Nanofios Semicondutores
Aplicações e Crescimento

PM – II

2012

Aplicações
(nanofios de GaN)

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Gallium Nitride-Based Nanowire Radial Heterostructures for Nanophotonics

Fang Qian,[†,§] Yat Li,[†,§] Silvija Gradečak,[†,§] Deli Wang,[†] Carl J. Barrelet,[†] and Charles M. Lieber*[,†,‡]

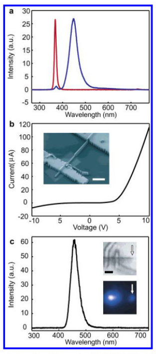


Figure 4. Optoelectronic properties of n-GaN/InGaN/p-GaN CSS nanowires. (a) Normalized PL spectra obtained from single n-GaN (red) and n-GaN/InGaN/p-GaN CSS (blue) nanowire. (b) Current vs voltage data recorded on a n-GaN/InGaN/p-GaN CSS nanowire device. Inset: field emission SEM image of a representative CSS nanowire device prepared using the FIB technique to selectively etch the outer shells from one end (lower right) of the CSS nanowire prior to contact deposition. Scale bar is 1 μm. (c) EL spectrum

(a) PL

Red – single n-GaN

Blue n-GaN/InGaN/p-GaN

(b) SEM - Nanowire device

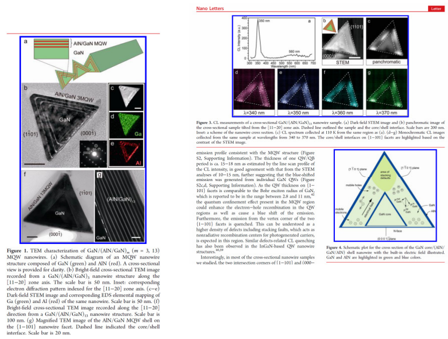
Bar - 1μm

(c) Eletroluminescência, 4K, V = 12V

Controlled Synthesis of AlN/GaN Multiple Quantum Well Nanowire Structures and Their Optical Properties

Fang Qian,[†] Megan Brewster,[‡] Sung K. Lim,[‡] Yichuan Ling,[§] Christopher Greene,[§] Oleg Laboutin,[⊥] Jerry W. Johnson,[⊥] Silvija Gradečak,[‡] Yu Cao,*[,⊥] and Yat Li*[,§]

barra – 200 nm



dx.doi.org/10.1021/nl301690e | *Nano Lett.* 2012, 12, 3344−3350

Estrutura e Crescimento

Como é o crescimento desses nanofios e qual sua estrutura?

GaN - MBE

3156 K.A. Bertness et al. / Journal of Crystal Growth 310 (2008) 3154–3158

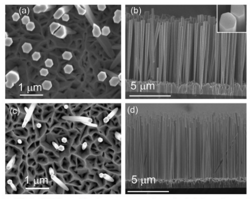


Fig. 2. FESEM top views (a–c) and side views (b–d) of the morphology for two spontaneous nanowire runs showing the hexagonal cross-section and upright growth habit. The upper set of micrographs (a,b) shows the increase in diameter during growth that results when nanowires are close enough to recapture Ga atoms desorbing from neighboring wires. A tilted close-up of the nanowire tips shows that no Ga droplets are present after growth [inset in (b)], nanowire diameter about 500 nm.

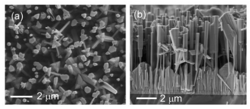


Fig. 3. FESEM top view (a) and side view (b) of GaN nanowire growth in which the nanowires were cooled to less than 300 °C under Ga and N flux, as described in the text. If Ga droplets had been present during growth, they would have been expected to persist and even enlarge because Ga re-evaporation is reduced at lower temperatures. Instead the growth of GaN continues in crystalline layers with side branches (top view) and clear overcoats (side view).

LETTERS

Crystallographic alignment of high-density gallium nitride nanowire arrays

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Published online: 25 July 2006; doi:10.1038/nmat1177

GaN - MOCVD

LETTERS

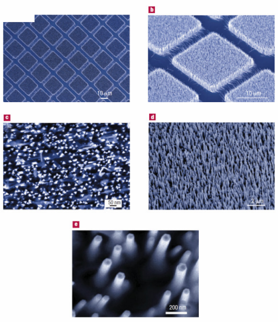

Figure 1 SEM images of the GaN nanowires. a–c, Wires grown on (100) γ-$LiAlO_2$. **d–e**, Wires grown on (111) MgO substrates.

LETTERS

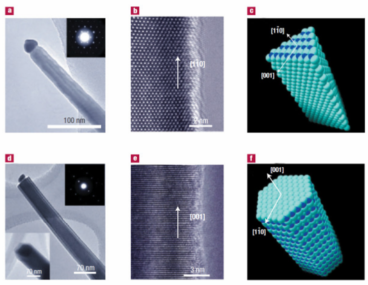

Figure 3 TEM images of the GaN nanowires. a–c, Wires grown on (100) γ-$LiAlO_2$. The inset in **a** is an electron-diffraction pattern recorded along [001] zone axis. **d–f**, Wires grown on (111) MgO substrates. The insets in **d** show the hexagonal cross-section of the wire and an electron-diffraction pattern recorded along the [1$\bar{1}$0] zone axis. **c** and **f** show space-filling structural models for the nanowires with triangular and hexagonal cross-sections.

Quais são os modelos de cresciemnto?

Modelo V-L-S

J. Am. Chem. Soc. **2001,** *123,* 3165−3166 3165

Direct Observation of Vapor−Liquid−Solid Nanowire Growth

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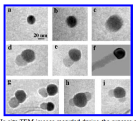
Received December 20, 2000

Nanotubes and semiconductor nanowires are of fundamental importance to the study of size- and dimensionality-dependent chemical and physical phenomena.[1,2] How to rationally synthesize these 1-dimensional nanostructures has been a major challenge, although several strategies have been pursued recently.[3−16] For example, carbon nanotubes have been prepared via condensation of hot carbon plasmas in the presence of certain metals, although the real growth mechanism has been elusive.[3−5] Recently, semiconductor nanowires with different compositions have been successfully synthesized using either vapor[6−12] or solution-based methodologies.[13−16] One key feature of these syntheses is the promotion of anisotropic crystal growth using metal nanoparticles as catalysts. The growth mechanism has been extrapolated from the vapor−liquid−solid (VLS) mechanism which was proposed in the 1960s−1970s for large whisker growth,[17−19] although an oxide-assisted growth mechanism has also been proposed.[2,20] Direct evidence for the nanowire growth mechanism, however, is still lacking except for the fact that these nanowires generally have alloy droplets on their tips. Hence, a better understanding of the nanowire growth process in the vapor phase is necessary to pin down the growth mechanism and to be able to rationally control their compositions, sizes, crystal structures, and growth directions. Herein we report the first real-time observation of semiconductor nanowire growth in an in situ high-temperature transmission electron microscope (TEM), which unambiguously demonstrates the validity of the VLS growth mechanism at

(1) Hu, J.; Odom, T. W.; Lieber, C. M. *Acc. Chem. Res.* 1999, *32*, 435−445.
(2) Prokes, S. M.; Wang, K. L. *Mater. Res. Bull.* 1999, *24*, 13−36.
(3) Colbert, D. T.; Zhang, J.; Mcclure, S. M.; Nikolaev, P.; Cheng, Z.; Hafner, J. H.; Owens, D. W.; Kotula, P. G.; Carter, C. B.; Weaver, J. H.; Rinzler, A. G.; Smalley, R. E. *Science* 1994, *266*, 1218−1222.



Au-Ge

Figure 1. In situ TEM images recorded during the process of nanowire growth. (a) Au nanoclusters in solid state at 500 °C; (b) alloying initiates at 800 °C, at this stage Au exists in mostly solid state; (c) liquid Au/Ge alloy; (d) the nucleation of Ge nanocrystal on the alloy surface; (e) Ge nanocrystal elongates with further Ge condensation and eventually a wire forms (f). (g) Several other examples of Ge nanowire nucleation, (h,i) TEM images showing two nucleation events on single alloy droplet.

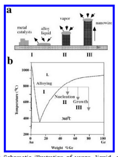


Figure 2. (a) Schematic illustration of vapor−liquid−solid nanowire growth mechanism including three stages (I) alloying, (II) nucleation, and (III) axial growth. The three stages are projected onto the conventional Au−Ge binary phase diagram (b) to show the compositional and phase evolution during the nanowire growth process.

Modelo de crescimento espontâneo

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

Mechanism for spontaneous growth of GaN nanowires with molecular beam epitaxy

K.A. Bertness *, A. Roshko, L.M. Mansfield, T.E. Harvey, N.A. Sanford

GaN

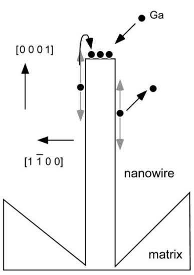


Fig. 1. Schematic of differential sticking coefficient mechanisms for spontaneous nanowire growth in MBE. Ga atoms that impinge on the nanowire tip or within a surface diffusion length of the tip (illustrated on the left side of the wire) will incorporate at the tip; adatoms arriving farther down the sides (illustrated on the right side of the wire) are likely to desorb rather than incorporate. The nanowire is shown growing out of a GaN matrix layer, as we typically observe for MBE growth on AlN buffers on Si (1 1 1) substrates. The sidewalls of the matrix pits are {1 1̄ 0 2} planes.

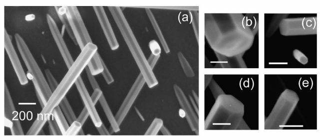


Fig. 4. FESEM views of GaN nanowires cooled under Ga flux without nitrogen overpressure (see text for details). (a) Low-magnification view, (b)–(e) higher magnification images of ends, marker bar of 100 nm. All the nanowires are free of catalyst-size Ga droplets. (b) illustrates a small Ga surplus accumulated during the cooling phase.

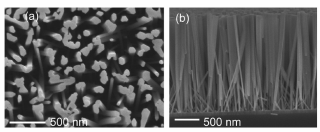


Fig. 5. FESEM top view (a) and side view (b) of MBE nanowire growth on Si (1 0 0). Relative azimuthal orientation is more random and nucleation more dense than for nanowires grown on Si (1 1 1), leading to high coalescence and increasing diameter as growth progresses. The hexagonal cross-section is visible for a few isolated wires in the top view, and coalesced wires retain angular sidewalls. The AlN buffer is visible in the side view as a medium tone layer of uniform thickness about 100 nm thick. Nanowires nucleate at the AlN–GaN interface.

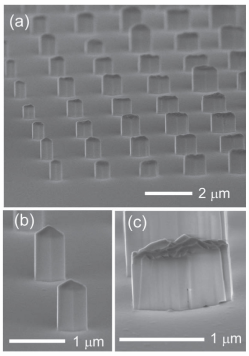


Figure 1. Arrays of selectively nucleated GaN nanowires with a FESEM view angle of 80° from the sample normal; a) array with openings from 500 to 1000 nm; b) close-up of nanowires growing in an opening of 500 nm; c) close-up of GaN in an opening with 1000 nm diameter from a different region on the same wafer.

Por que os cristais crescem dessa forma?

Como posso ter organização regular das estruturas?

Fundamentos

- Teorema de Wulff

$$\sum_{k} \gamma_k A_k = mínima$$

γ_k – energia de superfície (k)
A_k – área da superfície (k)

$$\frac{\gamma_k}{r_k} = cte$$

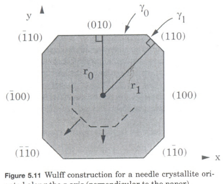
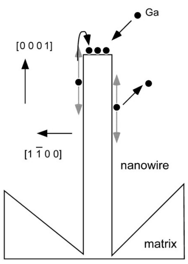


Figure 5.11 Wulff construction for a needle crystallite oriented along the z axis (perpendicular to the paper).

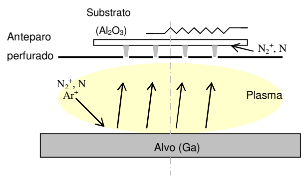
Fundamentos

- Cinética



S_c –sticking coefficient

SAG



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Controlled Nucleation of GaN Nanowires Grown with Molecular Beam Epitaxy

By Kris A. Bertness,* Aric W. Sanders, Devin M. Rourke, Todd E. Harvey, Alexana Roshko, John B. Schlager, and Norman A. Sanford

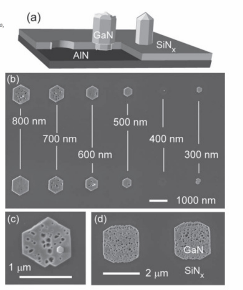
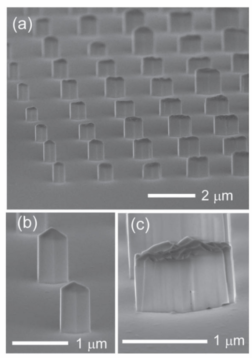


Figure 2. GaN selective area growth showing effect of mask opening dimensions on growth morphology. a) Schematic of the growth with perspective view with cut-away showing circular opening in mask down to the AlN layer and nanowire growth within the openings. b) Overhead-view images of nanowires grown in two rows with nominal opening diameter decreasing from left to right, as indicated; also shows effect of incomplete mask etching for 400 and 300 nm openings; c,d) openings were defined with photolithography and were initially rounded square openings. Note that the {1 –1 0 0} planes are still evident in d.



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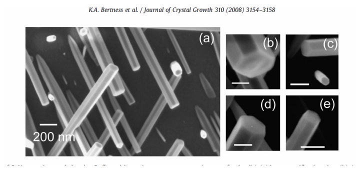

<u>Concluindo:</u>

Forma dos Cristais

- Teorema de Wulff (termodinâmica)
- Cinética