No. P39

Effect of cusp magnetic field on the turbulent melt flow and heat transfer during 300mm Czochralski silicon crystal growth

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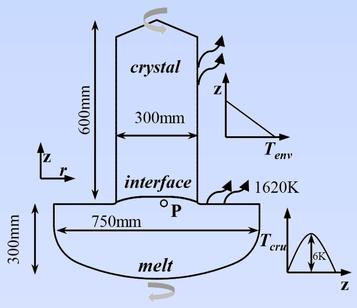
Introduction

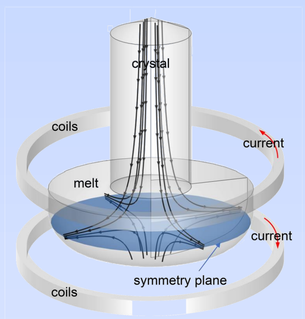
In recent decades, the silicon crystal size increases gradually. However, the melt flow in large crucible is always turbulent characterized by violent velocity and temperature fluctuations[1-3], which is unbeneficial to the crystal growth.

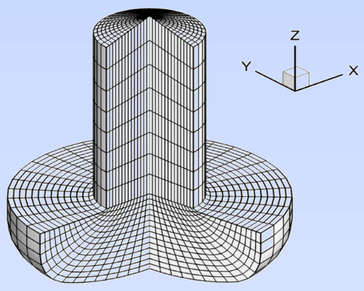
The cusp magnetic field (CMF) is a significant and promising technique to regulate the convection of conductive melt as well as the impurity transport and crystallization interface shape, which adopts the advantage of the horizontal magnetic field to keep the radial convection near the crystallization interface while dampening the turbulent convection in most melt regions relies on the advantage of the vertical magnetic field[4-7]. In this work, the horizontal symmetry plane position (HSP) of CMF is discussed.

Models

Model description







Governing equations

LES method is adopted to explore the turbulent flow and heat transfer in the melt

$$\nabla\cdot\overline{\mathbf{V}}=0,$$

$$\rho\frac{D\overline{\mathbf{V}}}{Dt}=-\nabla\overline{p}+\nabla\cdot[\mu_{\text{eff}}(\mathbf{V}\overline{\mathbf{V}}+\mathbf{V}\overline{\mathbf{V}}^{\mathrm{T}}]-\rho g\beta_{\mathrm{T}}(\overline{T}-T_0)-\rho\left[2\omega\times\overline{\mathbf{V}}+\omega\times(\omega\times\vec{r})\right]+\mathbf{F}_L,$$

$$\frac{D\overline{T}}{Dt}=\nabla\cdot(\alpha_{\text{eff}}\nabla\overline{T}),$$

Governing equations for the electromagnetic field

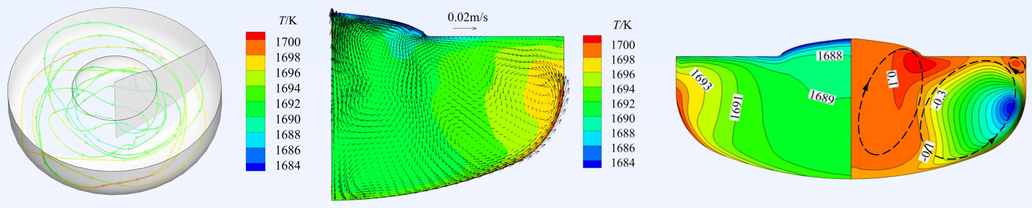
$$\nabla\cdot\mathbf{J}=0,$$

$$\mathbf{J}=\sigma(\mathbf{E}+\mathbf{V}\times\mathbf{B}),$$

$$\mathbf{E}=-\nabla\Phi,$$

$$\mathbf{F}_L=\mathbf{J}\times\mathbf{B}$$

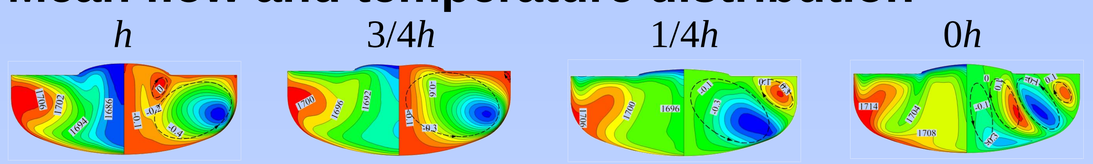
Results-I



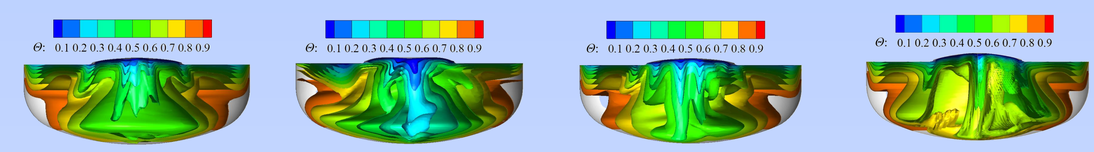
Results-II

The influence of the HSP position on the turbulent melt flow, heat transfer, and crystal/melt interface is investigated. Four CMF configurations are studied, i.e., HSP is located at *h* (melt free surface), 3/4*h*, 1/4*h* and 0*h* (bottom of crucible). *h* is the melt depth.

Mean flow and temperature distribution

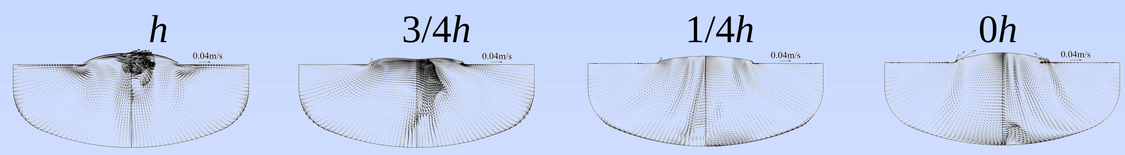


mean melt temperature and stream function

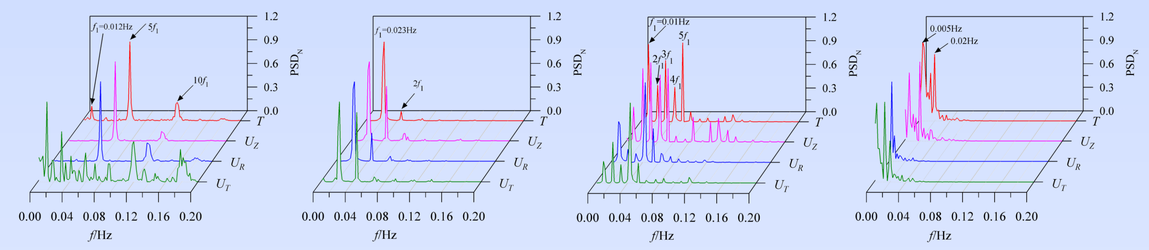


Instantaneous dimensionless temperature distribution

Pulse information near the interface

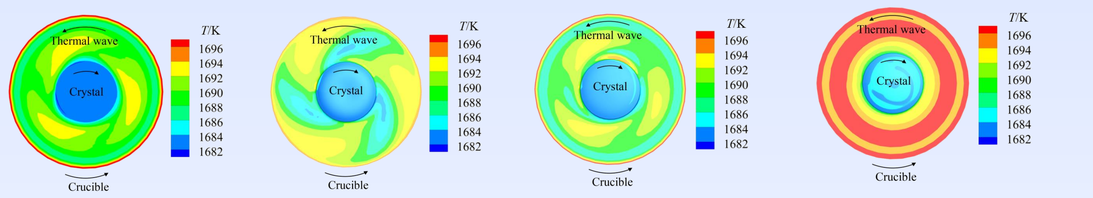


Instantaneous velocity distribution

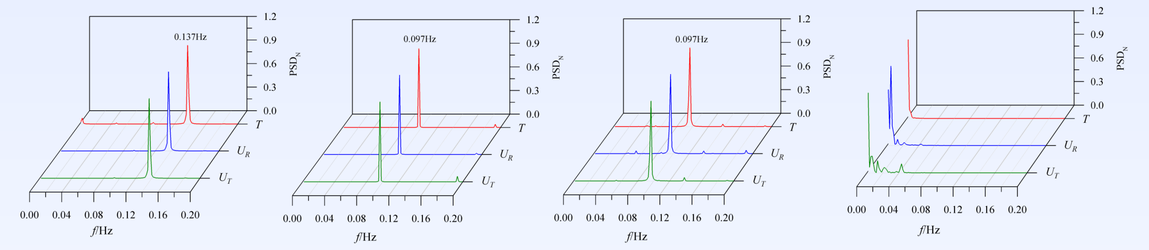


Frequency analyses of melt velocity and temperature fluctuations

Thermal waves on the melt free surface

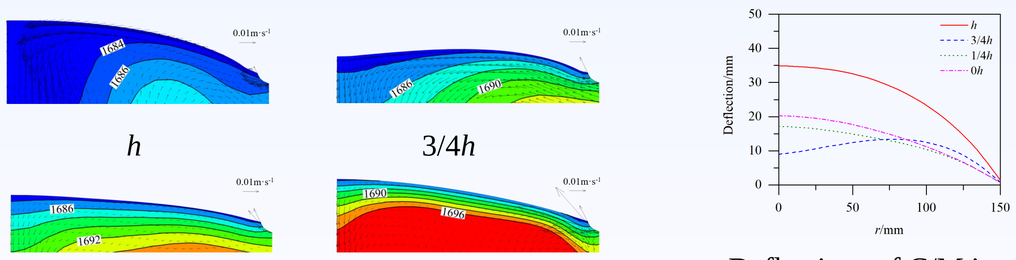


Temperature on the free surface and crystallization interface



Frequency analyses of melt velocity and temperature fluctuations

Mean flow and temperature distribution



Deflections of C/M interface

Summary

1. The CMF can significantly improves the melt flow, depresses the interface deformation, reduces the temperature fluctuation.
2. With CMF, the oscillation frequencies of melt temperature and velocity consist of a basic frequency and its integer multiple frequencies.
3. Thermal waves with a regular shape rotate on the melt-free surface, and the rotational direction is consistent with the crucible rotation.
4. The interface shape depends on the melt flow direction and velocity magnitude as well as the temperature gradient below the crystal.

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