Investigation of the turbulent silicon melt flow in a model geometry under a horizontal magnetic field

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Silicon monocrystals are widely used in different industrial applications such as solar cells, memory elements, microcircuits. The majority of the silicon monocrystals are grown by the Czochralski (Cz) technique. The melt flow is turbulent during growth of the 300 mm diameter crystals. To damp the turbulent fluctuations in the melt the horizontal magnetic field is applied (HMCz). Experimental investigation of these processes is difficult due to high melt temperatures and limitations of the experimental equipment, in particular the thermal inertia of thermocouples which hinders capturing high-frequency temperature fluctuations [1]. Numerical simulation is quite promising to obtain the detailed information about the flow structure and turbulence characteristics inside the melt.

Direct Numerical Simulation (DNS) is the most accurate approach of modelling turbulence and provides complete spatial and time resolution of the flow characteristics. However, it requires a lot of computational resources and is very time consuming. Yokoyama et al. performed 3D transient computation of melt flow for the industrial scale 300 mm diameter silicon crystal growth process and validated the computational results by comparison with experimental data [2]. The mechanisms of periodic flow patterns changes were discussed. Kalaev [3] performed hybrid unsteady LES/RANS simulation in a CZ puller geometry. Based on the estimated size of Kolmogorov eddies in the melt [3] it was concluded that performing high quality DNS requires computational grid with hundreds of millions of cells or even more, which requires very significant investments in computational resources. To investigate the influence of the magnetic field on turbulent melt convection, we have performed a DNS computation in a model cubic geometry which physically represents a small region at the periphery of the melt with applied horizontal magnetic fields. First, we demonstrated that such strong magnetic field does not completely suppresses the turbulence, but converts it from 3D to 2D unsteady turbulence. Second, the increase of magnetic field from 0.1 T to 0.3 T surprisingly results not in suppression, but in enhancement of turbulent heat transfer, which is in a good agreement with published experimental data [4].

References

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