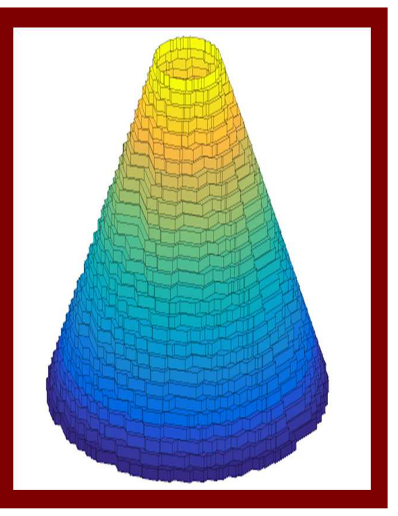
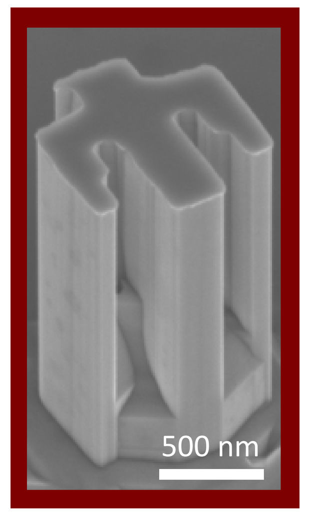
SAND2015-10469D

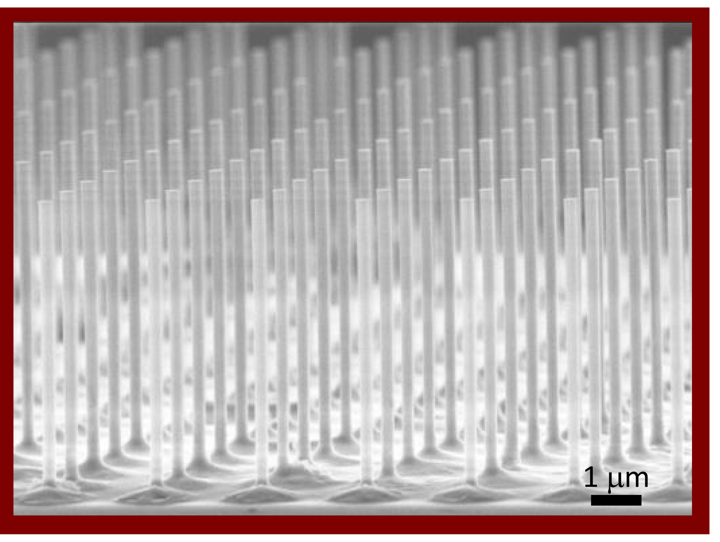
Sandia National Laboratories

Crystallographic etching of GaN: Fundamentals and applications to nanostructure synthesis

Benjamin Leung[1], Miao-Chan Tsai[2], Changyi Li[2], Sheng Liu[1], Jeffrey J. Figiel[1], Andy Allerman[1], Mary Crawford[1], Ganesh Balakrishnan[2], Steven Brueck[2], and George T. Wang[1,*]
[1]Sandia National Laboratories, Albuquerque, NM, [2]Center for High Technology Materials, University of New Mexico, NM, *gtwang@sandia.gov







Abstract

Chemical etch processes for GaN materials and devices are severely underdeveloped due to its apparent inertness to all common wet etchants. Here, we revisit the etch characteristics of GaN using the general geometric principles of crystallographic dissolution processes, and show significant etch rates albeit with extremely high crystallographic anisotropy, reaching ratios of > 2000:1 (compared to Si of up to ~160:1 and GaAs of ~4:1). We utilize this unique property to produce high aspect ratio, exactly vertical facetted nanostructures. This new understanding can aid in realizing useful facet-scale designed structures for nanophotonics or NOEMS.

Summary

- Facet mediated etch morphology evolution for GaN under KOH based etches is described through a fast etch facet generation model
- Polar etch rate diagrams experimentally determined for several OH based etch, and the Wulff-Jaccodine method is used to predict convex etch profiles
- The extremely high etch rate anisotropy is used here to produce perfectly verticaly, nanoscale GaN structures, including vertical nanowire arrays with controlled cross-section, AlGaN nanowires, sub 10nm structures with nanoparticle masks, and lateral nanowires with aspect ratios > 400:1

Motivation

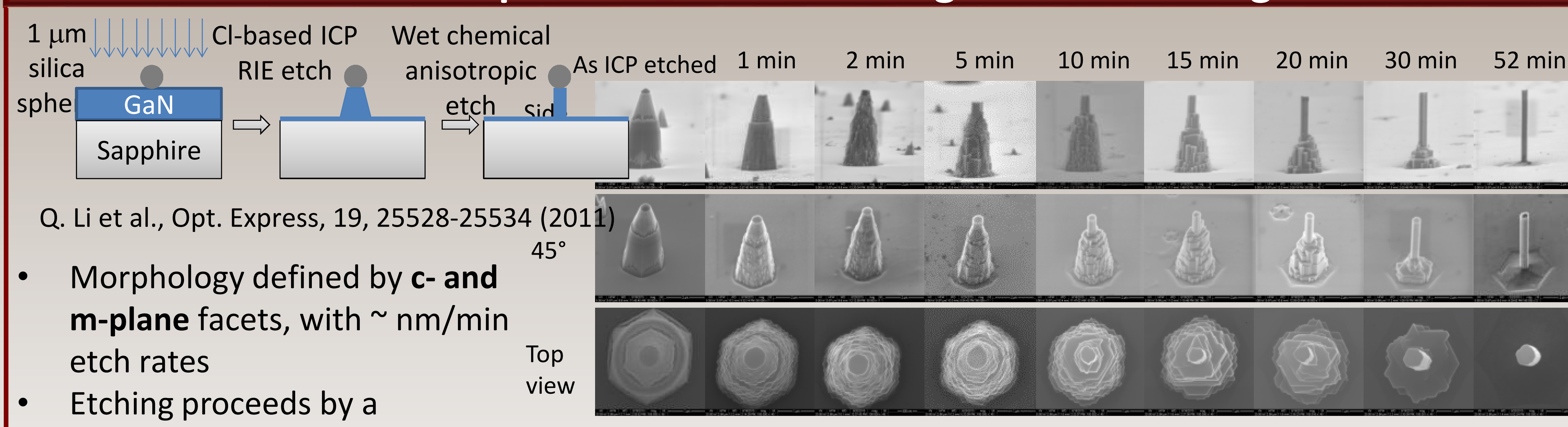
Crystallographic chemical etching is an enabling process for semiconductor device technologies.

Wet etch processing of GaN is limited due to chemical inertness, but actually GaN has a substantial etch rate albeit highly anisotropic

Silicon: (100)/(111) ~ 160 (30% KOH, 70^{o}C)
GaAs: (110)/(111)A ~ 6 (1% Br_2-CH_3OH, RT)
GaN (0001) ~μm/min, **(0001)** ~nm/min (AZ400K, 65^{o}C)

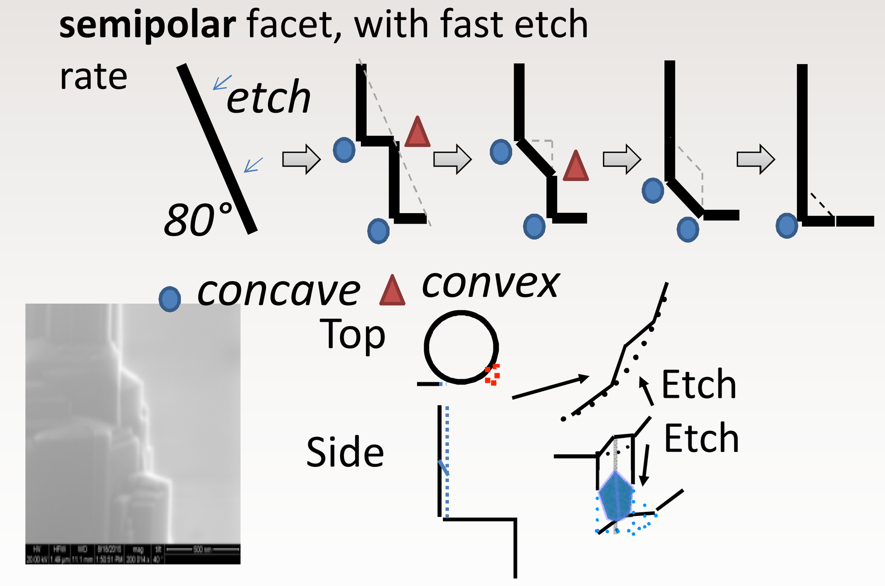
Fabricating novel GaN based devices (nano/opto -> NOEMS) requires predicting geometries resulting from the extremely high etch rate anisotropy

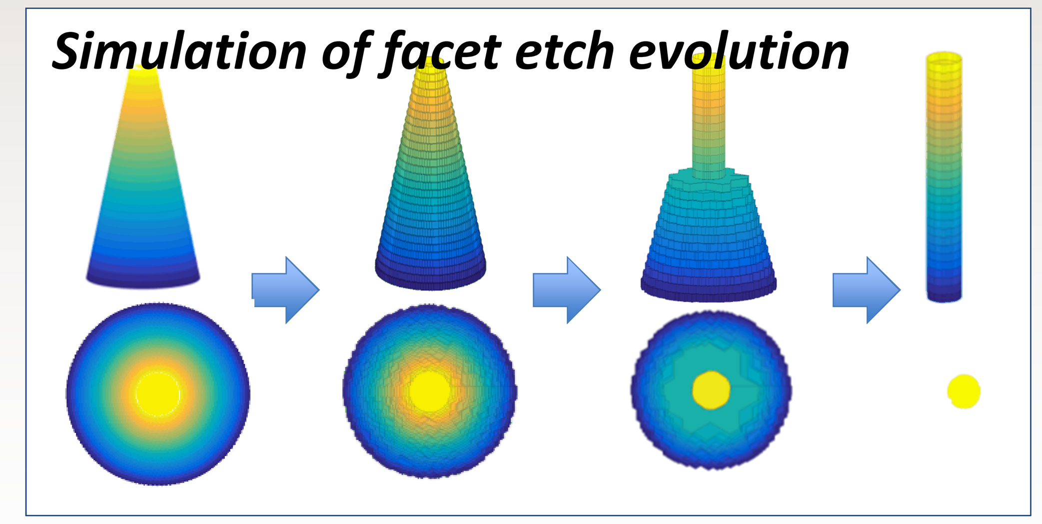
Etch evolution – From tapered to vertical through microfaceting



Q. Li et al., Opt. Express, 19, 25528-25534 (2011)

- Morphology defined by **c- and m-plane** facets, with ~ nm/min etch rates
- Etching proceeds by a **semipolar** facet, with fast etch rate

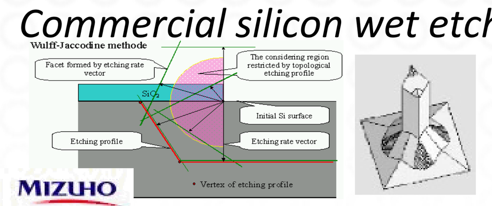




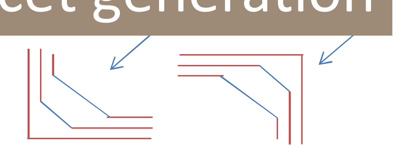
Predicting etches

Facet-limited etch model

Commercial silicon wet etch simulator



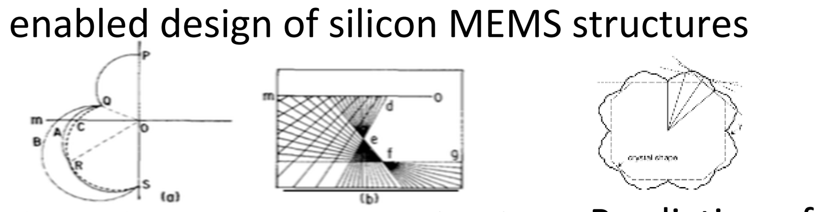
Facet generation



Based on *slow etch rate facets* appearing in *concave* geometries, *fast etch rate facets* in *convex* geometries

Facet evolution

Full knowledge of **orientation-dependent etch rates and geometry evolution** has enabled design of silicon MEMS structures

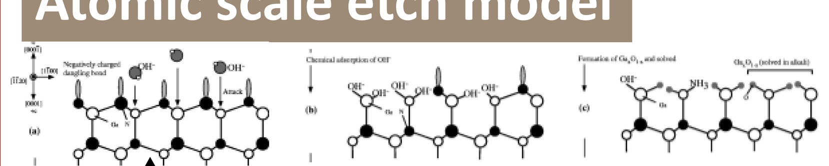


D. Shaw et al., J. Cryst. Growth 47, 569 (1979)

Orientation dependent etch rate | Predicted cross-section | Prediction of equilibrium shapes in growth

Predicting the geometry of the resulting facets uses the *Wulff-Jaccodine* method, (first developed for the inverse problem of etching - crystal growth)

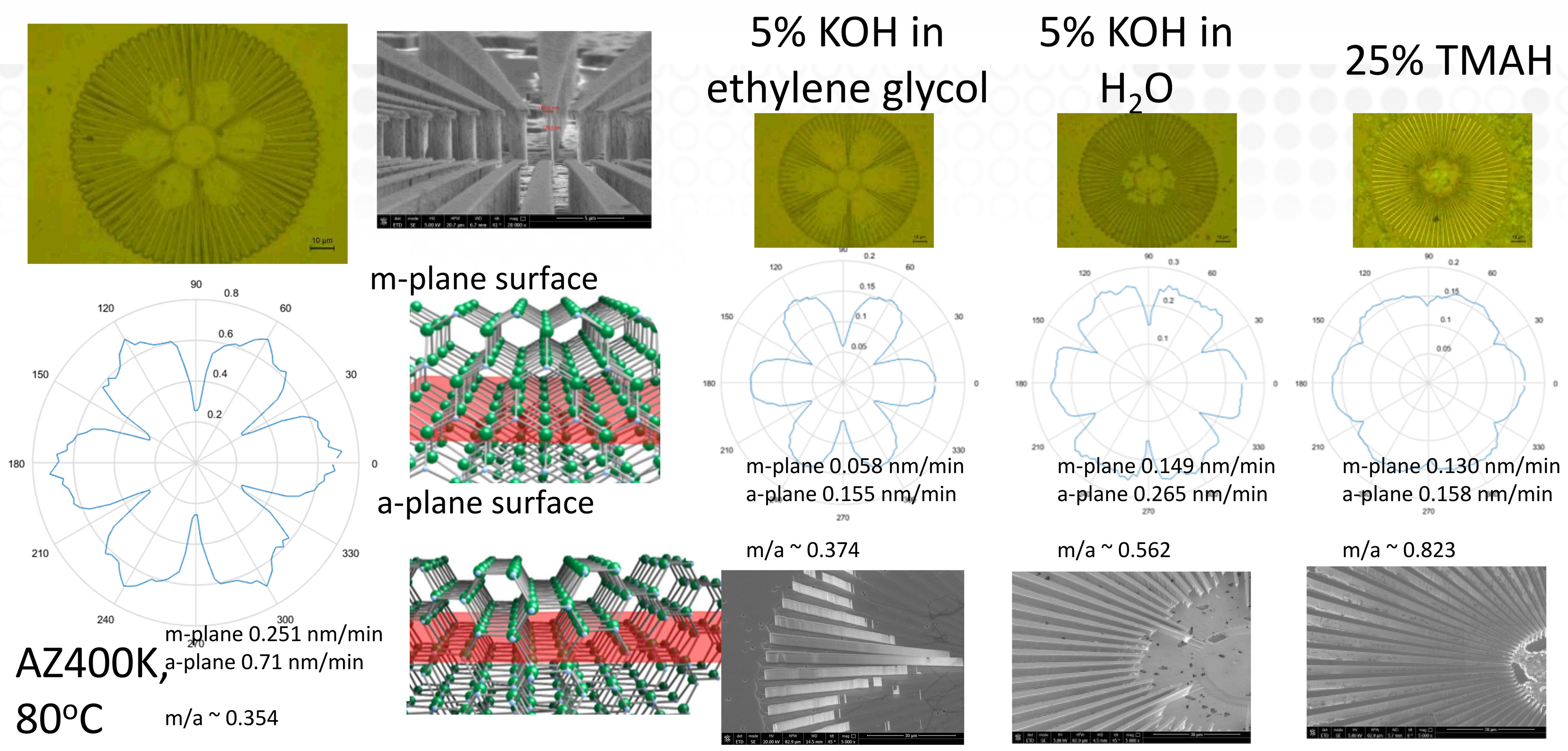
Atomic scale etch model



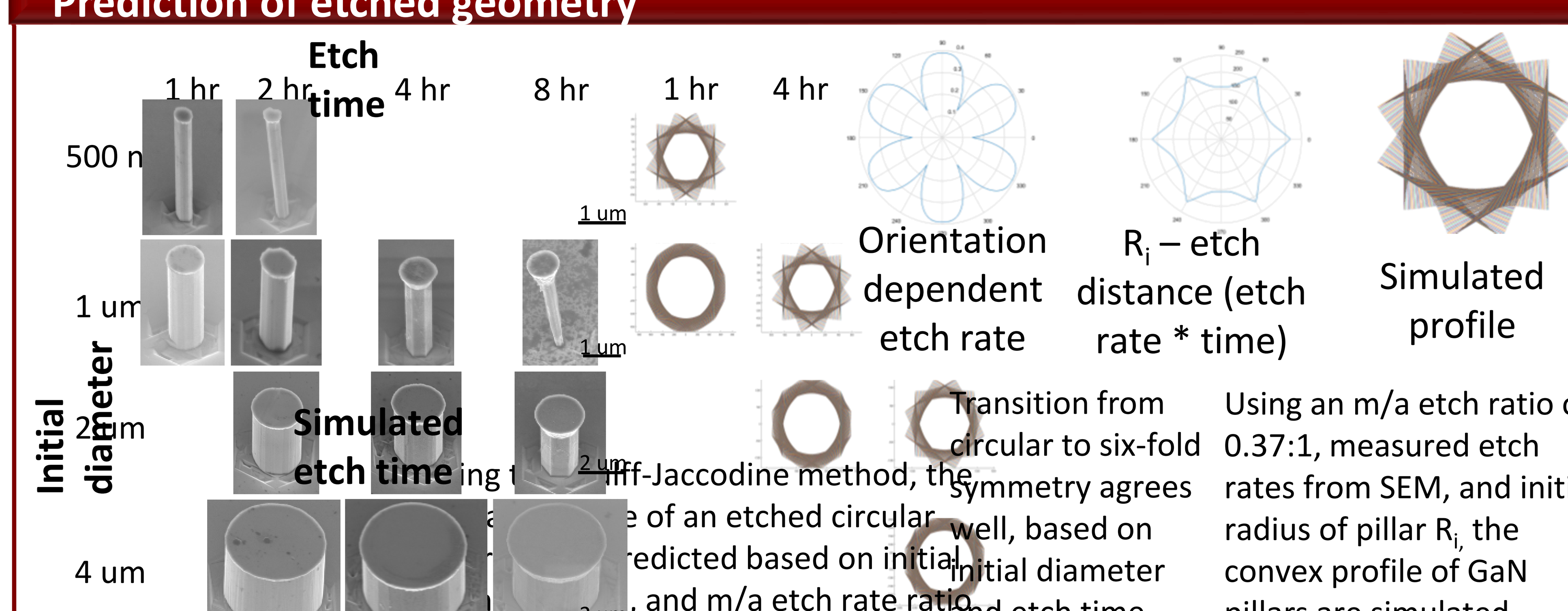
D. Li et al., J. Appl. Phys. 90, 4219 (2001)

Polarity dependence on the etch explained by OH^- repulsion by N dangling bonds

Measurement of polar etch rate diagram



Prediction of etched geometry



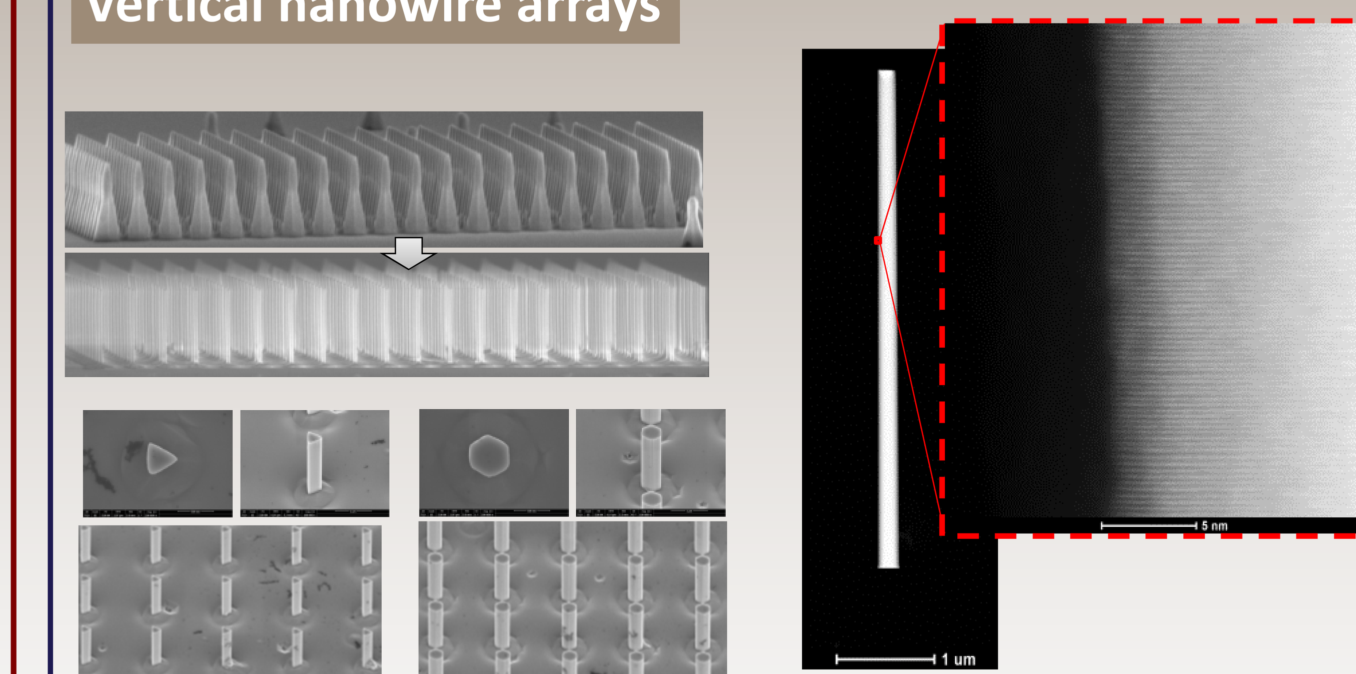
Using the Wulff-Jaccodine method, the profile of an etched circular pillar is predicted based on initial diameter and m/a etch ratio

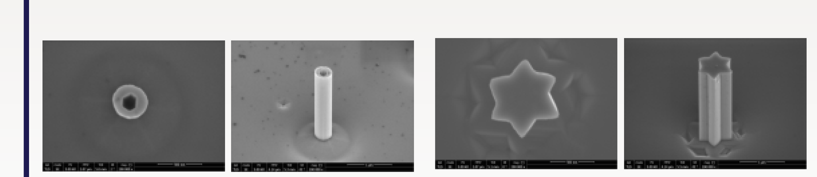
Transition from circular to six-fold symmetry agrees well, based on initial diameter and etch time

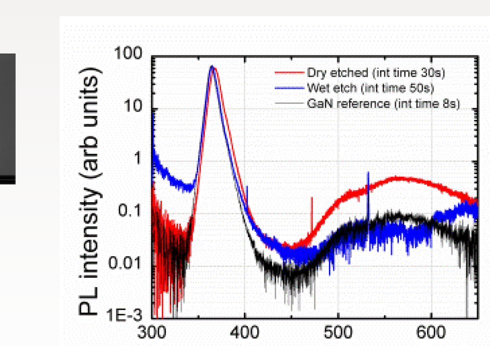
Using an m/a etch ratio of 0.37:1, measured etch rates from SEM, and initial radius of pillar R_i, the convex profile of GaN pillars are simulated

Application to nanostructure synthesis

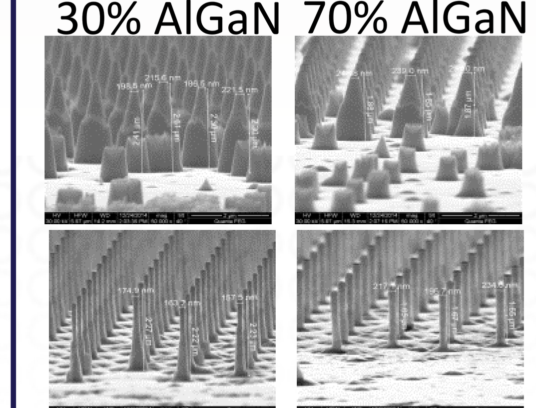
Vertical nanowire arrays

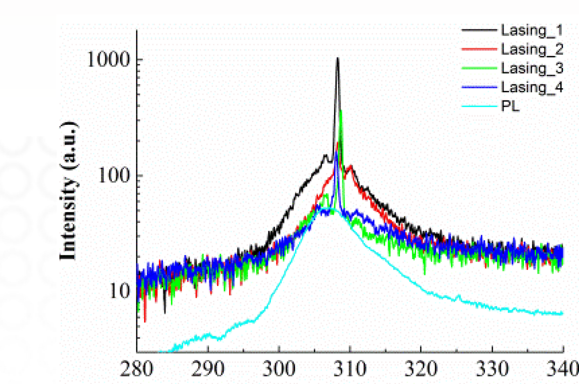






AlGaN nanowires

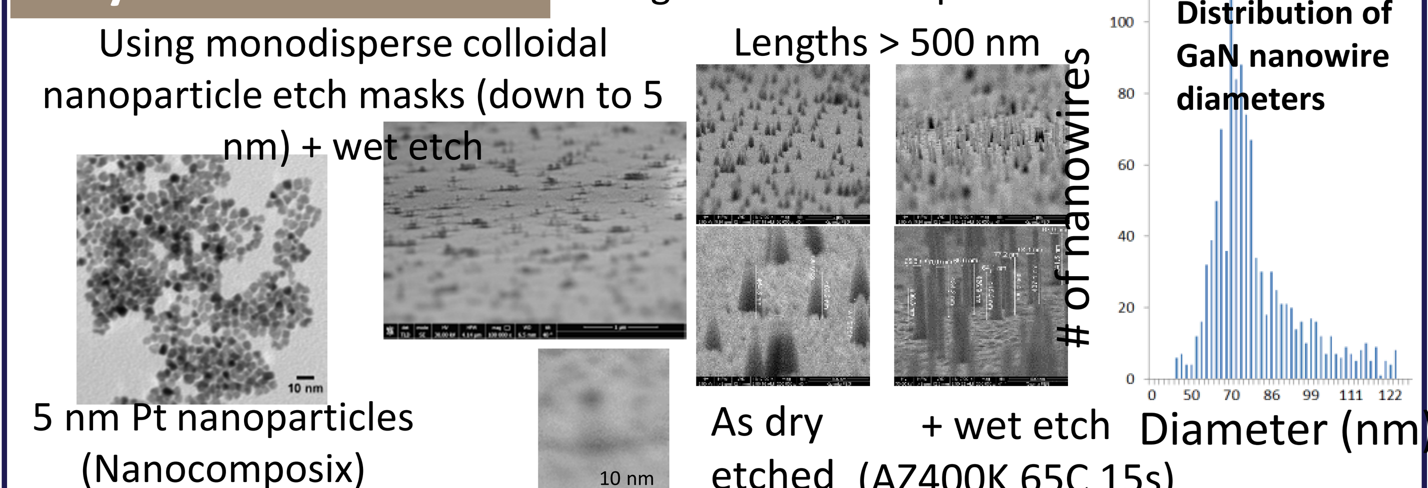




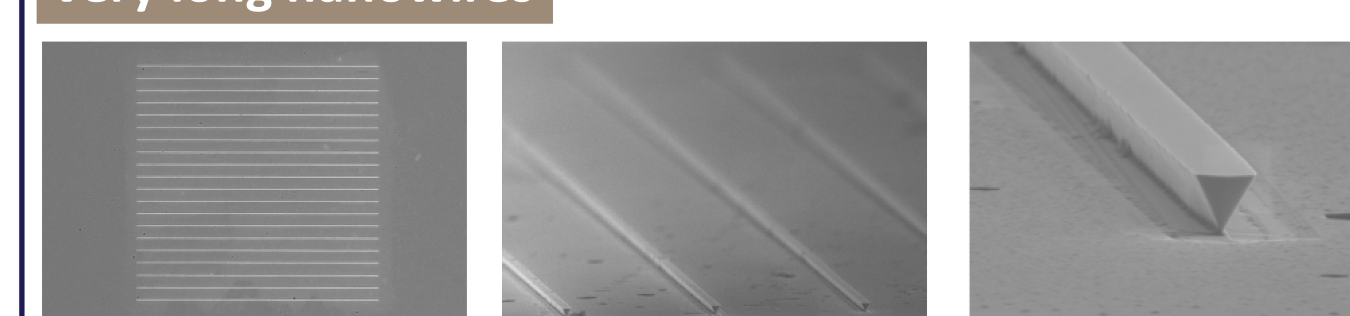
200 nm diameter, ~2 um length | Optically pumped lasing observed

Very small nanowires

Using 50 nm Pt nanoparticle masks



Very long nanowires



Lateral nanowires of 500 nm diameter, 200 μm length have been fabricated, i.e. ultra high aspect ratios of > 400:1 have been achieved

Acknowledgements

Sandia National Laboratories Laboratory Directed Research and Development (LDRD) Program
US DOE Office of Science, Basic Energy Sciences, Materials Science and Engineering Division
Work was performed at CINT facilities under user proposal U2014B0089

U.S. DEPARTMENT OF ENERGY
NNSA National Nuclear Security Administration