# Research proposal:
# Multi-zone Thermal PID modelling using Neural networks

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**Abstract**

We propose to research and develop and improvement a three-zone neural network to model and predict the PID parameters of temperature controller. The model will adjust the various PID terms based on the variances in the process conditions like target temperature, thermal ramp rate, thermal load, chamber pressure, process gas type and other external factors with a potential influence on the chamber thermal performance.

The purpose of the modelling is to provide a single solution capable of achieving multiple target temperatures with a tight distribution of temperatures across a stack of silicon wafers and across the wafer surfaces withing the target deviation specification during the three stages of the thermal cycle, i.e. heating, steady state and cool down.

The software program will create a model from existing thermal profiles and recorded process variables and attempt to construct a time based neural network model that can predict and transmit the PID terms to use given a predetermined set of process requirements and a real time measured set of environment variables with a potential impact on the process performance.

## 1 Introduction

The fundamental temperature challenge faced is to achieve a very tight thermal gradient over a stack of semiconductor silicon wafers, across the stack and across the individual wafer surfaces of plus/minus 1.5 °C during ramping up and steady state to a target temperature of anything from around 200 °C to 600 °C.

The challenge is compounded by the space constrains driven by the superconducting magnet wrapped around the thermal process. Increasing the bore size of the oven to facilitate a batch oven running a thermal process inside a magnet, exponentially increase the size, weight and cost of the superconducting magnet system.

The optimal thermal solution is to run a multi-zone element with multi zone PID controls to balance the thermal load on the wafer stack, however other external factors influences the thermal behavior and interaction of zones.

The three zone controller approach also creates PID challenges as thermal zones interact, so PID tuning is quote tedious and time consuming. Tuning multiple target temperatures for a system can take weeks to hit the specifications for all target temperature simultaneously.

The challenge is compounded further by other external factors that also have a significant influence on temperature performance once tuned.

- Multiple target temperatures between 200-600 °C per system.
- Variance in thermal load of product wafers varying by wafer types and deposition and variance in batches.
- Variance in thermal emissivity of different products
- Variance in process chamber condition running in vacuum or various process gasses like Helium, Nitrogen, Argon etc.
- Other external factors that have potential influence on the processes, like temperatures of cooling water loops, room temperatures, atmospheric conditions like moisture, starting temperature of thermal job, for example the time duration started after previous job.

The introduction should also give a short overview of the rest of the document – a one or two sentence overview of each part of the document.

# 2 Literature

The idea of using modelling to solve the long standing PID problem started with the first machine learning projects to demonstrate the functionality of neural networks.

The concept was further encouraged by the article describing a similar PID problem solved for tuning a variety of PID loops for underwater vehicles with constantly changing ballast and ocean conditions. [1]

Conceptually the idea for the theses is that given access to around 20 years worth of real time thermal process information across a fleet of thermal processing tools, there should be enough data to build a neural network using all the variables listed previously and using existing control parameters with the potential addition of other potential unrecorded variables to improve the predictions, one should be able to create a neural network to model the three decoupled thermal PID control zones and underlying PID terms to compensate for variations dynamically as they occur.

While this sound simple and straight forward, the challenging aspects for this approach would be the big time lags in the PID control system and finding time based modelling methods to facilitate the solution. From doing some basic initial checks for literature and tools it seems feasible to achieve. [2]

Although the application is slightly different the decoupling concept of PID zones is very similar and the concepts should translate.

To elaborate on the thermal challenge [3], thinking about a stack of twenty five, 200mm or 300mm silicon wafers, spaced a few millimeters apart, pretty much looks like a solid mass to a thermal process and there is a direct correlation of the thermal gradient to the speed of thermal increase, in other words the speed at with the target set-point is driven. [4] The thermal gradient is reduced by introducing a ramp rate on the target temperature set-point and is typically achieved over the course of an hour or more, so modelling techniques will have to consider time delay compensation and this will be the challenging part of the project as far as I can determine. [2]

# 3 Research question

The basic idea is to design and train a neural network to dynamically model and predict appropriate PID sets for the variances in process conditions and adjust decoupling and the degree of interaction between the overlapping thermal control zones.

- Can we establish meaningful correlations between inputs and outputs
- Can we find a time delayed solution for parameter predictions
- Can we measure and sufficiently decouple control zones and determine decoupling constants
- Can we subsequently find a unified model that accurately predicts the PID sets
- Can we get the model to feed the predictions dynamically to our PID controller

# 4 Timeline

It is estimated that this project will take two years to complete. The Gantt chart in Figure 1 gives an overview of the expected timeline.

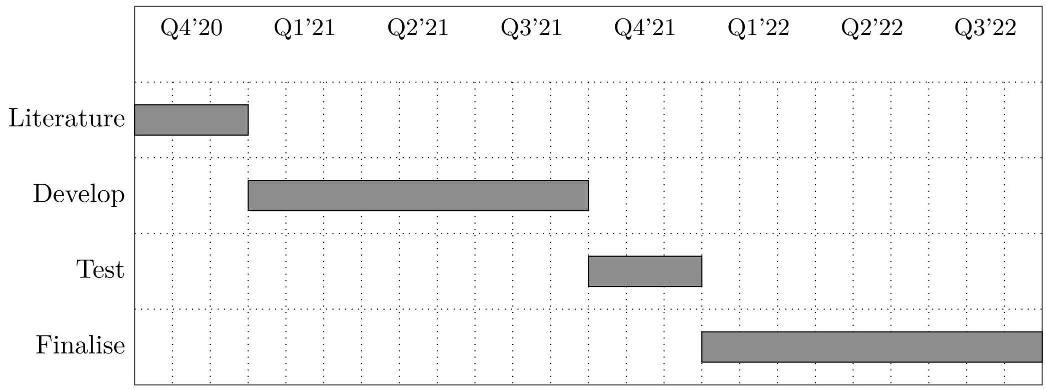


Figure 1: Gantt Chart

## 4.1 Milestones

The project will be delivered through a series of milestones. The milestones will have the follow deliverables.

**Literature review:** this will be delivered at the end of month 3.

**Sofware Model:** this will be delivered at the end of month 12.

**Tests:** the tests will be completed at the end of month 15.

**Thesis:** the thesis will be delivered at the end of month 24.

# References

[1] H.-A. Rodrigo, G.-V. Luis Govinda, S.-J. Tomás, G.-E. Alfonso, and F.-N. Fernando, "Neural network-based self-tuning pid control for underwater vehicle," Sept. 2016.

[2] S. Huailin and P. Youguo, "Decoupled temperature control system based on pid neural network," (CICC, Cairo, Egypt), ACSE 05 Conference, Department of Information and Control Engineering, 2005.

[3] W. S. Yoo, T. Fukada, I. Yokoyama, K. Kang, and N. Takahashi, "Thermal behavior of large-diameter silicon wafers during high-temperature rapid thermal processing in single wafer furnace," *Japanese Journal of Applied Physics*, vol. 41, pp. 4442–4449, 07 2002.

[4] Senpuu Lin and Hsin-Sen Chu, "Thermal uniformity of 12-in silicon wafer in linearly ramped-temperature transient rapid thermal processing," *IEEE Transactions on Semiconductor Manufacturing*, vol. 14, no. 2, pp. 143–151, 2001.