Nanoporous Films for Epitaxial Growth of Single Crystal Semiconductor Materials

LABORATORY DIRECTED RESEARCH & DEVELOPMENT

Physical & Engineering Sciences

Sandia National Laboratories

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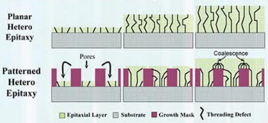
Problem

- 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.
- 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.

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***

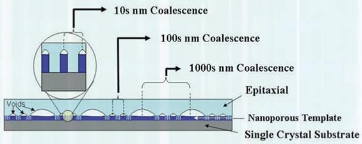
Project Purpose and Approach

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.

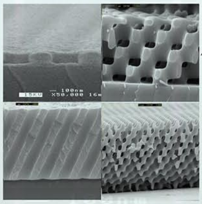
Our approach:

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))

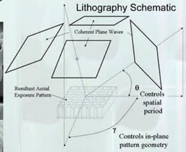


Photolithographically Defined High Aspect Ratio 2-D and 3-D Photoresist Structures

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



2-D Interferometric Lithography Schematic

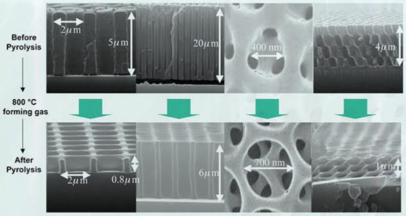


Interferometric Lithography Capabilities

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

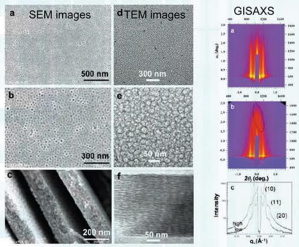
SEM Images of Carbonized Macroporous Templates

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



Soft Self-Assembly of Nanoporous Carbon Templates

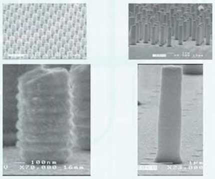
Hydrogen bonding assisted self-assembly to synthesize nanoporous carbon templates



Templated Growth of Metals and GaN

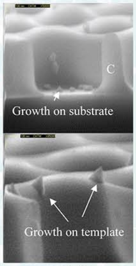
Applications of High Aspect Ratio Metallic Structures

- Wavelength Scale Photonic Structures
- Cellular probes (Au with a lipid-capped thiol)
- Tungsten Emitter Tips (THz generation)
- High surface area electrodes for electrochemistry and catalysis (Pt, Au posts)
- Adhesive surface (structure + surface chem)



(Galvanic Plating - John Williams, Adam Rowen, Christian Arrington and Rusty Gillen, 1725).

Preliminary GaN Growth in Carbon Templates



~ 20 nm GaN Nucleation Layer

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.

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.

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