Temperature Uniformity Characterization of Single Wafer Furnace using Titanium Silicide Process

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Titanium silicide formation and annealing were done in a dual chamber, single wafer furnace (SWF) system. The shape effect of heated cavities on within wafer temperature uniformity was investigated using two different types of SiC cavities. Change in sheet resistance and sheet resistance uniformity after silicide formation and anneal was investigated as a function of annealing temperature and annealing time. As sputtered Ti film thickness and within-wafer temperature uniformity are found to be the most critical factors to determine the sheet resistance uniformity of titanium silicide (TiSi) films. Uniformity change in sheet resistance as well as the spatial correlation between sheet resistance change ratio and film thickness were investigated to separate the temperature effect from the thickness effect. Temperature uniformity and process performance of SWF system were characterized using titanium silicide process.

INTRODUCTION

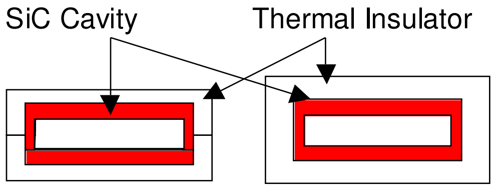
Within wafer and wafer-to-wafer temperature uniformity and repeatability are the most important equipment performance evaluation factors in thermal processing. Many different instrumentation techniques were proposed. Wafers with embedded thermocouples are commonly used to emulate temperature uniformity and repeatability of furnace and rapid thermal processing (RTP) systems during process. [1] A multi-point, *in-situ* optical temperature measurement technique is also used for monitoring wafer temperature and controlling RTP systems during process. Change in sheet resistance uniformity of silicide films and thickness uniformity of oxide films after process are most frequently used for determining thermal processing equipment performance. [2-4]

In this paper, titanium silicide formation and annealing characteristics are investigated in a dual chamber, single wafer furnace (SWF) system. Change in sheet resistance and sheet resistance uniformity after silicide formation and anneal was monitored as a function of annealing temperature and annealing time. Effect of as sputtered Ti film thickness uniformity on the sheet resistance uniformity of titanium silicide (TiSi) films after silicidation. A characterization method for temperature uniformity of a thermal processing equipment using titanium silicide process is proposed. Temperature uniformity of SWF system was characterized using titanium silicide process.

EXPERIMENTAL

A dual chamber, SWF system with a vacuum loadlock is used in this study. Two vertically stacked process chambers (furnace), a vacuum loadlock and two cooling stations are attached to the wafer transport module. By stacking two furnaces, the footprint of the system is greatly reduced. The process tube has three standoffs made of quartz. The process tube uses no moving parts for simplicity and system reliability. The wafer is placed on the quartz standoffs (8~9mm tall) in the middle of quartz process tube. The distance between the wafer and the 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 heat distributor to create isothermal process environment. The SiC cavity is surrounded by a three zone heater assembly. The temperature of the SiC cavity is monitored and controlled at a predetermined process temperature by three embedded R-type thermocouples and the three zone heater assembly to provide identical and nearly isothermal environment to wafers regardless of wafer types and conditions. Detailed configuration, thermal characteristics and process performance of the system has been reported. [5, 6]

The shape effect of heated cavities on within wafer temperature uniformity was investigated using two different types of SiC cavities. One cavity was configured with a SiC plate and a bridge shaped SiC plate which was surrounded by a heater assembly (Fig. 1 (a)). The other cavity was configured with a one piece SiC tube with a rectangular cavity inside (Fig. 1 (b)). The distance between the SiC planes in both cavities were kept constant. The within wafer temperature uniformity was evaluated in terms of TiSi process uniformity in the temperature range of 600~800°C.



(a) (b)

Fig. 1 Schematic illustrations of two types of SiC cavities used in this study.

Silicon wafers with Ti films were processed in the temperature range of 600~800°C in 1 atm N_2 atmosphere for 60~90s. The average thickness and sheet resistance of as sputtered films used in this study were ~80nm and ~7.0Ω/sq., respectively. The wafers were handled as follows. A wafer was picked from the cassette at room temperature and transferred into a preheated process chamber. After the wafer was placed in the process chamber, it remained for a predetermined process time. The wafer is then removed from the process chamber at process temperature and transferred to the cooling station under 1 atm N_2 atmosphere. After 60~90s of wafer cooling, the wafer is returned to the cassette. The sheet resistance of Ti films were measured at 49 points using a four-point probe before and after the process. 5mm edge exclusion was used during the sheet resistance measurement.

RESULTS AND DISCUSSIONS

Sheet resistance contour maps of Ti films before and after annealing in the two piece SiC cavity were shown in Fig. 2. Annealing time was fixed at 60s and annealing temperature was varied from 600°C to 800°C. Process conditions and results were summarized in the figure. As seen in the figure, the sheet resistance value of Ti films decreases as annealing temperature increases. It is because Ti film forms high resistivity C49 phase ($TiSi_2$) at low temperature and the C49 phase transforms into a low resistivity C54 phase (Ti_2Si) at high temperature. [7, 8] The sheet resistance uniformity change before and after annealing increased significantly near the C49 to C54 phase transformation temperature of 750°C. The sheet resistance uniformity was kept below 2.0% (1σ) at annealing temperature below 700°C and above 800°C. As the annealing time increases, the phase transformation temperature becomes lower.

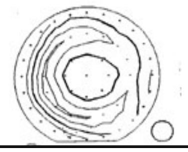
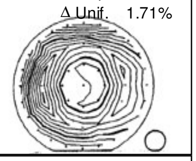
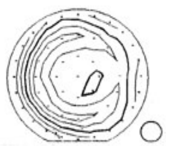
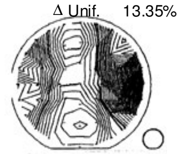
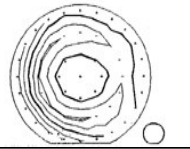
	Pre	Post
600°C 60s	7.03 ohm/sq 1.46% 	12.56 ohm/sq 3.17% Δ Unif. 1.71% 
750°C 60s	7.12 ohm/sq 1.76% 	2.07 ohm/sq 15.11% Δ Unif. 13.35% 
800°C 60s	7.02 ohm/sq 1.55% 	0.97 ohm/sq 1.56% Δ Unif. 0.01% 

Fig. 2 Sheet resistance contour maps of Ti films before and after annealing in the two piece SiC cavity.

Figure 3 shows sheet resistance contour maps of Ti films before and after annealing in the one piece SiC cavity. Annealing was done for 90s at 600°C and 800°C. While both wafers showed similar sheet resistance with wafers annealed under same conditions in the two piece SiC cavity, the uniformity change was maintained below 1.0% (1σ). The one piece SiC cavity has better temperature uniformity than the two piece SiC cavity and provides better sheet resistance uniformity in the temperature range of 600 ~800°C. Temperature below 600°C and above 800°C, it is difficult to determine temperature uniformity of cavity using Si wafers with 80nm thick Ti films unless annealing time or Ti film thickness is changed because temperature sensitivity of sheet resistance is small.

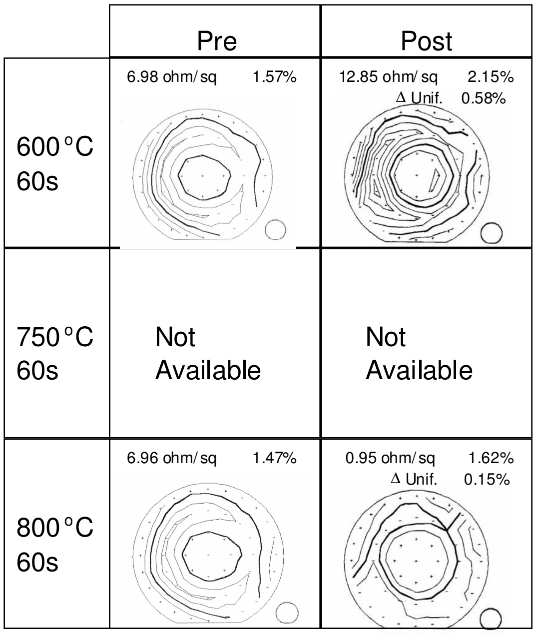


Fig. 3 Sheet resistance contour maps of Ti films before and after annealing in the one piece SiC cavity.

At a given annealing time, titanium silicide formation rate strongly depends on annealing temperature. The temperature for C49 to C54 phase transformation is strongly dependant on the starting Ti film thickness. [7, 8] In order to characterize within wafer temperature uniformity during annealing, it is important to estimate the effect of Ti film thickness variation (nonuniformity) within wafer.

To estimate the effect of Ti film thickness variation within wafer, sheet resistance were measured at 49 points before and after annealing. Wafers were aligned before the measurement to measure the sheet resistance at same points on the wafer before and after anneal. Figure 4 shows the relationship between the final sheet resistance and the initial sheet resistance under different annealing temperature and time in two piece SiC cavity. Higher initial sheet resistance results in higher sheet resistance after annealing at 600°C. Above 750°C, influence of initial sheet resistance (Ti film thickness) on final sheet resistance is less significant because of progress in the C49 to C54 phase transformation. If wafer temperature is very uniform during annealing, the final sheet resistance is strictly dependent on initial sheet resistance below the C49 to C54 phase transformation temperature. The final sheet resistance plot versus initial sheet resistance would be straight lines. The variation from the straight line would be the contribution from the temperature nonuniformity (variation) within wafer during annealing.

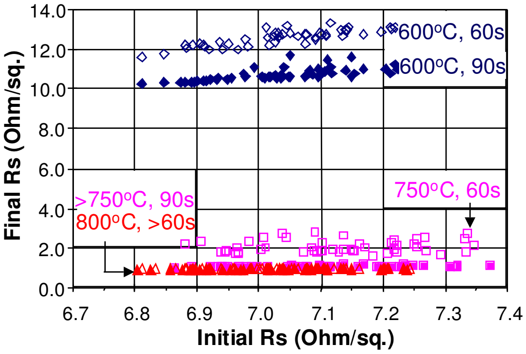


Fig. 4 Final sheet resistance versus initial sheet resistance under different annealing conditions in two piece SiC cavity.

To compare the effect of temperature uniformity within wafer during annealing, the final sheet resistance values of annealed wafers at 600°C and 800°C for 60s in one piece cavity were plotted against the initial sheet resistance values. In the wafer annealed at 600°C for 60s, higher initial sheet resistance results in higher sheet resistance after annealing. At 800°C, the influence of initial sheet resistance (Ti film thickness) on final sheet resistance is negligible because of the progress in the C49 to C54 phase transformation. Since the final sheet resistance is strictly dependent on initial sheet resistance in the wafer annealed at 600°C for 60s (below the phase transformation temperature) it would safe to conclude that the wafer temperature during annealing was very uniform in the one piece SiC cavity.

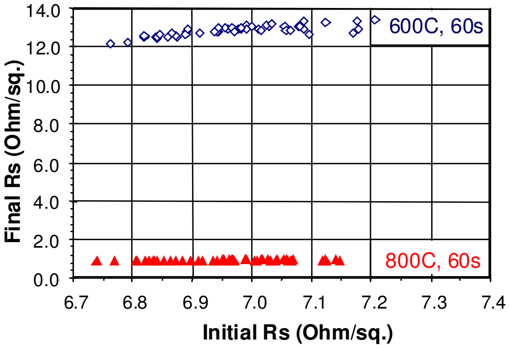


Fig. 5 Final sheet resistance versus initial sheet resistance under different annealing temperatures in one piece SiC cavity.

In additional experiment, we have found that the uniformity change before and after the process does not reflect the temperature uniformity of the process equipment when the starting Ti film has a poor thickness uniformity and the process temperature is near the C49-C54 phase transition region. When the heat source is very uniform in temperature, preexisting thickness nonuniformity (variation) can be used for monitoring thickness dependence of sheet resistance at a given temperature. When the Ti film thickness on wafer is very uniform, uniformity change before and after annealing can be used for temperature uniformity monitoring specimens.

Annealing temperature, time and Ti film thickness are found to be important process parameters in TiSi process. Uniformity change in sheet resistance as well as the spatial correlation between sheet resistance change ratio and film thickness were investigated to separate the temperature effect from the thickness effect. The uniformity change less than 1.0% (1σ) after TiSi formation and anneal was achieved using one piece SiC cavity. This result suggests that the within-wafer temperature uniformity during the process was excellent. The SWF system provides excellent within-wafer temperature uniformity in the entire silicide formation and annealing temperature range.

SUMMARY

To evaluate system performance, titanium silicide formation and annealing were done in a dual chamber, single wafer furnace (SWF) system. The shape effect of heated cavities on temperature uniformity within wafer was investigated using two different types of SiC cavities. Change in sheet resistance and sheet resistance uniformity after silicide formation and anneal was investigated as a function of annealing temperature and annealing time. As sputtered Ti film thickness uniformity and within-wafer temperature uniformity are found to be the most critical factors to determine the sheet resistance uniformity of resulting titanium silicide (TiSi) films. Uniformity change in sheet resistance as well as the spatial correlation between sheet resistance change ratio and film thickness were investigated to separate the temperature effect from the thickness effect on sheet resistance nonuniformity of resulting titanium silicide. Temperature uniformity of two types of SiC cavities used in SWF system and process performance of the SWF system were characterized using titanium silicide process.

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