Results in Physics 16 (2020) 102919

Contents lists available at ScienceDirect

Results in Physics

journal homepage: www.elsevier.com/locate/rinp

Microarticle

HRXRD study of the effect of a nanoporous silicon layer on the epitaxial growth quality of GaN layer on the templates of SiC/por-Si/c-Si

P.V. Seredin[a,b,*], H. Leiste[c], A.S. Lenshin[a], A.M. Mizerov[d]

[a] Voronezh State University, Universitetskaya pl. 1, Voronezh 394018, Russia
[b] Ural Federal University, 19 Mira Street, Ekaterinburg 620002, Russia
[c] Karlsruhe Nano Micro Facility, H.-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany
[d] St. Petersburg National Research Academic University of the Russian Academy of Science, ul. Khlopina, 8, Block 3 A, St. Petersburg, Russia

ARTICLE INFO

Keywords:
GaN
SiC
por-Si
MBE PA
HRXRD

ABSTRACT

Using High Resolution X-ray Diffraction (HRXRD) diagnostic techniques the influence of the transition layer of nanoporous silicon on the practical implementation and certain features of the epitaxial growth of GaN layers with the use of molecular beam epitaxy were investigated by means of plasma activation of nitrogen (MBE PA) on the templates of SiC/por-Si/c-Si. For the first time it was shown that introducing of the transition layer of nanoporous silicon in the template of SiC/por-Si/c-Si where the layer of 3C-SiC was obtained by substitution of the atoms had a number of indisputable advantages as compared with conventional silicon substrates. Particularly, such an approach, in fact, enabled a 90% reduction in the level of stresses in the crystalline lattice of the epitaxial GaN layer which was synthesized on SiC surface of SiC/por-Si/c-Si template by means of MBE PA technique as well as to decrease some of vertical dislocations within GaN layer.

Introduction

Gallium nitride (GaN) and silicon carbide (SiC) are the most necessary representatives of the wide band-gap semiconductors and they are of a special interest for researchers, technologists and engineers. Their excellent structural, optical and electro-physical properties make GaN and SiC especially perspective materials for design of the electronic components base [1]. Based on the properties of the mentioned materials and the current progress of the growth technologies, it is possible to note that hybrid heteroepitaxial GaN/SiC will take a preferable place in the commercial devices. A lot of technological techniques were proposed for improvement of crystalline perfection of the hybrid GaN/SiC heterostructures [2]. One of the approaches to the above described problems is utilization of the transition nanoporous layer of silicon (por-Si), proposed in a number of our previous works [3,4]. There is a number of works describing the growth of GaN layer on SiC/Si templates, but there are no actual studies concerned with a direct growth of GaN on the templates of SiC/por-Si/c-Si. Therefore, the aim of this work is to HRXRD study of the effect of a por-Si on the epitaxial growth quality of GaN on the templates of SiC/por-Si/c-Si.

Materials and methods of investigations

Epitaxial GaN layers on the substrates of two types were grown in the common growth process by MBE PA with the use Veeco Gen 200. In order to grow unnon-doped GaN layers, SiC/c-Si(111) and SiC/por-Si (111) templates were utilized where SiC layer was formed by the atoms substitution technique [5]. A porous layer of silicon was formed on the half of single-crystalline c-Si (111) plate by its electrochemical etching. The thickness of the obtained porous layer was 30 nm. The specified technological mean diameter of the pores was ~1–5 nm. The structural quality of the samples was employed with the use of HRXRD applying reciprocal q-space mapping (RSM) of the samples with the diffractometer Seifert 3003 HR.

Experimental results and discussion

In Fig. 1 (a and b) the maps of the intensities distribution for the diffracted radiation in q-space around a symmetric node of (0002) of GaN are presented for heterostructures of both types. It is clearly seen that for both RSM obtained around (0002) reflection of GaN (see Fig. 1a and b) there is an additional node that is due to the reflection form the plane of (111) in SiC layer. Based on the experimental data, it is possible to calculate crystal lattice parameters, also the distortion of a

* Corresponding author at: Voronezh State University, Universitetskaya pl. 1, Voronezh 394018, Russia.
E-mail address: paul@phys.vsu.ru (P.V. Seredin).

https://doi.org/10.1016/j.rinp.2019.102919
Received 22 November 2019; Received in revised form 29 December 2019; Accepted 29 December 2019
Available online 03 January 2020

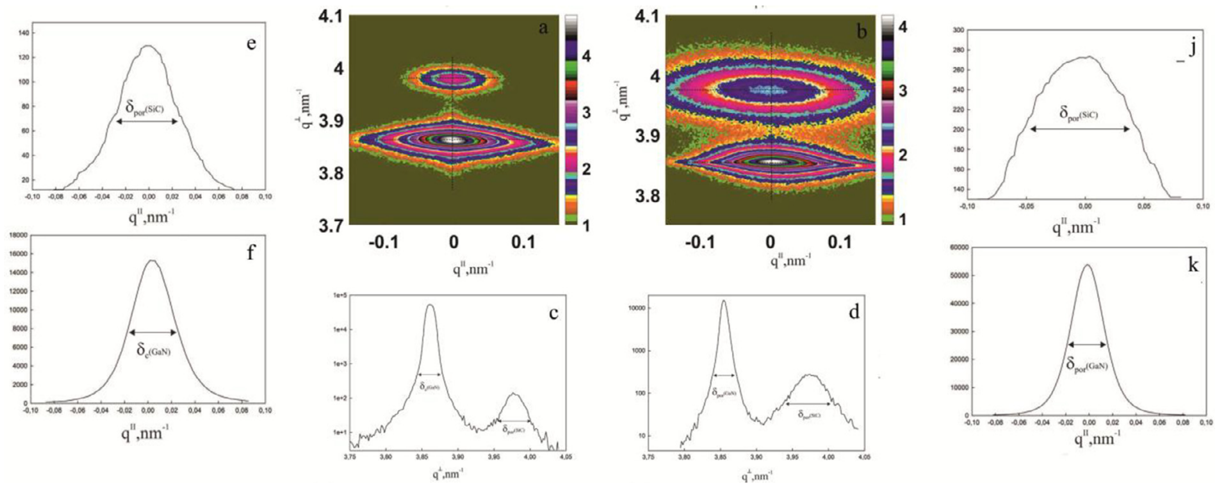

Fig. 1. RSM for (0002) GaN and (111) Si node for the heterostructures on the SiC/c-Si template (a) and on the SiC /por-Si template/s-Si (b). Cross sections of the (0002) GaN and (111) SiC nodes for heterostructures on the SiC/c-Si template (c, e, f) and on the SiC/por-Si/c-Si template (d, j, k).

Table 1
HRXRD results.

Sample		Lattice parameters		Defor-mation	Stress, σ
		c, Å	a, Å	ε_{zz}	
GaN/SiC/c-Si(111)	GaN	5.1813	3.1835	$-9{\cdot}10^{-4}$	0.93
GaN/SiC/por-Si(1 1)	GaN	5.1894	3.1933	$6{\cdot}10^{-4}$	0.28

lattice (deformation) and the level of stresses in the epitaxial GaN layer. The calculated parameters are presented in Table 1. The analysis of the shape and location of the nodes in the RSM provides additional information on the structural properties of the samples as well. Broadening of the node for the inverse lattice in the RSM is known to occur in two directions – parallel to the diffraction vector and perpendicular to this one. The parameters of the broadening can be estimated with the use of their cross-sections are presented in Fig. 1. According to the analysis of the information presented in Fig. 1 (f and k) one can see that GaN (0002) node in the RSM of heterostructure grown as on SiC/c-Si template, as on template of SiC/por-Si/Si with the porous sub-layer both have actually the same half-width in the plane of growth.

As for the size of GaN (0002) node in the direction of growth in the map of heterostructure grown on the template with the porous layer (see Fig. 1d), it is 15% less than the similar one in the map of the heterostructure grown on the conventional template of SiC/c-Si (see Fig. 1c). This can indicate that in the case of heterostructure growth on the por-Si substrate compared with the substrate of c-Si a percentage of the vertical dislocations in GaN layer reduces considerably while the contribution of the horizontal dislocations remains approximately the same. It should be noted that the analysis of the shape of the intensity distribution for the diffracted radiation around the node of (111) SiC-3C (see Fig. 1c–e, and j) demonstrated a considerably greater half-width of this node as in the plane as in the direction of growth in the case when GaN was grown on the template with the porous layer. A similar situation was observed for the node of (111) Si. First, this fact supports the idea on porosity as of the substrate as of SiC layer and it can possibly indicate the redistribution of stresses from the epitaxial GaN film into the layers of SiC/por-Si template.

The results of the HRXRD demonstrate that GaN layer formed on SiC/por-Si/c-Si template compared with the one formed on SiC/c-Si template shows much greater level (−90%) of the stresses in crystal lattice (see Table 1). Based on the analysis of the RSM, it is concluded that in the heterostructure grown on SiC/por-Si/c-Si template the stresses caused by a mismatch of crystal lattices in GaN-SiC-Si system are quite efficiently redistributed into the layer of por-Si and the layer of silicon carbide. As a result, structural quality of GaN film increases and therefore, a more uniform layer of GaN layer is formed with a higher quality without visible extended defects.

It should be noted that prior to our investigations there had been no any reports concerning with the growth of GaN films on the templates of SiC/por-Si. There are several known works where GaN layers were successfully grown on the porous Si substrates [6,7]. However, GaN layers in [6,7] were grown by MOCVD on the por-Si with different degrees of porosity with the use of transition AlN layer while in our work we rejected its use in favor of SiC layer. Moreover, the application of MBE PA for GaN synthesis on the SiC/por-Si/c-Si template made it possible to obtain GaN film with a considerably higher structural quality than was achieved in [6]. These films are characterized by lower stresses and at a much lower temperature of growth than in similar works where growth of films was employed with the use of Si porous substrates [6,7]. Summarizing all of the ideas presented above, we think that the use of SiC/por-Si templates as substrates for the following growth of GaN films has a number of indisputable advantages compared with the conventional ones.

CRediT authorship contribution statement

P.V. Seredin: Conceptualization, Methodology, Supervision, Investigation, Writing - original draft. **H. Leiste:** Investigation. **A.S. Lenshin:** Investigation, Writing - original draft. **A.M. Mizerov:** Investigation, Writing - original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We acknowledge the Karlsruhe Nano Micro Facility for provision of access to instruments at their laboratories. Authors also grateful to Dr. Sergey Kukushkin for his help with SiC layer formation.

Funding

The work was executed under support of the grant of Russian Science Foundation 19-72-10007. Access to KNMF equipment was obtained under the grant of the President of the Russian Federation MD-

42.2019.2.

References

[1] Leone S, Benkhelifa F, Kirste L, Manz C, Quay R, Ambacher O. J Appl Phys 2019;125. https://doi.org/10.1063/1.5092653. 235701.
[2] Gkanatsiou A, Lioutas ChB, Frangis N, Polychroniadis EK, Prystawko P, Leszczynski M. Superlattices Microstruct 2017;103:376–85. https://doi.org/10.1016/j.spmi.2016.10.024.
[3] Seredin PV, Lenshin AS, Zolotukhin DS, Arsentyev IN, Nikolaev DN, Zhabotinskiy AV. Physica B 2018;530:30–7. https://doi.org/10.1016/j.physb.2017.11.028.
[4] Seredin PV, Lenshin AS, Mizerov AM, Leiste H, Rinke M. Appl Surf Sci 2019;476:1049–60. https://doi.org/10.1016/j.apsusc.2019.01.239.
[5] Kukushkin SA, Osipov AV. J Phys D Appl Phys 2014;47. https://doi.org/10.1088/0022-3727/47/31/313001. 313001.
[6] Ishikawa H, Shimanaka K, Tokura F, Hayashi Y, Hara Y, Nakanishi M. J Cryst Growth 2008;310:4900–3. https://doi.org/10.1016/j.jcrysgro.2008.08.030.
[7] Chaaben N, Yahyaoui J, Christophersen M, Boufaden T, El Jani B. Superlattices Microstruct 2006;40:483–9. https://doi.org/10.1016/j.spmi.2006.09.022.