The morphology in the transition range of doublon and dendrite with phase-field model

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I. Introduction

I(A) Dendrite

Dendrite grows in nonequilibrium conditions. The tip has a form like parabola, and in the backward of the interface, there are many side branches. The whole shape looks like a trunk of tree with branches.

I(B) Doublon

The doublon has a form of pair of symmetry broken fingers and has the strong stability, that is, even if one of the two fingers wins, the other finger catches up. Therefore, the oscillating groove pattern certainly exists in the transition range of stable and diffusion equation because the boundary conditions are defined on the moving interface. Instead, we use Phase-field Model.

I(C) Motivation

We would like to make clear the unclearly boundary line of dendrite and doublon in the phase diagram.

II. Computational method

II(A) Phase-field model

\[
\begin{aligned}
\partial_t \theta &= \nabla^2 \theta - \delta (\theta) \epsilon_1 \nabla \cdot \nabla (\nabla \theta) \\nabla \theta + \frac{1}{2} \nabla^2 (\nabla \theta^2) \\
\partial_t u &= \nabla^2 u - \delta (\theta) \epsilon_2 \nabla \cdot (\nabla \theta \nabla \theta) \\nabla \theta + \frac{1}{2} \nabla^2 (\nabla \theta^2) \\
\end{aligned}
\]

- The tuned parameters are the degree of supercooling \( \theta \) and the strength of surface tension anisotropy \( \epsilon \).
- Points to distinguish between stable or unstable are following.
  - The difference of two tip positions.
  - Diffusion length \( D/v \)
  - Apperances.

II(B) Initial condition

The simulations were performed in a channel (rectangular box) of size \( 480 \times 192 \). Mirror symmetric boundary condition is applied.

II(C) Stable or unstable

- The tuning parameters are the degree of supercooling \( \theta \) and the strength of surface tension anisotropy \( \epsilon \).

III. Result

III(A) Surface tension doublon

We show several growth pattern for surface tension doublon. (a) Stable doublon made by surface anisotropy. (b) One finger wins. (c) Surface tension doublon whose groove is partially buried. (d) Two finger pattern. (e) Oscillating groove. (f) A surface tension dendrite.

III(B) Phase diagram of surface tension doublon

Fig. 2 is a phase diagram of surface tension doublon. The vertical axis is the degree of supercooling, the horizontal axis is the strength of surface anisotropy.

- As the anisotropy increasing, the doublon pattern is likely to be collapsed.
- In the high supercooling region, burried groove pattern is appeared.
- Two finger pattern exists in the low supercooling region. The effect of boundary condition is important because the diffusion length \( D/v \) is too large.
- The transition range between doublon and dendrite, oscillating groove pattern is appeared.

III(C) Oscillating groove

Figs. 3 show the patterns simulated in long channel. (a) Stationary oscillating pattern. (b) Irregular oscillating pattern. (c) The oscillation is gradually decaying.

Figs. 4 show the difference between two tip positions.

Figs. 5 shows the standard deviation of the difference between two tip positions changing the surface tension anisotropy and supercooling.

- Stationary tip oscillation is appeared in narrow parameter range and the amplitude is larger as \( \theta \) is increasing.
- Irregular tip oscillation is found in the transition range of stationary oscillation and decaying oscillation.
- As the strength of anisotropy increasing, the oscillation starts suddenly and finishes gradually.

IV. Summary

- Oscillating groove pattern certainly exists in the transition range of stable and collapse patterns.
  - In narrow parameter range, amplitude of oscillating one could give out. In this case, doublon pattern gradually collapsed as the development of time.

V. Reference