Melting Efficiency in β-Ga_2O_3 through Induction Skull Melting Technology

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Abstract: Oxides crystal growth using the cold crucible (OCCC) method is a new application of induction skull melting technology (ISM). In this study, a 3D numerical model was proposed by analyzing the ignition efficiency of starting material and the influence of power, frequency, and crucible diameter on the area of steady melting zone during β-Ga_2O_3 melting by ISM. The steady Ga_2O_3 temperature by ISM was calculated under different start-up conditions, which considers the effects of electrical properties, locations, and shaped of starting material. In addition, the minimum power required to hold the melt without the starting material and corresponding melt volume under different frequencies and crucible diameter were also calculated. The results show that starting material with an electrical conductivity of 10^4 to 10^5 S/m, location at the middle of coils, and plate shape exhibited high ignition efficiency. After removing the starting material, the critical power and steady melt volume decrease with increased frequency. Crucibles with 90 mm diameter and power supply with frequency of 200 kHz are suitable for the melting of β-Ga_2O_3 considering the energy loss and economic efficiency.

Keywords: Ga_2O_3; ignition; ISM; numerical simulation

1 Introduction

With the development of semiconductors in the field of microelectronics, researchers have increasingly favored semiconductors with wider bandgaps. Gallium oxide (Ga_2O_3), one of the fourth-generation ultra-wide bandgap (UWBG) semiconductors, has become a competitive candidate due to its excellent properties. With a bandgap of more than 4.5eV, Ga_2O_3 has a higher breakdown electric field and better tolerance to high temperature and radiation than those of the third-generation semiconductors[1-3]. Coupled with a superior Baliga's figure-of-merit (BFOM) and low on-resistance, Ga_2O_3 becomes a promising material for high-power applications in electronic devices[4]. Moreover, the large bandgap leads to its cut-off wavelength located in the deep ultraviolet region ranging from 250nm to 280nm, which meets the requirements of deep ultraviolet light (DUV) detection. Photodetectors based on Ga_2O_3 are insensitive to visible and infrared light exhibiting highly accurate ultraviolet (UV) detection [5]. Besides, Ga_2O_3 offers great potential for nuclear radiation detection with high density (6.44 g·cm^{-3}), excellent scintillation properties, and radiation resistance [6]. However, it is difficult to reduce the cost of β-Ga_2O_3 single crystal growth due to the fact that precious metal crucibles are essential for the oxygen-rich growth environment. In recent years, oxide crystal growth from cold crucible (OCCC), which was a new application of induction skull method, was proposed to reduce the single crystal cost with the substitution of cold copper crucible for precious metal crucibles. As a new process for β-Ga_2O_3 single crystal growth, it is quite effective to reduce the cost of trail by using numerical simulation. In this paper, the ignition efficiency of starting material and the influence of power, frequency, and crucible diameter on the area of steady melting zone during β-Ga_2O_3 melting by ISM were analyzed.

2 Experimental procedure

Figure 1 depicts the ISM melting system. Periodic boundary condition was applied to a portion of the crucible to reduce the simulation calculations.

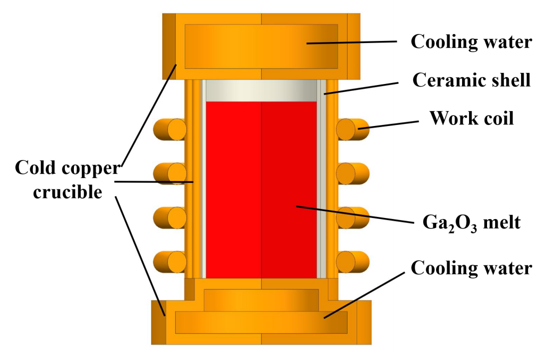

Figure 1 Schematic view of ISM melting system

Result and discussion

Effect of start-up conditions on the steady Ga_2O_3 temperature.

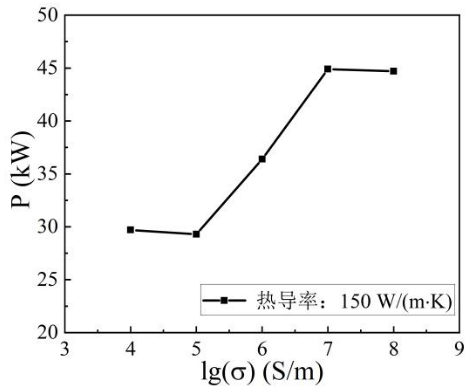

Figure 2 Minimum power required to hold the melt under different electrical conductivity of ignitions

Ignitions with an electrical conductivity of 10^4 to 10^5 S/m, location at the middle of coils, and plate shape exhibited high ignition efficiency.

Effect of frequency on the minimum power required to hold the melt.

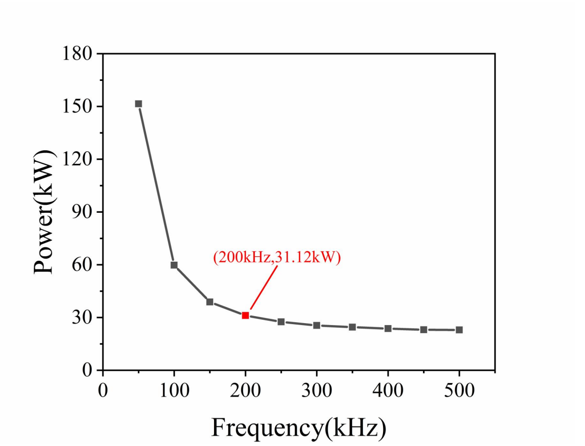

Figure 3 Minimum power required to hold the melt under different frequency

The minimum power required to hold the melt reduced with increased frequency. In addition, the minimum power under 200 kHz is 31.12 kW, which is similar to the experimental power 30 kW. Crucibles with 90 mm diameter and power supply with frequency of 200 kHz are suitable for the melting of β-Ga_2O_3 considering the energy loss and economic efficiency.

3 Conclusion

In this work, we proposed a numerical model for Ga_2O_3 melting with ISM technology. The simulation results showed that ignitions with an electrical conductivity of 10^4 to 10^5 S/m, location at the middle of coils, and plate shape exhibited high ignition efficiency. In addition, the minimum power required under different crucibles diameters and frequencies are calculate. Crucibles with 90 mm diameter and power supply with frequency of 200 kHz are suitable for the melting of β-Ga_2O_3.

References

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