Reliability of LTCC using Electroless Nickel Immersion Gold (ENIG) Plating Technology

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Abstract

In an effort to address the impact of rising gold costs on the fabrication expense for high frequency circuits, and maintain circuit quality and reliability, the DuPont™ GreenTape™ 9K7 low temperature co-fired ceramic materials (LTCC) with top silver conductors have been evaluated using electroless nickel immersion gold (ENIG) plating. Results comparable to the quality of efficiency and reliability of traditional gold conductor systems were achieved at reduced costs.

LTCC coupons produced using the ENIG process were tested and compared to standard specifications for coupons with gold printed conductors. The test methods used include wire bond and adhesion pull tests on eight layer coupons, and MIL-STD-883 [1] temperature cycle testing on a layered high frequency test pattern. The reliability of the high frequency characteristics including insertion loss and return loss measurements were evaluated periodically throughout 1090 temperature cycles. Adequate results for most applications were obtained using the ENIG plated system compared to gold printed coupons.

In an attempt to better understand the boundaries of the ENIG process on 9K7 LTCC and its use as an alternative for gold conductor systems; future testing will explore the effects of additional environmental testing. The added tests will include thermal shock, and temperature and humidity cycling on 9K7 LTCC test coupons. The testing will be conducted in accordance with MIL-STD-883 as a benchmark, and also evaluate wire bond and adhesion properties. This paper will report the reliability test results on plated GreenTape™ 9K7 LTCC systems after exposure to the stated environmental conditions.

Key words

Reliability, LTCC, GreenTape, ENIG, high frequency)

I. Introduction

Low Temperature Cofired Ceramic (LTCC) material systems offer excellent electrical, mechanical, and thermal properties for electronic packaging especially for microwave, Millimeter wave circuits and systems. Traditionally, LTCC uses noble metals such as gold and silver conductors. While gold conductor systems provide the best available reliability of packaged circuits, the cost of gold can be prohibitive for cost sensitive applications that may not require the same level of reliability. Silver is a good choice in this case but will require surface passivation and surface finishing compatible with downstream packaging processes such as wire bonding and soldering. One excellent means of providing surface finishing for LTCC circuits with silver conductor systems is electroless nickel immersion gold (ENIG) plating.

The research described in the paper was motivated by the need to extend reliability testing of DuPont™ GreenTape™ 9K7 LTCC materials with ENIG plating to the next level. Prior work published in Advancing Microelectronics, March/April 2014 showed that LTCC coupons plated using ENIG plating met or exceeded the MIL-STD-883H temperature cycling requirements [2]. Two sets of test coupons were built, one set for adhesion and the second set for high frequency testing. Both groups were then evaluated after exposure to thermal shock, and high humidity conditions. The MIL-STD-883H was used as a guide; however, slight modifications due to available equipment were made without compromising the test standard. The robustness of the standard was not reduced as a result of these modifications.

II. Experimental Procedure

DuPont™ GreenTape™ 9K7 LTCC materials with 0.005” thickness was used to fabricate the test samples along with LL601 (via fill), HF602 (ground plane), and 6118A (top signal conductor) compositions. Pd plated samples were also included as a plating control alongside the ENIG samples.

The vias were formed using an UHT MP-8200Z Multipunch unit, and a MSP-9156PC screen and stencil printer for metal deposition onto the tape. Once all layers of the build had been metalized they were laminated together using an Autoclave Engineers OIT (Isostatic) Laminator at 3000psi. The furnaces used for firing and re-firing were Sierratherm Batch Firing Furnace and Sierratherm 11-Zone Conventional Firing Furnace respectively. The initial firing was for 24hrs at a maximum temperature of 850C and the re-fire was for 30min with a maximum temperature of 850C.

A standard adhesion test pattern was used and is pictured in Fig. 1, and the screen used for printing was a 325 mesh 1.1w screen. A pull test was used to test adhesion that included soldering wire to the part to be tested using 63Sn/37Pb solder paste. An initial measure of the force required to break the solder bond, as well as the failure modes, was taken for unplated, ENIG plated, and Pd plated parts using a MTS 1122 Renew Instron. The test parts were then subjected to 15 thermal shock cycles with temperature extremes of 125C and -55C with a dwell time of 15min per extreme, and 10 cycles of temperature and humidity testing with the maximum humidity being 90%RH and the temperature ranging for 25C to 65C. The dwell time at maximum temperature and humidity was 3hrs per sub-cycle with a total of 9hrs for 5 cycles, and 6hrs plus a 3hr dwell time at -10C for the remaining 5 cycles. A total of 36 parts were tested over the stated conditions.

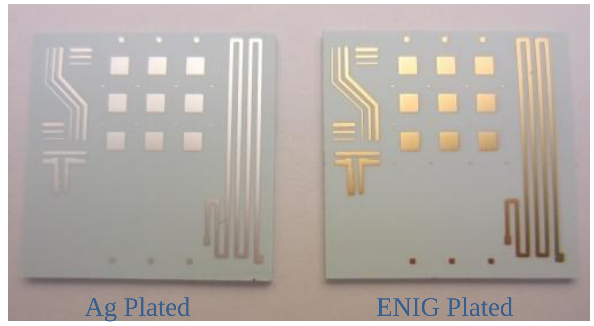

Fig. 1 Standard 1”x1” pattern for adhesion test parts.

The high frequency test pattern used is shown in Fig. 2 with the area of interest being the coplanar waveguide (CPW) transmission lines with lengths of 5mm and 10mm. Initial measures of insertion and return loss for the 5mm and 10mm CPW lines were measured for unplated, ENIG plated, and Pd plated parts using a Cascade Microtech probestation with ground-signal-ground probes connected to an Anrtisu ME 7828 A Vector Network Analyzer. The parts were then subjected to 15 thermal shock cycles ranging from 125C to -55C with a dwell time of 15min per extreme, and 10 cycles of temperature and humidity testing with the maximum humidity being 90%RH and the temperature ranging from 25C to 65C. The dwell time at maximum temperature and humidity was 3hrs per subcycle with a total of 9hrs for 5 cycles, and 6hrs plus a 3hr dwell time at -10C for the remaining 5 cycles. A total of 39 parts were tested over the stated conditions.

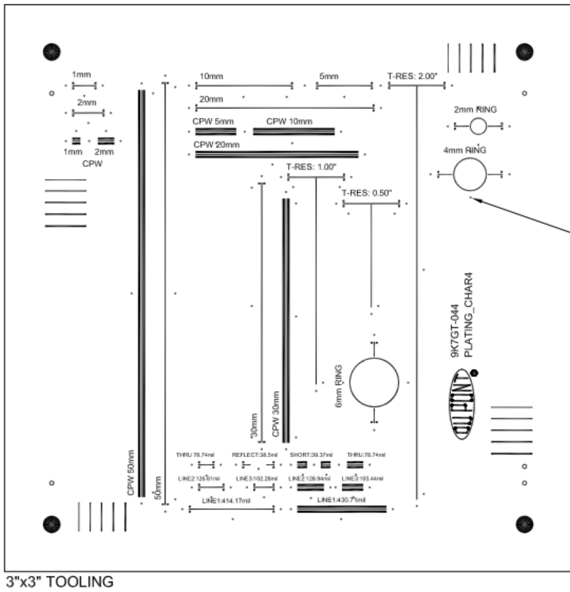

Fig. 2 High frequency test pattern.

The MIL-STD-883H methods used as a guide were 1004.7 for Moisture Resistance (Humidity), and 1011.9 Thermal Shock. This thermal shock method was written for liquid fluids. The chamber available for the test uses an air system.

III. Results

The adhesion tests for samples stressed under both thermal shock and humidity environmental conditions, compared to the initial baseline, showed a decrease in most cases for maximum force needed to break the solder bond. The exception was the humidity tested Pd plated samples, which showed an increase. The results for the humidity samples had similar peak load measurements compared to the baseline. The ratio of the differences between plating conditions was upheld, showing that the bond strength increase across plating conditions is stable, Fig. 3. In all cases the unplated samples showed a higher peak load followed by Pd plated samples and then ENIG plated samples. The failures in all cases involved the metallization pulling away for the 9K7 tape substrate entirely as shown in Fig. 4 & 5. The wires attached remained flat while exposed to temperature and humidity testing. To perform the adhesion pull test the wires were bent at a 90° angle. In several instances, concerning the thermal shock samples, the bonded wire and the metallization around it detached from the tape before a pull test could be conducted, as shown in Fig. 5.

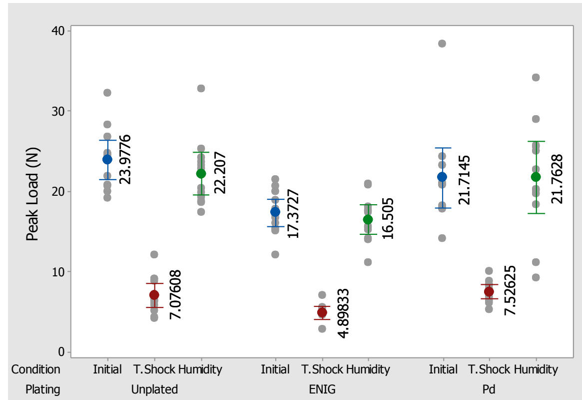

Fig. 3 Thermal Shock and Humidity of Initial, ENIG, and Pd Plated Samples - Peak Load (N) - 95% CI for the Mean.

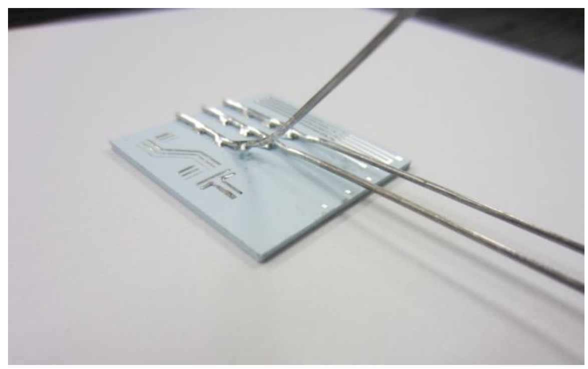

Fig. 4 Adhesion failure.

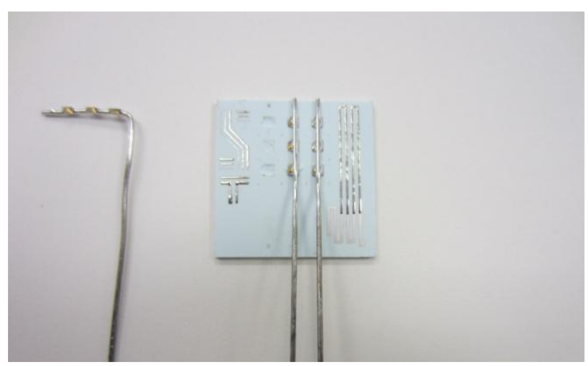

Fig. 5 Loss of the adhesion wire during the pull test.

The ENIG and Pd plated high frequency insertion loss (IL) and return loss (RL) data, for samples tested under thermal shock conditions, showed minimal change in cumulative IL or RL for both the 5mm and 10mm CPW lines, Fig. 6. The unplated samples in one case, sample 18, showed a dramatic change in both IL and RL after thermal shock exposure on the 10mm CPW line, but minimal change in the 5mm CPW line compared to the initial measurements, Fig. 7. Of the remaining 5 unplated samples tested through thermal shock 4 showed a minimal change from the initial measurements, and the 5th was defective at the 10mm CPW line. Both the initial and the stressed measurements for sample 5 showed high IL and RL, therefor this sample was excluded from the study.

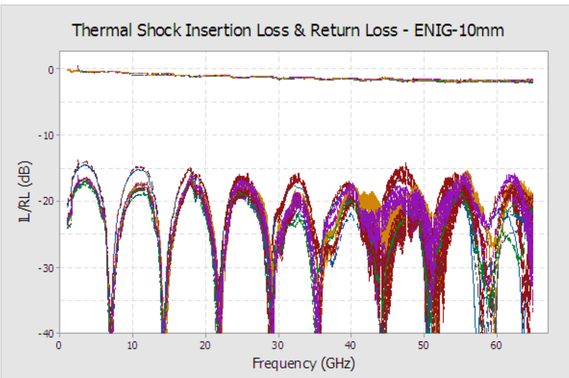

Fig. 6 Example of good thermal shock IL & RL results.

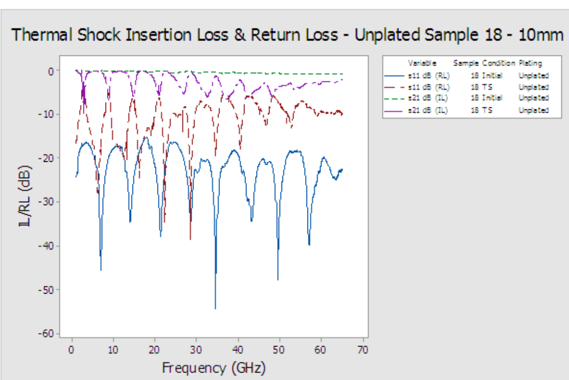

Fig. 7 Disrupted IL & RL results of sample 18 after thermal shock.

Similar to sample 5 above, the high frequency test results for the humidity test samples showed one defective circuit at the 10mm CPW line for sample 6, which was plated with ENIG. The remaining samples for all plating conditions showed slight changes (1 to 2 dB) in cumulative RL or IL after humidity testing. A dramatic disruption, as in sample 18 above, was not observed in the humidity test samples. There did, however, appear to be more noise in the humidity results as shown in fig. 8.

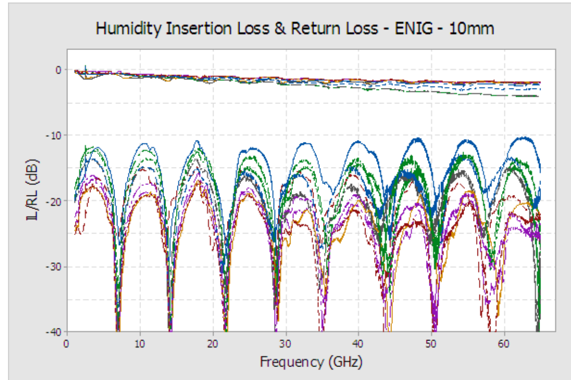

Fig. 8 Example of humidity IL & RL results.

IV Conclusion

Test results for adhesion samples revealed an unacceptable decrease in the average peak loads of 16.90, 12.47, and 14.19(N) for unplated, ENIG, and Pd plated samples respectively compared to the initial measurements. The adhesion results of the humidity samples showed much lower average peak load decreases of 1.77 and 0.87(N) for the unplated and ENIG samples. The Pd samples showed an increase in average peak load of 0.05(N). This difference in performance could be due to the metal contracting and pulling away from the tape during the -55C portion of the thermal shock test.

The high frequency samples overall showed minimal change in cumulative IL and RL after thermal shock and humidity testing. Of the 18 thermal shock samples test, there was a 94.12% yield observed in maintaining the reliability of the electrical connections. The unplated samples showed a yield of 80%, while the ENIG and Pd plated samples had a yield of 100%. With all electrical connections remaining open, and having minimal changes in cumulative IL or RL after humidity testing, a 100% yield was observed from the 18 humidity samples. These results show excellent high frequency reliability under the tested conditions, and excellent adhesion reliability for humidity tested samples.

V Acknowledgments

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VI References

[1] MIL-STD-883H

[2] Allan Beikmohamadi, Patricia Graddy, Deepukumar Nair, Jim Parisi, and Steve Stewart, Plating Reliability and High Frequency Testing of DuPont GreenTape 9K7 LTCC. Advancing Microelectronics, March/April 2014 Vol. 41 No. 2 pg 6.