최적 반복 학습 제어기법을 이용한 RTP의 웨이퍼 온도균일제어

Control of Wafer Temperature Uniformity in Rapid Thermal Processing using an Optimal Iterative Learning Control Technique

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Abstract : An iterative learning control technique based on a linear quadratic optimal criterion is proposed for temperature uniformity control of a silicon wafer in rapid thermal processing.

Keywords : Rapid Thermal Processing, Iterative Learning Control, Optimal Control

1. Introduction

After a decade of continuous researches from academia and industries, rapid thermal processing (RTP) has recently emerged as one of the indispensable semi-conductor manufacturing processes. In the operation of an RTP system, the most important aspect is to attain the temperatures uniformity across the wafer surface over the whole processing time. As the standard size of silicon wafers has grown from 6 to 8 inches and is expected to move to 12 inches, however, achieving that goal has been continuously posing new challenges to control engineers.

From the view point of control system design, the RTP system has several unique traits. First, it is a typical nonlinear highly interacting MIMO batch system requiring tracking control for heating, processing, and cooling of a wafer. Secondly, due to its fast dynamics, the available sampling interval is very limited (usually less than 0.2 sec down to 0.02 sec sometimes). Computational efficiency is a `must' for the control algorithm. Thirdly, the temperature measurements are frequently corrupted with significant noise by the high power electric circuits as well thermal noise from the tungsten-halogen lamps. This tells that a filtering algorithm should be an integral part of the controller design.

The purpose of this research is to propose an iterative learning control (ILC) technique[9] for high performance temperature uniformity control in RTP. The proposed technique is based on a time-varying linear state space model identified along the reference trajectory. It conducts run-wise information feedback. The real-time feedback rejects randomly occurring disturbances and accelerates the convergence of ILC at the same time. Deterministic formulation of the proposed control was originated by Amann et al.[4], but extended to an LQG form through this research for efficient filtering of measurement noises. As an integral part of the controller design, a simple but effective identification method for a time-varying linear state space model of an RTP system is also presented. The proposed control technique has been evaluated numerically in an 8-inch wafer RTP system.

2. Process Description

The RTP system considered in this research is of the same type studied by Norman[7]. We scaled up the system for 8-inch wafer processing. Fig. 1 shows a schematic diagram of the system. It has three concentric tungsten-halogen lamp arrays with maximum powers of 5, 20, and 50Kw. The silicon wafer is assumed to be a cylinder with radius R(=101mm) and thickness Z(=0.68mm) and placed on a rotating support to avoid azimuthal temperature distribution The temperatures are assumed to be measured at four radial positions (r=0, R/3, 2R/3, R) on the wafer bottom surface.

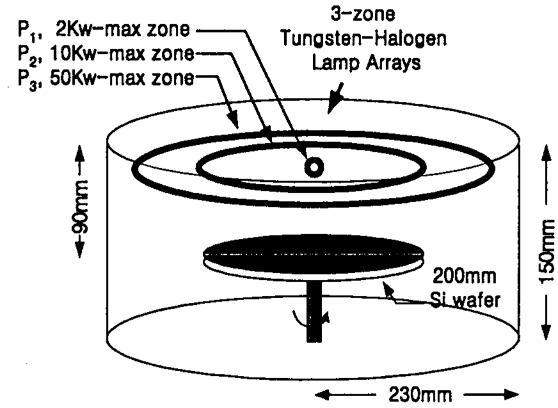

Fig. 1. Schematic diagram of the RTP system

1. Mathematical Modeling

The heat conduction within the wafer is described by the following parabolic partial differential equation: