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Copper Electrodeposition in Blind Mesoscale Through-Silicon-Vias

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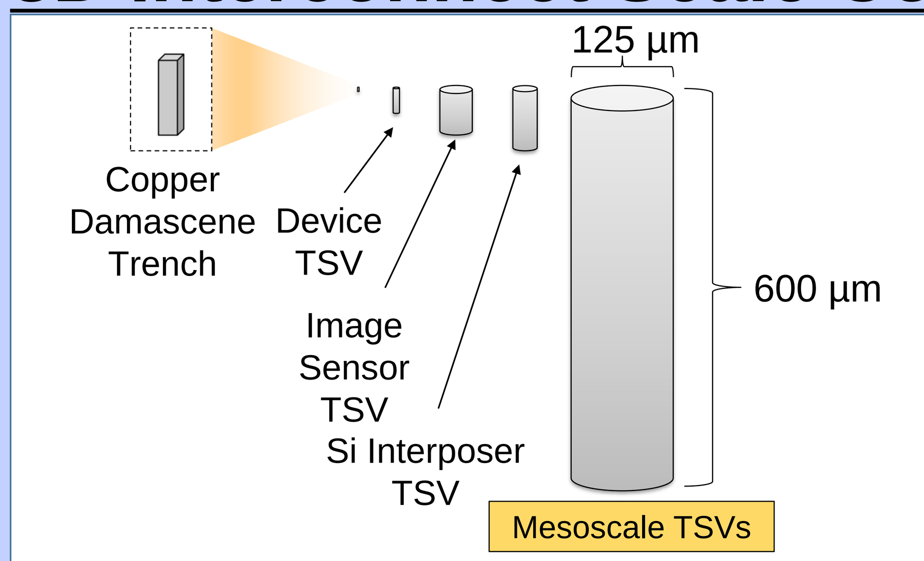
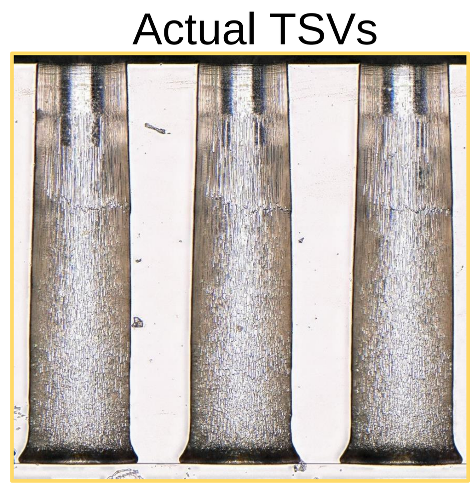
Motivation

This work aims to develop an optimal copper electrodeposition process for electroplating full-wafer thickness blind through-silicon-vias (TSVs) at a depth of 600 µm and an aspect ratio of 4.8. We have demonstrated the ability to electroplate copper conformally into these features at a sufficient thickness, and we are progressing towards developing a method for fully filling, or 'superfilling' these features with Cu as well.

3D Interconnect Scale Comparison

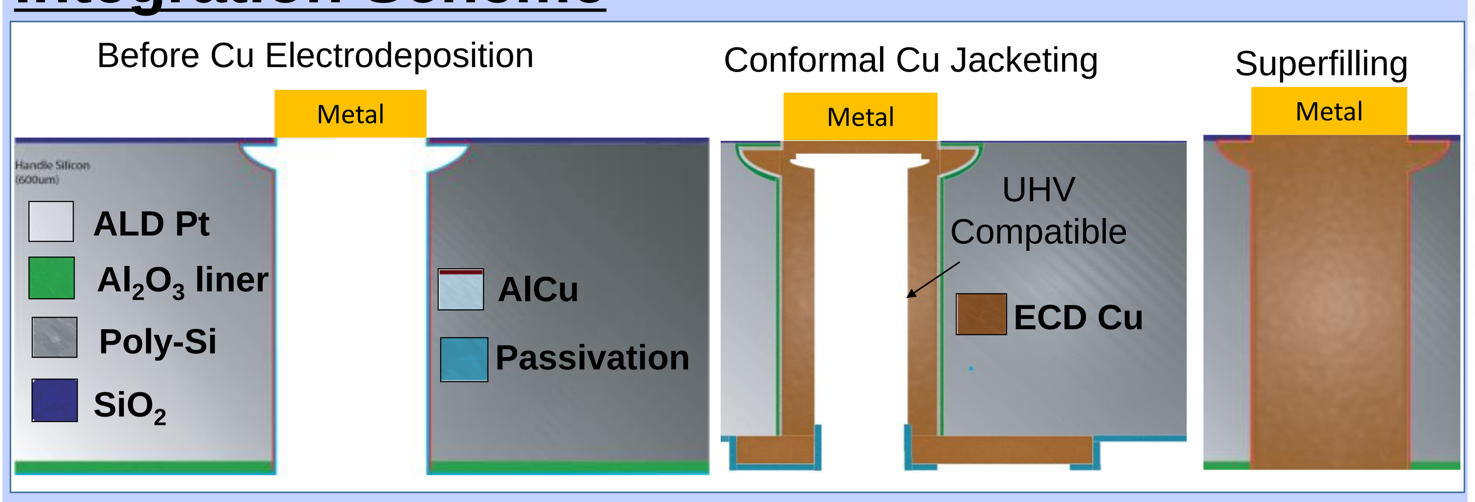




Type	Depth (µm)	Aspect Ratio
Cu-Damascene	<1	10
Device	20-60	5-15
Interposer	50-150	4-8
Image Sensor	50-100	1-3
Full-Wafer TSV	600	5

High density copper filled or jacketed 3D IC scales vary from <1 µm to 150 µm in length, with aspect ratios from 1-15. Compared to the device examined herein, which has a length of 625 µm and an aspect ratio of 4.8.

Integration Scheme

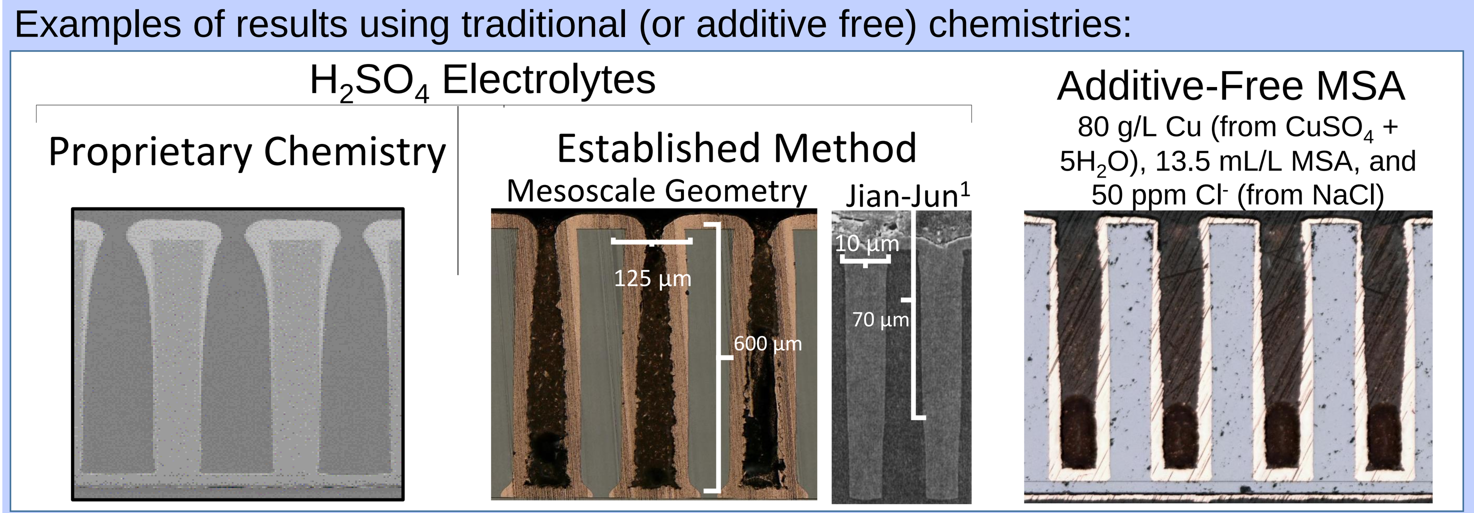


Traditional Acidic Copper Chemistries

Chemistries used for copper electroplating typically consist of a simple copper sulfate solution with either sulfuric acid (H_2SO_4) or methanesulfonic acid (MSA) as the electrolyte. This standard chemistry is modified through the use of a three or four-additive system, in order to improve the quality of the plated copper. These four additives are described below:

- Accelerator - Fast-diffusing molecule that forms an intermediate near the via bottom, increasing plating rate in this region
- Suppressor - Slow-diffusing, large chain polymer (1k-20k mW) that selectively adsorbs to large planar surfaces near the via entrance
- Leveler - Reduces overburden thickness and acts as grain refiner
- Chloride – Competitively complexes with suppressor and accelerator species at electrode surface

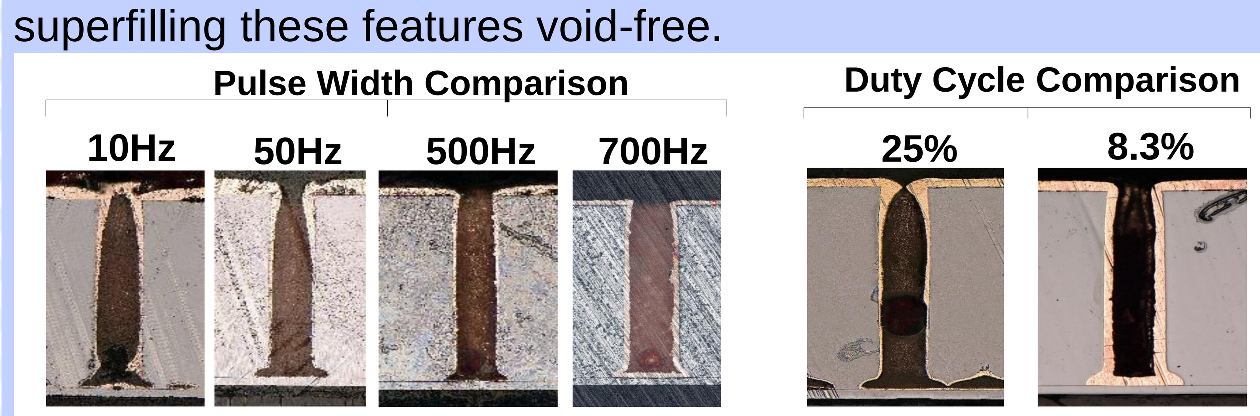
Examples of results using traditional (or additive free) chemistries:

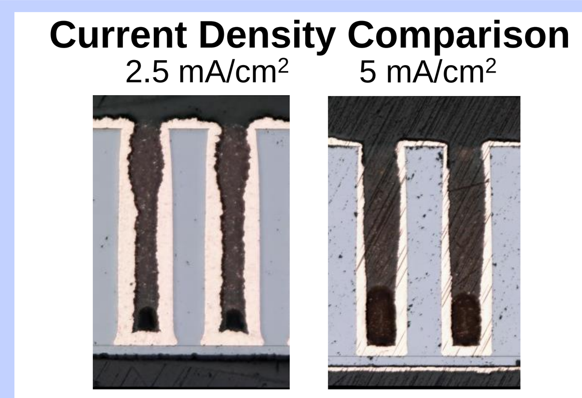


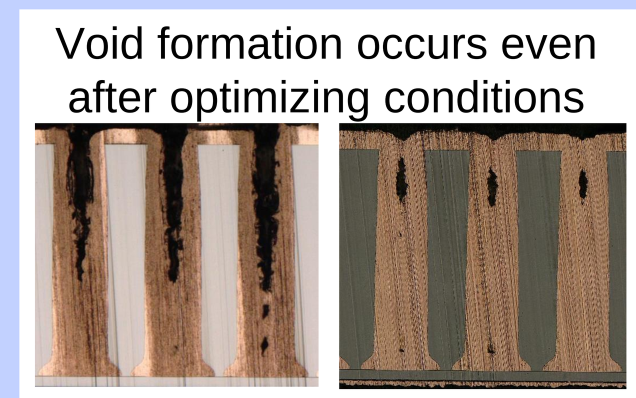
[1]Sun, Jian-Jun, et al. "High-aspect-ratio copper via filling used for three-dimensional chip stacking." *Journal of The Electrochemical Society* 150.6 (2003): G355-G358.

Conformal Cu Jacketing

Using a traditional MSA electrolyte with various additive concentrations, applied pulse widths, duty cycles, and current densities has been examined for optimal conformal jacketing of these mesoscale vias, but this technique is insufficient for superfilling these features void-free.

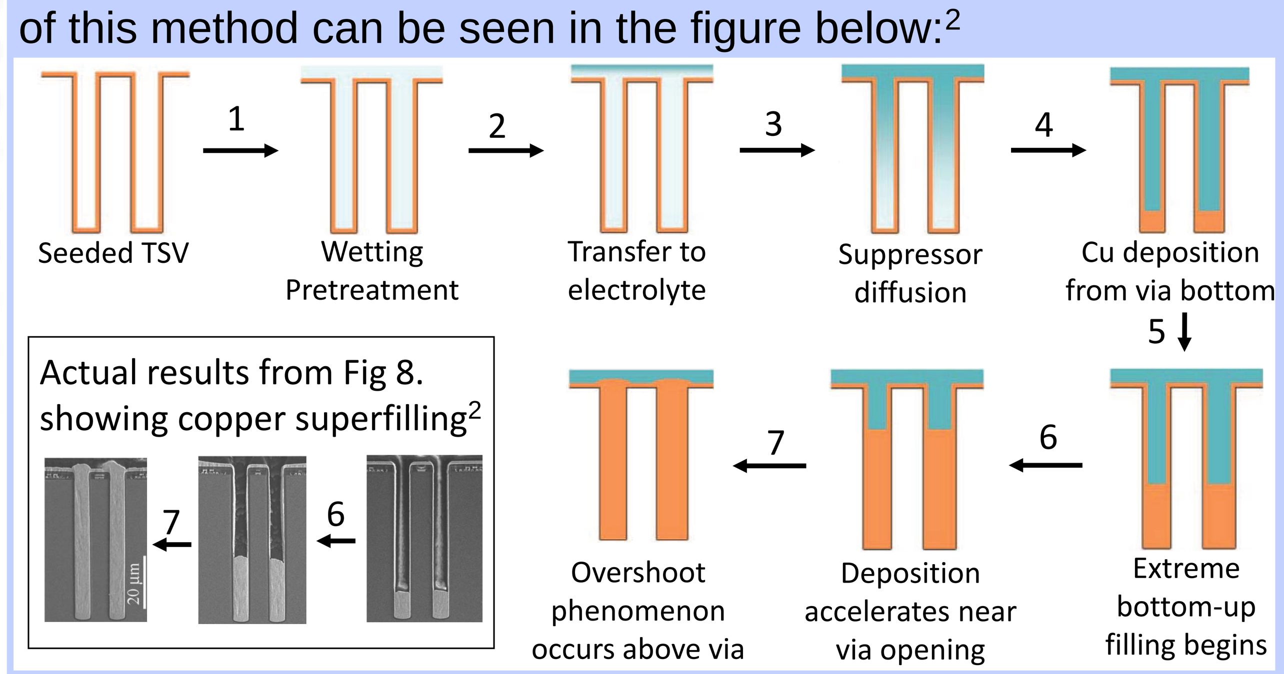




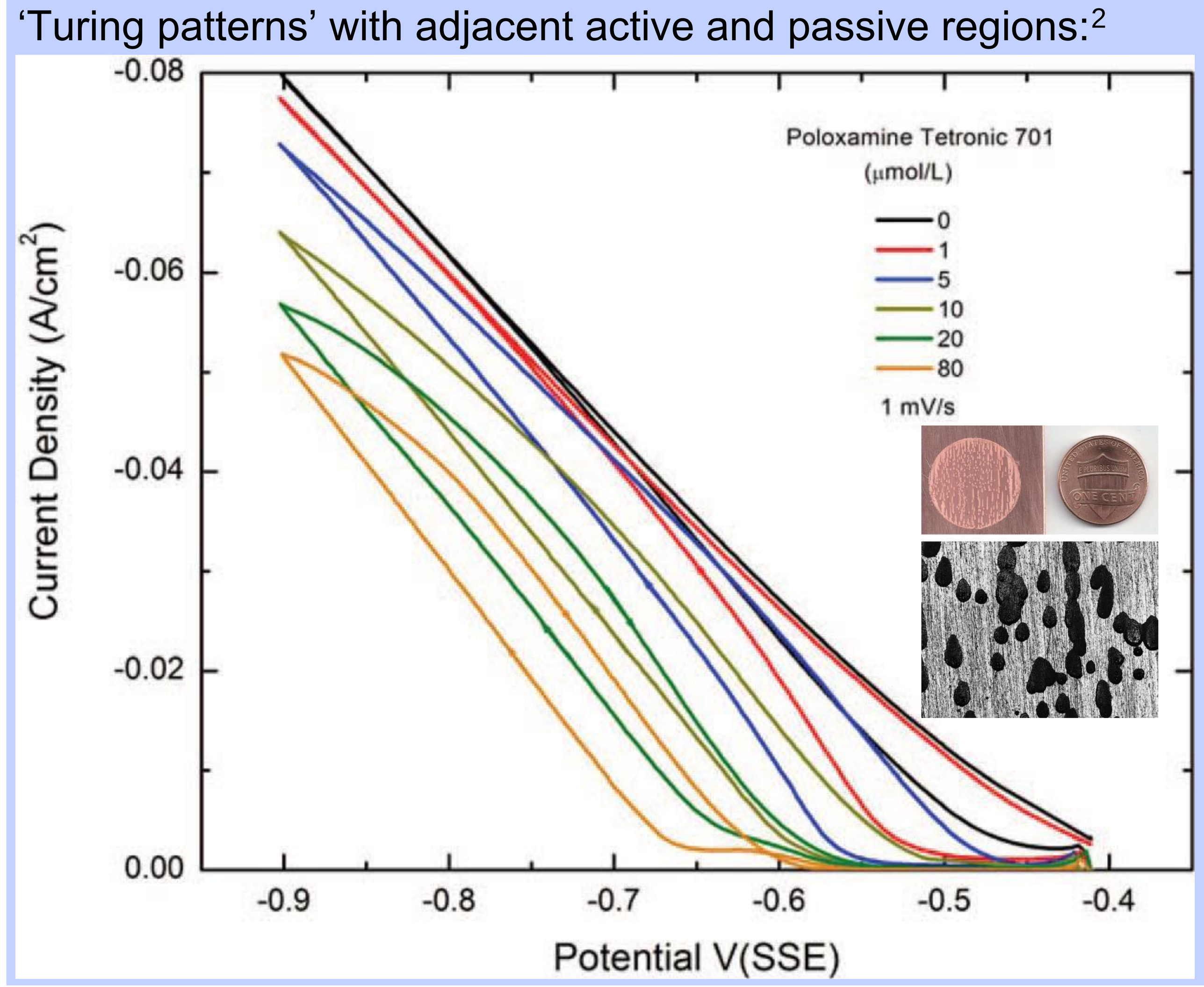


S-NDR Approach Fundamentals

'Bottom-up' growth has been demonstrated using a $CuSO_4$-H_2SO_4 electrolyte with only chloride and a polyether suppressor additive in 50 µm deep annular TSVs. A simple representation of this method can be seen in the figure below:[2]



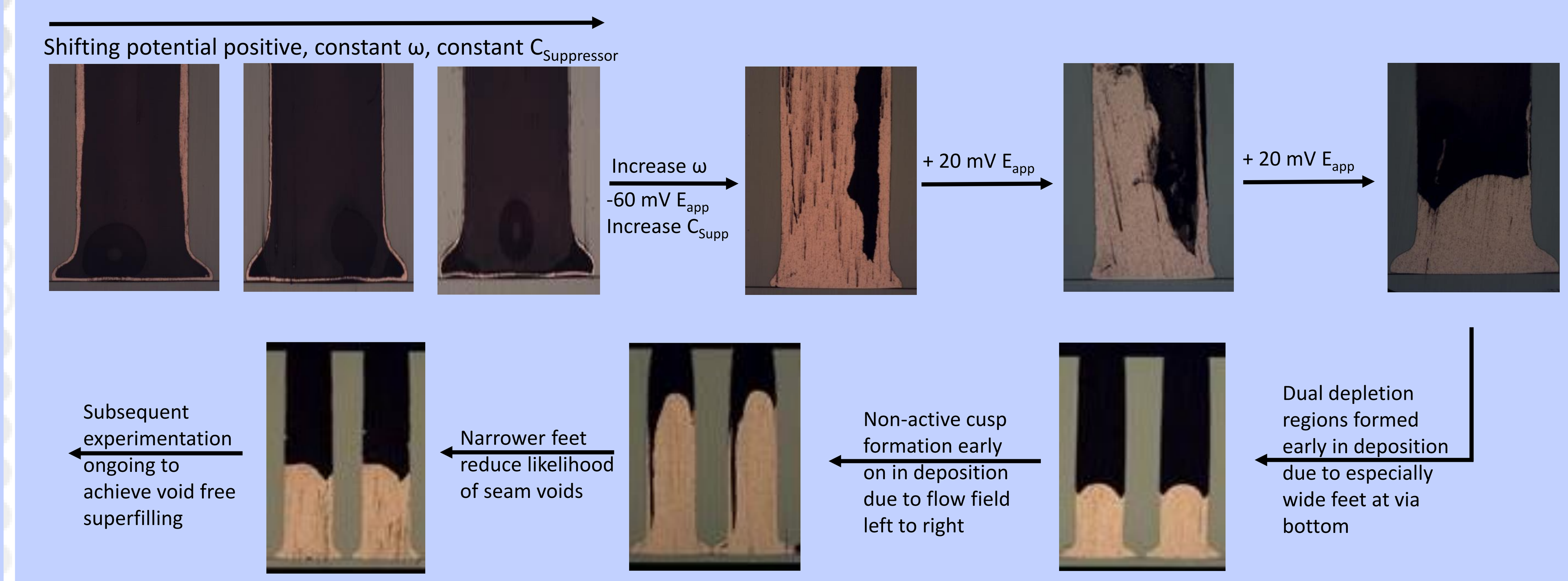
This S-NDR mechanism shows a distinct hysteretic response associated with the breakdown of the adsorbed suppressor in cyclic voltammograms, and this hysteretic region produces 'Turing patterns' with adjacent active and passive regions:[2]



Mesoscale TSV Filling with S-NDR Approach

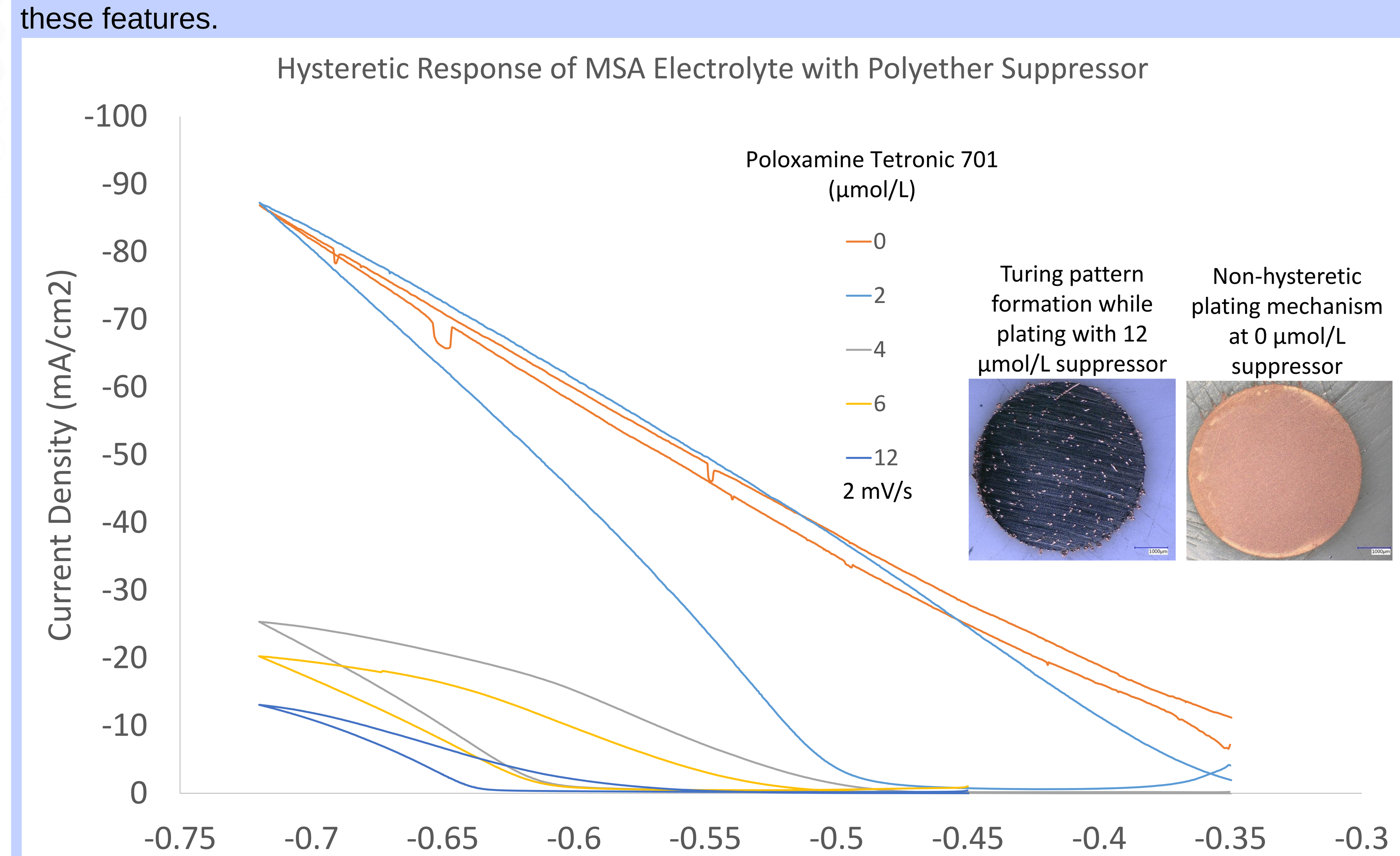
Below one can see that there has been initial progress made in filling these mesoscale TSVs using the previously established H_2SO_4 chemistry and S-NDR approach. Ongoing experimentation is being conducted to develop a repeatable process for fully filling these TSVs. The three variables manipulated in these experiments are suppressor concentration, sample rotation rate, and applied potential.

$$\text{Diffusion Layer Thickness} \propto \omega^{-1/2} = \delta_f = 1.61\,(D_f)^{1/3}\nu^{1/6}\omega^{-1/2}$$



S-NDR Approach in $CuSO_4$-MSA Electrolyte

Utilizing MSA as the electrolyte in an acid copper plating chemistry rather than H_2SO_4 provides the distinct advantage of allowing for a significantly increased Cu^{2+}/H_3O^+ ratio because Cu is significantly more soluble in MSA versus H_2SO_4.[3] This leads to a decrease in Cu^{2+} depletion at the electrode interface, so if we combine this chemistry with the S-NDR method, we can ultimately improve throughput while retaining the distinct benefits of the technique presented above. The figure below shows that there is indeed a similar hysteresis as well as the 'Turing pattern' deposition that we saw in the H_2SO_4 electrolyte above. Subsequent feature filling experiments will be conducted to optimize the filling rate of these features.



[3]Cho, Sung Ki, Myung Jun Kim, and Jae Jeong Kim. "MSA as a supporting electrolyte in copper electroplating for filling of damascene trenches and through silicon vias." *Electrochemical and Solid-State Letters* 14.5 (2011): D52-D56.

Conclusions

Despite over two decades worth of copper TSV and trench filling experimentation for 3D interconnects, the established 4-additive electroplating chemistry is opaque and often unpredictable. The S-NDR approach, first discovered by Josell Et. Al., can predictably yield bottom-up superfilled TSVs at sufficiently high aspect ratios. This technique likely works in both H_2SO_4 and MSA based chemistries, and subsequent research will be conducted in order to optimize the deposition rate and quality of these interconnects.

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