Annealing Characteristics of Copper Films for Power Device Applications

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The semiconductor industry has developed a number of metrology capabilities in order to quantify the different phenomena accompanying copper (Cu) annealing processes: sheet resistance drop, grain size growth and preferred crystallographic orientation formation, electro-migration etc. Generally, the quality of the annealing process is defined by these parameters: once specified values are met, the process is considered to be sufficient. However this approach ignores the other thermal stresses which will be applied to the Cu film after annealing. It has been found that characteristics of annealed Cu film can be further influenced by the subsequent thermal processes (passivation, sintering etc.) and even device operation.

If the Cu annealing process was insufficient, device reliability may be impacted by the various stresses due to the additional changes in Cu films. A proper annealing of Cu films is very important especially when they operate at large current density since they have to handle large thermally and electrically induced stresses during device operation . This is the case of the application we describe where thick Cu films are used for power devices to carry large amounts of current.

This study evaluates the annealing characteristics of Cu films using a thermal processing system called Stacked Annealing Oven (SAO) which has been specially designed for low temperature thermal treatment in controlled process ambient. The system is able to process five wafers simultaneously under 1 atm and sub-atmospheric N_2 or forming gas pressure at temperatures up to 500℃ in an O_2 free environment. The wafers are slowly heated to the process temperature between the heated stacked hot plates with no direct contact.

Various thickness of electro-chemically deposited (ECD) copper films on blanket and patterned wafers in the range of 0.7µm ~ 5.5µm were annealed and characterized electrically and crystallographycally as a function of annealing temperature, annealing time, process atmosphere. The annealing temperature and time were respectively varied from 2 through 15 min and from 100℃ up to 400℃. Sheet resistance, uniformity, grain size, crystallographic orientation and surface roughness were investigated before and after annealing. Electro-migration characteristics of Cu films was also investigated. Based on the experimental results, proper Cu annealing conditions were summarized.

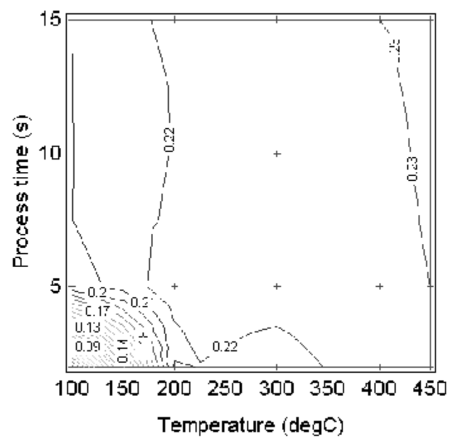
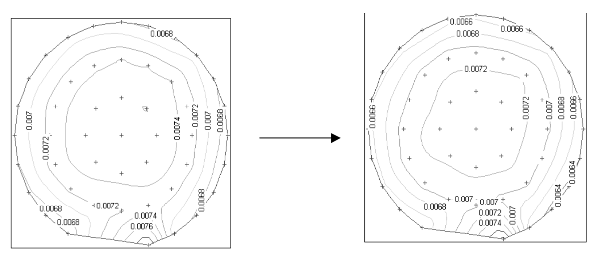


Figure 1. Surface response of 3.0 µm Cu film vs. annealing temperature and time.



Rs: 7.14mΩ, Unif.:4.88% Rs: 6.88mΩ, Unif.:5.43%

Figure 2. Self annealing effect observed 2,5 hours after insufficient annealing at 100℃ for 2 min.