composition of the quantum dots obtained by the EDAX method)

The observed PL spectra of quantum dots on the GaN surface are characterized by the main PL band shift to the short-wave spectral region that can be explained by the quantum-size effect (electronic and optical properties of the quantum-dimensional structures depend on the crystal size in the direction along which the charge carrier motion is restricted).

Energy of high-energy quantum transitions, which is conditioned by the size restriction of quantum objects, can be represented as the function of the nano-object diameter d

$$\hbar\omega = E_g + \frac{\hbar^2\pi^2}{2R^2}\left[\frac{1}{m_e} + \frac{1}{m_h}\right] - \frac{1{,}786e^2}{\varepsilon_1 R},$$

where the second term is responsible for the energies of electron and hole placed into the potential well; the third term takes into account their Coulomb interaction.

Substituting the obtained data into the equation, we find at $d = 20\text{-}30$ nm the energy value of $\Delta E = 3.6$ eV ($\lambda = 345$ nm), and shift of the spectrum will be equal to 23 nm. These results are demonstrated by the PL spectrum of GaN quantum dots illustrated in Fig. 2. PL has shown that the size of GaN quantum dots is approximately equal to 20-30 nm.

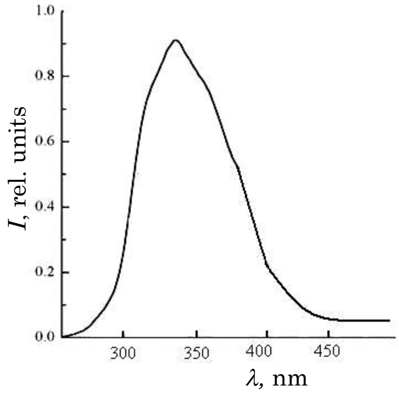

Fig. 2 – PL spectrum of GaN quantum dots

3. CONCLUSIONS

Thus, the investigation results imply that GaN quantum dots are formed on the porous GaAs surface. The size of GaN quantum dots is approximately equal to 20-30 nm. Shift of the PL spectra of GaN quantum dots obtained by annealing of porous GaAs layers in atomic nitrogen is explained by the quantum-size effect.

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