Modeling Analysis of GaN/InGaN Deposition in MOCVD Vertical Rotating Disk Reactors

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MOCVD Vertical Rotating Disc Reactors (RDR) are widely used for large−scale production of GaN−based semiconductor devices such as blue, green, and ultra−violet LED s, along with microwave FET structures. In RDR reactors, rotation of the wafer carrier results in an effective averaging of the deposition rate distribution across the wafer. This is a key mechanism providing growth of epitaxial layers with highly uniform characteristics.

One of the most important tools used to optimize the design and performance of Emcore RDR reactors is advanced computer modeling. Detailed process modeling and the ability to predict GaN and InGaN growth rate and uniformity under different process parameters are critical factors for proper equipment design and process optimization.

We have developed calculation models that adequately represent the effects of process parameters (such as reactor pressure, shroud and reactants flow) and reactor features (such as flow flange and reactor chamber design) on growth rate and uniformity of GaN/InGaN in the D180 and E300 platforms. It has been proven that the use of very detailed geometrical models is of crucial importance for accurate predictions [1].

Recent modeling of growth processes within the D180 and E300 systems has lead to improvements in the design and operation of the tools for the growth of GaN/InGaN structures. The following paper outlines the results of one of these improvements: a modification to the alkyl injection system, which improves growth uniformity and alkyl efficiency while optimizing uniformity tuning for various reactor conditions during LED process development.

It is known that the flow in the reactor greatly affects the quality of the materials grown. Computer modeling shows that if very different inflow velocities are established between the alkyl zones, recirculation patterns are introduced as shown in Figure 1. However, when the alkyl zone velocities are matched to the hydride injector velocity, the result is almost perfect vortex−free flows, as shown in Figure 2.

To achieve alkyl and hydride zone flow velocity matching within the reactor, an additional push flow mass flow controller (MFC) was added to each alkyl injection zone. The additional MFC per injection zone provides the ability to control the velocity of the gas injected into each zone, while being able to independently control the alkyl concentration injected into each zone. This flexibility allows one to take advantage of superposition to optimize the growth rate deposition uniformity across the susceptor for a given growth condition. For superposition, a set of independent runs (a number of runs is equal to the number of the alkyls zones) are conducted wherein each run, the alkyls flow into the reactor only in a single zone. All of the other zones contain push gas to keep the velocity matched as described above. Each run gives an individual growth rate/composition "response" for the zones, as shown in Figure 3. The information from the combined responses allows one to calculate the alkyl distribution for each zone which provides the best possible uniformity for the given flow conditions.

Experimental results using this modification showed marked improvements in thickness, compositional, and brightness uniformity of InGaN MQW LED structures. Wavelength uniformity is better and more stable than before the modification, with typical on−wafer uniformity of < 2 nm for a 460 nm LED, as shown in Figure 4. In addition, interface abruptness for the MQW active region was improved, as shown by the increased number of higher−order satellite fringes as shown in Figure 5.

Another advantage is that the alkyl utilization efficiency was improved by this enhancement. We believe the efficiency was improved due to suppression of gas phase reactions that occurred within the recirculation areas. The achieved on−wafer alkyl efficiencies for the D180 reactor increased by 204% for the high−temperature GaN, 285% for the active region InGaN/GaN and 227% for the AlGaN growth processes. Similar efficiency increases have been achieved for the E300 reactor.

Conclusions

Based on modeling results, we introduced the new hardware modification that provides for simultaneous control of alkyl concentration and injection speed. This resulted in significant improvement of growth uniformity and alkyl efficiency. Additionally, it provides the ability to use superposition for thickness and composition uniformity adjustment which drastically speeds−up uniformity tuning for various reactor conditions during GaN−based LED process development.

[1] L. Kadinski, R.Birkhahn, J.P.Debray, R. Stall, A. Gurary, Modeling Analysis of GaN Deposition in MOCVD Vertical Rotating Disk Reactors, Proceedings of the IC MOVPE XI, Berlin, 2002, p. 154.

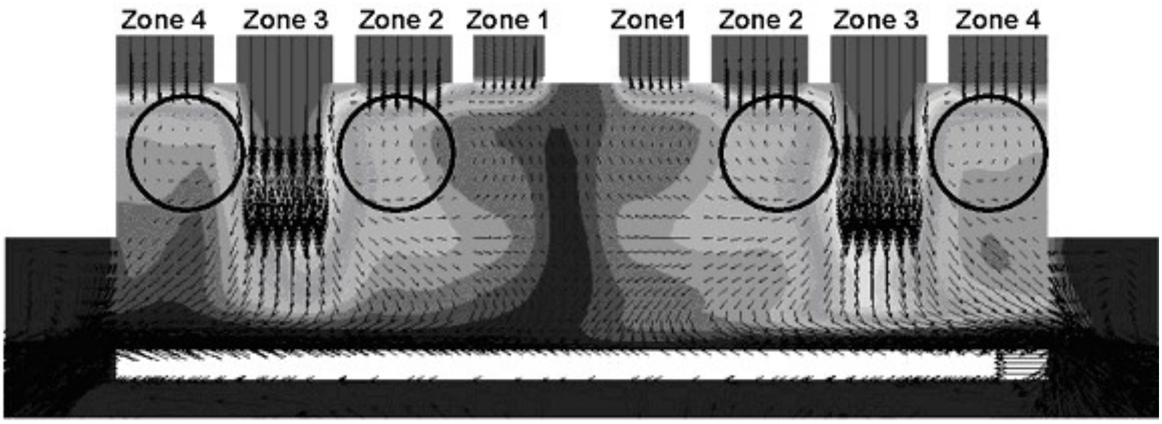

Figure 1. Simulated Flow in E300 Reactor with different inflow velocities through alkyls zones (circles represent the recirculation areas).

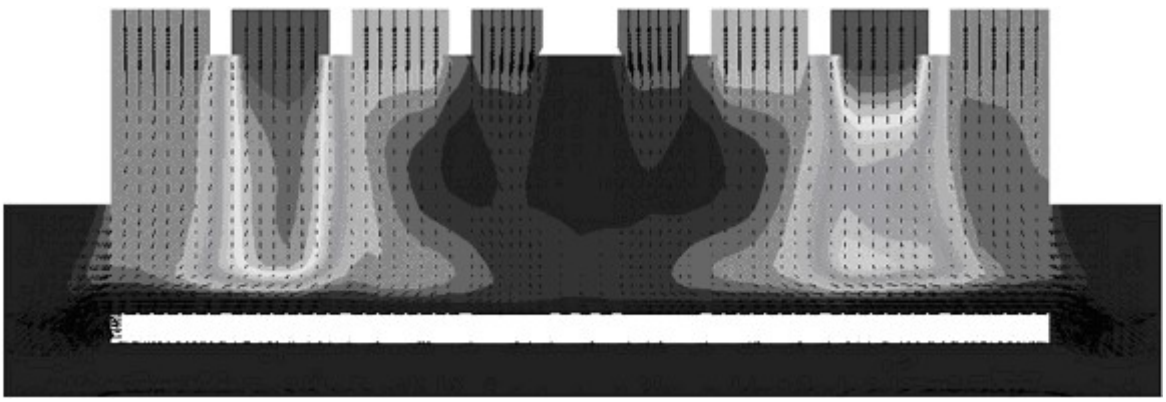

Figure 2. Simulated flow in E300 Reactor with the same inflow velocities through alkyls zones.

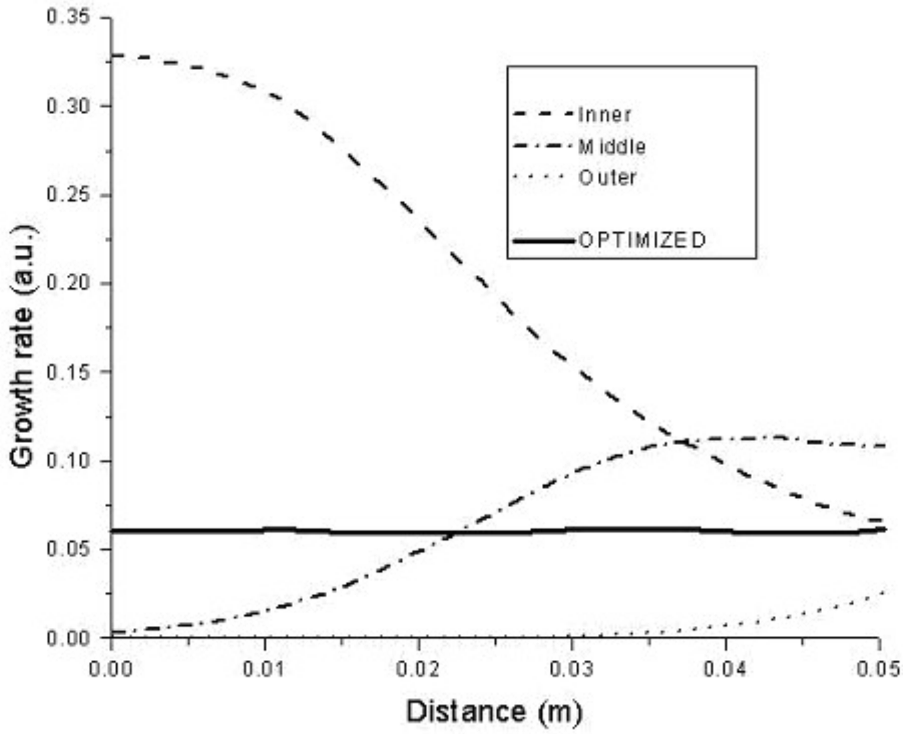

Figure 3. Simulated growth rate "responses" and optimized growth rate in the reactor with 3 zones of alkyl injectors.

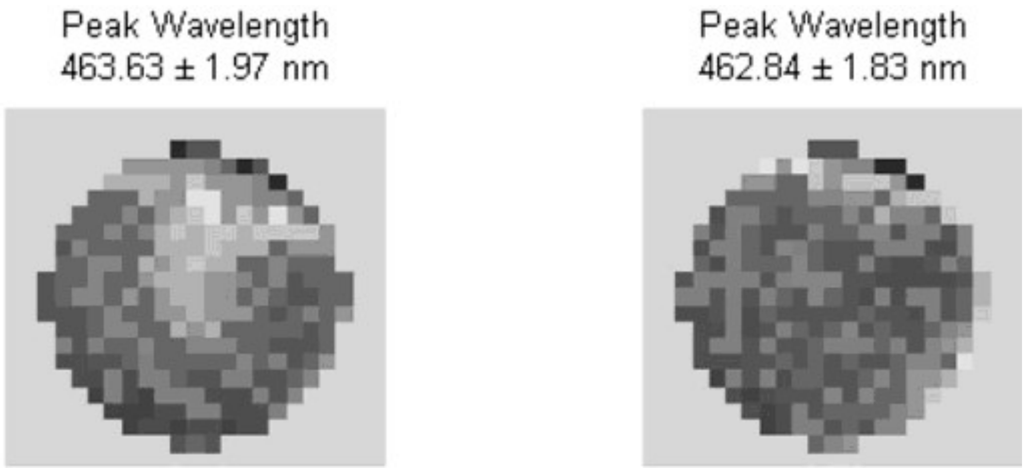

Figure 4. Typical inner and outer 460nm LED wafers after the modification from an E300 reactor.

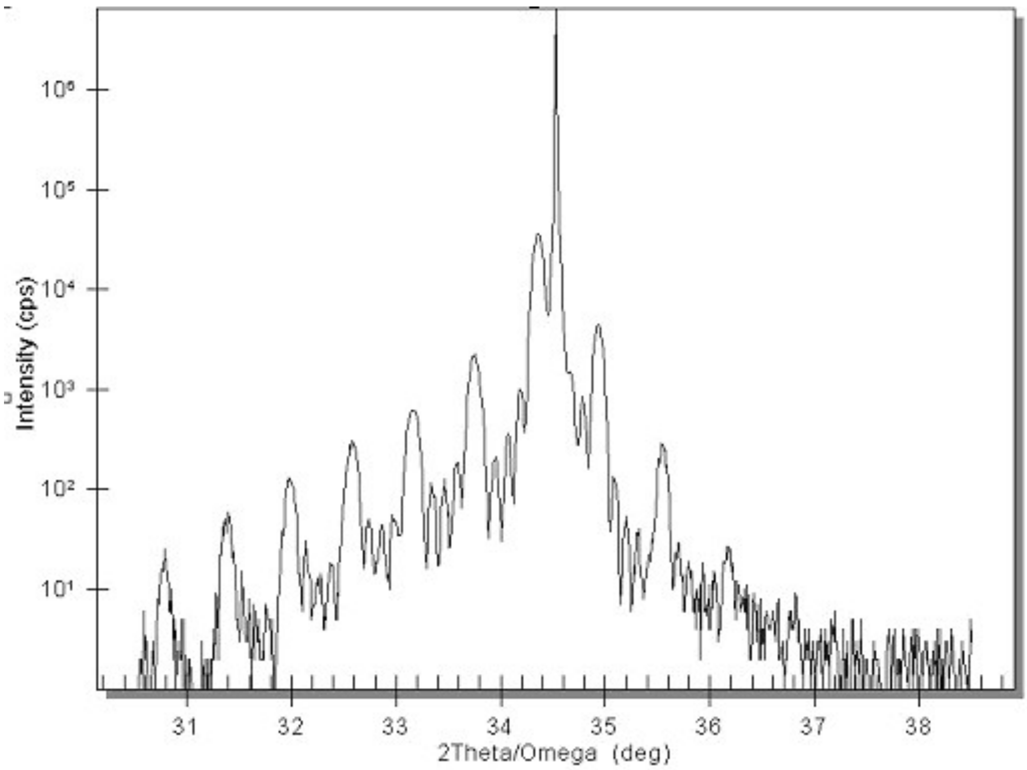

Figure 5. HRXRD scan of an InGaN/GaN MQW structure, after the modification.