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Control of the seed crystal melting interface for the growth of monocrystalline silicon ingots

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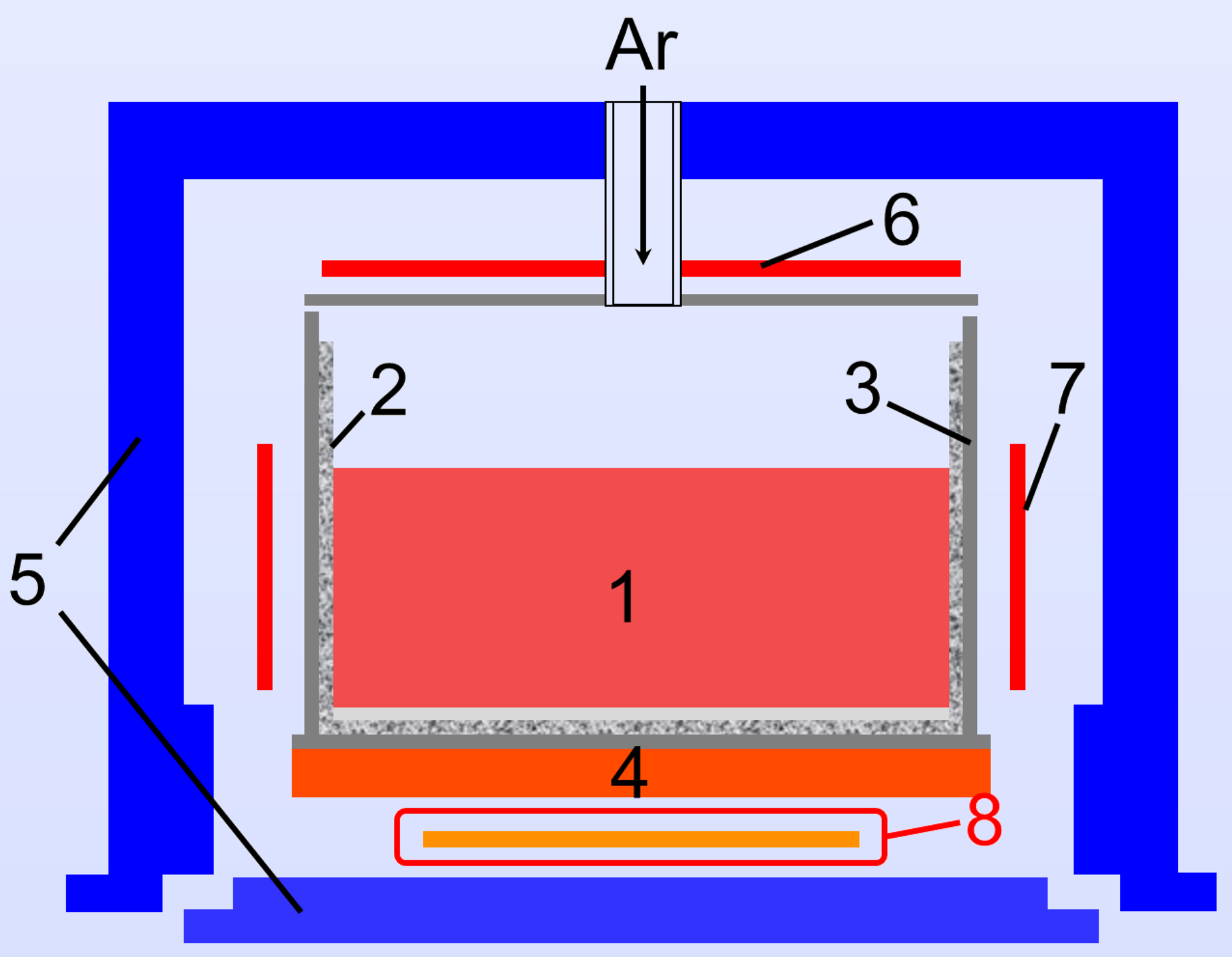
Introduction

Monocrystalline silicon ingot grown by directional solidification is a very promising material for solar cells because of its high photovoltaic conversion efficiency and low production cost. With the increase of ingot size, the control of the seed crystal interface in the late melting stage becomes more difficult. Therefore, it is of great importance to study and control the seed crystal melting interface.

Model description

Geometric model

- Furnace size: height is about 2.26m, diameter is about 2.36m
- Volume of the Si region: 1.18 x 1.18 x 0.28 m³



1. Silicon melt
2. Crucible
3. Susceptor
4. Heat exchanger
5. Insulations
6. Top heater
7. Side heater
8. Hanging plate

Fig. 1 Schematic of the furnace

Governing equations

- Melt area

$$\nabla \cdot \vec{u} = 0$$

$$\rho \frac{\partial \vec{u}}{\partial t} + \rho \vec{u} \cdot \nabla \vec{u} = -\nabla p + \nabla \cdot \left[\mu \left(\nabla \vec{u} + \nabla \vec{u}^T \right) \right] + \rho \vec{g} \beta (T - T_m)$$

$$\rho C_P \frac{\partial T}{\partial t} + \rho C_P \vec{u} \cdot \nabla T = \lambda \nabla \cdot (\nabla T)$$

- Argon area

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{u}) = 0$$

$$\frac{\partial (\rho \vec{u})}{\partial t} + \nabla \cdot (\rho \vec{u} \vec{u}) = -\nabla p + \nabla \left(-\frac{2}{3} \mu \nabla \cdot \vec{u} \right) + \nabla \cdot (2 \mu S) + (\rho - \rho_0) \vec{g}$$

$$\frac{\partial (\rho C_p T)}{\partial t} + \nabla \cdot (\rho C_p \vec{u} T) = \Delta (\lambda T)$$

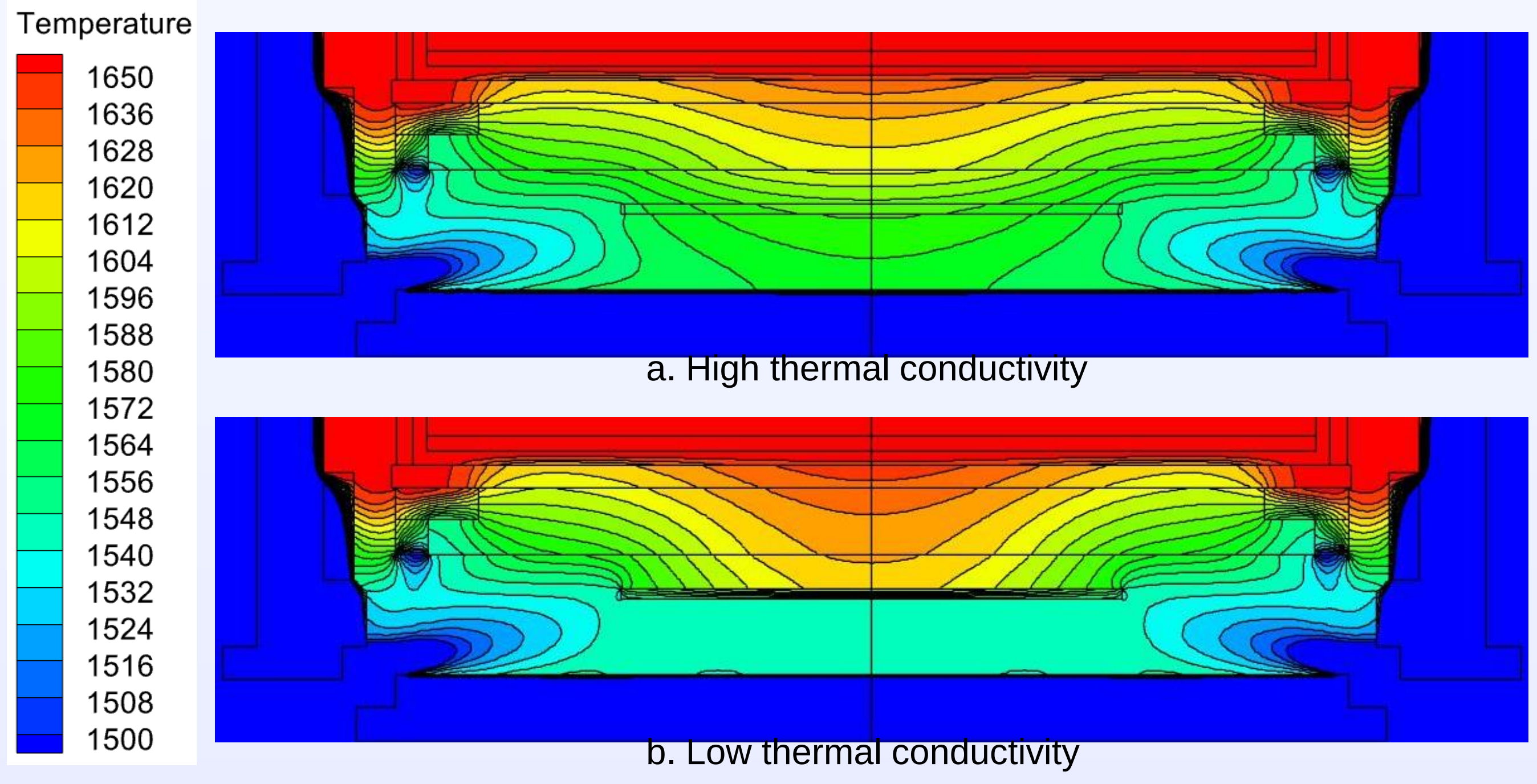
$$\rho = \frac{p_0}{R_g T}$$

- Heater area $$\rho C_P \frac{DT}{Dt} = \lambda \nabla \cdot (\nabla T) + Q$$

- Other solid area $$\rho C_P \frac{DT}{Dt} = \lambda \nabla \cdot (\nabla T)$$

Results

Comparison of different thermal conductivity



a. High thermal conductivity

b. Low thermal conductivity

Fig. 2 Simulation comparison diagram of temperature distribution near hanging plate with different thermal conductivity (Unit: K)

- As the thermal conductivity decreases, the temperature distribution above the hanging plate is more concave.

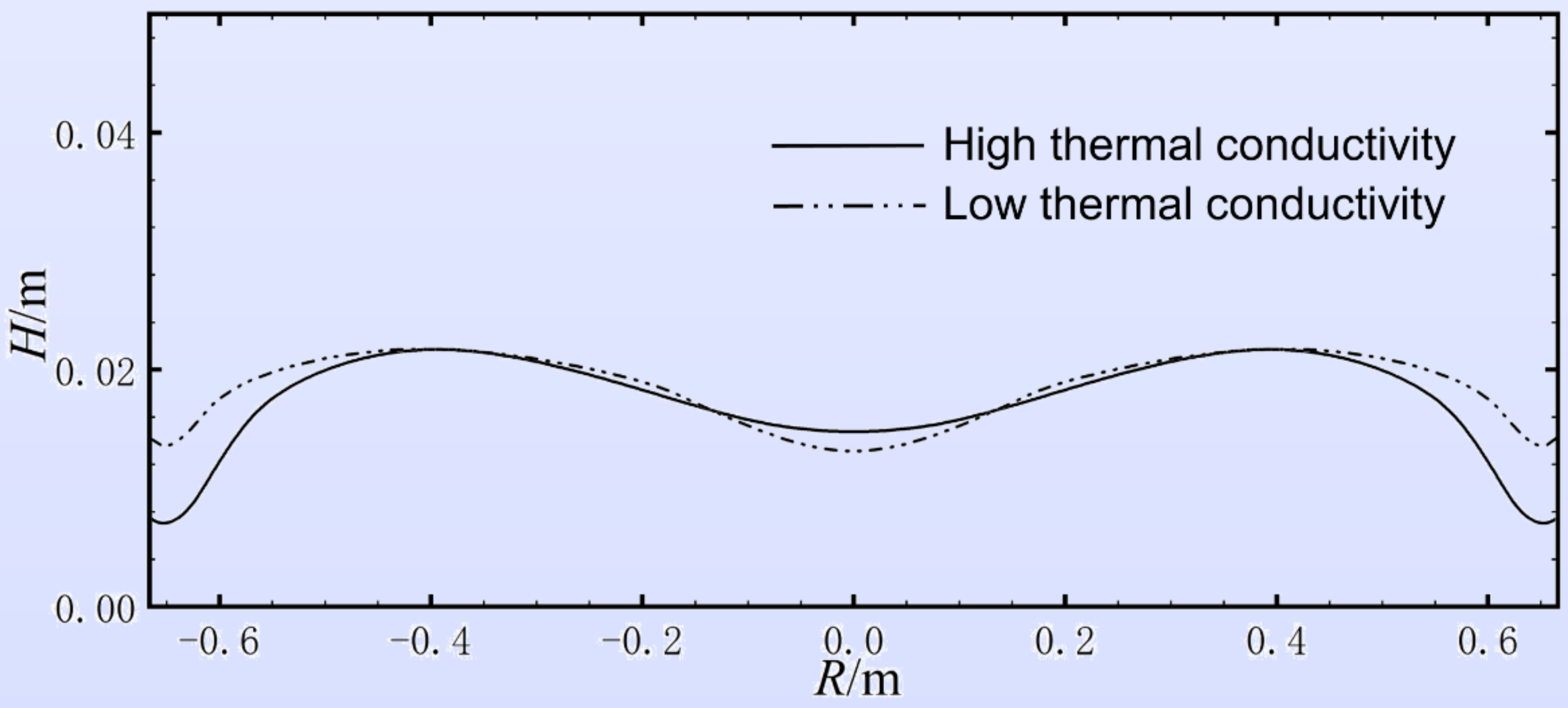


Fig. 3 Seed crystal melting interface for different conductivity

- Due to the small thermal conductivity of the crucible and the large internal temperature gradient, the temperature distribution at the seed crystal is less affected by the hanging plate.
- With the increase of thermal conductivity, the center of the seed crystal melting interface is more downward. But near the side of the wall there is an increase.
- It is speculated that increasing the size of the suspension plate can improve the upturning of the edge of the seed crystal.

Comparison of different dimensions

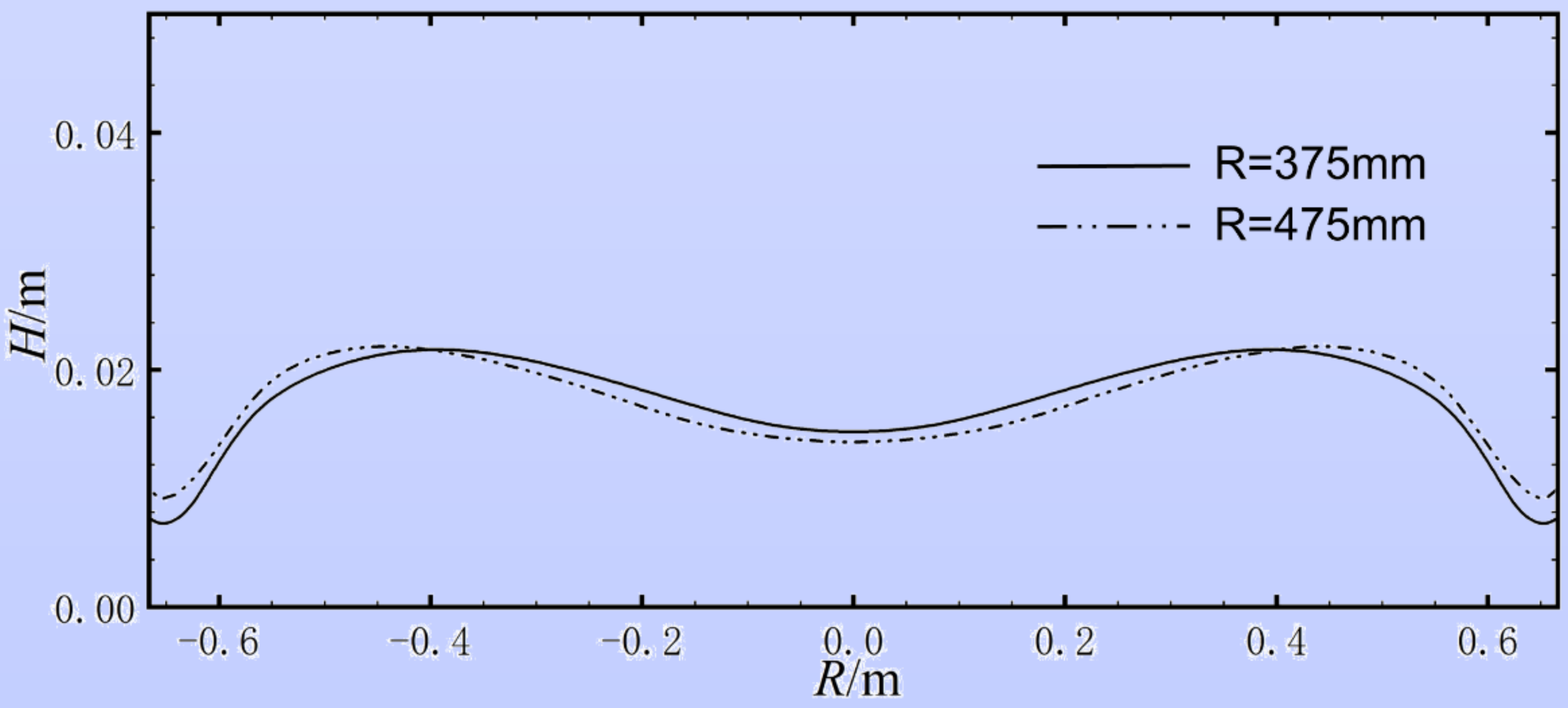


Fig. 4 Seed crystal melting interface for different dimensions

- With the increase of the size of the hanging plate, the highest point of the seed crystal has the phenomenon of moving outward.

Conclusions

- The hanging plate enhances the heat absorption under the DS board, which significantly affects the temperature distribution around the heat sink.
- The smaller the thermal conductivity of the hanging plate, the greater the influence on the interface of the seed crystal. It is more effective for improving the convex phenomenon of the seed crystal melting interface.
- The small thermal conductivity of the crucible leads to a large temperature gradient, which will reduce the effect of the hanging plate on the seed crystal melting interface.