MBE synthesis and properties of GaN NWs on SiC/Si substrate and InGaN nanostructures on Si substrate

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Abstract. A possibility of GaN NWs and InGaN nanostructures of a branched morphology MBE growth on SiC/Si and Si substrate has been demonstrated. It was found that the intensity of the photoluminescence spectrum of the GaN NWs on SiC/Si(111) substrate integrally more than 2 times higher than that of the best structures of GaN NWs without a buffer layer of silicon carbide. The results of morphological studies have shown that InGaN synthesis occurs in several stages. InGaN nanostructures turned out to be optically active at room temperature and have a wide radiation visible range.

1. Introduction

Nowadays, semiconductor compounds of III-Nitrides are of great interest for modern optoelectronics due to its unique properties [1]. Nanostructures of wide band-gap gallium nitride are of particular interest because of their applications in short-wavelength optoelectronic devices and high-power/high-temperature electronics. GaN nanowires (NWs) represent unique nanostructures that can be used as high mobility field effect transistors, photodetectors as well as miniaturized UV-blue nano lasers. Moreover, due to their high surface to volume ratio, nanowires are potential candidates for sensor applications and they are also under discussion in a view of the next generation of solar cells. Besides, InGaN ternary compounds are promising for building devices for emitting in the visible range [2]. Interest in obtaining such structures is due, inter alia, to the prospects for integrating III-N semiconductors and silicon electronics, the possibility of using substrates of large (up to 150-200 mm) dimensions, their low cost, good electrical conductivity, as well as obtaining 'template' structures. However, the synthesis of high-quality direct-gap InGaN two-dimensional layers on silicon substrates leads to the appearance of a high density of defects in the InGaN layer due to the significant difference in the lattices constants and thermal expansion coefficients. Significant efforts are being made to successfully tackle these problems. In particular, to suppress the process of misfit dislocations occurrence and reduce the number of defects, barrier intermediate layers are formed in the epitaxial
semiconductor nitride layer \{SiC/Si(111), AlGaN/SiC/Si(111) \text{ and GaN/AlN-GaN/SiC/Si(111)} \} \cite{3,4}. This approach contributes to a decrease in the efficiency or in general impossibility of creating devices based on InGaN. At the same time, an alternative way to overcome the problem — the synthesis of nonplanar InGaN nanostructures of complex shape on the surface of a silicon substrate — is very promising. Due to the complex morphology, the mechanical stresses in semiconductor nanostructures relax and the number of defects decreases significantly \cite{5}. However, it was possible to synthesize structures based on InGaN nanostructures of complex shape on silicon only using pre-growth surface preparation procedures \cite{6}.

This paper presents the results of experimental studies on the synthesis by molecular beam epitaxy (MBE) and studies of morphological and optical properties of GaN NWs on SiC/Si substrates and InGaN nanostructures of branched morphology directly on the unprepared silicon surface.

2. Experimental procedures
Nanowires were grown by MBE using Riber Compact 12 setup equipped with Ga and In effusion sources and nitrogen plasma source First, substrates were transferred into the growth chamber and the substrate temperature was set to 950°C for thermal treatment. Then the substrate temperature was lowered to the actual growth temperature of 700°C in case of GaN growth and 700°C in case of InGaN growth. The nitrogen plasma source is ignited and the N flux is set at 0.4 scam and 400 W. Finally, the gallium (Ga) or Ga and indium (In) sources were opened. Ga and In partial pressures were equal and set to $10^{-7}$ Pa as pre-specified by the Bayard-Alpert detector. The total growth time for both structures was about 20 hours.

The surface morphology and optical properties were studied by scanning electron microscopy (SEM) and room-temperature photoluminescence (RT PL) techniques.

3. Results
Figure 1 shows typical SEM images of GaN nanowires grown on SiC/Si combined substrate. It is seen that on the substrate SiC/Si(111) GaN NWs formed mainly in [111] direction and their average height is about 1.6 μm. It should be noted that grown structures have high surface density ~ $2\times10^{16}$cm$^{-2}$, that’s why some of the nanowires tend to merge. From SEM image (figure 1, a) it is clear that some NWs are inhomogeneous by their diameter - it increases to the top of NWs, possibly due to the rather high substrate temperature. Moreover relatively low N/Ga fluxes ratio can play an important role in density and shape of nanowires.

![Figure 1. SEM images of GaN NWs grown on SiC/Si(111) substrate: (a) tilted by 20 cross section view; (b) top-view.](image_url)
Figure 4 shows a comparison of room temperature PL spectra of the grown sample and the most successful of GaN NWs sample grown directly on silicon. Maxima of both spectra coincide in wavelength and conform to experimentally measured radiation value GaN. At the same time, the integral PL intensity of GaN NWs grown on SiC buffer layer more than 2 times higher than that grown on silicon at the same growth conditions.

![PL Spectra Comparison](image)

**Figure 2.** The typical PL spectra of grown samples and the most successful GaN structures grown on silicon.

Typical scanning electron microscopy image of InGaN nanostructures grown on Si(111) substrate are shown in Figure 3. It is seen that synthesized InGaN nanostructures have a complex morphology. The average height of the grown structures was 5 μm. It should be noted that, based on the figure, the synthesis of InGaN nanostructures occurred in several stages: first, nanocolumns were formed, then a transition layer, and, finally, nanostructures with more complex morphology. Probably, different stages of growth correspond effectively to different (despite the constancy of its maintenance by thermocouple measurements) temperature on the surface, which decreases with increasing height of the nanostructure. This may be due to a change in the thermal absorption coefficient of the growing structure due to the formation of complex surface [7, 8].

![SEM Image](image)

**Figure 3.** SEM image of InGaN nanostructures grown on Si(111) substrate

Figure 4 shows the photoluminescence spectrum at room temperature of the grown sample. The measurement results showed that the InGaN nanostructures are optically active up to room
temperature. This fact indicates the high optical quality of the grown structures. It can be seen from the figure that InGaN nanostructures emit in a wide range of wavelengths - from 400 to 900 nm. We assume that this is due to a change in the percentage ratio of In and Ga in a solid solution, which may be caused, inter alia, by an effective change in surface temperature during growth. Such nanostructures are promising for creating white LEDs based on a single material.

![RT PL spectra K of InGaN nanostructures grown on Si(111) substrate.](image)

Figure 4. RT PL spectra K of InGaN nanostructures grown on Si(111) substrate.

4. Conclusions
In summary, we have demonstrated the possibility of synthesizing GaN and InGaN nanostructures by the method of molecular beam epitaxy on SiC/Si(111) and on the unprepared surface of the silicon substrate, respectively. It was found that the intensity of the photoluminescence spectrum of the GaN NWs on SiC/Si(111) substrate integrally more than 2 times higher than that of the best structures of GaN NWs without a buffer layer of silicon carbide. The developed growth technology makes it possible to synthesize InGaN nanostructures of branched morphology without the use of pre-growth surface preparation procedures, which contributes to a significant reduction in the price and time to create such nanostructures. The results of morphological studies have shown that growth occurs in several stages. The grown structures turned out to be optically active in a wide range of wavelengths at room temperature. All these facts indicate the promise of such structures for optical applications.

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