GROWTH OF HIGH QUALITY SILICON MONO INGOTS BY THE APPLICATION OF A MAGNETIC CUSP FIELD IN CZ - PULLER

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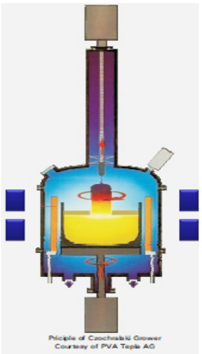
Magnetic Czochralski Method (MCZ)

The primary effect of a magnetic field on a moving electrically conductive melt is to damp natural convection in the melt, especially to avoid turbulence in large melt volumes. The cusp magnetic field configuration is generated by two separated solenoid coils which produce opposite fields.

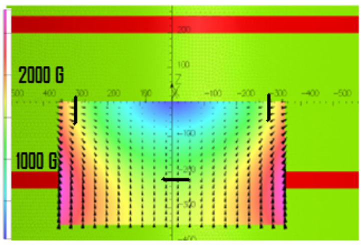


Magnetic CUSP field arrangement In CZ- puller

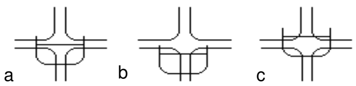
EKZ 3500 with superconducting CUSP magnet

Crystal after growth run in the gate

A Czochralski puller EKZ 3500 from PVA Tepla AG was equipped with a cryogen-free superconducting CUSP magnet system from Bruker ASC. The magnet system is integrated in the process control system of the puller.



Magnetic field pattern in the lower half plane of the symmetric CUSP – field for an induction current of 135 A. The lines indicate the border of the crucible with a magnetic induction of 1500 G at the bottom and 1300 G at the melt surface at the crucible rim.



CUSP plane configurations relative to the melt level: a) CUSP plane on melt level, b) CUSP plane in the growing crystal, c) CUSP plane in the melt

Crystal growth experiments

	field configuration		rotational conditions	
Ingot	current [A]	CUSP-plane	crucible	crystal
MCZ 1	0	ml	10	-10
MCZ 7	0	ml	10	-10
MCZ 2	135	ml	10	-10
MCZ 8	135	ml	10	-10
MCZ 3	135	ml - mh/3	10	-10
MCZ 4	135	ml + mh/6	10	-10
MCZ 6	80	ml	5	-10
MCZ 5	135	ml	5	-10
MCZ 9	135	ml	2	-10
MCZ V	100	ml	10	-10

The magnetic field configuration is characterized by the induction current [A], which is identical in both coils. The position of the CUSP plane: "ml" means CUSP plane on melt level, "ml – mh/3" means CUSP plane 1/3 of the initial melt height below melt level, "ml + mh/6" means CUSP plane 1/6 of the initial melt height above melt level.

Results

Raw wafer analysis

The crystallized ingots were wafered in a standard production environment. The specific resistivity was measured by the eddy current method. The defect characteristics were revealed by MWPCD lifetime measurements and photo-luminescence imaging on as cut wafers and on finished solar cells. The interstitial oxygen and substitutional carbon content were determined by means of FTIR spectroscopy.

References

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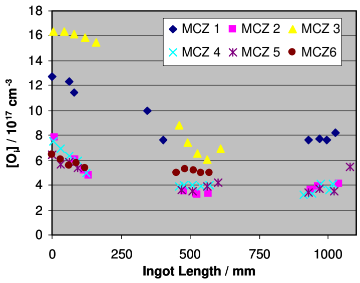
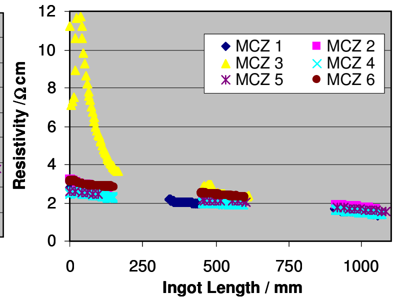
Wafer results: oxygen distribution, resistivity distribution



Variation of the interstitial oxygen content Oi along the axis of the ingots. For the initial part of MCZ 3 the O_i-content is increased in comparison to the reference ingot (MCZ 1) grown without field .



Variation of the wafer resistivity along the axis of the ingots. The high resistivity of MCZ 3 in the first part results from a large number of thermal donors.

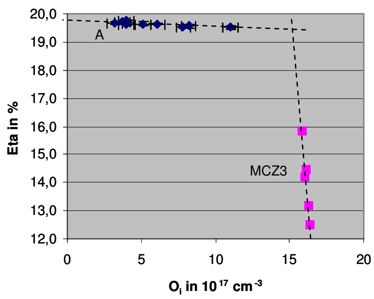
With the exception of MCZ 3 the specific resistivity of all crystals is in the scheduled range of 3 to 1 Ωcm. The large deviation of the resistivity of MCZ 3 from the target value is attributed to the presence of thermal donors due to a high concentration of interstitial oxygen [O_i].

The oxygen concentrations segregated in the crystals depend on the position of the CUSP field relative to the melt surface and the field strength.

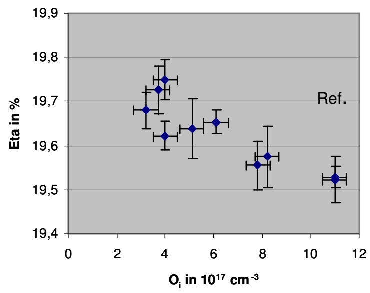
A CUSP plane below the melt surface effectuates an increased oxygen incorporation in the crystal, whereas a CUSP plane at or slightly above the melt surface leads to reduction of the oxygen content in the crystal.

Solar cell results

All cells (PERC) presented here were processed in the same run. An increase of conversion efficiency up to 0,2 …0,3 % absolute to reference cells was achieved.



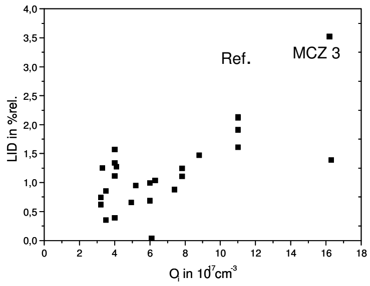
Variation of the PERC Eta versus oxygen content. The low efficiencies of MCZ 3 result from the high oxygen content in the crystal causing precipitations



Enlarged section of A: the points named Ref. are standard material grown without magnetic field application

Light induced degradation (LID)

The finished cells were tested for light induced degradation (LID). In this procedure the cells were exposed to a light intensity of 400 W/m² for a duration of up to 140 h at an elevated temperature of 55°C.



Rel. LID of PERC-Cells as a function of the oxygen content. The reference material grown without magnetic field application and the cells from the high efficiency region of MCZ 3 are explicitly marked.

Conclusions

The amount of oxygen distributed in the crystals depends mainly on the position of the CUSP field relative to the melt and the strength of the magnetic field. A reduction of the oxygen content about the half is shown resulting in a higher cell efficiency and a lower LID by a factor of 2 - 3.

A further decrease of the oxygen content by the application of higher magnetic induction during the crystal growth seems to be possible.

Additionally the CUSP field has a positive impact on production yield. An increase of the pulling speed of 15% is achieved.

It can be anticipated that future types of solar cells with efficiencies beyond 20% will be even more sensitive to lifetime affecting defects. Therefore the need for silicon with low oxygen content will increase even further. MCZ offers a unique solution to this task.