Cathodoluminescence and electron microscopy studies of gallium nitride nanowires with passivated surfaces

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Introduction

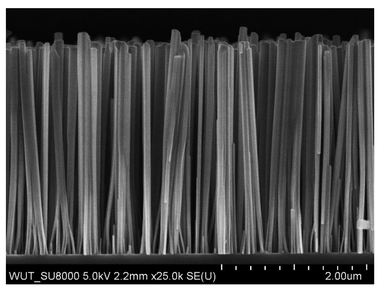
Although the influence of surface conditions on transport and optical properties of semiconductor nanowires (NWs) has been identified, the methods of controlling it and inhibiting its detrimental impact on the NW characteristics still remain an important subject of research. This applies especially to nanowires, also those made of the group III nitrides. For example, as the depth of the depletion or accumulation layer induced by surface band bending may become comparable with the diameter of the NW, its part available for transport, charge carrier injection or light generation can be markedly reduced. Therefore, we carry out complementary studies of cathodoluminescence of GaN NWs with surfaces modified by etching in KOH and HCl solutions or by deposition of a HfO_x shell.

Samples

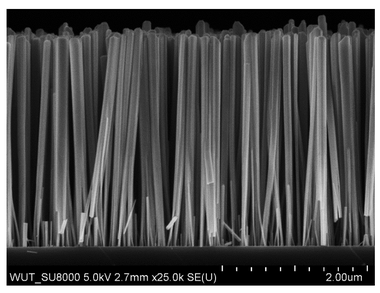
The GaN NWs were grown on in-situ nitridated 3" Si (111) substrates using plasma-assisted molecular beam epitaxy (PA MBE) in a Riber Compact 21 system with elemental sources of Ga, Al, Si, and Mg. A radio frequency Addon nitrogen plasma cell, controlled by an optical sensor of plasma light emission, was used as the source of active nitrogen species. No catalyst was applied to induce nucleation of NWs.

GaN nanowires etched in KOH and HCl

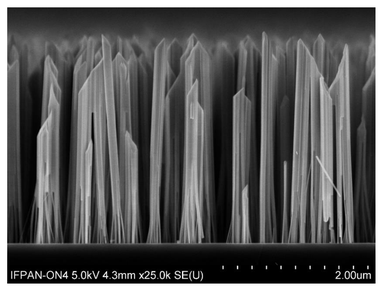
The morphology of the samples was assessed by scanning electron microscopy (SEM) using a field-emission scanning electron microscope.



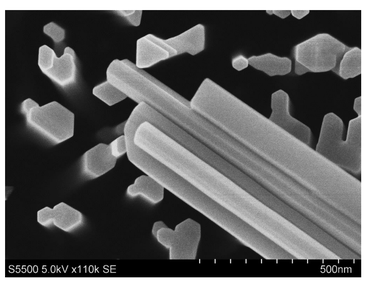
GaN NWs grown by PA MBE on a Si wafer

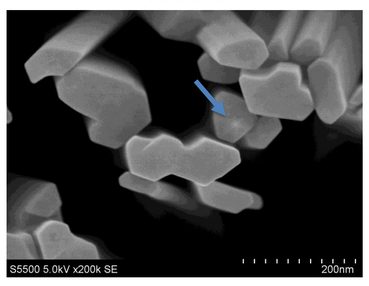


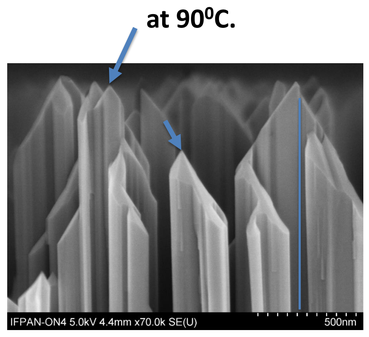
GaN NWs etched in a 10% solution of KOH in water, 40 s at 56^{0}C.



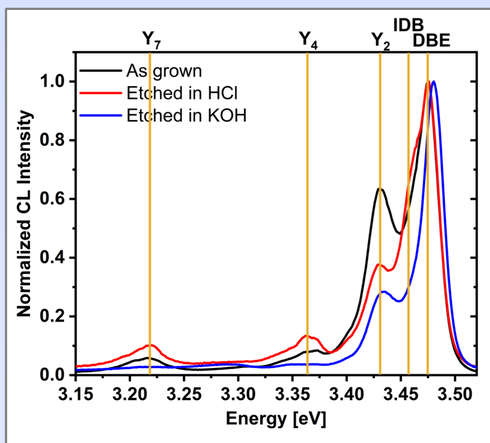
GaN NWs etched in HCl, 15 min. at 90^{0}C.







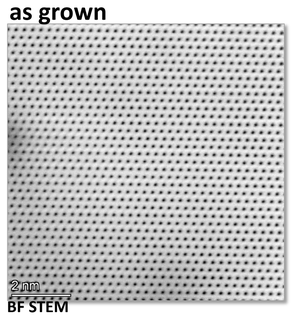
Cathodoluminescence



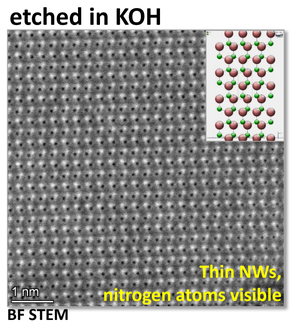
DBE - donor-bound exciton (shift due to strain?)
IDB - exciton bound to an inversion domain interface - better discernible after etching in HCl
Y_2 - exciton bound to a structural defect at the surface / stacking faults at the coalescence area - weaker after etching processes – coalescence related stacking faults removed?
Y_4 - exciton bound to a structural defect at the surface - disappeared after etching in KOH
Y_7 - exciton bound to a structural defect - disappeared after etching in KOH

Transmission Electron Microscopy (TEM)

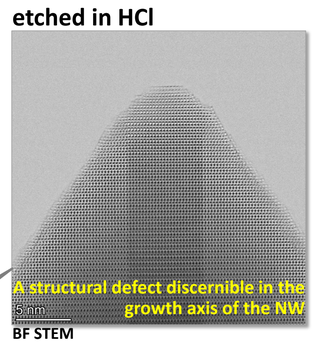
as grown



etched in KOH

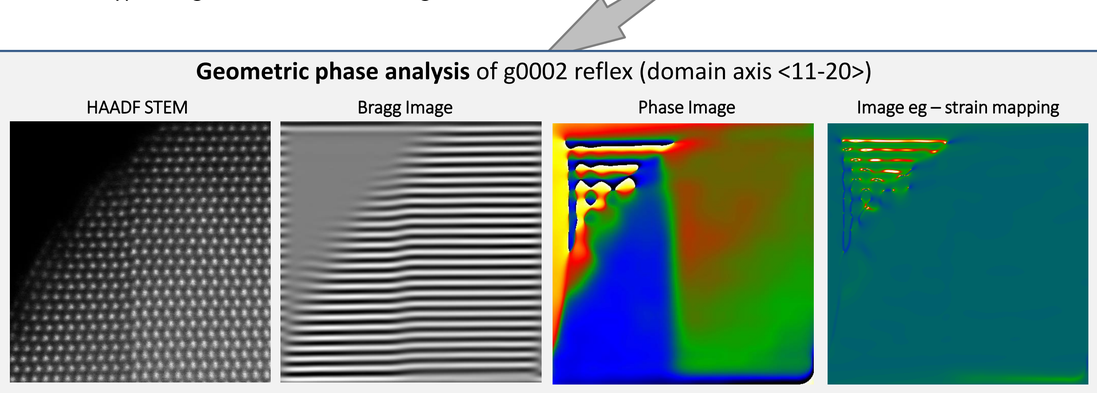


etched in HCl



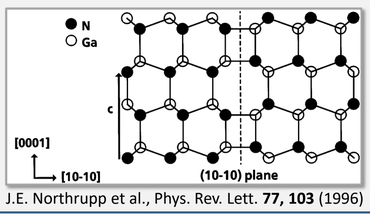
Typical high resolution STEM images

Geometric phase analysis of g0002 reflex (domain axis <11-20>)



The evidence of the presence of an inversion domain

Phase shift (1/2 c) – characteristic of inversion domains
No evidence of strain change in the defect region



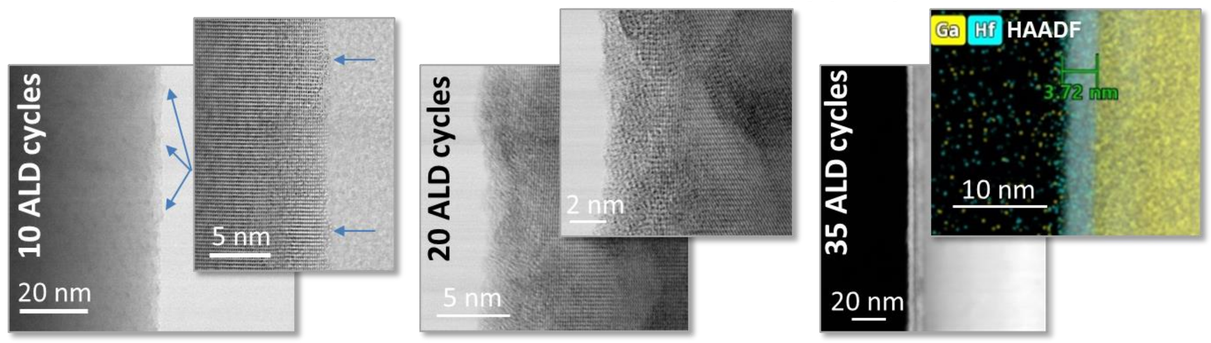
J.E. Northrupp et al., Phys. Rev. Lett. **77, 103** (1996)

Analysis: **Julita Smalc-Koziorowska**

GaN/HfO_x core/shell heterostructures

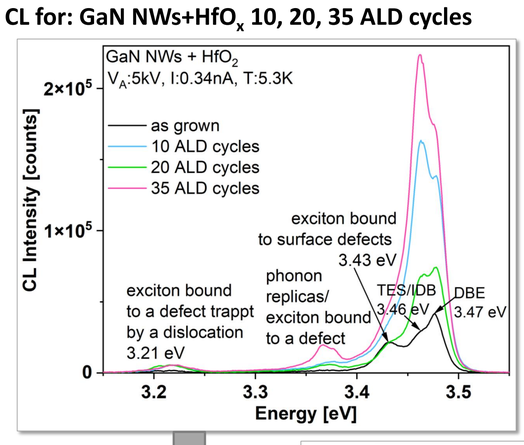
The GaN nanowires grown by PA MBE were covered with HfO_x shells by atomic layer deposition (ALD).

Transmission Electron Microscopy (TEM)

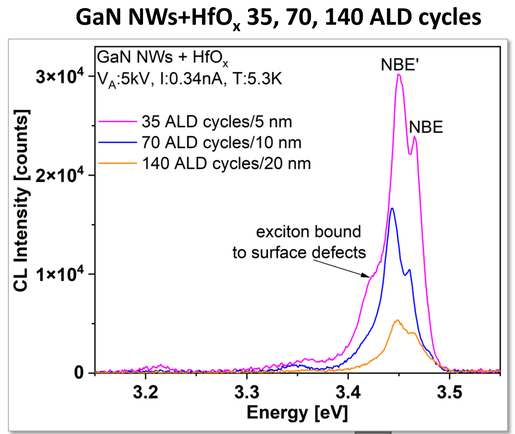


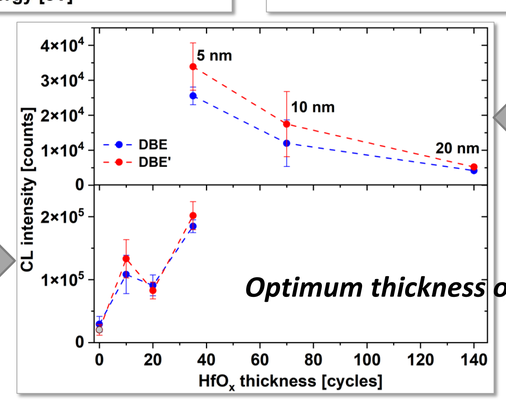
Cathodoluminescence

CL for: GaN NWs+HfO_x 10, 20, 35 ALD cycles



GaN NWs+HfO_x 35, 70, 140 ALD cycles

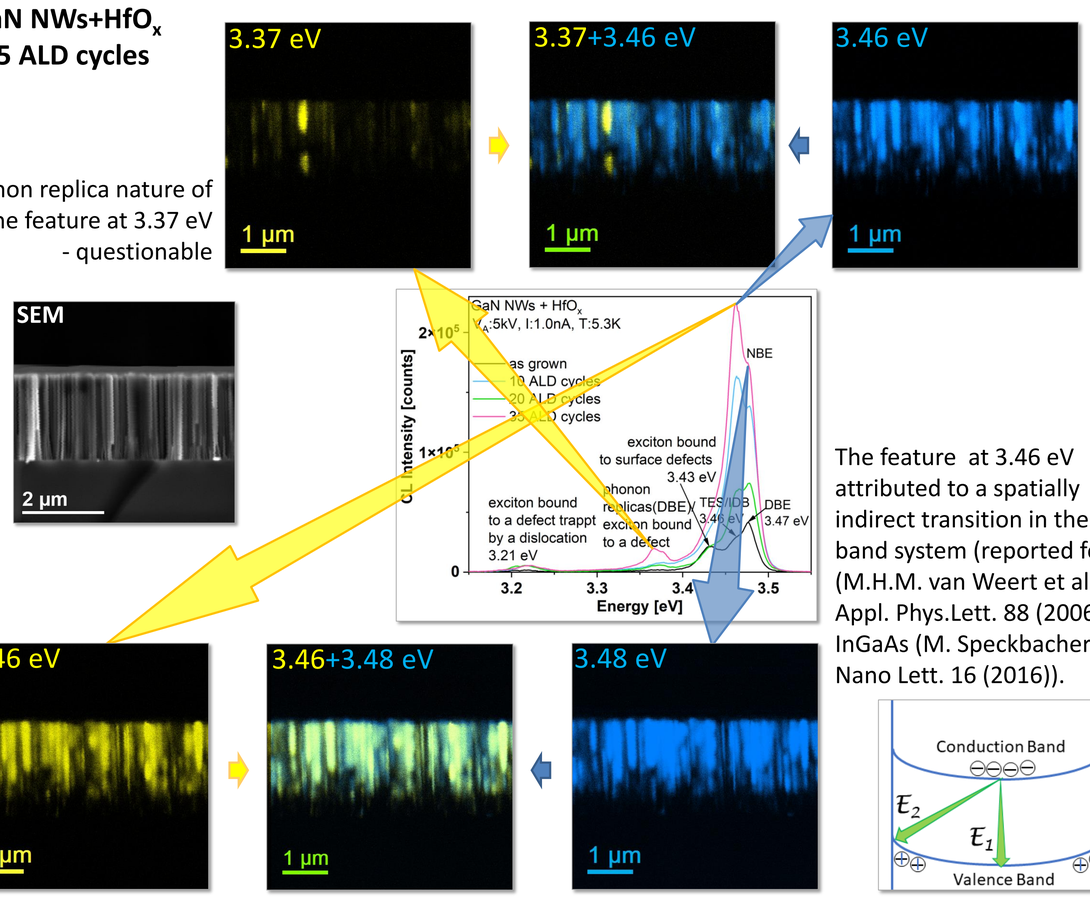




Optimum thickness of the HfO_x shell ~ 5 nm

GaN NWs+HfO_x 35 ALD cycles

Phonon replica nature of the feature at 3.37 eV - questionable



The feature at 3.46 eV attributed to a spatially indirect transition in the bent-band system (reported for InP (M.H.M. van Weert et al., Appl. Phys.Lett. 88 (2006)) and InGaAs (M. Speckbacher et al., Nano Lett. 16 (2016)).

CONCLUSIONS

- HR STEM observations of the GaN NWs etched in HCl, supported by a geometric phase analysis, revealed the presence of inversion domains along the growth axis of the GaN NWs.
- Etching nitride nanowires in HCl turns out to be an effective method for visualizing inversion domains, defects important for optoelectronic applications of nanowires.
- Optimum HfO_x shell thickness determined for maximum luminescence intensity (~5 nm).
- The phonon satellite nature of the CL feature at 3.37 eV (for GaN/HfO_x core/shell structures) has been questioned.
- Strong feature appearing at 3.46 eV for the GaN/HfO_x core/shell structures attributed to a spatially indirect transition in the bent-band system.

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