MODELLING AND CONTROLLING OF WEAK LAMINAR FLOWS WHEN GROW CRYSTALS FROM THE MELT BY THE AHP METHOD

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Introduction. Widely recognized methods for single crystal growth are known to be characterized by a complex, instable in behavior melt flow, appearing at the interaction of buoyancy, thermocapillary and forced convections. Previously, some methods of growth have been proposed [1, 2] when an additional heater is arranged inside the crucible, in the melt, at the phase interface. Serving as a partition [1], the submerged heater splits the melt in two zones. Buoyancy convection is relatively weak in the zone of crystallization (under the heater); a weak melt flow driven by the motion of the crucible with the crystal about the heater is laminar and stationary. The zone about this submerged heater supplies the zone of crystallization with the melt. The processes, occurring in the two zones, almost do not affect each other. When thermocouples are arranged along all boundary surfaces and an axial heat flux is implemented at the interface [2], during the entire growth cycle there appears a possibility to control the basic technological parameters, the position and the shape of the interface, the actual crystal growth rate and the temperature gradient at the phase interface.

Computer simulation has a major relevance as a tool of analysis of the experimental studies or for the design of engineering hardware. It is necessary to find out first appropriate physical models and then to develop numerical procedures for solving the resulting set of equations. In order to assess a satisfactory level of confidence of the simulation tools, both the model and the procedure have to be tested through properly designed validation experiments, reproducing the basic features of the simulated phenomena. Therefore, besides well-established numerical benchmarks for code verification, experimental benchmarks for code validation have gained a special attention in the recent years, including recent achievements in measurement techniques (optical and electro-optical methods like thermography, tomography or particle image velocimetry). Applying a modern toolkit for visualization, which enables to carry out thermometric measurements and velocimetry [3, 4], and extending a set of model liquids, it is possible to conduct heat and mass transfer researches during solidification process in a wide range of driving parameters, including the imposition of external fields.

A steady magnetic field of $B \approx 0.2$–0.3 T was earlier proved to be one of the most important kind of external fields, allowing suppression of the strength of convective flow in 30-50 times, and to get an almost molecular mass transfer at a much more uniform distribution of the dopant along the crystal radius. Yet, the influence efficiency by steady magnetic field greatly depends on the thickness of the melt layer at the interface. Therefore, the imposition of magnetic field as an additional tool to control the melt flow allows to enhance the crystal homogeneity, along with the advantages of single crystal growth in thin melt layers.

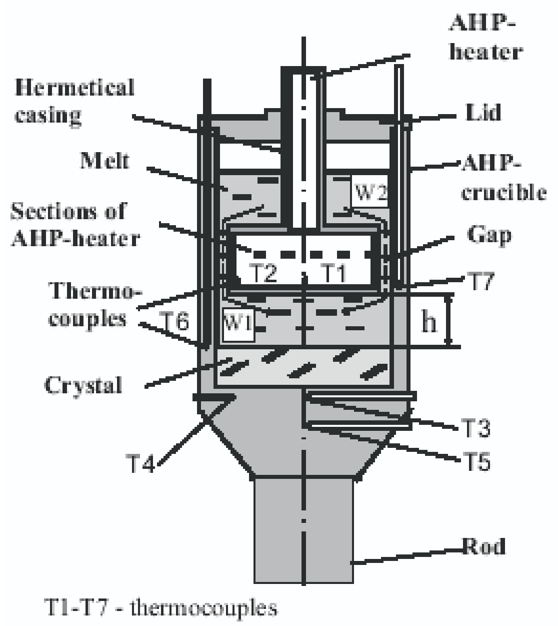

Fig. 1. Schematics of the AHP crystal growth.

The aim of the paper is to develop an instrument for experimental investigation of weak laminar melt flows, including its visualization by introducing tracers into transparent dielectrics [5] and a number of temperature probes into the volume of a conducting liquid [6]. The latter makes it possible to study the influence of magnetic fields on the behaviour of convection.

1. Experimental technique and procedure. A novel AHP method for crystal growth under conditions of Axial Heat flux close to the Phase interface has been developed to provide a stable weak laminar flow close to the melt-crystal interface and a way of its flat curvature control using a number of heater sections inside and outside the crucible (not shown in Fig. 1).

With the aim to observe the behavior of a low AHP flow, an experimentalAHP setup for visualization of $NaNO_3$ crystal growth [5], employing 20 μm particles of aluminum powder as tracers, was designed. The fragment of the crystallizer is presented in Fig. 2. A charge of $NaNO_3$ was completely molten by a background heater, the AHP-heater was submerged into the melt, and thermal conditions were achieved, under which a part of the melt was solidified. In this case, the solid-liquid interface was formed at a certain distance within 5–20 mm from the AHP-heater bottom. Varying the power of the background and AHP-heater sections, the planar shape of the phase interface was obtained. The crucible was pulled down, while the AHP-heater was stationary.

In order to study the steady magnetic field influence on the heat/mass transfer when grow single crystal by the AHP method, the method for flow hydrodynamics investigation has been modified [6]. For that reason, the model of pulled single crystal was changed to an AHP heater, the conducting fluid was being solidified from the bottom. As previously, the flows and temperature fields were visualized via computer processing of the data measured by velocity and temperature probes.

2. Results and discussion. One can see in Fig. 2 that laminar convection is established during $NaNO_3$ solidification by the AHP method, with its character strongly depending on the melt layer thickness.

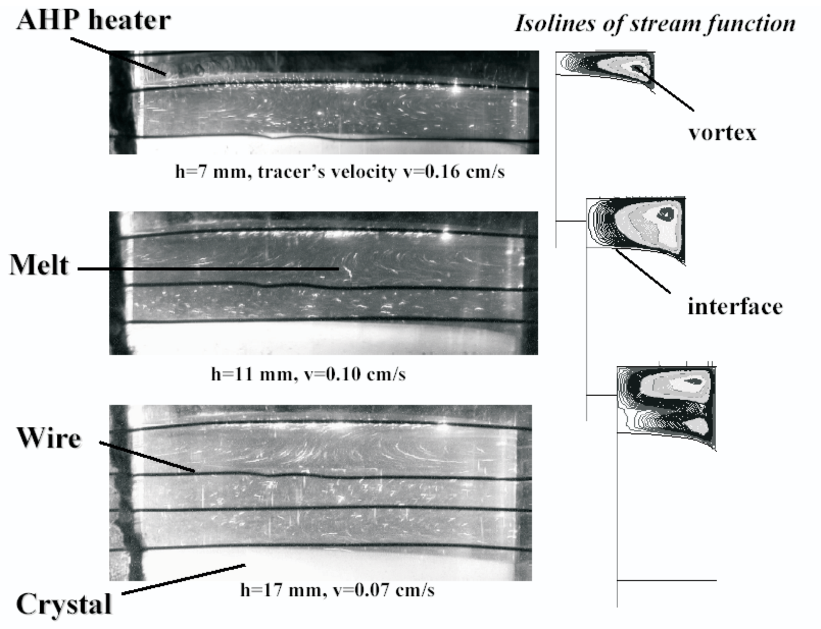

Fig. 2. Melt flow character for different $NaNO_3$ melt layers, h.

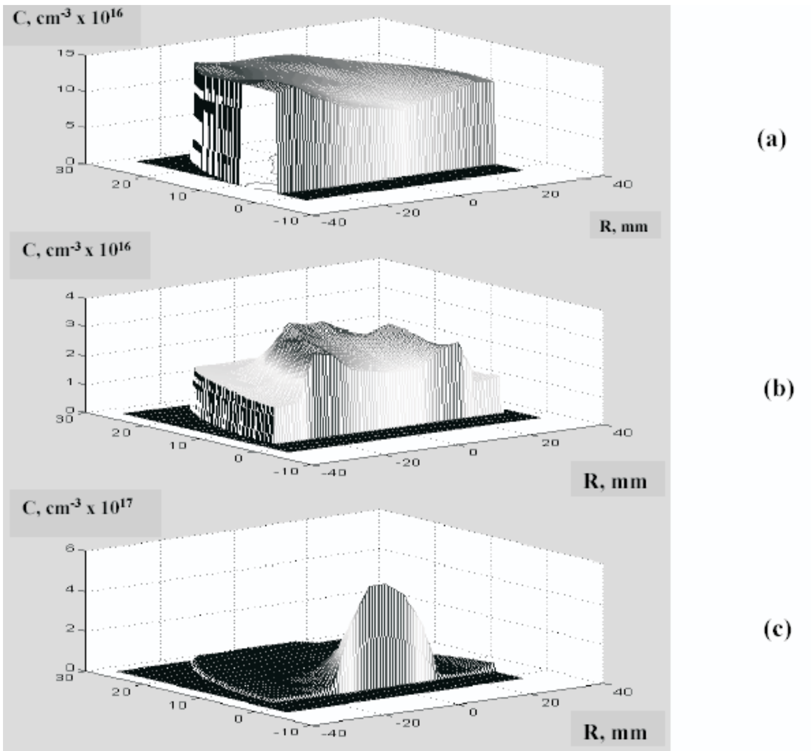

Fig. 3. Actual variation of the lateral Sb impurity distribution in a Ge crystal when a natural-convective flow (a) changes to a forced one (c) (data measured by a four-point probe technique).

For thin enough melt layers between the interface and an additional heater, the flow behaviour under the AHP method is similar to the one found under microgravity [7]. The convective flow is relatively weak, but the mass transfer remains convective, as illustrated by the distribution of Sb in the grown Ge single crystal in Fig. 3 and by numerical calculations [8]. As a result, the dopant gathers in the middle of the crystal, so causing a noticeable non-uniformity of the dopant distribution along the crystal radius.

As said above, the influence by a steady magnetic field should greatly decrease the strength of the mean flow and suppress possible fluctuations [6]. Therefore, some experiments, investigating the influence of a vertical magnetic field on the flow velocity and fluctuations of velocity and temperature are planned to be carried out in a low-temperature InGaSn melt using a conductive anemometer.

The serviceability of the method has been tested for numerous single crystals, either dielectrics or semiconductors [8, 9]. The results obtained for Ge single crystals allow to expect high perfection of single crystals and economic efficiency of the technology. Combined with electro-magnetic devices, the AHP method is considered to be a very promising one to realize the entire control of the heat and mass transfer process in crystal growth from the melt, providing perfect crystals of very high uniformity.

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