CFD analysis of smart semiconductor electro-conductive Marangoni melt cavity flow

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1. INTRODUCTION

When free surfaces are present in natural convection flows it has been shown that motion is induced in the fluid at surface tension at the free surfaces. This so-called Marangoni convection or thermocapillary convection plays a crucial role in various aspects of industrial applications. Magnetic fields have been shown to effectively regulate the heat transfer rates and stabilize flows in semiconductor crystal growth. Oscillatory instability driven by Marangoni forces on crystal surfaces and magnetic fields have been shown to produce compositional instabilities and misfit dislocations. A further intriguing mechanism for Marangoni magnetic convection is offered by deploying porous media in these systems. In this work, we present a mathematical and numerical study of the transient thermo-hydraulics of the melt of gallium arsenide (GaAs) containing conducting fluid in a rectangular porous medium enclosure with buoyancy and internal heat generation effects. The governing equations comprising the mass conservation, momentum, energy, and magnetic field are solved in their coupled form in a finite-volume context using a finite-difference scheme. The magnetic field is applied as an elevated magnetic bias over a horizontal lid-longitudinal wall (or vice versa). The upper enclosure lid is assumed to be isothermal and at zero temperature gradient and an impermeable bottom boundary is imposed on the enclosure. The governing thermo-physical parameters are shown to be the Marangoni number for surface tension (thermocapillary) effects, Prandtl number (Pr), conductive number for buoyancy effects (Da), aspect ratio (A), Nusselt-hydrogen number (Nu), Darcy number for bulk porosity resistance (Da), Forchheimer number (Fr), and the internal heat generation parameter (Gr) for the latter being a function of the solid (a) and liquid (b) thermal conductivities. The Darcy number is employed to identify the boundary value problem numerically: rectangular and circular [100] substrates are compared. Solutions for the case of A = 1.0 (darcy number 100 porous medium) are compared with similar studies showing excellent correlation. The model field applications in the bulk crystal growth of semiconductors, electromagnetic control of materials processing, etc.

2. MATHEMATICAL MODEL AND DATA

Marangoni-convection flow problems in the presence of magnetic fields have been studied extensively due to semiconductor and fuel-cell applications. Magnetic fields have been shown to effectively regulate the heat transfer rates and stabilize flows in semiconductor crystal growth. Oscillatory instability driven by Marangoni forces on crystal surfaces and magnetic fields have been shown to produce compositional instabilities and misfit dislocations. Magnetic field dampens hydrodynamic oscillations and can increase the stability number of the crystal growth process. Magnetic heat generation effects in the circulating fluid are also important in the context of laser crystallization. Here we study the effects of magnetic field on the convection heat transfer in a 2-D rectangular enclosure.

The key parameters are: Surface tension (thermocapillary) effect number (Ma), Prandtl number (Pr), Conductive number for buoyancy effects (Da), aspect ratio (A), Nusselt-hydrogen number (Nu), Darcy number for bulk porosity resistance (Da), Forchheimer number (Fr), heat generation parameter (Gr) for the latter being a function of the solid (a) and liquid (b) thermal conductivities. We present some representative solutions for Darcy number effect (Da) permeability of the enclosure porous medium. In all these simulations we have constrained Marangoni number (Ma) to be 100. A balance thermal transport via flow (convection) due to a gradient in surface tension, with thermal diffusion. When Ma is small thermal diffusion dominates and the there is no flow, but for large Ma, there is a convection dominated flow. This is called Bénard-Marangoni convection. Isotherms are plotted on the left and streamline on the right of all subsequent visualizations.

Fig 3: MAC Computations with different Darcy number and/or aspect ratio

3. VORTICITY FORMULATION

Transforming the boundary value problem with appropriate dimensionless numbers and the vorticity formulation, we have the new model.

Fig 1: Marangoni convection phenomena

4. SELECTED MAC SIMULATIONS

The heat transport phenomena are studied to internal data, surface, and boundary conditions are required. A balance is needed between the surface tension gradient and shear stress at the free surface essential for generating thermo-capillary (Marangoni) convection in the enclosure. These are defined as follows:

Fig 2: Model for Marangoni semiconductor melt enclosure

REFERENCES