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- AIXTRON White Paper -

AIXTRON Sees "Green" Route to Reduced Manufacturing Costs

To make LEDs a truly "green" product, the MOCVD process must be as resource-efficient as possible. With its latest CRIUS® II-XL reactors, AIXTRON demonstrates an impressive way to achieve this target, providing substantial manufacturing cost benefits on top. Key to this is a scale-up of the CRIUS® II reactor chamber, a sophisticated optimization of the inner reactor geometry and a unique high growth rate process.

Introduction

After 20 years of R&D in the field of GaN based LEDs SSL products are now widely available. Market forecasts indicate double-digit penetration rates of SSL into the general lighting market. Solid state lighting is regarded as a "green" product par excellence, as it promises to reduce the worldwide energy consumption for lighting purposes dramatically.

However, sustainability is not only a question of resource consumption of the final product, but spans the entire value chain. Therefore, one has to take a thorough look at every step in the manufacturing process. Only if every player in the chain contributes, a final product can be considered truly resource-friendly and energy-efficient.

Although this aspect has not been a major focus yet, we can expect that, similar to other industries, it will gain much more relevance in the future. And even more important for any LED manufacturer, economic benefits are a direct result of ecological ones. Certain raw materials, such as Gallium or Indium, already suffer from increasing prices and temporary shortages, and prices for gases, water and electricity also cannot be expected to be stable in the future. As a result the LED industry has a vital interest in a resource-friendly way of manufacturing, as this will make sure that the cost reduction that is still required through the next ten years can actually be achieved. In this article we will focus on AIXTRON's CRIUS® II-XL reactor and show to what huge extent this platform can contribute to a resource- and ecofriendly manufacturing.

General considerations

MOCVD (Metal Organic Chemical Vapor Deposition) is the key manufacturing step to produce white LED chips. The process is run at high temperatures (typically up to 1200 °C) for several hours, which means that the electrical heating system consumes a large amount of electricity. Those parts that are not actively heated must be cooled, which requires a significant amount of cooling water.

The LEDs consist of (Al, In) GaN layers, which are synthesized from Alkyl compounds like TMGA, TMIn and TMAl. Some of the pure elements – in particular Gallium and Indium – are available only in limited quantities, and for all of them the manufacturing process of the Alkyls is quite complex, resulting in relatively high cost. Thus there are good reasons to utilize these materials as efficient as possible in the MOCVD process.

Finally there are large quantities of carrier gases employed, in particular hydrogen. Hydrogen as such is available in very large quantities; however, it has to be generated and purified which again consumes energy.

Three approaches to save resources and cut manufacturing cost

From the above, the key indicators for any resource and cost efficient epi process are:

- Precursor material consumption per wafer
- Carrier gas consumption per wafer
- Electricity consumption per wafer
- Cooling water consumption per wafer.

We have identified three major methods to save the resources mentioned above. These are:

- Upscaling of the MOCVD reactor chamber: ***CRIUS® to CRIUS® II and CRIUS® II-L***
- Geometrical optimization of showerhead (gas injection) and wafer arrangement (reactor fill factor): ***CRIUS® II-L to CRIUS® II-XL***
- Reduction of total process cycle time (through high growth rates and fast temperature ramps in the process to eliminate unproductive time): ***CRIUS® II-XL short cycle (SC)***

1. Upscaling

Some of the resources consumed are significantly reduced by simply scaling the MOCVD reactor to a larger size. This is in particular true for electricity and cooling water. The electrical power required to maintain an MOCVD reactor at a typical Gallium Nitride growth temperature (~1150 °C) does not exactly scale with the reactor size, which means that even though the total power consumption per growth run is higher for a larger reactor, the amount of electricity consumed per single wafer is much less. As most of the heat which is generated is dissipated into the cooling water, a similar consideration is applicable for the water consumption. MOCVD systems are typically supplied with cooling water from a closed loop. Therefore the water is re-used, however, circulation and cool down of the water require electrical energy which needs to be taken into account when calculating the reactor's energy consumption.

The saving of electrical power consumption by scale-up can be nicely seen in Fig 1, showing the electricity consumption of various CCS reactors. CRIUS®, CRIUS® II and CRIUS® II-L are a sequence of reactor up-scales, which results in impressively reduced consumption figures.

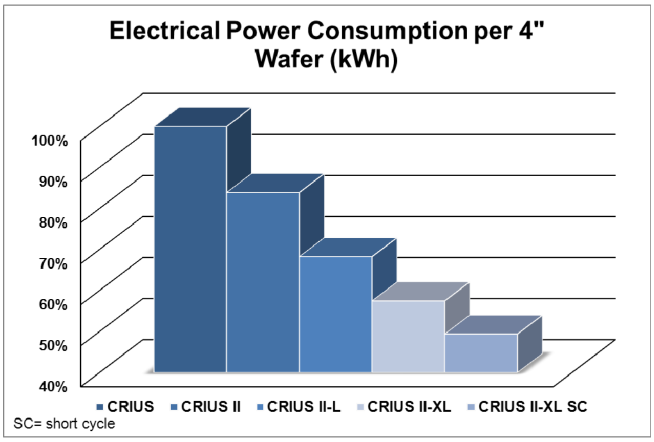

Fig. 1: Electrical power consumption per 4" wafer for Close Coupled Showerhead® reactors

2. Geometrical optimization

AIXTRON's MOCVD reactors are known to have the highest utilization rates for MO precursors and gases. For CRIUS® reactors, this is a result of the unique Close Coupled Showerhead® design, which inherently provides highest precursor utilization. This utilization is available on the entire wafer carrier or susceptor. Thus the way how substrates are arranged on the susceptor, or, in other words, which area fill factor is achieved, defines the on-wafer utilization efficiency for MOs and gases. Furthermore, the showerhead can be most exactly matched to the active susceptor area (i.e. the area where the wafers are actually placed), which again improves the efficiency.

A typical example of such an geometrical optimization is the transition from CRIUS® II-L to CRIUS® II-XL. CRIUS® II-XL utilizes the same susceptor diameter as CRIUS® II-L, however with maximized fill factor and optimum matching of showerhead area and growth area. As a result, dramatic improvements in electricity and water consumption per wafer could be achieved. Even more impressive is the reduced TMGa consumption per wafer, as shown in Fig. 2.

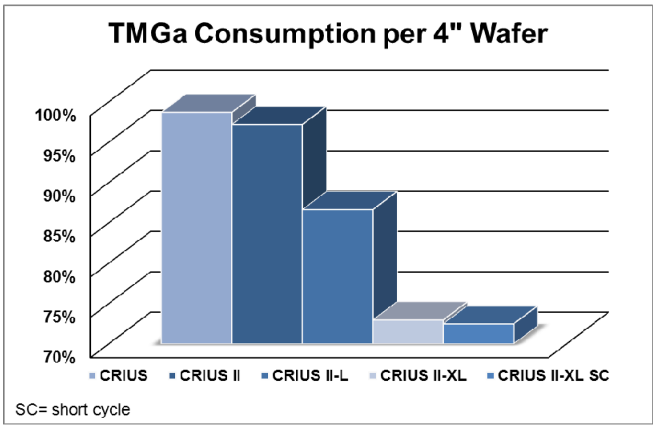

Fig. 2: Trimethylgallium (TMGa) consumption per 4" wafer for Close Coupled Showerhead® reactors

3. Process cycle time reduction

Another unique way to reduce the resource consumption of an MOCVD tool is to shorten its cycle time. The total cycle time includes growth time and non-growth time. While the non-growth time has already been significantly reduced, e.g. by loading and unloading at elevated temperatures, most of the LED manufacturers have not yet exploited the potential of reduced growth time.

AIXTRON has recently addressed this in two distinct ways. The first is to apply an active top side temperature control (TTC) in the latest generation of CRIUS® II-XL systems. The second is to introduce a high growth rate process without compromising the MO and gas efficiency.

a. TTC – Top side Temperature Control

The TTC setup uses an "ARGUS" pyrometer array to read the actual surface temperature of the wafer carrier. This temperature reading is processed and fed back into the control of the three independent heater zones that heat the wafer carrier (Fig. 3). This principle allows not only adjusting temperatures precisely, it also shortens the settling times required after changing the growth temperature. Such changes occur frequently, for example when growing the multi quantum well structure which is the core part of any LED.

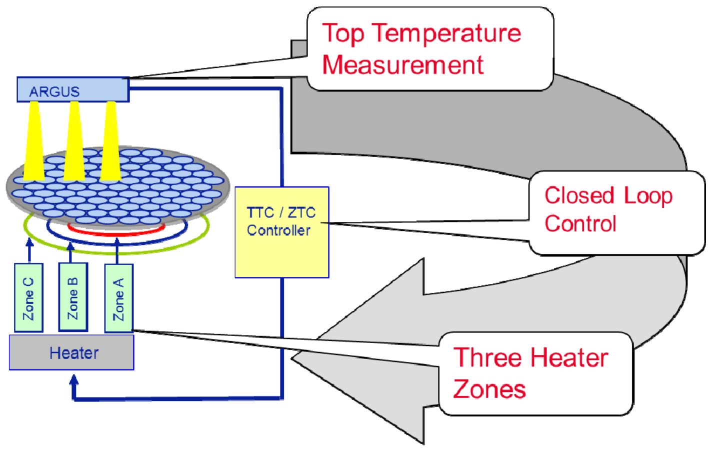

Fig. 3: Schematic of the TTC (Top side Temperature Control) in a CRIUS® II-XL MOCVD reactor

b. High growth rates

Combining higher growth rates with maximized utilization efficiency of the MO precursors is the ultimate way to achieve short cycle times. However, most of the MOCVD tools available today cannot reach this goal, as they are suffering from too low MO efficiencies. In order to increase growth rates, the amount of TMGa fed into the reactor usually is simply increased. In a certain "classical" regime this works for most MOCVD reactors, allowing growth rates of 2 to 3 µm/h. (Fig. 4, lower left part). However, once a certain threshold is exceeded, these MOCVD reactors simply will not increase growth rates substantially, even while larger quantities of TMGa are used. This additional material is then simply wasted.

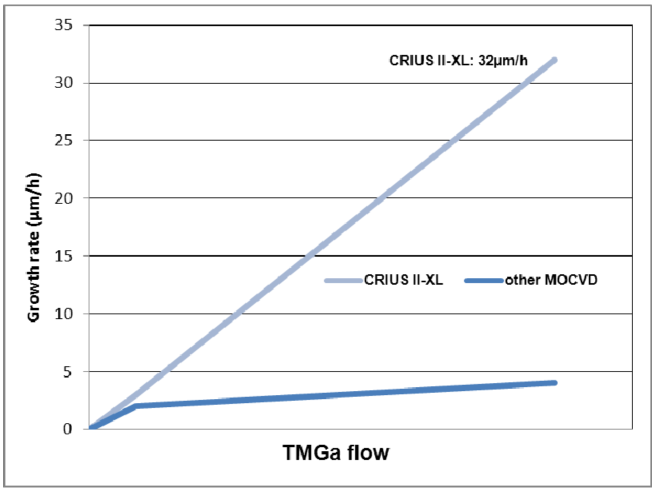

Fig. 4: Growth rate of CRIUS® II-XL and other MOCVD reactors as a function of the TMGa flow

Due to their design, AIXTRON reactors do not suffer from such shortcomings. Even in the low growth rate regime their MO utilization efficiency is better than others. More important, they allow adjusting growth rates beyond 30µm/h without compromising the MO efficiency at all (Fig. 4, upper right part).

Combining high growth rates and fast temperature control, a unique advantage is created. It allows achieving a drastic cycle time reduction, which translates into impressive resource savings. As an example, Fig. 5 shows the reduction of hydrogen consumption in CRIUS® reactors. Implementing the short cycle, almost 40% of the initial hydrogen consumption of the CRIUS® reactor can be saved.

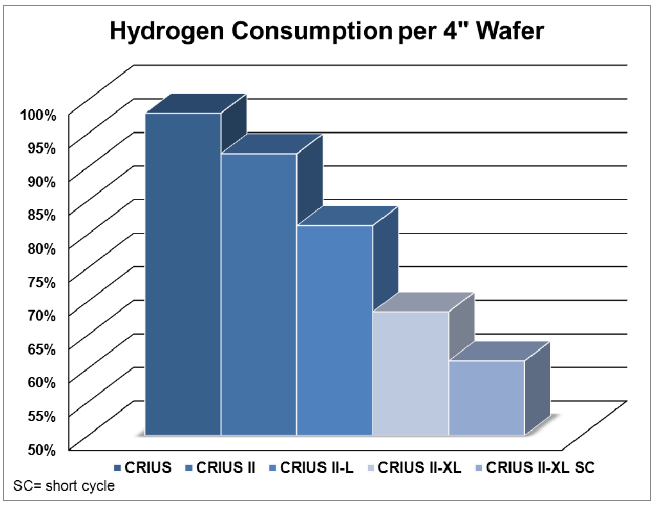

Fig. 5: Hydrogen consumption per 4" wafer for Close Coupled Showerhead® reactors

Besides the ecological aspect of saving electricity, water and precious raw materials, it is finally worthwhile also to look at the financial impact. In Fig. 6, cost for gases, MOs, water and electricity have been taken into account to calculate the actual cost. It is obvious that all the saving measures described above provide a significant economic advantage on top of the "green" aspect.

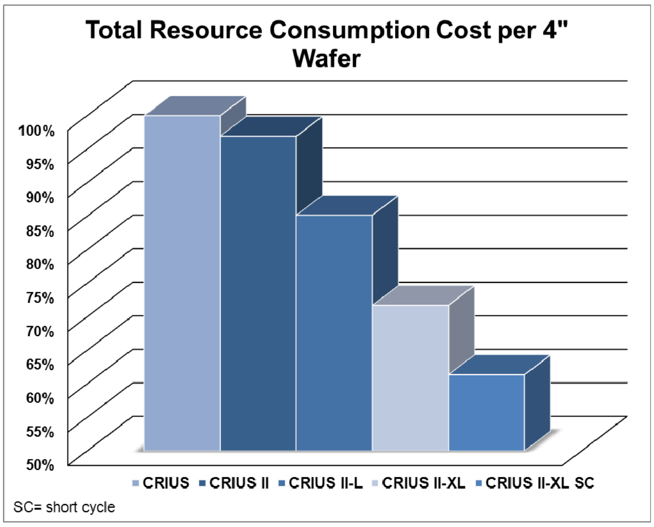

Fig. 6: Total resource consumption cost per 4" wafer for Close Coupled Showerhead® reactors

Summary

MOCVD has a large potential for a more efficient utilization of required resources. In particular gases, metal organics, electricity and water can be significantly saved. AIXTRON’s CRIUS® II-XL platform offers the industry’s most comprehensive portfolio of resource-saving technologies. A straight forward scale-up from CRIUS® to CRIUS® II and CRIUS® II-L already offered a major opportunity for savings. The more recent introduction of CRIUS® II-XL allows exploiting the potential of an optimization of the reactor geometry. Finally, as the latest improvement, a combination of uniquely high growth rate and fast temperature control increases the overall resource efficiency of the CRIUS® II-XL reactor once more.

About AIXTRON

AIXTRON is a leading provider of deposition equipment to the semiconductor industry. The Company’s technology solutions are used by a diverse range of customers worldwide to build advanced components for electronic and optoelectronic applications based on compound, silicon, or organic semiconductor materials, as well as carbon nanotubes (CNT), graphene and other nanomaterials. Such components are used in displays, signaling, lighting, fiber optic communication systems, wireless and mobile telephony applications, optical and electronic storage devices, computing, as well as a range of other leading-edge applications.

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