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Study on Diameter Control of Czochralski Silicon in Shouldering

Author: Jing Zhang, Ding Liu, Xinrui Lv, Xiaojun Chang

Abstract

Growing large size, low defect silicon single crystals is the development direction of the semiconductor industry. The difficulty of controlling the temperature variation increases with the increase of the thermal field, and the growth process of the rotating shoulder causes the diameter fluctuation to reduce the effective length of the crystal isometry.

In order to solve this problem, this paper proposes a constant-drawing-rate temperature control process control method and obtains the model type and order of this system by designing an open-loop step response experiment of the crystal growth temperature control diameter system, using the least squares method to identify the model parameters, revealing the temperature and diameter variation law of the shoulder turning process and explaining the causes of the shoulder turning fluctuation. On this basis, a generalised predictive adaptive control algorithm is used to design an automatic silicon single crystal growth controller to solve the pure hysteresis problem of the crystal growth temperature and diameter control system.

The method not only ensures that the microscopic quality of the crystal meets the V/G growth process curve requirements, but also suppresses the diameter fluctuation phenomenon after shoulder turning, thus increasing the usable length of the crystal. The experimental results show that the method proposed in this paper establishes an effective temperature prediction model for the crystal growth process with high accuracy when compared with the conventional PID and Smith methods.

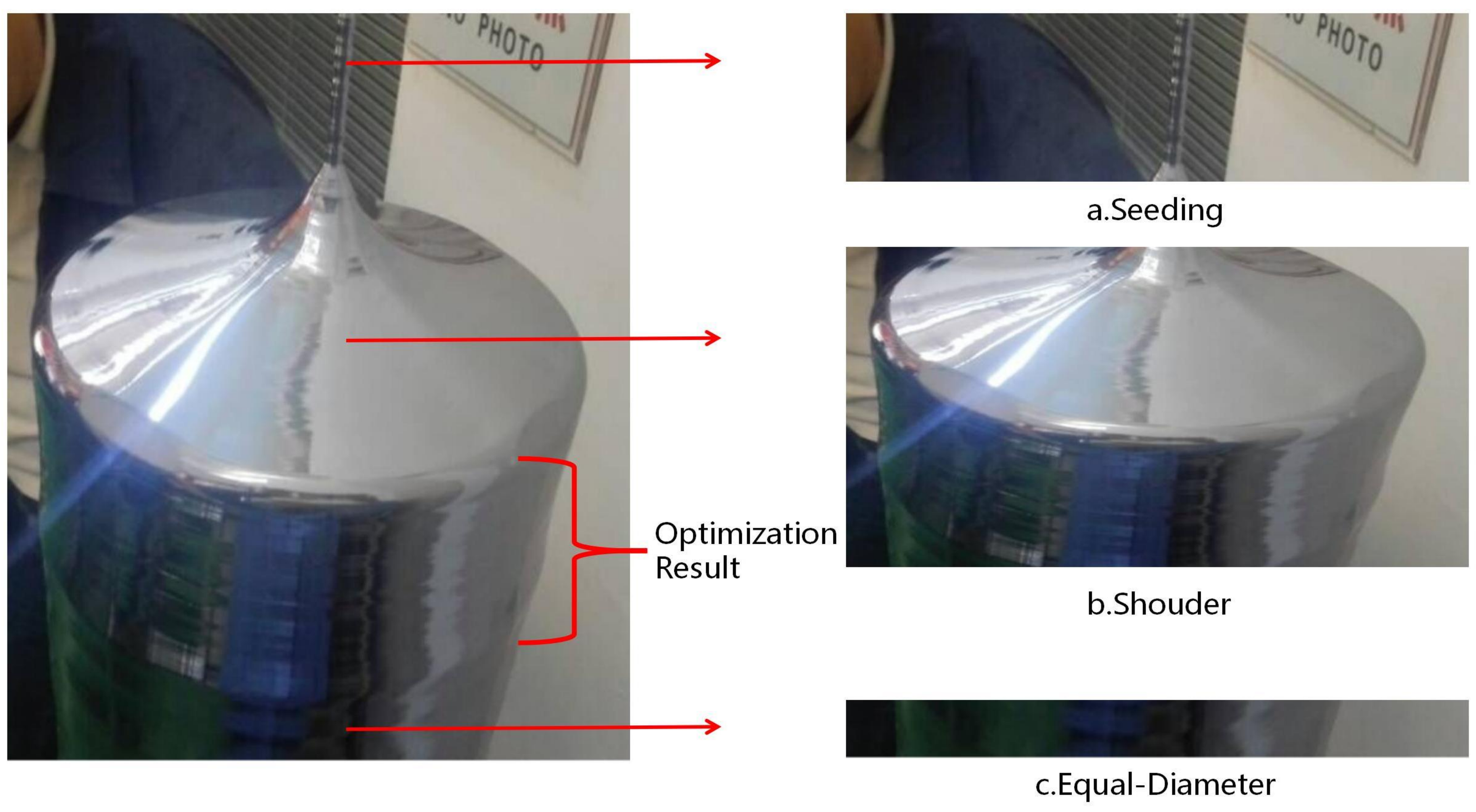

Fig. 1. Silicon Ingot after Optimization

Principle of GPC algorithm

The GPC algorithm is divided into the following three main steps:

- Identification of temperature system parameters
- Calculation of intermediate parameters
- Solving for the control rate

Results

To verify the correctness of the above analysis and the effectiveness of the control method, the control method of shoulder rotating was verified by the experiment. A TDR direct-pull Czochralski silicon (Cz-Si) furnace and corresponding thermal system were provided by National and Local Joint Engineering Center for Crystal Growth, Xi 'an University of Technology. The experimental result is as follows in **Fig. 1**.

Introduction

With the rapid development of integrated circuit electronics, the manufacture of large diameter, high quality silicon single crystal is in line with the development of the times inevitable trend.

- The need for larger diameters leads to a more complex thermal field design. Due to the dynamic coupling of multiple fields, the heat transfer during crystal growth is characterised by non-linearity and time lag.
- According to V/G theory crystals in a zero defect state should be controlled to within 10% of the V/G fixed value.
- A constant pulling speed diameter control method is proposed to control the pulling speed during the crystal growth process and to control the crystal diameter by adjusting the heater power.

Methods and Analysis

Proposed control process and principle analysis based on temperature time lag and non-linearity.

- Studying only the effect of temperature issues on single crystal diameter, this process approach addresses the correlated coupling of pulling speed and temperature, while determining the pulling speed control process parameters based on the study of temperature time lag, not only illustrating the theoretical relationship between temperature and diameter, but also improving crystal diameter control accuracy.
- Design of an open-loop step-response experiment to analyse the temperature variation pattern in conjunction with the principle.As shown in **Fig. 2.**

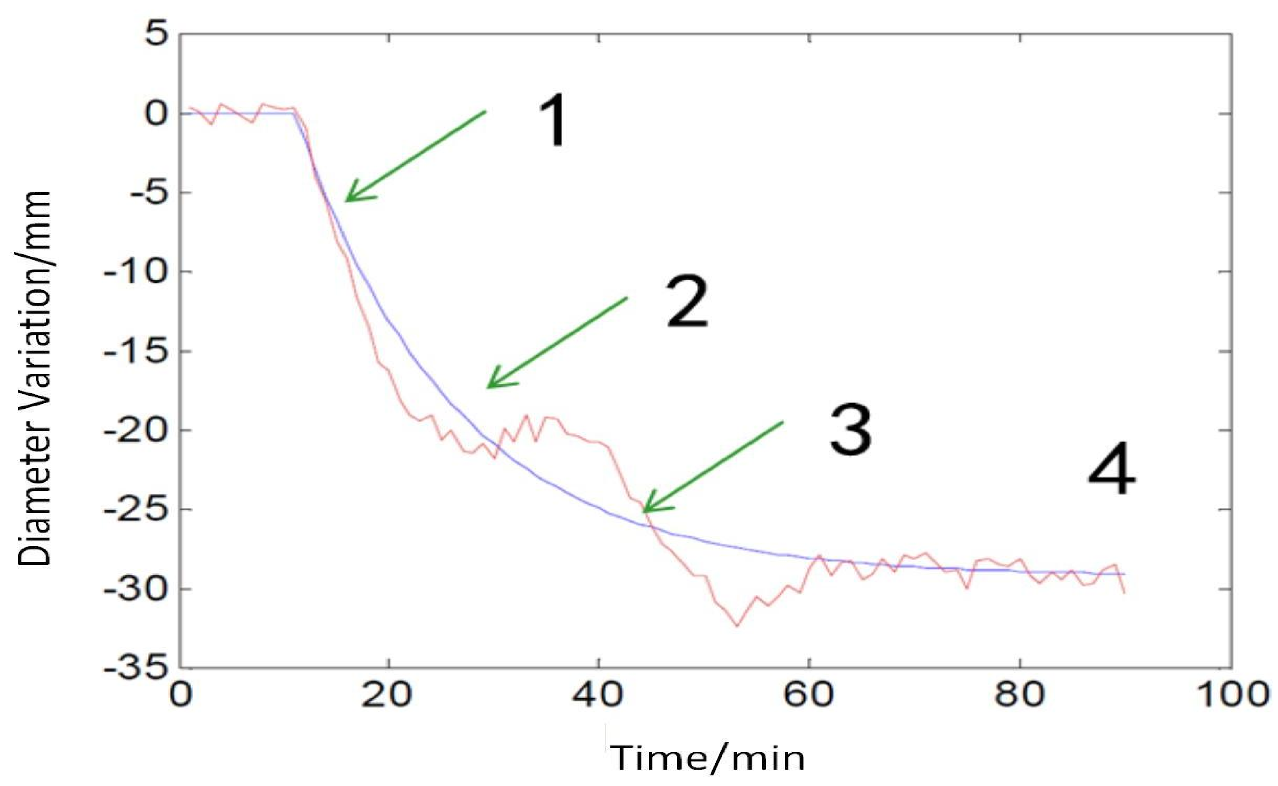

Fig. 2. Temperature Step Change's Impact on Diameter

Conclusions

Generalised predictive adaptive control is used to solve the fluctuation phenomenon of the shoulder turning process brought about by the temperature transfer time lag problem, using the past and current temperature data to predict the future temperature data, and updating the control rate in real time to ensure that the crystal pulling process is stable on the ratio setting curve.

Based on theoretical analysis as well as simulation and experimental verification, the proposed process control algorithm avoids the fluctuation of crystal diameter during the shoulder turning process and increases the effective length of the isochrones while ensuring the quality of silicon single crystal growth.

FOR MORE INFORMATION:

Shaanxi Key Laboratory of Complex System Control and Intelligent Information Processing,

Email:zj.8467@163.com

Adress:Xi'an 710048, China

Xi'an University of Technology