COST EFFECTIVE GROWTH OF SILICON MONO INGOTS BY THE APPLICATION OF THE MULTIPULLING TECHNIQUE COMBINED WITH ACTIVE CRYSTAL COOLING

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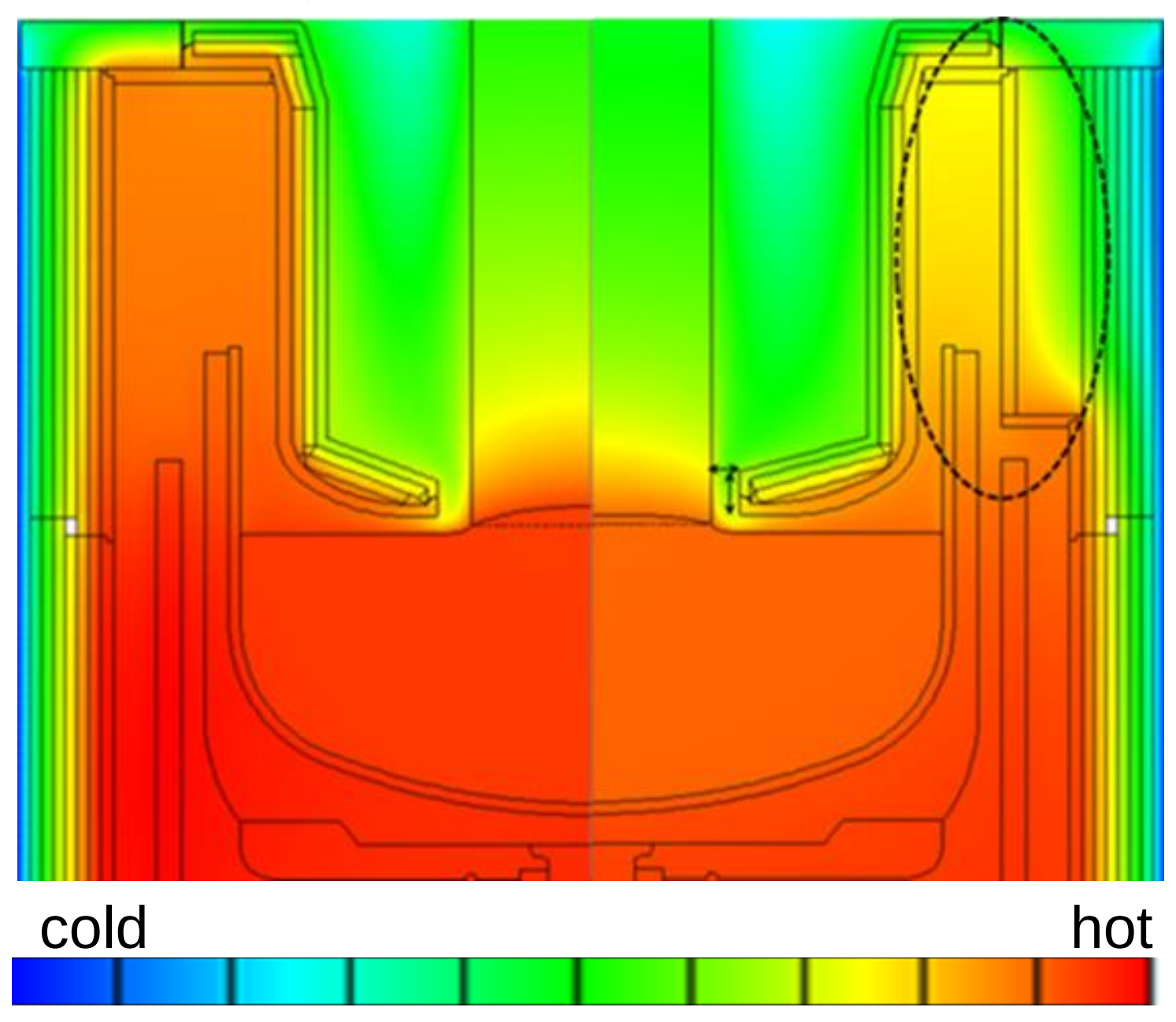
Increased productivity due to high pull speed using ACC

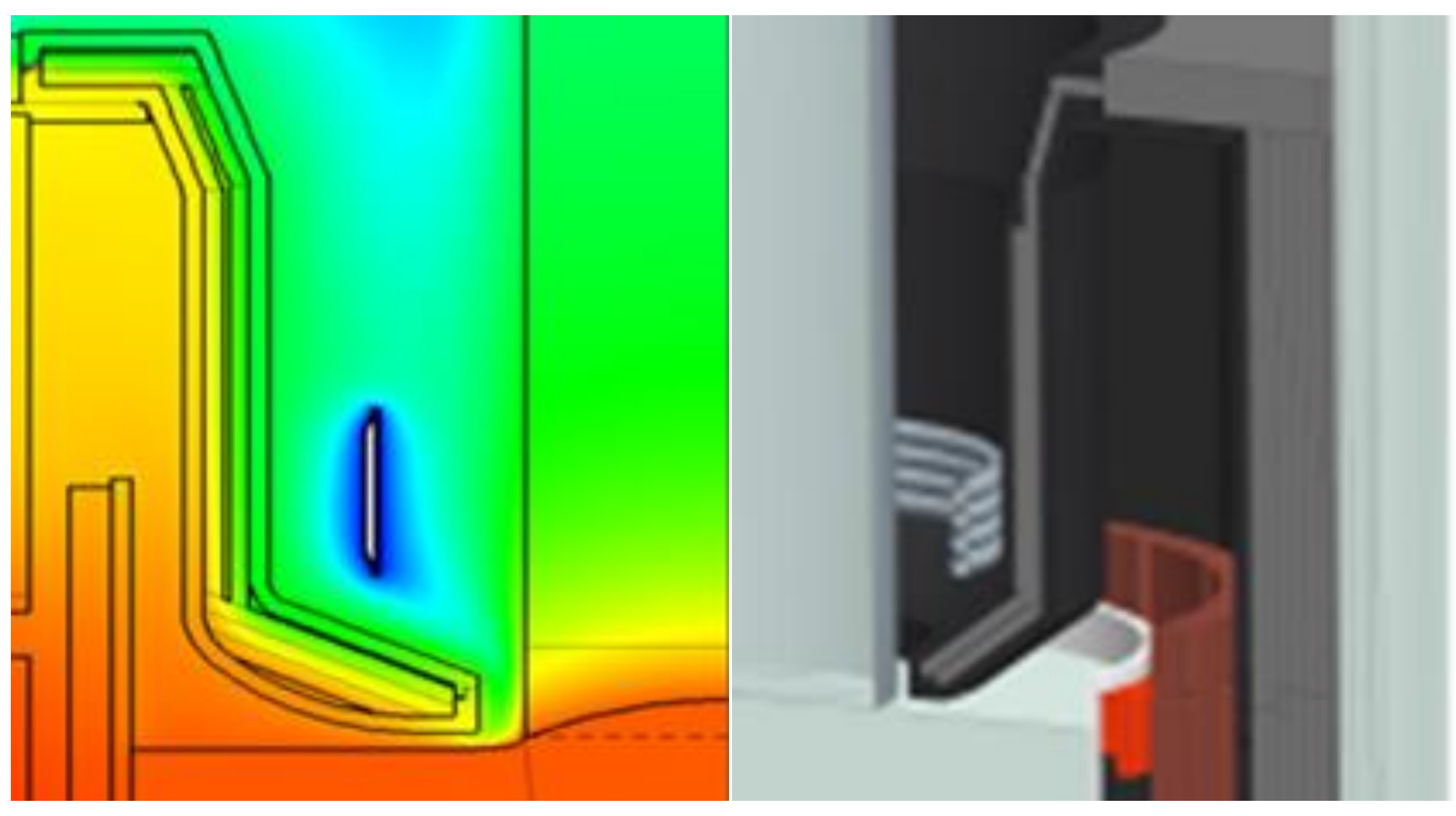
At present, silicon monocrystals are still produced mostly according to the standard Cz-technology. In order to enhance the productivity combined with a reduction of the production costs, the growth configuration was optimized using the commercial program package CGSim [1] for numerical simulation. Two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

I) Optimization of the hotzone without active crystal cooling (ACC) (left hand side of fig. below)

II) Optimization of the hotzone including active crystal cooling (ACC) (right hand side of fig. below)



Geometry and temperature distribution in the standard (left hand side) and optimized (right hand side) hot zone.



Arrangement of the active crystal cooling (ACC)- device in the hot zone.

Multipulling of silicon monocrystals using MRS

In order to reduce the production costs, in particular the crucible costs, and to economize the Cz-process by avoiding unproductive down times during the heat-up and cool-down cycles, multiple batch recharging is a favorable track. This multiple batch recharging is also called "multipulling Czochralski" (MPCz) and is defined as the growing of several ingots out of one crucible with melt replenishment after each growth process. In this case the MRS (Mobile Recharge System) from PVA Crystal Growing Systems GmbH was used, which can serve several pullers time delayed.

Mobile Recharge System (MRS) from PVA Crystal Growing Systems GmbH

Crystal growth

Crystals have been grown in the growth configurations V1, V2 and V5 in the SC24/26-puller from PVA Crystal Growing Systems GmbH. In growth configuration V1 and V2 no active cooling device was applied, whereas in the growth configuration V5 the optimized hotzone design and the Active Crystal Cooling device were applied.

growth configuration	hotzone	active crystal cooling	mean pull speed in body phase [mm/min]	measured deflection of interface in crystal center [mm]
V1	standard	no	0.9	13
V2	optimized	no	1.3	22
V5	optimized	yes	1.8	20

Growth configurations with main parameters

References

[1] CGSim package, STR Group,Ltd.
[2] F. Mosel et al., Proceedings 32nd EUPVEC, 1064-1068
[3] F. Mosel et al., Proceedings 33rd EUPVEC, 495-500
[4] M. Herms, M. Wagner, Phys. Status Solidi C **12**, No.8, 1085-1089 (2015)

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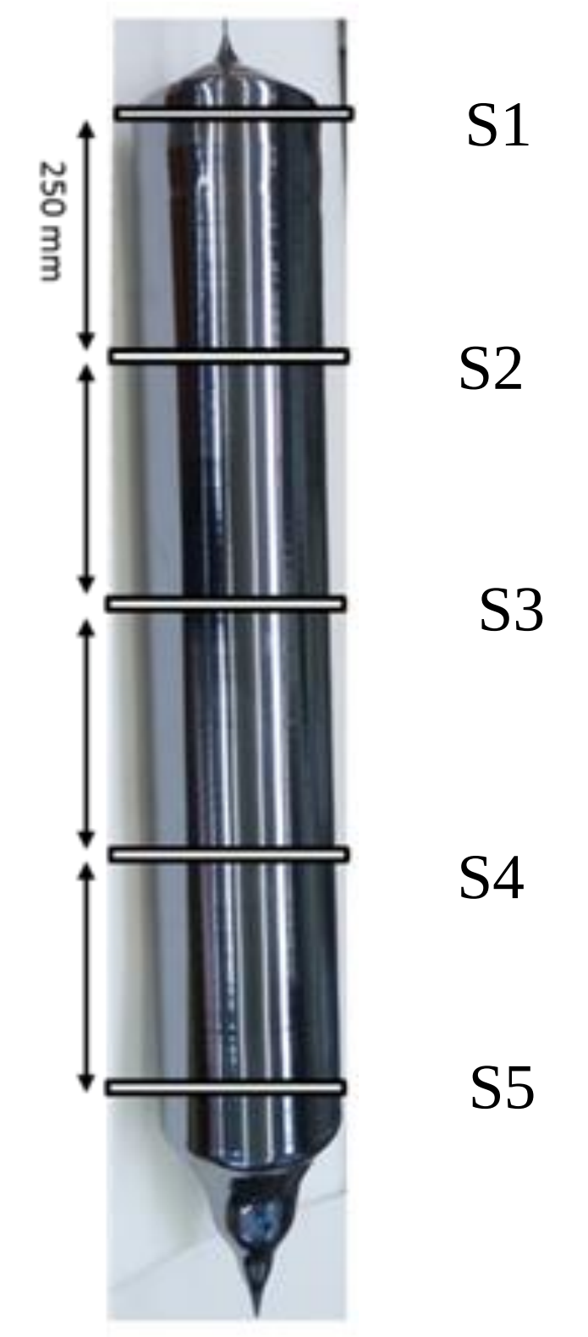
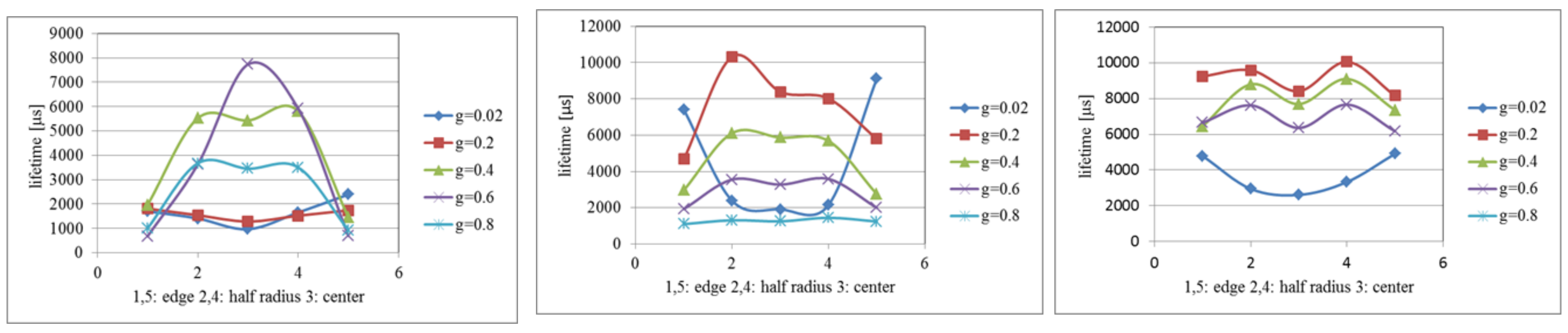
Crystal characterization

All crystals are n-type by phosphorus doping revealing a resistivity in the range of 3-1 Ωcm. The minority carrier lifetime measurements on the crystal slices were performed with a Sinton BCT-400 / BLS-I (photoconductivity measurement) using the transient measuring method. The lifetime values were determined at a minority carrier density of 5×10^{14} cm^{-3}. The interstitial oxygen and substituted carbon concentrations were measured by means of FTIR. The conversion factor is 3.14×10^{17} cm^{-2} for O_I and $1.0 \times 10^{17} cm^{-2}$ for C_S. Measurements were taken 7 mm from the edge, at half radius and in the center. The samples are designated 1 to 5 from top to tail. The results for the O_I-concentrations are summarized in the table below. In 95% of all samples the C_S-concentrations were below detection limit (<10^{16} cm^{-3}). The samples were also evaluated by means of Scanning Infrared Stress Depolarization (SIRD). For this characterisation technique we applied the SIRD system from PVA Metrology & Plasma Solutions GmbH [4].

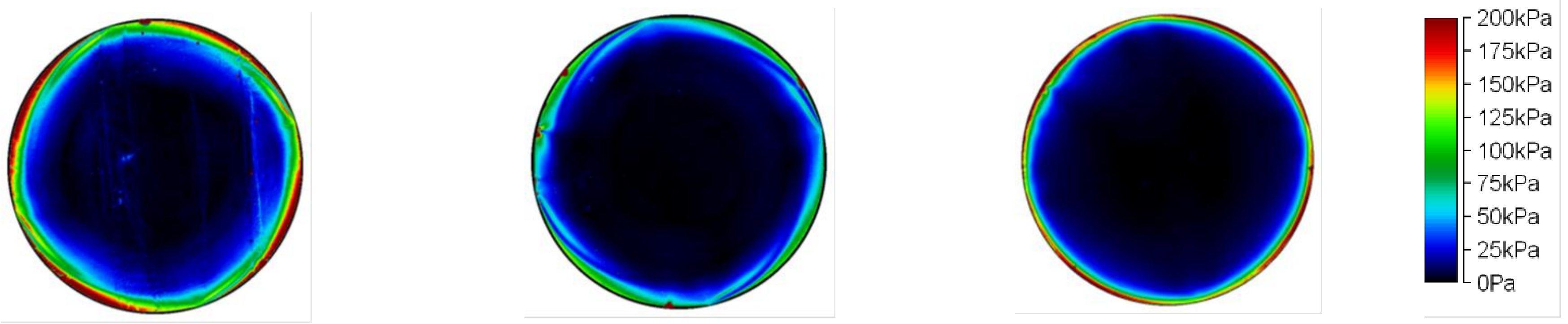
config. V1	sample 1	sample 2	sample 3	sample 4	sample 5	
center	10.8	9.1	8.2	7.5	6.5	x 10^{17} cm^{-3}
half radius	10.4	8.9	8.1	7.7	6.4	x 10^{17} cm^{-3}
edge	6.3	5.7	4.6	5.6	5.8	x 10^{17} cm^{-3}
config. V2	sample 1	sample 2	sample 3	sample 4	sample 5	
center	9.5	6.6	5.8	4.6	4.7	x 10^{17} cm^{-3}
half radius	9.2	6.6	5.6	4.0	4.3	x 10^{17} cm^{-3}
edge	3.6	3.2	2.3	1.6	3.6	x 10^{17} cm^{-3}
config. V5	sample 1	sample 2	sample 3	sample 4	sample 5	
center	9.8	6.9	6.7	7.8	9.3	x 10^{17} cm^{-3}
half radius	9.6	6.4	6.1	7.5	9.0	x 10^{17} cm^{-3}
edge	7.6	5.2	3.7	7.7	6.4	x 10^{17} cm^{-3}



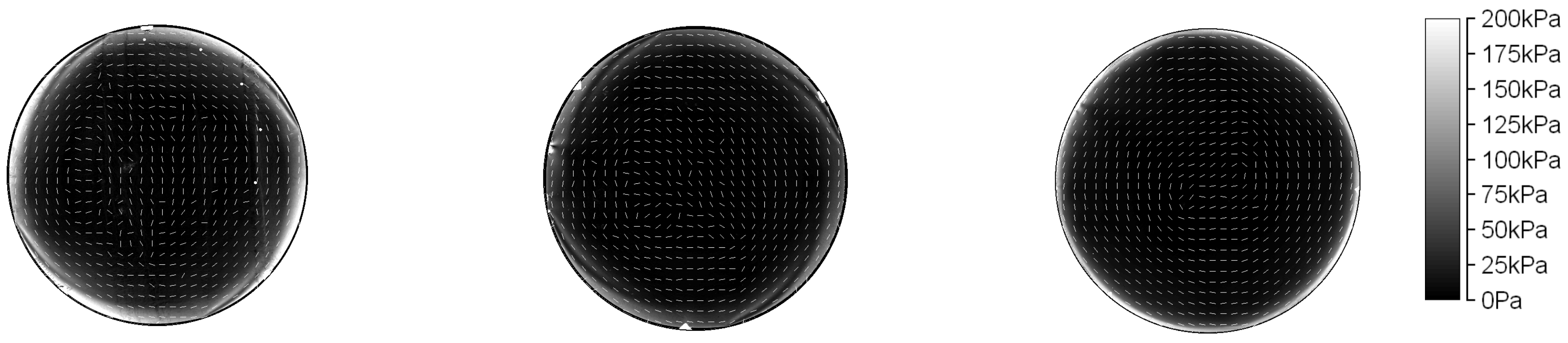
O_I-concentration in the crystals grown in configurations V1, V2, V5. The C_S-concentration in 95% of all samples were below detection limit (<10^{16} cm^{-3})



Minority carrier lifetime [µs] measured on the samples grown in crystal growth configurations V1, V2, V5.



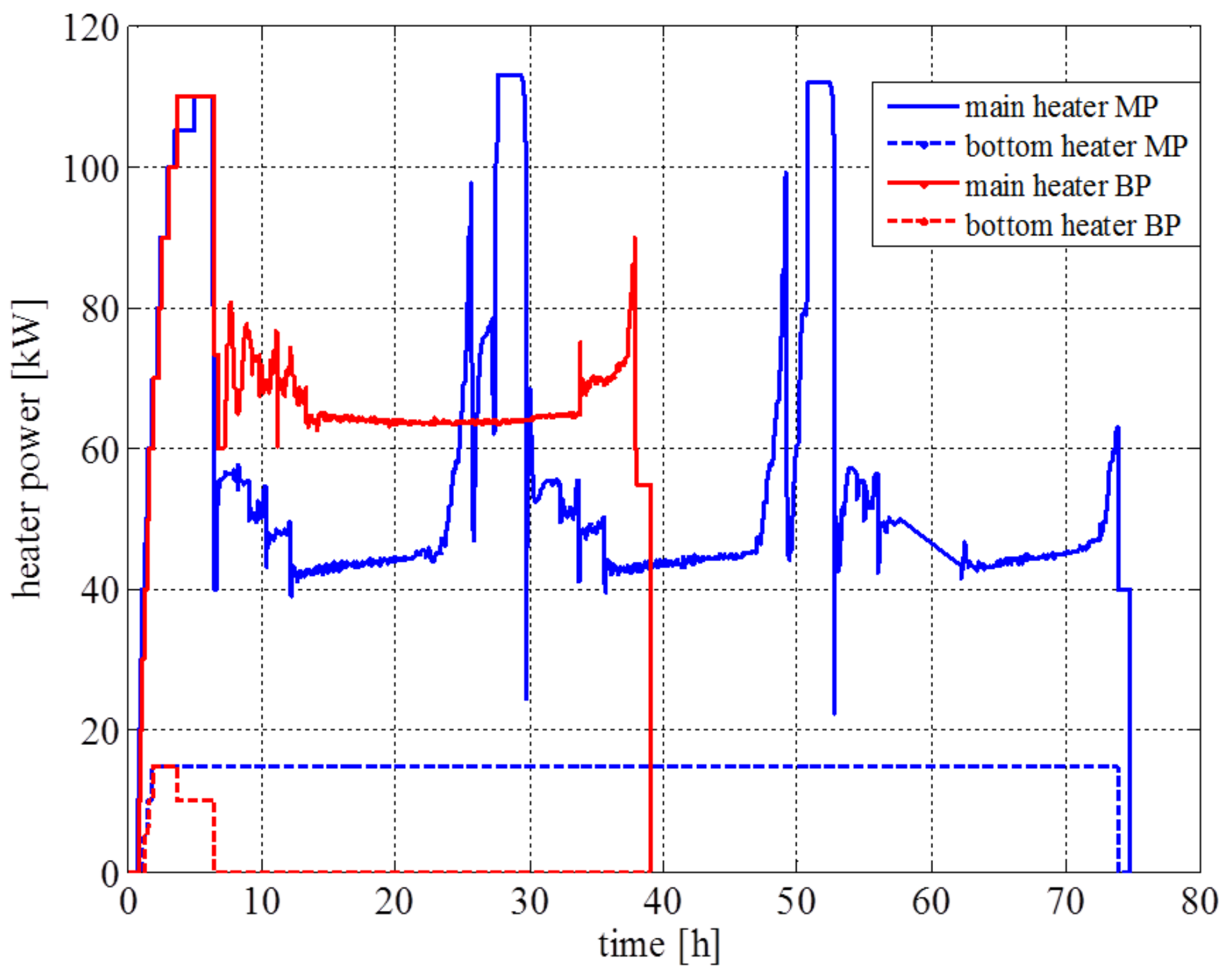
Shear stress maximum in the samples cut from the middle of the crystals grown in configurations V1, V2, V5



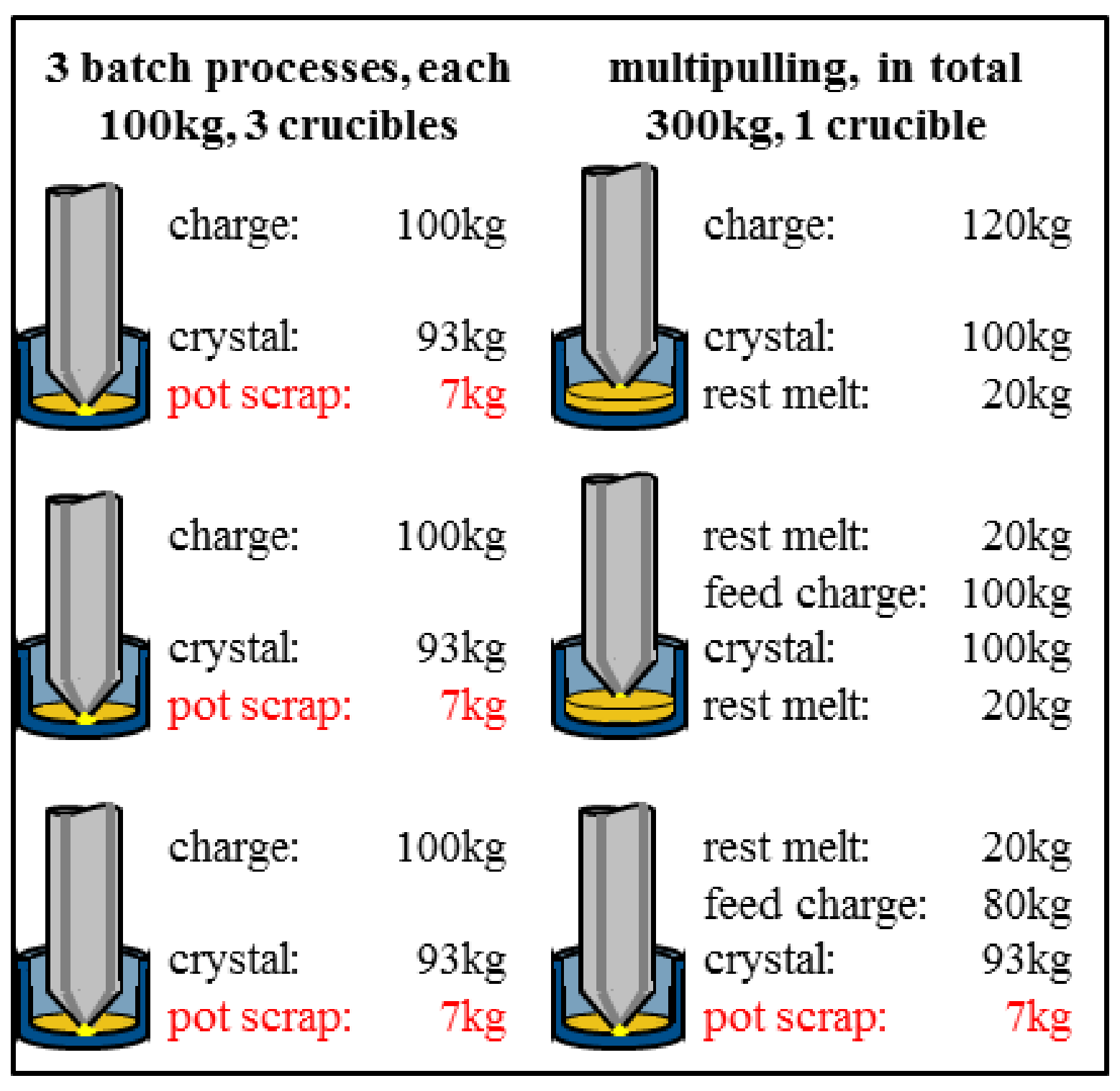
The white lines are the isostats, showing the direction of the greater principal stress

The examined samples show practically no differences between each other and are stress-free except for the outer edge area. Along the circumference, the samples show slight tensile stresses and in radial direction slight compressive stresses.

Economic analysis of the combination of the multipulling technique and the active crystal cooling



Power consumption of the main heater and the bottom heater versus process time for standard Cz (red curve) and multipulling process combined with ACC (blue curve).



Material consumption of a batch process compared to multipulling

growth config.	mean pull speed [mm/min]	Δ time body phase [%]	Δ energy [%]
V1	0.9	0	0
V2	1.3	29	32
V5	1.8	49	53

Measures of the productivity of the examined crystal growth configurations in the body phase. The Δ-data represent savings potentials referred to V1.