MOCVD OF III-NITRIDE NANOSTRUCTURES FOR ELEMENTS OF RADIATION, CONVERSION AND ENERGY STORAGE

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INTRODUCTION

MOCVD can allow a greater flexibility in dopant selection and great control over the compound stoichiometry. But it has not been systematically studied as for III-nitride nanowire physical properties. So, integration of nanowire components into current thin-film technologies is an important consideration.

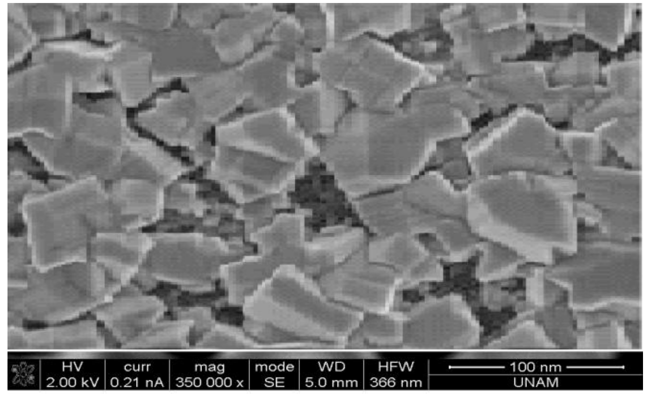
Using site-controlled III-nitride quantum dots (QDs) has many advantages for the converting and emitting elements, including its quantum variant [1, 2] with possibility to realize single photon sources (SPS) for quantum processing in contrast to the self-assembled Stranski–Krastanov QDs [3]. We outline some general aspects of the optical properties of III-nitride QDs formed on non-polar surfaces of hexagonal nanowires discussing its high temperature properties for quantum processing.

We also discuss integration possibility of energy storage elements in a single process of MOCVD reactor as for sapphire nano-templates. It has been observed, that, on the nano-templated sapphire surface, a dense transparent film of anomalous surface resistance an order of magnitude lower compared to the original one may be formed through clustering of consolidated phases of BCN in the stream of triethylboron. It has been considered fittingness of such sapphire nano-templates for super capacitor through formation of h-BN in which graphene can be encapsulated

Integration motivation as for choice of site-controlled InGaN/GaN QDs for light emitting and conversion elements

- **efficient radiative recombination and radiating capacity within the wide spectral range (from infrared to ultraviolet spectral regions)**
- **ideal candidate as sources of single-photon emitters for quantum information processing and quantum cryptography at room temperature** Unlike to commonly used ***site-controlled InAs QDs which need cryogenic temperatures***
- **are able to optimize absorption coefficient in the converting part of enestor and to provide phosphor-free white emitting without current degradation i**n contrast to the self-assembled Stranski–Krastanov QDs with very limited position and dimension control
- **possibility of integrating with Si-CMOS technology**

Anodic alumina nanotemplates in MOCVD process



SEM image of an overgrown anodic alumina nano template surface

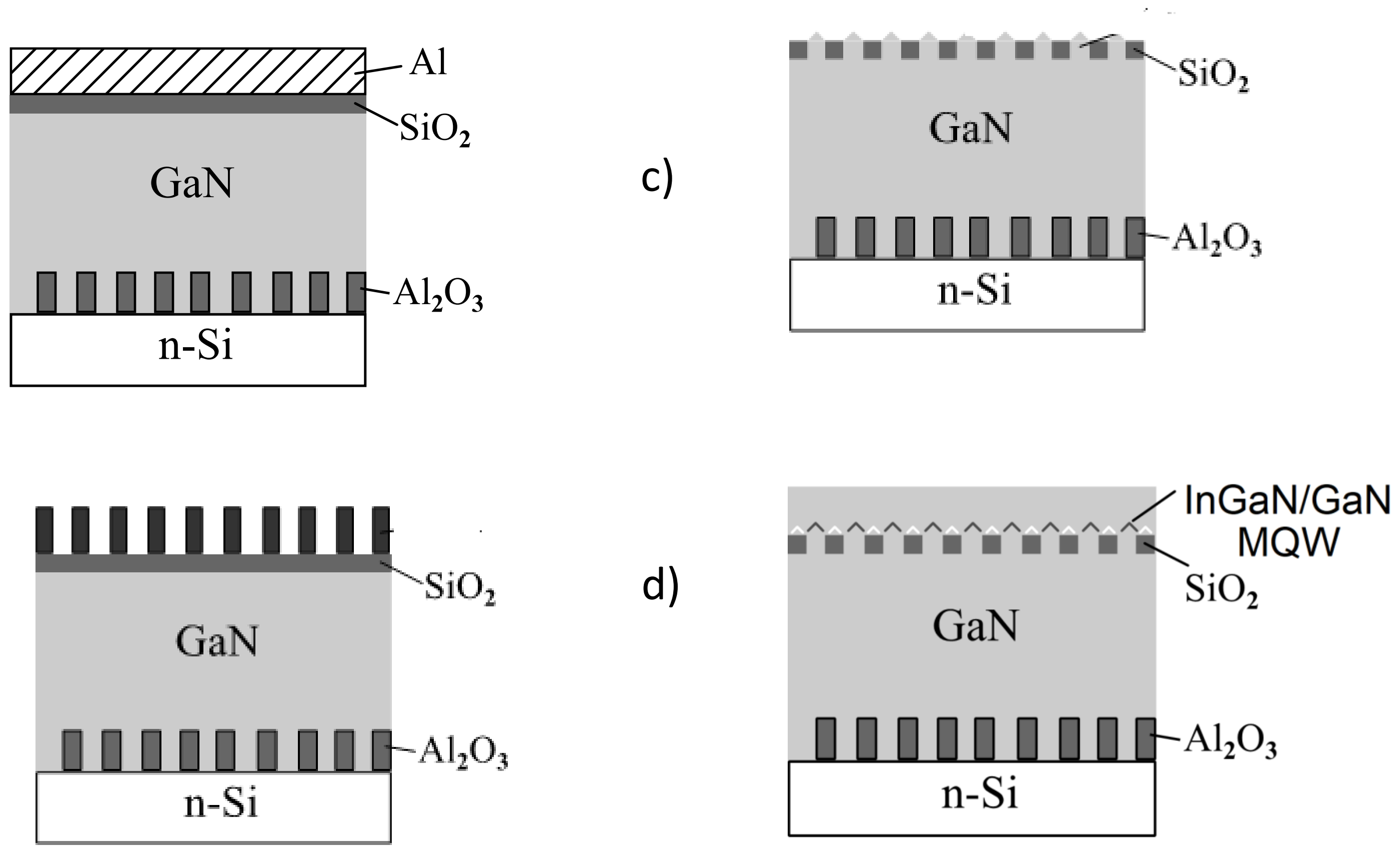
- Under standard MOCVD modes of GaN, the Al_2O_3 templet intensively overgrows due to the high sticking coefficient (~ 1) of Ga atoms .
- It makes impossible to form GaN nanorods with QDs.
- Therefore, a transition to a SiO_2 mask is proposed, since the sticking coefficient of Ga and In atoms to SiO_2 is 0.

a)

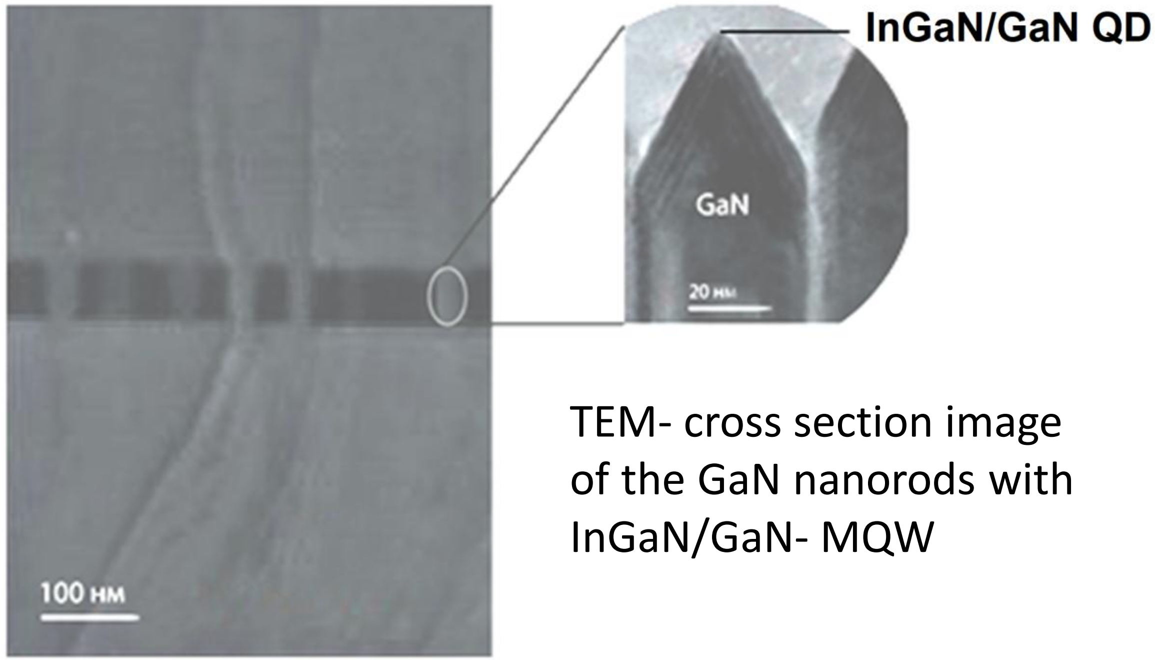
b)

c)

d)



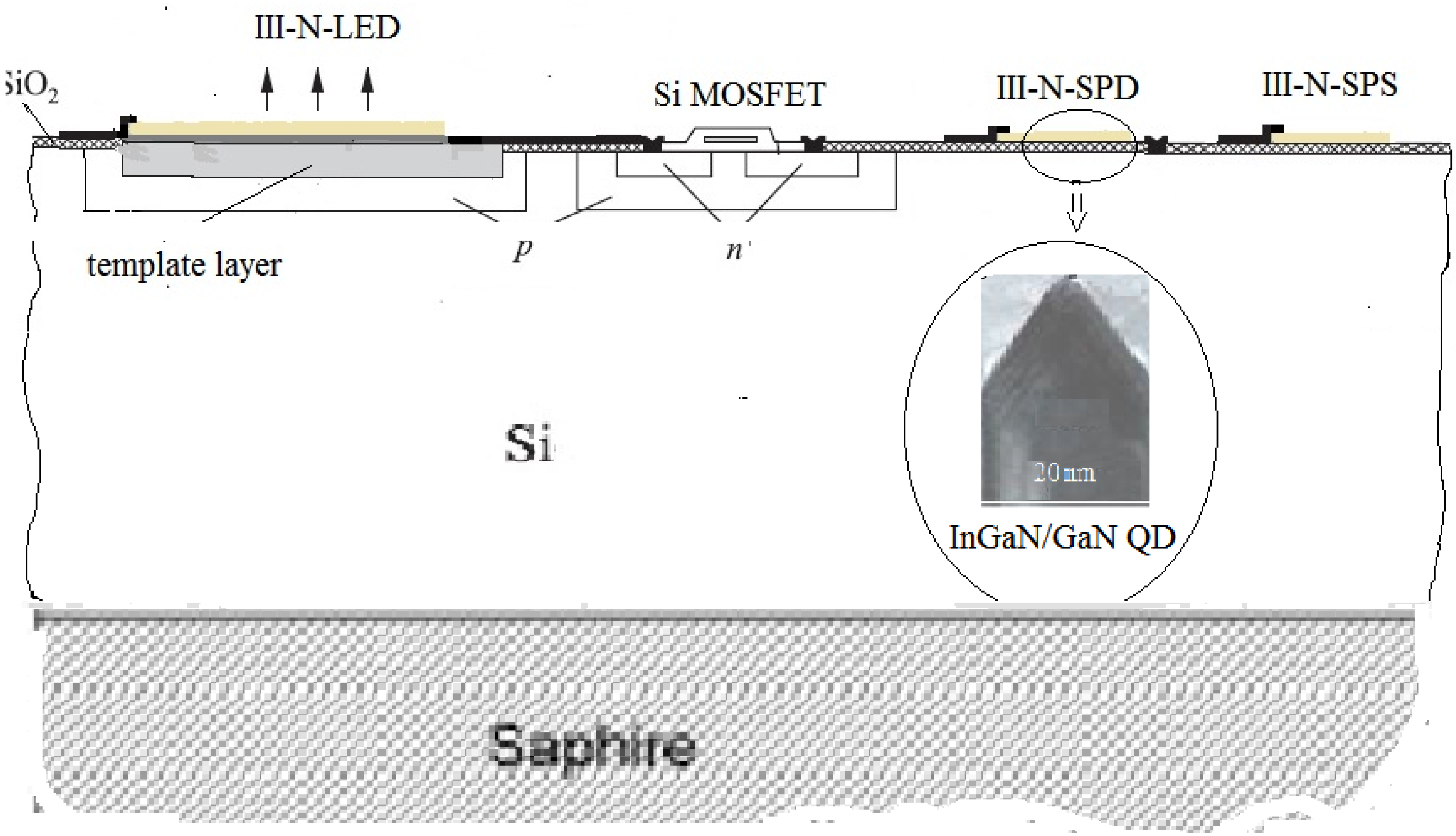
Process layout: (a) deposition of a 0.1 µm thin SiO2 film on a GaN layer using plasma chemical deposition, followed by sputtering Al 1 µm film (b) formation of AAO template (d = 60 nm), (c) plasma chemical etching to transfer the hexagonally ordered pattern AAO nano pores on SiO_2 mask with subsequent removal of AAO template, overgrowing of the formed SiO_2/GaN template by MOCVD (c); MOCVD formation InGaN/GaN MQW and GaN layer (d)



TEM- cross section image of the GaN nanorods with InGaN/GaN- MQW

It has been established in the study of the cross section of GaN nanorods by transmission electron microscopy that the dislocation density is less than $3x10^6$ cm^{-2} and that the nanorods have vertical side walls in the pores of the SiO_2 mask and their height is determined by the mask thickness

Fragment of Si-CMOS and III-N QD SPS/SPD integration for enestor



Template layers of nano-textured sapphire

Processing sapphire substrate in a stream of ammonia:

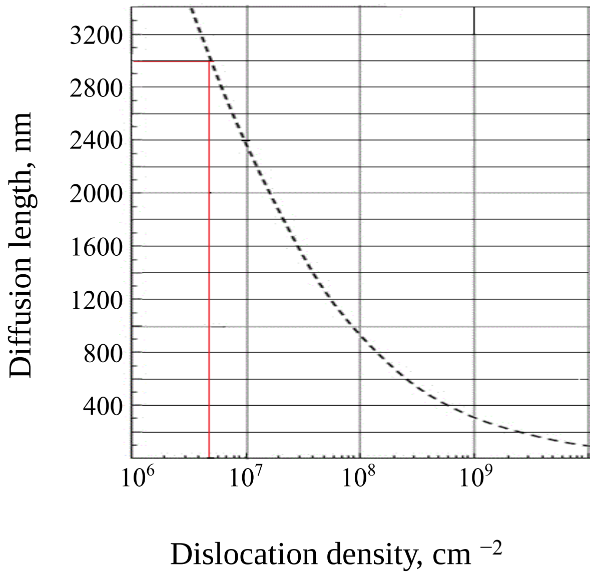
equipment	horizontal reactor, EPIQUIP installation
temperature	1050° C
time	20 min
preasure	20 mbar

The calculated effective diffusion length of non-equilibrium carriers for the p-GaN epitaxial layer was Ld ≈ 3.0 μm, which within the modified model corresponds to the threading dislocation density of ~ 5 × 10^6 cm^{-2} and an internal quantum yield of ~ 70%.

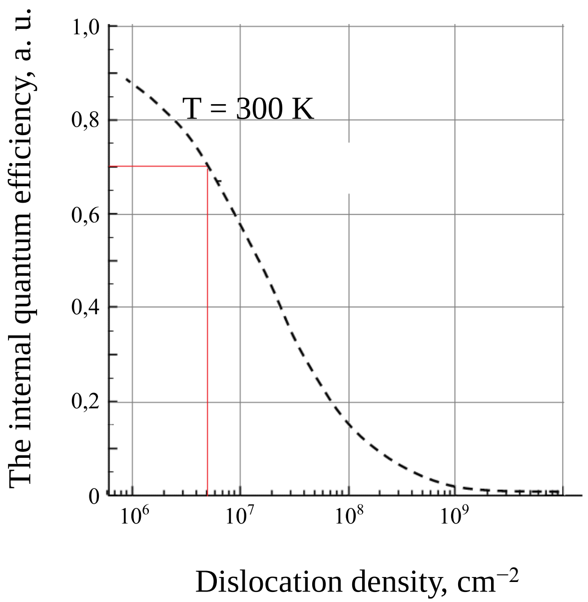
The dependence of the induced current on the coordinates

$$I = I_0 e^{-x/L_d}$$

I_0 — maximum current on the investigated segment of the surface; x – distance along the end; L_d – the diffusion length of nonequilibrium carriers.



Dependence of the diffusion length of nonequilibrium carriers on the dislocation density



Dependence of the internal quantum efficiency of the dislocation density for GaN. structures

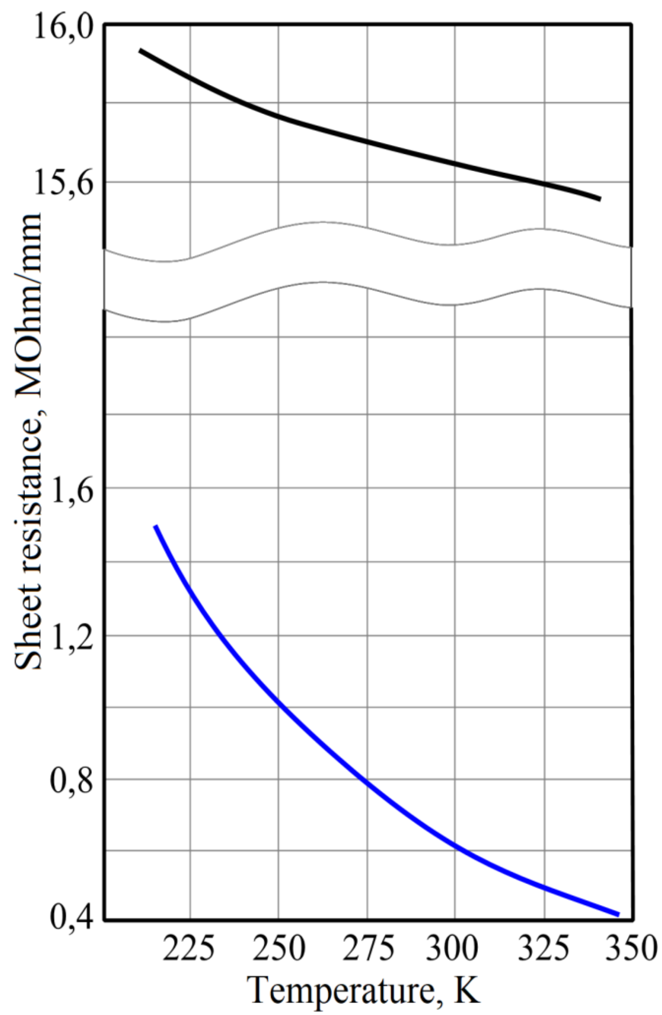
Textured sapphire nanotemplates for energy storage layers

The thermodynamic, physical and chemical conditions in the MOCVD reactor are very favorable for the formation of nanocarbides. We considered MOCVD processes on the sapphire substrate as for decomposition of trimethylaluminum, (triethylboron):

$$Al(CH_3)_3 \rightarrow Al + C + H_2\uparrow$$

The carbon atoms form clusters easier than any element of the periodic system. The presence of trimethyl aluminum, (triethylboron): inside MOCVD reactor may cause carbon nanostructure formation.

Параметры получения нанокарбидизированного сапфира	
Precursors	Trimethylaluminum Al(CH3)3 Triethyl boron (C2H5)3B
T	250 - 1100oC
preasure	20 mbar



Temperature dependence of the surface resistance of nanocarbidized sapphire (blue) and sapphire nano-template (black).

Textured sapphire nanotemplates for energy storage layers

For nanotemplates of textured sapphire in the process of MOCVD-heteroepitaxy of III-nitrides (AlN, BN) on the basis of experimentally determined thermodynamic parameters nanopores with radius R_c<10 nm were obtained, which showed the possibility of forming low-dislocation heteroepitaxial layers and the following possible applications are proposed:

- obtaining supercapacitors based on nanoteplets formed on textured sapphire layers of low-defect hexagonal boron nitride (h-BN), in which graphene is encapsulated;
- formation of nanocarbides and consolidated phases AlCN and BCN in MOCVD-reactor in the flow of TMA and TEV, respectively, on the surface of nanotamples of textured sapphire for layers of energy accumulation.