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DEPOSITION TECHNOLOGY FOR BEGINNERS

How **MOCVD** works

AIXTRON

Our technology. Your future.

Contents

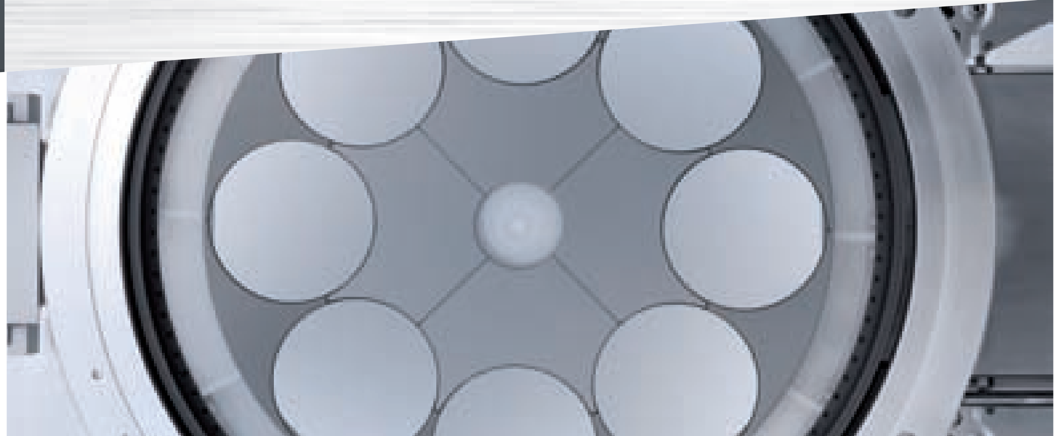
MOCVD for Beginners

Metal Organic Chemical Vapor Phase Deposition (MOCVD) is a highly complex process for growing crystalline layers.

MOCVD is used in manufacturing light-emitting diodes (LEDs), lasers, transistors, solar cells and other electronic and opto-electronic devices, and is **the key enabling technology** for future markets with high growth potential.
The LED lighting applications that will soon become the widespread standard in the private, commercial and public lighting market are a prime example of this trend.

In this brochure, we would like to provide basic information on how MOCVD works and explain which applications are produced with this technology.

The booklet is not intended to serve as a scientific paper for experts; its purpose is to explain to a non-specialist in an understandable way how vapor phase deposition works and why this technology has so much future potential.



Top view on **Planetary Reactor®** – an example for our key technology

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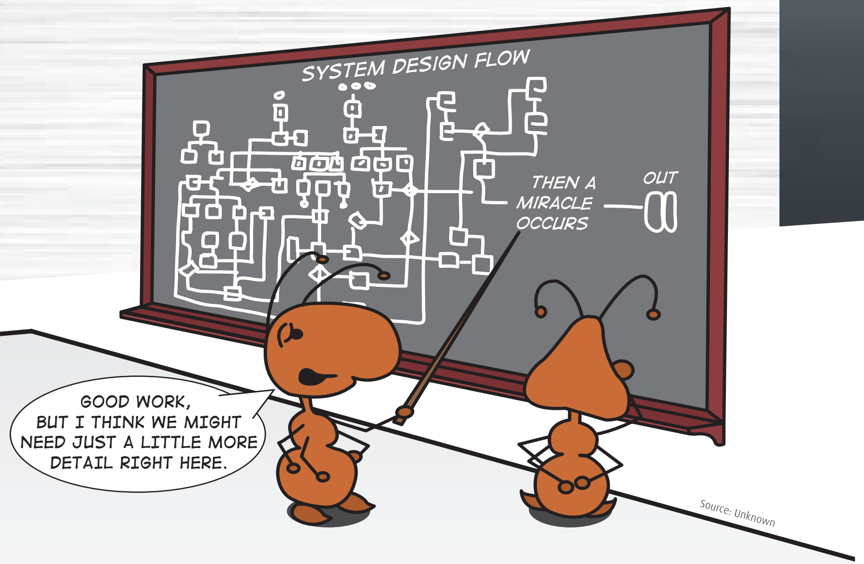
MOCVD – A Definition

MOCVD (metal organic chemical vapor deposition) is a technology that is used to deposit very thin layers of atoms onto a semiconductor wafer (wafers are thin disks mostly made of saphire or silicon). It is the most significant manufacturing MOCVD process for **III-V compound semiconductors**, especially for those based on Gallium Nitride (GaN).

These semiconductors are the most important base materials for manufacturing red, blue, green and white LEDs.

AIXTRON provides mainly two different system types for MOCVD deposition processes: The **Planetary Reactor®** and the **Close Coupled Showerhead®** technology.



Not a miracle but high tech engineering:
MOCVD technology

Planetary Reactor® Technology

The **Planetary Reactor®** technology is based on the principle of **horizontal laminar flow**. The required process gases enter the deposition chamber through a special **gas inlet** (nozzle) located in the center of the reactor ceiling. A process pump extracts the gases from the chamber edge and forces them to flow radially and very homogeneously from the center to the edge of the process chamber, passing over the hot semiconductor substrates. This causes the chemicals to break up and to react. The desired atoms diffuse through the gas phase onto the wafer surface, atomic layer by atomic layer.

Each individual wafer is located in a separate small pocket, which is rotating slowly during this deposition process, providing a uniform distribution of the materials across not only each single wafer but also wafer-to-wafer.

The properties of the deposited crystal at an almost atomic scale can be modified by varying the introduced gases. This enables customers to design and manufacture the highest quality semiconductor layers (as thin as a millionth of a millimeter), which can be used to manufacture electronic or **optoelectronic devices such as LEDs, lasers, solar cells** etc.

Planetary Reactor® – 8x6 inch

Close Coupled Showerhead® Technology

With Close Coupled Showerhead® technology, chemicals are **introduced vertically** into the process chamber where semiconductor crystals are formed.

In the reactor, the gases are introduced through a huge number of very small gas channels in the reactor ceiling, just like a bathroom showerhead.

The design of this showerhead assures that the process gases are always distributed evenly throughout the entire wafer surface. The showerhead is located very close to the heated wafers.

The chemicals decompose and the targeted atoms diffuse very quickly through the gas phase onto the wafer surface.

The method of how the gases are introduced and how they reach the wafer and are deposited onto the crystal is different in both technologies.
However, both processes lead to similar results.

Close Coupled Showerhead® –
AIX R6 · 31x4 inch

Showerhead

AIXTRON MOCVD

The chosen deposition process takes place within the reactor chamber of the system.

Here the semiconductor layers are deposited on the underlying wafers – at various temperatures (up to approximately 1,200°C).

Further important components modularly used in the systems ...

- Gas mixing system
- Process pump vacuum system
- In-situ metrology (measuring systems controlling what happens inside the reactor)
- Integrated wafer handlers for automation
- Power supply unit

Close Coupled Showerhead® technolgy
AIX R6 system

What are III-V Semiconductors?

MOCVD is a process for manufacturing complex semiconductor multilayer structures used in electronic or optoelectronic components such as LEDs, lasers, high-speed transistors or solar cells. Unlike the better-known Silicon (used in the production of computer chips, for example), these semiconductors consist of not just **one element**, but rather of two or even more. They are therefore referred to as "compound semiconductors". They include Gallium Arsenide (GaAs), Indium Phosphide (InP), Gallium Nitride (GaN) and related alloys.

They are also called "III-V semiconductors" because they are made from elements of group III and V of the Periodic Table and can interact to form crystalline compounds.

Compound semiconductors have significant advantages over Silicon. Because electrons can move very fast in III-V materials, those devices containing III-V semiconductors can "process" the very high frequencies in mobile phones, for example. Moreover, they can also function even at very high temperatures.

Most importantly, they are highly efficient at converting light into electric power and vice-versa – this is what high-performance solar cells and all LEDs are based on.

Periodic table
(excerpt)

Periode	Gruppe II	Gruppe III	Gruppe IV	Gruppe V	Gruppe VI
2	9,0 Be 4	10,8 B 5	12,0 C 6	14,0 N 7	16,0 O 8
3	24,3 Mg 12	27,0 Al 13	28,1 Si 14	31,0 P 15	32,1 S 16
4	40,1 Ca 20	69,7 Ga 31	72,6 Ge 32	74,9 As 33	79,0 Se 34
5	87,6 Sr 38	114,8 In 49	118,7 Sn 50	121,8 Sb 51	127,6 Te 52
6	137,3 Ba 56	204,4 Tl 81	207,2 Pb 82	209,0 Bi 83	209 Po 84

Al = Aluminium
Ga = Gallium
In = Indium
N = Nitrogen
P = Phosphorus
As = Arsenic
Sb = Antimony

! The chemicals used for the deposition process are atoms of group III such as Ga, In, Al, combined with complex organic gas molecules, and atoms of group V such as As, P, N, combined with hydrogen atoms.

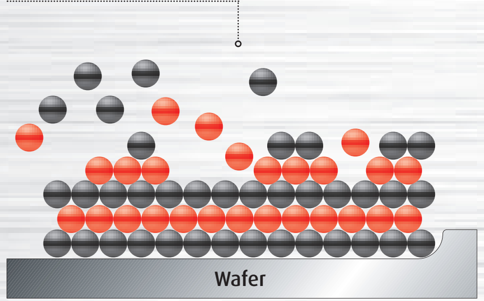
How MOCVD works

To produce **compound semiconductors**, the chemicals are vaporized and transported into the reactor together with other gases. There, the critical chemical reaction takes place that turns the chemicals into the desired crystal (the compound semiconductor).

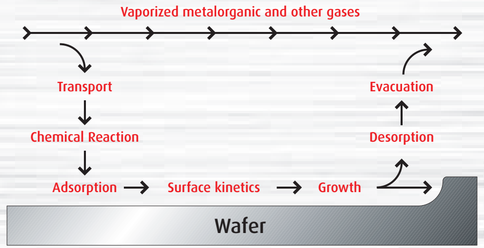
In MOCVD the injected gases are ultra-pure and can be finely dosed. AIXTRON MOCVD equipment enables the deposition on large areas and is therefore the first and most cost-effective choice for compound semiconductor manufacturers.

AIXTRON is a global leader in this technology.

Surface processes while growing layers on the substrate

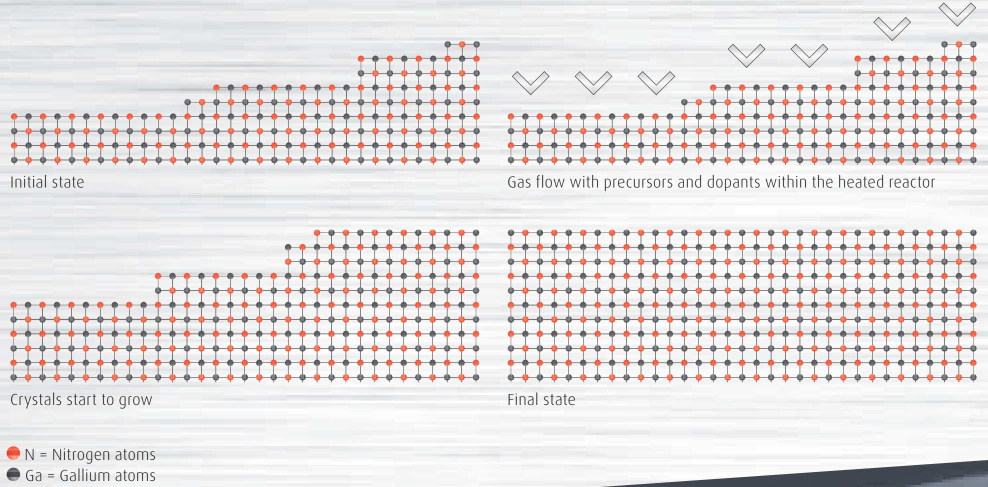


Deposition process takes place on the substrates (wafers)



Epitaxy: Growth of Crystalline Layers

Epitaxy refers to the deposition of thin, single layers onto a suitable substrate on which they grow in the form of crystals. The word stems from a Greek term meaning “stacked” or “arranged in layers”.



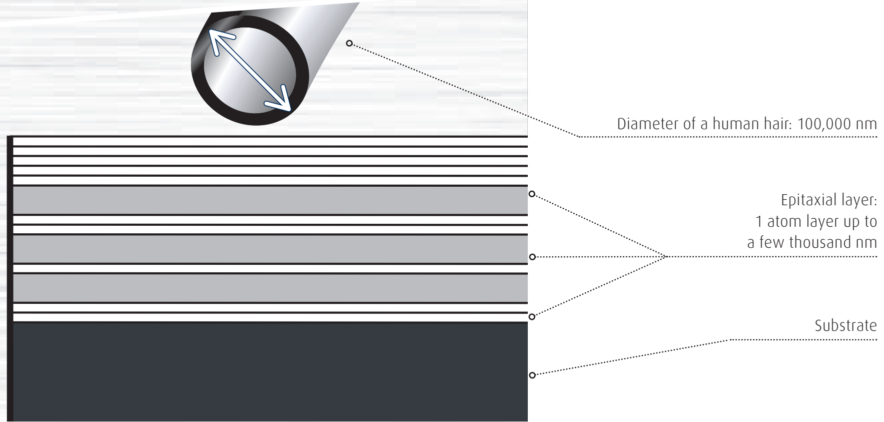
Substrates in a reactor made by AIXTRON

Precision in Deposition

Precision is everything: The thinnest films required in an LED structure are less than one nanometer thick (which is 0.000001 mm). Such thin film layers are usually deposited onto substrates of four inch size (100 mm Ø). If we apply this precision to Germany it would mean that a thin film of snow of just 1 cm height would have to be spread uniformly across the entire country.

The thickness of a single layer has to be very homogenous

In the subsequent LED chip processing stage, precision is measured in nanometers. This diagram compares the diameter of an average human hair to the epitaxial layers on the substrate.

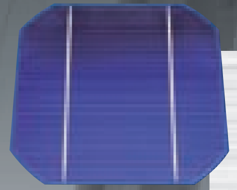


The Laser Diode

A **laser device** emits a narrow beam of concentrated light with a high density of energy and a very sharp color.

The crystal structure of a laser looks similar to that of an LED. In order to create laser light from a diode, it is very important to have ultra high crystal quality and atomically sharp layer interfaces. The main advantage of laser diodes as compared to other laser types is the high speed of light availability. They can be switched on and off easily and have a very small device footprint.

From Deposition to Device



The Solar Cell

A **solar cell** is a solid state device that converts the energy of sunlight directly into electricity by the photovoltaic effect. Assemblies of cells are used to make solar modules, also known as solar panels. Materials presently used for photovoltaic solar cells include Silicon, cadmium telluride and copper indium selenide/sulfide.

Most currently available solar cells are made from Silicon. III-V solar cells are mainly used on satellites, as they are very robust against radiation in space. In so-called concentrator solar cells, III-V solar cells are being used for terrestrial applications.

Aboute the pictures on these pages ...
After the MOCVD deposition process, the different crystal structures are processed into numerous different electronic or optoelectronic devices, such as LEDs, lasers, transistors and solar cells.

The Transistor

A **transistor** is a semiconductor device used to amplify and switch electronic signals.

Transistors are commonly used as electronic switches, both for high-power applications such as switched-mode power supplies and for low-power applications such as logic gates.

III-V transistors are the key electronic devices of applications such as mobile phones, hybrid cars or smart grids.

From Deposition to Device

The LED

LEDs are among the world's smallest light sources. Their low power consumption and low heat generation make LEDs more economical and safer in use than traditional lighting devices.

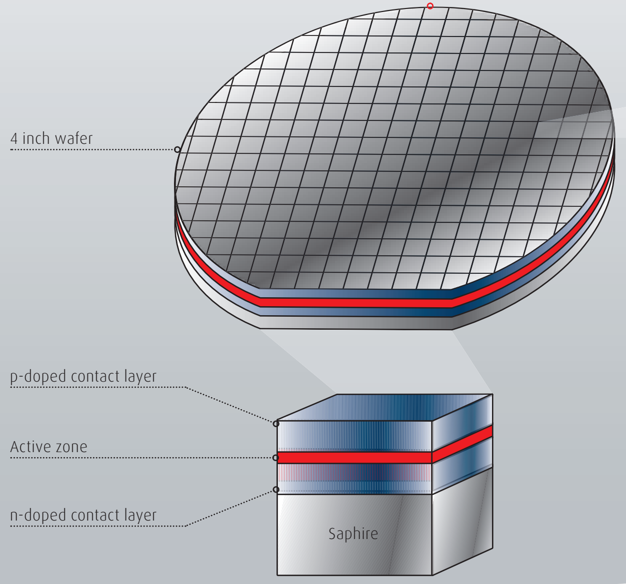
The smallest LEDs measure about 0.1 mm^2, whereas the "power LED" may be up to several square millimeters large and provides output of several hundred lumens.

Lighting source of the future ...
The latest-generation LEDs for general lighting are also offered in standard commercial "bulb format", in order to facilitate the changeover from traditional lighting, such as in private households.
The description on the following pages explains exactly what LEDs are made of and how they work.

How LEDs Work

Construction & Operation Mode

1



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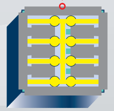
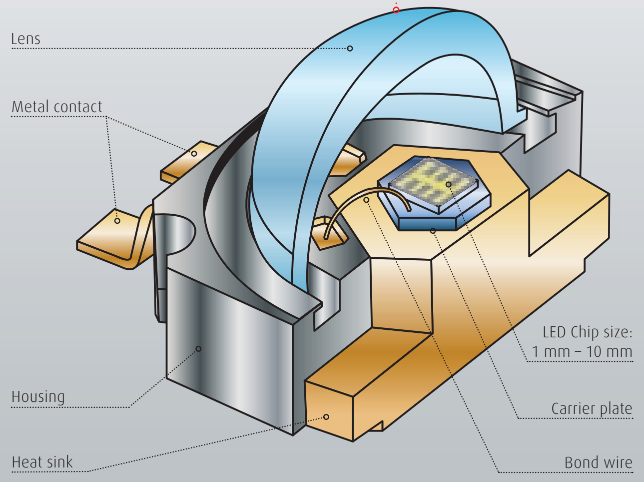


Power chip (example):
1 mm x 1 mm

After the **deposition process**, the wafers are processed into chips, finally resulting in the production of a finished LED. Depending on the chip size, a 4 inch wafer can deliver between 4,000 and 120,000 LED chips.

3

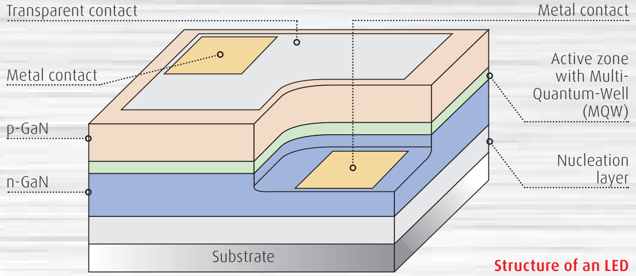


4

Power chip package
Ostar LED chip

5

LED-TV backlight unit with LED



Structure of an LED

Did you know … ? The scientific explanation of how an LED works: An LED has an active zone that determines the color of the light. This is embedded in a p-doped layer and an n-doped layer that transport electrons (n-doped side) and so-called “holes” (p-doped side) to the active layer when current is flowing.

The electrons and holes are then transformed into photons (light) in the active zone. Doping atoms are used for n- and p-doping (for example, Silicon for n-doping or Magnesium for p-doping). During MOCVD growth, these doping atoms can be interspersed into the growing layer via the gas flow.