Analysis of the Engulfment of Argon Bubbles during Silicon Crystal Growth

Swanand C. Pawar, Jeffrey J. Derby*
*derby@umn.edu
Chemical Engineering & Materials Science, University of Minnesota, Minneapolis, MN 55455, USA

Bubbles of 5–100 microns in size are observed in many crystals grown from the melt. While some materials, such as sapphire, readily incorporate bubbles, a single argon bubble engulfed during the Czochralski growth of single-crystal silicon can produce stresses high enough to generate dislocations, resulting in a catastrophic loss of structure. A better understanding of the fundamentals of bubble engulfment will increase process yields and reduce costs.

The engulfment of bubbles during solidification is determined by a balance of repulsive van der Waals forces between the bubble and the solidification interface and drag forces arising from the flow around the bubble and into a thin liquid gap between particle and interface, typically on the order of 10 nanometers in thickness. When drag forces overcome repulsive forces, the bubble is engulfed, otherwise it is steadily pushed ahead of the advancing interface. Since drag increases with bubble size and velocity, there exists a critical growth velocity at which a bubble of a certain size is engulfed. However, drag forces are strongly dependent upon the nature of flows along the bubble surface (which may include thermo-capillary effects) and shape of the solid-liquid interface as the bubble approaches. Thus, the critical velocity is affected by significant and nonlinear interactions involving heat transfer, pre-melting, and Gibbs-Thomson phenomena.

We present new results from a finite-element, moving-boundary analysis of argon bubble engulfment during silicon crystal growth. We highlight significant differences between argon bubble and silicon carbide particle engulfment [1–3]. The relationship between critical growth velocity and bubble size is presented, which establishes guidelines to avoid engulfment.

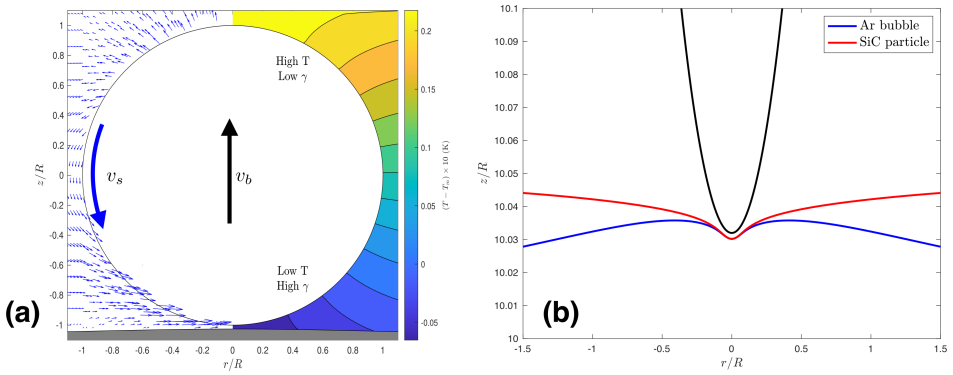

Figure 1: (a) Melt flow is affected by thermocapillary surface forces (left), and the thermal field is affected by low conductivity of the bubble (right). (b) Very different solidification interface shapes arise during engulfment of a SiC particle versus an Ar bubble, respectively shown by blue and red curves (bubble is shown by black curve).

References

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