Thermal mechanical behavior of TSVs with WN/Ni as barrier/seed layer system for 2.5D integration

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Abstract
Through silicon vias (TSVs) are regarded as one of the key enabling components to achieve next generation system integration. Many efforts in recent years have paid on new TSV barrier/seed layer schemes to improve step coverage and lower down overall TSV fabrication cost. In this paper, we report on the thermal mechanical assessment of Cu “pumping” (i.e. protrusion) of TSVs with WN/Ni treated at different annealing conditions. Moreover, the impact of different barrier/seed layer systems on the TSV pumping behavior is also investigated. The thermo-mechanical behavior under different annealing temperatures of TSVs having a diameter of 10 µm and a depth of 100 µm has been evaluated by white light optical profiler inspection. The protrusion can be reduced and stabilized when annealed at the higher temperature. Therefore, higher annealing temperature than processing temperature is recommended. Compared to PVD Ti/Cu system, WN/Ni, as TSV barrier/seed layer, tends to have higher Cu protrusions.

1. Introduction
Through silicon vias (TSVs) are regarded as a key enabling technology for the realization of highly miniaturized and complex next-generation systems, as TSV helps in significantly reducing wiring lengths, interconnection latency, and power dissipation. Filling of high aspect ratio TSVs is mainly by means of electro-chemical deposition (ECD) Cu due to its optimal electrical properties, ease of processing and lower cost. However, the coefficient of thermal expansion (CTE) of Cu is much higher (16.7 ppm/°C) than that of Si (2.3 ppm/°C). Therefore, the CTE mismatch between ECD Cu and Si substrate can induce thermal stresses, which may lead to TSV protrusion and interfacial delamination [2-5]. When the ECD Cu is subjected to repeated thermal loadings during the subsequent fabrication process, for instance redistribution layer (RDL), bumping, temporary bonding, die-stacking processes, the induced thermal stress can be accumulated and then result in fatal reliability problems. One way to release the stress and TSV pumping is by annealing. In fact, the TSV wafers could be annealed right after the copper plating process, or after the chemical mechanical polish (CMP) process, or both. To lower down the cost and minimize the CMP steps is one of the concerns from industry.

Physical vapor deposition (PVD) is the most frequently utilized method for barrier/seed layer deposition. However, PVD still suffers some limitations, for instance poor step coverage, overhang, costly and less extendable. Pulsed nucleation layer technology is capable of depositing highly conformal WN films with excellent adhesion and dielectric properties. This paper reports our latest results on fabricating TSV with WN/Ni as barrier/seed layer and the thermal mechanical evaluation of the newly achieved TSV structure.

2. TSV fabrication
The TSV fabrication process are as follows: (a) the TSV fabrication process starts with a 300mm diameter and double-side polished Si wafer. (b) the vias are etched using deep reactive ion etch (DRIE) with the vias having 10 µm in diameter and 100 µm in depth, respectively. (c) after the steps of photoresist stripping and via residue cleaning, a layer of 400nm thick silicon dioxide (SiO2) is deposited by atom layer deposition (ALD). (d) a 20nm WN/W layer is deposited by pulsed nucleation layer deposition as adhesion layer. (e) a 100nm Ni is deposited by electroless plating as barrier/seed layer. (f) the via conductor is copper, which is deposited by electroplating. The wafer was then examined by X-ray microscopy, which reveals the void free filling of TSVs. (g) The wafers are annealed in an N2 furnace at 200 °C, 350 °C, 450 °C, 600 °C, for 30 minutes, respectively. (g) the Cu overburden layer and barrier/seed layer are removed by CMP, respectively.

Fig. 1 FIB cross section of TSV with WN/Ni for barrier/seed layer system
3. Results and discussion

After CMP, the wafers are diced into $5 \times 5$ cm samples and then tested at $200 \, ^\circ C$ for 60 minutes, and $250 \, ^\circ C$, $300 \, ^\circ C$, $350 \, ^\circ C$, $400 \, ^\circ C$, $420 \, ^\circ C$ for 30 minutes, respectively. The Cu protrusion is measured by white light optical profiler. Initial protrusion (or dishing) at room temperature is due to the deviation of planarization in the CMP process. For ease of comparison, the initial height (or dishing) is set as zero, while protrusion height at other temperatures is the measured height subtracts the initial height. Figure 2 compares the Cu protrusion of the annealed TSVs as a function of test temperature. When the TSVs being annealed at $200 \, ^\circ C$, they show large protrusion at $200 \, ^\circ C$, and then decrease the protrusion at $250 \, ^\circ C$. The protrusion increases when tested at $300 \, ^\circ C$, and drops at $350 \, ^\circ C$. From $350 \, ^\circ C$ to $420 \, ^\circ C$, the protrusion increases with test temperature, and the highest protrusion occurs at $420 \, ^\circ C$. When the annealing temperature is $350 \, ^\circ C$, the protrusion of TSVs shows similar trend with that of $250 \, ^\circ C$, but with less protrusion value. When the annealing temperature is $450 \, ^\circ C$, TSVs show the highest protrusion at $200 \, ^\circ C$. When the annealing temperature being further increased into $600 \, ^\circ C$, the Cu protrusion is stabilized with less protrusion level. Compared with different annealing temperatures, TSVs annealed at higher temperatures tends to have less protrusion. Note that there are high Cu protrusion at $200 \, ^\circ C$. This may be due to the annealing duration is 60 minutes, longer than others.

![Fig. 2 Cu protrusion as a function of test temperature](image_url)

PVD Ti/Cu is most widely used material system for TSV barrier/seed layer. For the same TSV geometry and plating chemistry, Figure 3 shows the comparison of Cu protrusion for different barrier/seed systems. When TSVs being annealed at $350 \, ^\circ C$, the Cu protrusion of Ti/Cu shows different trend to that of WN/Ni. Except $350 \, ^\circ C$, Ti/Cu shows less Cu protrusion than WN/Ni system. Note the Ti/Cu layer thickness is 100nm/1500nm, which is much thicker than the WN/Ni.

![Fig. 3 comparison of Cu protrusion for Ti/Cu and WN/Ni systems](image_url)

4. Conclusions

The thermal mechanical assessment of Cu protrusion of TSVs with WN/Ni treated at different annealing conditions is reported in this paper. The TSVs with 10 $\mu m$ in diameter and 100 $\mu m$ in depth on the 300-mm silicon wafer are annealed at $200 \, ^\circ C$, $350 \, ^\circ C$, $450 \, ^\circ C$ and $600 \, ^\circ C$, respectively. According to the Cu protrusion measurement results, the protrusion can be reduced and stabilized when annealed at the higher temperature. Therefore, higher annealing temperature than processing temperature is recommended. Moreover, the impact of different barrier/seed layer systems on the TSV pumping behavior is also investigated. Compared to PVD Ti/Cu system, WN/Ni, as TSV barrier/seed layer, tends to have higher Cu protrusions. And for the industrial usage, to minimize the protrusion not only considering process sequence but also various insulations, barrier/seed and ECD chemistries combinations are still carrying out.

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References