Simulations On A Heater Plate Assisted Bake/Chill System For Photoresist Processing

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ABSTRACT

Simulation results on a thermal processing module for photoresist processing in microlithography is presented, with emphasis on the spatial and temporal temperature uniformity of the substrate. The system consists of a mica heater, coupled with numerous small, disjoint and in-dependently controlled thermoelectric devices (TEDs) capable of precise substrate spatial temperature control. The TEDs also provide active cooling for chilling the substrate to a temperature suitable for subsequent processing steps, hence eliminating the need for substrate transfer between separate baking and chilling units. Two different arrangements of TEDs for the system are simulated and a comparison of the results is made.

INTRODUCTION

Control and uniformity of gate critical dimension (CD) becomes extremely important and stringent as the semiconductor industry approaches the 23nm technology node (International Technology Roadmap for Semiconductors, 2006). Of the methods to maintain CD uniformity during etching processes, controlling the uniformity of the wafer temperature is much effective as it directly affects the sticking coefficient of the reaction products to the gate sidewall (Holmes and Sturtevant, 1993). An example is the bake plate operation in the post-exposure baking (PEB) of deep-ultraviolet (DUV) lithography. Sturtevant et al.(1993) reports a 9% variation in CD per 1°C variation in temperature for a DUV photoresist. Furthermore, other investigations by Goto et al. (2006), Friedberg et al. (2004) and Cain et al. (2005) also show the importance of temperature uniformity, both in steady-state and transient, in CD uniformity across wafer.

To optimize the processing of temperature sensitive photoresist, a thermal processing system has been proposed to replace the conventional hotplate design to improve temperature control across the wafer (Chua et al., 2007). This new system consists of a mica heater, which has a lower thermal mass than the hotbake plate, hence allowing rapid dynamic response and good controllability of the temperature. It also has an array of TEDs, which can provide spatial and temporal temperature uniformity control and active cooling, hence eliminating substrate movement during the baking and chilling processes. As a result, this system offers excellent temperature control during the entire thermal cycle, and even allows temperature measurement for real-time control. Furthermore, the practical system simulation shows that a 6-zone thermal system can satisfy the performance objective of temperature non-uniformity of being less than 0.1°C. In this
paper, simulation results of a 7-zone thermal system with less number of TEDs employed is presented and compared with the that of the 6-zone thermal system.

**SYSTEM DESCRIPTION**

Two arrangements of TEDs are simulated. In Arrangement A, a total of 30 TEDs of different sizes are used, while in Arrangement B, a total of 18 TEDs are used.

For Arrangement A, each TED is 26.4mm by 26.4mm. The arrangement is illustrated in Figure 1. For Arrangement B, the big TED is 52.8 mm by 52.8 mm, which is 6 times that of each discrete wafer unit, while the small TED is 26.4mm by 26.4mm., which is 3 times that of each discrete wafer unit. The arrangement is illustrated in Figure 2.

Squares with thick outline represent the TED, while those with dotted outlines represent the discrete wafer unit used in the simulations.

![Figure 1. Arrangement A. A total of 30 TEDs and 6 sensors are used.](image1)

![Figure 2. Arrangement B. A total of 18 TEDs of two sizes and 7 sensors are used.](image2)

**TEMPERATURE CONTROL**

There are 2 stages in the simulation: baking and cooling. Temperature control in the cooling stage is easier to manage, unlike during the heating stage, when the rate of heat loss through convection and radiation increases with temperature and varies across the wafer.

In the course of the simulation, the placement of the sensors on the wafer is an important aspect in negative feedback temperature control. As the main temperature nonuniformity comes from the edge of the wafer, the TEDs along the wafer edge are discretized into different control zones and the inner TEDs are powered by one controller. Furthermore, to better control the temperature, a tuning method Ziegler-Nichols is used to obtain the initial set of PID parameter values, and further tuned to the desired performance by trial and error. A more systematic and mathematical approach can be used.
Figure 3. Control structure of system during baking.

From the figure, it is evident that the control structure is split into 2 parts. The first half portion of the control structure is to maintain the wafer temperature at the reference temperature (signal), while the second part is to maintain temperature uniformity across the wafer. In other words, temperature across the wafer should not differ greatly (>0.1°C), which is one of the objectives.

During baking, the mica heater supplies the thermal energy to the wafer, and is controlled by the signal $U_{\text{mica}}$. This single signal is calculated with a PID algorithm, reference signal and negative feedback, which is provided by the temperature at the centre of the wafer. On the other hand, TEDs can supply additional or remove excess thermal energy from the system and is controlled by the group of control signals $U_{\text{TEDX}}$. These signals are also calculated with a PID algorithm, wafer centre temperature as the reference signal and negative feedback, provided by the sensors in the other zones. The number of control signals will be equal to the number of control zones on the wafer.

Figure 4. Control structure of system during cooling.

Similarly, during the cooling stage, the TED(1,1) control the temperature of the wafer centre according to the reference temperature. The single signal $U_{\text{TED(1,1)}}$ is calculated with a PID algorithm, reference signal and negative feedback, provided by the sensor in the centre of the wafer. On the other hand, the group of signals, $U_{\text{TEDX}}$, controls the other TEDs such that to maintain temperature uniformity across the wafer. This group of signal is again calculated using a PID algorithm, wafer centre temperature as its reference signal and feedback provided by other sensors on the wafer. Once again, the number of control signals will be equal to the number of control zones on the wafer.
SIMULATION RESULTS

The main differences of the simulation results are listed in the table below. In summary, the performance of the new arrangement B is slightly worse than that of arrangement A. However, it is still within the performance objective of temperature nonuniformity of less than 0.1°C. The reference temperature is presented in Figure 7.

Figure 5. In Arrangement A, the 30 TEDs are split into 6 control zones, each represented by a colour code.

Figure 6. In Arrangement B, the 18 TEDs are split into 7 control zones, each represented by a colour code.

Figure 7 illustrates the plot of the reference temperature signal with time used in the simulation.
Figure 8 plots the temperature nonuniformity of each wafer zone against time, using arrangement A.

Figure 9 plots the temperature nonuniformity of each wafer zone against time in arrangement B.
Figure 10 plots the control signal to the TED of each wafer zone against time in arrangement A.

Figure 11 plots the control signal to TED of each wafer zone against time in arrangement B.
CONCLUSIONS

As it can be observed from these figures, the difference in performance from using arrangement A (30 TEDs) and arrangement B (18 TEDs) is minimal. However, using less number of TEDs will reduce the number of signals required, since each TED will require a control signal. As a result, this can reduce the power consumption of the entire setup.

REFERENCES


