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Stability of interfacial thermal balance in thick β-Ga_2O_3 crystal by edge-defined film-fed growth

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Abstract

1.A furnace structure with larger axial temperature gradient (from 17.40K/mm to 27.46K/mm) over the die was designed by ANSYS FLUENT software.

2.Considering the interface thermal balance and the pressure balance of the meniscus, the relationship between the overheating temperature on the upper surface of the die and the pulling speed was calculated.

Background

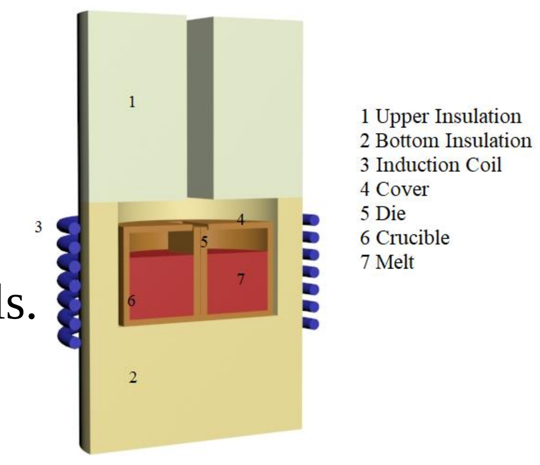


Fig.1 Schematic diagram of EFG method for β-Ga_2O_3 ribbon crystals.

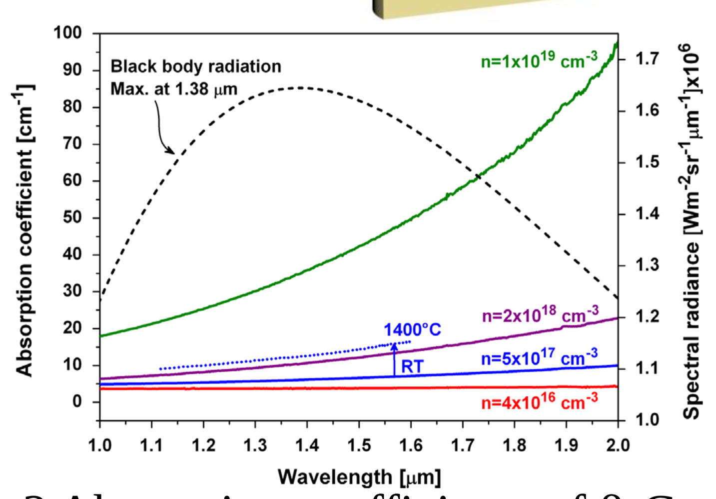


Fig.2 Absorption coefficients of β-Ga_2O_3 with different carrier concentrations

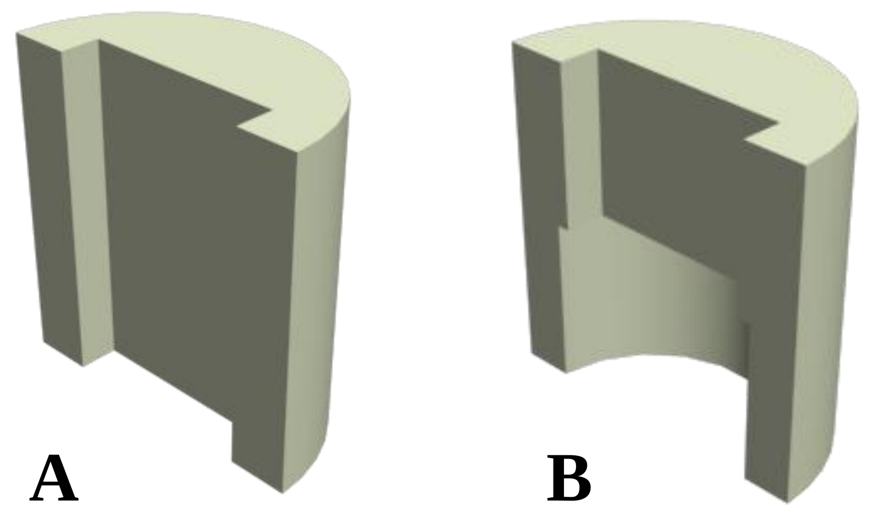
The EFG method is commonly used to grow large size β-Ga_2O_3 single crystals, which have good application prospects in high power electronic devices. When growing n-type thick crystals with high carrier concentration, the growth failure is often caused by the thermal imbalance of the growth interface even with a very slow pulling speed. Thus a larger axial temperature gradient is necessary for n-type β-Ga_2O_3 crystal growth. The maximum pulling speed is also calculated.

Objectives

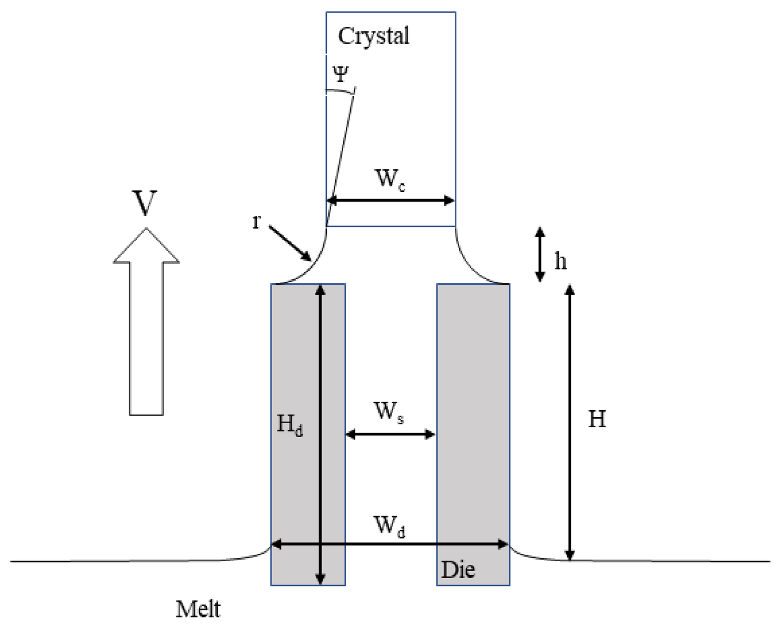
By changing the thermal field structure and growth process, the appropriate temperature field is designed to solve the problem of thermal imbalance at the crystal growth interface.

The temperature gradient in the crystal is approximated as a reference in calculating the maximum pulling speed.

Methods



Thermal insulation structure adjustment:
Original (A) and adjusted (B) upper insulation, respectively. The latter has a larger cavity.



Growth process adjustment: Considering the pressure balance and heat transfer on the meniscus, the maximum pulling speed at different positions in the crystal is calculated.

Fig.3 A and B upper insulation and meniscus diagram.

$$\gamma\frac{(W_d-W_c)\cos\Psi-2h\sin\Psi}{h^2}=\rho_l gH+12\mu v\frac{\rho_s}{\rho_l}\frac{W_c}{W_s^3}H_d$$

$$K_s grad_s=K_l grad_l+\varepsilon\sigma\left((T_m+\Delta T)^4-T_m^4\right)+\rho_s vL_s$$

Results and discussions

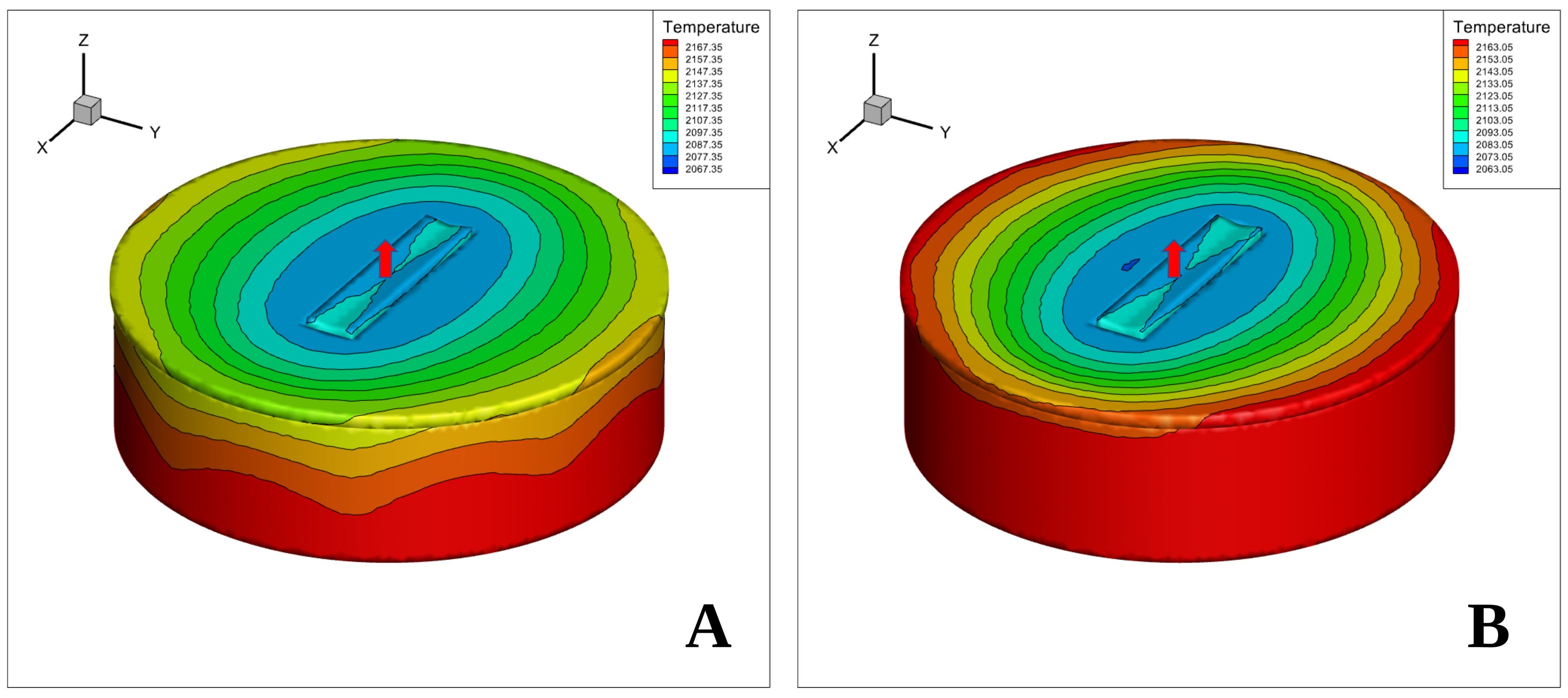


Fig.4 Temperature field in A and B configurations, respectively.

The temperature distribution on the upper surface of the die is almost the same. However, in the B configuration, the temperature gradients of the crucible and cover are larger. The axial temperature gradient at the red arrow of the two configurations are 17.40K/mm and 27.46K/mm, respectively. It increases by about 57.5%.

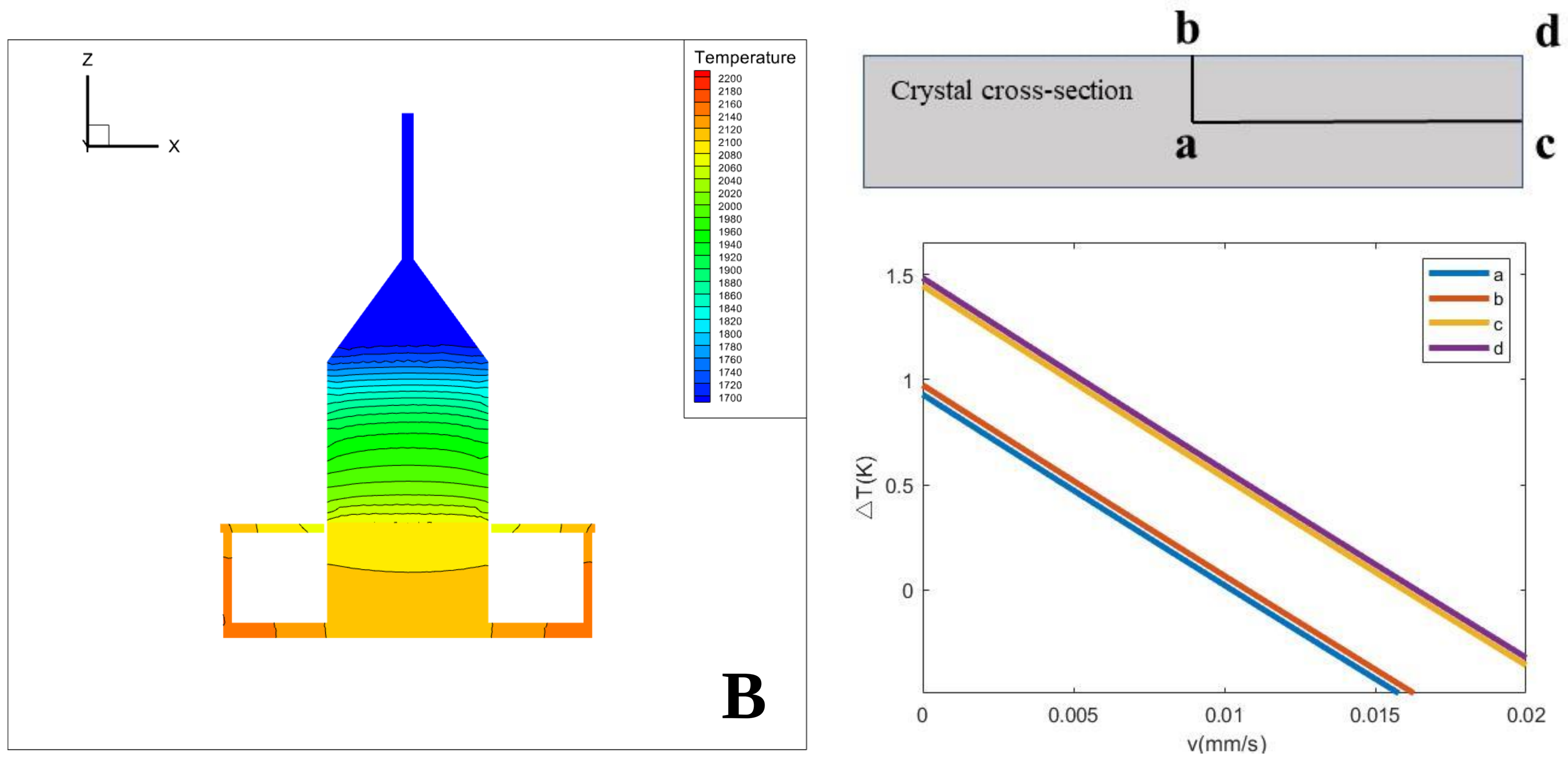


Fig.5 The temperature field in B after adding a crystal. Four different positions in the crystal and the function of their die upper surface overheating temperature and pulling speed.

The temperature gradients at four positions a, b, c and d are 7.02K/mm, 7.36 K/mm, 10.92 K/mm and 11.2 K/mm, respectively. The maximum allowable pulling speed at these four positions is calculated, and the crystal center will pull off first, and then the edge. This is consistent with the realistic crystal growth. The speed of 20mm/h is selected for crystal growth experiment. High quality β-Ga_2O_3 single crystals were obtained through these two improvements.

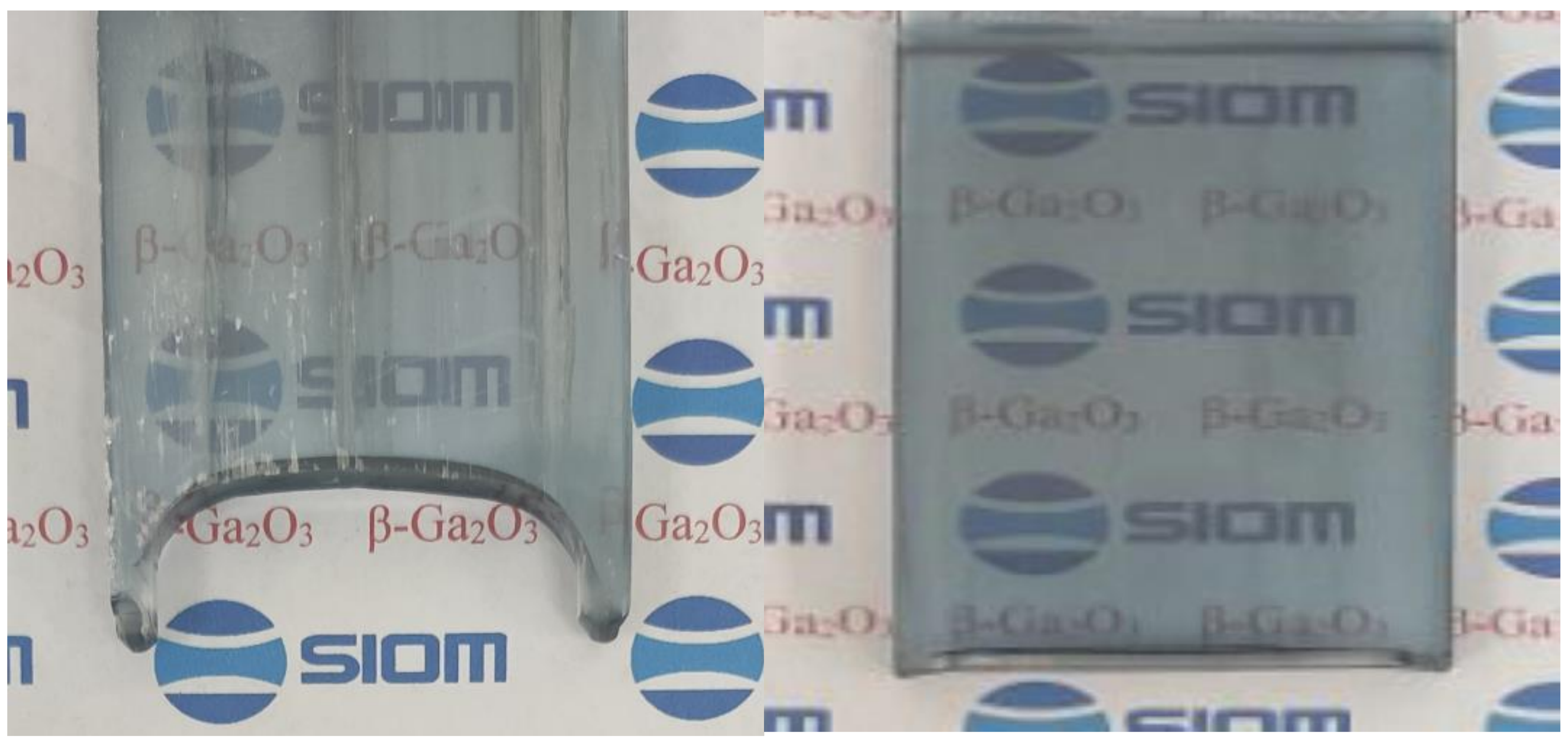


Fig.6 Crystals with unstable (left) and stable (right) growth interface.

Summary

The overheated fusing starts from the center of the crystal and then to the edge, which is consistent with the actual growth of the crystal. The pulling speed of 20mm/h was selected for the growth experiment. Through the optimization of thermal field environment and the selection of pulling speed, high-quality two-inch β-Ga_2O_3 crystals without overheat fusing was realized.