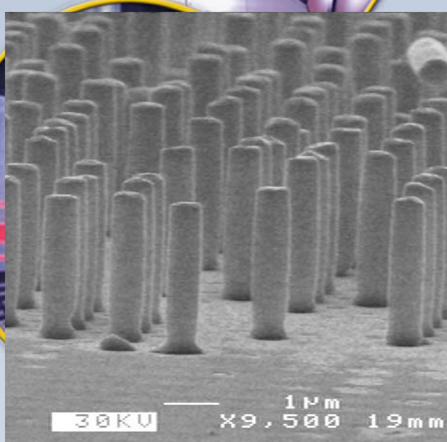
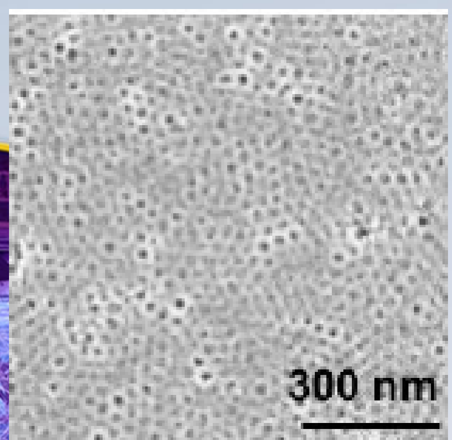
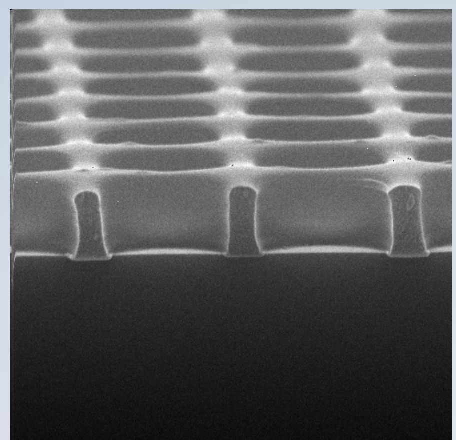
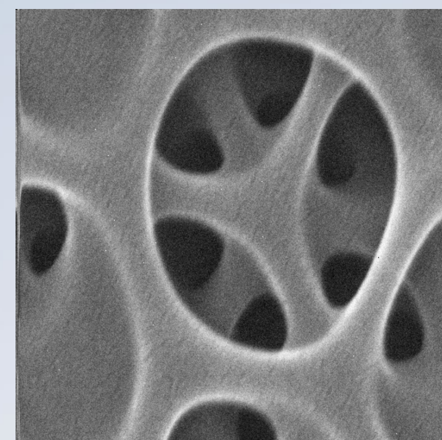
Nanoporous Films for Epitaxial Growth of Single Crystal Semiconductor Materials

Project Number: 104953
Investment Area: Senior Council Tier 1
Funded date: 2006-2007
Team:

Hongyou Fan	(1815, PI)
Jeffrey Brinker	(1002, PM)
Bruce Burckel	(1815)
Dan Koleske	(1126)
Adrian Rodriguez	(UNM student)





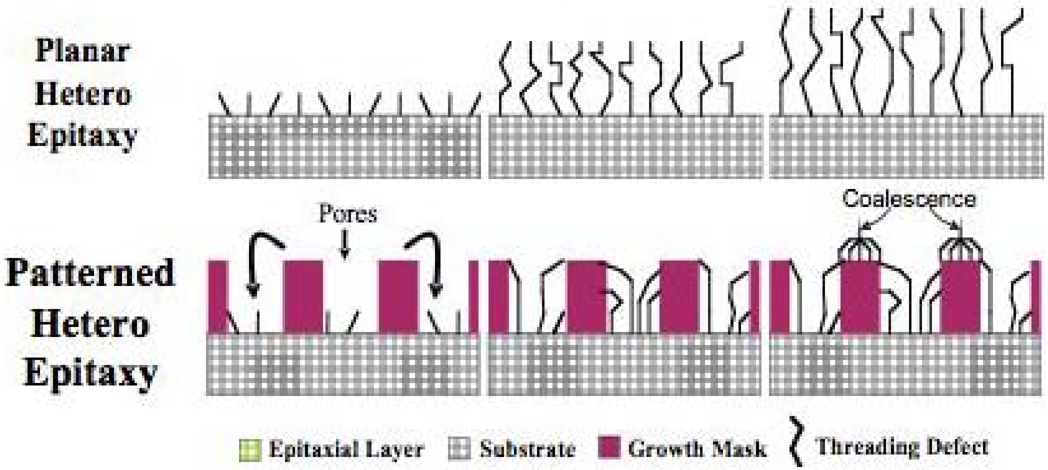
Continued late LDRD - #99405, Jan 06-Sep 06

Problem/Challenge

Defect reduction strategies for Group-III Nitride semiconductors are of immense technological importance.

- Lack of suitable bulk substrates relegates GaN and AlN growth to lattice mis-matched substrates (heteroepitaxy) resulting in a high defect density in the epitaxial layer, degrading optical and electrical performance as well as device reliability.-- defect reduction
- The harsh growth conditions of GaN typically restrict choice of growth templates to etched, inorganic growth masks, making nano-scale and non-line-of-sight growth templates impossible.-- stable templates

Schematic of Defect Filtering in Patterned Growth



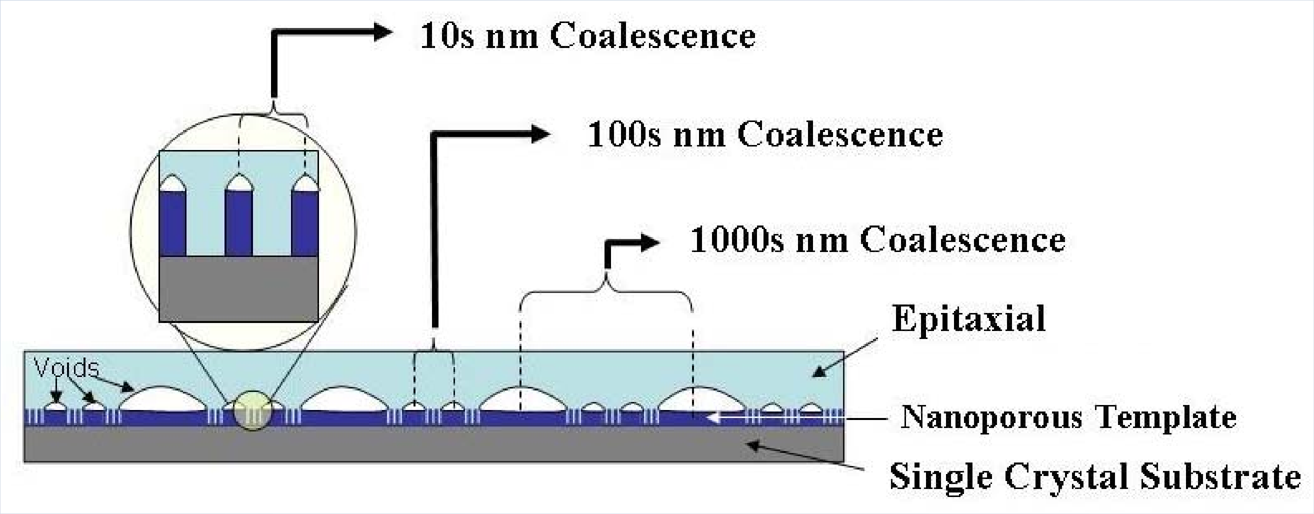
An Illusive Goal

"The extremely high dislocation density of AlGaInN alloys grown on sapphire substrates is a cause of non-optimum LED performance ... ELO (ELOG, pendeoepitaxy, etc) are effective, but add significantly to the cost of the end product." - ***National Center for SSL R&D***

Project Purpose and Approach

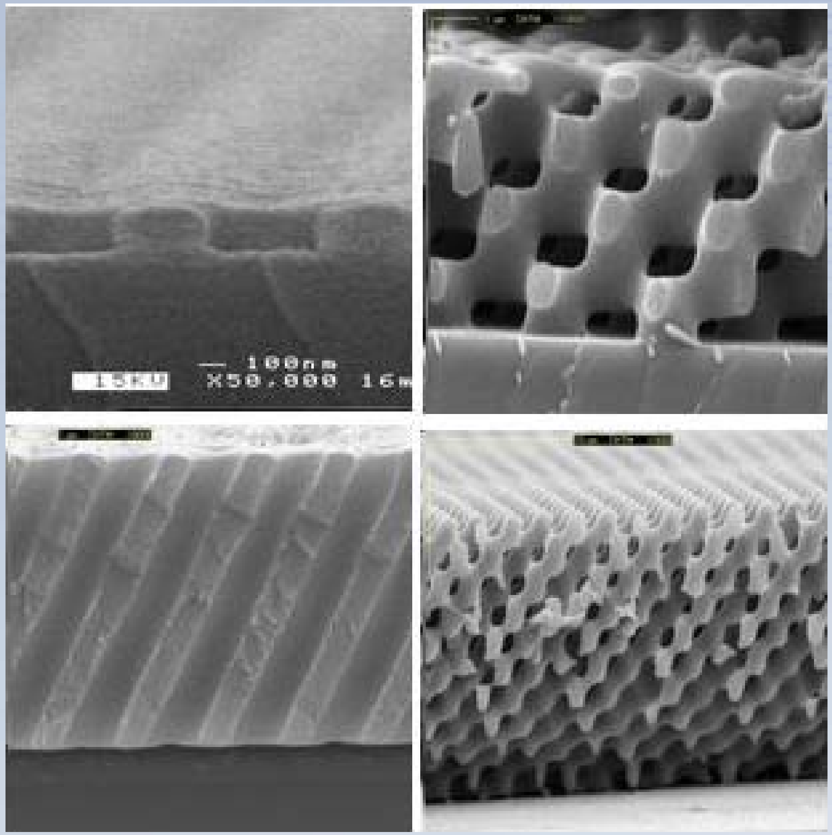
Purpose: to develop new nanoporous templating materials for heteroepitaxial growth of single crystal GaN on patterned substrates to reduce defect density, yielding higher quality material.

Our approach is to combine self-assembly and top-down photolithography to devise hierarchical carbon growth templates with pattern features in the nanometer, sub-micron and micrometer range to allow multiple length scales of defect filtering and termination of dislocations. (continued late LDRD - #99405 (Jan 06-Sep 06))

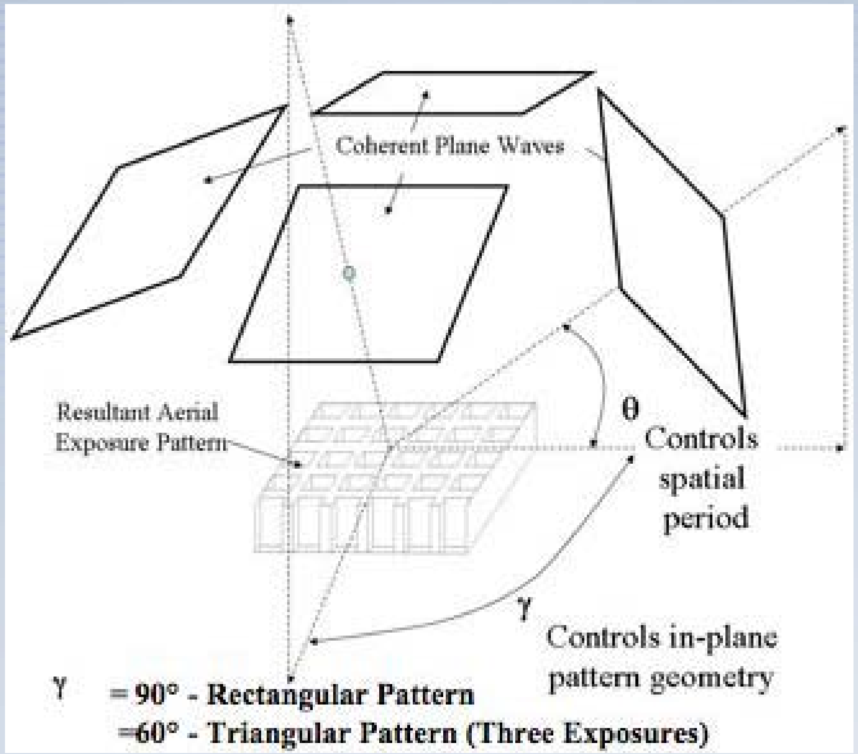


Photolithographically Defined 2-D and 3-D Templates

SEM images of 2, 3D macroporous templates fabricated via Interferometric Lithography



2-D Interferometric Lithography Schematic



Interferometric Lithography Capabilities

- Deep Sub-μm Patterns
- High Aspect Ratio Structures
- Complex 2-, 3-D geometries
- Large Area Patterning

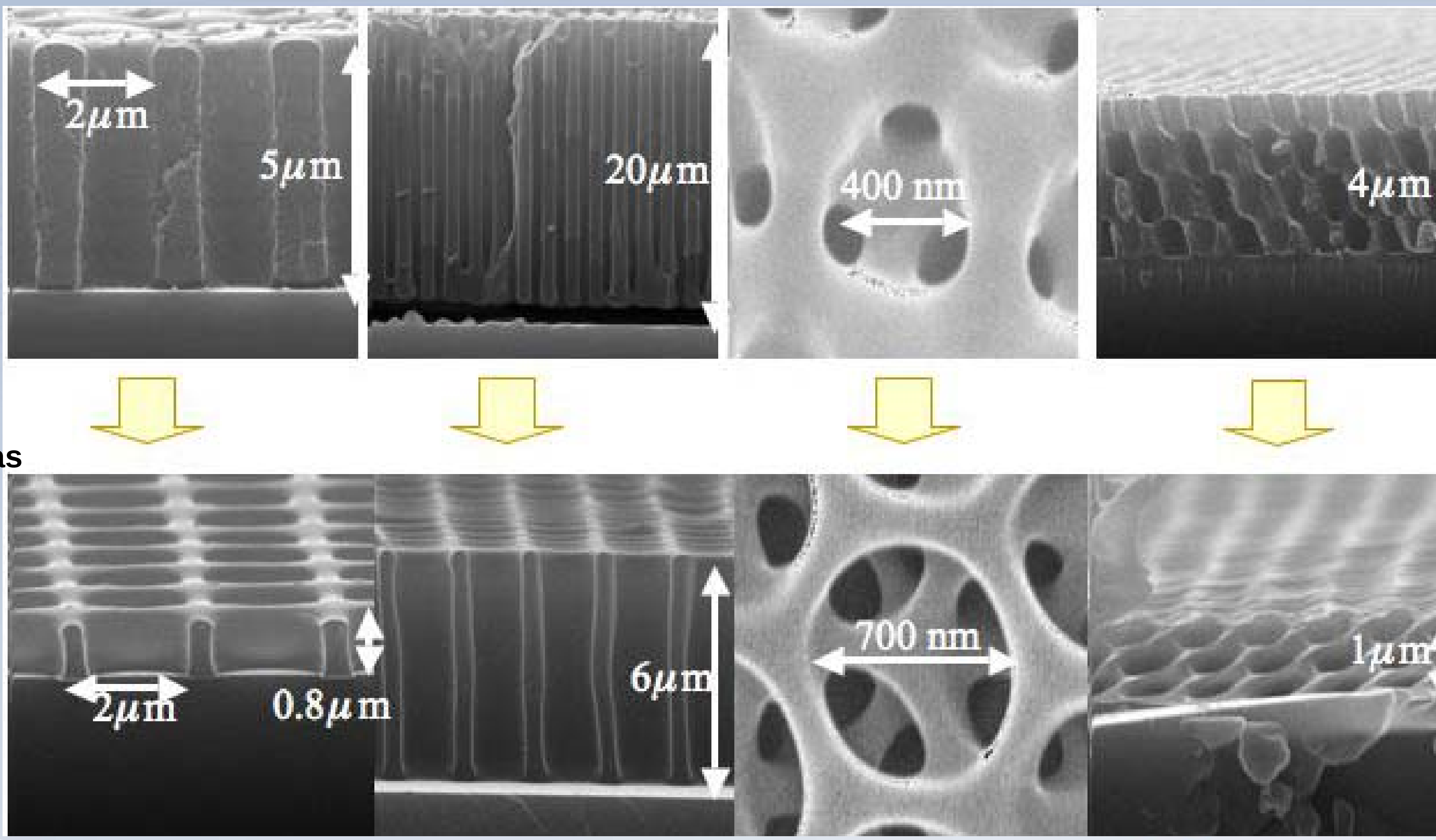
SEM images of Carbonized Macroporous Templates

SEM images of 2, 3D macroporous templates fabricated via Interferometric Lithography

Before Pyrolysis

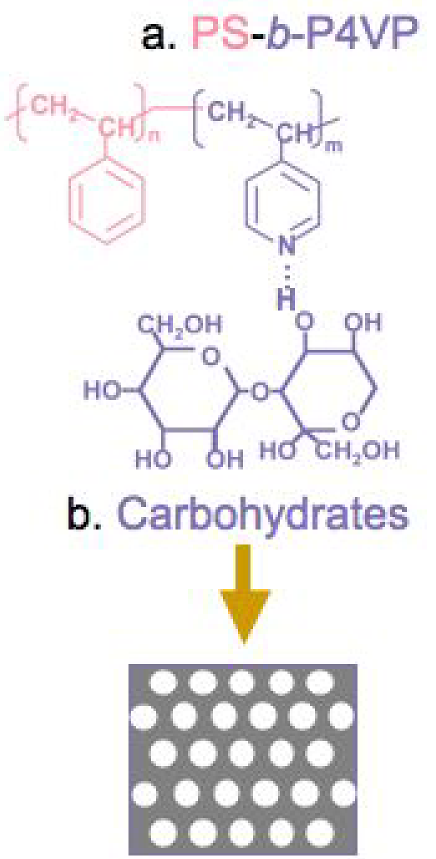
800 °C forming gas

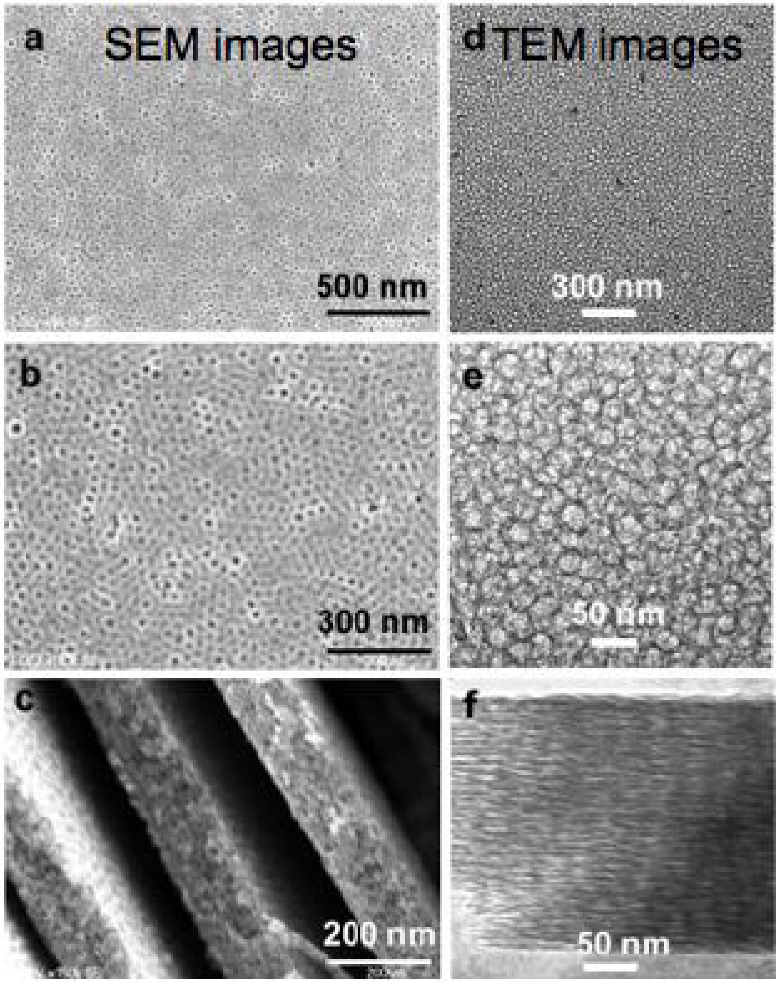
After Pyrolysis

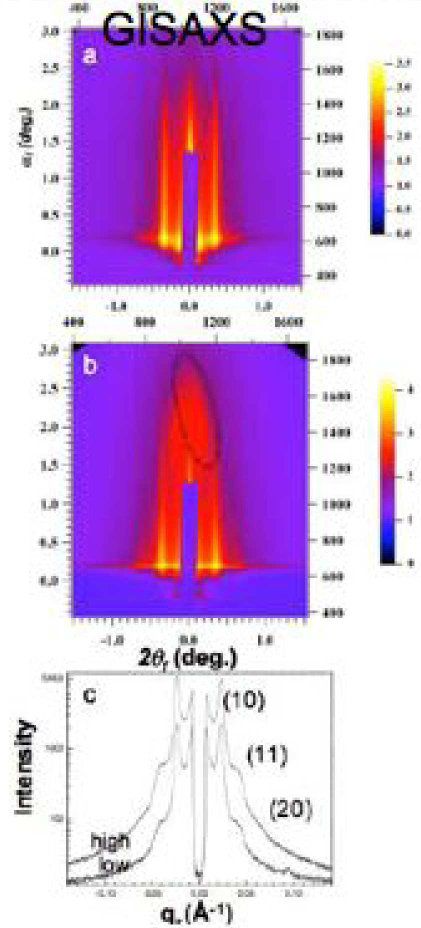


Soft Self-Assembly of Nanoporous Carbon Templates

Hydrogen bonding assisted self-assembly to synthesize nanoporous carbon templates



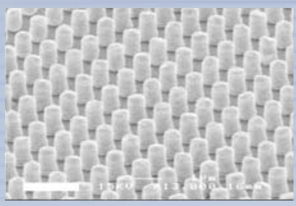


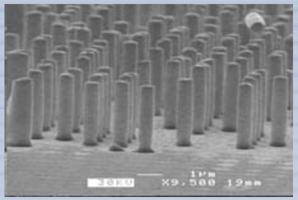


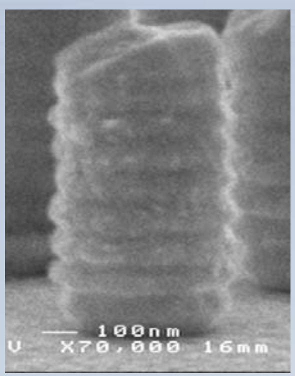
Templated Growth of Metals and GaN

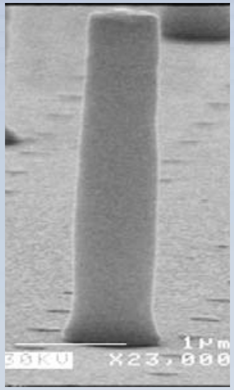
Growth of metal nanorod arrays through galvanic plating.

Successful growth of gold nanorod arrays indicated the accessibility of the substrate.









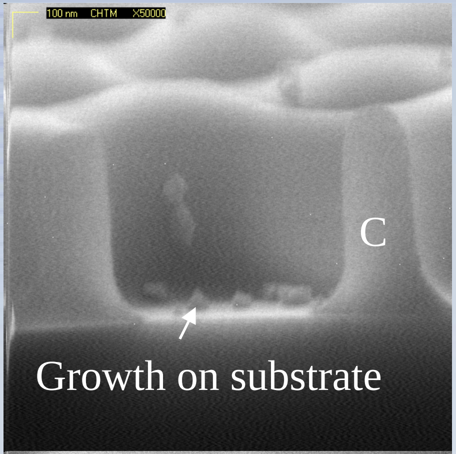
- Wavelength Scale Photonic Structures
- Cellular probes (Au with a lipid-capped thiol)
- Tungsten Emitter Tips (THz generation)
- new surface plasmon devices

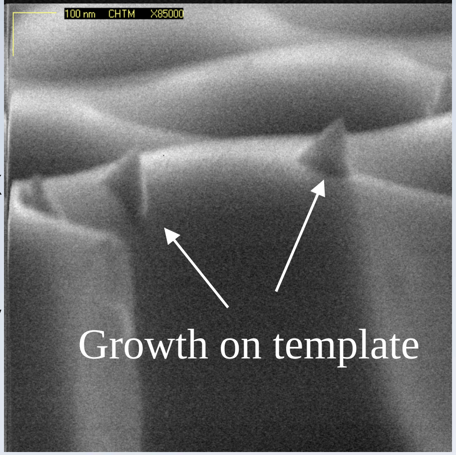
Preliminary GaN Growth in Carbon Templates

Carbon template pyrolyzed at 800 °C survives nucleation temperature (~700 °C), but does not survive growth temperatures (~1050 °C).

Future Work:

- Pyrolyze above growth temperature (~1200 °C) to improve template survivability.
- Pursue carbide or fluorocarbon formation to improve selectivity
- Investigate growth in complex 2D and 3D geometries which are beyond the capability of current patterned heteroepitaxy approaches.





~ 20 nm GaN Nucleation Layer

Conclusion

- **Successful synthesis of hierarchical and porous high temperature stable carbon templates.**
  - Photolithography-defined Macroporous carbon templates.
  - Self-assembly-defined mesoporous carbon templates.
- **Successful demonstration of growth of ordered metal nanorod arrays.**
- **Templates survived the harsh condition at the GaN nucleation temperature (~750 $^{\circ}$C)**
- **Preliminary growth of GaN.**

Significance

- Tightly aligned with Sandia/DOE missions : Solid state lighting initiative; Next generation RF electronics; Impacts all forms of heteroepitaxy and could lead to Compound Semiconductor on Si.
- Use of lithographically and self-assembled templates offers freedom from conventional top-down etched-template approaches, and hence new opportunities.
- Porous carbon work – water purification, nuclear waste sorption and separation, sensors, catalysis matrices, energy conversion and storage.

Accomplishments

1. A. T. Rodriguez, M. Chen, Z. Chen, C. J. Brinker, and H. Fan, "Nanoporous carbon nanotubes synthesized through confined hydrogen-bonding self-assembly," *Journal of the American Chemical Society,* 128 (29): 9276-9277, 2006.
2. A. T. Rodriguez, X. Li, J. Wang, W. A. Steen, and H. Fan, "Facile Synthesis of Nanostructured Carbon through Self-Assembly between Block Copolymers and Carbohydrates," *Advanced Functional Materials* (in press).

TA SD#	10647	High Aspect Ratio Carbonized Resist Epitaxial Growth Masks.
TA SD#	10810	Lithographically Defined Microporous Carbon Structures.
TA SD#	10324	Method for Synthesizing Carbon Nanomaterials.

Contributed to winning 2007 R&D 100 Award.

Acknowledgment

- Galvanic Plating team (1725):

John Williams, Adam Rowen, Christian Arrington and Rusty Gillen.

- William Steen (1825) for electrochemical characterizations.
- John Emerson for initiating/supporting/nominating this project.
- Elmer Klavetter for filing TAs for this project.
- Bill Hammetter (Manager,1815).