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MARANGONI EFFECT INDUCED CONVECTION IN MATERIAL PROCESSING UNDER MICROGRAVITY

M-18

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Objective of Flight Experiment

On the ground the upper layer of the liquid in a vessel heated from below becomes hotter than the lower layer. This well-known phenomenon results from buoyancy-induced convection. Though this means that the buoyancy-induced convection is not dominant under microgravity conditions in space, another convection called Marangoni convection may possibly occur. This convection results from an intermolecular force which acts on a free surface, that is surface tension. Since it is stronger at lower temperatures, the liquid surface near the heated wall is pulled to the cooled side as shown in Figure 1. This surface movement causes the inner convection. Marangoni convection, however, may be negligible on the Earth, for the molecular force is generally smaller than buoyancy.

Various tests on material processing have recently been conducted in space and some high quality crystals free from buoyancy convection were obtained. But, at the same time, others proved to be less uniform than expected in the components' distribution. This nonuniformity seems to be mainly caused by Marangoni convection. It is, therefore, very important to know how to control the convection by studying its characteristics, but the problem is that on the ground it is impossible to carry out the experiment without gravity. That is why a space experiment aboard the space shuttle is planned as the First Material Processing Tests (FMPT) of Japan.

The experiment on Marangoni flow visualization is being performed in order to investigate the characteristics of convection in uni-dimensional melt growth under microgravity conditions.

Outline of Flight Experiment

The configuration simulates a possible case of the melt state in Bridgman growth as shown in Figure 2(a). We use a paraffin (n-eicosane) as a transparent liquid sample and fill the cylindrical space enclosed by glass cover, cold top wall, and hot bottom wall with the liquid. The free surface is formed just below the cold top wall, and the temperature gradient on the surface generated by controlling both the heater and the cooler drives Marangoni convection.

The convective motions in the liquid column can be visualized by tracers, fine aluminum flakes, and the optical fibers used to observe a section in the liquid column in two different angles as shown in Figure 2(b). The flow field is recorded on video tape. Three experiment runs of 40 minutes each, with different temperature gradients shown in Figure 3, are planned. In the third run the cold wall will be cooled under the melting point of liquid and the solidification front will move slowly from the cold to the hot wall. A schematic view of the Marangoni Convection Unit (MCU) is shown in Figure 4. From the visualized data the velocity and stream line are obtained. Temperature distribution and Nusselt number will be analyzed later.

Future Contribution of the Experimental Results

By data analysis of Marangoni convection in the space experiment, the flow pattern, the velocities, and their distribution can be determined. The boundary flow near the cooled side of the wall is particularly important, for the wall is situated at the solidification front in crystal growth. Since the experiment for producing semiconductors by the Bridgman method is also planned in the FMPT, the flow difference between the model liquid and the melted semiconductor will be made clear. The numerical simulation can be modified by the results, and it will become easy to predict a liquid flow field in crystal manufacturing.

The Bridgman method is often used for the production of the compound semiconductors, which can be applied to such devices as light emission/absorption elements of infrared rays. When Marangoni convection is sufficiently understood and controlled, large-sized crystals of high quality will be able to be produced. The technique is also useful for manufacturing other semiconductors and alloys at a lower cost on the ground.

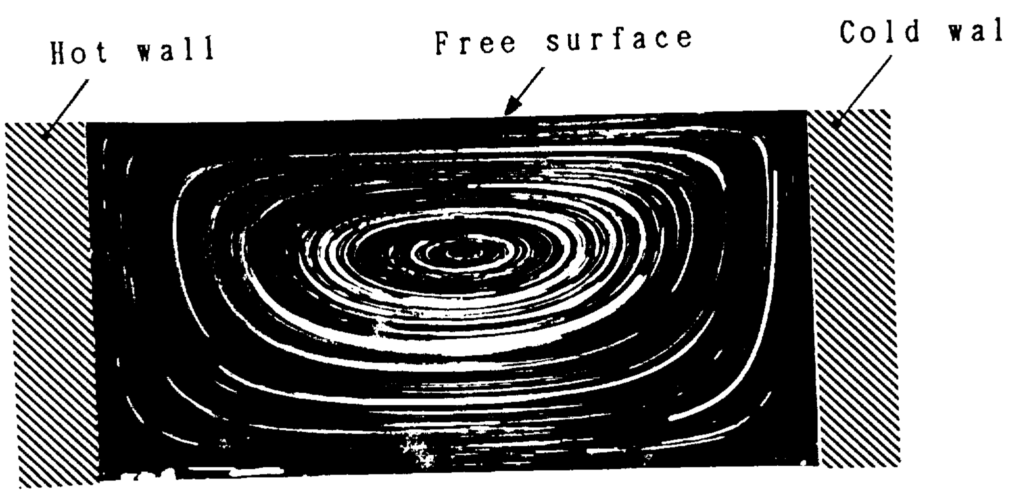
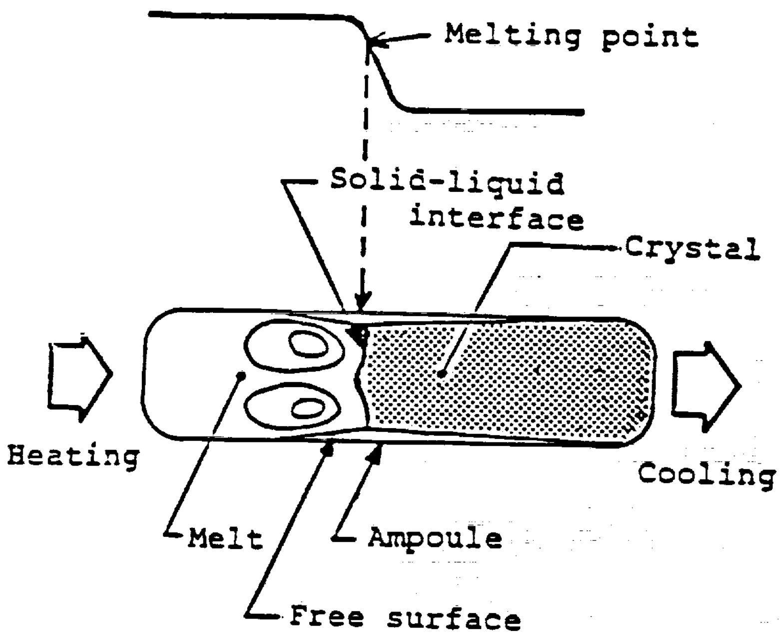
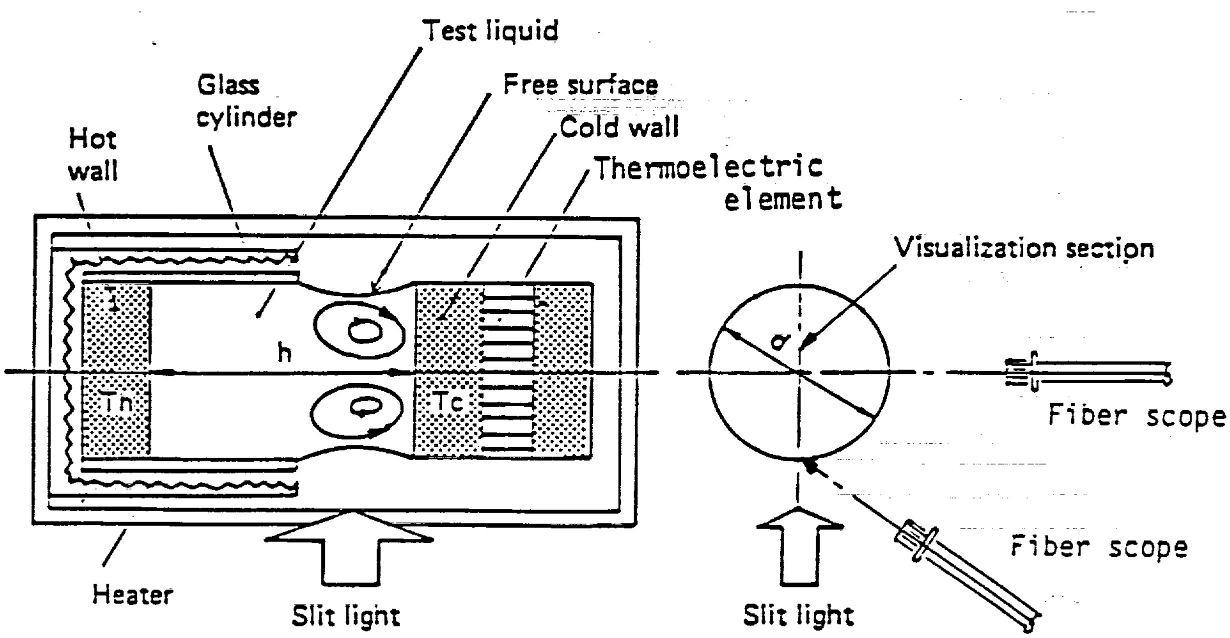


Figure 1. Flow visualization of Marangoni convection on the ground.



(a) Bridgman method



(b) Experimental apparatus of Marangoni convection in space

Figure 2. Schematic diagram of Marangoni convection experiment in FMPT.

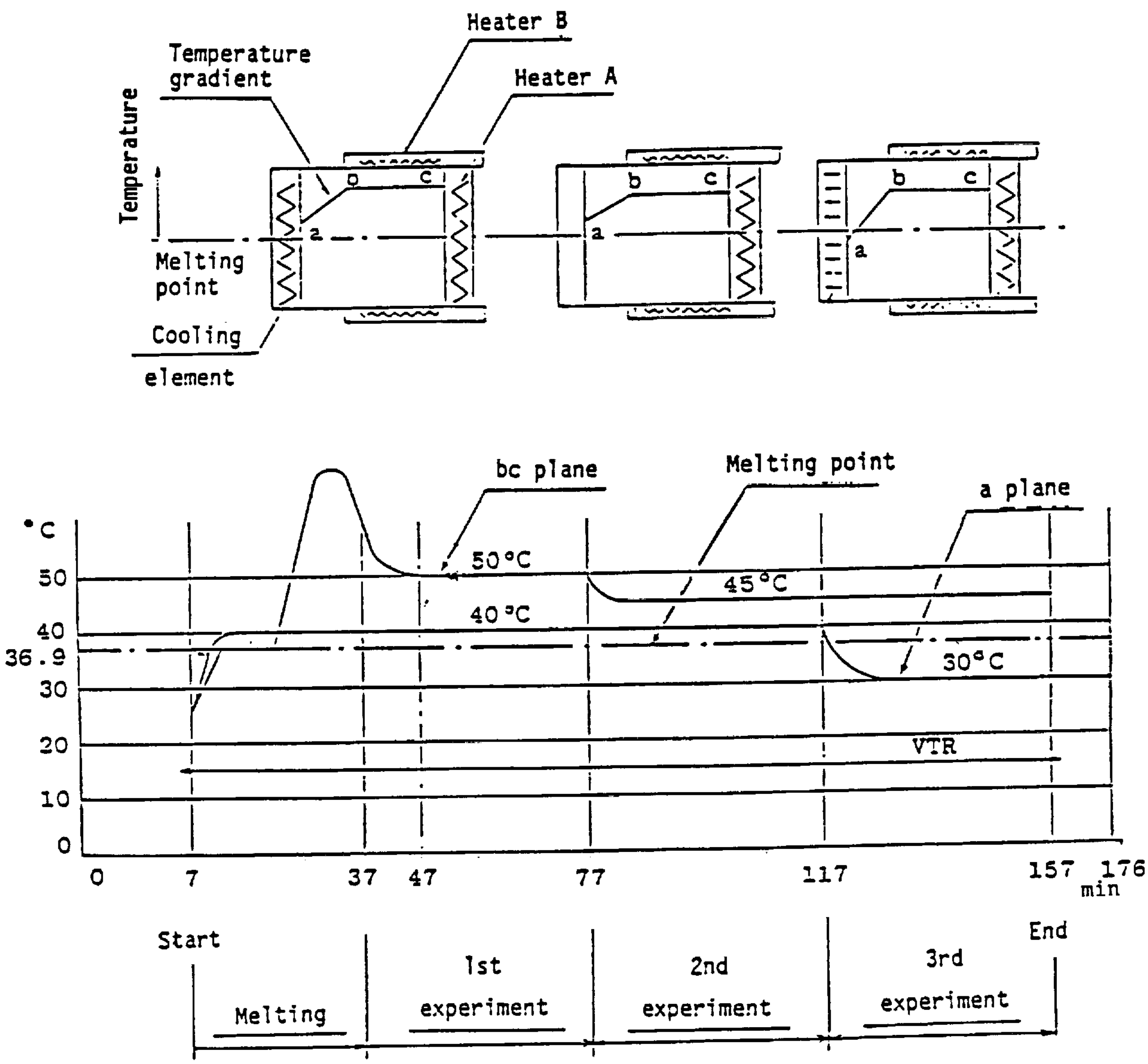


Figure 3. Experiment sequence of M18.

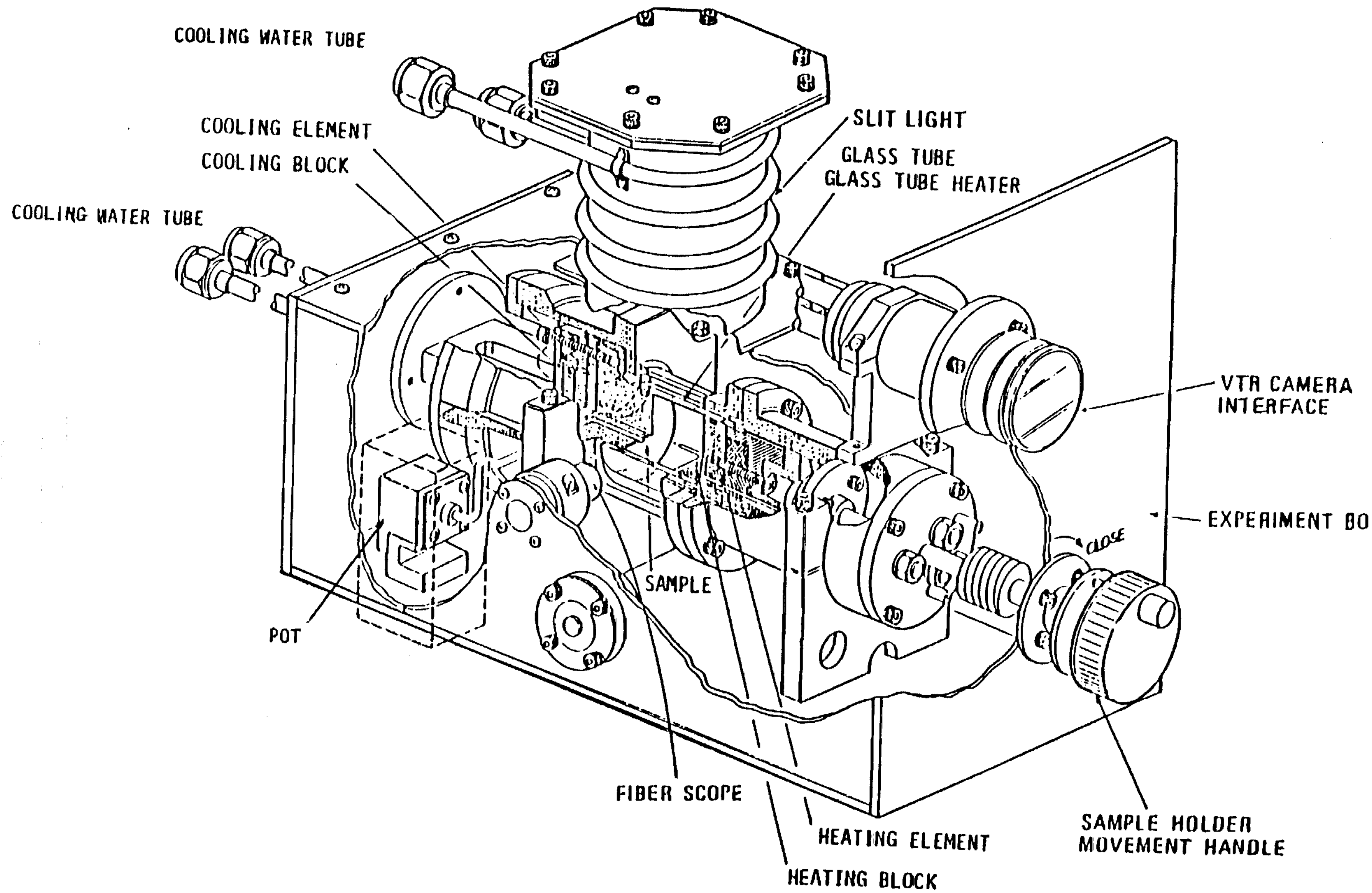


Figure 4. Marangoni Convection Unit.