深層強化学習を用いたRF-TSSG法によるSiC結晶成長プロセスの最適化

The optimal control of SiC crystal growth in the RF-TSSG system using deep reinforcement learning

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RF-TSSG process is utilized to grow high quality SiC crystals. The authors previously found that Marangoni convection is dominant in this system [1]. This strong convection makes supersaturation in the melt nonuniform and enhances growth rate variations. Thus, in turn it affects the crystal quality adversely. In order to minimize this adverse effect of Marangoni convection, a combination of computational fluid dynamics (CFD) and deep reinforcement learning (DRL) was introduced to the present research for obtaining the optimal melt flow pattern.

The governing equations for the melt flow are the continuity, momentum balance, energy balance, and mass transport equations. The initial RF-coils frequency and the peak current are 25 kHz and 6.285 A/m^2. The process of DRL introduced to the present study is shown in Fig. 1. An agent is consists of deep neural networks that input flow field (state) and output action to control the environment. The agent tries to learn through the feedback of a reward. In our case, the controlling problem is expressed as:

$$\boldsymbol{F}_{\mathrm{E}}(t) = \boldsymbol{a}(t)\boldsymbol{F}_{\mathrm{E\_intial}}, \qquad r = -G_{xy} + v_g,$$

where $\boldsymbol{a}$ is a *virtual actuator* that adjusts the EM, r is the reward function for the calculation of growth rate gradient G_{xy} and magnitude v_g. The target is to obtain the maximum r.

Figure 2 shows the evolution of actions and corresponding supersaturation distributions and flow patterns. As seen, the optimal value of action is located between 1.2 and 1.4, which means the enhancement of EM at different times is effective to improve growth conditions.

In the present study, an unrealistic actuation was used to adjust the EM for the sake of simplicity. The future work is to design the temperature actuation and establish the correlation between RF-coils, EM and temperature field.

[1] T. Yamamoto, Y. Okano et al., *J. Cryst. Growth*, **470** (2017), 75-88.

Fig. 1 Schematic view of DRL process.

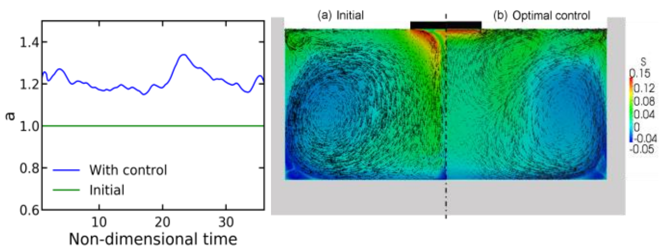

Fig. 2 Development of actions in DRL (left), and transport phenomena (right) without and with control.