

Dry Oxide Film Formation using Single Wafer Furnace

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Dry oxide film formation/growth is investigated using a vacuum and atmospheric pressure compatible single wafer furnace (SWF) system. Oxide formation/growth rate and film thickness uniformity were investigated as a function of temperature, oxygen partial pressure and time. Silicon wafers were processed in the temperature range of 1000~ 1100°C in the pressure range of 100~760 Torr (pure or diluted O₂) for 60~3600s. The wafers were placed in the 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 even for thin oxide films in the thickness ranges of 2~20nm. Typical throughput for 5nm dry oxidation process (60s process at 1050°C) in a dual chamber system is 60~70 wph.

INTRODUCTION

Rapid thermal processing (RTP) is widely introduced in device manufacturing today due to its superior process and operational (lot size) flexibility compared to conventional large batch furnaces. [1,2] Two types (cold wall type and hot wall type) of RTP system have been developed and introduced in the market. [3-5] The cold wall type and hot wall type systems typically use tungsten halogen lamp array and resistively heated thermal mass (susceptor or bell jar) as heat source, respectively. [5] The lamp based RTP systems have very poor energy efficiency and require complicated temperature measurement and control algorithms. Although the susceptor or bell jar based RTP systems have higher energy efficiency, they have limitations in oxidation process environment 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, the authors have designed a single wafer furnace (SWF) with a vacuum loadlock for RTP applications. [6-9]

In this paper, dry oxide film formation/growth is investigated using the SWF system. Oxide formation/growth rate and film thickness uniformity were investigated as a function of temperature, oxygen partial pressure and time.

SINGLE WAFER FURNACE

A cross-section of the SWF is shown in Fig. 1. The process tube has three standoffs made of quartz and no moving parts inside. 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. The quartz process tube is located in a SiC cavity which acts as a heat distributor to create an isothermal process environment. The SiC cavity is surrounded by a three zone heater assembly.

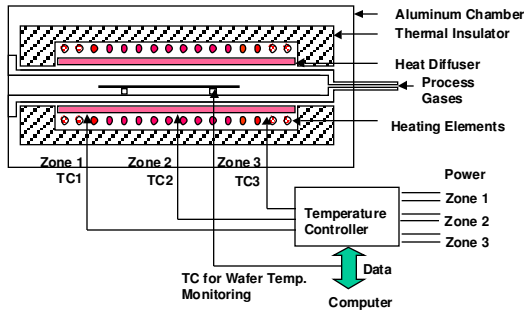


Fig. 1. Schematic diagram of individual furnace.

The SWF 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 SWF system configuration and thermal characteristics are published elsewhere. [8,9]

EXPERIMENT

200 mm diameter silicon wafers were processed in the temperature range of 1000~1100°C in the pressure range of 100~760 Torr for 60~3600s. Dry oxidation was done in a mixture of N₂ and O₂ gases to investigate the effect of O₂ partial pressure on oxidation rate of oxide films. The pressure was also changed. The thickness and thickness uniformity of film grown under various process conditions were measured at 49 points with 3 mm edge exclusion using ellipsometry.

For the dry oxidation experiment, 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 process temperature in 15~20s from wafer transfer to process chamber in the temperature range of 1000~1100°C. The oxidized wafer was removed at oxidation temperature under 1 atm O₂ atmosphere after oxidation and placed into cooling station without changing pressure 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

Effect of Temperature and Time

Thickness of thermally grown dry oxide films were plotted in Fig. 2 as a function of oxidation temperature and time. 3 slm of 100% O₂ flow was maintained during the oxidation process. As seen in the figure, the oxide thickness increases as oxidation temperature and/or oxidation time increases. For 60s (from wafer in to wafer out) of dry oxidation process in the SWF process chamber, 3.6nm, 5.3nm and 7.7nm thick oxide can be grown at 1000, 1050 and 1100°C, respectively. Oxide films up to ~72nm have been grown at 1050°C, O₂ 760 Torr for 3600s in the SWF system. Desired thickness oxide films can be grown by selecting appropriate temperature and time.

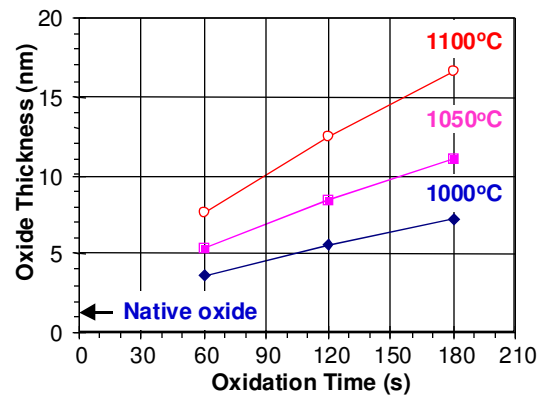


Fig. 2 Oxide film thickness as a function of temperature and time. (100% O₂ 3slm, 760 Torr)

Effect of Oxygen Concentration

To investigate the effect of O₂ concentration and/or partial pressure on oxidation rate of oxide films, dry oxidation was done in a mixture of N₂ and O₂ gases under various pressure conditions. Figure 3 shows the effect of O₂ concentration on the resulting oxide film thickness at three different temperatures of 1000, 1050 and 1100°C. The total gas flow (N₂ + O₂ flow) and pressure were fixed at 3 slm and 760 Torr for this experiment. As expected, the oxide thickness increases as the O₂ concentration increases. The maximum oxide thickness was achieved at 100% O₂ atmosphere.

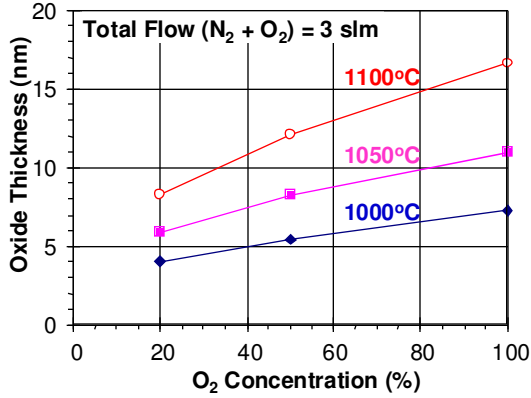


Fig. 3 Oxide film thickness as a function of O₂ concentration and temperature. (N₂+O₂=3slm, 760 Torr, 180s)

The O₂ partial pressure can be reduced by lowering total pressure without reducing the O₂ concentration. 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% O₂ pressure of 200, 400 and 760 Torr. The oxide film thickness was almost proportional to the partial pressure of oxygen.

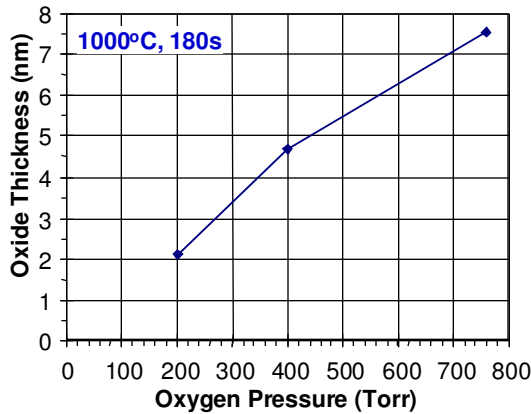


Fig. 4 Oxide film thickness under various O₂ pressure (100% O₂, 1000°C, 180s).

Oxide Thickness Uniformity

The oxide film thickness uniformity is one of the most important process results to be monitored in production environment. Homogeneous process

results in good thickness uniformity and is considered to be ideal. 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 heat transfer. The oxide film thickness uniformity is strongly influenced by temperature (within process chamber and within wafer) and gas flow (O₂ partial pressure and gas velocity). Figure 5 and 6 show typical oxide thickness contour maps of 4.5 and 10.2nm dry oxide films grown under 100%, O₂ atmosphere. The thickness uniformity in 1 σ is typically below 1% of average thickness after temperature and gas flow. No slip line was observed from oxidized wafers even after rapid temperature ramp up and ramp down under 760 Torr, 100% O₂ atmosphere.

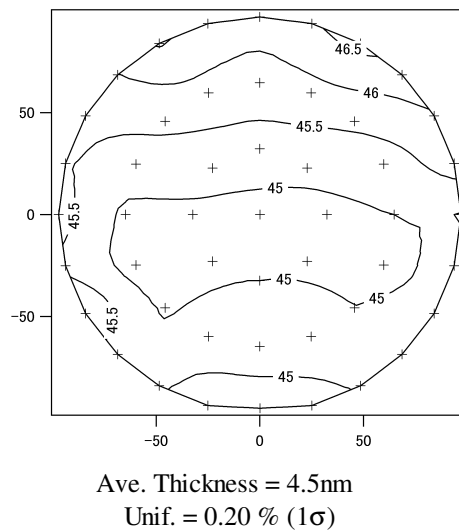
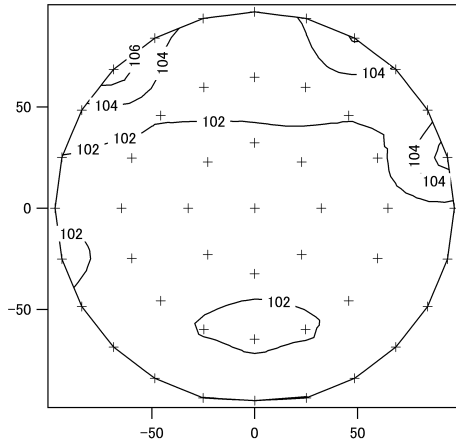


Fig. 5 Typical oxide thickness contour map of 4.5 nm thick film. (1000°C, 400 Torr, O₂=0.5 slm, 180s)



Ave. Thickness = 10.2nm
Unif. = 0.69 % (1σ)

Fig. 6 Typical oxide thickness contour map of 10.2 nm thick film. (1000°C, 760 Torr, O₂=0.5 slm, 300s)

To determine the influence of O₂ flow rate on oxide thickness uniformity, the O₂ flow was varied from 0.5 slm to 5 slm. Oxide thickness uniformity is strongly influenced by O₂ flow rate (more precisely O₂ flow pattern) during process and process chamber temperature. Gas flow dynamics changes as we place a wafer into the process chamber and as wafer temperature rise. Faster O₂ velocity generally provides better oxide thickness uniformity. When there is stagnant or slow O₂ flow in the high temperature process chamber, poor oxide thickness uniformity was obtained. As long as the process chamber temperature is stable, excellent oxide thickness uniformity of <1% (1σ) can be obtained in the wide thickness range of 2~20nm by flowing optimal O₂ flow.

PRODUCTIVITY

Dry oxidation and slip test results obtained using the SWF 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 SWF has no hardware limitations affecting the length of process time, many batch furnace processes can also be performed in the SWF system with increased process flexibility and short process cycle time.

Stacked dual furnace configuration of the SWF system provides greater flexibility in process temperature while keeping process chamber temperature constant. In the SWF system, each process chamber can be set at different temperature. One SWF 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 SWF system, a very high wafer throughput is achieved. Throughputs of 60~70 wafers per hour can be achieved for 60s processes with a 60s cool down step. 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 SWF system provides high quality process results and high process flexibility at reasonable throughput and high energy efficiency.

SUMMARY

Dry oxide film formation/growth was performed using a vacuum and atmospheric pressure compatible SWF system. Oxide formation/ growth rate and film thickness uniformity were investigated as a function of temperature, oxygen partial pressure, flow rate and time. Silicon wafers were processed in the temperature range of 1000~1100°C in the pressure range of 100~760 Torr (pure or diluted O₂) for 60~3600s. The wafers were placed in a preheated, nearly isothermal process chamber for a 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 even for thin oxide films in the thickness ranges of 2~20nm. Typical throughput for 5nm dry oxidation process (60s process at 1050°C) in a dual chamber is chamber system is 60~70 wph.

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