Hot Plate Emissivity Effect in Low Temperature Annealing

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The effect of hot plate emissivity on wafer temperature was investigated using a stacked hot plate system in the temperature range of 100°C to 500°C. Aluminum was used as the hot plate material. The emissivity of the hot plates was modified by selecting appropriate machining precision, intentional surface roughening and surface oxidation (aging). As the emissivity of the hot plates increases from 0.06 (as machined aluminum) to ~0.8 (oxidized aluminum with rough surface), the wafer temperature stabilized at higher temperatures. The difference in stabilized wafer temperature increased as the hot plate temperature increased. The difference in stabilized wafer temperature between low emissivity and high emissivity hot plates, at hot plate temperatures of 200°C and 500°C, were ~20°C and ~80°C, respectively. The effect of hot plate emissivity on wafer stabilization temperature was also verified by inserting high emissivity (~0.9 in the infrared region) quartz plates between low emissivity, stacked aluminum hot plates. The emissivity enhancement of the hot plate system was effective in bringing the stabilized wafer temperature close to that of the surrounding hot plates, even at temperatures below 500°C.

INTRODUCTION

Low temperature annealing (<500°C) is one of the key processes in highly advanced semiconductor device manufacturing. A stacked hot plate type of annealing system [1-3] was proposed for low temperature applications such as SOD (organic/inorganic SOG [1], low-k, polyimide etc.) annealing, post-electroplated Cu layer annealing [4] and nickel silicide formation [5, 6] processes.

A Si wafer is heated from both lower and upper hot plates in the stacked hot plate system. Heat transfer from the lower hot plate to the wafer mainly takes place by natural convection with a small contribution from conduction through the ambient gas. The radiation heat transfer component is quite small relative to the other two. While heat transfer from the upper hot plate is radiation dominant, the amount is quite small compared to the convection heat transfer from the lower hot plate to the wafer. No convection heat transfer to the wafer from the upper hot plate is expected because the heat receiver (wafer) is located below the heat source (hot plate). The correlation between the upper and lower hot plate emissivity and saturated temperature for various types of wafers were previously reported as a function of hot plate temperature. [7]

In this study, the effect of hot plate emissivity on wafer temperature was investigated using a stacked hot plate system in the temperature range of 100°C to 500°C. Aluminum hot plates were used with various emissivity values. High emissivity quartz plate inserts were also used between the aluminum hot plates for further changes to emissivity.

EXPERIMENTAL SYSTEM

To process five Si wafers simultaneously without deteriorating process results, six hot plates are stacked with a 20 mm gap between hot plates. Figure 1 shows a schematic diagram of the experimental system (stacked annealing oven: SAO). Except for the top hot plate, the other plates have three 9mm-long, wafer supporting standoffs from the surface. A K-type sheathed thermocouple and a circular-shaped resistive heating element are embedded

in the individual hot plates to monitor and control hot plate temperature. Once a wafer is placed between the preheated stacked hot plates, the wafer is gradually heated, mainly by natural convection, from the lower hot plates. There are also minor heat transfer paths: conduction through ambient gas and radiation from both lower and upper hot plates.

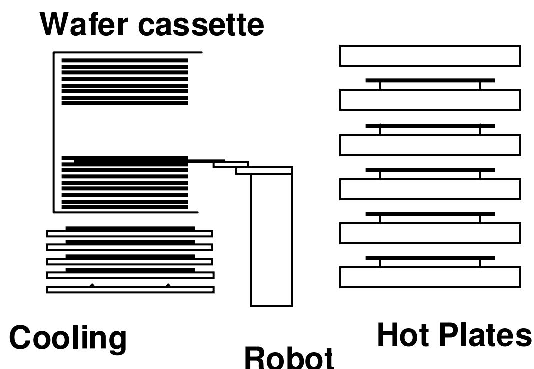

Fig. 1. Schematic diagram of stacked annealing oven.

RESULTS and DISCUSSION

Aluminum Hot Plate

Aluminum has a high thermal conductivity of 2.37 W/cmK at 300K and maintains it nearly to its melting point. For designing a highly uniform and stable heat source, aluminum is an excellent candidate hot plate material for temperatures below 500°C. Polished aluminum is very reflective in the wide wavelength range from visible to near-infrared, so that it is commonly used as the material for optical mirrors. It is well-known that the emissivity of a hot plate is dependent on its surface conditions, primarily determined by the surface roughness and level of oxidation.

To investigate the effect of surface roughness and oxidation of aluminum hot plates on their emissivity, three types of aluminum hot plates were prepared: as machined, and sandblasted with 120µm powder or 600µm powder. Hot plates were then oxidized (aged) at 550°C, in 1atm air for up to 54 hours. The emissivity was monitored in the infrared region (λ:3µm~5.5µm).

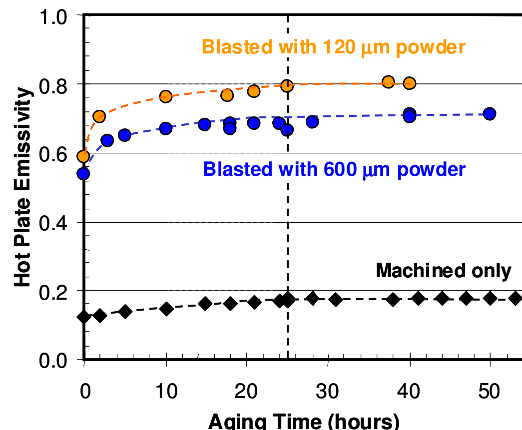

Fig. 2. Hot plate emissivity as a function of aging time at 550°C in 1atm air.

In order to understand the emissivity variation of aluminum hot plates under different surface conditions, the emissivity was monitored as a function of aging time at 550°C (Fig. 2).

The initial emissivity values at room temperature were 0.12, 0.59 and 0.54, for as machined, sandblasted with 120µm powder, and 600µm powder, respectively. As expected, the emissivity is strongly dependent on the surface roughness. As oxidation (aging) time increased, emissivity gradually increased from the initial values. After 25 hours at 550°C, the emissivity stabilized at values of 0.18, 0.80, and 0.70, respectively.

Figure 3 shows the dependence of saturated wafer temperature as a function of hot plate emissivity at various hot plate temperatures. Even for the same hot plate temperature, the saturated substrate temperature is different from hot plate to hot plate. In all cases, the 25 hour oxidized condition increased saturated wafer temperature for the hot plates, whether as machined or as blasted. Even a small increase of hot plate emissivity after oxidation brought

change in saturated wafer temperature. The largest change of saturated wafer temperature after oxidation was observed from the as-machined hot plate. For the sand blasted hot plates, an increase of saturated wafer temperature was still observed, but it was rather small. The largest difference of saturated wafer temperature between the lowest emissivity and highest emissivity hot plates was seen in the as machined plate at the hot plate temperature of 200°C and 500°C, where ~20°C and ~80°C increases were measured, respectively. In order to reduce the saturated wafer temperature variation with time, hot plates should be conditioned properly prior to the production use.

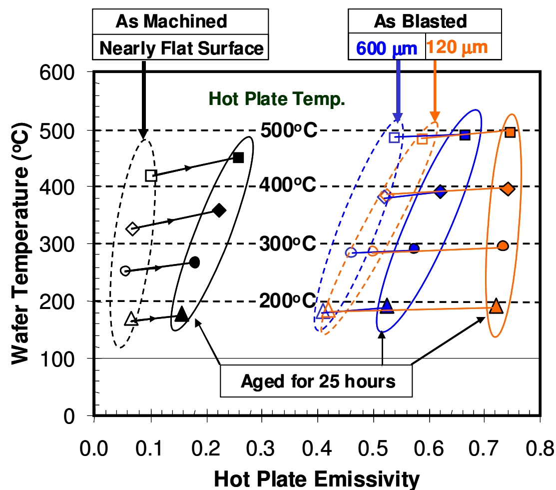

Fig. 3. Correlation between saturated wafer temperature at various hot plate temperatures and hot plate emissivity of as-prepared and plates aged at 550°C for 25 hours.

Emissivity Enhancement using Quartz Plates

In an effort to find an alternate long term emissivity stabilization method other than lengthy, high temperature oxidation, insertion of high emissivity quartz plates between hot plates was investigated. By inserting quartz plates with an emissivity value of ~0.9, the variation of saturated wafer temperature between as machined and highly oxidized hot plates can be significantly reduced. The saturated wafer temperature would only be affected by the high emissivity quartz plates, regardless of the aluminum hot plate conditions. From the wafer's point of view, the emissivity of the heat source is significantly enhanced by inserting quartz plates.

Figure 4 shows wafer temperature profiles in the hot plate temperature range of 200°C and 450°C with (a) bare aluminum (ε=0.15) hot plates, (b) quartz plates placed between aluminum hot plates. In both cases, the saturated wafer temperature increased significantly with the placement of a quartz plate between the hot plates. By inserting the quartz plates, the wafer temperature approaches the hot plate temperature without overshoot.

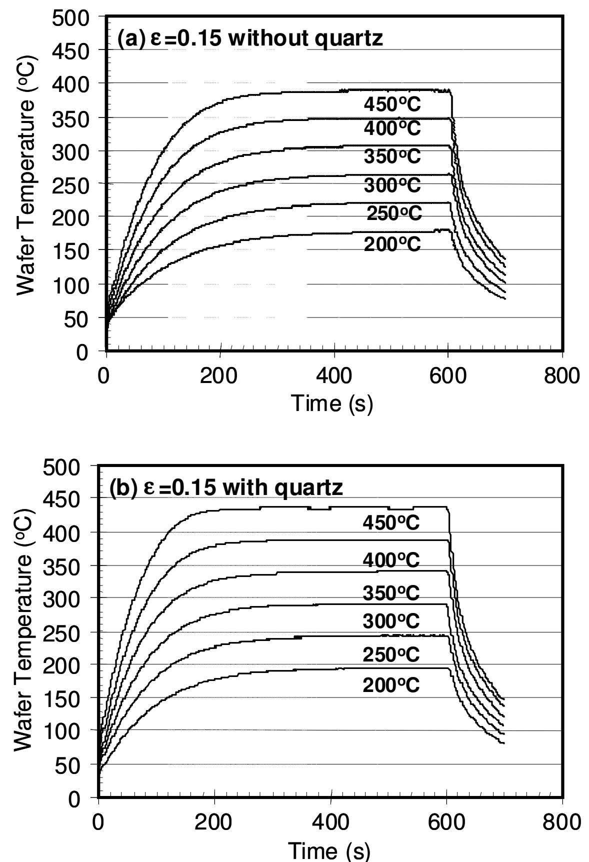

Fig. 4. Wafer temperature profiles under various hot plate temperatures. (a) Bare aluminum (ε=0.15) hot plate, (b) Quartz plate placed on the hot plate.

Figure 5 shows the saturated wafer temperature as a function of hot plate temperature with various hot plate conditions. As the hot plate emissivity is increased, the saturated wafer temperature is also increased and approaches the hot plate temperature. The saturated wafer temperature with quartz plates is closest to the hot plate temperature regardless of the aluminum hot plate condition or emissivity. Thus, the use of the quartz plates removes the dependence on aluminum hot plate emissivity and provides repeatable wafer temperature.

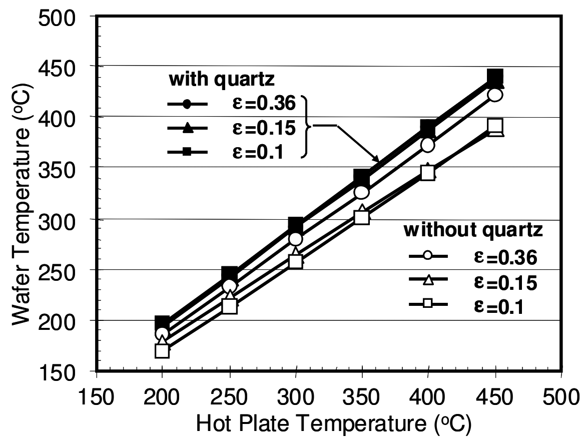

Fig. 5. Saturated wafer temperature with different hot plate assemblies (aluminum hot plate with and without quartz plate) as a function of hot plate temperature.

In this study, the following facts became clear. Even though the radiation heat transfer component is smaller than the convection and convection heat transfer, radiation (and hence, emissivity) from the lower and upper hot plates has significant impact on the saturated wafer temperature. The saturated wafer temperature can be stabilized and brought close to the hot plate temperature through (effective) emissivity stabilization by either complete oxidation of aluminum hot plates or the insertion of high emissivity quartz plates between aluminum hot plates.

SUMMARY

Positioning a wafer between two hot plates is an effective way to accomplish low temperature annealing, an increasingly important process in advanced semiconductor manufacturing. As the wafer is placed in the space between the hot plates, the wafer temperature immediately begins to increase until it reaches a saturation temperature for this configuration, which is somewhat below the hotplate temperature. Heat transfer from the hot plate to the wafer is primarily accomplished by natural convection and conduction through the ambient gas. Radiation transfer, as a transfer component, is relatively small compared to the other two. However, the final saturation wafer temperature is very dependent on the radiation characteristics of the heating surfaces, mainly, their emissivity. The emissivity of a hot plate surface is primarily a function of its surface roughness and the level of oxidation.

The emissivity of the aluminum hot plate surfaces were modified from the as machined condition by sandblasting with either 120µm powder or 600µm powder. The surfaces were then fully oxidized by ageing at 550°C for 25 hours. Emissivity values for the different configurations ranged from 0.12 (as machined) to 0.8 (sandblasted with 120µm powder and oxidized). In addition a quartz plate inserted between the wafer and the hot plates enhanced emissivity to approximately 0.9. Wafers were run in each configuration for hot plate temperatures ranging from 200°C to 500°C and the saturated wafer temperature measured. In all cases, higher emissivity lead to higher wafer saturation temperatures. For the modified aluminum surfaces, the saturated wafer temperature increased by ~20°C for 200°C hot plates and ~80°C for 500°C hot plates.

In the case of the quartz plates inserted between the wafer and the hot plate surfaces, the saturated wafer temperature was both higher and independent of the surface condition of the hot plates. The quartz determines the emissivity of the system and eliminates sensitivity to the condition of the aluminum surface. The saturated wafer

temperature can be stabilized and brought close to the hot plate temperature through (effective) emissivity stabilization by either complete oxidation of aluminum hot plates or the insertion of high emissivity quartz plates between aluminum hot plates.

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