

Cost of ownership dictates new MOCVD reactor design

Throughput, yield and the deposition of expensive metal-organic precursors dominate the cost of ownership of MOCVD reactors, according to research at Aixtron. **Rainer Beccard** explains how these three factors have driven the design of the company's latest planetary reactor.

During the last 20 years the MOCVD process has matured from a technique used in research laboratories to a common method for manufacturing high volumes of compound semiconductor devices.

The driving force for new developments has also moved on from its original form, which was to demonstrate the suitability of an MOCVD process for a specific device. Today manufacturers employing MOCVD technology are concerned with high-volume manufacturing, and use multiwafer platforms such as Aixtron's planetary reactors to carry out simultaneous epitaxial growth on several substrates. This technique produces large quantities of epiwafers with good uniformity and has enabled the expansion of the LED manufacturing industry.

The industry is now entering a third stage of development that reflects the maturity of both MOCVD and LED technology. The focus is directed at reducing manufacturing costs, so that LED makers can achieve profitable margins despite the year-on-year falls in the average selling price of their devices. Since the MOCVD process is one of the key manufacturing steps, cutting costs here can reduce the cost of ownership (CoO) of an MOCVD reactor.

Aixtron has redeveloped its planetary reactor mass-production platforms to reduce the CoO of these systems. This approach has been applied to reactors for both GaInN-based blue, green and white LEDs, and AlGaInP-based red and yellow LEDs. There is much interest in red LEDs owing to their expected application in red, green and blue (RGB) backlighting systems for large LCD screens.

The design process began with an investigation of the CoO of existing reactors, using standards defined by the Semiconductor Equipment and Materials International organization. Calculations revealed that the key parameters were throughput, yield and the deposition efficiency of costly metal-organic precursors.



Aixtron's fully loaded 49 × 2 inch planetary reactor can produce epiwafers with uniformity suitable for LED manufacturing.

After defining a CoO target value, a detailed theoretical study of reactor and MOCVD system configurations was undertaken, including comprehensive numerical modeling of the reactor geometry. These efforts led to a reactor design that delivered CoO improvements verified by actual growth runs.

Increasing wafer coverage

Throughput is defined by the reactor's load capacity, the wafer size, and the time taken for a complete growth cycle.

Today most LED manufacturers work with 2 inch substrates, despite the promises of higher yield, reduced edge effects and greater wafer area offered by 4 inch material. Consequently, the reactor had to be designed for both 2 inch and 4 inch processes. The reactor geometry also had to optimize the growth area, which resulted in a design suitable for either a 12 × 4 inch or 49 × 2 inch configuration, and with a total wafer area of 150 inch². This represented an increase of 50% and 40% on the standard platforms of 8 × 4 inch and 35 × 2 inch, respectively.

To optimize throughput it is also necessary to minimize growth cycle times, which are a combination of the time taken for material growth, the loading and unloading of wafers, and the heating and cooling of the reactor. This

was partly accomplished by introducing a novel automated handling system to load and unload at high temperatures, which eliminated the time lost while the reactor cooled down. Although automatic loading has already been used for GaAs/AlGaAs-based HEMT and HBT processes, a refined version has been developed that is suitable for the much thicker AlGaAs/AlGaInP/GaP LED structures.

Another approach to reducing growth cycle times was to develop a reactor that could produce the same material quality more quickly. Previously, growth rates were limited by parasitic reactions that occurred before the gases reached the wafer surface, an effect that is more likely at higher precursor concentrations.

The second criterion that strongly impacts the CoO is yield, which can be considered either in terms of epiwafers or LED chips, although the latter are more appropriate as they are related to the final product. The MOCVD process influences the uniformity of LED properties on each wafer and from wafer to wafer. Efforts were directed to optimize the uniformity of film thickness, layer composition and doping for both 2 inch and 4 inch processes.

The third factor controlling CoO is the growth efficiency of the relatively expensive metal-organic precursors that are used for the epitaxial process. Efficiency was defined as the ratio of group III atoms incorporated into the grown layers to the number of group III atoms entering the reactor through the metal-organic sources.

Optimizing the reactor's growth efficiency for novel geometries is a time-consuming process that has to take into account details relating to both reactor hardware and process parameters. High efficiencies are frequently achieved by adjusting the parameters that also affect film thickness uniformity, so the solution must balance optimizing the efficiency while ensuring high levels of uniformity for all relevant materials within the LED structure. →

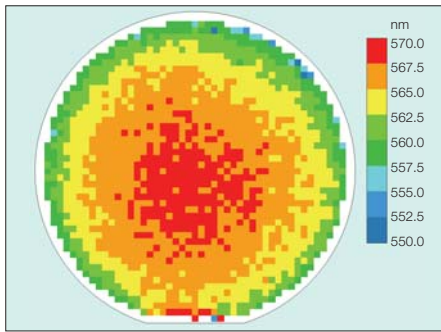


Fig. 1. The reflectivity from an AlGaAs/GaAs distributed Bragg reflector deposited on a 4 inch wafer reveals thickness uniformity values required for LED production.

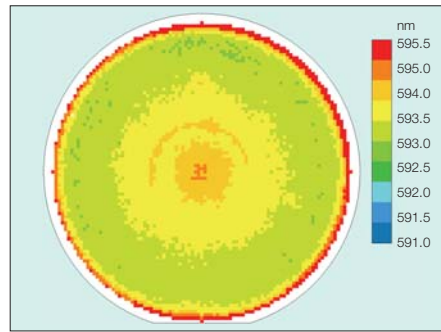


Fig. 2. Photoluminescence uniformities of <math><0.45\text{ nm}</math> across these 4 inch wafers, grown on AlGaInP, indicate this reactor's excellent growth temperature homogeneity.



Aixtron's latest design uses either a 12×4 inch or a 49×2 inch configuration to deliver growth on substrates with a combined area of 150 inch^2 .

Table 1: Metal-organic deposition efficiency

	AlGaAs		AlGaInP	
	12 × 4 inch	49 × 2 inch	12 × 4 inch	49 × 2 inch
TMGa	36%	43%	38%	44%
TMAI	36%	44%	39%	45%
TMIn	n.a.	n.a.	28%	30%

Metal-organic precursors are one of the top three contributors to the total production cost of LED epiwafers, and so increasing the efficiency with which they are used can reduce the cost of MOCVD reactor ownership. The 12×4 inch and 49×2 inch configurations are calculated to deliver an improvement of over 20% in growth efficiencies of the metal-organic precursors trimethylgallium (TMGa), trimethylaluminum (TMAI), and trimethylindium (TMIn). These calculations use precise measurement of the growth rates and assume nominal consumption of the metal-organic precursors according to the adjusted carrier gas mass flows and the given vapor pressures of the metal-organic chemicals. The vapor pressure data for TMGa and TMAI were provided by the material's suppliers, but data for TMIn was taken from O Kayser *et al.* (*Chemtronics* 1988 **3** 90).

The novel reactor design is based on Aixtron's earlier 2600 planetary platforms but uses different hardware including an improved gas inlet geometry. Measurements of composition and thickness on all of the materials used to produce red and yellow LEDs (GaAs, AlGaAs, AlGaInP, GaInP and GaP) verified that the reactor's growth process fulfilled the theoretical predictions. The reactor's capability was assessed for both the 12×4 inch and 49×2 inch configurations, and the effect of the standard p- and n-type dopants, tellurium and magnesium. Results revealed that the reactor can meet and even surpass the typical epiwafer specifications for doping uniformity, thickness and so on demanded for LED production.

LEDs contain distributed Bragg reflectors – alternating GaAs and AlGaAs layers – that reduce light loss into the substrate. The thickness uniformity of these layers is revealed by their reflectivity profiles (figure 1). Uniform-

ities across a 4 inch wafer and between wafers from the same growth run are better than 0.5%, assuming an edge exclusion zone of 3 mm, showing that the process is suitable for producing LED material.

Although the growth and uniformity of GaAs and AlGaAs layers depend predominantly on the reactor's flow dynamics, other LED materials such as AlGaInP are more temperature dependent. Consequently a large-scale reactor's temperature uniformity can be revealed through the growth of AlGaInP layers. Epiwafers produced on a 12×4 inch platform show typical photoluminescence (PL) uniformities of less than 0.45 nm (3 mm edge excluded) and a wafer-to-wafer variation below 0.8 nm, indicating excellent growth temperature homogeneity (figure 2).

Aixtron's reactor is also suited to high epi-wafer yields using the 49×2 inch configuration. PL on-wafer uniformities of 0.53 nm (3 mm edge excluded) and wafer-to-wafer uniformi-

ties of 0.78 nm were achieved from a full load of wafers containing an AlGaInP multiple quantum well active region emitting at 630 nm.

The growth efficiencies of the metal-organic materials used in LEDs were determined for both 12×4 inch and 49×2 inch reactor configurations (table 1). These efficiencies, which are delivered without compromising material uniformity, are 20% higher than those achieved with the 8×4 inch and 35×2 inch standard configuration. This improved performance results from the optimization of the gas inlet and the susceptor geometry.

The CoO of the new reactor will be reduced even more through faster growth rates. Although faster growth rates can deteriorate material quality, the very high precursor efficiency and the minimization of parasitic reactions through optimized design of the reactor chamber and the gas inlet were expected to enable rapid growth of high-quality films.

X-ray diffraction and electrical characterization measurements revealed no loss of film quality, despite an increase in the growth rate of AlGaInP and GaAs from $1.5\text{ }\mu\text{m/h}$ and $2\text{ }\mu\text{m/h}$ to $4.3\text{ }\mu\text{m/h}$ and $16.7\text{ }\mu\text{m/h}$, respectively. These significant increases indicate the huge potential for additional cuts in growth time that will lead to lower production costs.

These new 12×4 inch or 49×2 inch planetary reactors, which are suitable for red and yellow LED production, satisfy the requirements for high-quality material and meet well defined CoO targets. This design, which is also suitable for solar cell or laser manufacturing, reflects the growing level of maturity within the III-V industry. ●

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