

MOCVD automation and fab integration

You've heard it many times before. But this time it's true... the LED industry is at a key inflection point, writes Dr Rainer Beccard of Aixtron.

The end-application drivers are changing; in a very short period of time we have seen the original momentum — coming from mobile phone applications — progress to the backlighting applications that are so dominant today and now increasingly coming from emerging solid-state lighting applications.

The manufacturers of LEDs are also changing, as new players emerge, bigger than we have seen before, and, perhaps significantly; some of them are coming from the traditional silicon or display sector.

This development brings with it some positively disruptive changes in the manufacturing process, in particular in connection with MOCVD (metal-organic chemical vapor deposition) technology, which remains the key enabling technology in this field.

As we saw with the evolution of silicon wafer sizes, we are now clearly seeing the start of the transition of gallium nitride (GaN) LED manufacturing processes from 4" to 6" diameter sapphire wafers and beyond. This widescale development will also require an acceleration of the integrated automation of MOCVD processes, maximizing the throughput of high-volume-manufacturing MOCVD systems and minimizing human intervention.

Manufacturing fabs will inevitably become much bigger and with a high likelihood of multi-site LED fabs, each of them equipped with multiple, but identical, MOCVD tools delivering consistent and precise process control.

To deliver that control in a high-volume manufacturing environment creates specific challenges with respect to the manufacturing volume, coupled with the required yield improvement. To achieve such a challenging objective, fab integration is a must, as this allows a manufacturer to manage and analyze process data and control tools from a central and even, potentially, a remote location.

These novel technological approaches may appear radical to some existing LED manufacturers, but it is a perfectly logical step for many new customers. Indeed, automation of single MOCVD tools and clusters as well as MES (manufacturing execution system) fab integration is not new and is already available from Aixtron.

As a manufacturer of both silicon-related CVD (chemical vapor deposition), ALD (atomic layer deposi-



Figure 1. 300mm MOCVD cluster tool with two process modules for III-V on silicon processes.

tion) tools and III-V MOCVD systems, we have for many years already delivered tools with front-end cassette-to-cassette automation and with interfaces for full fab integration. Critically, these integrated automation solutions have been delivered to LED-making customers based on what is already our well proven III-V MOCVD technology.

The details of these technologies — MOCVD automation, clusters and fab integration — will be discussed in the following sections.

Compound semiconductor MOCVD and automation

The concept and the potential benefits of automation are obvious today. The best example is the car industry, which was one of the first sectors to move to robot-assisted manufacturing.

The silicon industry has also taught us that, at a certain level of maturity, automation becomes a must, in order to maintain leadership in terms of throughput, yield and cost. By looking into the short history of compound semiconductors, we can see that, even in this relatively young industry, automation is not entirely new.

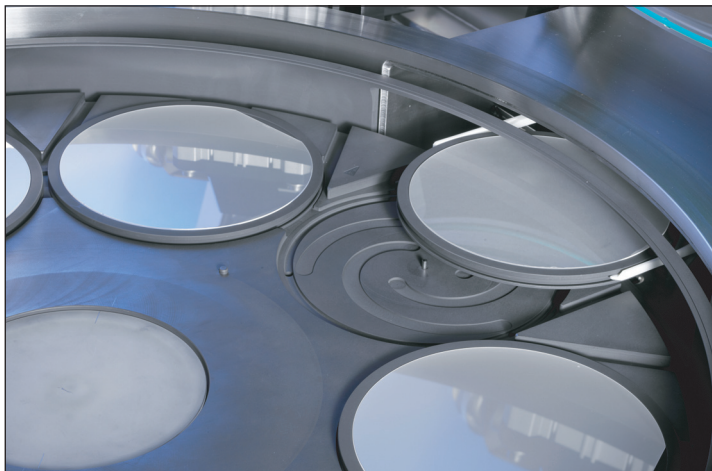


Figure 2. Automated loading and unloading of an Aixtron G5 HT MOCVD reactor. The transfer system picks up the entire wafer platform satellite disk pre-loaded with wafers. The reactor shown here is opened for demonstration purposes only.

► There are many motivations to take the automation approach. On a pure time perspective, for any given MOCVD process, once the cost-reduction benefits of saving wafer loading and unloading time is larger than the additional equipment cost, an automation solution economically makes sense.

This was the case in HEMT and HBT production in the late 1990s, when Aixtron introduced the world's first true cassette-to-cassette wafer handler for its III-V MOCVD systems. As these processes were based on relatively short growth cycles, the benefits of reduced loading and unloading times by automation were significant. But it wasn't just a question of saving time; from a process quality perspective, the consequent very low particle counts achieved also led to significantly improved yields.

More recently, in another semiconductor application, an Aixtron automation solution was also introduced in a very successful manner. III-V on silicon for future CMOS applications is particularly challenging and requires advanced MOCVD processes on 200mm or 300mm wafers. Needless to say that, in this particular customer case (involving high-mobility materials in logic circuits), silicon-style automation was a pre-condition.

Aixtron developed a new concept 300mm III-V on Si cluster MOCVD tool, merging decades of compound semiconductor MOCVD experience with state-of-the-art silicon automation standards (see Figure 1). This tool consists of a standard 300mm wafer handler with a front-opening unified pod (FOUP) equipment front-end module (EFEM), connected to two specially developed MOCVD modules.

Drawing on this and similar experiences, Aixtron was in a strong position to be able to develop dedicated automation solutions for high-brightness LED (HB-LED)

manufacturing. As a starting point, a comprehensive analysis of current and emerging market requirements, limitations and benefits of automation was conducted in detail, talking to customers from all regions.

The most obvious benefit of automation is the reduced loading and unloading time. In an Aixtron G5 HT reactor, for example, as many as 56x2" wafers (or 14x4" or 8x6" wafers) have to be exchanged after each process run. Manually, this can only be done after cooling the reactor down to workable operating temperatures and by purging the reactor with an inert gas. The automated solution that we have developed allows unloading at temperatures as high as 600°C under hydrogen atmosphere, saving significant time.

The concept that we adopted is based on a robot that handles the entire wafer platform satellite rather than each individual wafer, achieving a complete wafer exchange in just a few minutes (Figure 2).

There are good reasons why the Aixtron G5 HT reactor was chosen to be the first generation of reactors with automation as a standard option. Apart from the increased wafer capacity, the reactor design is such that it allows continuous growth runs without any cleaning, baking or the exchange of parts between runs — a clear pre-requisite for any kind of automation. Furthermore, it also offers a new capability to use very high growth rates, shortening the total LED growth time. By exploiting the potential of automated processes, in terms of increased throughput at lower cost per wafer, we are able to increase our customer's competitiveness and reduce their cost of ownership.

There are some less obvious factors which make adopting automation attractive. A manual wafer loading operation has always been linked with a degree of process variation, which in turn leads to reduced yield. This can be completely eliminated by automatic loading.

Operator resources and utilization can be managed more efficiently, as the loading/unloading schedule is no longer determined by the growth sequence. Finally, using large wafers (6" and above) will be more technically and commercially feasible earlier, if standardized, automated handling procedures are adopted.

All these benefits potentially occur as soon as one MOCVD system is linked to an automatic transfer module (as shown in Figure 3, top). However, it does not stop there. Further benefits can be achieved through clusters (i.e. more than one MOCVD process module served by one automatic transfer module). Offering the opportunity to share the automation capital cost, they offer greater and more efficient utilization of the transfer system and on a smaller footprint per tool (Figure 3, bottom). Additionally, the LED growth process can be split into separate processes run in separate MOCVD modules (e.g. to grow the buffer layer in one module, and the rest of the LED epi structure in the other ones), leading to even higher efficiency of the processes. ►



Figure 3. Single MOCVD module with automated transfer system (top) and MOCVD cluster tool with two process modules (bottom).

► Fab integration

The efficient operation of multiple MOCVD tools, even if they utilize the automation options described above, depends critically on the correct exchange and management of data (such as recipes, process and log data) and on the co-ordinated control of the tools throughout the entire fab.

Again, it makes sense to adopt the fab integration approach that the silicon industry has developed to meet the challenge of delivering consistently high-quality, high-volume product.

Our approach is to use an MES, i.e. a system that controls tools and manages and analyzes data in real time in a central, remote location for a complete fab or fabs.

The MES requires appropriate interfaces in the individual tools. In Aixtron MOCVD systems, these

interfaces can be provided easily as part of the individual control system of the MOCVD tool — or whenever an automated/cluster solution is chosen — as part of the Cluster Tool Controller (CTC). MES interfaces are individually configured for a specific fab. Aixtron's MOCVD systems generate huge amounts of data through the MES interface, such as mass flow controller (MFC) settings and actual values, as well as temperature, pressure and statistical process control (SPC) data. We can also add and manage additional events which can be communicated to and from the MOCVD tool to the MES, e.g. alarms, warnings or specific log data. Process recipes can be managed centrally, and finally the individual MOCVD system can even be remote controlled through the MES.

Because of the modular structure by which we manage this kind of data exchange and control, it is feasible for any size of fab, running any number of MOCVD tools, and even for multiple fabs run in different locations — ensuring that absolutely identical processes are performed on all MOCVD tools, with the highest possible reproducibility and yield.

Summary

We are evidently at a significant crossroads in the development of the LED industry.

LED applications are expanding rapidly from the mobile applications of old to new generation displays and

emerging general lighting applications.

The customer base is also changing equally rapidly, as the lead customers of a few years ago are getting bigger and new customers from the silicon or display industries are influencing the speed and direction of the industry.

These evolving market changes require new solutions for the LED manufacturing process. Aixtron's MOCVD systems, as one of the key enabling technologies in this process, offer solutions that are tailored to meet the new challenges. The availability of efficient and precise automated loading of MOCVD tools, novel MOCVD cluster architectures and additional options for powerful fab integration are already available today, ensuring that the LED industry is fully prepared for the opportunities ahead. ■

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