Behavior of particle depots in molten silicon during float-zone growth in strong static magnetic fields

T. Jauß1, A. Cröll1, T. Sorgenfrei1, M. Azizi2, C. Reimann2, J. Friedrich2, M. Volz3

1Kristalllographie, Institut für Geo- und Umweltwissenschaften, Albert-Ludwigs-Universität, Hermann-Herder-Straße 5, 79104 Freiburg
2Fraunhofer IISB, Schottkystraße 10, 91058 Erlangen
3 NASA Marshall Space Flight Center, Huntsville, Alabama, USA

Introduction:
Solar cells made from directionally solidified silicon cover 57% of the photovoltaic industry’s market [1]. One major issue during directional solidification of silicon is the precipitation of foreign phase particles. These particles, mainly SiC and SiN4, are precipitated from the dissolved crucible coating, which is made of silicon nitride, and the dissolution of carbon monoxide from the furnace atmosphere. Due to their hardness and size of several hundred micrometers, those particles can lead to severe problems during the wire sawing process for wafering the ingots. Additionally, SiC particles can act as a shunt, short-circuiting the solar cell. Even if the particles are too small to disturb the wafering process, they can lead to a grit structure of silicon micro-grains and serve as sources for dislocations. All of this lowers the yield of solar cells and reduces the performance of cells and modules. We studied the behaviour of SiC particle depots during float-zone growth under an oxide skin, and strong static magnetic fields. For high field strengths of 3T and above and an oxide layer on the sample surface, convection is sufficiently suppressed to create a diffusive-like regime, with strongly dampened buoyancy convection.

Experimental:
Mirror furnace in superconducting magnet:
- Translation: -2mm/min (120s)
- Rotation rate 8rpm
- Rods with oxide layer to suppress Marangoni convection
- 3 Silicon rods [111] @ 0T, 3T, and 5T
- 3 Silicon rods [100] @ 0T, 3T, and 5T
- Rods with oxide layer to suppress Marangoni convection
- SiC particle depot mix of: - 4mg 7µm dia.
- 2mg 60µm dia.

Samples:
- Rotation rate 8rpm
- 10mm/min (40s)
- Translation: -2mm/min (120s)

Results:
[100] Orientation

0 T

A: DIC micrograph of Si sample grown at 0T field strength
B: IR transmission micrograph
C: Growth velocity from striation evaluation

3 T

A: DIC micrograph of Si sample grown at 3T field strength
B: IR transmission micrograph
C: Growth velocity from striation evaluation

5 T

A: DIC micrograph of Si sample grown at 5T field strength
B: IR transmission micrograph
C: Growth velocity from striation evaluation

[111] Orientation

0 T

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A: DIC micrograph of Si sample grown at 3T field strength
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5 T

A: DIC micrograph of Si sample grown at 5T field strength
B: IR transmission micrograph
C: Growth velocity from striation evaluation

Strong variations in growth velocity are due to heating power variations. Intervention was necessary since flogging of the ampoule influenced the zone height.

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References:

Conclusions:
- Buoyancy convection seems to have no significant effect on depot incorporation
- Crystal orientation seems to have no significant effect on depot incorporation
- Depots of 7µm particles get incorporated with growth rates higher than 5 mm/min
- Depots/parts of depots of 60µm particles get incorporated at first lower phase boundary

References: