

Electroplating and Electroless Plating Process Development for DuPont™ GreenTape™ 9K7 LTCC

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Abstract - Low Temperature Co-fired Ceramic (LTCC) technology provides an attractive packaging platform for microwave and millimeter wave circuits and systems due to its unique properties. Generally, thick film gold or silver conductors are used as metallizations on LTCC substrates along with occasional use of copper thick films. This paper reports methods and results of extensive process development experiments DuPont Microcircuit Materials has undertaken to establish a commercially viable plating process for the market leading DuPont™ GreenTape™ 9K7 LTCC system. Both Electroplating and Electroless plating processes are investigated in this work. These techniques provide certain advantages when used in isolation or in combination with standard thick film metallizations, helping to extend their applicability. Electroplating of copper on LTCC provides a means of using copper as the external conductor without having to use complicated firing processes in oxygen-free atmosphere as required for copper thick film. This approach leads to a much more cost effective approach if copper is required as the external metal. Electroless Nickel/Gold plating (ENIG) of both silver and copper (electroplated and/or thick film) provides an industry standard, highly reliable, robust surface finish. Such surface finish enables easy integration of both soldering and wire bonding processes.

Key Words: LTCC, packaging, electroplating, Electroless plating, GreenTape™ 9K7

Introduction

Gold and silver Thick Film (T/F) compositions are used on Low Temperature Co-fired Ceramic (LTCC) as internal and external conductors. The rising cost of gold makes LTCC cost sensitive on some applications. To reduce dependency on gold and lower the cost of ownership to customers, plating on T/F silver and copper top conductors were explored-see Figure 1. Both Electroplating and Electroless plating (Electroless Nickel Immersion Gold – ENIG) processes were investigated in this work. Electroplating copper was accomplished by use of standard TiW adhesion / seed layer.

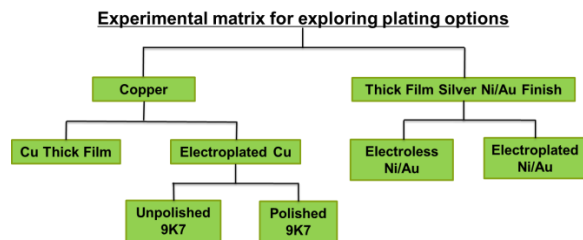


Figure 1. Experimental matrix to explore plating options.

Investigation / experiments

To lower the cost of external metallization for DuPont™ GreenTape™ 9K7 LTCC, many options were explored. The options included electrolytic, and Electroless plating of thick film silver & copper top conductors with Ni/Au surface finishes. The top layer of gold provides low contact resistance, excellent shelf-life, and very good wetting for soldering and wire bonding. The nickel provides a barrier layer to prevent silver or copper and gold inter-diffusion. Additionally, polished and unpolished 9K7 LTCC were electroplated with copper, followed by Electroless Nickel Immersion Gold (ENIG) Ni/Au surface finish. Following sections will describe processing of each option.

Electroplating T/F silver & Cu top conductors

Electroplating uses applied electrical current to reduce metal ions; therefore, all features need to be electrically connected. The test samples were prepared using four layers of 3"x3" DuPont™ GreenTape™ 9K7 LTCC, LL602, 6118A co-fired T/F silver top conductors, and copper thick film top conductor 9922. The test samples were laser ablated

after plating to form nine adhesion test pads of 2mm x 2mm in dimension. Then, the lead wires were placed across the surface of each column of conductor pads as shown on Fig. 2.

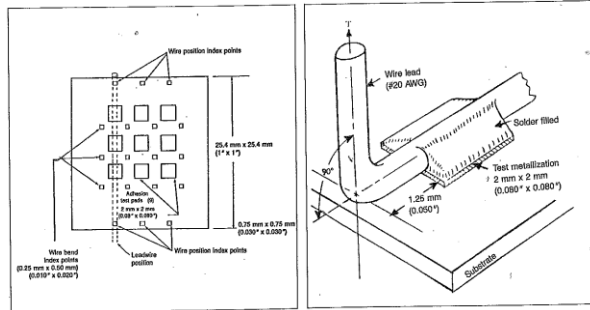


Figure 2a. IPC-TM650-2.4.1.2 adhesion test pattern

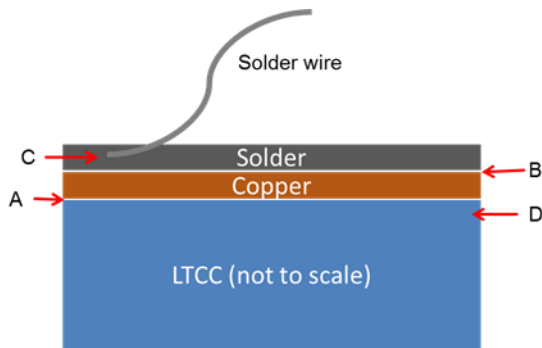


Figure 2b. Adhesion pull test failure modes.

The samples were fluxed, preheated and soldered by immersing the samples into molten solder for 5 sec. Then; the samples were placed in a chamber for 100 hours at 150°C. Aged samples were then tested using MTS, model 1122 adhesion tester.

Another set of DuPont™ GreenTape™ 9K7 LTCC test samples were prepared without any metallization. The test samples were divided equally into two groups. The first group of the samples was polished prior to plating processes, and the second group of samples was not. Both polished and unpolished samples were electroplated copper by use of standard TiW adhesion / seed layer prior to Ni deposition. Test results for aged adhesion (100 hr. @ 150°C) pull test are summarized on Table 1.

Sample ID	Aged adhesion
9K7_LL602 Ag	25 N
951_6118A Ag	26 N
9K7_9922 Cu	22 N

Table 1. Adhesion pull test summary of Electroplated samples (aged adhesion 100 hrs. at 150°C).

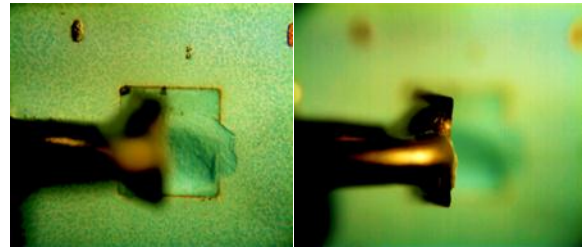


Figure 3. Adhesion pull test with failure mode D – breaks substrate.

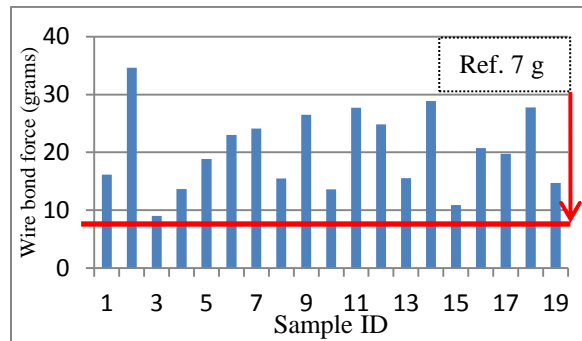
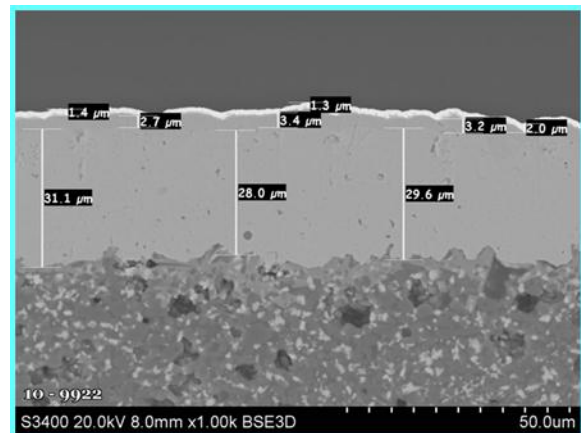


Figure 4. Wire bond pull test on electroplated Ni/Au finish on 9922 T/F Cu top conductor (K&S 4522, with 0.002” gold wire).



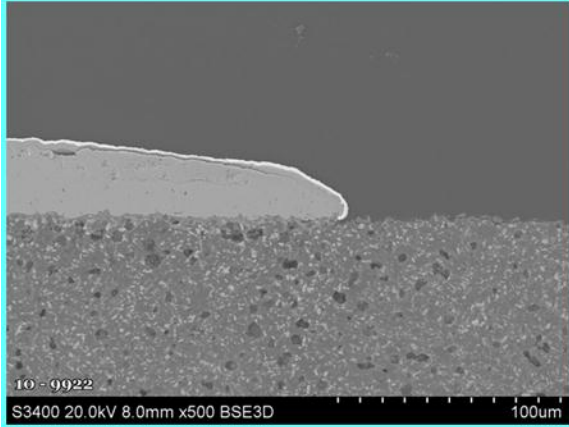


Figure 5. SEM cross section of T/F Cu top conductor (9922) with electroplated Ni/Au surface finish

Electroless Nickel Immersion Gold (ENIG)

ENIG is another surface plating process used on circuit boards and LTCC surface finishes. The ENIG plating consists of an Electroless nickel deposition (1.5 – 3 µm) followed by a thin layer of immersion gold (0.5 to 2 µm), to protect the nickel from oxidation. Nickel acts as a diffusion barrier. ENIG provides excellent surface planarity and large area plating. Very good soldering and gold wire bonding. Unlike electroplating, the ENIG is nonelectrolytic, requiring no electrical current. Plating takes place on non-conductive substrate surfaces - see figure 6

The test samples were prepared using the LTCC standard processes, consisting of four layers of 3”x3” DuPont™ GreenTape™ 9K7 LTCC: LL602, LL612, 6118A co-fired thick film silver top conductors. Circuitized test samples were processed through ENIG plating processes with Ni/Au surface finishes. Test samples with Ni/Au finishes were prepared for soldering per IPC-TM650-2.4.1.2, then placed in thermal aging chamber at 150°C for 100 hours. Then, the samples were tested for adhesion using the procedure described in the previous section. Thermal aged adhesion of GreenTape™ 9K7 with LL602, LL612, and 6118 T/F silver top conductors along with DuPont™ GreenTape™ 951 LTCC as a control, is shown on Table 2.

Sample ID	Aged adhesion
9K7_LL602 Ag	26 N
9K7_LL612 Ag	21 N
9K7_6118A Ag	19 N
9K7_9922 Cu	22 N
951_6118A Ag	23 N
FR-4 Reference	22N
Polished 9K7	22N
Unpolished 9K7	23 N

Table 2. Aged adhesion test results of samples with ENIG Ni/Au surface finish (100 hrs. at 150°C).

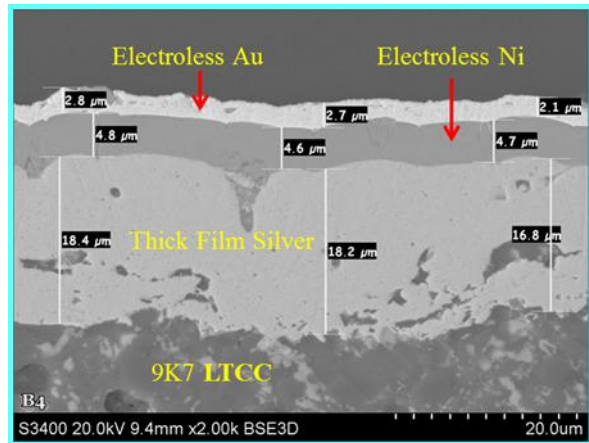


Figure 6. Cross section of 9K7, T/F LL602 Ag top conductor and ENIG Ni/Au surface finish.

Interface characterization

Plated test samples with Ni/Au finishes provided planar surface for easy soldering and wire bonding. Aged adhesion results on this exploratory phase of the program is as good as or better than the standard thick film and FR-4 pull test results. The wire bonding pull test results far exceeded the Mil-883 of 7 gram on 0.002” gold wire – See Figure 7.

The organic packaging industry uses a peel test rather than a pull test for adhesion force testing. For comparison purposes, FR-4 board with ½ Oz Cu was patterned per IPC-TM650-2.4.1.2, and soldered. Then, the test samples were place in a 150°C chamber for 100 hours. Aged adhesion test results are shown on Table 2.

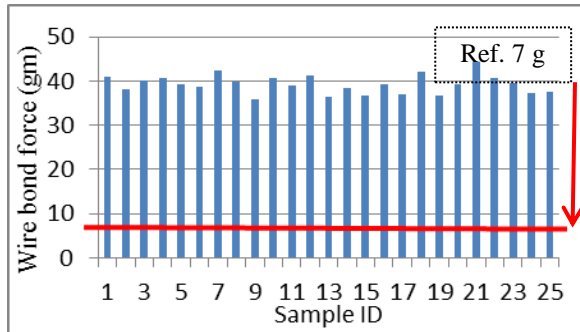


Figure 7. Wire Bond pull test results on DuPont™ GreenTape™ 9K7 LTCC with LL602 silver top conductor and ENIG Ni/Au surface finish (K&S 4522, with 0.002” gold wire).

Effect of Ni/Au surface finish on high frequency characteristics

Usage of nickel within the ENIG stackup raises a key concern about the microwave / millimeterwave transmission properties due to the ferromagnetic nature of nickel. Various microwave transmission lines were designed, fabricated, and tested before and after ENIG plating to quantify any detrimental impact nickel has on transmission properties. S parameter data from testing a coplanar waveguide (CPW) transmission line up to 65 GHz is shown in figure 8. As expected nickel adds additional insertion loss and results in higher return loss compared to unplated silver lines. However, the amount of added losses was found to be still adequate for most of the applications. Worst case insertion loss better than 2.2 dB/cm and return loss better than 10 dB through 10 MHz-65 GHz are obtained for ENIG plated CPW line. These figures compare to worst case insertion loss of 1.05 dB and return loss of 14.90 dB for the same silver thick film CPW before plating.

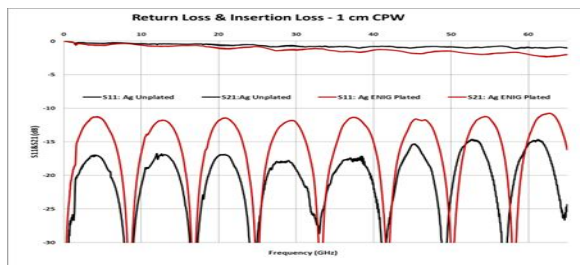


Figure 8. Insertion loss and Return loss for a 1 cm long CPW transmission line with and without ENIG plating showing the impact of Ni.

Learning

- DuPont™ GreenTape™ 9K7 LTCC with co-fired silver conductors and post fired copper thick film top conductors exhibited excellent wire bond force and solder adhesion results equal to or better than the conventional thick film results.
- Test results revealed that aged adhesions of 9K7 with silver and copper conductors are equal or greater than the aged adhesion of FR-4. Comparatively speaking, organic packaging (PTFE) requirements are 5-10 N/cm.

Conclusion, path forward

- Current results provide a clear path forward to use electroplated copper on GreenTape™ 9K7 with a standard seed layer and Cu deposition without having to use controlled atmosphere as required for T/F copper conductor, if copper is required as the external metal.
- Both electrolytic and Electroless plating processes are compatible with GreenTape™ 9K7 top silver and copper conductors based on the initial results.
- Observed aged adhesions of thick film silver and copper conductors are equal or greater than FR-4.
- Further reliability testing of GreenTape™ 9K7 LTCC with co-fired thick film silver top conductors is underway in accordance with MIL-STD-883H.

References

- [1] MIL-STD-883H
- [2] IPC-TM650 test methods
- [3] Don Cullen, et al., “Effect of surface finish on high frequency signal loss using various substrate materials”.
- [4] P. Ollivier, M Rine, “Material and Process Development for Plateable Conductors on LTCC”, Proceedings IMAPS Nov 14-18, 2004 Long Beach, CA.

[5] M. Skurski, et al, "New Plateable Thick Film Silver Conductors for DuPont 951 Green Tape™ LTCC", IMAPS 2009 Nov 1-5, 2009 San Jose, CA.

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