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Study of GaPN(As) layers grown by molecular beam epitaxy on silicon substrates

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Abstract. In this work bulk layers of GaPN(As) solid solutions grown by plasma assisted molecular beam epitaxy on gallium phosphide and silicon substrates are studied. The morphology, structural and optical properties of diluted nitride epilayers synthesized on GaP and Si are compared. The possibility of obtaining GaPN(As) epitaxial layers of optical quality on lattice-mismatched silicon substrates is demonstrated.

Keywords: dilute nitride semiconductors, molecular beam epitaxy, silicon, gallium phosphide

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Материалы конференции
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Исследование слоев GaPN(As), выращенных методом молекулярно-пучковой эпитаксии на кремниевых подложках

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Аннотация. В работе исследованы объемные слои твердых растворов GaPN(As), выращенные методом молекулярно-пучковой эпитаксии на подложках фосфида галлия и кремния. Проведено сравнение морфологии, структурных и оптических свойств синтезированных эпитаксиальных слоев разбавленных нитридов. Показана возможность получения эпитаксиальных слоев GaPN(As) оптического качества на решеточно-рассогласованных кремниевых подложках.

Ключевые слова: разбавленные нитриды, молекулярно-пучковая эпитаксия, кремний, фосфид галлия

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Introduction

Solid solutions of materials containing a small mole fraction of nitrogen, the so-called dilute nitrides, are difficult to theoretically describe and experimentally grow, but are of great interest for many optoelectronic applications. It is known, that the addition of nitrogen to GaP makes this ternary solution GaPN direct gap and, with a nitrogen mole fraction of about three percent, makes it lattice matched with silicon [1]. Moreover, by varying the composition of a quaternary solution of GaPNAs, it is possible to obtain a semiconductor material with the bandgap range from 1.5 to 2.0 eV which is also lattice-matched with silicon [2, 3]. Thus, dilute nitride semiconductor compounds have a potentially wide application range, especially for integration with silicon in optoelectronic integrated circuits, and also as top cascades in multijunction solar cells on silicon substrates [4, 5].

Unfortunately, the epitaxial growth of dilute nitrides directly on the silicon substrates is impossible. Therefore, it is necessary to use the buffer layers. Unfortunately, there are unsolved problems such as high point defect density, connected with the nitrogen incorporation, Ga and Si interdiffusion on the GaP/Si interface, and high surface roughness. Here we report the results of the dilute nitrides growth experiments.

Materials and Methods

In this study heterostructures with bulk GaPN and GaPNAs layers were grown by plasma assisted molecular beam epitaxy on GaP(100) substrates and on Si(100) substrates misoriented in the [110] direction by 4°. The morphology of the obtained heterostructures was characterized using a Supra 25 Zeiss scanning electron microscope (SEM). Structural properties of the samples were studied by X-ray diffraction analysis (XRD) using a high-resolution X-ray diffractometer DRON-8, the anode material was Cu-Kα1 (λ = 1.5405 Å). The optical properties of the resulting heterostructures were studied by photoluminescence (PL) spectroscopy.

Results and Discussion

Samples with a GaPN epilayer on Si and GaP substrates were obtained using the same growth parameters. The growth of the GaPN layer on the GaP(100) occurs in a homogeneous and dislocation-free manner, as it can be seen from Fig. 1, *a*. At the same time, the GaPN epilayer,

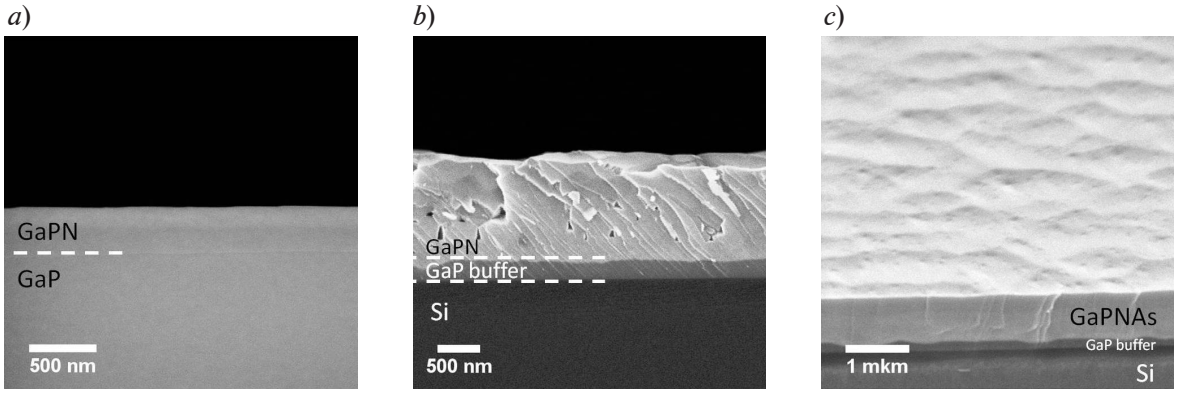

Fig. 1. SEM images of GaPN/GaP structure (*a*), GaPN (*b*) and GaPNAs (*c*) epitaxial layers on Si substrate with GaP buffer

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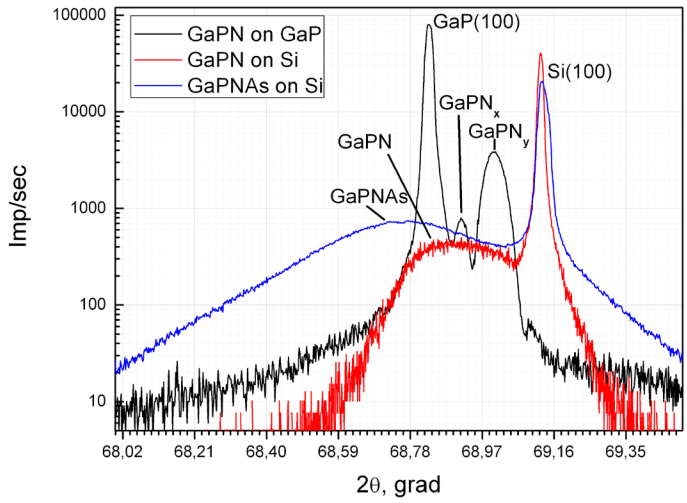

Fig 2. XRD curves of the grown samples

grown on a Si substrate with a GaP buffer layer, demonstrates the formation of a porous structure associated with stress relaxation in the GaPN layer (Fig. 1, *b*). The addition of As to the GaPN and epitaxial growth of a GaPNAs quaternary solid solution on a Si substrate with a GaP buffer layer demonstrates an improvement in the morphology of the epilayer (Fig. 1, *c*).

The XRD curves of the samples are shown in Fig. 2. Despite the fact that samples with a GaPN epilayers on Si and GaP substrates (black and red line respectively) were obtained using the same growth parameters, the corresponding XRD reflexes do not match. This can be connected with the mechanical stress difference in epilayers due to the difference in the lattice constants of the substrates. Moreover, a sample grown on a GaP substrate (black line) shows two peaks from the GaPN layer, which may arise due to the decomposition of the material into two solid solutions with different nitrogen content. The XRD reflex from the GaPN layer grown on a Si substrate (red) is wider, which indicates that the composition of the solid solution has a different nitrogen content. The addition of As leads to a greater broadening of the reflex from the GaPNAs layer (blue) indicating a gradual composition change in a solid quaternary solution.

The photoluminescence spectra of the samples are presented in Fig. 3. First of all, it is clearly seen that the synthesized dilute nitride materials GaPN and GaPNAs are direct gap semiconductors. The peak PL intensity of the GaPN layers grown on GaP and silicon substrates are comparable.

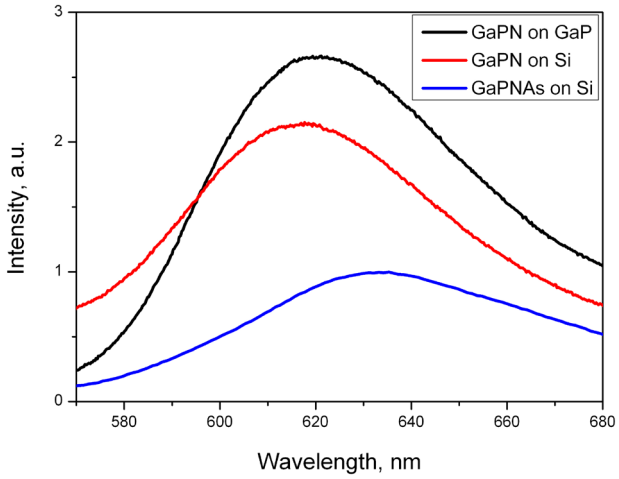

Fig 3. PL spectra of the obtained samples

Moreover, as it can be seen from PL spectra, the porous structure of the GaPN grown on Si (red line) does not affect the optical characteristics of the layer. It means that GaPN layer grown on Si substrate has good crystalline quality. One can note a slight shift in the peak position from sample to sample. This connected with the large defect density in the GaPN layer grown on a Si substrate (it is clearly seen from SEM Fig. 1, *b*), as well as the difference in the lattice constants of the used substrates and different type of mechanical stresses consequently. The addition of As to the GaPN layer leads to a decrease in the band gap of solid solution and a shift of the photoluminescence spectrum to longer wavelengths.

Conclusion

In this work GaPN and GaPNAs epitaxial layers were synthesized on GaP(100) and misoriented Si(100) substrates by plasma assisted molecular beam epitaxy and their morphology, structural and optical properties were studied. It is shown that the epitaxial synthesis using the same growth parameters of GaPN on GaP substrate and on Si substrate with GaP buffer layer can lead to different morphology and structural properties of dilute nitride layer. The improvement of the morphology of GaPNAs dilute nitride layer with addition of As compared to GaPN grown on Si substrates is demonstrated. A comparable PL peak intensity of the GaPN layers grown on GaP and Si substrates is observed. The possibility of growth of the optical quality dilute nitride epitaxial layers nearly lattice-matched with Si(100) is shown.

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