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Two bands in PL spectra of InGaN/GaN superlattice embedded in GaN nanowire

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Abstract. We present a study of the growth and optical properties of an embedded InGaN/GaN superlattice in nanowires. Nitride nanowires with embedded superlattice were grown by molecular beam epitaxy on a silicon substrate. The optical properties of the resulting nanostructures were studied using low-temperature photoluminescence. Photoluminescence spectrum of InGaN/GaN superlattice exhibits two distinct emission bands. These bands correspond to the radiation from the different parts of the InGaN insertions. The second band in the photoluminescence spectrum is associated with the penetration of In into the GaN barrier.

Keywords: photoluminescence, nanowires, indium gallium nitride, molecular beam epitaxy

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Две полосы в спектре фотолюминесценции от сверхрешетки InGaN/GaN, заключенной в нитевидный нанокристал GaN

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Аннотация. В данной работе мы представляем описание синтеза и оптических свойств сверхрешетки InGaN/GaN внедренной в нитевидный нанокристалл GaN. Синтез массива нитевидных нанокристаллов осуществлялся методом молекулярно-пучковой эпитаксии на кремниевой подложке. Оптические свойства наноструктур на основе нитридных нитевидных нанокристалов были изучены методом низкотемпературной фотолюминесценции.Нитевидные нанокристаллы GaN с квантовыми дисками InGaN демонстрируют две отчетливые полосы излучения в спектре фотолюминесценции. Полосы соответствуют излучению от квантовых дисков InGaN. Возникновения второй полосы в спектре фотолюминесценции может быть связано с проникновением In в барьер в барьер GaN.

Ключевые слова: фотолюминесценция, нитевидные нанокристалы, нитрид галлия, молекулярно-пучковая эпитаксия

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Introduction

Recently, the study of the optical properties of nitride nanowires (NWs) has attracted the interest of researchers. The unique properties of these direct-gap semiconductors allow for the wavelength to be changed from the near-UV range to the near-IR range by changing the chemical composition [1]. While the geometry of NWs allows them to grow directly on silicon. The opportunity to create diodes based on GaN NWs with InGaN insertions has already been demonstrated [2]. Even more single-photon emission at room temperature from InGaN quantum dots in NWs was shown [3]. InGaN ternary compounds with a high In content (In > 30%) have a tendency toward phase decomposition due to the notable difference in bond lengths between In–N and Ga–N, so-called “miscibility gap” [4, 5]. This feature complicates the growth of InGaN thin films with high In content. Moreover, the growth of high-quality InGaN/GaN epilayers with high In content is also complicated due to the high dislocation density, resulting from the notable lattice mismatch between InN and GaN. We investigate InGaN/GaN heterostructures through the NW growth to overcome these limitations. Due to a very efficient relaxation of elastic stress on strain-free sidewalls, NW heterostructures can be grown in lattice-mismatched systems without structural defects or with a largely reduced dislocation density compared to epi-layers [6].

Materials and Methods

Growth experiments were carried out on one-side polished *n*-type Si substrates in a Riber Compact 12 MBE system. The surface orientation of the substrate was (111) with a 4° miscut toward the [110] direction. The MBE chamber is equipped with Addon RF-N 600 plasma source and Knudsen cells of Ga and In. Prior to loading into the growth chamber, the substrate was etched in a 47.5% hydrofluoric acid solution for 40 seconds, followed by a 60 second washing in deionized water. After that, the substrate was transferred into the MBE chamber and thermally cleaned at 855 °C for 20 min. Then, the substrate temperature was cooled down to 620 °C. The substrate temperature was obtained using an Optris CT Laser 3MH1 pyrometer calibrated on the 7×7 to 1×1 surface reconstruction of the Si(111) substrate. Next, the nitrogen plasma was ignited at a source power of 350 W with a nitrogen flow of $4.4\cdot10^{-6}$ Torr, and the substrate was nitridated for 20 min to form thin SixNy layer. At the next stage, two monolayers of Al were deposited onto the formed SixNy layer for 6 seconds in the absence of nitrogen plasma. Next, the substrate temperature was increased to 805 °C, the nitrogen plasma was ignited at the same parameters, and the Ga source was opened to grow GaN NWs. This procedure allowed one to achieve N-polar GaN NWs. The beam equivalent pressure (BEP) of Ga corresponded to $1.5\cdot10^{-7}$ Torr.

After a 18h of growth, the Ga source was closed, and the substrate temperature was decreased to 600 °C. The In and Ga sources were opened with BEPs equal to $1 \cdot 10^{-7}$ Torr each other to form InGaN insertions. After the formation of each 3–4 nm InGaN insertion, a 9–10 nm GaN barrier was grown at the same substrate temperature. This process was repeated 15 times to obtain a stack of InGaN quantum wells (QW) in GaN NWs. A scheme and SEM image of the obtained nanostructure is shown in Figure 1.

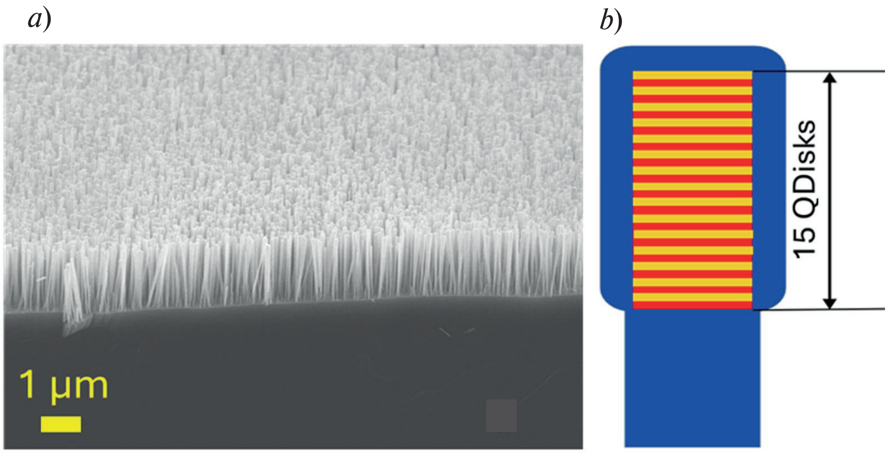

Fig.1. SEM image of GaN NWs with InGaN superlattice(*a*) and a scheme of the NW with the superlattice structure (*b*)

To study the opportunity of increasing indium content in active region during the growth, a second growth was carried out with the BEPs of In and Ga set to 1.2×10^{-7} Torr and 0.8×10^{-7} Torr, respectively.

Results and discussion

The optical properties of the synthesized samples were studied using an MDR-204-2 monochromator. The samples were placed in a closed-cycle helium cryostat. The photoluminescence (PL) was excited by a He-Cd laser (excitation wavelength λ = 325 nm, radiation power $W = 50$ kW·cm^{-2}) at $T = 5$K.

The PL spectra of InGaN/GaN superlattices embedded in GaN NWs demonstrate two PL bands in both samples, see Fig. 2. The PL band maxima were for 2.8 eV; 3.2 eV Sample 1 and for 2.1 eV; 2.6 eV Sample 2, respectively. The PL maxima were successfully shifted from the blue to the orange spectral region by increasing the In BEP and decreasing the Ga BEP. The In/Ga ratio was 1/1 for Sample 1 and 1.2/0.8 for Sample 2.

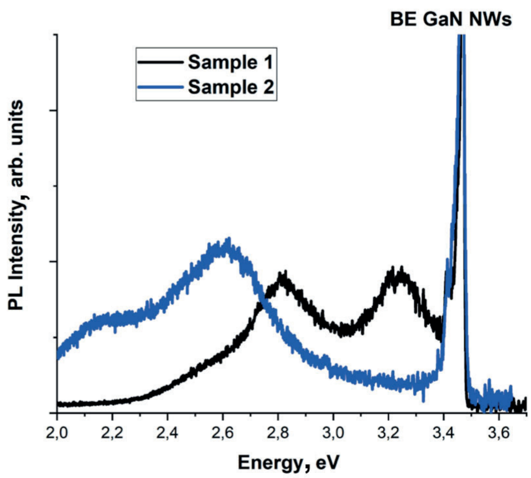

Fig. 2. PL spectra of GaN nanowires with fifteen InGaN quantum disks

Previously, the properties of InGaN/GaN superlattices embedded in GaN NWs were investigated in paper [7], where two PL bands with the spacing between maxima about 0.5 eV were also observed on the spectrum. The authors of that paper assumed that the observed PL bands are related to the formation of two emission levels from the superlattice regions with different indium concentrations and thicknesses. The In-rich region has greater thickness and less indium content near the sidewalls [7]. Our additional studies confirm that, in our case, the situation is similar. The existence of two bands could be explained in terms of spontaneous radial segregation.

Conclusion

GaN NWs with fifteen InGaN quantum disks were grown on a Si(111) substrate using MBE with different In/Ga flux ratios. The opportunity to overcome "miscibility gap" in InGaN NWs is shown. InGaN NWs without structural defects and with high indium content are demonstrated. The PL spectra of InGaN superlattices exhibit two distinct emission bands. The existence of two bands can be explained by spontaneous radial segregation. The PL band maxima were successfully shifted from the blue to the orange spectral region by increasing the In BEP and decreasing the Ga BEP. Which allows us to effectively change the wavelength of radiation from the InGaN QWs embedded in GaN NWs. The increase in the In content does not lead to the formation of additional nonradiative recombination centers.

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