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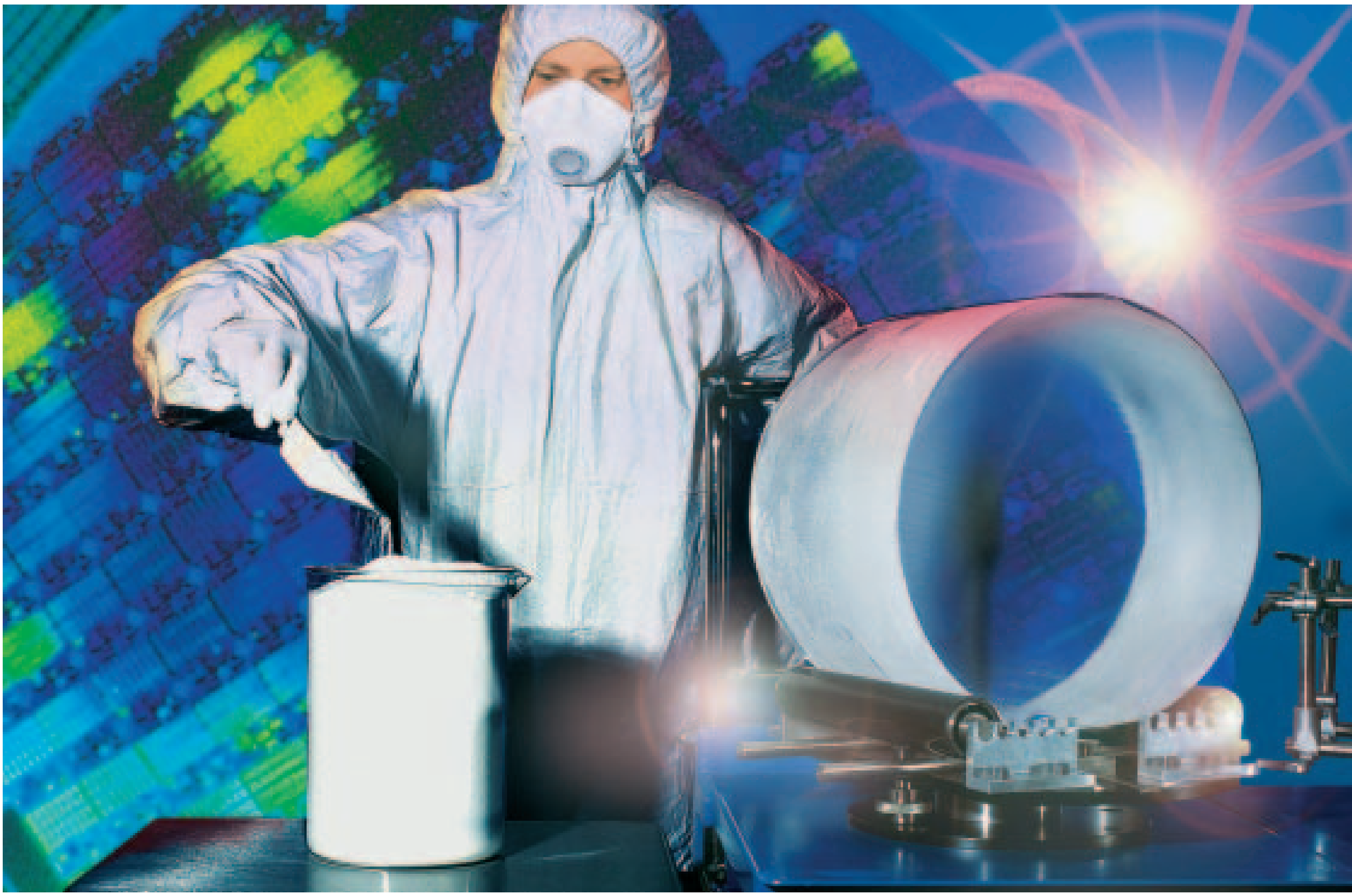
"Jewels" for **Innovations**

In the form of jewels, monocrystals have fascinated people for centuries. New methods of analysis are now making it possible to grow them for demanding applications, for example in microlithography.



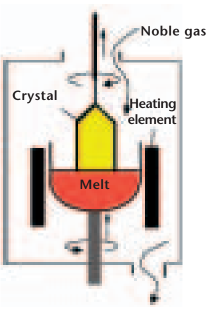
Schott Lithotec manufactures calcium fluoride crystals for use in wafer stepper optics. The Erlangen Crystal Growth Laboratory is developing special furnaces in cooperation with Schott for growing the material.

In addition to their beauty, monocrystals are now of extremely great significance for technical reasons. Many revolutionary new products developed in the past 50 years would not have been possible without monocrystals. They are absolutely essential for a whole range of modern technologies. Monocrystal semiconductors play an important role in microelectronics and information technology. In optics, monocrystals are incorporated, for example, in highly developed optical systems, in the form of windows and lenses. Instruments equipped with laser crystals are facilitating the development of new types of treatment methods in medicine. In modern metrology and materials processing, laser tools have now become standard.

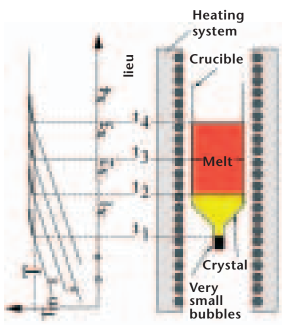
The enormous importance of monocrystals is reflected in the production figures. The world annual production of large monocrystals rose from 5,000 tonnes in 1979 to around 20,000 in 1999.

Growing monocrystals

The great number of materials to be grown and their individual material properties call for a range of different crystal growth processes. Present-day crystal growth technologies are usually based on the phase transition from the liquid to the solid state,



Schematic view of the Czochralski (Cz) method.



Sketch of the furnace temperature profile for various time stages in a Vertical Gradient Freeze (VGF) configuration.

known as melt growth. Only a few materials of industrial importance, such as the semiconductor silicon carbide, are grown from the gas phase.

The fundamental principles of the melt growth technologies for the manufacture of monocrystals were established in the first half of the 20th century. The most important technique for the manufacture of semiconductor and oxide crystals used today is what is known as the Czochralski method. With two other techniques, the Bridgman-Stockbarger and the VGF (Vertical Gradient Freeze) methods, the polycrystalline raw material is melted in a crucible and then directionally solidified from a single-crystalline seed at the bottom of the crucible. In the VGF process this is achieved by lowering the temperature while maintaining a positive temperature gradient in the melt. In the Bridgman-Stockbarger process, on the other hand, the crucible is moved relative to the furnace.

The advantage of these two techniques over the Czochralski method is that the temperature conditions during the melting process can be controlled better. As a result

State-of-the-art:
Crystal growth facility for the manufacture of 300-millimeter diameter silicon monocrystals at Wacker Siltronic AG.

crystals can be grown with lower fault density. The drawback is that the crystals grow in contact with the crucible wall and cannot be observed during growth. That can reduce the crystal production yield.

Defect engineering, a modern solution strategy

Researchers and developers are using what is known as defect engineering to help them grow larger crystals, and at the same time improve their quality in the microscopic or even to the atomistic range. This is achieved by a precisely controlled choice of growing conditions. The formation of defects is, in the majority of cases, coupled directly to the temperature field during growth. The solution strategy, therefore, takes two routes. On the one hand the crystal growth process is carefully analyzed to discover the relationship between the important growth conditions and then to draw up a fault model with this information. On the other hand a process model is needed that places the growth parameters (i.e. those elements of the growth process that can be manipulated directly) in relation to the growth conditions – mainly the temperature field. This is achieved by the combined use of experimental analysis and computer simulation.

Outstanding results

The Erlangen Crystal Growth Laboratory is a worldwide-acknowledged competence center for crystal growth. It has both the necessary experimental infrastructure and also powerful simulation tools to develop and apply innovative methods. Its successes are impressive. The Crystal Growth Laboratory played a crucial role in the development of the VGF process for the industrial production of GaAs and InP monocrystals and has grown crystals of this type with extremely low defect densities.

In cooperation with Schott Lithotec AG the Crystal Growth Laboratory has developed special furnaces for growing calcium fluoride (CaF_2) crystals that are used as lens material for microlithography. Schott Lithotec's production facilities are now the largest in the world. In addition the Crystal Growth Laboratory has developed and built a new prototype furnace with which it will be possible to gain valuable knowledge for growing CaF_2 crystals. ◀

"Jewels" for the semiconductor industry
Overview of the areas of application for monocrystals

Areas of Applications	Estimated share of world production (20,000 t)
Semiconductors	60%
Scintillation	12%
Optics	10%
Acoustic optics	10%
Laser & non-linear crystals	5%
Jewelry & watch industry	3%

Calcium fluoride monocrystals have a high resistance to radiation and a complete absence of compaction (= local change in density) under laser irradiation.

Current crystal growth research topics

Research and development activities are determined by the specific requirements of the particular application. There are, however, common problems for all crystal growth technologies that are waiting for a solution.

- The facilities need to be enlarged so that bigger crystals can be grown and, as a result, productivity and yield increased.
- Crystal defects, which have an adverse effect on the performance and function of the products manufactured from the crystals, must be avoided.
- The formation of certain crystal defects must be controlled to adapt the physical and chemical properties of the crystals to the requirements of the particular applications.
- A high degree of reproducibility must be achieved for all the relevant crystal properties in the micro and macro range.