Extreme Bottom-up Filling of Through Silicon Vias

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I describe bottom-up filling of through silicon vias (TSV) over 50 µm tall with Cu[1] and Au[2] and detail the mechanism underlying the processes, which both utilize a single deposition-suppressing additive in their electrolytes. With the gold, deposition transitions from slow suppressed deposition to faster unsuppressed deposition over a distance of approximately 5 µm down the TSV (Fig. 1); the transition for the Cu case is sharper and more extreme, yielding deposition that is entirely localized to the bottom surface of the TSV.

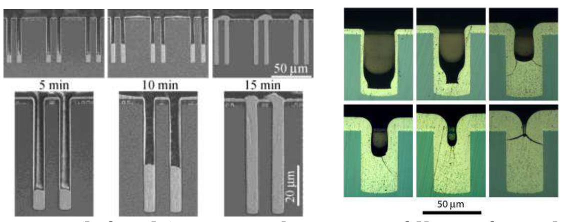

Fig. 1: (left side) Extreme bottom-up filling of annular TSVs with copper[1]; (right side) analogous result for gold[2].

The growth dynamics of these systems cannot be accounted for using shape change models based only on suppressor consumption induced gradients (traditional leveling) or area change coupled with adsorbate coverage (the Curvature Enhanced Accelerator Coverage mechanism). Rather, feature filling arises from unstable deposition characterized by S-shaped negative differential resistance (S-NDR) where deposition is also limited by resistivity of the electrolyte[3]. Critical behavior manifesting such S-NDR is evident in Fig. 2.

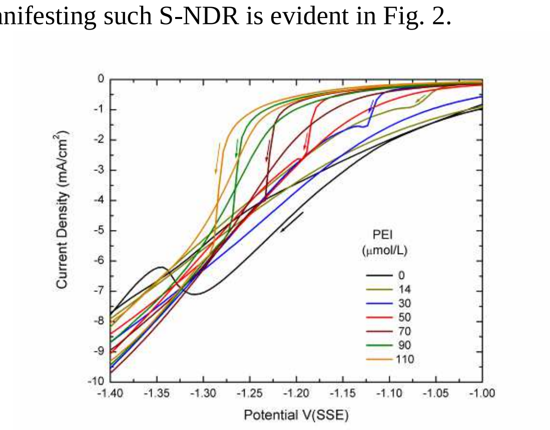

Fig. 2 Critical behavior showing a transition from suppressed to unsuppressed Au deposition that is a function of applied potential and additive concentration is evident in cyclic voltammograms on planar substrates[2].

I present electrochemical studies including cyclic voltammetry and chronoamperometry on planar substrates to understand the phenomenon, explaining how parameters for modeling by the resistivity stabilized S-NRD mechanism can be extracted. I describe the role of geometry, kinetics, and experimental conditions on the nature of predicted feature filling. I detail deposition profiles ranging from extreme bottom-up filling with growth fully localized to the bottom surface to a more relaxed version of superfilling where sidewall deposition attenuates with height in the feature. Finally, I detail experiments demonstrating controlled deposition within TSVs, including vertical placement of the transition from suppressed to unsuppressed deposition within the TSV (Fig. 3). Both experimental TSV filling and filling of submicrometer damascene features in the same electrolytes are placed in the context of model predictions; operational conditions (Fig. 4) and filling behavior (Fig. 5) of Cu are seen to be accurately predicted.

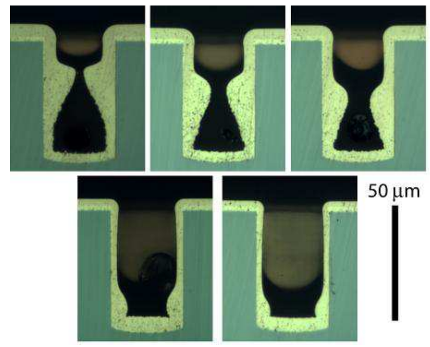

Fig. 3: Within the hysteretic region positive of the critical potential observed in CV, the deposition potential determines the location of the transition from suppressed to unsuppressed Au deposition within the filling TSV[2].

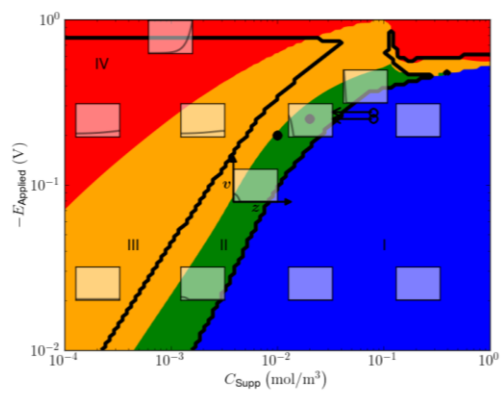

Fig. 4 Predicted Cu filling vs additive concentration and deposition potential; experimental bottom-up filling is observed within the green zone as anticipated (dots).[3]

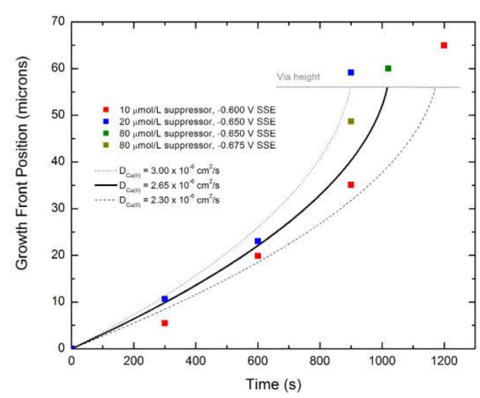

Fig. 5 Comparison of predicted and experimental Cu filling of TSV vs time.[3]

1. T.P. Moffat and D. Josell, J. Electrochem. Soc., **159**(4), D208 (2012).
2. D. Josell and T.P. Moffat, “Extreme Bottom-up Filling of Through Silicon Vias and Damascene Trenches with Gold in a Sulfite Electrolyte”, Journal of the Electrochemical Society, **Submitted for publication**.
3. D. Josell, D. Wheeler and T.P. Moffat, J. Electrochem. Soc., **159**(10), D570 (2012).