TRAVELLING MAGNETIC FIELD INFLUENCE ON CRYSTAL GROWTH BY BRIDGMAN METHOD

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Summary The paper presents the results of fully unsteady numerical simulation of travelling magnetic field (TMF) influence on semiconductor crystal growth by vertical Bridgman method. We obtained the fields of stream function, temperature, dopant distribution in melt and in grown crystal with and without TMF, and analysed the influence of TMF on crystal growth.

PROBLEM FORMULATION

The usage of magnetic fields is known to be an efficient way to control the flows of electrically conductive fluids and therefore allowing to control heat and mass transfer in the melt and, in turn, in the resulting crystal. Bridgman method is employed both under microgravity conditions and at the Earth. In the present paper we consider the growth under terrestrial conditions.

The following model is used in the numerical simulations. A cylindrical domain is filled with two phases of a semiconductor: the melt is on top, the crystal is at the bottom. The solid-liquid interface is curved and is subjected to determination along the simulation process. The position and shape of interface are determined from the temperature distribution in both melt and crystal.

Both the experimental observation and numerical simulation indicate that the Bridgman growth is greatly influenced by buoyancy-induced convection. The application of magnetic field during the growth gives an instrument for the convective flow control.

Governing equations and boundary conditions

The melt is assumed to be Newtonian and isothermally incompressible; hence it is possible to use time-dependent Navier-Stokes equations in the Boussinesq approximation. We use the following boundary conditions. On the lateral wall of ampoule the Biot law is imposed. The top and lateral wall of the domain, and the interface are impermeable for the liquid as well as for the dopant; the no-slip boundary conditions are applied there as well. The position and shape of interface are determined front velocity from the temperature balance condition on the crystal/melt interface. Latent heat and the difference in heat conductivities of phases are taken into account. For the detailed description of the model and method we refer to [1,2]. Application of TMF could significantly influence the flow structure. It can even establish meridional flow, directed opposite to the buoyancy convection, which seems attractive for crystal growth. The low frequency approximation is adopted for the calculation. In this approximation, induced magnetic field is neglected. The average Lorentz force for the non-zero motion of the medium contains terms linear in velocity. Theoretical basis for TMF application technique with substantiation of all approximation is described in details in [3]. The frequency of the applied voltage is 50 Hz. Other ampoule and material parameters are taken from [1,2].

ALGORITHM AND NUMERICAL PROCEDURE

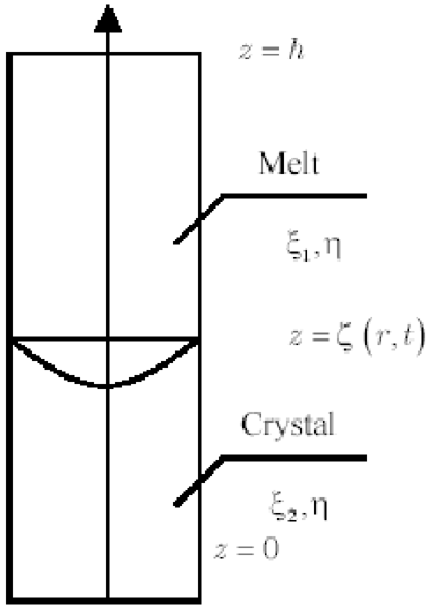
We solve the problem in 2-d approximation using stream function - vorticity formulation. However, the geometry of problem is still very complex due to the moving curved melt/crystal interface.

In this situation it is convenient to make coordinate transformation:

$$\eta = r\,,\ \xi_2 = \frac{zf}{\zeta}z\,,\ \xi_1 = h + a\left(z - h\right);$$

where $a = \dfrac{zf - h}{\zeta - h}$, zf - front position.

Here r, z is physical curvilinear coordinate, ξ_1, ξ_2, η are computational rectangular orthogonal coordinates in computational domain with unmoving flat interface. Expressions for derivatives are not written here because of their complexity. The equations and boundary conditions were rewritten in new coordinates and solved by finite difference method.



Computational procedure:

1. Temperature & solid/liquid interface setup (go to 2).
2. Momentum equation for vorticity, Poisson equation for stream function, equation for solute concentration (go to 1), while characteristics will be settled.
3. Temperature & solid/liquid interface setup. Calculate new position of moving heater (go to 4).
4. Momentum equation for vorticity, Poisson equation for stream function, equation for concentration. Go to next time step while heater arrive at the top of ampoule. (go to 3)

NUMERICAL RESULTS

Numerical results obtained for GaAs growth under TMF at different intensity are presented in Figs.1-3. Fig.4 demonstrates longitudinal crystal slices. In our case TMF intensify upper vortex and weaken down vortex. From the figs it is shown that TMF flows leads to interface decreasing.

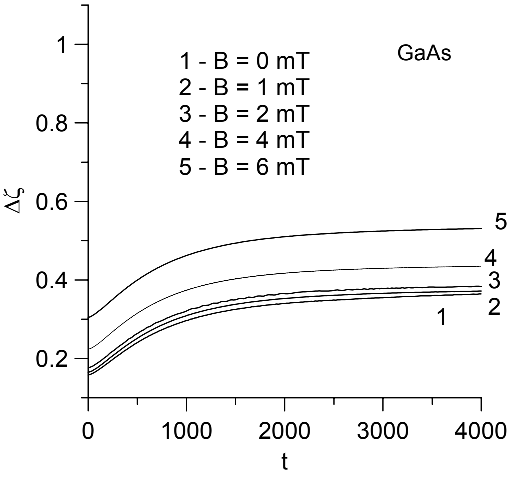


Fig.1. Effect of TMF on the temporal evolution of interface deflection GaAs

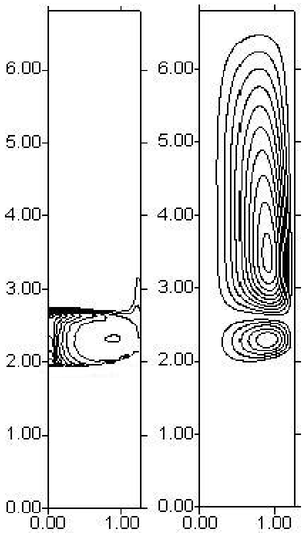


Fig.2 Snapshots for concentration and stream function was taken at t=800 s, B=0mT

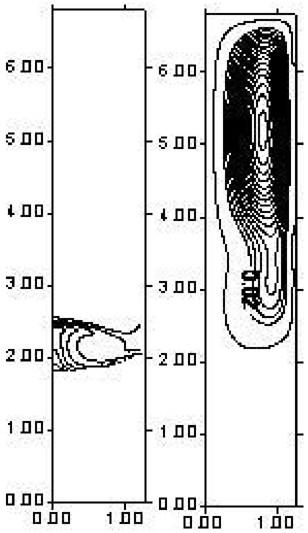
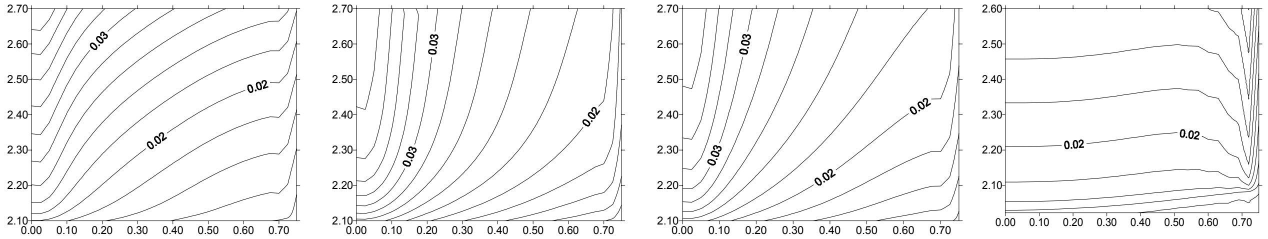


Fig.3. Snapshots for concentration and stream function was taken at t=800 s, B=4mT



B=0 mT

B=4mT

B=6mT

B=10mT

Fig.4

CONCLUSION

We can resume that, in contrast to alternating axial magnetic field, TMF even of not very high intensity greatly influences the melt flow structure, and hence the dopant distribution in the resultant crystal. Under the influence axisymmetric traveling magnetic field intensity of buoyancy-induced flow increases and interface deflection decreases, which is favorable for crystal growth.

References

[1] Adornato P.M., Brown R.A.. J. Cryst.Growth 80 155-190, 1987.

[2] Lan C.W., Ting C.C. J. Cryst.Growth 149 175-186, 1995.

[3] Mazuruk K. Adv. Space Res. 29, 4, 541-548, 2002.