The Software for
Bulk Crystal Growth Simulation

Center for Systems Engineering
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GLOBAL MODELING OF CZOCHRALSKI SILICON GROWTH UNDER THE EFFECT OF A TRANSVERSE MAGNETIC FIELD BY MEANS OF THE SIMPLIFIED FLET METHOD

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In Czochralski (Cz) silicon (Si) growth, crystal quality strongly depends on the melt flow pattern, which has major influence on the solid-liquid interface shape and deeply affects defect formation and oxygen incorporation into the crystal. However, melt convection generally exhibits complex instabilities associated with buoyancy, surface tension, and rotational forces, and becomes more and more turbulent in large crucibles. Therefore, vertical, configured and transverse rigid magnetic fields are frequently used in order to damp out the flow oscillations and improve the growth technique.

Flows with magnetic fields often exhibit complex structures, with thin Hartman boundary and/or internal layers and clearly separated cells. In particular, in Si Cz growth, the transport of oxygen to the crystal is strongly affected by the flow pattern, whose design must be such that most of the oxygen released from the crucible wall either evaporates at the melt-atmosphere interface or remains trapped in internal cells. To this end, configured fields are developing, but knowledge is missing concerning their optimal design, while transverse fields represent a satisfactory solution, but exhibit some drawbacks resulting from process axisymmetry loss and the associated crystal quality problems.

The model used by the FEMAG simulation software is axisymmetric, global and dynamic. Diffuse surface radiation is considered. Laminar and non-laminar flow models are available, without or with considering the effect of rigid or rotating magnetic fields. A new FEMAG generation was further developed in order to provide a fully automatic simulator able to predict the entire growth process, from seeding to tail-end and post-growth cooling stages. On this basis, the objective of the present work has been to extend FEMAG global and dynamic capabilities to Si Cz growth under the effect of a transverse magnetic field.

To this end, the simplified FLET method ("Fourier Limited Expansion Technique") was developed by using a limited Fourier development of the velocity, temperature, pressure, and electric potential fields in the melt as a function of the azimuthal coordinate, the ultimate goal being to couple non-axisymmetric flow calculations with axisymmetric global time-dependent simulations. To validate the FLET method and to determine the lowest number of Fourier modes providing sufficient accuracy, simulations performed by means of this method have been compared with fully 3D flow simulations using the FEMFLOW3D software. By this way it has been shown that rapid convergence of the Fourier expansion is achieved, thereby allowing the use of a low number of modes in the approximation.

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