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The Reconstruction of GaSb:Te Crystal Growth in Space Experiment

A.I. Prostomolotov [1], **N.A. Verezub** [1], **A.E. Voloshin** [2], **and T. Nishinaga** [3]

[1] Institute for Problems in Mechanics of RAS, prosto@ipmnet.ru
[2] Institute of Crystallography of RAS
[3] University of Tokyo

Quantitative X-ray topography of GaSb:Te crystal, grown during Chinese unmanned space experiment [1] has showed a high structural perfection in its greater area, which corresponds to the crystallization of a rounded interface. At the same time, the defects in the field of a face growth have been revealed after some time of the crystallization onset. The control of parameters during the growth process was absent. It was a reason for the reconstruction of the crystal growth history using a two-dimensional map of the measured Te concentrations (Fig. 1) in the crystal and mathematical modeling of the growth process and taking into account the analysis of possible factors that influenced the crystal growth characteristics [2].

The work has developed the mathematical models of various levels of complexity for calculating the crystallization process of GaSb:Te (from semi-analytic and 2D-hydrodynamic models describing the convective heat and mass transfer in the melt [3] to the conjugate thermal models (Fig. 2) that calculate the crystallization process in the real heating conditions and geometry of ampoule assembly).

Analysis of the applicability of analytical models (Barton Prima-Slichter (BPS) and Ostrogorsky-Muller (OM)) was carried out in comparison with 2D-modeling of convective impurity transport. The dependences of the effective segregation coefficient upon the maximum melt velocity, $K_{eff}(V_{max})$, under variations of the microgravity values, the geometrical melt parameters and the thermal conditions of the crystallization process. It gave a possibility to consider BPS-model as a more accurate one, as well as offer its formula expressions for highly elongated melt areas and large velocities. We showed the non-monotonic variation of macro-inhomogeneity impurity distribution on the crystallization interface (CI) upon the Grashoff number [3].

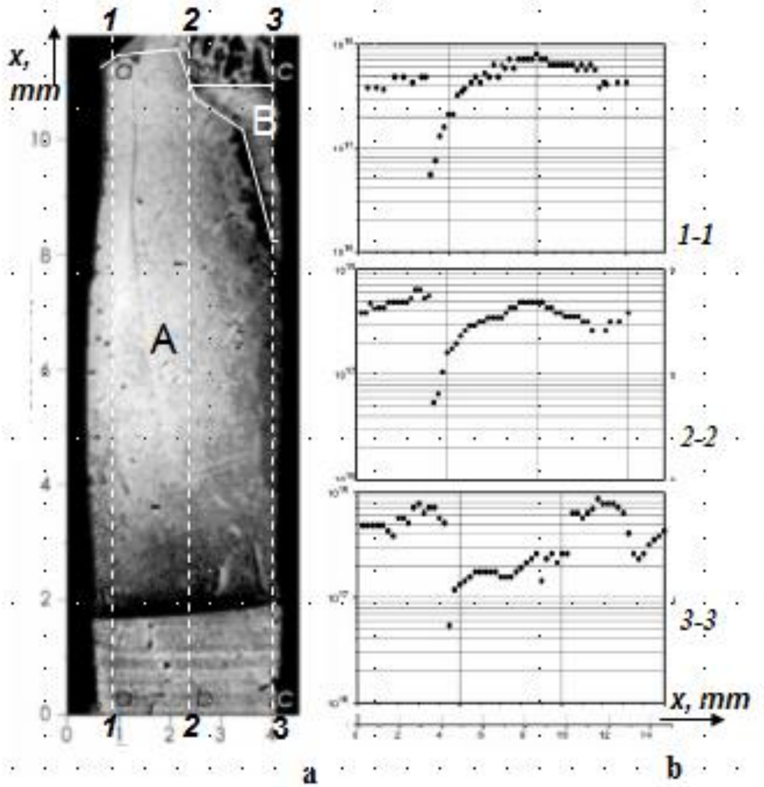

Fig. 1. Space grown single crystal of Te-doped GaSb: a – plane wave reflection topograph of the longitudinal cut with two crystallization areas (A – the rounded interface and B – the face growth); b – Te distribution along paths (*1–1*), (*2–2*) and (*3-3*) (see Fig. 1a) measured by spatially resolved photoluminescence.

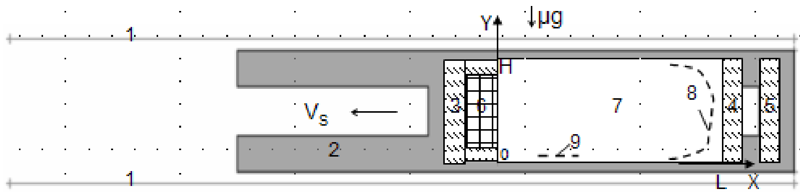

Fig. 2. The conjugated model of GaSb:Te Bridgman's crystallization: 1 – heater, 2 – quartz ampoule moving with V_S rate (see the arrow), 3 ÷ 5 – graphite inserts, 6 – seed, 7 – melt under μg - gravity, 8 – free melt surface at the crystallization onset, 9 – free melt surface arising in crystallization process.

The influence of the heating conditions and the ampoule velocity on the crystallization rate and CI shape was investigated. We studied the influence of main factors that influenced on the crystal quality: on the K_{eff} values, growth faces and transverse impurity inhomogeneity on the CI. The main factors were the thermal conditions (the values of the axial and radial temperature gradients, cooling rate) and the transverse ampoule size. It may be noted that the space experiment was carried out in conditions close to optimal. The realized values of the crystal growth rate have provided an acceptable level of radial inhomogeneity and temperature gradient (the relatively small size of the faces growth). The small diameter of the growth ampoule has provided a large "margin of safety" in relation of a convective influence on the heat transfer.

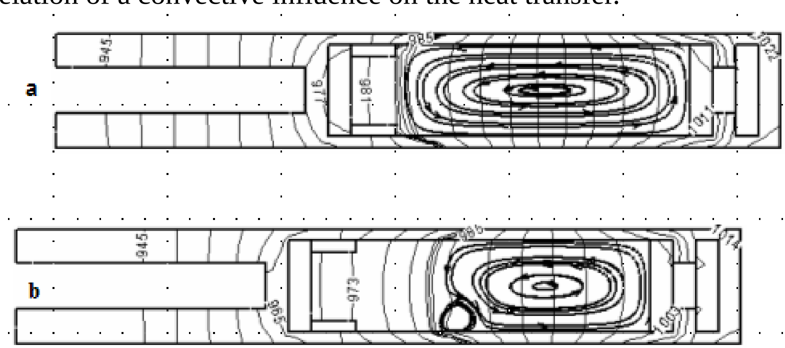

Fig. 3. The isotherms (K) and the streamlines for two crystallization stages, and μg = 9.81 cm/s^2, corresponding to the maximal melt velocity V_{max} [cm/s]: a – 0.012, b – 0.057.

The only deficiency of this experiment was the faces growth some time after the onset of crystallization. It was shown that the moment of the additional free surface formation near CI corresponds to the contact of the melt with the graphite insert. The non-coaxial contact relatively to the ampoule may be the possible reason of a thermal asymmetry and a growth process disturbance. The face growth was caused by such sharp change of the thermal conditions that led to the stronger thermocapillary effect and dramatically increasing the convection velocity. For $K_{eff}(V_{max})$ dependence it corresponds to a shift in the field of sharp change of K_{eff} for small variations in the thermal parameters. It explains the observed features of the impurity distribution in the field of faces growth.

References

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