A SIMPLIFIED METHOD TO TAKE UNTO ACCOUNT THE EFFECT OF HORIZONTAL MAGNETIC FIELDS IN THE NUMERICAL MODELING OF CZOCHRALSKI SILICON GROWTH

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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 temperature distribution under the crystal and the crystal-melt interface shape and deeply affects defect formation and oxygen incorporation into the solid. However, without appropriate action, melt convection exhibits complex instabilities associated with buoyancy, surface tension and rotational forces. Therefore, magnetic fields are often introduced to control the melt flow.

In practice, vertical, configured and horizontal rigid magnetic fields are frequently used. Rotating fields are not applied to the industrial production of single crystals. In general, it is expected that magnetic fields will play an increasing role in the future, especially to grow large diameter crystals. Hence, prediction and control of their effect by means of simulation tools represent major development objectives.

However, flows with magnetic fields often exhibit complex structures, with thin Hartman boundary and/or internal layers and clearly separated cells – since turbulent mixing has a quite low level. Therefore, in Si Cz growth, the transport of oxygen to the solidification front is strongly affected by the flow pattern, whose design must be selected in such a way that most of the oxygen released from the crucible wall either evaporates at the melt-atmosphere interface or remains trapped in internal cells, without reaching the crystallization interface. To this end, configured fields are developing, but knowledge is often missing concerning their optimal design. On the other hand, horizontal fields represent a quite satisfactory solution, but exhibit some drawbacks resulting from process axisymmetry loss and the associated crystal quality problems.

The FEMAG software is currently used by major crystal growth companies. The model is axisymmetric, global and dynamic, and takes convection effects into account. Laminar and non-laminar flow models are available, without or with considering the effect of rigid or rotating magnetic fields. Diffuse surface radiation is considered. The objective of developing the FEMAG-2 software generation has been to provide a fully automatic simulator predicting the entire growth process. To achieve coupling with global thermal calculations, the melt flow problem is solved at several stages of the simulation by using a quasi-steady model. Interpolation between the collected results provides the flow field at each time step of the dynamic simulation. Easy time-dependent simulations can be performed with this method even for stages of the process where important geometrical changes occur. This paper investigates the use of a simplified method devoted to predict the effect of horizontal magnetic fields in Si Cz growth. The mathematical-numerical model is based on using a limited Fourier development of the velocity, temperature and pressure 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 and, by this way, to extend FEMAG-2 capabilities to semiconductor crystal growth with horizontal magnetic fields.