A SIMPLIFIED METHOD TO TAKE INTO ACCOUNT THE EFFECT OF TRANSVERSE MAGNETIC FIELDS IN THE GLOBAL MODELING OF CZOCHRALSKI SILICON GROWTH

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Proposed session topics: global modeling or convection

In Czochralski (Cz) silicon (Si) growth, crystal quality strongly depends on the melt flow pattern, which has major influence on the crystal-melt interface shape and deeply affects defect formation and oxygen incorporation into the solid. However, melt convection exhibits complex instabilities associated with buoyancy, surface tension, and rotational forces. Therefore, vertical, configured and transverse rigid magnetic fields are frequently used in order to improve Cz Si or other semi-conductor growth techniques.

However, 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. The FEMAG-2 generation was further developed in order to provide a fully automatic simulator predicting the entire growth process, from seeding to tail-end and post-growth cooling stages. On this basis, the objective of the present work was to extend FEMAG-2 global and dynamic capabilities to Si Cz growth under the effect of transverse magnetic fields.

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 melt flow calculations with axisymmetric global time-dependent simulations. A typical result is shown in Figs. 1-2.

In order 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 successfully 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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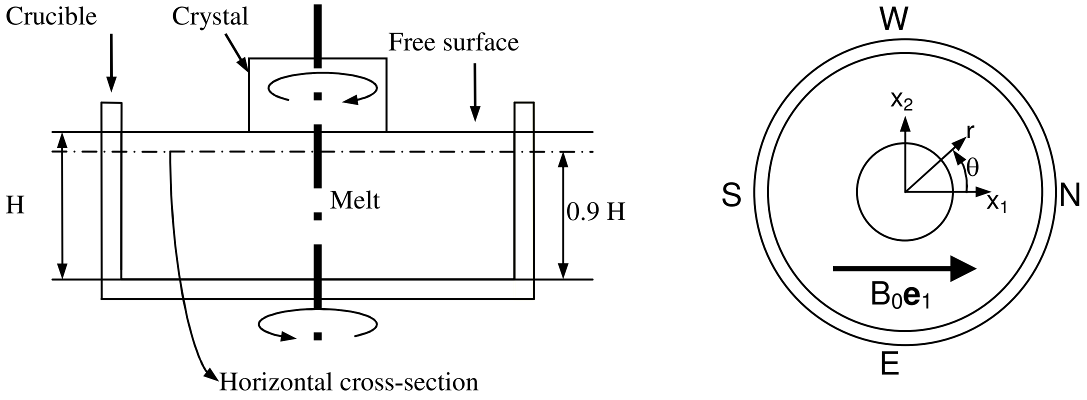
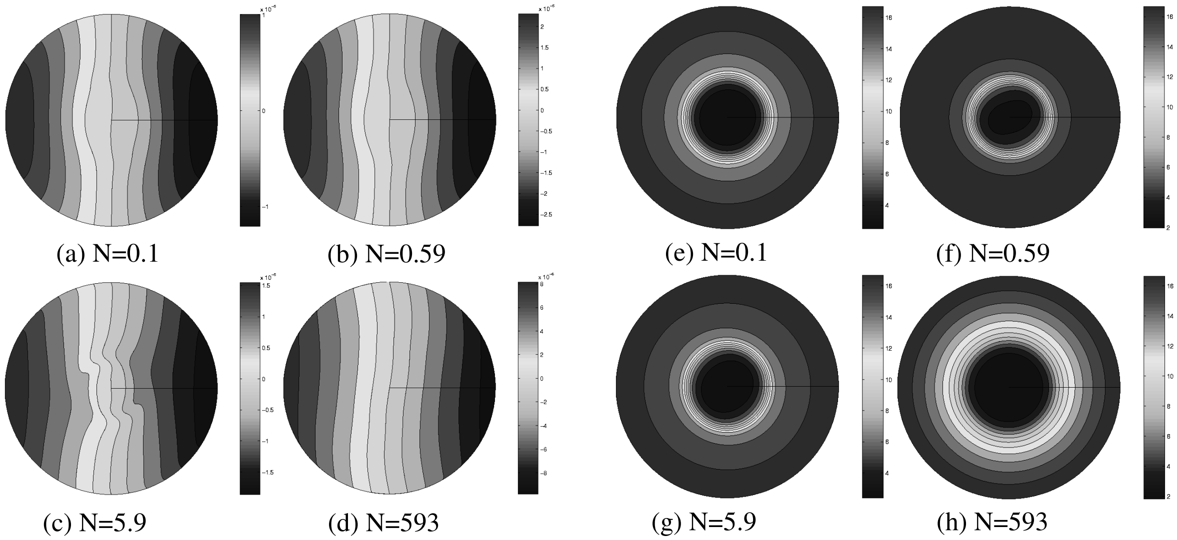


FIG. 1: Sketch of a simple crucible with axisymmetric boundary conditions; geometrical data and parameters from Williams & Walker (1990); Pe=390, Gr=6.9x10^3, Ma=123.


(a) N=0.1 (b) N=0.59 (e) N=0.1 (f) N=0.59

(c) N=5.9 (d) N=593 (g) N=5.9 (h) N=593

FIG. 2: Same problem as in Fig. 1. Electric potential (a-d) and temperature field (e-h) in the horizontal cross-section as a function of the magnetic interaction parameter N. For N=0.1 and N=0.59, $Re_{crucible}$=122 and $Re_{crystal}$=244. For N=5.9 and N=593, $Re_{crucible}$=12208 and $Re_{crystal}$=24416.

References:

[1] F. Dupret, P. Nicodème, Y. Ryckmans, P. Wouters, and M.J. Crochet, Int. J. Heat Mass Transfer **33**, 1849 (1990).

[2] F. Dupret and N. Van den Bogaert, in: Handbook of Crystal Growth, vol. 2b, ch. 15, Ed. D.T.J. Hurle, North-Holland 1994, p. 875.

[3] N. Van den Bogaert and F. Dupret, J. Crystal Growth **166**, 446 (1996); **171**, 65 (1997); **171**, 77 (1997).

[4] M.G. Williams, J. S. Walker, W. E. Langlois, J. Crystal Growth **100**, 233 (1990).

[5] J. S. Walker, M.G. Williams, J. Crystal Growth **137**, 32 (1994).

[6] L.M. Witowski, J. S. Walker, Fluid Dynamics Research **30**, 127 (2002).

[7] N. Ma, J. S. Walker, A. Lüdge, H. Riemann, J. Electromech. Soc. **147**, 3529 (2000).