Increased productivity due to high pull speed

At present, silicon monocrystals are still produced mostly according to the standard Cz-technology. In order to enhance the productivity combined with a reduction of the production costs, the growth configuration was optimized using the commercial program package CGSim [1] for numerical simulation. Two approaches were followed:

I) Optimization of the hotzone without a cooling jacket
II) Optimization of the hotzone including a cooling jacket

Limitation of pull speed in Cz-configuration

The physical rate limiting parameter for the growth of ingots in a Czochralski configuration is the dissipation of the latent heat of fusion of silicon at the interface crystal/melt by heat conduction through the growing ingot.

A model first derived by E. Billig [2] assumes the absence of thermal convection and a radiation from the crystal surface to the environment at zero Kelvin. It shows the inverse diameter square root dependency of the pull rate: \( \nu \propto \frac{1}{\sqrt{d}} \). Several models have also been published which take into account certain boundary conditions. Especially the model of S. N. Rea seems to be realistic.

Numerical simulation

The calculations were performed for 8 inch crystals in a 24 inch hot zone in a SC 24/26 crystal puller of PVA Crystal Growing Systems GmbH. In our development work the CGSim software package from STR [2] was applied.

The standard hot zone was subjected to an extended analysis. The most important evaluation criteria are the deflection of the phase boundary (concavity), the radial temperature distribution on the melt surface and the axial temperature gradients in the center of the crystal and on its surface. The simulation calculations were carried out at a grown crystal length of 500 mm, since from this length no further change of the phase boundary shape is to be expected.

In order to achieve a further increase in the pull speed, an active crystal cooling device has been specifically integrated into the hot zone. This active crystal cooling device is a water-cooled container, often referred to as a cooling jacket, placed between the inner heat shield and the growing crystal. The crystal cooling device configuration was first published by S. N. Rea in 1977 [3].

Different geometries with different surface characteristics of the cooling devices have been tested and are still under investigation.

Crystal growth

Several crystals have been grown in 4 different growth configurations V1 – V4. In growth configuration V1 and V2 no active cooling devices were applied, whereas in the growth configurations V3 and V4 two different cooling devices were tested. All growth configurations and their potential regarding the maximun pull speed are shown in the state diagram.

Economic analysis of the high pull speed

Measures of the productivity of the examined crystal growth configurations in the body phase. The \( \Delta \) data represent savings potentials referred to V1.