High Elongation Electroless Copper

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ABSTRACT
A novel high build electroless copper system exhibiting superior ductility and adhesion with no internal deposit stress has been developed for advanced metallization of substrates that undergo high stresses; bending, thermal cycling/expansion, CTE mismatch etc. A detailed examination of the ductility, stress and adhesion properties of the new electroless copper system has been performed. The new electroless copper deposit exhibits; greater than 12% elongation, zero internal stress, no blistering, no cracking under extreme bending tests, and excellent adhesion to various substrates.

Key words: Electroless Copper, Molded Interconnect Devices (MID), High Elongation.

INTRODUCTION
Increased usage in electronics is reaching all market segments and with that comes unique designs and substrate materials. Today's applications are exposed to any imaginable environment even those that were not considered safe for electronics historically. As electronics proliferate though various applications there is always a desire and inherent need for improved reliability. The strongest influx of unique environments and uses can be found in the automotive space and of course the Internet of Things. Improved mechanical properties is a desire and need for applications such as flexible circuits, semi additive processing, molded interconnect devices (MID) and even formable electronics. This puts strain on the circuit and the plating materials used to metalize those circuits. The proposed electroless copper system has been designed with increased elongation and improved performance associated to CTE mismatch between copper plating and various substrate materials.

Figure 1. Substrates requiring copper deposits with superior physical properties.

EXPERIMENTAL
High build electroless copper systems are employed to selectively plate a patterned copper circuit onto many substrates. No electroplating is required, the high build electroless copper deposit can be anywhere from about 10 to 25 µm thick. A novel high build electroless copper system has been developed to solve the problems usually associated with high build electroless copper systems. Conventional high build electroless copper systems suffer from internal deposit stress, low percent elongation and cracking under extreme bending tests. A new high build electroless copper system is required in order to pass the stringent demands placed on the copper deposit for modern electronic devices, especially in the automotive field. The physical properties, adhesion to various substrates, and the propensity for stray plating with fine line circuitry of high build electroless copper systems was tested using several methods.

The internal stress of the deposit was evaluated by plating high build electroless copper onto test spirals plated with a thin layer of electroplated nickel in order to initiate the electroless copper reaction onto one side of the spiral. The stress of the electroless copper was measured using a Yamamoto JIS-H8626 spiral contractometer per ASTM B 636-84. The percent elongation was measured by plating high build electroless copper films onto a polished stainless steel substrate, peeling the deposit off of the substrate, and testing the resulting films according to ASTM method E345-16.

The ability of the deposit to withstand bending of the substrate was performed on MID substrates by plating 10-20 µm of high build electroless copper and then bending the substrate over circular mandrels of various sizes and fasteneing the parts to the mandrel so the deposit could be inspected for cracking while in the bent condition.
In addition to testing the physical properties of the deposit, the ability to plate fine lines with no stray plating was also tested by plating 12-20 µm of high build electroless copper on a fine line MID substarte with 50 µm lines and spaces. The adhesion of the deposit to various MID substrates was tested after high build elecroless copper deposition (10-20 µm), subsequent electroless nickel deposition (2-5 µm), submerging the parts in boiling water for 4 hours, scoring 1mm squares in the deposit with a razor blade, and tape testing for adhesion loss with 3M 610 tape.

RESULTS AND DISCUSSION

The internal stress of the new high build electroless copper deposit is shown in figure 2. Other conventional electroless copper baths are shown for comparison. The Internal stress of the new bath is extremely low, typically, the stress cannot be measured and is about 0 MPa. A typical electroless copper bath will show compressive stress. Compressive stress will manifest itself as blisters on the substrate, tensile stress will manifest itself as curling off of the substrate. Conventional high build electroless copper baths are highly stressed with typical values of over 500MPa.

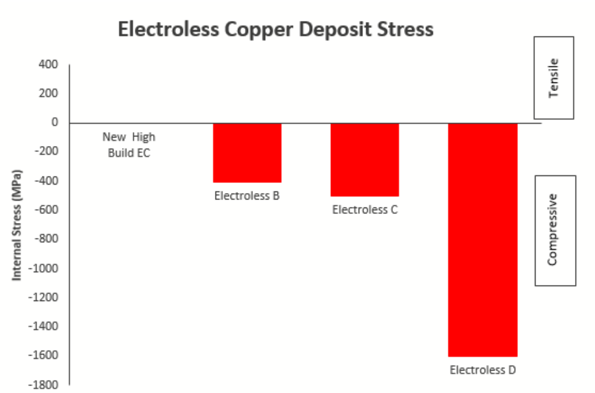


Figure 2: Internal stress of various electroless copper systems. The Electroless B, C, and D, are commercially available electroless copper systems.

The elongation properties of copper deposits from commercially available high build electroless copper systems is normally less than 3 percent. The deposit is very brittle and cracks easily under stress. The ASTM procedure for measuring the percent elongation of metal films was performed by plating the film onto a polished stainless steel substrate and peeling the film from the substrate for pull testing to produce the elongation curve. The adhesion of the electroless copper deposit to the polished stainless steel substrate is low. For electroless copper deposits with high internal stress, the copper deposit will blister off of the stainless steel substrate. Figure 3 shows two stainless steel substrates, one plated from the new high build electroless copper with a stress free deposit and one plated with a conventional high build electroless copper available in the market that has internal compressive stress. The deposit from the conventional bath is blistering off of the substrate, while the deposit from the stress free high build electroless copper bath lays flat on the surface.

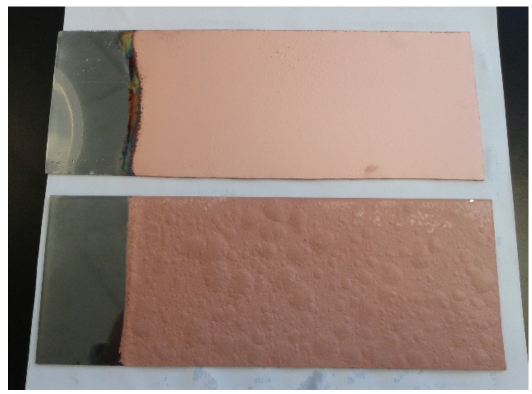
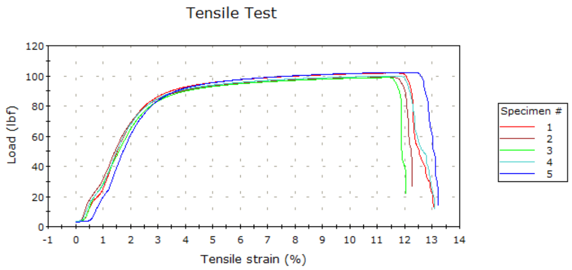


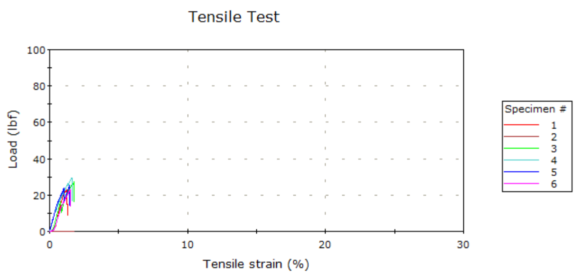
Figure 3. Films produced on polished stainless steel substrates for elongation testing. Top - stress free copper deposit from the new high build electroless copper system Bottom – Conventional high build electroless copper.

The resulting copper films are peeled from the polished stainless steel substrate, cut into ½” wide strips, fastened to a pull tester and pulled until they break according to ASTM method E345-16. The percent elongation is measured as the percent of stretch of the strip before breaking. A typical curve of the percent elongation and tensile strength of the copper deposit from the new high build electroless copper is shown in figure 4. The same curve performed with a conventional high build electroless copper deposit is shown in figure 5.



	Break Force (lbf)	Elongation (%)	Tensile Strength (PSI)
1	101.88	13.03	54,122.07
2	99.00	12.26	55,846.54
3	98.85	12.04	53,835.81
4	99.88	13.06	53,535.14
5	102.37	13.21	54,148.03
Mean	100.40	12.72	54,297.52

Figure 4. Typical elongation curve obtained from the new high build electroless copper deposit.



	Break Force (lbf)	Elongation (%)	Tensile Strength (PSI)
1	23.12	1.28	12,063.33
X 2	0.02	1.83	8.84
3	27.14	1.77	14,370.95
4	29.36	1.63	15,972.50
5	25.37	1.44	13,407.49
6	22.92	1.48	12,096.46
Mean	25.58	1.52	13,582.15

Figure 5. Typical elongation curve obtained from a conventional high build electroless copper deposit.

Note that for the new high build electroless coper deposit, after the maximum strain is reached, the deposit stretches a great deal before breaking. For conventional high build electroless copper baths as in figure 5, the deposit breaks during the initial building of the strain curve and there is no flat portion to the curve. Usually the break occurs at less than 2-3% elongation for conventional high build electroless copper deposits.

The ability of the electroless copper deposit to stretch without breaking is critical for applications where thermal cycling will cause device substrates to expand and contract (such as in automotive applications).

The ability of the new high build electroless copper deposit to withstand bending of the substrate was tested using MID substrates. After depositing the high build electroless copper deposit the parts were bent around a circular mandrel and fastened down onto the mandrel so the deposit could be inspected for cracks while in the bent condition. Figure 6 shows a picture of the set up used and an example result from two different high build electroless copper baths. The new high build electroless copper bath does not show any cracking from these bend tests while deposits from conventional high build electroless copper deposits show many cracks in the deposit.

Figure 6. Example mandrels used for bending tests and two examples of typical results for cracking under extreme bending of the substrate.

The adhesion of the high build electroless copper deposit was tested on numerous MID substrates by plating both electroless copper and electroless nickel onto the substrate, boiling the part in water for 4 hrs., scoring the part to about 1 mm squares and performing tape testing. Both the conventional high build electroless copper deposits and the new high build electroless copper deposit pass these tests. Figure 7 shows some examples of MID parts plated with the new high build electroless copper system tested using this procedure.

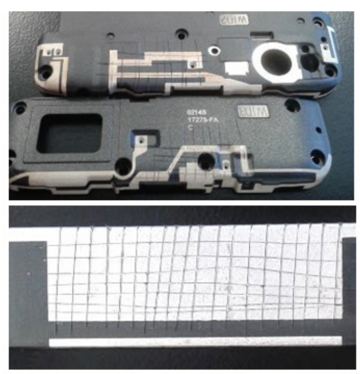


Figure 7. Adhesion testing using MID substrates.

The propensity to have stray plating was tested using fine line MID substrates with 50 µm lines and spaces. The new high build electroless copper bath was found to have much less stray plating than conventional high build electroless copper baths. This is critical for many of today's more sophisticated circuit designs. This property allows the new high build electroless copper system to be used on fine line designs that were previously not possible to produce with conventional high build electroless copper systems.

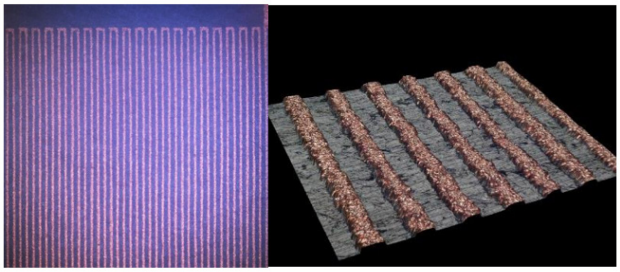


Figure 8. 50 µm line patterns plated with the new high build electroless copper show no stray plating.

Conclusion

The physical properties of high build electroless copper deposits have been improved. Such electroless copper systems are required to meet the demands from harsh environments, CTE mismatch, and new demanding applications such as those found in the automotive industry. The new high build electroless copper system surpasses these demands by providing a stress free, highly ductile copper deposit with excellent adhesion, no deposit cracking and no stray plating. These improved properties of the high build electroless copper system allow for this type of technology to be utilized on more sophisticated devices that require these improved properties.

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