Thermomechanical Properties of Electroplated Cu and its Effect on BEOL Leakage for Logic Devices

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Through Silicon Via (TSV) 3D stacking technology is being actively developed by the industry in order to provide higher bandwidth and lower power consumption for future logic devices. The large volume of Cu in TSVs (Through Silicon Vias) however results in expansion and extrusion of the Cu during the back end of the line (BEOL) process when a TSV middle scheme is applied, which may result in reliability issues leading to BEOL metal line leakage. While a macroscopic understanding of the extrusion behavior is well understood, understanding the crystallographic effects and controlling the extrusion vis-à-vis its crystal orientation is much more difficult. The crystal orientation of Cu can be engineered by electroplating (EP) chemistry, EP conditions (current), and pre-annealing conditions, but little work has been done on the crystallographic effects on TSV extrusion.

In this work, X-ray diffraction (XRD) of Cu films with different Cu electroplating (Cu-EP) parameters, chemistry, and anneal conditions were conducted to observe its effects on preferred crystal orientation. Results show that controlling the Cu-EP and anneal conditions has a significant effect on controlling the (111) texture (and thus preferred orientation) of the Cu film. Preferred crystal orientation data was extracted by peak (integrated) intensity ratio. Thermal cycling of the different Cu-EP films with varying pre-thermal treatment history was tested to see their plasticity response at elevated temperatures that simulate post processing where extrusion of the copper occurs. Results show that even with pre-thermal treatments, plasticity of the Cu films can vary significantly depending on electroplating conditions, with either strong elastic or plastic components.

Although XRD data suggests that films may exhibit preferred crystal orientation as a function of deposition and post-processing, crystallographic analysis on real TSVs may be different than that for film. Since damascene structures (<200 nm in width) exhibit a strong preferential crystal structure where (111) crystals have <110> parallel to the rolling direction (to minimize strain energy), the crystal orientation of Cu grains in TSVs were analyzed via EBSD to observe such similar behavior at TSV edge. This data has significance in that it is the top side grains that are subjected to maximum stress. Based on preliminary data, there seems to be no clear preferred orientation of the top grains with its surroundings. The lack of any correlation between top side copper grain orientation and Cu/dielectric interface is most likely due to much weaker stress levels and much larger grain size than that of very fine Cu interconnects. Similarly, no correlation between extruded grains and particular crystal orientations were observed. More likely, extrusion is a combination effect where the particular crystals extruding during thermal treatments are influenced by the surrounding grains. In order to fully understand the extrusion behavior, a full 3D stress simulation using individual crystallographic information of the Cu grains would be required, which goes beyond the scope of this study. Using EBSD data, preferred crystal orientation of Cu grains in TSV structures, and average grain size measurements were also conducted as a function of pre-thermal treatments. While grain sizes do increase for higher thermal treatments, the grain size on the order of microns most likely plays a minimal role. The results from this study show that while the film texture/thermal behavior can be engineered to a certain degree, optimal texture, thermal behavior conditions for minimizing extrusion/leakage must be understood to fully apply these findings to TSV processing,

[Acknowledgements]
The authors gratefully acknowledge Mr. Jinsang Hyun and Prof. Bongyoung Yoo of Hanyang University for their assistance with EBSD analysis and discussions.