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COST EFFECTIVE GROWTH OF SILICON MONO INGOTS BY THE APPLICATION OF ACTIVE CRYSTAL COOLING IN COMBINATION WITH LARGE MELT VOLUMES IN CZ-PULLER

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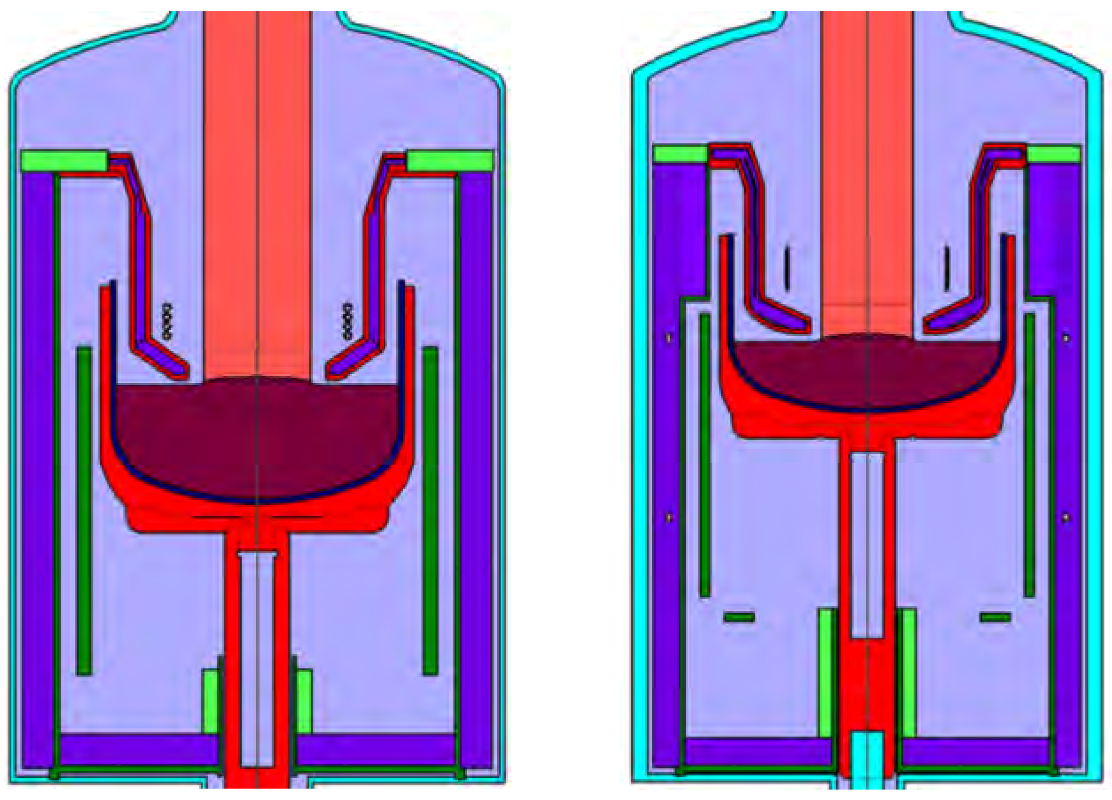
Increased productivity due to high pull speed using ACC in combination with large melt volumes

The combination of active crystal cooling (ACC) with multipulling enables a strong reduction in production costs of silicon crystals. Another way to reduce costs is to use larger melt volumes (primary loadings) to minimize unproductive crystal growing process times (neck, shoulder, cone phase). When increasing the primary loadings, however, the process stability must be taken into account. This raises the question to what extent large melt volumes with the resulting turbulent convection phenomena can be controlled without the use of magnetic fields to dampen the convection phenomena.

Crystal growth equipment



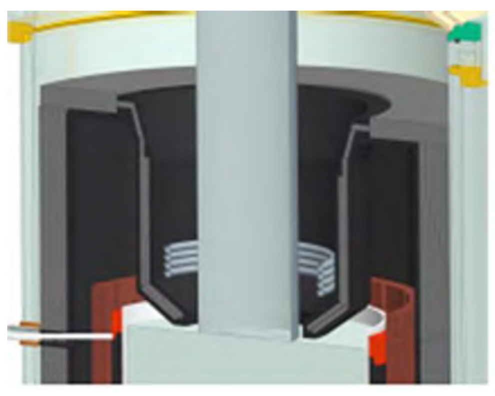
Crystal growth configuration of V1 and V2basic (left) and V2, V3 (right)

Mobile recharge system docked on a Cz-puller

The crystal growth experiments were performed in different hot zones, the most important parameters of which are given in tab.I. All crystals had a diameter of 8 inches. The maximum crucible loading in these experiments was 300 kg in a 26-inch crucible.

growth configuration	Cz-puller type	hotzone	crucible dimension [inch]
V1	SC 22	fig.1 left	22
V2 basic	SC 24	fig.1 left	24
V2	SC 24	fig.1 right	24,26
V3	SC24/26	fig.1 right	26

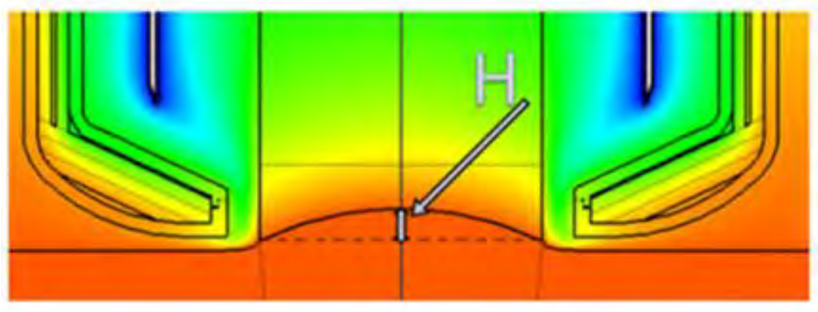
Tab.I: crystal growth configurations



Active crystal cooling device

Crystal growth

Crystals have been grown in the growth configurations V1, V2basic, V2 and V3 in the SC 22 and SC 24/26-puller from PVA Crystal Growing Systems GmbH. In all growth configurations active cooling was applied

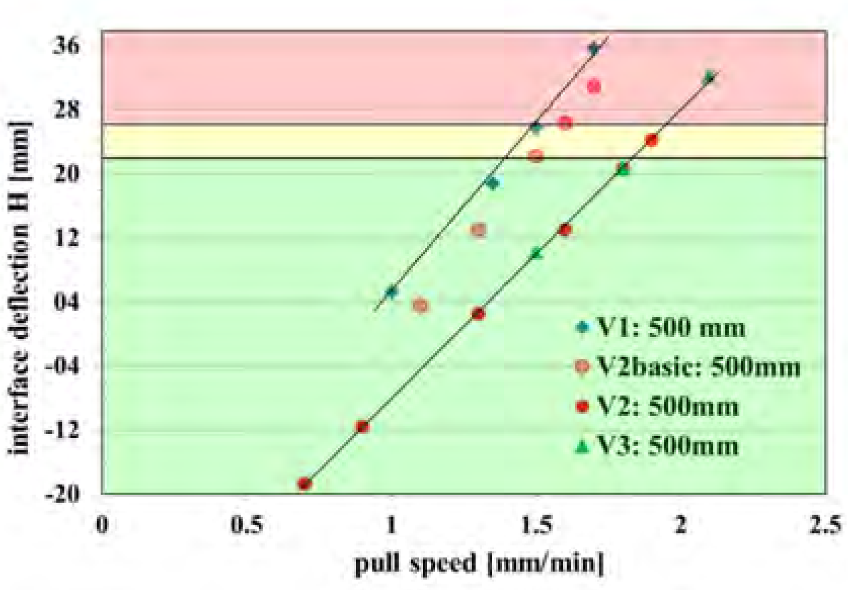


Sketch of the cooling device and the inner heat shield. H indicates the deflection of the phase boundary.

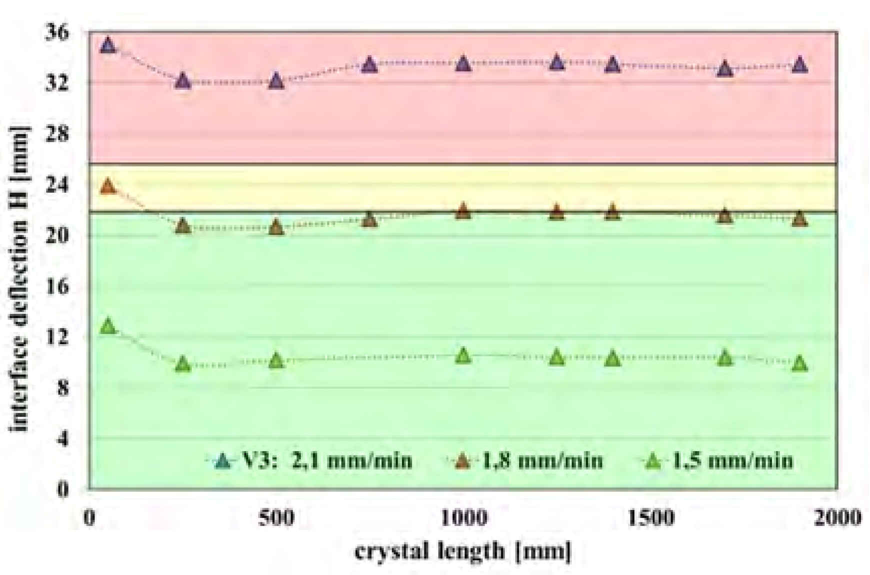
	crystal rotation	crucible rotation	growth rate	bottom heater
V 1	10	-10	1.1 -1.5	no
V 2	10	-6	0.9 -1.8	yes
V 3	10	-6	1.6 -1.8	yes

Main growth parameters in the different growth configurations

Results: interface deflection



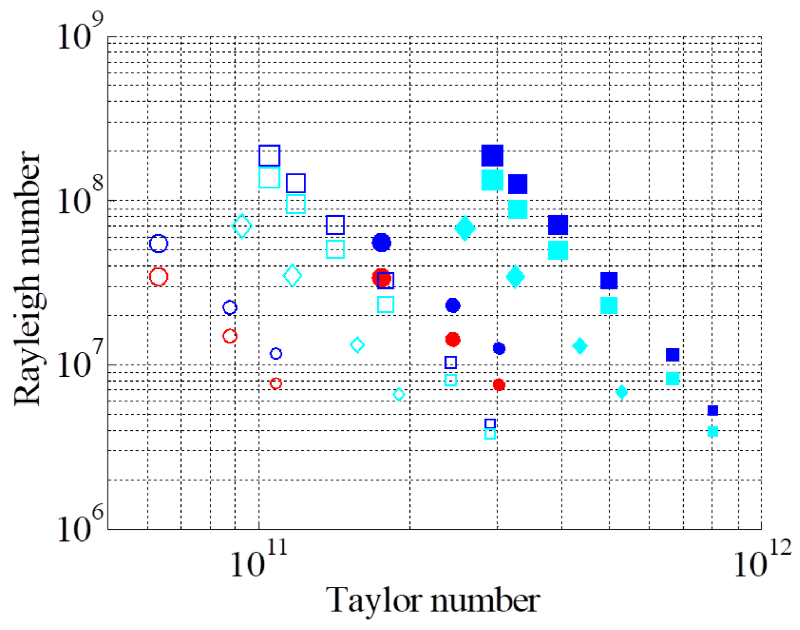
Stability diagram for the different crystal growth configurations



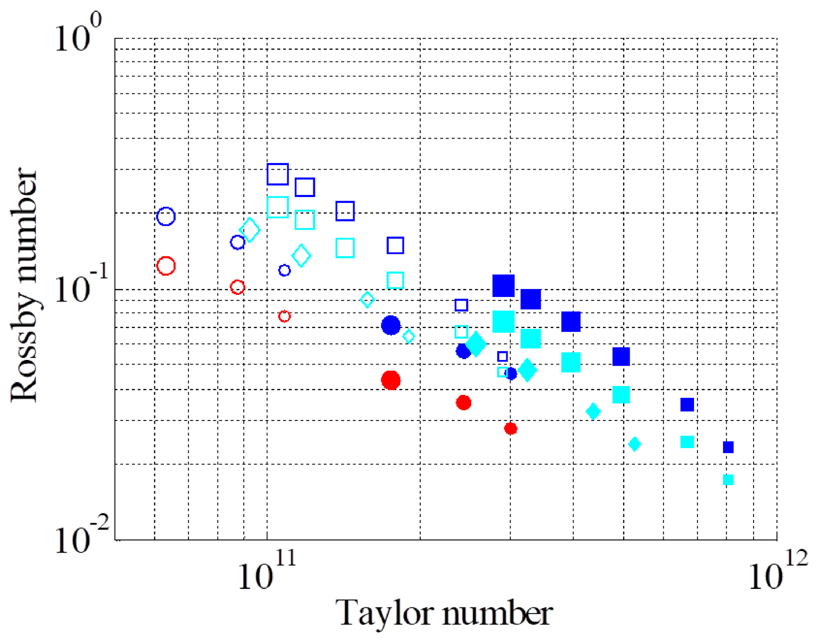
Stability diagram for the different pull speeds in the body phase versus crystal length in V3

The points represent individual results of numerical simulation calculations for the various crystal growth configurations. Green area: stable growth conditions, yellow area: metastable growth conditions, red area: no regular growth conditions

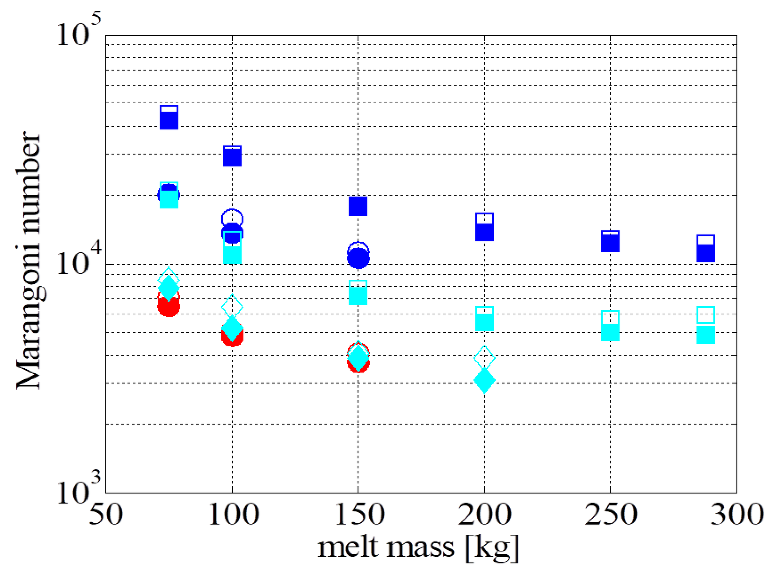
Results: hydrodynamic numbers



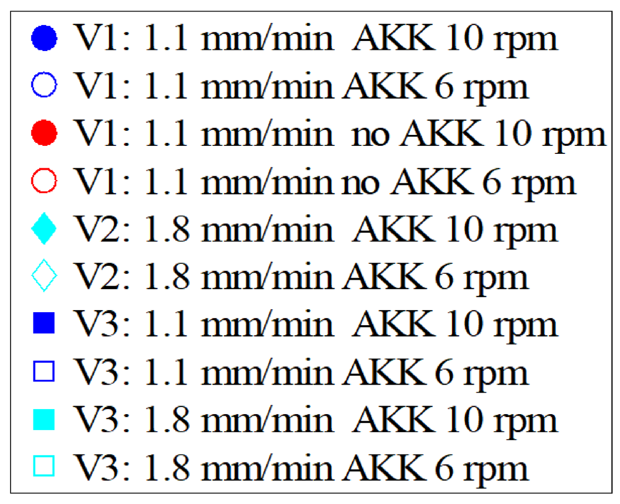
Rayleigh number versus Taylor number in different crystal growth configurations. The size of the symbols corresponds to the melt quantity (75 kg, 100 kg, 150 kg, 200 kg, 250 kg and 300 kg).



Rossby number versus Taylor number in different crystal growth configurations. The size of the symbols corresponds to the melt quantity (75 kg, 100 kg, 150 kg, 200 kg, 250 kg and 300 kg).

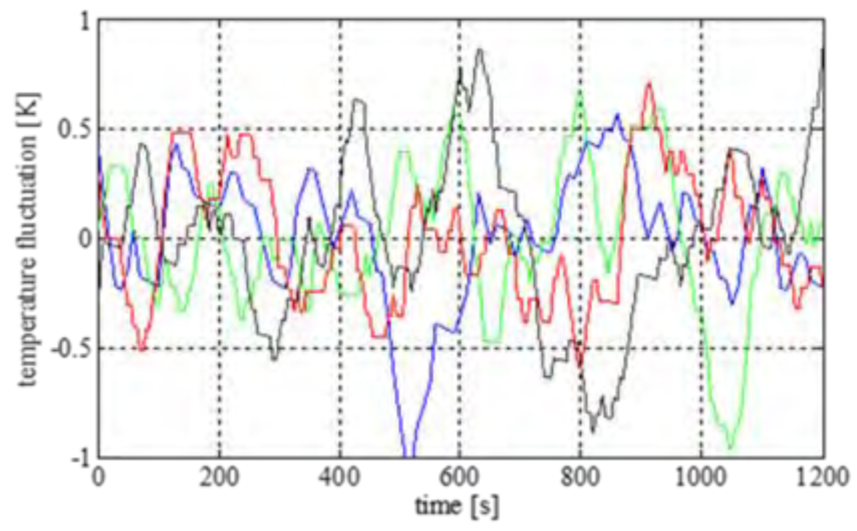


Marangoni number versus melt mass for the different crystal growth arrangements.



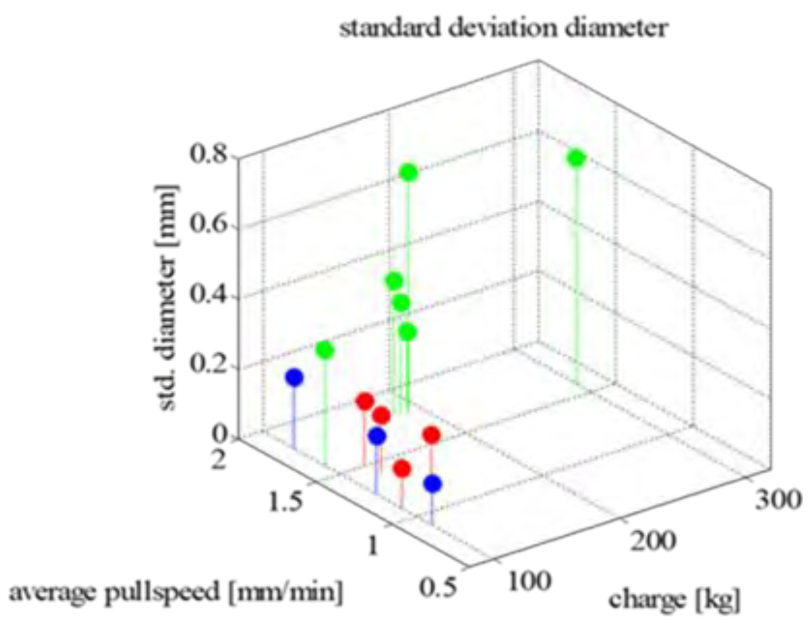
Main growth parameters in the different growth configurations

Results: temperature fluctuations on the melt surface

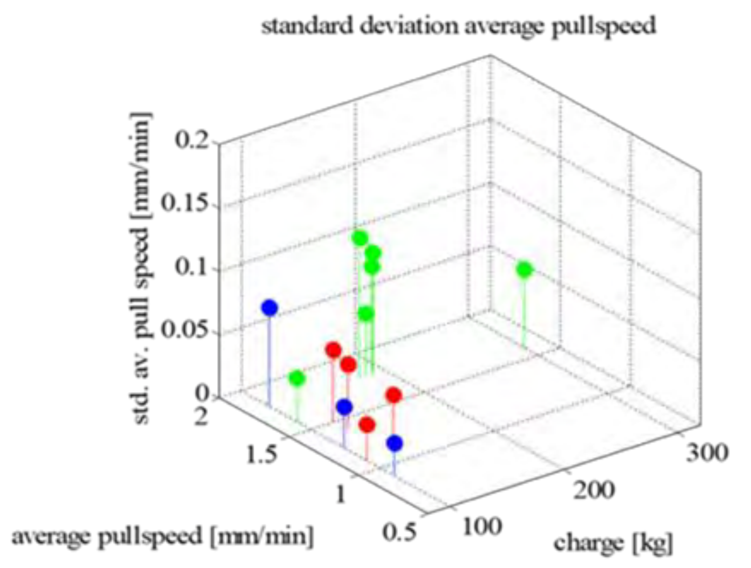


Measured temperature fluctuations on the stabilized melt surface 20 minutes before the start of the neck phase in the different growth configurations: blue line: V1, ACC, 120 kg; green line: V2, ACC, 100 kg; red line: V3, ACC, 185 kg; black line: V3, ACC, 300 kg.

Results: control parameters



Standard deviation of the diameter versus charge quantity and setpoint of the average pull speed for crystal growth experiments in V1 (blue symbols), V2 (red symbols) and V3 (green symbols) growth configurations.



Standard deviation of the average pull speed versus charge quantity and setpoint of the average pull speed for crystal growth experiments in V1 (blue symbols), V2 (red symbols) and V3 (green symbols) growth configurations.

Acknowledgements

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