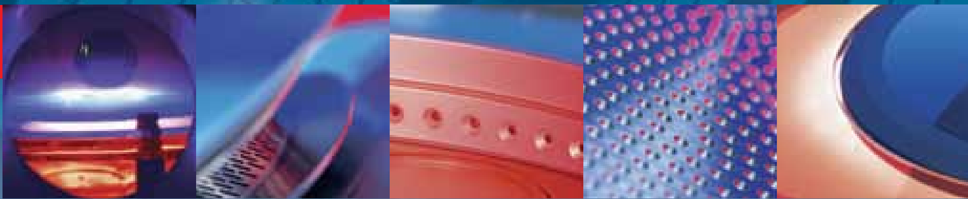
AIXTRON



How MOCVD Works

Deposition Technology for Beginners

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MOCVD for Beginners

Metal Organic Chemical Vapor Phase Deposition – or MOCVD for short – 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 become the widespread standard in the private, commercial and public lighting market in the coming years are a prime example of this trend.

In this brochure, we would like to provide basic information about how MOCVD works and explain which applications contain 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

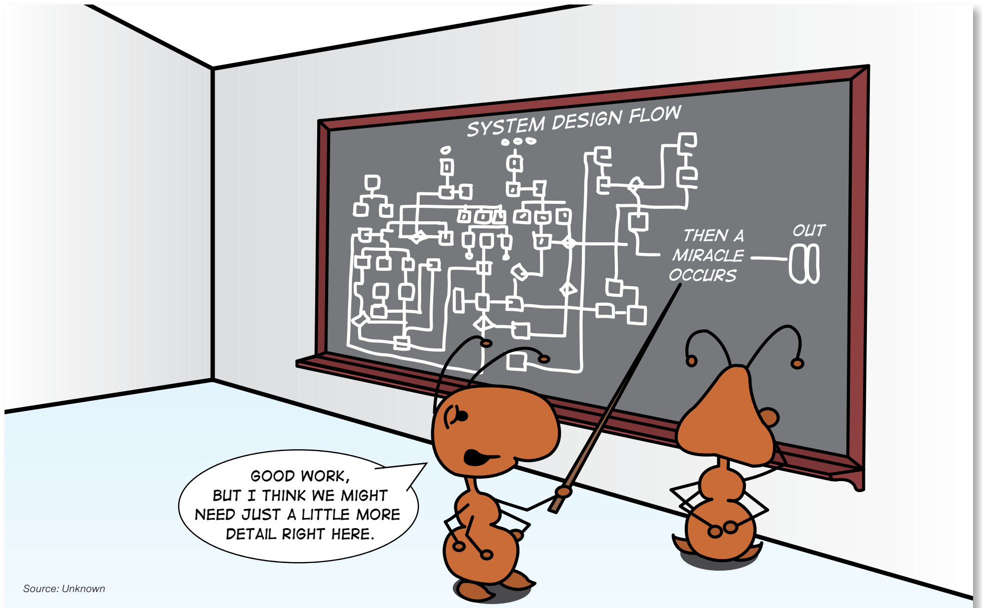
MOCVD – A Definition

MOCVD (metal organic chemical vapor deposition) is a technique that is used to deposit very thin layers of atoms onto a semiconductor wafer. It is the most significant manufacturing process for III-V compound semiconductors, especially for those based on Gallium Nitride (GaN).

These semiconductors are the most important base material for manufacturing red, blue, green and white LEDs. MOCVD is also known as: MOVPE (metal organic vapor phase epitaxy), OMVPE (organo-metallic vapor phase epitaxy) and OMCVD (organo-metallic chemical vapor deposition).

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

Not a miracle but high tech engineering: MOCVD technology

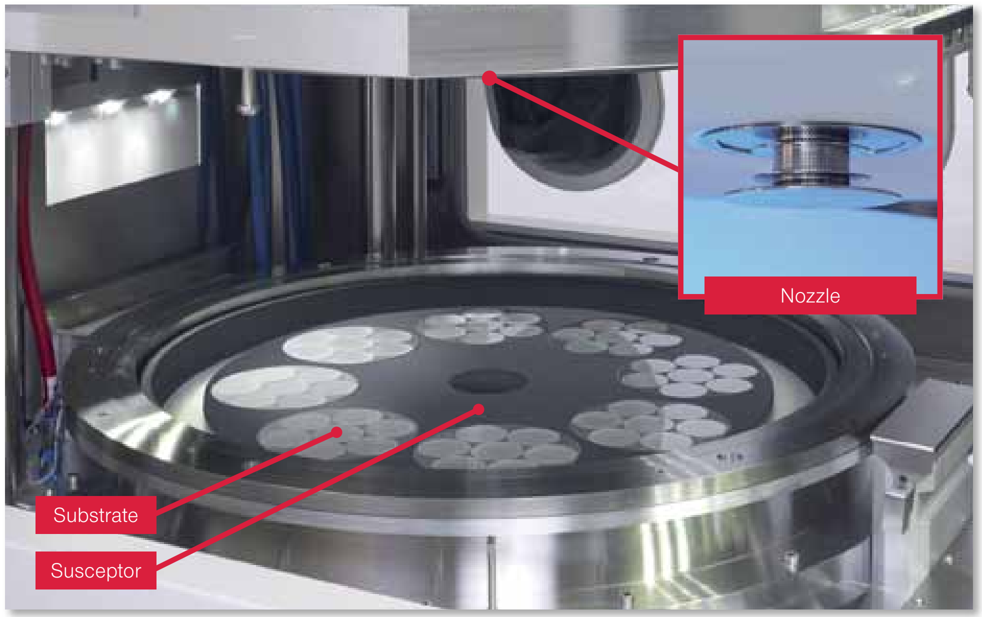


Planetary Reactor® Technology

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 is extracting 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 on a separate small disk, which is rotating slowly during this deposition process, providing a uniform distribution of the materials across each single wafer. The properties of the deposited crystal at an almost atomic scale can be modified by varying the introduced gases. This enables crystal growers to design and manufacture the highest quality semiconductor layers (as thin as a millionth of a millimetre), which can be used to manufacture electronic or optoelectronic devices such as LEDs, lasers, solar cells etc.

Planetary Reactor® 56x2 inch



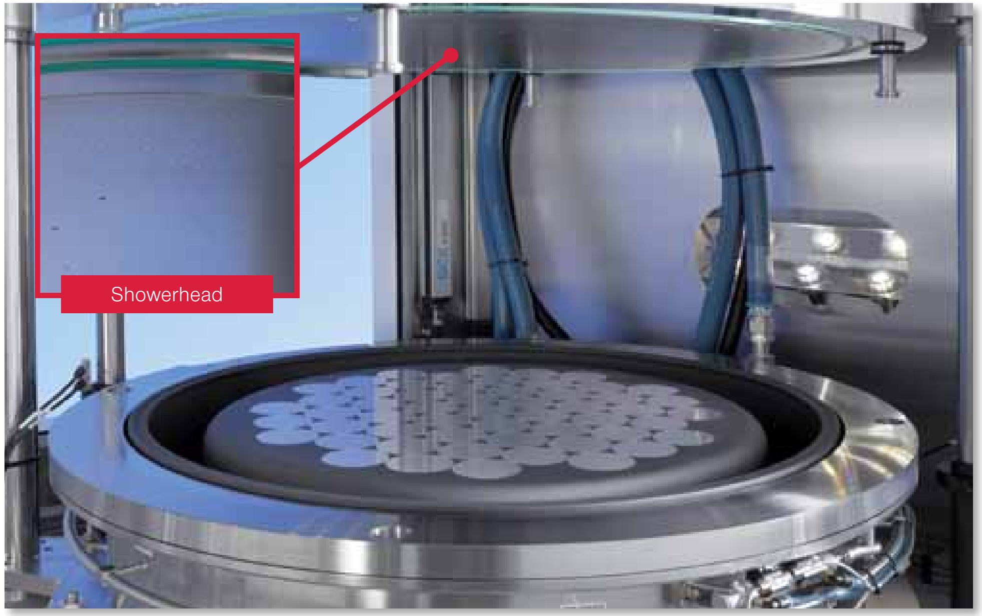
Close Coupled Showerhead® Technology

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

In the Close Coupled Showerhead® reactor, the gases are introduced through a huge number of very small gas channels in the reactor ceiling, just like a showerhead in your bathroom works. The design of this showerhead assures that these process gases are always distributed very uniformly throughout the whole wafer carrier 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 way how the gases are introduced and how they get to the wafer and onto the crystal is different to Planetary Reactor® technology, however, both technologies lead to similar results.

Close Coupled Showerhead® 55x2 inch



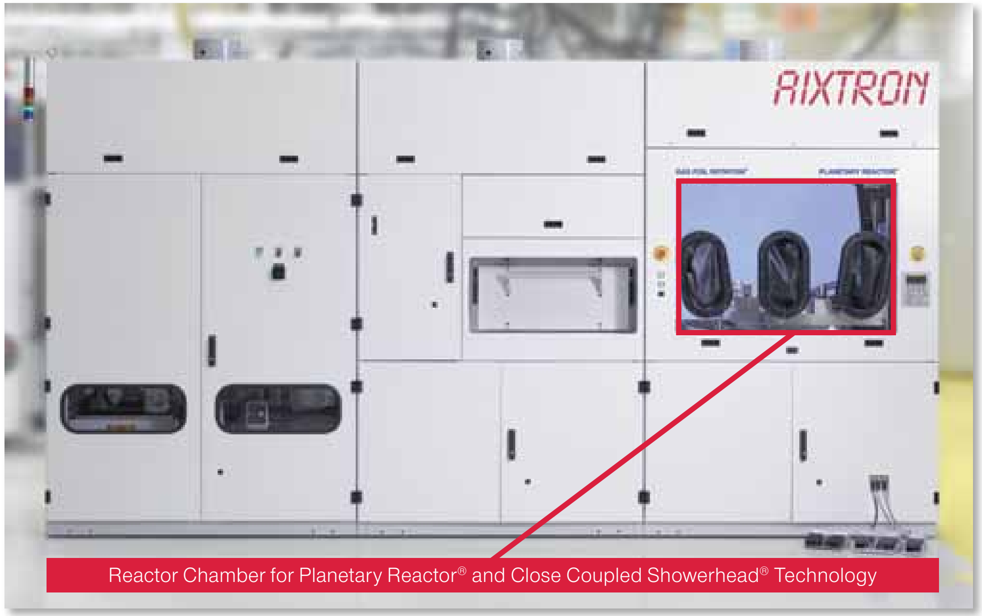
AIXTRON MOCVD Production Platform

Both reactor concepts (Planetary Reactor® and Close Coupled Showerhead®) can be integrated into our platforms, which are built in a highly modular and very flexible design, called an IC system (IC = Integrated Concept).

The platform concept allows us not only to offer both reactor types on a cost-saving, efficient platform but also to realize customer-tailored variations.

Within this platform system, the chosen deposition process takes place within the reactor chamber of the system. Here the semiconductor layers are deposited on the underlying substrate (wafer) – at various temperatures (up to approximately 1,200°C).

AIXTRON IC 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.

Periodic Table (Detail)

Period	Group II	Group III	Group IV	Group V	Group 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

Compound semiconductors have several significant advantages over Silicon semiconductors. 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 efficient at converting light into electric power and vice-versa – this is what high-performance solar cells and all LEDs are based on.

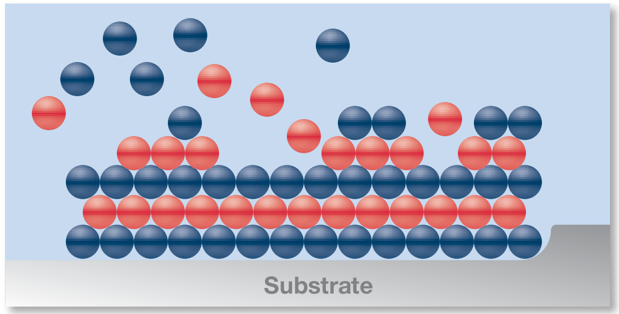
> ! *The chemicals used for the deposition process are atoms of group III such as Ga, In, Al, combined with complex organic gas molecules, and atoms of group V such as As, P, N, combined with hydrogen atoms.*

How MOCVD Works

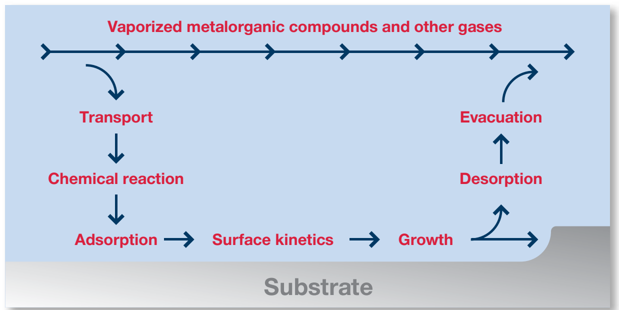
To produce compound semiconductors, the chemicals are vaporized and transported into the reactor together with other gases. There, the critical chemical reaction takes place that turns the chemicals into the desired crystal (the compound semiconductor).

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

AIXTRON is the global market leader in this technology.



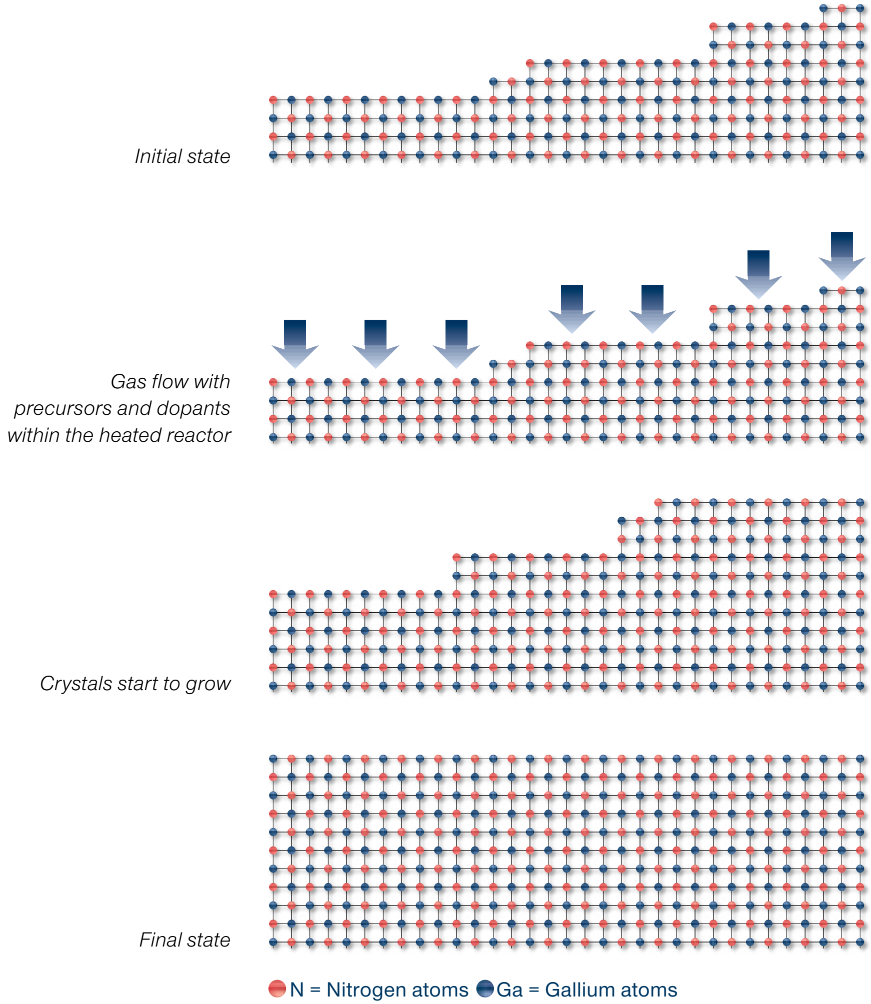
Deposition process takes place on the substrates (wafers)



Surface processes while growing layers on the substrate

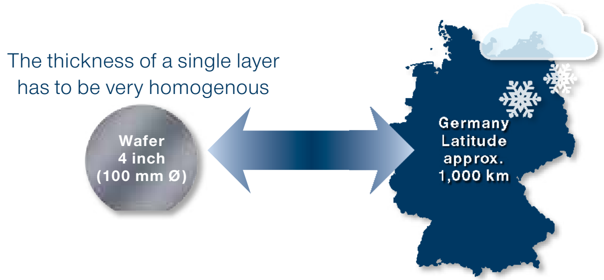
Epitaxy:
Growth of Crystalline Layers

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

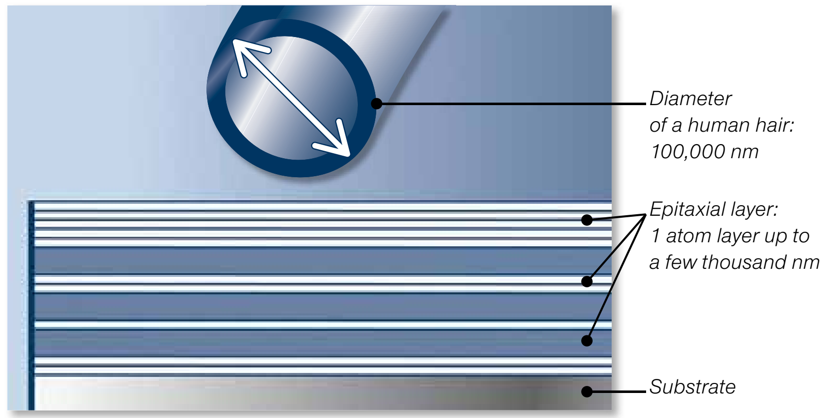


Precision in Deposition

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 on substrates of four inch size (100 mm Ø). If we compare this precision to the territory of Germany it means that a thin film of snow of just 1 cm height would have to be spread uniformly across the whole country.



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.



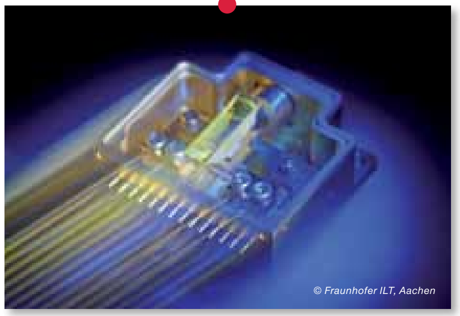
From Deposition to Device

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.

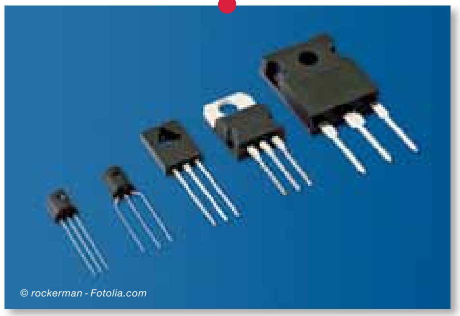
The Laser Diode

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

The general crystal structure of a laser looks similar to that of a LED. In order to create laser light from a diode, it is very important to have ultra high crystal quality and atomic sharp layer interfaces. The advantage of laser diodes over 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.



The Transistor

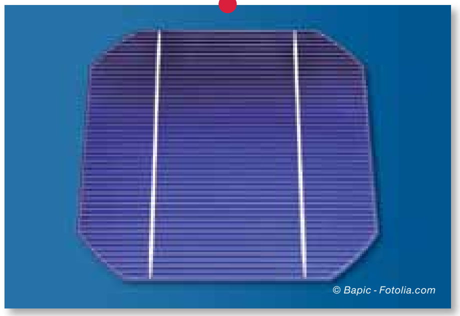


A *transistor* is a semiconductor device used to amplify and switch electronic signals. It is made of a solid piece of semiconductor material, with at least three terminals for connection to an external circuit.

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 mobile phones and for hybrid cars.

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 monocrystalline Silicon, polycrystalline Silicon, amorphous 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 may now be used for terrestrial applications.



The LED

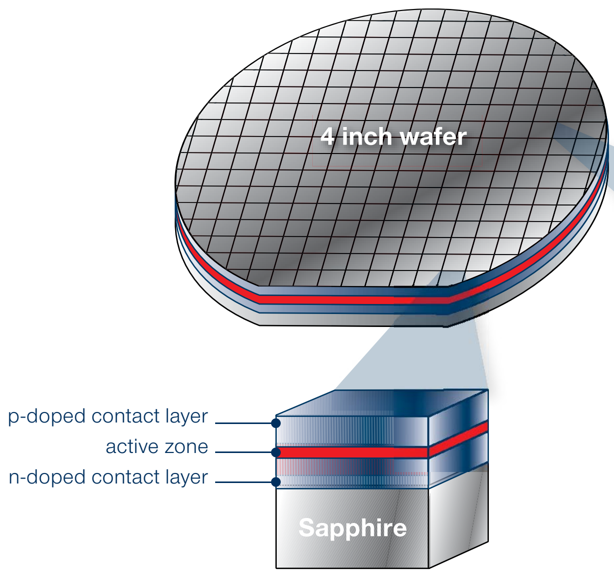
LEDs are among the world's smallest light sources.

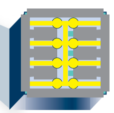
Their low power consumption and low heat generation make LEDs more economical and safer than traditional lighting devices.

The smallest LEDs measure about 0.1 mm^2, whereas the "power LED" may be up to 4 mm^2 and provides output of several hundred lumen.

The excursus on the following pages explains exactly what LEDs are made of and how they work.

How LEDs Work

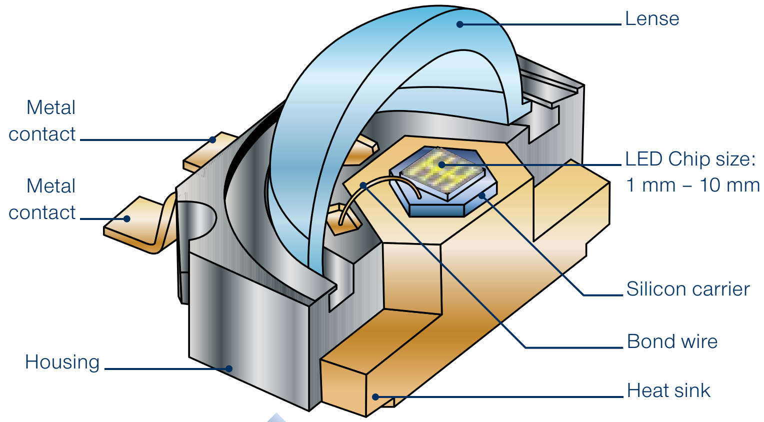




Power chip
(example):
1 mm x 1 mm

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.

Construction & Operation Mode



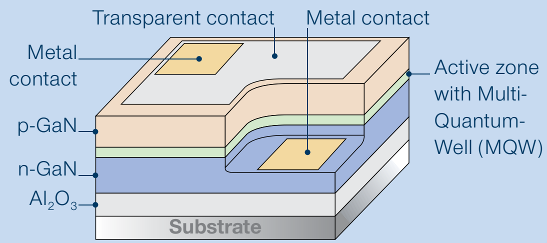
Power chip package
Ostar LED chip

Top LED
Backlight unit

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 the MOCVD growth, these doping atoms can be interspersed into the growing layer via the gas flow.



Structure of an LED

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.

ALWAYS ONE STEP AHEAD