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Physical properties of GaN/InGaN nanowires grown by PA-MBE on silicon substrate

D. N. Bondarenko [1,2]✉, V. O. Gridchin [1,2,3], K. P. Kotlyar [1], A. I. Baranov [2], A. A. Maksimova [2], R. R. Reznik [1,2,3,4], G. E. Cirlin [1,2,3,4]

[1] St. Petersburg State University, St. Petersburg, Russia;

[2] Alferov University, St. Petersburg, Russia;

[3] IAI RAS, St. Petersburg, Russia;

[4] ITMO University, St. Petersburg, Russia

✉ bondarenko.dariya.spb@gmail.com

Abstract. The paper presents an approach to growth of GaN nanowires with thick core-shell InGaN insertions with a high indium content for creation of LED structure. The study of the electrical properties shows typical diode dependence. The results obtained can make a significant contribution to the development of light emitting diodes on silicon substrates.

Keywords: micro light-emitting diodes, molecular beam epitaxy, GaN/InGaN nanowires, silicon substrates, thick core-shell InGaN insertions

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Материалы конференции
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Физические свойства GaN/InGaN нитевидных нанокристаллов выращенных методом МПЭ с плазменной активацией на кремнии

Д. Н. Бондаренко [1,2]✉, В. О. Гридчин [1,2,3], К. П. Котляр [1], А. И. Баранов [2], А. А. Максимова [2], Р. Р. Резник [1,2,3,4], Г. Э. Цырлин [1,2,3,4]

[1] Санкт-Петербургский государственный университет, Санкт-Петербург, Россия;

[2] Санкт-Петербургский академический университет им. Ж. И. Алферова РАН, Санкт-Петербург, Россия;

[3] Институт аналитического приборостроения РАН, Санкт-Петербург, Россия;

[4] Национальный исследовательский университет ИТМО, Санкт-Петербург, Россия

✉ bondarenko.dariya.spb@gmail.com

Аннотация. В данной работе представлен подход к синтезу светоизлучающей структуры на основе нитевидных нанокристаллов GaN с объемными вставками структуры «core-shell» InGaN с высоким содержанием индия. Изучение электрических свойств показывает типичную диодную зависимость. Полученные результаты могут внести весомый вклад для разработки светоизлучающих диодов на кремниевых подложках.

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Ключевые слова: микросветодиоды, молекулярно-пучковая эпитаксия, нитевидные нанокристаллы GaN/InGaN, кремниевые подложки, объемные вставки структуры «core-shell» InGaN

Финансирование: Экспериментальные образцы были синтезированы при поддержке государственного задания ИАП РАН № 075-00761-22-00, FFZM-2022-0008. Исследования морфологических свойств выращенных образцов были выполнены при финансовой поддержке Российского Научного Фонда грант № 21-72-00099. Электро-физические свойства выращенных образцов были исследованы при финансовой поддержке Министерства науки и высшего образования Российской Федерации, проект тематики научных исследований № 2019-1442.

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Introduction

Nowadays, the area of research of the development of micro light-emitting diodes (LEDs) based on InGaN ternary compounds is strictly relevant [1]. Since these semiconductors with a direct band gap have unique properties, from which one can distinguish the ability to control the emission wavelength from near UV to near IR by changing the chemical composition [1]. However, during the synthesis of homogeneous InGaN layers with different chemical compositions, internal strains and phase separation (“miscibility gap”) appear, associated with a large lattice mismatch between InN and GaN [2]. Also, the problem of the synthesis such layers with high crystalline quality is the lack of lattice-matched substrates compared to InGaN. As shown earlier, one of the ways to solve the problems described above is the synthesis of nanowires (NWs) [3]. One of the advantages of NWs is the possibility of obtaining practically defect-free structures on substrates with different lattice parameters and different thermal expansion coefficients [4]. Due to this, it is possible to use silicon wafers as substrates for growing NWs. Also, it is possible to circumvent of “miscibility gap” due to which it is possible to obtain an InGaN solid solution with any required chemical composition [5]. In this case, InGaN NWs grown with a high In content can have a spontaneously formed core–shell structure [6]. In this connection, at present, a large number of studies are aimed at creating light-emitting devices in the visible range based on GaN/InGaN NWs, where thick core-shell InGaN serves as the active region.

In this work, we study the structural and optoelectronic properties of GaN NWs with a thick core-shell InGaN active region grown on n-Si (111) substrates by plasma-activated molecular beam epitaxy (PA-MBE).

Materials and Methods

The GaN/InGaN NWs were grown by PA-MBE using a Riber Compact 12 MBE setup equipped with Ga, In, Mg, and Si effusion cells and a nitrogen plasma source. We used n-Si(111) substrates with 0.002–0.004 Ω·cm electrical resistivity. The growth process consists of major steps. The pretreatment of the substrates, necessary for the removal native silicon oxide layer, was carried out using an aqueous solution of hydrofluoric acid. After treatment, the substrates were transferred to a growth chamber and subjected to thermal treatment at a temperature of 950 °C. Then the temperature was lowered to a value of 600 °C, and Ga droplets were formed on the surface of the substrate for 15 sec. Then the substrate temperature was raised to 820 °C. After stabilization of the temperature, a nitrogen plasma source with a power of 450 W was ignited, the flux of which was set at 0.4 sccm. At this stage, GaN NWs with n-type conductivity were formed due to the simultaneous opening of Ga and Si effusion cells. After that, InGaN active regions were formed. Finally, p-type GaN NWs were formed by doping with Mg. The total growth time was 17 h.

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The morphological properties of the sample were studied using scanning electron microscopy (SEM supra 25 Zeiss). The electrical properties of the NWs were studied by measuring the current–voltage (I-V) curves at room temperatures.

Results and Discussion

Fig. 1, *a*, *b* show typical SEM images of grown GaN/InGaN NWs and a schematic representation of GaN/InGaN NWs. As can be seen from figure 1, the morphology of the grown structures is close-packed GaN/InGaN NWs with an average length of 1.5 μm and the diameters at the base and top of about 90 nm and 350 nm, respectively. Also, it can be seen that the sample consists of both separated and partially coalesced NWs.

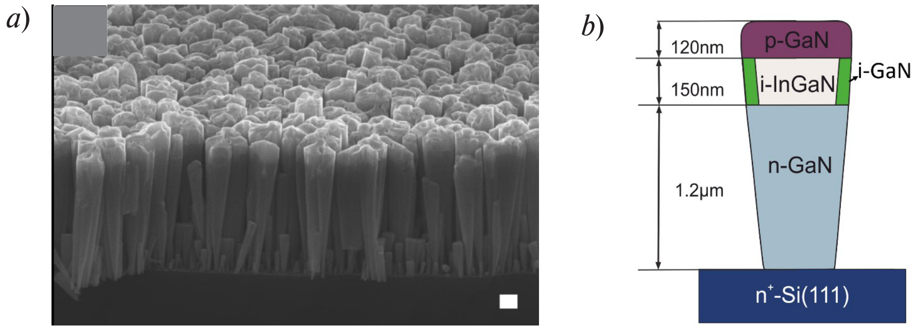

Fig. 1. SEM images of GaN/InGaN NWs: isometric view (*a*) and schematic image of the NW structure (*b*). The scale bars correspond to 200 nm

Before measuring the I-V curves the aluminum ohmic bottom contacts were formed on the n-Si substrate, and contacts were formed face top contacts on the p-GaN NWs by coating Ag paste (Fig. 2, *a*). Fig. 2, *b* shows the results of the measurements of I-V curves. As can be seen from the figure, the sample demonstrates typical diode behavior with an opening voltage of about 8V. High opening voltage can be caused by the Schottky barrier at the p-GaN/Ag interface [7]. The insertion to Fig. 2, *b* shows a photograph of the glow of the created structure.

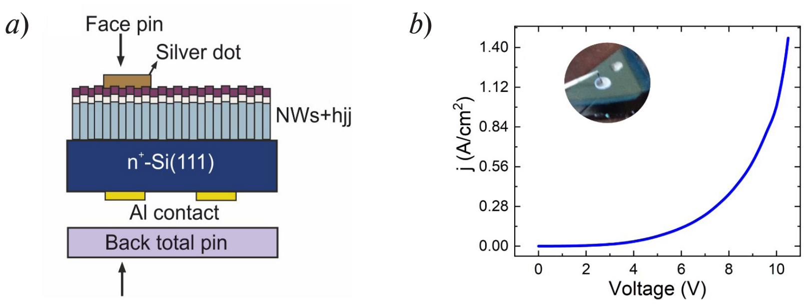

Fig. 2. Scheme of an LED based on an array of GaN/InGaN NWs on the n-Si(111) substrate (*a*); The current-voltage curve of GaN/InGaN NWs LED (*b*)

Conclusion

In summary, the growth of the GaN/InGaN nanowires on the n-Si(111) substrate by the PA-MBE method was demonstrated. The results of grown NWs morphological properties showed that the morphology of both samples is a close-packed array of cone-shaped NWs with an average length of about 1.5 μm. The I–V curves of the samples show typical diode characteristics. The preliminary results showed the glow of the created structure when voltage is applied.

REFERENCES

1. **Bui H. Q. T., Velpula R. T., Jain B., Aref O. H., Nguyen H. -D., Lenka T. R., Nguyen H. P. T.,** Full-Color InGaN/AlGaN Nanowire Micro Light-Emitting Diodes Grown by Molecular Beam Epitaxy: A Promising Candidate for next Generation Micro Displays, Micromachines. 10 (8) (2019) 492.

2. **Ho I., Stringfellow G. B.,** Solid phase immiscibility in GaInN, Applied Physics Letters. 69 (18) (1996) 2701–2703.

3. **Yan R., Gargas D., Yang P.,** Nanowire photonics, Nature Photonics. 3 (10) (2009) 569.

4. **Dubrovskii V. G., Cirlin G. E., Ustinov V. M.,** Semiconductor nanowhiskers: Synthesis, properties, and applications, Semiconductors. 43 (12) (2009) 1539–1584.

5. **Roche E., Andre Y., Avit G., Bougerol C., Castelluci D., Rйveret F., Gil E., Médard F., Leymarie J., Jean T., Dubrovskii V. G., Trassoudaine A.,** Circumventing the Miscibility Gap in InGaN Nanowires Emitting from Blue to Red, Nanotechnology. 29 (46) (2018) 465602.

6. **Gridchin V. O., Kotlyar K. P., Reznik R. R., Dragunova A. S., Kryzhanovskaya N. V., Lendyashova V. V., Kirilenko D. A., Soshnikov I. P., Shevchuk D. S., Cirlin G. E.,** Multi-colour light emission from InGaN nanowires monolithically grown on Si substrate by MBE, Nanotechnology. 32 (33) (2021) 335604.

7. **Picozzi S., Continenza A., Satta G., Massidda S., Freeman A. J.,** Metal induced gap states and Schottky barrier heights at non–reactive GaN/noble-metal interfaces, Physical Review B. 61 (24) (2000) 16736.

THE AUTHORS

BONDARENKO Daria N.
bondarenko.dariya.spb@gmail.com
ORCID: 0000-0003-4537-069X

GRIDCHIN Vladislav O.
gridchinvo@yandex.ru
ORCID: 0000-0002-6522-3673

KOTLYAR Konstantin P.
konstantin21kt@gmail.com
ORCID: 0000-0002-0305-0156

BARANOV Artem I.
baranov_art@spbau.ru
ORCID: 0000-0002-4894-6503

MAKSIMOVA Alina A.
deer.blackgreen@yandex.ru
ORCID: 0000-0002-3503-7458

REZNIK Rodion R.
moment92@mail.ru
ORCID: 0000-0003-1420-7515

CIRLIN George E.
george.cirlin@mail.ru
ORCID: 0000-0003-0476-3630

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