In-situ determination of crystal-melt interface shape evolutions via probing growth interface electromotive force

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A stable and controllable crystal-melt interface is the primary goal of directional solidification technology, and has been studied extensively owing to its fundamental importance in materials science and industry. Although the microscale *in-situ* observations of phase boundary have shown magnificent results, the macroscopic crystal-melt interface evolution of bulk crystal growth has puzzled crystal growers for decades. For example, even for the widely-used melt growth method, the interface state of a growing boule in the Czochralski system is unobservable. Unfortunately, precisely in this blind spot, the complex melt flow pattern and elusory thermal field induce crystallization fluctuation, enrich defects, and damage the uniformity of a growing crystal. Once we can trace the real-time kinetics of the boundary layer, a significant step forward in understanding the hydro- and thermo-dynamic behaviors that drive boundary phase change can be achieved, which is closely linked to current challenges in interface stabilization, solute homogenization, and defect propagation for oxide, semiconductor, and metal crystalline materials.

We determine interface shape evolutions via analyzing the time series of growth interface electromotive force (GEMF) of a growing boule, which visualizes some fundamental unobserved phenomena during a practical bulk crystal growth [1,2]. Specifically, the GEMF-based *in-situ* diagnostics not only trace the phase change kinetic trajectory in the crystal-melt boundary layer, but also quantify the corresponding interface heat and mass transfer, and even generalize an evaluation principle for interface stability. More significantly, experimental as-grown boules and hydrodynamic numerical simulations confirm the feasibility of and provide physical insights into our GEMF-based determination, respectively [3,4]. This breakthrough offers significant evidence of understanding the macro near-equilibrium phase-change kinetic process traveling through thermodynamic equilibrium states, and clarifies the unrecognized factors affecting interface evolutions. Moreover, it creates a real-time and quantitative interface feedback method for industrial melt-growth systems and will inspire diverse melt growth technologies to manufacture high-quality and large-size crystalline materials.

References

[1] Yunzhong Zhu, Junling Ding, Decai Ma, Biao Wang, Interface diagnostics: In-situ determination of crystal-melt interface shape evolutions via probing growth interface electromotive force, *Acta Materialia* 2022; 238: 118242.

[2] Yunzhong Zhu, Zhihua Liu, Wenjia Wang, Decai Ma, Biao Wang, In situ visualization of the quasi-periodic crystal growth interface fluctuation by growth interface electromotive force spectrum in a Czochralski system, *Crystengcomm* 2019; 21: 1107.

[3] Yunzhong Zhu, Feng Tang, Decai Ma, Yang Liu, Shaopeng Lin a, Biao Wang, In-situ detection of convection and rotation striations by growth interface electromotive force spectrum, *Journal of Crystal Growth* 2018, 487: 120–125.

[4] Yunzhong Zhu, Decai Ma, Siwei Long, Biao Wang, In-situ detection of growth striations by crystallization electromotive force measurement during Czochralski crystal growth, *Journal of Crystal Growth*, 2017; 475: 70–76