Conference materials
UDC 538.975
DOI: https://doi.org/10.18721/JPM.183.129

Effect of GaAs buffer layer on the characteristics of GaAs nanowires grown by molecular beam epitaxy on Si(111) substrates

V.V. Lendyashova [1] ✉, K.P. Kotlyar [1, 2, 3], A.I. Khrebtov [2],
G.E. Cirlin [1, 2, 3], I.V. Ilkiv [1, 2, 3]

[1] Alferov University, St. Petersburg, Russia;
[2] St. Petersburg State University, St. Petersburg, Russia;
[3] Institute for Analytical Instrumentation of the RAS, St. Petersburg, Russia
✉ erilerican@gmail.com

Abstract. The possibility of depositing colloidal nanoparticles onto an amorphous GaAs layer grown on Si(111) substrates and the direct molecular beam epitaxy of size-uniform GaAs nanowires with diameters below 20 nm were demonstrated. Examination of the nanowires revealed a nearly pure wurtzite crystal structure with low stacking fault density.

Keywords: nanowire, molecular beam epitaxy, semiconductors

Funding: For sample growth the authors acknowledge St.-Petersburg State University for a research project No. 129360164. TEM study was performed under the support of the Ministry of Science and Higher Education of the Russian Federation (state task No. 0791-2023-0004).

Citation: Lendyashova V.V., Kotlyar K.P., Khrebtov A.I., Cirlin G.E., Ilkiv I.V., Effect of GaAs buffer layer on the characteristics of GaAs nanowires grown by molecular beam epitaxy on Si(111) substrates, St. Petersburg State Polytechnical University Journal. Physics and Mathematics. 18 (3.1) (2025) 152–155. DOI: https://doi.org/10.18721/JPM.183.129

Материалы конференции
УДК 538.975
DOI: https://doi.org/10.18721/JPM.183.129

Влияние буферного слоя GaAs на характеристики нитевидных нанокристаллов GaAs, выращенных методом молекулярно-пучковой эпитаксии на подложках Si(111)

В.В. Лендяшова [1] ✉, К.П. Котляр [1, 2, 3], А.И. Хребтов [2],
Г.Э. Цырлин [1, 2, 3], И.В. Илькив [1, 2, 3]

[1] Академический университет им. Ж.И. Алфёрова РАН, Санкт-Петербург, Россия;
[2] Санкт-Петербургский государственный университет, Санкт-Петербург, Россия;
[3] Институт аналитического приборостроения РАН, Санкт-Петербург, Россия
✉ erilerican@gmail.com

Аннотация. Показана возможность осаждения коллоидных наночастиц на аморфный слой GaAs, выращенный на поверхности Si(111) подложек. С использованием полученных подложек методом молекулярно-пучковой эпитаксии продемонстрирован прямой рост однородных по размеру GaAs нитевидных нанокристаллов с диаметром менее 20 нм. Установлено, что формируемые нитевидные кристаллы обладают вюрцитной кристаллической структурой с низким количеством дефектов упаковки.

Ключевые слова: нитевидные нанокристаллы, молекулярно-пучковая эпитаксия, полупроводники

Финансирование: Синтез образцов выполнен при поддержке СПбГУ, шифр проекта 129360164. ПЭМ исследования выполнены в рамках государственного задания Минобрнауки (0791-2023-0004).

Ссылка при цитировании: Лендяшова В.В., Котляр К.П., Хребтов А.И., Цырлин Г.Э., Илькив И.В. Влияние буферного слоя GaAs на характеристики нитевидных нанокристаллов GaAs, выращенных методом молекулярно-пучковой эпитаксии на подложках Si(111) // Научно-технические ведомости СПбГПУ. Физико-математические науки. 2025. Т. 18. № 3.1. С. 152–155. DOI: https://doi.org/10.18721/JPM.183.129

Introduction

During recent years, semiconductor nanowires (NWs) have attracted great attention due to their unique optical and electronic properties. On the practical side, semiconductor NWs are very attractive for the direct integration of III-V materials on Si, opening up new possibilities for the design and fabrication of various applications, such as light-emitting diodes [1], field-effect transistors [2], etc. For a large number of devices, it is essential to synthesize ensembles with well-defined dimensions, size, shape, and phase purity of NWs because even small variations in size can have a large effect on overall device performance. Up to now, the most common technique for NW synthesis is vapor-liquid-solid growth using Au metal seed particles, which act as catalysts to initiate and guide the growth, directly controlling both diameter and orientation. Recent advances in this area have demonstrated the use of size-selected colloidal particles as seeds for MBE growth of GaAs NWs directly on Si [3–5]. However, there are several key issues concerning the use of colloidal nanoparticles as seed particles for the growth of NWs on Si. Specifically, the formation of GaAs NWs with diameters of about 50–100 nm is typically observed despite the use of nanoparticles 2–20 nm in diameter [4]. Besides that, diameter stabilization at the early growth stages also results in the tapering of NW bases [5]. The observed NW broadening effects are assumed to be due to the presence of Si atoms in the catalyst, which diffuse into the droplet during the high-temperature annealing of Au nanoparticles deposited on Si substrates [5–7].

In this work, we investigate the deposition of gold colloidal nanoparticles on a thin amorphous GaAs layer grown on Si(111) and how the presence of this GaAs layer affects the Au-assisted growth of GaAs NWs.

Materials and Methods

A Compact 21 Riber MBE system was used for the growth experiments. The investigations were carried out using a gold colloid containing 10-nm-diameter nanoparticles and Si(111) wafers. Two approaches for colloid deposition were applied. In the first case, colloid deposition was carried out on Si(111) substrates covered by native oxide with an Ar-plasma-irradiated surface. The plasma treatment was performed to improve the wetting properties of the silicon surface, enabling the direct deposition of Au nanoparticles onto the substrate [7]. In the second case, Si(111) substrates were etched by dipping in an HF solution to remove the native SiO_2 layer. After etching, the substrates were immediately loaded into the MBE chamber to prevent the formation of a new SiO_2 layer. The substrates were then annealed at 800 °C, after which a GaAs layer with a thickness of 50 nm was grown at 330 °C. Finally, the substrates were unloaded for colloidal deposition and loaded back for NW growth.

After the preparation step, NW growth was carried out. Upon loading the substrates, the temperature was ramped up to 520 °C and maintained throughout the process. NW growth was initiated by the simultaneous opening of the Ga and As shutters and lasted for 10 min. The Ga deposition rate was 0.9 ML/s, and the V/III flux ratio was ~20. After growth completion, the samples were cooled to room temperature and unloaded for morphological characterization via scanning electron microscopy (SEM) and transmission electron microscopy (TEM).

Results and Discussion

It is well established that the specific surface states of silicon substrates significantly affect colloidal nanoparticle deposition [8]. The deposition of Au nanoparticles (NPs) from colloidal solutions has been previously demonstrated using short Ar plasma modification [4]. The wettability of the GaAs surface layer grown on Si(111) substrates was significantly improved, resulting in a homogeneous distribution of Au nanoparticles across the substrate.

Bird-view SEM images of the grown samples are shown in Fig. 1. As seen in the figure, GaAs NWs grown on the GaAs/Si(111) substrate exhibited near-vertical alignment, consistent with the {111} crystal orientation family. These NWs maintained a uniform diameter along their entire length. In contrast, most GaAs NWs grown directly on Si(111) were non-directional and exhibited pronounced tapering (Fig. 1, *b*). This non-ideal growth behavior is attributed to suboptimal annealing temperatures for the Au NPs. To address this issue, an additional annealing step at 850 °C was performed to remove the native oxide underneath the Au seed particles. This modification increased the number of vertically aligned GaAs NWs. However, the NW morphology remained inhomogeneous, with noticeable tapering at both the bases and tips. The narrowing of the NW bases suggests the incorporation of Si atoms from the substrate into the Au-Ga catalyst droplet.

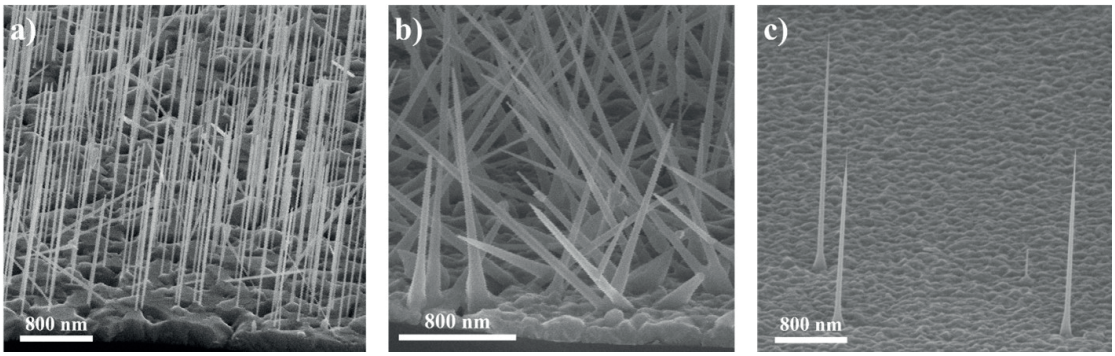

Fig. 1. GaAs NW ensembles grown on GaAs/Si(111) (*a*) and Si(111) surface without (*b*) and with (*c*) high-temperature annealing

Cross-sectional SEM imaging was used to determine the mean nanowire (NW) diameters. For GaAs NWs grown on GaAs/Si(111), the diameters of ten carefully measured nanowires ranged from 13 to 18 nm. In contrast, GaAs NWs grown directly on Si(111) exhibited a mean diameter approximately five times larger, despite the use of identical seed nanoparticles and growth conditions. The average NW length was similar for both samples, measuring approximately 2 μm.

Characterization of thin GaAs NWs by scanning TEM (STEM) was conducted in high angular annular dark field mode. GaAs NW in Fig. 2 exhibited a wurtzite structure. It was uniform along

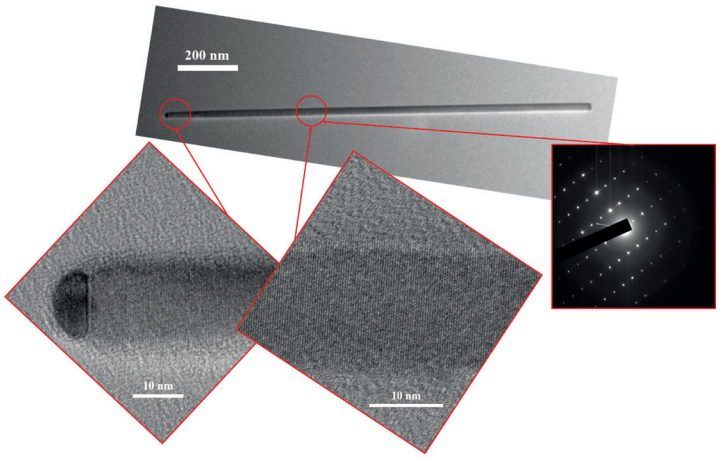

Fig. 2. TEM images of GaAs NW grown on GaAs/Si(111) substrate. Right inset is the diffraction pattern corresponded to wurtzite crustal structure

its length and shows no evidence of zinc-blend structure segmentation. Actually, stacking faults density was found to be around 0.5 μm^{-1}. The diameter of GaAs NW, measured next to NW tops, was found to be consistent with diameter of the 10 nm Au seed nanoparticle used. It indicates the Au-rich growth regime. Meanwhile, the slight increase in diameter towards the NW base was likely due to radial growth during the later growth stage. This result show a possibility of exploiting the bandgap engineering and quantum confinement effects in GaAs.

Conclusion

In summary, the possibility of depositing colloidal nanoparticles onto an amorphous GaAs layer grown on Si(111) substrates and direct molecular beam epitaxy of size-uniform GaAs nanowires with diameters below 20 nm was demonstrated. Examination of nanowires revealed nearly pure wurtzite crystal structure with low stacking fault density.

REFERENCES

1. **Park K., Lee J., Kim D., Seo J., Kim J., Ahn J. P., Park J.,** Synthesis of polytypic gallium phosphide and gallium arsenide nanowires and their application as photodetectors, ACS omega. 4 (2) (2019) 3098–3104.

2. **Patera M., Zieliński M.,** Antibonding ground states in crystal phase quantum dots, Physical Review B. 106 (4) (2022) L041405.

3. **Ilkiv I., Kirilenko D., Kotlyar K., Bouravleuv A.,** Thermal decomposition of GaAs nanowires, Nanotechnology. 31 (5) (2019) 055701.

4. **Bouravleuv A. D., Ilkiv I. V., Reznik R. R., Kotlyar K., Soshnikov I., Cirlin G. E., ... Lipsanen H.,** New method for MBE growth of GaAs nanowires on silicon using colloidal Au nanoparticles, Nanotechnology. 29 (4) (2017) 045602.

5. **Berdnikov Y., Ilkiv I., Sibirev N., Ubyivovk E., Bouravleuv A.,** Comparison of GaAs nanowire growth seeded by Ag and Au colloidal nanoparticles on silicon, Nanotechnology. 31 (37) (2020) 374005.

6. **Hijazi H., Dubrovskii V.G., Monier G., Gil E., Leroux C., Avit G., ... Andre Y.,** Influence of silicon on the nucleation rate of GaAs nanowires on silicon substrates, The Journal of Physical Chemistry C. 122 (33) (2018) 19230–19235.

7. **Andersen C.R.Y., Lehmann S., Tornberg M.U., Maliakkal C.B., Jacobsson D., Mшlhave K., Dick K.A.,** Direct observations of nucleation and early-stage growth of Au-catalyzed GaAs nanowires on Si (111), Nanotechnology. 36 (2025) 13560.

8. **Kolibal M., Konecny M., Ligmajer F., Skoda D., Vystavel T., Zlamal J., ... Sikola T.,** Guided assembly of gold colloidal nanoparticles on silicon substrates prepatterned by charged particle beams, ACS nano. 6 (11) (2012) 10098–10106.

THE AUTHORS

LENDYASHOVA Vera V.
erilerican@gmail.com
ORCID: 0000-0001-8192-7614

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

KOTLYAR Konstantin P.
kopkot95@yandex.ru
ORCID: 0000-0002-0305-0156

ILKIV Igor V.
fiskerr@ymail.com
ORCID: 0000-0001-8968-3626

KHREBTOV Artem I.
khrebtovart@mail.ru
ORCID: 0000-0001-5515-323X

Received 21.08.2025. Approved after reviewing 04.09.2025. Accepted 09.09.2025.