

## **DuPont™ Green Tape™ Low Temperature Co-fired Ceramic (LTCC)**

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### **Abstract**

*Low Temperature Co-fired Ceramic (LTCC) provides a technology option for designers that combine the benefits of HTCC and thick film technologies and is the technology of choice for many complex automotive, consumer, and military applications. Circuit cost is always a primary consideration. The traditional method employed to address cost has been the use of mixed metallurgies, rather than using all gold. Silver based conductors for signal and ground are used internally, with precious metal based transition via fill compositions that interconnect to gold conductors used for wire bonding or brazing, or other solderable conductors, externally.*

*Plating external silver based conductors with electroless Ni/Au offers a reliable and lower cost alternative to the mixed metals approach. Some advantages of plating include; elimination of precious metal containing transition via fill compositions and gold external conductors, the use of a single metallurgy throughout the circuit, all resulting in the additional cost reduction, and a smooth gold plated surface ideal for wire bond acceptance, or pin brazing.*

*This paper introduces three new silver based thick film conductor compositions that are plateable with electroless Ni/Au for use with Green Tape™ 951. Reliability and performance are discussed in detail and include; 25 micron Au wire bonding, pin grid array brazing, and soldering. Data include thermal cycle/thermal shock evaluations, environmental performance using 85%RH/85°C, and thermal aging.*

*Key words: Plating, Electroless Ni/Au, LTCC*

### **Introduction**

Low Temperature Cofired Ceramic (LTCC) technology continues to grow as advantages with reliability and performance are demonstrated. Versatility and capability have been enhanced with the adoptions of cofireable internal thick film resistors, inductors, high K capacitors, and cofireable photoimageable Fodel® conductors, all of which can be buried into the ceramic circuit and used as embedded passive components which can free up valuable external real estate for other purposes [1, 2]. Cost savings are realized by eliminating process steps involved with soldering and placement of

external devices such as MLC's (Multilayer Capacitors) or chip resistors.

When using the traditional mixed metallurgy approach for cost reduction, the purpose of a transition via fill composition is to reduce the potential for Kirkendall voiding when transitioning from silver to gold. This paper discusses electroless nickel, immersion gold, and electroless gold plating onto silver thick film conductors, and whether silver based metallurgy for both internal and external conductors and via fill composition can provide the desired reliability

and performance. The potential for Kirkendall voiding is eliminated by using all silver thick film.

Three new plateable, screen printable thick film silver based conductors; 6117, 6118 & 6119, compatible with DuPont™ Green Tape™ 951 low temperature co-fired ceramic (LTCC) are introduced. Performance and long term reliability characteristics of each conductor presented here include; 1 mil Au wire bonding, 80Au/20Sn brazing, and Sn/Pb soldered adhesion. Reliability is characterized using accelerated life testing with thermal aging, thermal cycling and thermal shock testing, and environmental evaluations at 85% relative humidity at 85°C.

### Electroless Plating to LTCC

Electroless plating has advantages over electrolytic plating with LTCC materials because it allows circuits to be designed without requiring electrical connection to be applied to every plated surface. This gives the circuit designer flexibility for greater consideration of circuit size, performance and fabrication efficiencies.

Electroless nickel and gold plating of LTCC silver circuits is accomplished by a sequence that includes metals deposition from a variety of mechanisms including adsorption, immersion and autocatalytic plating. Electroless nickel is a well known and widely used autocatalytic plating process. The nickel metal deposited acts as the catalyst for continuing the reaction resulting in the reduction of nickel ions from solution to nickel metal on the surface. In this way, nickel continues to build thickness at a predictable rate.

During the electroless nickel plating reaction, phosphorus from the reducing agent sodium hypophosphite is also deposited with nickel, resulting in 6-8 weight % in the deposit. This is in the range of mid-phosphorus and is recommended for LTCC nickel-gold electroless plating applications. Electroless nickel thicknesses for LTCC should be from 100 to 200 microinches. Excessive nickel thickness can affect brazing and other processing later on. If thickness is too thin, it may affect plated porosity and thereby impact the plated gold deposit.

Silver metal itself, does not work as a catalyst for the reaction of electroless nickel plating. To plate electroless nickel onto silver patterns, they must first be activated. Activation

is accomplished by depositing a catalytic metal onto the silver surfaces. Typically, this is done using an activator solution such as palladium chloride in dilute HCl. This activator will deposit palladium on the silver using an adsorption mechanism.

Palladium is an excellent catalyst for electroless nickel plating. Palladium is not evenly deposited as a continuous film, but as scattered sites across the surface. Once the electroless plating reaction is initialized, the reaction sets up a small voltage over the silver surface and the electroless nickel quickly deposits as a continuous layer. The function of palladium is only to 'kick-off' the plating reaction. The palladium has very little to do with adhesion of the electroless nickel to the silver. The nickel does plate directly to the silver surface.

Electroless gold is also an autocatalytic plating process, working in the same manner as described above for electroless nickel with one exception. There is not a co-deposit of any materials from the reducing agent. Gold is deposited at a high purity (99.9+%) so that it works very well in semiconductor packaging applications requiring wire bonding and soldering. Typical thickness requirements range from 20 to 100 microinches (pinch) .

Unfortunately, electroless gold plating reactions are not catalyzed by nickel so an intermediate layer of gold needs to be plated over the electroless nickel by using an immersion gold plating bath, working by way of a metal displacement reaction. This is different from an activator bath however, since the immersion gold deposit does completely cover the electroless nickel surfaces and the immersion gold deposit does provide adhesion to the nickel and to the electroless gold deposit. A primary reason for coating all nickel surfaces in this step is to protect the electroless gold plating bath. Electroless gold plating baths are intolerant to nickel contamination. Immersion gold plating deposits are typically 6–8 microinches in thickness and do completely seal the nickel surfaces. Immersion gold also protects and seals all the nickel surfaces, and decreases the rate of oxidation and extends the shelf life of plated parts.

Illustration 1 shows the typical process flow for plating to silver on LTCC. The cleaning step removes contaminants (fingerprints, oil,

wax, dirt etc.) from the base metal [3] while etching is done to remove oxides from the surface of the base metal, providing a better surface for activation and good adhesion of the plated deposit.

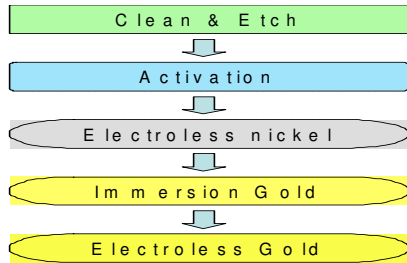


Illustration 1: Plating Steps

### Plateable Silver Composition 6118

6118 is a high solids, thick printing silver conductor that provides a high density, low porosity fired film, ideal characteristics for Ni/Au plating. Typical thickness is 18-22  $\mu\text{m}$ . The data presented below show excellent wire bonding capability with 1 mil Au wire, and excellent brazing performance with Au/Sn 80/20 when using a special brazing profile.

Reliability for wire bonding performance was determined by accelerated life testing which included thermal aging at 150°C to 1000 hours, exposure to environmental conditions of 85% RH and 85°C for up to 1000 hours, and thermal cycling using a 2 hour -40°C/+125°C schedule, to 1000 cycles. Multiple sets of test parts using several combinations of paste lots and tape lots were used for the analyses to help insure repeatability.

Table 1: Wire bond parameters

|                   |                |                  |        |
|-------------------|----------------|------------------|--------|
| <b>Bonder:</b>    | Palomar 2460-V |                  |        |
| <b>Wire:</b>      |                | Calif. Fine Wire |        |
|                   |                | 3-5% elon.       |        |
|                   |                | 8 gms min. BS    |        |
|                   |                | 99.99% Au        |        |
|                   |                | 0.001"           |        |
|                   |                | 12/9/2008        |        |
| <b>Capillary:</b> | Gaiser Tool    |                  |        |
|                   |                | 1513-17-437GM    |        |
| <b>Stage:</b>     |                | 150C             |        |
| <b>Bonding:</b>   |                | First            | Second |
|                   | Force          | 50               | 90     |
|                   | Time           | 45               | 90     |
|                   | Power          | 75               | 95     |

Table 1 lists the wire bonding parameters. Excellent wire bonding results have been obtained on 6118 test parts at three thickness levels of plated electroless gold. All

wire bond strength values reported for 1 mil gold wire were above 11.0 grams regardless of the life testing condition measured. See charts 1, 2, & 3. For these wire bonding assessments, 1600 wires were bonded, 30 pulled per grouping. Early in this development program, 2 mil Au wire was tested to help understand adhesion of the silver conductor to the substrate, and adhesion of the gold plating to the conductor. These results were also good, 38.6 grams mean pull strength, with no bond lifts or metal lifts.

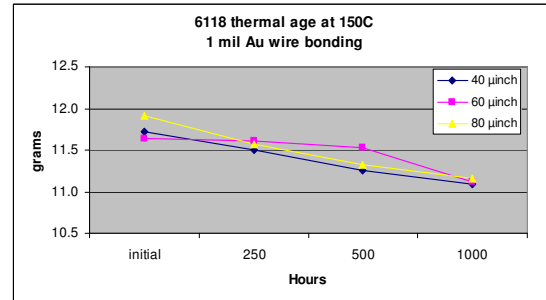


Chart 1: Thermal aging at 150°C

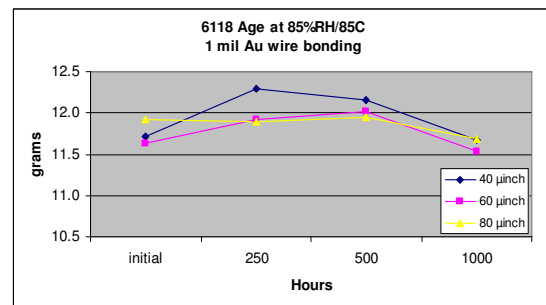


Chart 2: Exposure to 85%RH/85°C

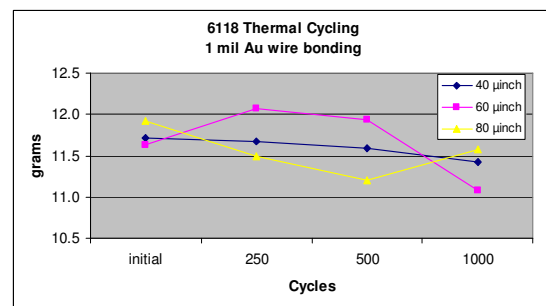


Chart 3: Thermal Cycling (-40°C/+125°C)

It is important to note that wire bond data obtained at greater thickness plated electroless gold exhibited periodic bond lifts after minimal thermal aging exposure. So a clear process window of plated gold thickness for 6118 was demonstrated. No bond lifts or metal lifts were observed when plated gold thickness

was between 40 to 90  $\mu$ inch. The typical failure modes were wire breaks or heel breaks at either first or second bonds.

In real life circuits, wire bonding can take place on a conductor trace that has been cofired & refired directly on top of a filled via. To characterize this, test parts were prepared using a daisy chain pattern with 10 mil diameter vias and 10 mil traces interconnecting the vias. See illustration 2. In this study, parts were subjected to 2x and 5x refires prior to plating. In many cases, a real circuit can be refired multiple times as post printed resistors or conductors and other processes are performed. During wire bonding, wires were attached directly over the vias.

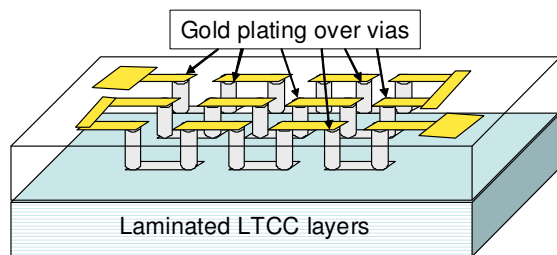


Illustration 2; Daisy chain concept

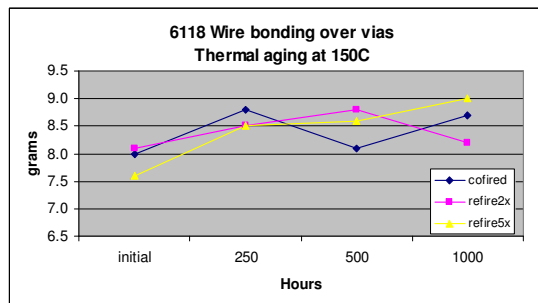


Chart 4: Wire Bonding over vias, age at 150°C

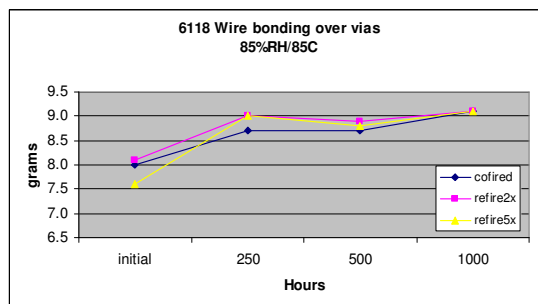


Chart 5: Wire Bonding over vias, 85%RH/85°C

The data in charts 4, 5 and 6 show good wire bonding results for all conditions. Actual pull strength values are slightly lower than the previous charts, but this can be explained by the need to adjust the loop geometries of the wire

bonder to accommodate the different test pattern. There were no wire bond lifts and no metal lifts. Typical failure modes were wire breaks and heel breaks.

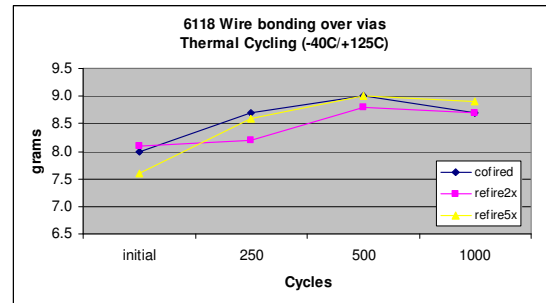


Chart 6: Wire Bonding over vias, TCA

Of the three new compositions developed, only 6118 is capable of being brazed. 6118 exhibits a high density fired film with low porosity (see illustration 6) and incorporates minimal binders so that purity of the silver surface remains high. Performance was determined by a standard pin pull adhesion method using Kovar pins with a pre-form of 80Au/20Sn. The (PGA) pin grid array pattern consists of .070" printed pads on .100" pitch. The pin or nail head diameter measures .025", with a shank diameter of approximately .018" and lead length of .150". A graphite braze fixture is positioned so that the metallized plated pads are in contact with the nail heads during the brazing profile. The temperature profile in illustration 3 was optimized for brazing performance of plated 6118. It provides optimum pull strength values for cofired 6118 on DuPont™ Green Tape™ 951 low temperature co-fired ceramic (LTCC).

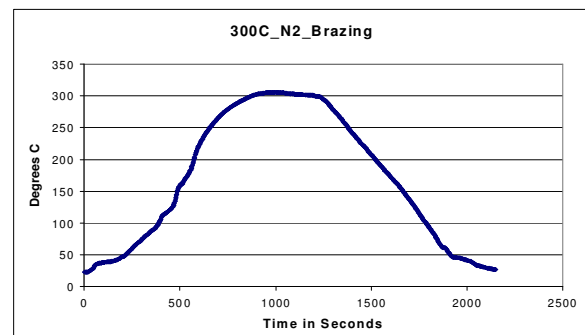


Illustration 3: 300°C Brazing Profile for 6118

Standard braze profiles using higher peak temperatures as high as 400°C resulted in blistered pads, with the pins basically falling off. The profile was adjusted several times and

finally optimized to peak at 300°C for 5 minutes in a nitrogen atmosphere (~2-10 ppm O<sub>2</sub>).

Data in charts 7 and 8 indicate that plated and brazed 6118 can achieve pull strength values above 10 pounds after 1000 thermal shock cycles (-40°C/+125°C, 60 minute cycles). Unlike the wire bonding work, brazing was tested using a more severe one hour thermal shock cycle. At the lower plated Au thickness of approximately 40-60 µinch, the mean pull strength was 16.1 pounds after 1000 thermal shock cycles. Thermal aging data at 150°C indicate strong values regardless of plated Au thicknesses evaluated. The right side of illustration 4 shows a typical failure mode, with ceramic being pulled out. These failures, and actual pin breaks may occur when values above 15 pounds are achieved. Failures between nickel and gold, or silver and nickel are much less frequent, but do occur and can range from 3-8 pounds. The left side of illustration 4 shows a brazed pin and the solder fillet. The appearance of the fillet is important as it indicates whether the part reached sufficient temperature for solder flow. The location on the pad is also critical, as the fillet can overflow onto the tape. This can cause a defect leading to unacceptable pull values.

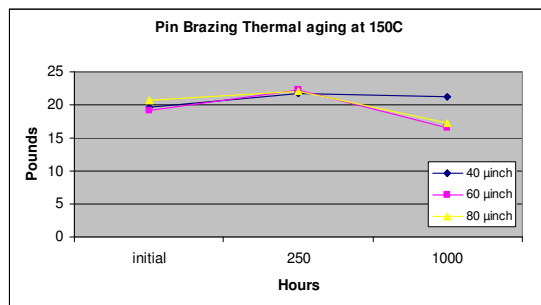


Chart 7: Thermal aging at 150°C

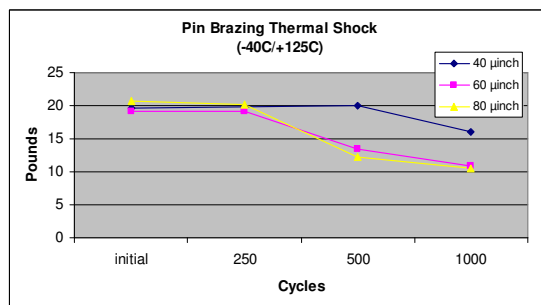


Chart 8: Thermal Cycling (-40°C/+125°C)

In another study, brazing test parts were refired 6x, again to mimic real life conditions

prior to plating. It is important to note that this refire study was not repeated at the time of this paper, but these results were of interest. Three groups of test parts were plated with three different levels of electroless gold thickness. Test parts were subjected to thermal aging at 150°C & thermal shock (-40°C/+125°C, 60 minute cycle). All pull strength values closely resemble values obtained for the single cofired test parts. See charts 9 and 10.

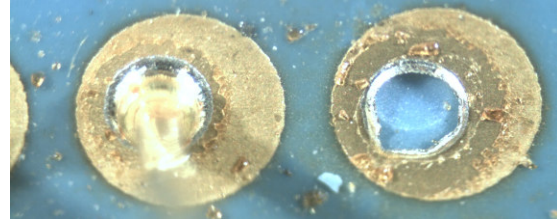


Illustration 4; Brazing Failure Mode

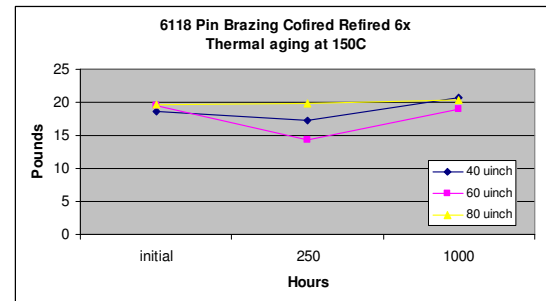


Chart 9: Cofired & Refired Brazing

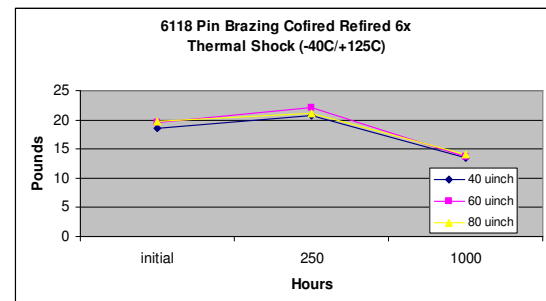


Chart 10: Cofired & Refired Brazing TCA

In the 2<sup>nd</sup> part of the same study, 6118 was post-fired, then refired 6x. Accelerated aging up to 1000 hours show excellent pull strength values above 15 pounds. These data sets may indicate that 6118 can be a possible brazeable candidate for post fire application (Chart 11). Further work in this area is necessary.

Wire peel adhesion by dip soldering was also evaluated. This test is based on an ASTM standard method, using 80 mil pads and #20

AWG tinned copper wire. After dip soldering with Sn62/Pb36/Ag2 solder at 220°C, 10 second dips, wires are bent at a 90 degree angle adjacent to the pad, then pulled using an Instron device. 40 & 60  $\mu$ inch thickness plated gold was evaluated. Illustration 5 shows the typical adhesion test pattern used in this study. The SEM cross section photomicrograph (illustration 6) shows the relative Au, Ni, Ag thicknesses of one plated 6118 test part and conductor porosity & density.

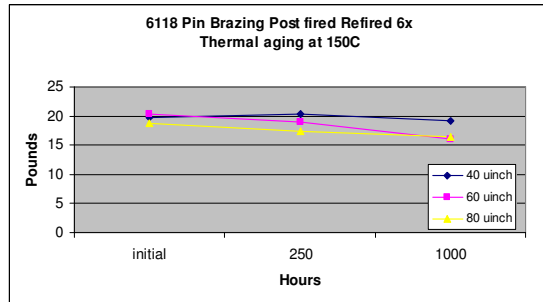


Chart 11: Post-fired & Refired Brazing

Data show that thinner plated gold provides slightly higher pull strength values after aging. Typical initial failure modes show pads pulling ceramic out. As aging proceeds, the more prevalent failure mode shows the pad lifting away from the ceramic. The data in table 4 also show that values drop dramatically after thermal cycling (-40°C/+125°C, two hour schedule).

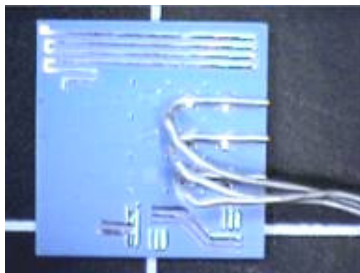


Illustration 5: Wire Peel Adhesion Test Pattern

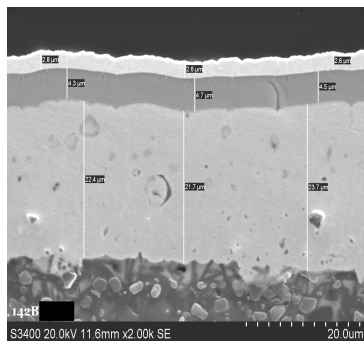


Illustration 6; SEM cross-section Plated 6118

Table 4: Wire Peel Soldered Adhesion

| hrs. | 6118          |             |             |             |                |             |
|------|---------------|-------------|-------------|-------------|----------------|-------------|
|      | aging at 150C |             | 85%RH/85C   |             | thermal cycles |             |
|      | 40 $\mu$ in   | 60 $\mu$ in | 40 $\mu$ in | 60 $\mu$ in | 40 $\mu$ in    | 60 $\mu$ in |
| 0    | 23.5          | 13.5        | 23.5        | 13.5        | 23.5           | 13.5        |
| 250  | 12.4          | 14.4        | 18.0        | 16.8        | 3.5            | na          |
| 500  | 21.5          | 9.2         | 22.1        | 17.1        | 5.5            | 6.4         |
| 1000 | 17.8          | 10.6        | 19.4        | 16.3        | 4.3            | 5.8         |

values in Newtons

### Immersion Gold Evaluation

Immersion gold plated 6118 parts were evaluated for functional properties.

The data in Chart 12 show wire peel adhesion pull strength values after dip soldering with Sn62/Pb36/Ag2 solder at 220°C and 10 second dips. (These data compare plated nickel thicknesses for silver conductor 6118). Wire bonding is not expected to be successful with immersion gold plated parts. Three levels of nickel thickness were tested to determine the optimum thickness for soldered adhesion. These test parts were thermally aged at 150°C for up to 300 hours. Parts plated using "Condition 3" exhibit consistent wire peel pull strengths over the length of the aging. Values remain between 18-20 Newtons (80 mil pads, #20 gauge wire).

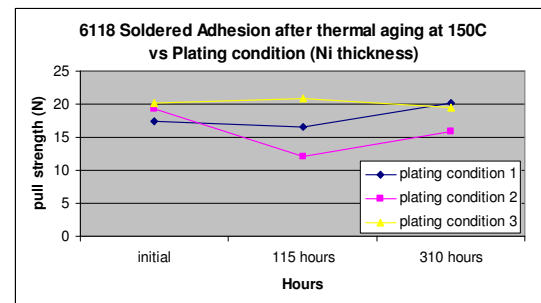


Chart 12: Wire Peel Adhesion, immersion gold

### Plateable Silver Composition 6117

6117 was designed as a cofireable, plateable conductor for DuPont™ Green Tape™ 951 low temperature co-fired ceramic (LTCC). It contains a small amount of binder glass and oxides to enhance adhesion to the tape. It is printed at a dried thickness of 15-20  $\mu$ m. 6117 is not brazeable, but can be wire bonded. The wire bonding data are comparable to the data obtained for 6118. All wire bond strength values reported for 1 mil gold wire were above 11.0 grams regardless of the aging condition tested. See charts 13, 14 & 15 below.

Another set of data points were obtained for test parts plated using a higher gold

thickness of  $\sim 150 \mu\text{in}$ . A single metal lift (ML) was observed after 1000 thermal cycles. At this higher plated gold thickness, the 1 mil Au wire bonding performance was slightly better than 6118, indicating that the Au plating process latitude may be wider, however the metal lift is a concern. As with 6118, electroless gold thickness should be limited to a maximum of 90-100  $\mu\text{in}$ .

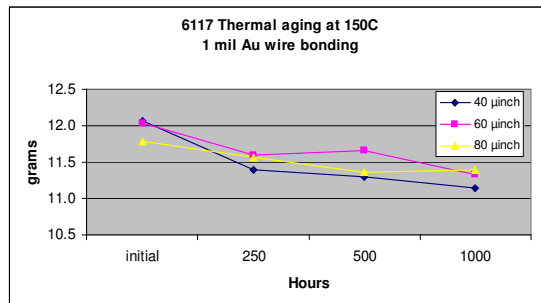


Chart 13: Thermal aging at 150°C

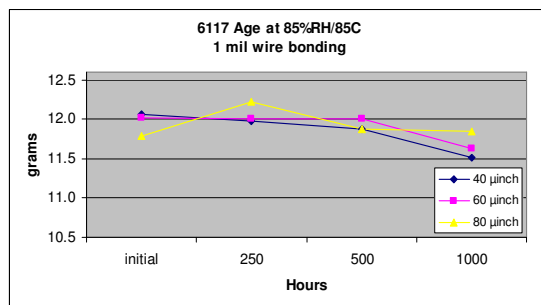


Chart 14: Exposure to 85%RH/85°C

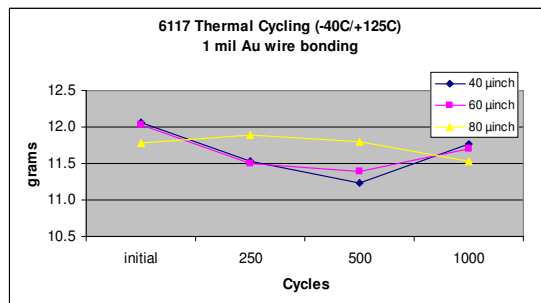


Chart 15: Thermal Cycling (-40°C/+125°C)

6117 was also evaluated using the daisy chain pattern and subjected to 2x and 5x refires using an 850°C/30 minute belt profile. Wire bonds were placed directly over the plated 6117 directly over filled vias. Vias were filled using standard via fill product 6141 (DuPont™). The data in charts 16, 17 & 18 show good wire bonding results for all conditions. Once again, values measured were lower than previous

charts but can be explained by the need for different wire bond loop geometries used to accommodate the alternate daisy chain test pattern. There were no bond lifts, no metal lifts, and no misses. Typical failure modes were wire breaks and heel breaks at the first and second bond sites.

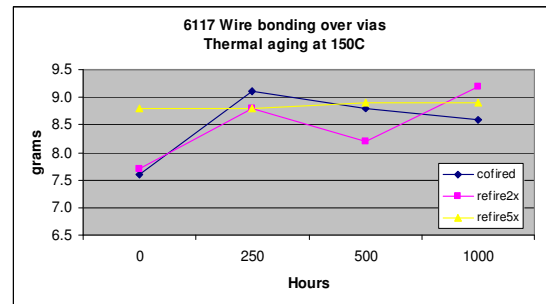


Chart 16: Wire Bonding over vias, age at 150°C

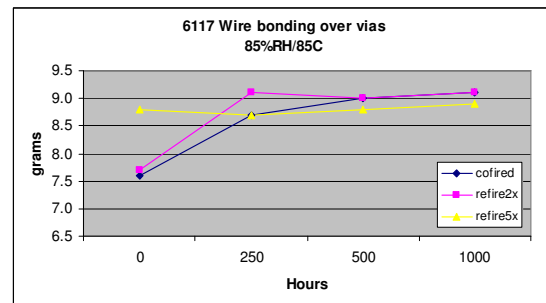


Chart 17: Wire bonding over vias, 85%RH/85°C

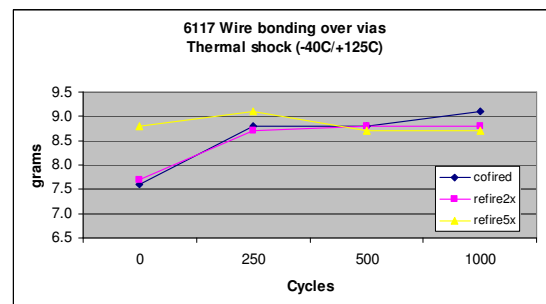


Chart 18: Wire Bonding over vias, TCA

Table 5: Wire Peel Soldered Adhesion

| 6117 |                   |                   |                   |                   |                   |                   |
|------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| hrs. | aging at 150C     |                   | 85%RH/85C         |                   | thermal cycles    |                   |
|      | 40 $\mu\text{in}$ | 60 $\mu\text{in}$ | 40 $\mu\text{in}$ | 60 $\mu\text{in}$ | 40 $\mu\text{in}$ | 60 $\mu\text{in}$ |
| 0    | 15.4              | 13.1              | 15.4              | 13.1              | 15.4              | 13.1              |
| 250  | 5.2               | 12.2              | 8.9               | 13.1              | 4.4               | na                |
| 500  | 12.5              | 10.6              | 9.5               | 11.8              | 5.3               | 6.6               |
| 1000 | 8.6               | 11.6              | 11.1              | 13.4              | 3.3               | 6.3               |

values in Newtons

Wire peel adhesion by dip soldering was evaluated on 6117 using the same method as

previously described above. Groups of parts with 40 & 60  $\mu$ inch plated gold thicknesses were evaluated. Table 5 shows a summary of soldered adhesion values obtained on the plated 6117 test parts. Thermal cycled adhesion using (-40°C/+125°C, 2 hour schedule) is a concern. Values were slightly lower than 6118.

### Plateable Silver Composition 6119

6119 was developed as a plateable silver conductor for post fired application on DuPont™ Green Tape™ 951 low temperature co-fired ceramic (LTCC). 6119 prints at 15-20  $\mu$ m dried thickness. It is not brazeable, but can be wire bonded. Accelerated aging and environmental studies were performed on 6119 at the higher plated gold thickness of approximately 150  $\mu$ inch only. Lower plated gold thicknesses were not evaluated at the time of this paper. Excellent wire bonding data were obtained with no bond lifts or metal lifts occurring at any stage of the aging study. See chart 19. Wire peel adhesion results are listed in table 6. A drop-off is noted after thermal cycling at the single plated thickness tested.

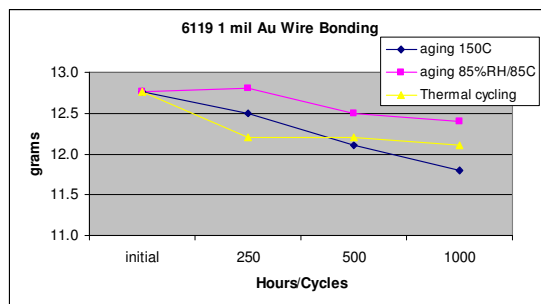


Chart 19: 6119 Wire Bonding performance

Table 6: Wire Peel Soldered Adhesion

| 6119 |               |             |             |             |                |             |
|------|---------------|-------------|-------------|-------------|----------------|-------------|
| hrs. | aging at 150C |             | 85%RH/85C   |             | thermal cycles |             |
|      | 40 $\mu$ in   | 60 $\mu$ in | 40 $\mu$ in | 60 $\mu$ in | 40 $\mu$ in    | 60 $\mu$ in |
| 0    | 17.3          | 20.9        | 17.3        | 20.9        | 17.3           | 20.9        |
| 250  | 5.8           | 12.4        | 17.7        | 23.9        | 5.6            | na          |
| 500  | 14.5          | 6.4         | 20.1        | 23.0        | 6.1            | 6.1         |
| 1000 | 9.0           | 0.0         | 18.5        | 23.5        | 4.1            | 6.0         |

values in Newtons

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### Summary & Recommendations

Although not mentioned elsewhere in this paper, yield is a major concern. Periodically, plated test parts can fail a simple scotch tape adhesion test on fine line (5 mil) features. Yields can vary, although the goal is 95%. Additional plating process development for large scale manufacturing is underway.

New silver conductor 6118 can be cofired on Green Tape™ 951 and is Ni/Au plateable. It can provide excellent 1 mil Au wire bonding performance if gold plating thickness is maintained between 40 to 80  $\mu$ inch with ~150  $\mu$ inch plated nickel. 6118 provides excellent brazing performance with Au80/Sn20 alloy, if brazed using a special profile previously outlined.

Cofireable, plateable silver conductor 6117 provides excellent wire bonding performance using 1 mil Au wire, however it is not brazeable. The plated gold thickness latitude is wide. Wire bonding characteristics have been presented here.

6119 can be post fired onto Green Tape™ 951, Ni/Au electroless plated and provide excellent wire bonding performance using 1 mil Au wire. Wire bonding data are presented in this paper using 150  $\mu$ inch plated Au thickness.

Most of the data presented here were generated using two dimensional planer test pattern parts. Additional work is ongoing to investigate complex three dimensional LTCC parts with multilevel cavities. Also, lower plated Au thickness evaluations have been initiated.

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