FZ シリコン結晶成長における非対称三相線の数値解析

Numerical analysis of asymmetric three-phase line in the floating zone silicon

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Numerical calculation has been conducted to investigate the asymmetric heat transfer, fluid flow and three-phase line in the floating zone (FZ) silicon crystal growth. In the FZ method, a needle-eye inductor is used to grow the large-diameter (≥100 mm) single crystal silicon. The needle-eye inductor has one main slit and three side slits. This asymmetric configuration induces the asymmetric heating on the free surface of the silicon melt and three-phase line. R. Menzel et al. [1] observed that the spillage down of melt occurred during the crystal growth because of the inhomogeneous heating on the three-phase line. To investigate the effect of asymmetric heating on the deflection of three-phase line, electromagnetic (EM) and heat transfer calculations are conducted [2]. Fig. 1 shows that the current density distribution along the three-phase line is not homogeneous as a result of asymmetric high-frequency inductor. The asymmetric current density caused asymmetric heating and defection of three-phase line. The deflection of three-phase line is calculated to compare with the experimentally observed results (Fig. 2). Both the calculation and experimental results show a trend that along the rotation direction, the three-phase line descends quickly and ascends slowly below the current supplier. The inhomogeneous local growth rate at the three-phase line causes the asymmetric deflection of the three-phase line below the current supplier. When the local growth rate is lower than the pulling rate, the re-melting phenomenon occurs.

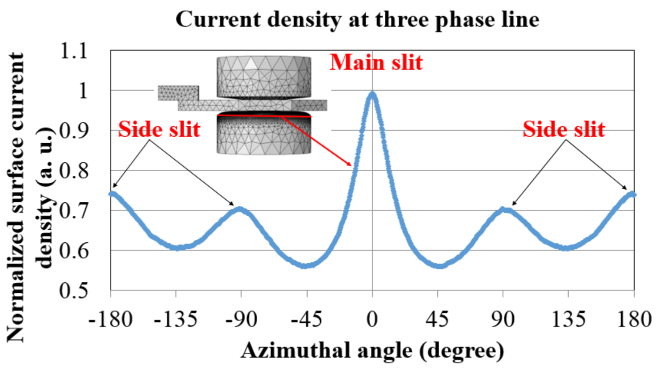

Fig. 1. Normalized surface current density distribution along the three phase line

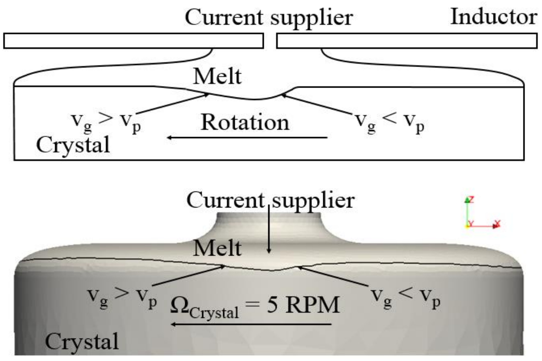

Fig. 2. Comparison of the shape of the three-phase line between experimental observation results [1] and calculation results.

Reference

[1] R. Menzel, Growth Conditions for Large Diameter FZ Si Single Crystals, PhD thesis, (2013).

[2] X.F. Han, X. Liu, S. Nakano, H. Harada, Y. Miyamura, K. Kakimoto, Crystal Research and Technology, (2018) 1700246.

Acknowledgement

This work was partly supported by the New Energy and Industrial Technology Development Organization (NEDO) under the Ministry of Economy, Trade and Industry (METI)

