



Crystallize Your Visions

Crystal Growing Systems

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Semiconductor Systems Division

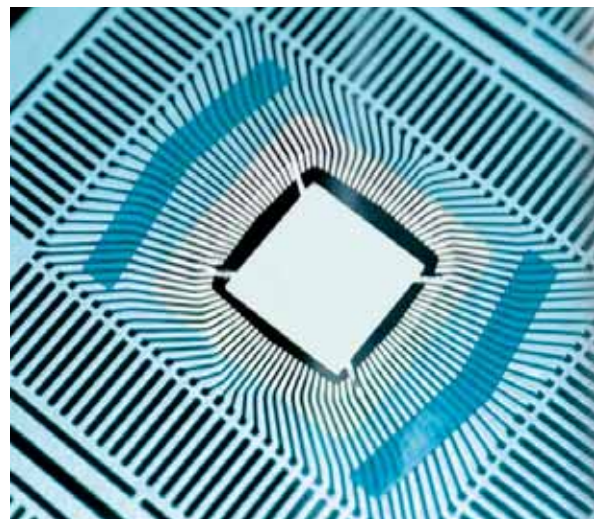
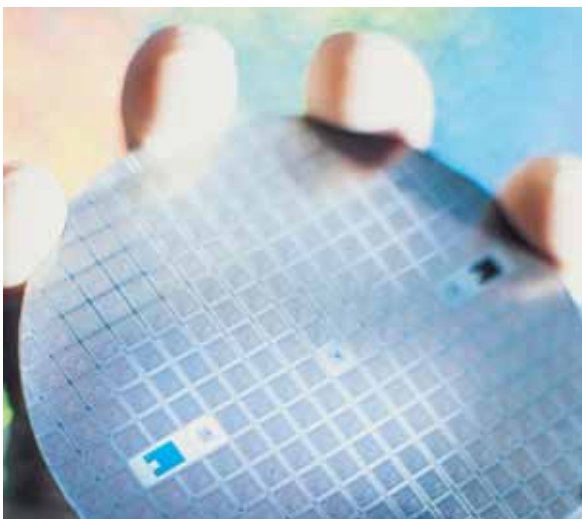
Setting up benchmarks as a global market leader

In the Semiconductor Systems Division, all PVA TePla systems are concentrated for customers from the semiconductor industry. The main areas covered here are systems for crystal growing, for plasma applications and for quality control of high-quality materials and semiconductor devices.

Crystal growing systems for wafer manufacturers

Rod-shaped silicon monocrystals, also called ingots, are cut into thin disks. Known as wafers in the semiconductor industry, they are the basic material for semiconductor production. The manufacture of 300mm silicon ingots, which must meet the most stringent quality standards, requires reliable crystal growing systems with very sophisticated process technology and a high level of automation. PVA TePla has been designing and building these kinds of systems for decades now. Also, systems for developing the next-but-one generation of crystals and wafers with a diameter of 450mm have already been delivered. Power semiconductors in high-performance electronics are playing an increasingly important role in the development of electronic products. For optoelectronic and high-frequency

applications, increasing use is being made of compound semiconductors. The gallium arsenide (GaAs) and indium phosphide (InP) base materials most frequently used for these applications differ from silicon (Si) in that they have greater electron mobility, thus enabling the construction of transistors with higher frequencies. These types of compound semiconductors are therefore ideally suited for use in mobile radio communication (e.g. UMTS network) and in fiber-optic networks. Extremely pure silicon crystals produced using the Floatzone process are also needed for the capacity expansions in silicon production that are currently being undertaken worldwide. The increasing use of hybrid technology in the automotive industry will also create extra demand for extremely pure crystals.



Solar Systems Division

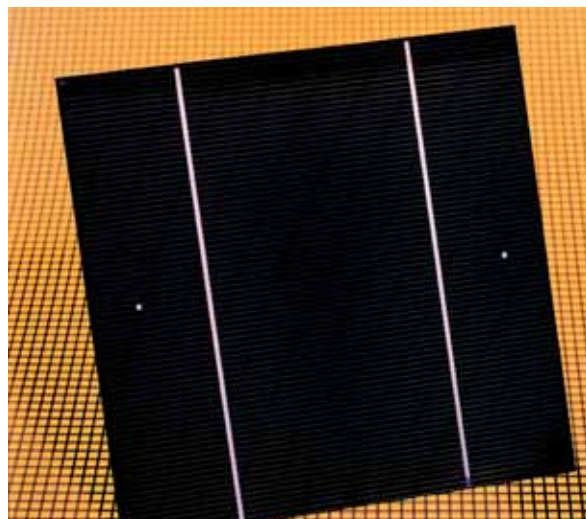
Systems for high-quality Crystals

In the Solar Systems Division systems for processing high quality crystals are produced in addition to a number of other products. PVA TePla AG is able to provide all relevant processes, especially in the area of growing mono- and multicrystalline silicon crystals.

The Solar Systems Division primarily builds systems for creating extremely high-quality silicon crystals and blocks. These crystals are vital components in the photovoltaics value chain. In the coming years, rising raw material prices, increasing scarcity of fossil fuel resources and global warming will spur on the market for alternative energies. In this field, PVA TePla systems dominate the whole range of manufacturing processes for growing mono- and multicrystalline silicon crystals. This thus allows the markets to be served so that the technological requirements of the customers are fulfilled in an optimal manner. The different types of systems for the production of mono- and multicrystalline crystals ensure the highest level of productivity:

- Cz (Czochralski) – monocrystalline
- FZ (Floatzone) – monocrystalline
- VGF (Vertical Gradient Freeze) – multicrystalline
- EFG (Edge Defined Film Fed Growth) – multicrystalline

The division of PVA TePla has a long tradition of growing crystals: Since 1958, over 600 systems have been installed.



PVA TePla: Crystal growing systems at a glance

PVA TePla AG is the leading crystal growing system provider for high-tech industries. The company has all industrially relevant methods for crystal growing, particularly for growing mono- and multicrystalline silicon crystals.

Integrated into the work of several research institutes, the company acts as a provider of high-quality systems and is also actively involved in the latest technological developments in the area of crystal growing. We constantly impress our industrial customers with our crucial technological edge and individually devised solutions.

The division originates from the Leybold Group, and has a long tradition in the area of crystal growing: a large amount of systems have been delivered since 1958.

High-quality and high-purity crystals are an essential component in a whole bunch of future-shaping industries such as the semiconductor, photovoltaic and optoelectronic industry.

Crystal Growing Systems

Crystals for the next generation

The highly innovative chip industry requires new materials and technologies for higher processing power, faster connections and higher memory capacity

Crystals for the semiconductor industry

However, all this can only be achieved with increasingly powerful semiconductor components. Therefore the requirements for perfectness of crystalline semiconductor materials, wafer dimensions and reproducibility in manufacture will continue to increase. This fact was recognized by Gordon Moore (co-founder of Intel) back in 1965, just a few years after the integrated circuit (IC) was invented in September 1958. The complexity of integrated circuits doubles approx. every 18 months. This development is also known as Moore's Law. In this respect, Moore's Law can also be regarded as a „blueprint for the semiconductor industry“. As a result of this rapid progress in the semiconductor industry, the process-related requirements for crystal growing also need to develop to the same extent.

Crystals for the photovoltaic industry

Given the finite nature of fossil fuel resources and the greenhouse gas (CO₂) produced when they are used, a fundamental change in power generation in the near future is essential if the current standard of living of our society is to be maintained whilst avoiding irreversible global warming. In contrast, regenerative energies such as solar, wind and hydro power are inexhaustible and ecologically sound.

The advantages of power generation with solar cells:

- The modules contain no moving mechanical parts and are therefore totally maintenance-free and silent.
- After manufacture, no further power (e.g. fuel) apart from sunlight needs to be supplied to the system.
- The size of a PV power station can be flexibly adapted to the power requirement. For instance, systems from a few kW to several MW can be built.



Crystals for optoelectronics

The days of the traditional light bulb are numbered. In February 2007, Australia became the first country to announce a ban on the sale of conventional light bulbs. In doing this, Australia intends to help reduce greenhouse gases (CO₂). „If the whole world switches to these bulbs today, we would reduce our consumption of electricity by an amount equal to five times Australia’s annual consumption of electricity“, says Malcolm Turnbull (Australian Environment Minister).

The alternative to the light bulb is the light-emitting semiconductor diode. Since the development of the first LED in 1962, the light yield has been increased by

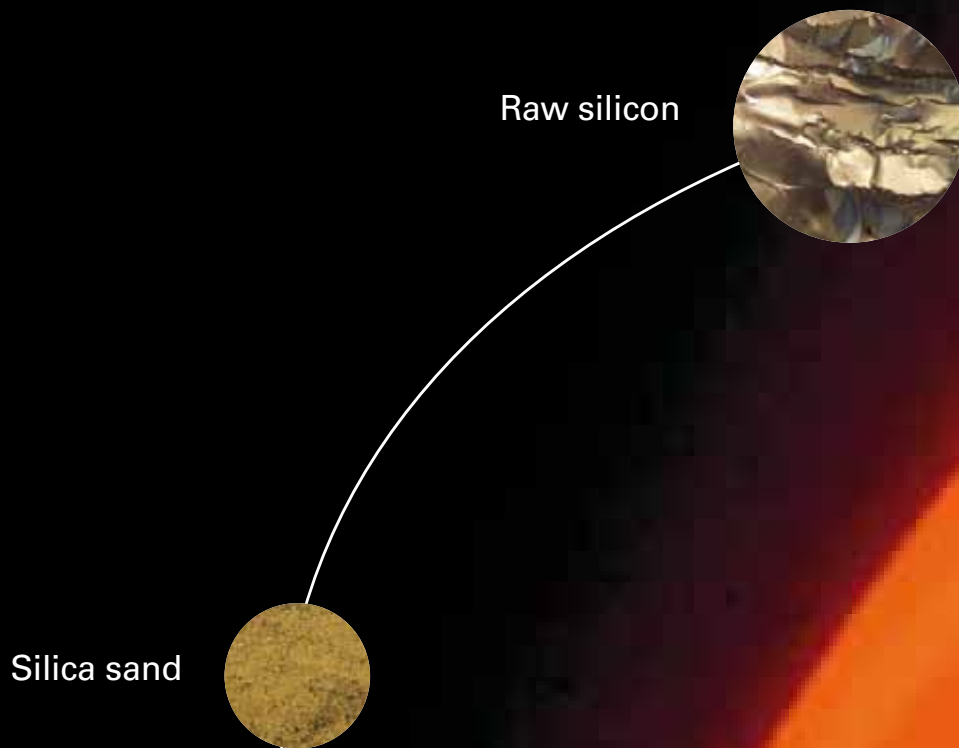
approx. three orders of magnitude to the current level of 100 lm/W (lumens/Watt). These development steps, which usually represented major leaps forward, are based on the ever-increasing quality of semiconductor layers, for instance lower defect densities and fewer impurities in the basic material for LEDs. Development is currently in progress in terms of light sources with a high light yield on the basis of light-emitting diodes that are already replacing other illuminants in many areas where low maintenance, long service life, low energy consumption and vibration resistance are important factors. The leading illuminant manufacturers already offer a wide range of LED-based lighting systems that are currently making a breakthrough.





The long journey

Silicon is not only one of the base elements of our planet, it is also the foundation of the modern information society. Without the development of silicon transistors, modern electronics would have been inconceivable, and this type of transistor is only possible thanks to the outstanding properties and stability of silicon and its oxide.





Pure silicon

View into the crucible with molten silicon

The origin is the sand

To obtain pure silicon, the oxygen must be extracted from silica sand (SiO_2) with the help of carbon. As silicon and oxygen are very closely related atomically, the carbon and oxygen in silica sand only combine to form carbon dioxide at very high temperatures (approx. $1,800^\circ\text{C}$). The carbon dioxide is drained off and silicon is left behind. This process is highly energy-intensive, requiring approx. 14 kWh per kg of raw silicon. Raw silicon extracted in this way still contains approx. 1% impurities. However, a purity level of at least 0.0000001% (1ppb) is required. The raw silicon is therefore still totally unsuitable for computer or photovoltaic purposes. For this reason, using pure hydrochloric acid, it is converted to trichlorosilane, a liquid with a boiling point of approx. 30°C that is distilled in large systems over 30 meters high. The distillate, „fired silicon“, only contains impurities below 1 ppb. The return to solid silicon is achieved via a reaction of trichlorosilane with high-purity hydrogen. To this end, a mixture of the gases is put into contact with hot „thin rods“ of high-purity silicon, on which new silicon precipitates in small, disordered crystals as polysilicon. The rods become increasingly thick. When a diameter of approx. 180mm is reached, the process is ended and the rod is broken into small pieces. The material that keeps the high-tech civilization moving is ready. However, it still lacks internal regularity. Essentially, there are four methods for this.



The CZochralski method

In Czochralski's crystal pulling method, the pure polycrystalline silicon is melted down in a silica crucible. A thin seed crystal with a monocrystalline orientation is dipped into the melt and slowly removed under rotation. The size and physical properties of the crystals are determined by variation of temperature and pulling speed.

Float-Zone method

With zone melting, the polycrystalline pure silicon rod is melted by an induction coil. As the Si rod is moved down through the coil, this causes the melting zone to move through the rod. The silicon rod is moved in a vacuum or in a controlled atmosphere. By dipping a seed crystal with a desired crystal orientation into the melting zone, monocrystalline solidification is attained. Extremely pure crystals for high-performance applications are manufactured using this method.

From silica sand to high-tech products

Wafers

The silicon monocrystals are subjected to mechanical circular grinding and markings for identifying the crystal orientations. The monocrystals are cut into thin discs using diamond or wire saws. To compensate for irregularities, the Si discs are subjected to coplanar grinding with fine-grained grinding discs made of diamond. Surface defects are also etched away by means of plasma in order to obtain a crystallographically perfect surface. The resultant roughening of the wafer is removed by polishing in cleanrooms.

Chips

Computer chips are manufactured photolithographically. Routing layers for the chips must be set up on the wafer. To do this, the entire wafer is metallized with a metal layer. In the next step the wafer is coated with a light-sensitive photoresist and exposed with the image of a photo mask. This mask contains the wiring diagram for a chip many times over. Next, the photoresist is developed and removed from the exposed areas by means of a solvent. The unprotected areas of the metal layer are then removed using a causticizer. A circuit path network in line with the pattern of the photo mask is left over. Several such superposed planes in combination then produce the basic framework of a processor or microchip.

Solar cells

Solar cells can be manufactured from monocrystalline and multicrystalline silicon. In both cases, the silicon is doped with boron when the crystals are produced, in order to generate one of the conductive layers of the solar cell. After manufacture of the wafers, another conductive layer is generated on the surface in a phosphoric atmosphere. These two layers form the p-n junction of the solar cell. The wafer thickness (p-type) is in the region of 300 μm , and that of the phosphor layer (n-type) is 1 μm . The solar cell is now provided with an anti-reflex layer in order to increase the efficiency by means of greater light absorption on the upper surface. Finally, using the film printing method, the front and back side of the solar cell are provided with circuit paths for current tapping.



Edge defined Film-fed Growth method

In a polycrystalline pure silicon molten mass, there is a structural part consisting of graphite with a predefined gap in which liquid silicon arises as a result of the capillary force. From above, a seed film is moved towards the gap and then pulled back upwards. On the back of the seed film, the liquid silicon solidifies to form a multicrystalline film with a wall thickness of less than 0.3 mm.

Vertical Gradient Freeze method

In the VGF method and the Bridgman method, the pure polycrystalline silicon is melted down in a crucible. The slow cooling of the melt, where areas of crystal with regular structure are formed, takes place in the melting crucible. The heating zone (and temperature gradient) is slowly raised upwards so that solidification of the multicrystalline silicon occurs from the crucible bottom, whilst liquid silicon is present at the top of the crucible until the end.

Individual solutions for individual customers





As an SME in the PVA TePla AG Group, our main priority is to offer customers solutions for their complex technological requirements. We see our customers as partners to achieve the following together in future:

- developing and implementing individual solutions
- maintaining close contact from the offer phase through to system commissioning and beyond
- developing procedures and processes as well as implementing process optimizations.

Quality awareness, adherence to deadlines and technical expertise set us apart as one of the world's leading companies in the sector.



„EKZ“ series for the semiconductor and solar industry

The **CZ**ochralski method

With these systems, monocrystalline materials are produced according to the „CZ method“. This is also known as „crystal pulling“ or „pulling from the melt“.

The method

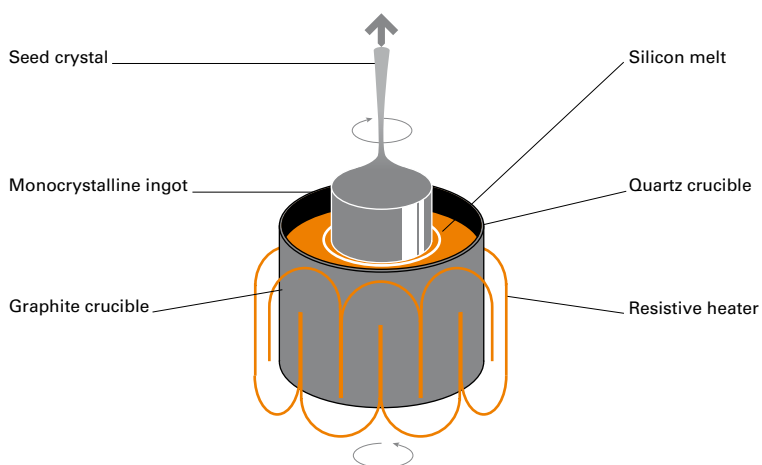
In the CZ process, high-purity, polycrystalline silicon is put into the quartz crucible of a monocrystal growing system. Next, the process room is evacuated and the silicon is then melted down in an argon controlled atmosphere via resistive heating.

After temperature stabilization of the melt (approx. 1420°C), a rotating monocrystalline silicon seed crystal

is dipped into the melt. As a result of a slight temperature decrease, crystallization of silicon material on the seed crystal is now initiated. As the seed crystal is slowly pulled upwards, a cylindrical silicon monocrystal hanging on the seed crystal is then formed.

The pulling speed and the temperature are regulated in such a way that a silicon monocrystal whose orientation and structure corresponds to the seed crystal can be grown with a constant diameter.

Technical implementation of the CZ method



Process steps of the CZ method

1. Fill the crucible with pure silicon
2. Melt down the material
3. Contact the seed crystal with the melt
4. Pull the thin neck
5. Pull the shoulder
6. Pull the body and end cone

The applications

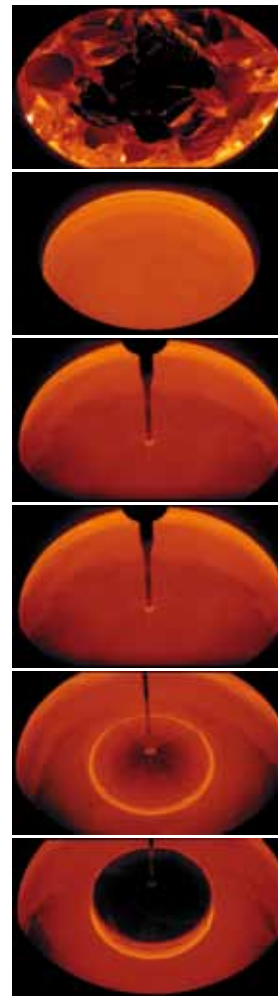
Industrially, silicon monocrystals are predominantly manufactured according to the CZ method and used, for example, in microsystems technology, in the computer industry for integrated circuits and in photovoltaics for production of solar cells. Because of its high level of effectiveness, this method has also become established for monocrystalline solar cells.

Our systems in the EKZ series are specially developed and designed for manufacturing high-purity, monocrystalline silicon crystals for the solar and semiconductor industries.

Other applications of the CZ method: Monocrystals made from

- oxides for numerous applications, primarily in laser and sensor systems
- salts (alkali metal halogenides) for optical crystals
- metals (palladium, platinum, gold, silver)
- germanium for detectors and multi-junction solar cells

Process steps of the CZ method



1. Fill the crucible with pure silicon
2. Melt down the material
3. Contact the seed crystal with the melt
4. Pull the thin neck
5. Pull the shoulder
6. Pull the body and end cone (7)





„MultiCrystallizer“ series for the solar industrie

The **V**ertical **G**radient **F**reeze method

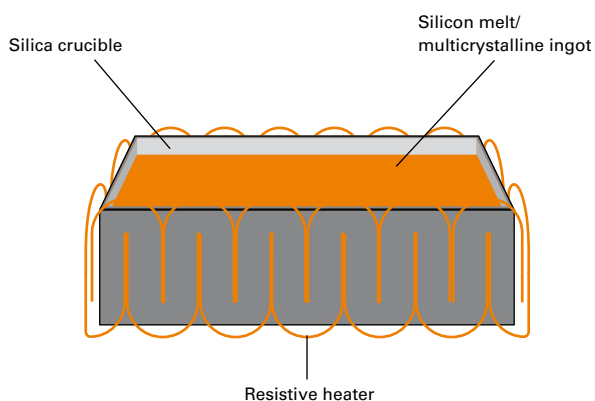
With these systems, multicrystalline materials are produced according to the „VGF method“. This is also known as „directional solidification“ or, in a similar form, the „Bridgman method“.

The method

The polycrystalline pure silicon is melted down in a silica crucible via resistive heating. The slow cooling of the melt, where large areas of crystal with regular structure are formed, takes place in the melting crucible. The heated zone (temperature gradient) is slowly moved upwards so that liquid silicon is present in the top area at the end of the process, whilst solidification into multicrystalline material takes place from the crucible bottom. Crystallization is controlled by the shifting of the temperature gradient.

In the Bridgman process, instead of the temperature gradient, the crucible with the melt is moved through the temperature field. The advantage of the VGF method over the Bridgman process is that no mechanical motion occur during the crystallization process.

Technical implementation of the VGF method



The applications

Multicrystalline silicon is now industrially manufactured in this way and used in photovoltaics for solar cells. The VGF method has particularly become established for multicrystalline solar cells.

Our systems in the „MultiCrystallizer“ series are specially designed for manufacturing this high-purity, multicrystalline silicon for the solar industry.

Process steps of the VGF method

1. Fill the crucible with pure silicon
2. Evacuate the process room and fill it with inert gas
3. Melt down the material
4. Directional solidification of the melt
 - by shifting the temperature field (VGF)
 - by means of the crucible method (Bridgman)
5. Leave the silicon block to cool
6. Remove the silicon block



„Multigeneration“ series for the solar industrie

The **E**dge-defined **F**ilm-fed **G**rowth method

With these systems, multicrystalline silicon is produced according to the „EFG method“. It is also known as the „string-ribbon growing method“.

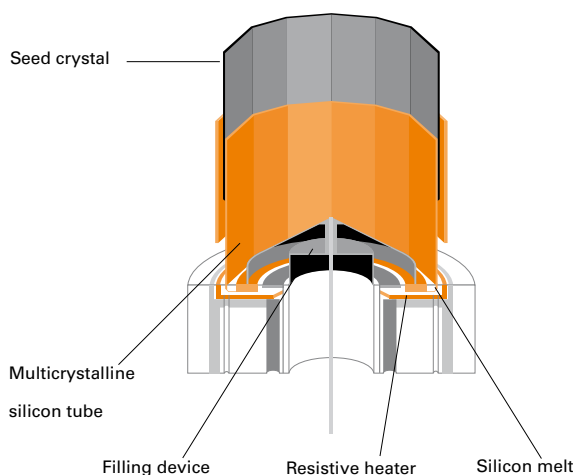
The method

In an electrically heated and continuously refillable graphite crucible silicon is molten. Integrated in the crucible is a die consisting of graphite with a predefined gap in which liquid silicon arises as a result of the capillary force. From above, a seed film is moved towards the gap and is pulled upwards after dipping into the melt. On the back of the seed film, the liquid silicon solidifies to form a multicrystalline layer with a wall thickness of less than 300 μm . A key advantage over the other crystal growing methods is the very high material efficiency, as there are hardly any cutting losses in wafer manufacture.

The applications

To make the most of the process, the graphite gap has the shape of an octagon or dodecagon when viewed from above. The edge length of the individual sides is variable. The pulling length can be up to several meters. A laser then cuts the solar wafers from the surfaces of the polygonal tube.

Technical implementation of the EFG method



Process steps of the EFG method

1. Continuously fill the crucible with pure silicon
2. Melt down the material
3. Dip the die with a defined gap into the melt
 - The silicon rises in the gap as a result of capillary action
4. Move the seed film to the melt in the gap from above
 - Silicon crystallizes on the seed film
5. Slowly remove the film with multicrystalline silicon from the melt
 - A thin-walled silicon tube is obtained (cf. CZ method)
6. Removal of the silicon tube



„HTCVD“ for the semiconductor and optoelectronic industry

The **C**hemical **V**apor **D**eposition method

With these systems, monocrystalline materials are produced according to the „CVD method“. It is also known as „chemical vapor phase deposition“.

The method

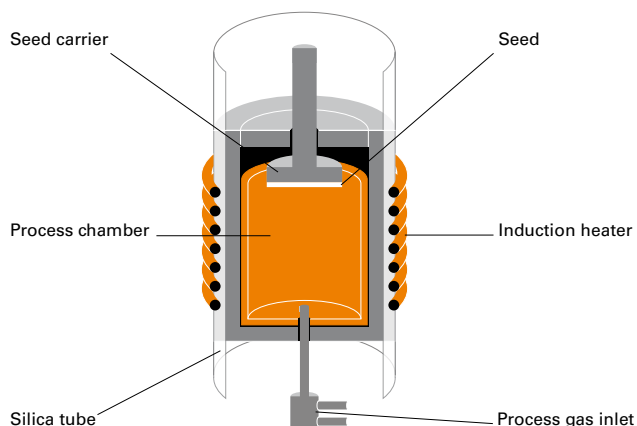
A solid component is deposited on the heated surface of a substrate as a result of a chemical reaction from the gas phase. For this to happen, gaseous compounds of the layer components that lead to growth of a solid layer at a specific reaction temperature must exist. The CVD method of chemical gas phases contains at least one chemical reaction on the surface of the seed to be coated. To favor the surface reaction over competing reactions in the gas phase and thus avoid formation of solid particles, chemical gas phase deposition processes are mostly undertaken under reduced pressure.

The applications

The CVD method enables the manufacturing of silicon carbide crystals. Silicon carbide (SiC) is used for Schottky diodes and blue LEDs, for example. In addition, silicon carbide is also used for electronic components that have to withstand high temperatures or high doses of ionizing radiation. Because of its high thermal conductivity, silicon carbide is also used as a substrate for other semiconductor materials.

Our systems in the HTCVD series are specially developed and designed for production of this high-purity silicon carbide for the semiconductor and optoelectronic industries.

Technical implementation of the CVD method



Process steps of the CVD method

1. Install the seed into the process chamber via a seed holder
2. Evacuate the process room
3. Heat up the process room
4. Let in the process gases and adjust the pressure
 - A solid component from the gas phase is deposited on the surface of the seed
5. Cooling of the crystal and removal



„FZ“ series for the semiconductor industry

The Float Zone method

With these systems, high-purity monocrystalline materials are manufactured according to the „FZ method“. This is also known as the „zone melting method“ or the „float-zone method“.

The method

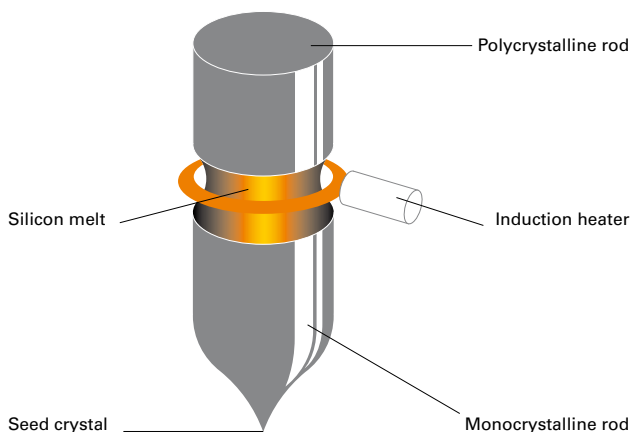
A pre-prepared, cleaned, polycrystalline silicon rod is positioned in a chamber in a controlled atmosphere. By means of a high-frequency induction coil as a heat source, a relatively narrow zone of the material is melted in a contact-free manner at the bottom end. So that the zone melts evenly, the rod is slowly rotated. The melted zone is put in contact with a monocrystalline seed crystal and grows, adopting its crystal structure and orientation. This melting zone is now slowly moved axially through the rod. As the melt cools down again, it solidifies across the entire crystal diameter with a uniform crystal structure so that the desired monocrystal forms behind the melting zone.

Chemical impurities remain to the largest possible extent in the melting zone, and ultimately migrate to the end of the monocrystal rod. If zone melting is repeated several times, the purity level can be increased further. Doping can be attained through the addition of gaseous substances that diffuse into the melt.

The applications

Manufacture of high-purity monocrystalline silicon is possible with this method. FZ Si crystals are used in components in high-performance electronics, Microsystems technology and the semiconductor industry for integrated circuits, for example.

Technical implementation of the FZ method



Process steps of the FZ method

1. Install the polycrystalline rod in the process chamber
2. Evacuate the process room and fill it with inert gas
3. Inductive melting down of the bottom area of the rotating polycrystalline rod
4. Seeding
5. Pull the thin neck
6. Manufacture the shoulder
7. Melt the body
8. Leave the monocrystal to cool then remove it



„Kronos“ series for the semiconductor and optoelectronic industry

The **V**ertical **G**radient **F**reeze (VGF) method

With these systems, low-dislocation crystalline materials are produced according to the „VGF method“. This is also known as „directional solidification“ or, in a similar form, the „Bridgman method“.

The method

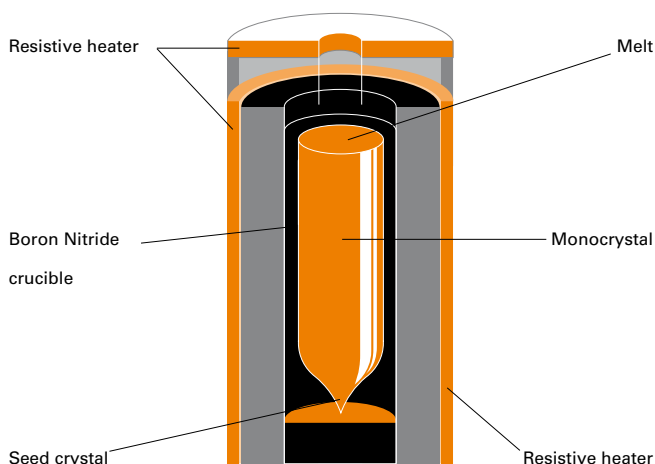
The polycrystalline raw material is melted down in a crucible (ampoule with a seed crystal in the bottom) with the assistance of a resistive heater. The slow cooling of the melt, where large areas of low-dislocation crystals are formed, takes place in the crucible. The heated zone (temperature gradient) is slowly moved upwards so that the melt is present in the top area at the end of the process, whilst solidification into low-dislocation crystalline material takes place from the crucible bottom. The crystallization speed is controlled by the speed of the temperature gradient.

The applications

The industrial growing of low-dislocation crystals such as gallium arsenide (GaAs), indium phosphide (InP) and gallium phosphide (GaP) is possible with this method. These crystals are applied in optoelectronics (LED and laser technology), semiconductor technology, high-frequency technology, solar technology and telecommunication technology.

„Kronos“ is a modular system that was developed and constructed for industrial growing of low-dislocation crystals with high productivity.

Technical implementation of the VGF method



Process steps of the VGF method

1. Fill the crucible with the seed crystal and raw material
2. Evacuate the process room and fill it with inert gas
3. Melt down the material
4. Directional solidification of the melt from the bottom to the top
5. Leave the solidified monocrystal to cool then remove it



„OKZ“ series for research and development

Methods for the crystals of tomorrow

Almost all methods described above can be performed on a smaller scale with this system. With its modular design, this system type is predestined for research and development of high-tech materials.

The method

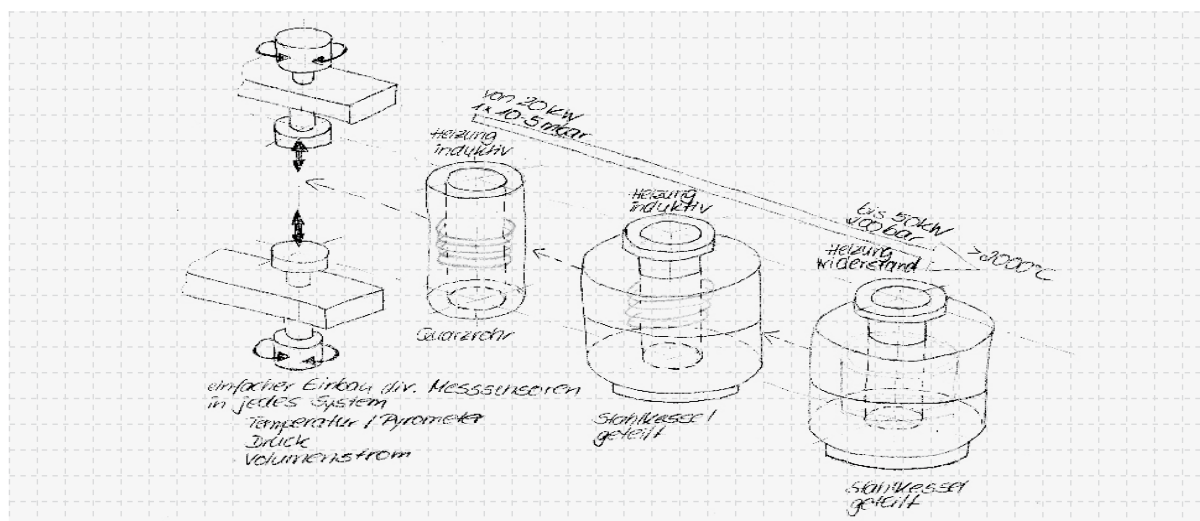
Through exchange of the process chamber, different environmental conditions from vacuum to high overpressure can be achieved. High-frequency induction coils or resistive heaters can be selected as heating units. The entire system is based on a universal rack for supporting the various process chambers. For performing processes like CZ and FZ the system is equipped with crystal and crucible drive units.

The puller is prepared for installations of electrical and optical systems as well as camera systems. A special software package has been developed for the data documentation and evaluation of various process parameters.

The applications

Material research of crystalline materials is particularly important to the semiconductor, solar and optoelectronic industry. In this respect, our systems in the OKZ series are used in research institutes and universities as well as in industry.

The technical concept



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