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MOTIVATION

Material systems such as gallium nitride (GaN) and silicon carbide (SiC) have shown tremendous potential in advanced electronic devices over the past few years due to their wide-bandgap and high breakdown field properties. GaN has a direct bandgap of 3.4eV making it suitable for manufacturing light emitting diodes (LEDs) capable of emitting light of any wavelength between blue and ultraviolet (UV) when alloyed with indium (In) and aluminum (Al). In addition, both GaN and SiC-based devices are used for high-frequency and/or high-power applications including aircraft radar electronics.

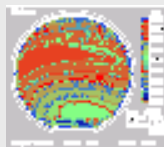
Metalorganic vapor phase epitaxy (MOVPE) is the principal method used to grow single-crystalline layers of these materials. Currently, manufacturers of gallium nitride and silicon carbide devices use both commercial and custom-built reactor designs. The wide range of reactor designs indicates a lack of a coherent framework on how to design reactors for optimal single-wafer and multiple-wafer production. As a result, significant research from both academic and industrial levels has enhanced manufacturing technology considerably within the past decade.

Benefits of Computational Modeling:

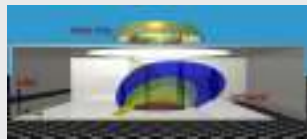
- 1) Better understanding of the manufacturing process
- 2) Enhances the traditional experimental methods
- 3) Accelerates the design and development process
- 4) Allows testing of new and exotic reactor configurations
- 5) Reduces overall development time and cost



CVD process operations leading to spatially non-uniform film growth



Simulation-based assessment of design and operation alternatives



Object-oriented CVD simulation tools for diagnosing factors responsible for non-uniformity

Acknowledgements

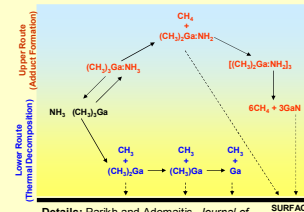
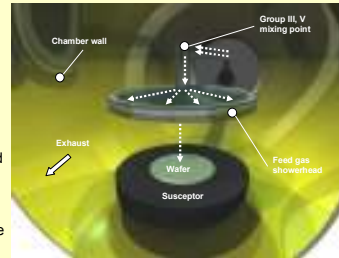
We would like to gratefully acknowledge the support and collaboration of Deborah P. Partlow, Michael E. Aumer, Darren B. Thomson, James D. Oliver, and Brian H. Ponczak of the Northrop Grumman Corporation

GALLIUM NITRIDE RESEARCH

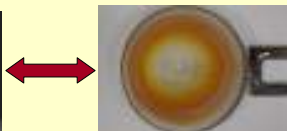
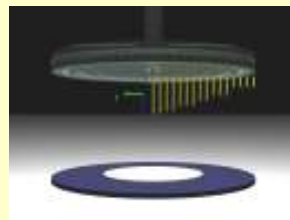
This work studies the interplay between the transport of reactants, adduct formation chemistry, and deposition kinetics within a MOVPE reactor showerhead system.

The reactor consists of a cooled-wall horizontal chamber with a showerhead above a single wafer resting on a heated susceptor.

The showerhead provides a unique design feature which enables us to make a connection between reactor design and chemical kinetics as concrete as possible.

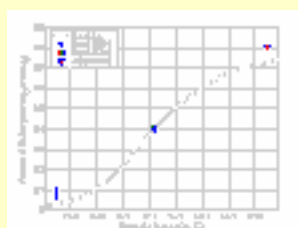


Details: Parikh and Adomaitis, *Journal of Crystal Growth*, 286 (2006) 259-278.

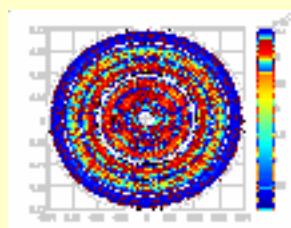


Reactant precursors are completely mixed before being fed to the showerhead. After each growth run, the showerhead is removed from the reactor and significant deposition is observed. More importantly, the deposition pattern is distinct.

A detailed kinetic model is developed and applied to the showerhead portion of this reactor configuration. The model attempts to capture the deposition process inside the showerhead in both a qualitative (spatial distribution of deposition pattern) and quantitative (weight measurements) fashion.



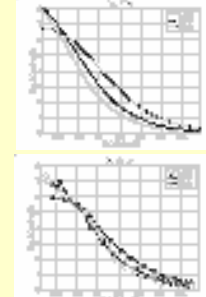
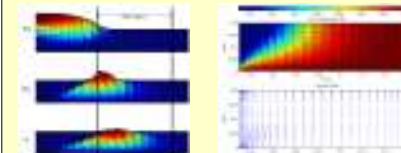
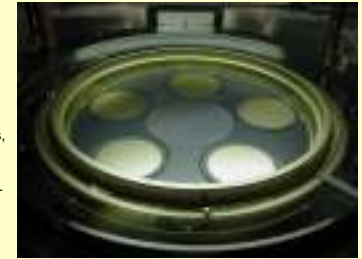
Details: Parikh, Adomaitis, Aumer, Partlow, Thomson, and Rubloff, *Journal of Crystal Growth*, submitted for publication (2006).



SILICON CARBIDE RESEARCH

In some manufacturing processes, the use of substrate (wafer) rotation is integral to achieving acceptable film properties across the substrate.

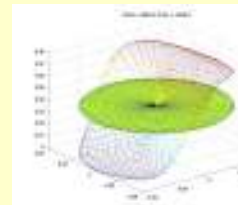
In planetary reactors, gas flows radially outward from the central feed point over the susceptor containing multiple wafers, each of which rotates on its individual axis. The design has the effect of eliminating reactor-induced angular non-uniformity generators through susceptor rotation, and wafer rotation is used to reduce the intrinsic (and completely unavoidable) effect of gas phase reactant decomposition and precursor depletion in the gas phase.



A detailed 2D transport and reaction-kinetic model is developed. Comparison of growth rate for simulation and experiments is shown on the right where the only operating parameter changing is flowrate.

Details: Parikh, Adomaitis, Oliver, and Ponczak, *Journal of Process Control*, accepted for publication (2006).

Nearest Uniformity Producing Profile

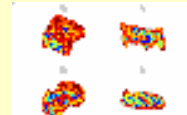


Question: "Which, if any, of the nonuniform deposition profiles in the reactor radial coordinate produce perfectly flat deposition profiles on the rotated wafers?"

β_n modes: a set of orthogonal deposition profiles that become uniform under rotation

All linear combinations also are uniform under rotation

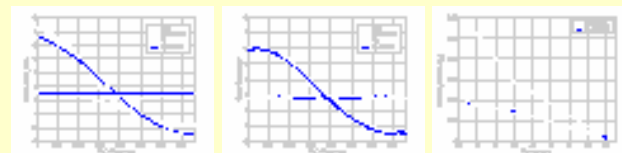
=> Basis for nontrivial uniformity producing film profiles



Projection of any deposition profile $\delta(r, \theta)$ onto the β_n :

$$\delta(r, \theta) = \sum_{n=0}^{\infty} \beta_n(r, \theta) \int_0^1 \delta(r, \theta) \beta_n(r, \theta) dr$$

Details: Adomaitis, *Computers and Chemical Engineering*, 29 (2005) 829-837.



A new approach for run-to-run uniformity control was applied to a SiC radial-flow chemical vapor deposition system with planetary wafer rotation. This approach provides a process engineer with physical insight on what design parameter(s) should be adjusted to improve uniformity. The results showed that by modifying the flowrate, uniform films of SiC can be produced upon rotation in the planetary radial-flow deposition system.