

## Very Thin Dry Oxide Film Growth using Single Wafer Rapid Thermal Furnace

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Very thin dry oxide film growth is investigated using a vacuum and atmospheric pressure compatible single wafer rapid thermal furnace (SWRTF) system. Oxide film growth rate and thickness uniformity were characterized in the temperature range of 1000~1150°C in the pressure range of 100~760 Torr (pure or diluted O<sub>2</sub>) for 60~3600s. Wafers were placed in a preheated, nearly isothermal process chamber for predetermined process time and removed from the process chamber at process temperature. Excellent film thickness uniformity and repeatable process results were obtained at a reasonable throughput for thin oxide films in the thickness ranges of 2~35nm.

### INTRODUCTION

Rapid thermal processing (RTP) is one of favorable methods to grow very thin thermal oxide in today's device manufacturing fabs due to its superior process and operational (lot size) flexibility compared to conventional large batch furnaces. [1,2] In general, there are two types (cold wall type and hot wall type) of RTP systems. [3-5] The cold wall type systems typically use tungsten halogen lamp array. The hot wall type systems employ resistively heated thermal mass (susceptor or bell jar) as heat source. [5] The lamp based RTP systems have very poor energy efficiency in wafer heating and require complicated temperature measurement and control algorithms. The susceptor or bell jar based RTP systems have superior energy efficiency in wafer heating, but they are limited to annealing applications in inert gas ambient due to the reaction between process gases and susceptor/bell jar material. To overcome operational inflexibility of furnaces and poor energy efficiency of lamp based RTP systems, a single wafer rapid thermal furnace (SWRTF) with a vacuum loadlock is proposed for RTP applications including thermal oxidation. [6-9]

In this paper, very thin dry oxide film growth was performed using the SWRTF system. Oxide film growth rate and thickness uniformity were characterized as a function of temperature, oxygen partial pressure and time.

### SINGLE WAFER RAPID THERMAL FURNACE

A schematic cross-section of process chamber assembly in the SWRTF system is shown in Fig. 1. A process tube is made of clear quartz and has three quartz standoffs. A R-type (Pt-13% Rh/Pt) thermocouple is embedded in one of the quartz standoffs to monitor idle process environment temperature and wafer temperature during process. The wafer is placed on the quartz standoffs (8~9mm tall) in the middle of quartz process tube. The distance between wafer and quartz walls is kept at ~10mm for both upward and downward directions. Wafer pick and place was done by the end effector of three-axis wafer handling robot. No moving parts was used inside the process tube from the reliability and particle reduction point of view. The quartz process tube is located in a SiC cavity which acts as a heat distributor to create a nearly isothermal process environment. The SiC cavity is surrounded by a three zone heater assembly. The process tube is preheated to a process temperature set point and stand by for wafer processing. The SWRTF controls the SiC cavity temperature steady state and moves wafers in and out of a preheated process tube instead of controlling the wafer temperature directly. Details of the SWRTF system configuration and thermal characteristics are published elsewhere. [8,9]

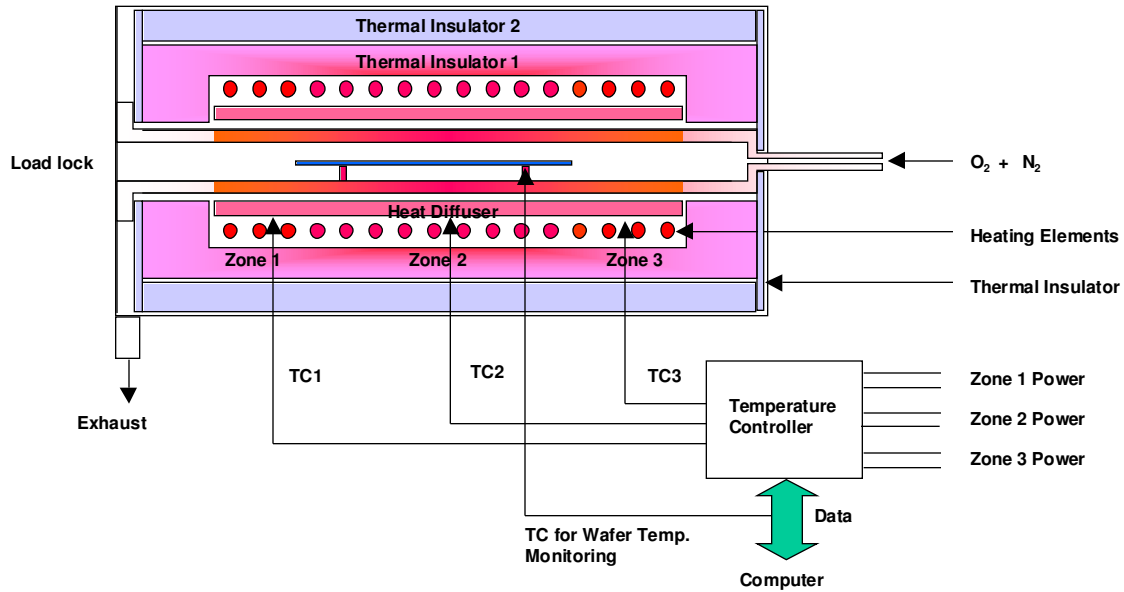


Fig. 1. Schematic illustration of process chamber assembly.

## DRY OXIDATION

Si (100) wafers with 200 mm diameter were processed in a preheated SWRTF process chamber. The oxidation temperature was varied between 1000°C and 1150°C in the pressure range of 100~760 Torr. The oxidation time for 60~3600s. Dry oxide films were grown in a mixture of N<sub>2</sub> and O<sub>2</sub> gases to investigate the effect of O<sub>2</sub> partial pressure on oxidation rate of oxide films. The thickness and thickness uniformity of films grown under various process conditions were measured at 49 points with 3 mm edge exclusion using ellipsometry.

The wafer handling sequence is as follows. The wafer was placed in a preheated, nearly isothermal process chamber for a predetermined process time and removed from the process chamber at process temperature. The wafer is heated as soon as it is introduced in the preheated furnace. The wafer temperature increases rapidly and approaches the furnace temperature with time. The higher the furnace temperature, the higher the initial ramp rate is. The wafer temperature reaches 95% of process temperature in 25~15s from wafer transfer to process chamber in the temperature range of 1000~1150°C. The oxidized wafer was removed at oxidation temperature and placed into a cooling station without changing pressure or O<sub>2</sub> concentration during the wafer transfer. The wafer temperature reaches 60°C in less than 60s from wafer retrieval at 1100°C when a cooling station is used. [6]

## RESULTS

### *Film thickness versus temperature and time*

Thickness of dry oxide films grown under 1 atm 100% O<sub>2</sub> environment were plotted in Fig. 2 as a function of oxidation temperature and time. The oxygen flow was maintained at 0.5 slm during the oxidation process. The oxide film thickness increases as either oxidation temperature or oxidation time increases. For 60s (wafer residence time in the preheated process chamber) of dry oxidation process in the SWRTF process chamber under 1 atm 100% O<sub>2</sub> environment, oxide film thickness of 3.6nm, 5.3nm and 7.7nm can be grown at 1000, 1050 and 1100°C, respectively. Oxide films up to ~72nm have been grown at 1050°C, 1 atm O<sub>2</sub> environment for 3600s in the SWRTF system. Desired thickness of dry oxide films can be grown by selecting appropriate temperature and time.

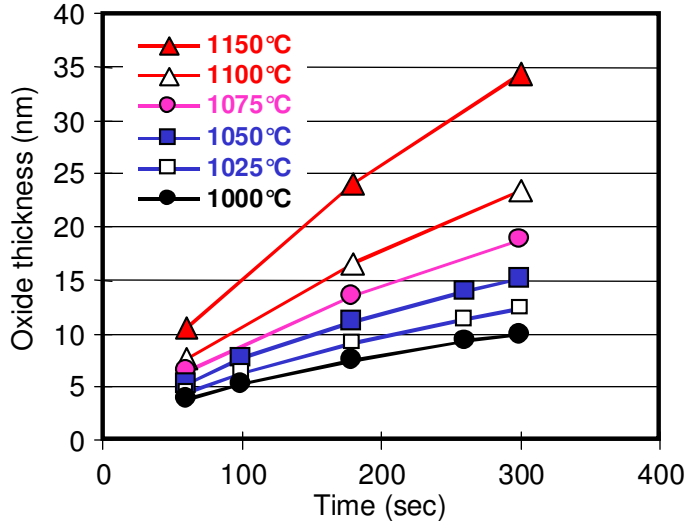


Fig. 2 Oxide film thickness as a function of temperature and time. (100% O<sub>2</sub> 0.5 slm, 1atm)

**Film thickness versus oxygen concentration and flow rate**

Dry oxidation was done in a mixture of N<sub>2</sub> and O<sub>2</sub> gases under various total pressure and O<sub>2</sub> partial pressure conditions to investigate the effect of O<sub>2</sub> partial pressure on oxidation rate of Si wafer. Figure 3 shows the effect of O<sub>2</sub> concentration under the total pressure of 1 atm on the resulting oxide film thickness at three different temperatures of 1000, 1050 and 1100°C. The total gas flow (N<sub>2</sub> + O<sub>2</sub> flow) was maintained at 0.5 slm for this experiment. The oxide film thickness increases as the O<sub>2</sub> concentration increases under the total pressure of 1 atm. The oxidation time was fixed at 100s. The maximum oxide thickness was achieved at 100% O<sub>2</sub> atmosphere at a given oxidation time.

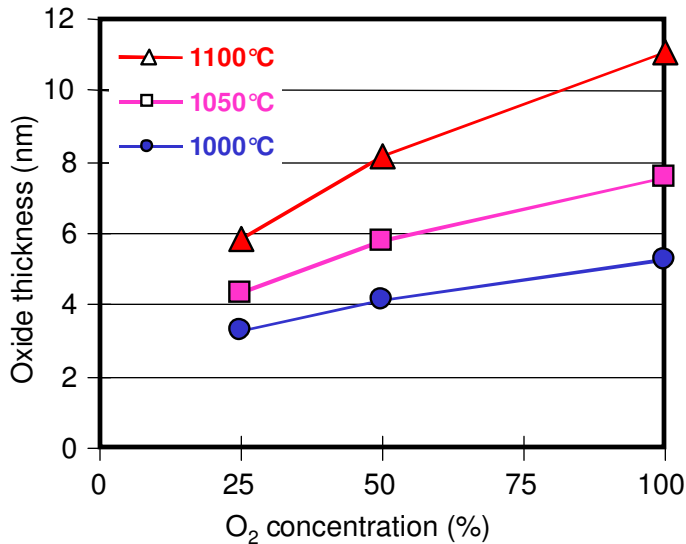


Fig. 3 Oxide film thickness as a function of O<sub>2</sub> concentration and temperature. (N<sub>2</sub> + O<sub>2</sub> flow = 0.5 slm, 1 atm, 100s)

The O<sub>2</sub> partial pressure can be adjusted by either changing the total pressure at a given O<sub>2</sub> concentration or diluting O<sub>2</sub> with inert carrier gas such as N<sub>2</sub>. The effect of oxygen pressure on oxidation rate was also investigated under atmospheric and reduced pressure oxidation conditions. Figure 4 shows the resulting oxide thickness after oxidation at 1000°C for 180s under 100% O<sub>2</sub> pressure of 100, 200, 400, 600 and 760 Torr. The oxide film thickness was almost proportional to the partial pressure of oxygen.

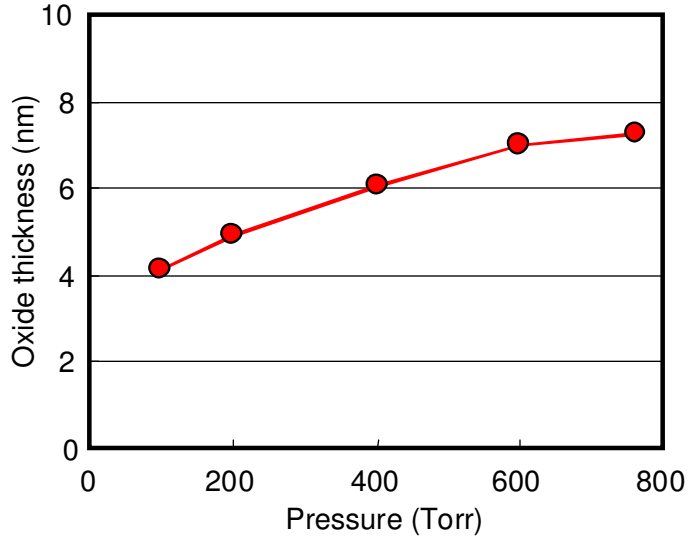
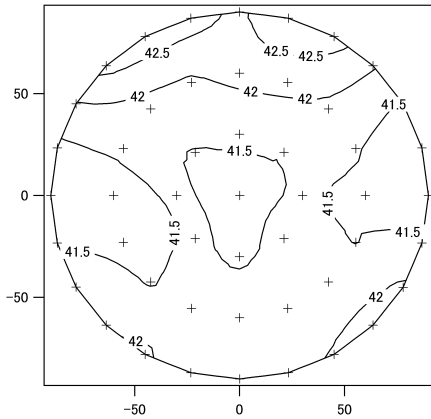


Fig. 4 Oxide film thickness under various O<sub>2</sub> pressure (100% O<sub>2</sub>, 1000°C, 180s).

The effect of total flow rate on oxide film growth was investigated in the range of 0.5-10.0 slm. The average oxide film thickness was constant within a range of measurement error regardless of the total flow rate. Oxide film thickness near the gas supply nozzle (up stream area) is slightly less than those values measured from the down stream area in case of the total flow rate greater than 5.0 slm due to the cooling effect. A total flow of 0.5 slm is sufficient to grow dry oxide films at all temperatures since the volume of process chamber is quite small.

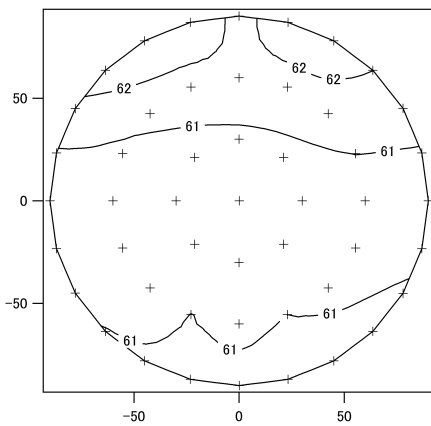
#### ***Film thickness uniformity***

To achieve very uniform oxide films, we have to maintain good within-wafer temperature uniformity and within-wafer oxygen concentration uniformity during oxidation. The within-wafer temperature uniformity is predominantly determined by characteristics of heat source. A small within-wafer temperature imbalance can be corrected by the three zone temperature controllers. The within-wafer oxygen concentration is determined by gas flow velocity, flow pattern and turbulence near and/or on the wafer caused by convection. The oxide film thickness uniformity is expected to be strongly influenced by temperature (within process chamber and within wafer) and gas flow (O<sub>2</sub> partial pressure and gas velocity). Figure 5 and 6 show typical oxide thickness contour maps of 4.2 and 6.1 nm dry oxide films grown under 100% O<sub>2</sub> atmosphere. The thickness uniformity in  $1\sigma$  is typically below 1.0% of average thickness after temperature and gas flow adjustment. The film thickness uniformity is sensitive to the temperature distribution in process chamber and easily optimized by adjusting temperature set points in the process region. No slip line was observed from oxidized wafers even after rapid temperature ramp up and ramp down under 760 Torr, 100% O<sub>2</sub> 1 atm.



Ave. Thickness = 4.2nm  
 Unif. = 0.14 % (1 $\sigma$ )

Fig. 5 Typical oxide thickness contour map of 4.2 nm thick film. (1000°C, 100 Torr, O<sub>2</sub>=1.0 slm, 180s)



Ave. Thickness = 6.1 nm  
 Unif. = 0.52 % (1 $\sigma$ )

Fig. 6 Typical oxide thickness contour map of 6.1 nm thick film. (1000°C, 400 Torr, O<sub>2</sub>=1.0 slm, 180s)

To determine the influence of total gas flow rate on oxide thickness uniformity, the total gas flow rate was varied from 0.5 slm to 10.0 slm. The film thickness sensitivity on the total gas flow rate is negligible when the total gas flow rate is less than or equal to 5.0 slm. Above 5.0 slm of total gas flow, the oxidation rate near the gas nozzle is slightly slower than the rest of wafer due to the cooling effect. The wafer cooling can easily be compensated by adjusting temperature set points near the gas nozzle. As long as the process chamber temperature is stable, excellent oxide thickness uniformity of <1.0% (1 $\sigma$ ) can be obtained in the wide thickness range of 2~35nm in the total gas flow rate of 0.5~5.0 slm.

## POWER CONSUMPTION AND PRODUCTIVITY

Very thin dry oxide growth and slip test results obtained using the SWRTF system are very promising. Feasibility of a new RTP system with a very simple design was demonstrated. High thermal conductivity

and thermal diffusivity of SiC cavity and optimized geometry of heater zones made this possible. Since the SWRTF has no hardware limitations affecting the length of process time, many batch furnace processes can also be performed in the SWRTF system with increased process flexibility and short process cycle time.

The stacked dual process chamber configuration of the SWRTF system provides greater flexibility in process temperature while keeping process chamber temperature constant. In the SWRTF system, each process chamber can be set at different temperature. One SWRTF system can handle two different process temperatures simultaneously. Due to the stacked dual process chamber configuration and very efficient temperature ramp up/down characteristics of the SWRTF system, a very high productivity is achieved. A throughput of 60~70 wafers per hour can be achieved for 60s processes with a 60s cool down step in a vertically stacked dual chamber SWRTF system. Average steady state power consumption at 1150°C is <3.5kW per process chamber. [9] Since the SiC cavity temperature is controlled at steady state, peak power requirement does not normally exceed twice the average steady state power consumption. The SWRTF system provides high quality process results and high process flexibility at reasonable throughput and high energy efficiency.

## **SUMMARY**

Single wafer rapid thermal furnace (SWRTF) system was proposed for RTP applications. Very thin dry oxide film growth using the SWRTF system is demonstrated. Oxide film growth rate and thickness uniformity were characterized in the temperature range of 1000~1150°C in the pressure range of 100~760 Torr (pure or diluted O<sub>2</sub>) for 60~3600s. Oxide films were grown in the thickness range of 2~35nm. Excellent film thickness uniformity and repeatable process results were obtained by placing a wafer in a preheated, nearly isothermal process chamber for predetermined process time. The processed wafer is removed from the process chamber at process temperature after predetermined process time. This gives fast cool down of wafer temperature and a reasonable throughput.

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