STUDY OF LOW MELT FLOWS DURING $NaNO_3$ SOLIDIFICATION BY AHP METHOD

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In the present study, The technique and results of experimental investigations of flow characteristics during $NaNO_3$ solidification by the AHP method are presented in the present study, and applied to verify a numerical melt flow model which is being developed

INTRODUCTION

Crystal growth under conditions of axial heat flux close to the phase interface (AHP method[1]) is a prospective area for crystal growth from the melt. In this method, a heater-baffle (AHP-heater) placed in the melt at a small distance from the melt-crystal interface is used. Due to small thickness of melt layer, the small radial temperature drop and the horizontal position of melt layer, the natural convection close to melt-crystal interface is suppressed. Low laminar melt flows results in high micro inhomogeneity of the crystal. Due to the strong control of temperature distribution over the boundaries of melt-crystal system, it is possible to quantitatively describe heat and mass transfer during crystal growth by computational modelling. However, the behavior of low flows in crystal growth by the AHP method is not well studied. In particular, computations of actual AHP growth process leads sometimes to discrepancy with experimental data[2].

EXPERIMENTAL

Solidification technique

Researches of $NaNO_3$ solidification have been performed using three setups. In the first setup, features of melt flow without a crucible variant of the AHP method[3] were studied. The melt flows in the crystallization by AHP method, in comparison with the Bridgman one, were studied in a specialized (for modelling of Czohralsky and Bridgman technique) second setup[4] provided with pulling and rotating devices. This setup has apparatus for vibration and makes it possible to perform experiments for investigating flows in modelling liquids under conditions of low-frequency vibrations in the range of frequencies up to 300 Hz and amplitudes to 500 μm.

The third setup was used for modelling of crucible AHP variant[1]. The schematic of the setup is present in Fig. 1. Thin-walled quartz tube with diameter of 80 mm served as a crucible. A hermetic casing of the AHP-heater submerged into the melt and crucible support were made of stainless steel. Temperatures of the hot surface of the AHP-heater and cold surface of the support, between which the growing crystal and the studied melt were located, were measured by chromel-copel thermocouples with diameter of 0.2 mm. The same thermocouples were used as probes for a computer system to control the operation of a two-sectional safeguard resistance heater. Temperatures in the experiment were maintained so that the melt layer from which the crystal grew remained constant.

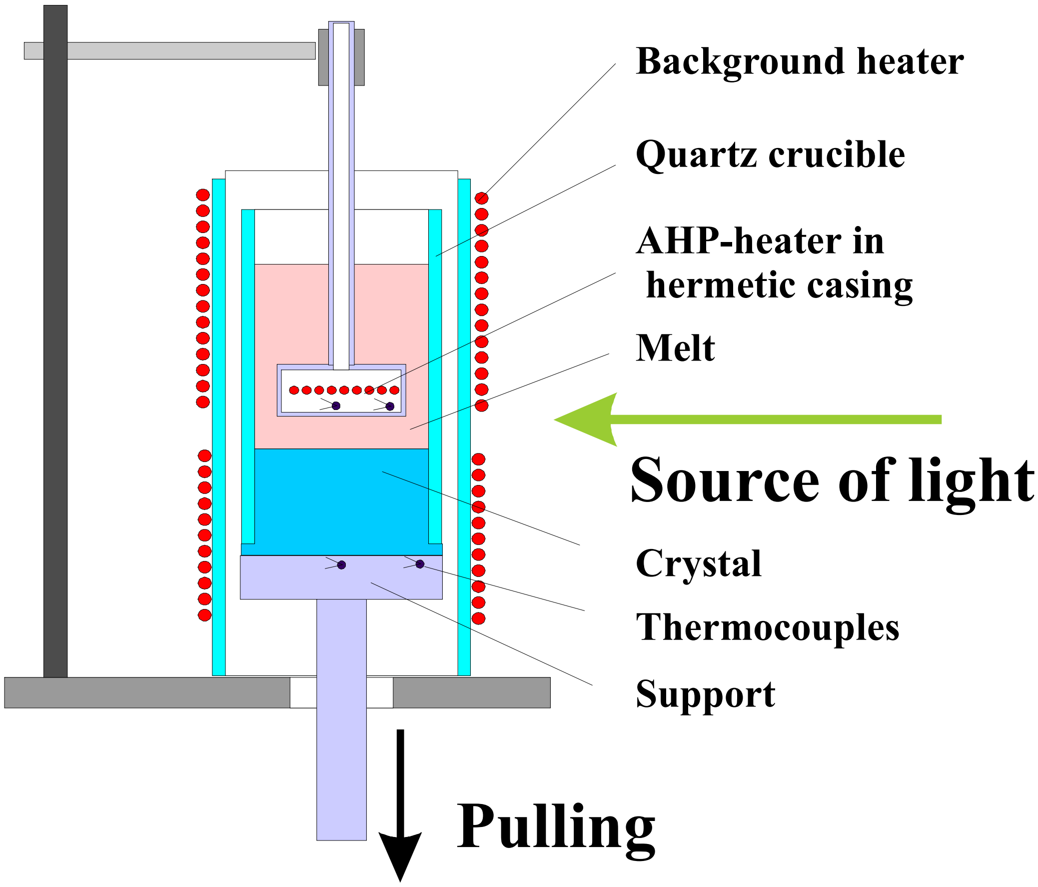

Figure 1. Schematics of $NaNO_3$ solidification by crucible variant of the AHP method for crystal growth from the melt

Visualization technique

To observe the melt flow a light probe ("knife") was applied. Its width could be varied from 500 μm to 2 mm. Visualization of flows was performed by adding into the melt aluminum particles with 20 μm in dimension as a tracers. Gas and semiconductor lasers were used as a light source.

A set of experiments were conducted in which basic parameters influencing the behavior of forced and natural convection in the thin melt layer close to the liquid-solid interface during the growth by the AHP-method were varied: pulling crystal rate and thickness of the melt layer under the AHP-heater.

RESULTS

Experiments have shown that the interface was flat over 90% of the crystal cross-section and was parallel to the surface of a hermetic casing of the AHP-heater. A deflection of the liquid-solid interface outside this area was in the range from 0 to ± 0.02. In our experiments the melt superheating $\Delta T = T_h - T_m$ equaled to 15-30K, where T_h is a temperature of the AHP heater, T_m - a melting point. The melt thickness was 1-7 mm. It was shown that in both crucible and without crucible AHP technique, melt flowed along the interface with the same maximum velocity. For pulling rate of AHP-crucible (crystal) equaled to 2 mm/h, melt flow velocity was 0.2 mm/sec. This value remained constant up to angles of deflection of AHP-heater relative the vertical line in several degrees. In this case, even inclination of 30^0 did not lead to distinguished change in melt layer thickness along the direction of melt flow. Thus, observed flow velocities corresponding to Rayleigh number Ra=100 for AHP geometry did not result in heat transfer. This result suggests that in case of using non-flat interface for AHP crystal growth it would be possible to neglect with influence of heat transfer by convection on the interface position. While using the AHP method without crucible, Marangoni convection occured at the free melt surface. The movement of tracers was observed with the velocity of ~1 mm/sec for the $NaNO_3$ melt layer with thickness of 1 mm and temperature drop of 20^0C near the free melt surface.

CONCLUSION

Direct observations prove the calculations that there are low melt flows in the thin AHP-layers of melt, which do not influence heat transfer. Maximum melt flow velocities were 0.2 mm/sec. Measured values for melt flows velocities will be further used to verify numerical model describing flows under conditions of crystallization from melt by AHP method.

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