

Development of a Scalable Two-Additive Electrodeposition System for Bottom-Up Copper Filling of Sub-Millimeter Through Silicon Vias

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Summary: A two-additive electrodeposition system for Cu feature filling of sub-millimeter scale through silicon vias (TSVs) is discussed. This 1.0 mol/L CuSO₄ – 0.5 mol/L H₂SO₄ acid sulfate electrolyte contains a polyether surfactant and halide additive which together promote a bottom-up Cu growth profile through positive feedback between localized disruption of the adsorbed polyether-halide layer and metal deposition.¹ The functionality of this system relies on a tightly controlled additive concentration gradient down the length of the feature at the onset of metal deposition to allow bottom-up Cu growth to propagate. Careful consideration of convective contributions is also made to ensure an appropriate boundary layer thickness is maintained for non-linear bottom-up filling, where localized active and passive zone bifurcation of rapid electrodeposition is present. Initial experiments demonstrate the efficacy of potentiostatic control in determining the applied current window by which galvanostatic control can ultimately be achieved for a sub-millimeter feature geometry. Nominally void-free bottom-up deposition of multiple recessed feature geometries is presented.

Cu interconnects for unique devices requiring heterogeneous integration (HI) can span multiple length scales, and their fabrication can require the optimization of similarly unique processing techniques. Traditionally, either through-mask deposition or damascene processing has been used to metallize micro and nanoscale features.^{2,3} While through mask deposition yields interconnects which are electrically tied, damascene processing can yield electrically isolated interconnects (assuming topside field metallization is removed via planarization). In damascene processing, superconformal deposition profiles has been implemented to achieve void-free feature filling. Historically, superconformal growth relies on a three or four-additive electrolyte and is explained by the curvature enhanced adsorbate coverage (CEAC) mechanism⁴. The CEAC mechanism relies upon high curvature areas and is thus most appropriate for micro and nanoscale features which exhibit proximity of locally high curvature areas due to area change affects. Void-free superconformal deposition is more difficult to achieve on larger, mesoscale features. Therefore, a fully bottom-up deposition technique to fill fully conductive features is desirable, instead of superconformal.

An important issue with developing these sensitive electrodeposition processes is scalability. Industrial scale full wafer plating systems implement sophisticated techniques to maintain uniform deposition rates across a full wafer through convection control and electric field regulation across the wafer. Further, these production-scale tools rely exclusively on galvanostatic control as they are not equipped with reference electrodes. To demonstrate the scalability of the two-additive chemistry, the effect of the field surface area, feature geometry, and sample rotation rate on the deposition profile at a given applied

potential or current is presented. By altering the area of the field while maintaining a constant feature quantity, the effect of field area on deposition profile is investigated and used to estimate the effective current density required to fill features at the same rate across different sample sizes is discussed. By altering the sample rotation rate in the otherwise quiescent electrolyte, the convective contribution is assessed. Cross-sectional images along with computed tomography (CT) produced images are produced to obtain images across large arrays of features to demonstrate Cu fill uniformity.

1. T. P. Moffat and D. Josell, *J. Electrochem. Soc.*, 159, D208 (2012).
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