SAND2007-6345 C

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Pull Strength Evaluation of Sn-Pb Solder Joints Made to Au-Pt-Pd Conductor on Low-Temperature Co-Fired Ceramic

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‡Sandia is a multi-program laboratory operated by Sandia Corp, a Lockheed Martin company, for the US Dept. of Energy under contract DE-AC04-94AL85000.

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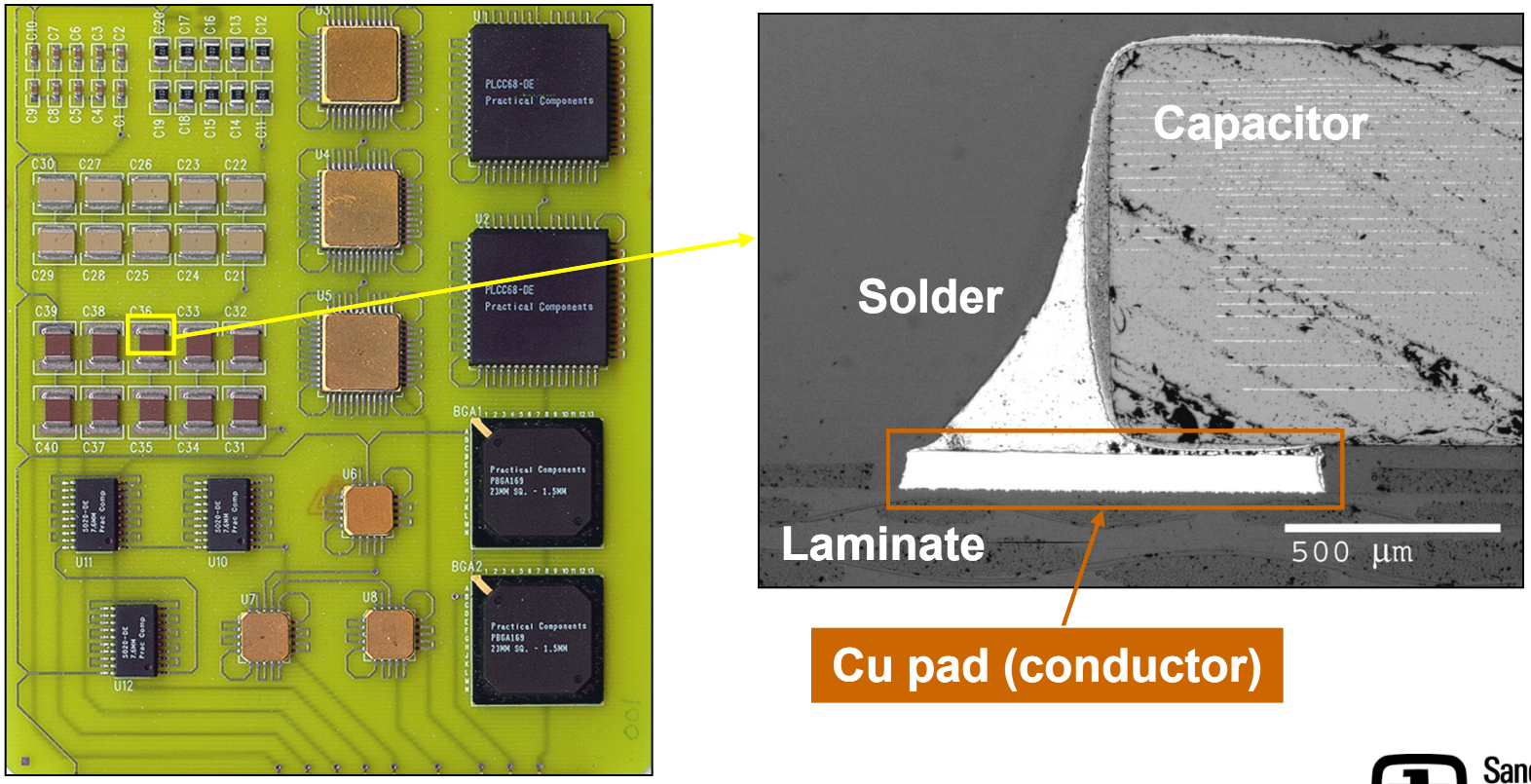
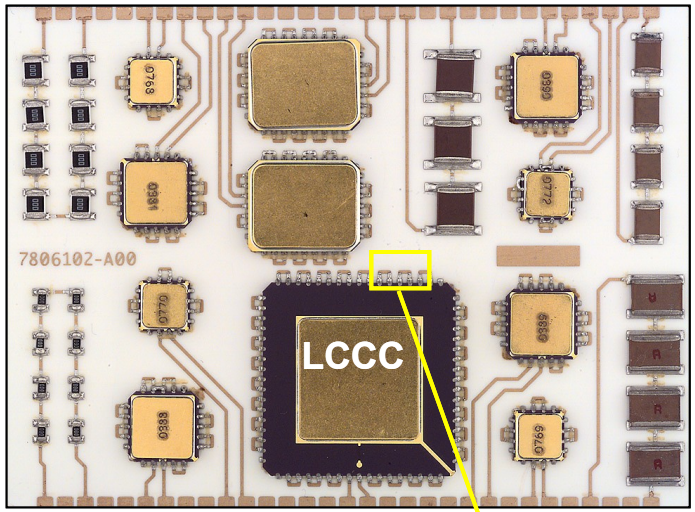
Introduction

“Traditional” printed wiring assemblies are comprised of an organic laminate (substrate) and built-up copper conductor.

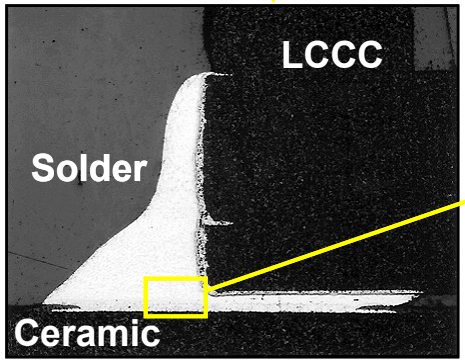


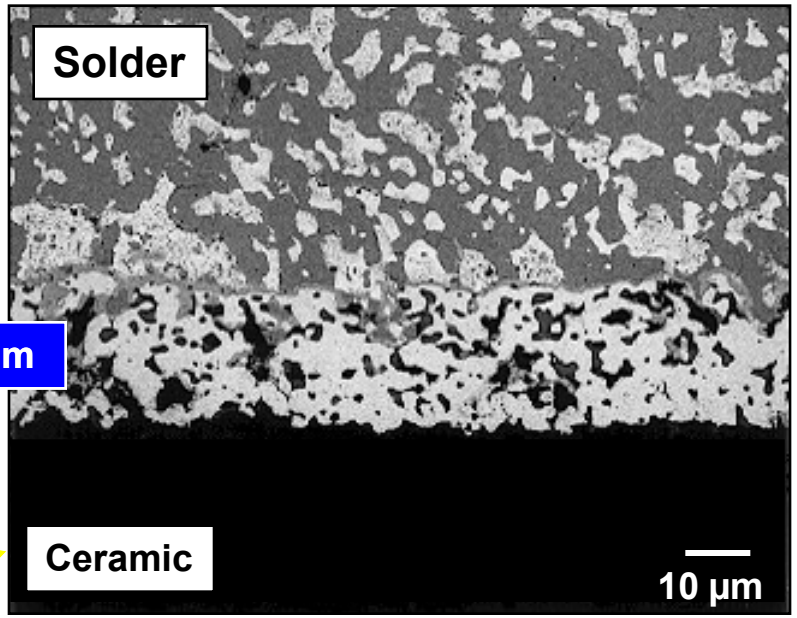
Introduction

Hybrid Microcircuit (HMC) assemblies are constructed of a ceramic substrate and thick film conductor layers.



alumina





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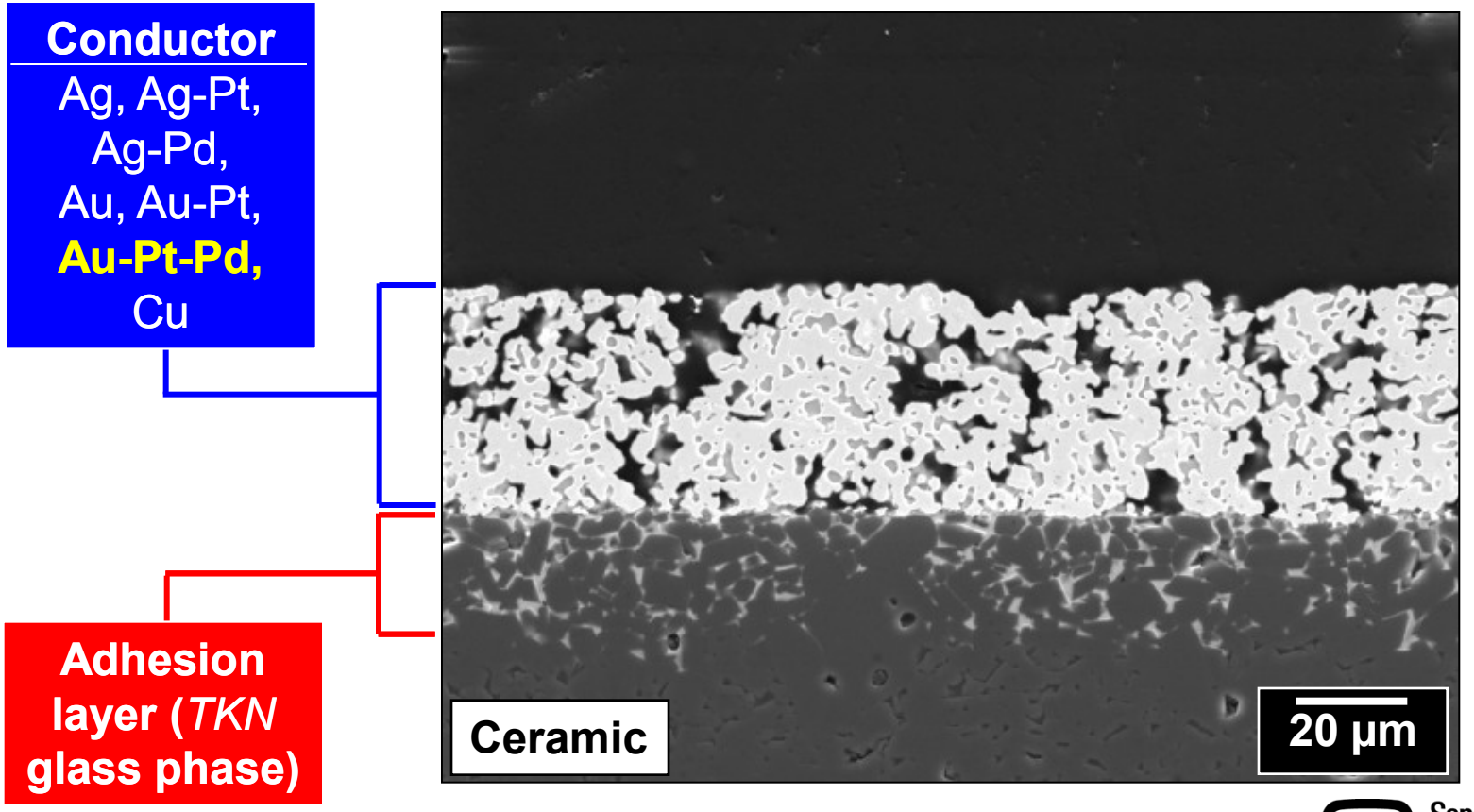
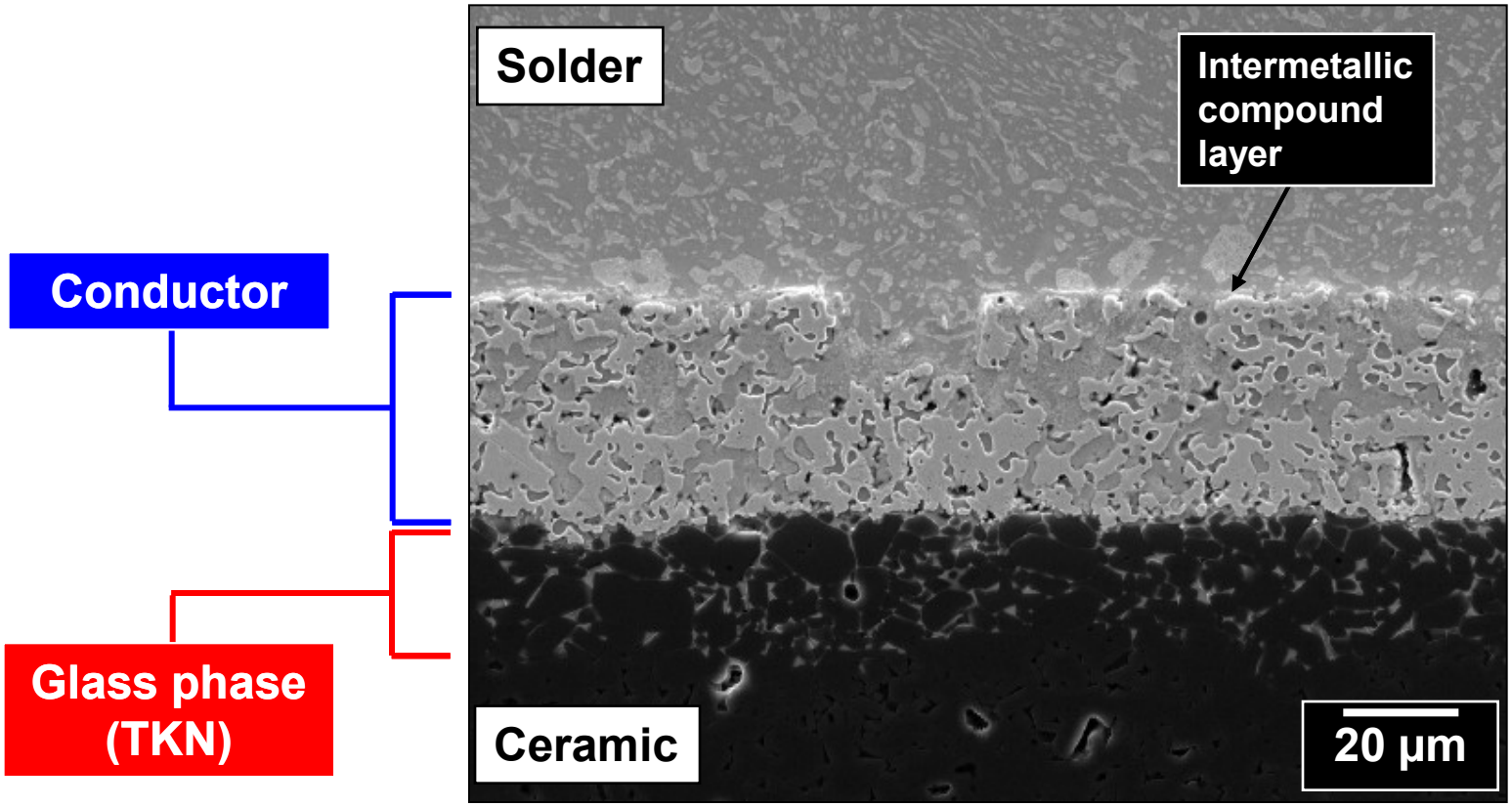
Introduction

The thick film (TKN) structure is comprised of a porous, sintered conductor (metal) layer and the adhesion "layer" (glass phase).



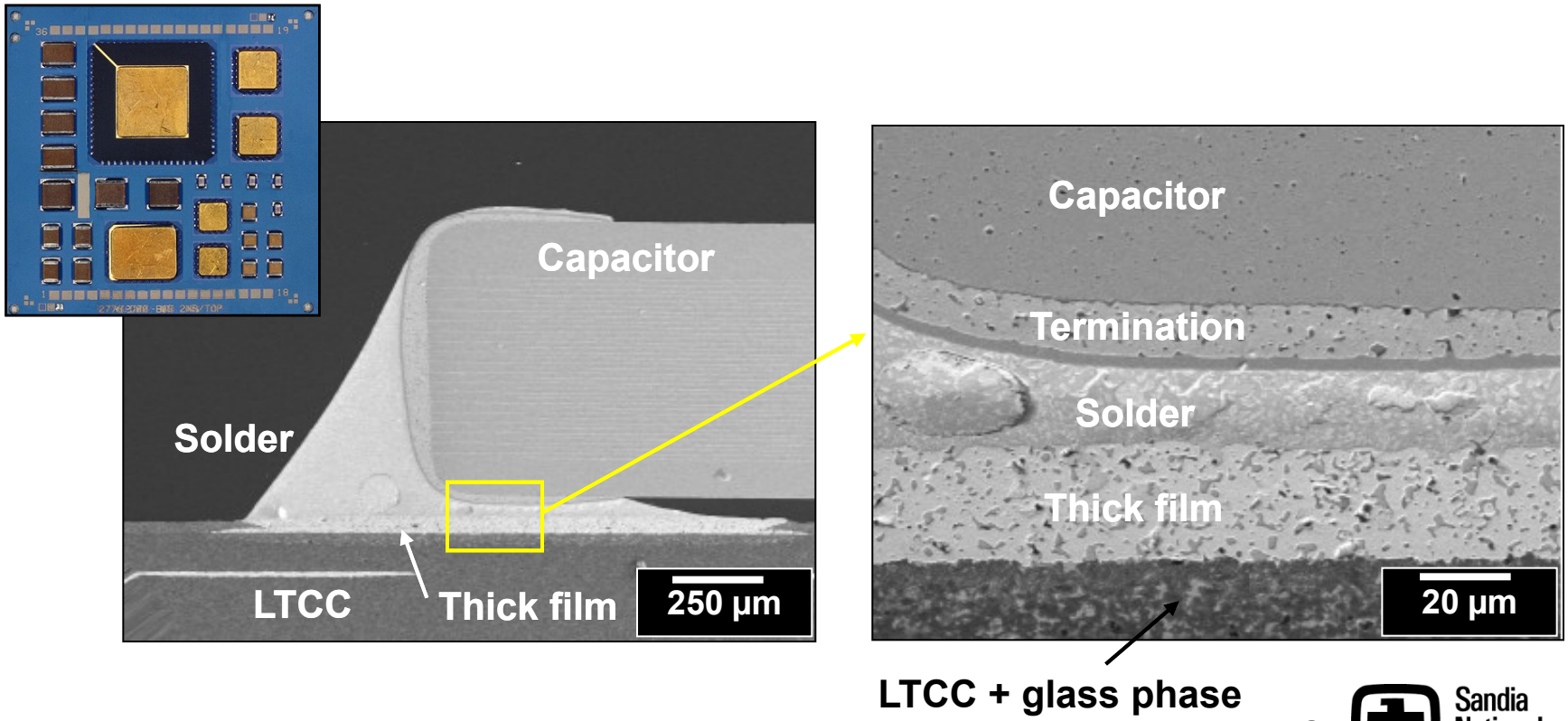
Introduction

The soldered interconnection results in a significant penetration of the conductor pores by the molten solder.



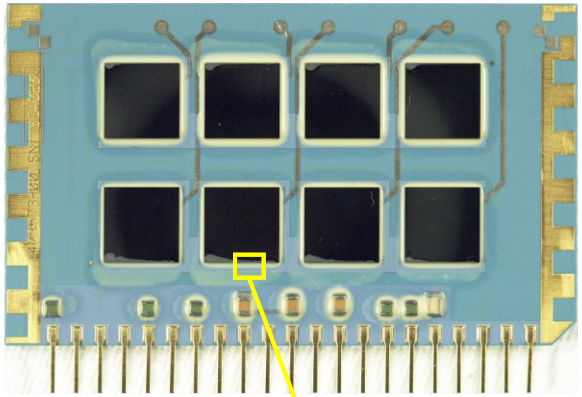
Introduction

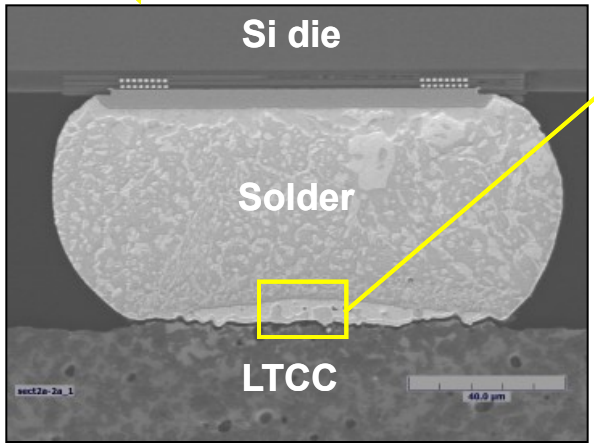
The glass phase adhesion layer exhibits a greater degree of interaction with low-temperature, co-fired ceramic (LTCC) due to the latter's higher concentration of glass phase.

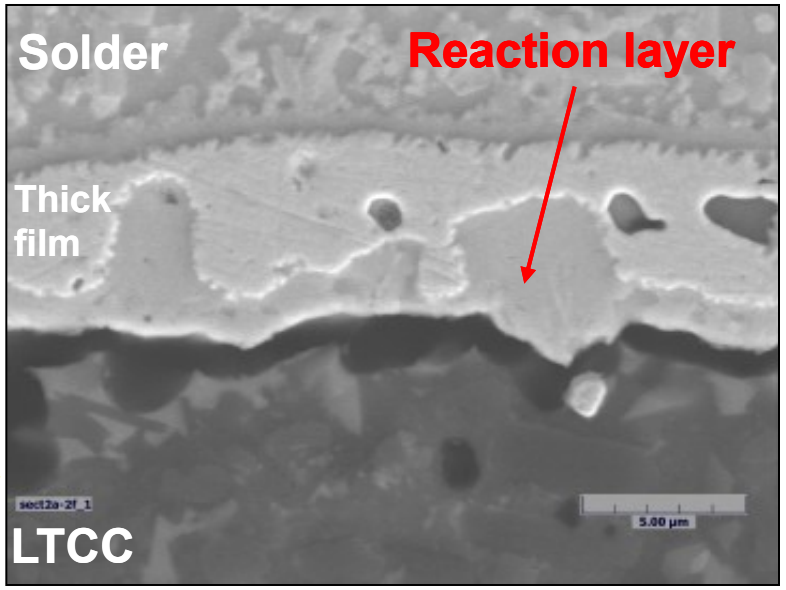


Introduction

Continued miniaturization of multi-chip modules on ceramic (MCM-C) is pushing the limits of thick film conductor technology.







Unexpected material interactions can jeopardize the long-term reliability of soldered interconnections.

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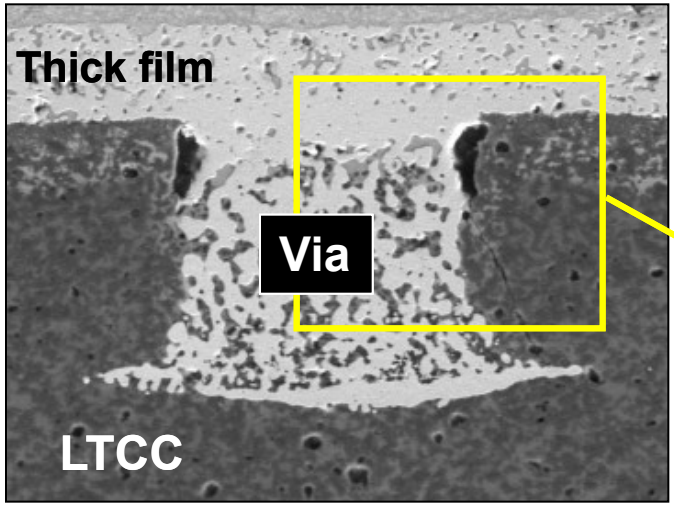
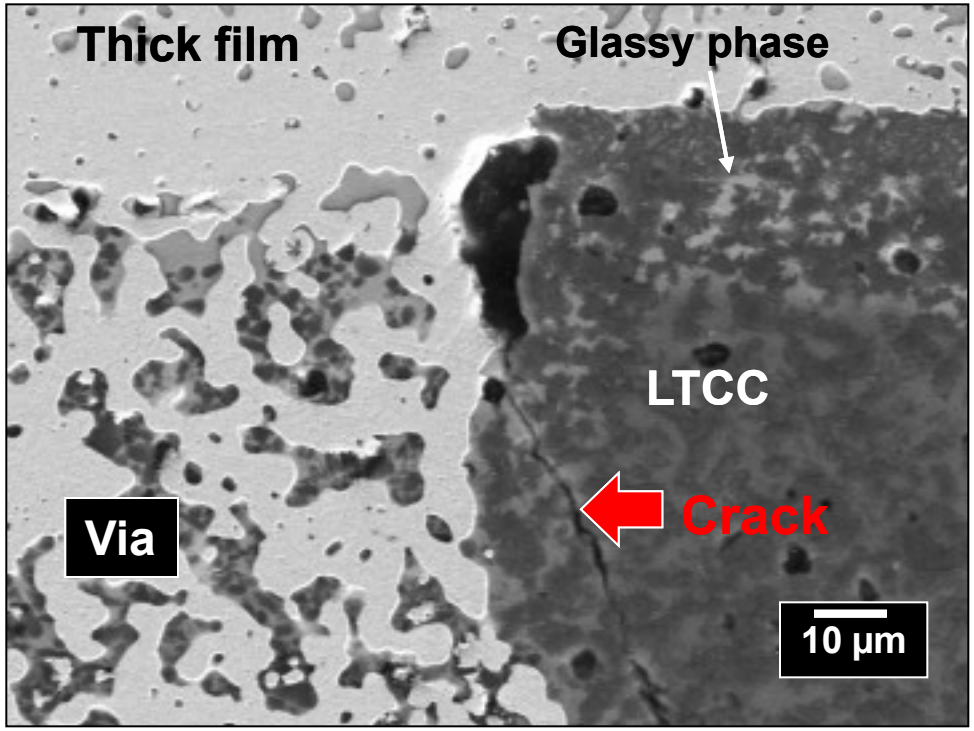
Introduction

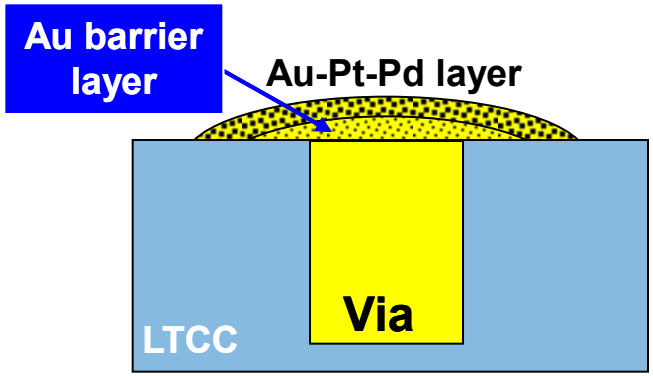
The use of a solderable Au-Pt-Pd thick film resulted in the formation of cracks in the via side wall of LTCC substrates.

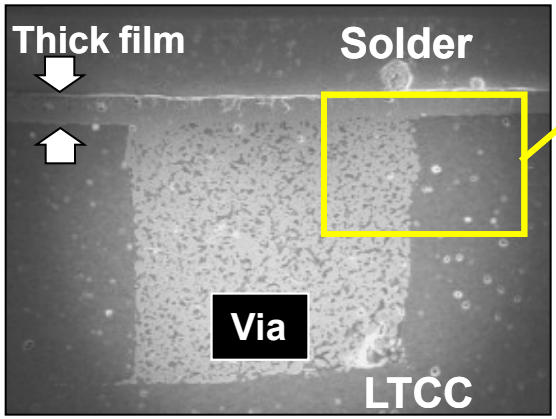


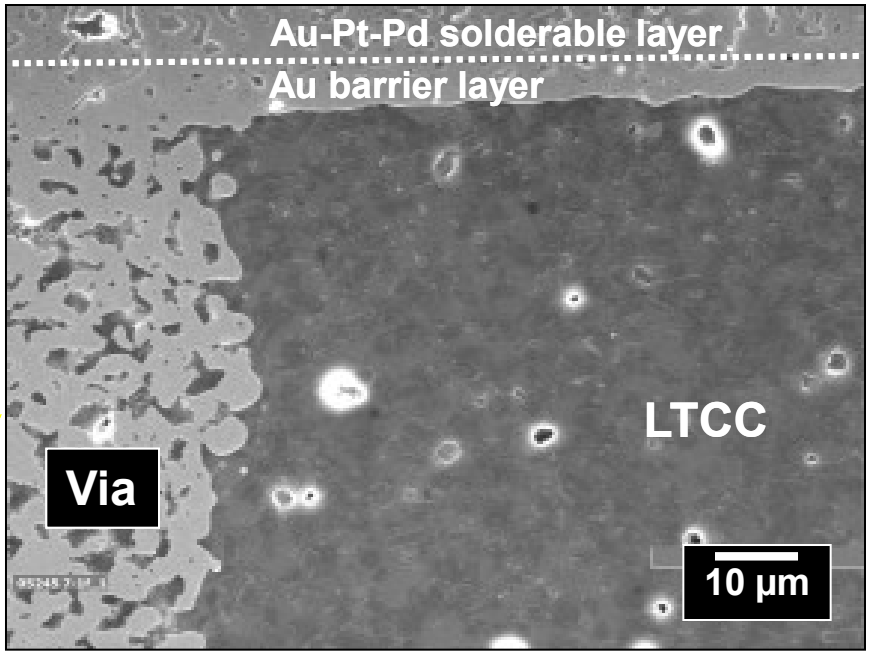


Introduction

The approach used to prevent via side wall cracks was to place a Au thick film barrier layer between the Au-Pt-Pd layer and LTCC substrate material.







This approach was successful!

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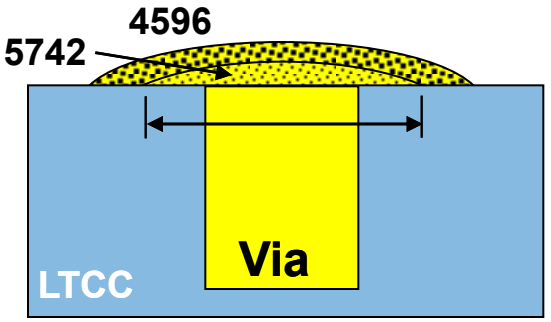
Objective

- **The concern was raised that there was limited understanding of the mechanical properties of these solder interconnections.**

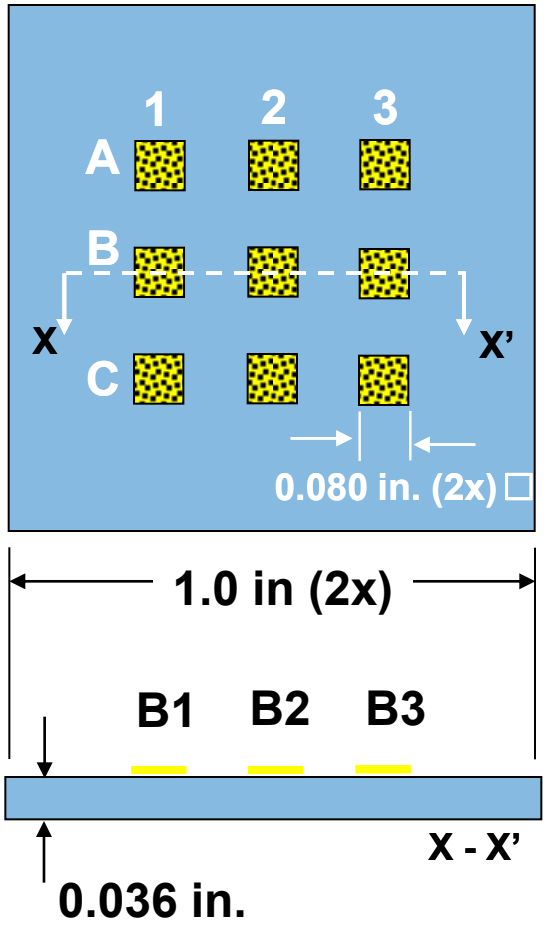
- **Therefore, a study was undertaken to investigate the mechanical strength of solder joints made to these alternative thick film structures.**

- **The variables were:**
  - **Barrier layer footprint**
  - **Solderable layer thickness**
  - **Presence or absence of vias**



Experimental procedures

- The test vehicles were constructed of DuPont™ 951AX green tape (four layers)*.
- Nine (9) pads were "post-processed" on one of the surfaces (850° C, 15 min per layer).
  - DuPont™ 4596 (76Au-21Pt-3Pd, wt.%)
  - DuPont™ 5742 (100Au)
- The vias were filled with DuPont™ 5738 Au-based material.



The use of DuPont™ materials and their product designations does not constitute an endorsement of these products by Sandia National Laboratories.

Experimental procedures

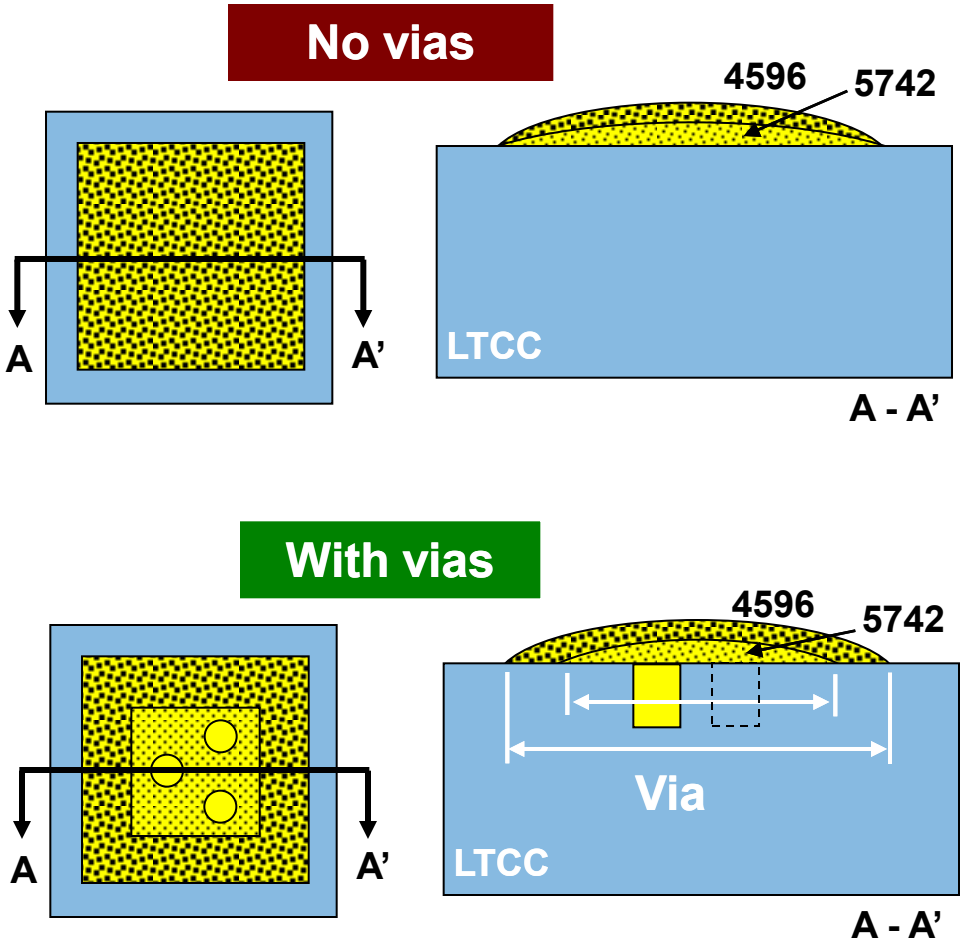
The matrix of test vehicle configurations included:

1. 1x 4596; no vias
2. 3x 4596, no vias
3. 1x 5742, 1x 4596; no vias
4. 1x 5742, 3x 4596; no vias

5. 1x 4596; [1.0:1.0] vias
6. 1x 5742, [1.0:1.0] vias

7. 1x 5742, 1x 4596, [1.0:1.0] vias
8. 1x 5742, 1x 4596, [1.0:0.5] vias
9. 1x 5742, 1x 4596, [1.0:0.2] vias

10. 1x 5742, 3x 4596, [1.0:1.0] vias
11. 1x 5742, 3x 4596, [1.0:0.5] vias
12. 1x 5742, 3x 4596, [1.0:0.2] vias

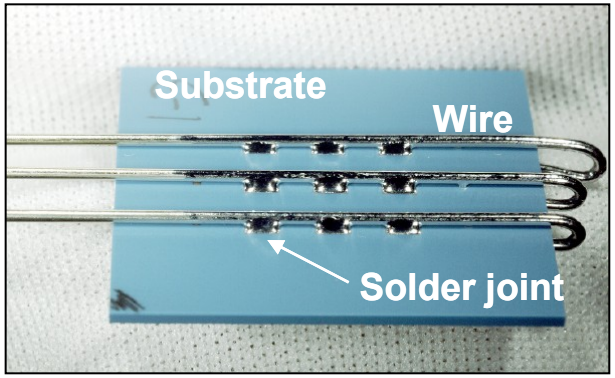


Experimental procedures

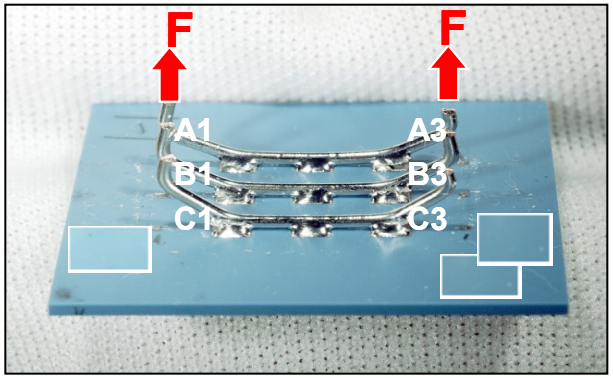
- The "shepherd's hook" pull test was used to evaluate the pull strength.
  - Cu wires, all cases *except …*
  - Au-Ni plated Cu with 1x 5742; no vias (case #6)

- Solder assembly:
  - 63Sn-37Pb (wt.%), all cases *except …*
  - 50In-50Pb was used with 1x 5742; no vias (case #6)
  - Hot solder dip (260° C, 5 s)

- Mechanical (pull) testing:
  - 12 mm/min
  - *Only* the outboard joints were tested
  - Eighteen (18) tests; mean and 95% CI



After solder assembly …



After pull testing …

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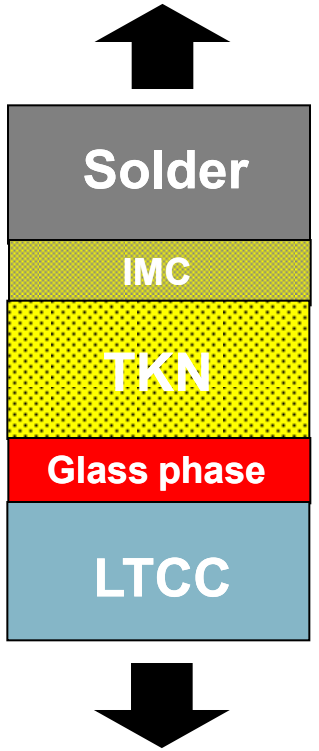
Experimental procedures

The complexity of the solder interconnection structure presents a challenge to the failure mode analysis.

- **The bulk materials are:**
  - **solder,**
  - **TKN, and**
  - **LTCC substrate.**

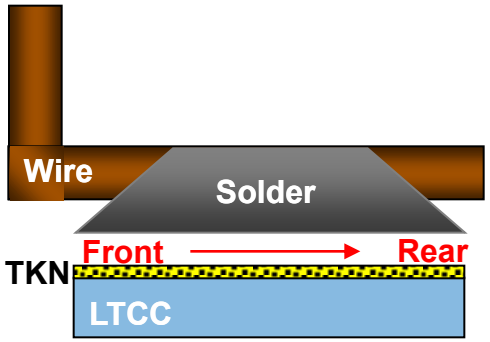
- **The interfaces are:**
  - **Solder/intermetallic compound (IMC),**
  - **IMC/TKN,**
  - **TKN/glass phase, and**
  - **Glass phase/LTCC.**

- **Because these members are in series, the weakest one determines the overall strength of the interconnection.**

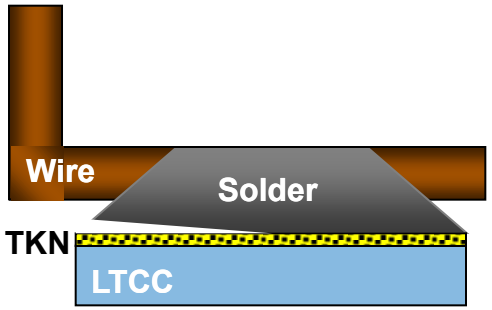


Experimental procedures

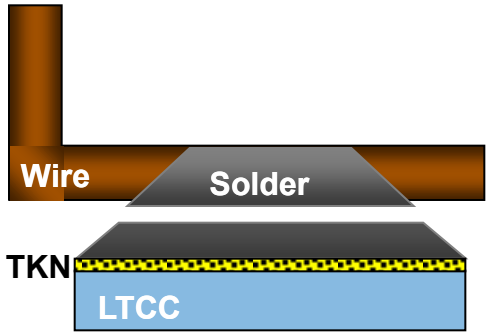
Four (4) failure modes were identified for the visual inspection.



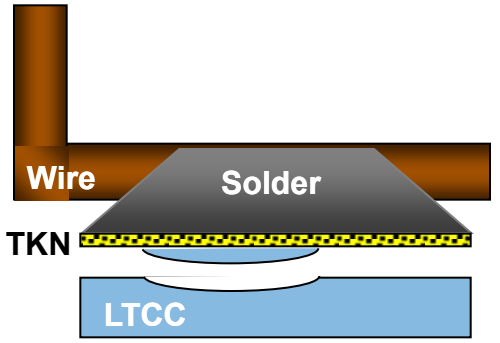
Failure Mode #1: Solder/TKN interface



Failure Mode #2: *Partial* solder/TKN interface



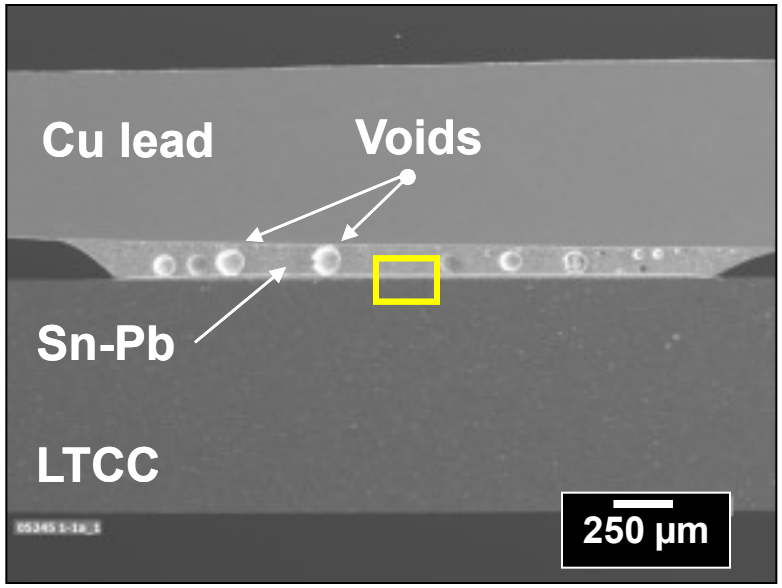
Failure Mode #3: Bulk solder

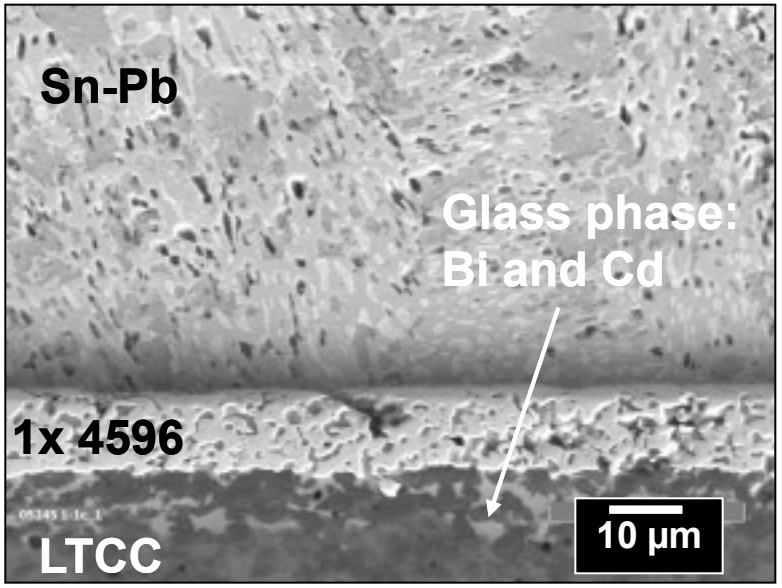


Failure Mode #4: TKN/LTCC interface w/ or w/o a divot

Results and discussion

The as-fabricated solder joints made to the 1x 4596 thick film showed good solderability and minimal void formation.



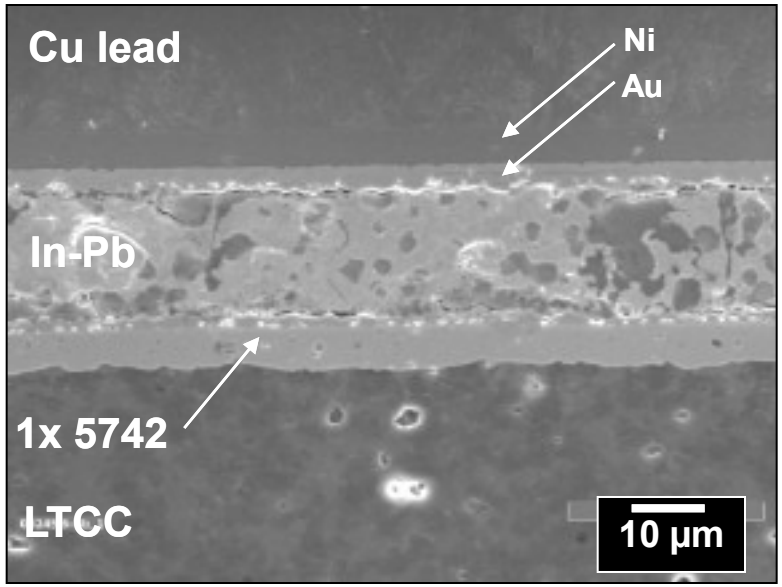


There is extensive diffusion of the TKN glass phase into the LTCC substrate material, more so, the Cd component.

Results and discussion

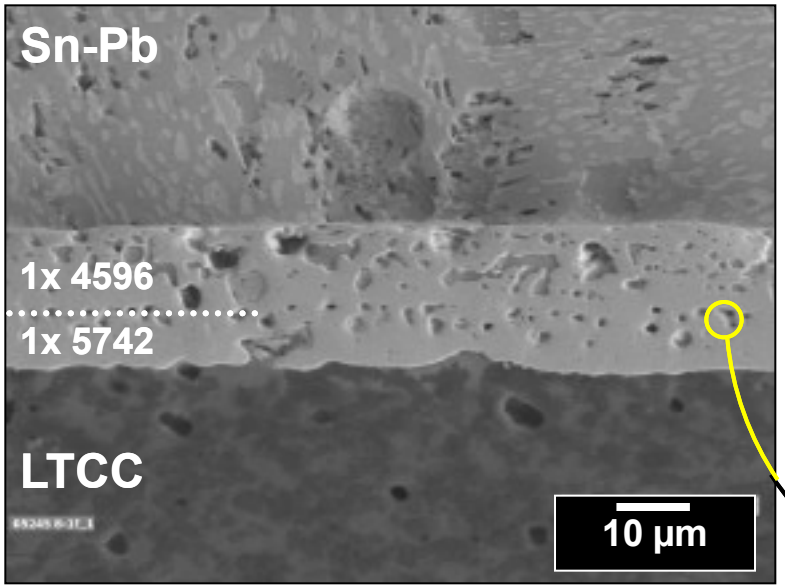
The as-fabricated solder joints made to the 1x 5742 thick film using the In-Pb solder exhibited, similarly, good integrity.

- **There is no significant presence of TKN glass phase in the LTCC.**
- **The 1x 5742 layer is more fully dense than the 1x 4596 layer:**
  - **Improved sintering properties of Au in the absence of Pt.**
  - **Absence of residual glass phase**

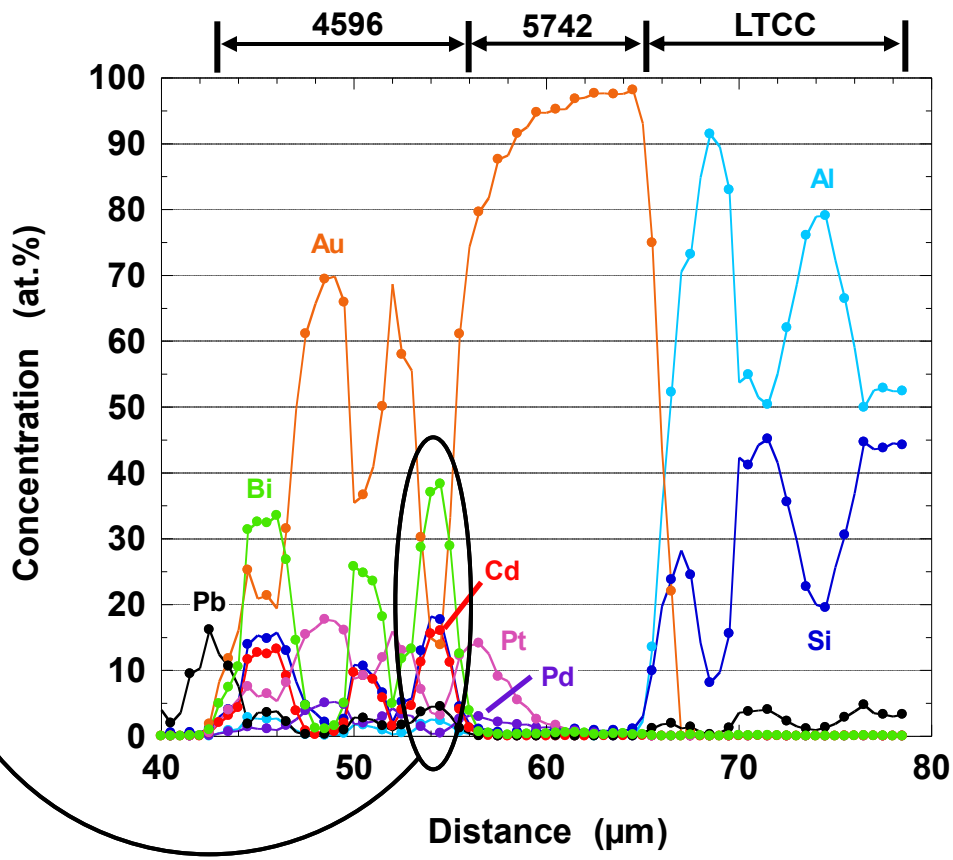


Results and discussion

The combination thick film 1x 4596, 1x 5742 exhibited excellent solderability and good interface adhesion.



Electron probe microanalysis (EPMA)



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Results and discussion

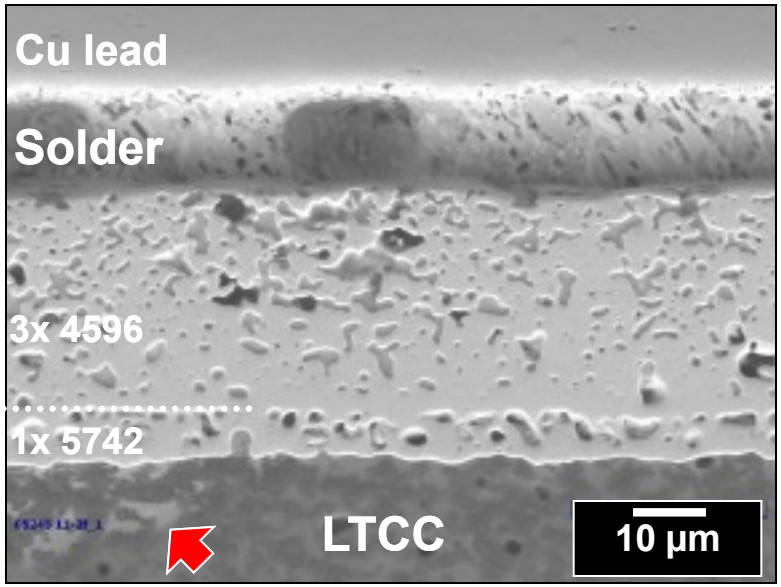
- The combination thick film 3x 4596, 1x 5742 exhibited excellent solderability and good interface adhesion.

- Other observations:

  1. A greater accumulation of Cd and Bi at the 4596/5742 boundary.

  2. A greater degree of Pt and Pd diffusion into the 5742 layer.

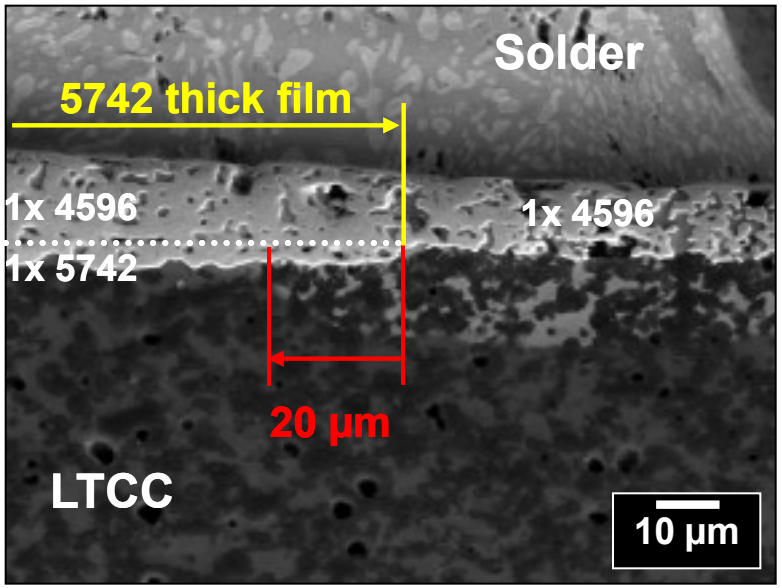
  3. More frequent breaches of the barrier layer by the 4596 glass phase (red arrow), typically on the order of 1 - 2 alumina grains.



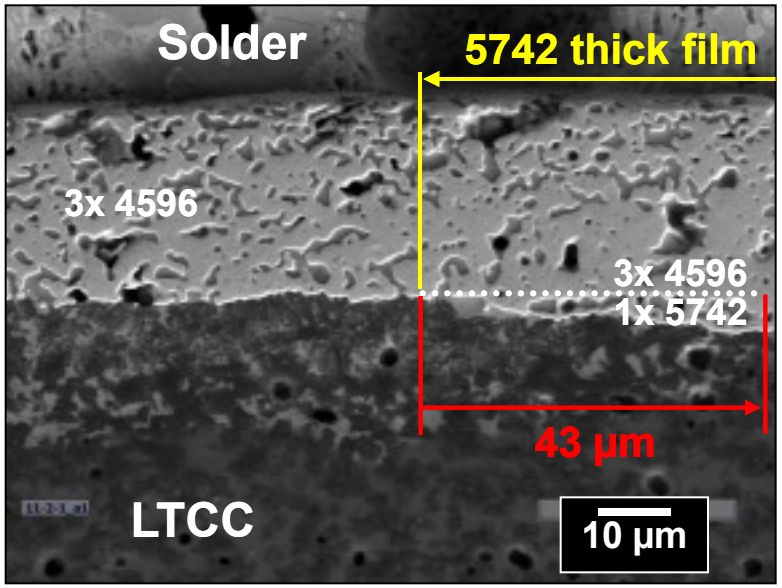
When vias were present, use of the 1x 5742 barrier layer eliminated side wall cracks for both 1x 4596 and 3x 4596 solderable thick film layer.

Results and discussion

The 1x 5742 footprint ratios of [1.0:0.5] and [1.0:0.2] were examined for the extent of 4596 glass phase lateral diffusion.



1x 4596, 1x 5742



3x 4596, 1x 5742

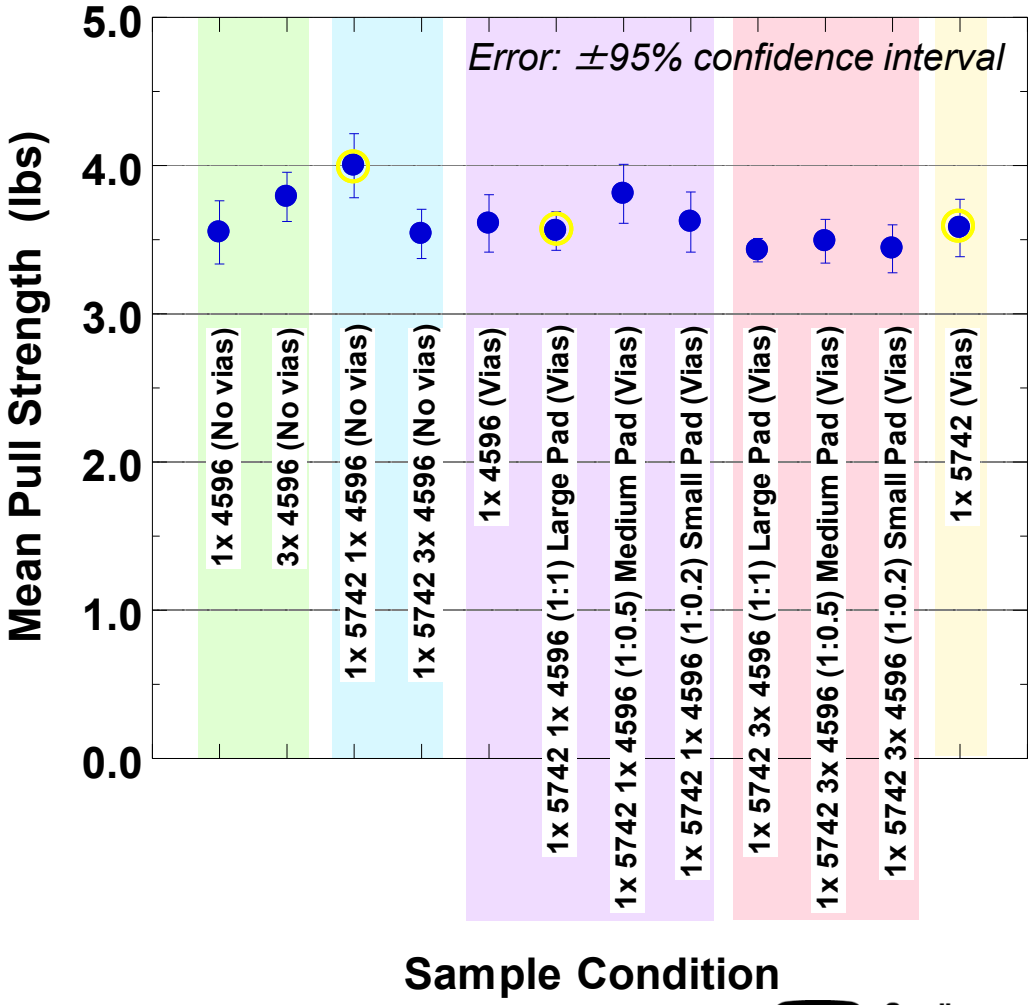
Results and discussion

Overall, the pull strengths were slightly less than historic values on alumina (4.3±0.87 lb), but still very acceptable.

1. **The addition of the 1x 5742 layer to a 1x 4596 caused a significant strength increase.**

2. **The 5742/LTCC interface was at least as strong as the 4596/LTCC interface.**

3. **The addition of vias had no significant effect on pull strength, except to have lowered the "advantage" exhibited by the combined layer, 1x 4596, 1x 5742.**



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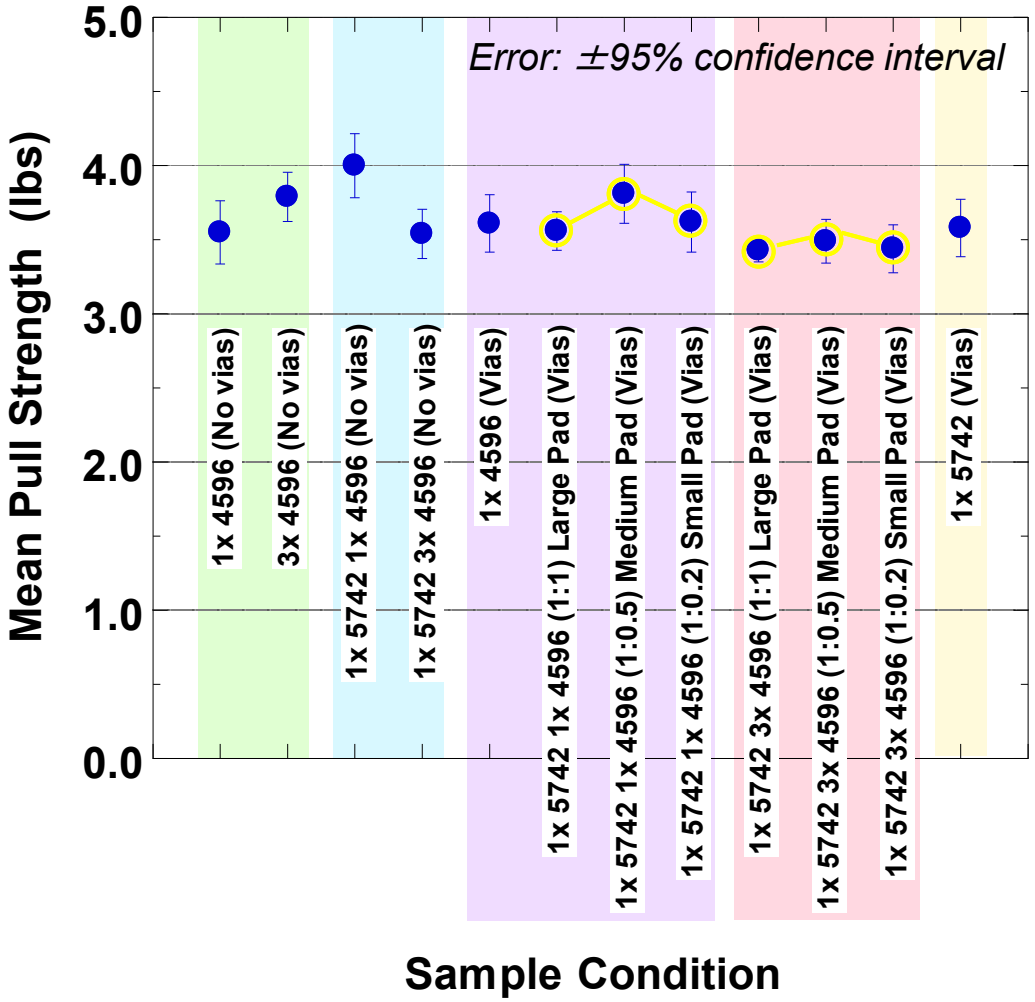
Results and discussion

The following pull strength trends were identified as a function of 5742 footprint:

1. **Overall, all pull strengths were statistically the same.**
2. **The mean strengths of the 3x 4596 samples were slightly lower than the corresponding value for the 1x 4596 layer.**
3. **The maximum mean strength occurred for the [1.0:0.5] ratio for both 1x and 3x 4596 cases.**
4. **The data scatter was least for the [1.0:1.0] ratio case.**



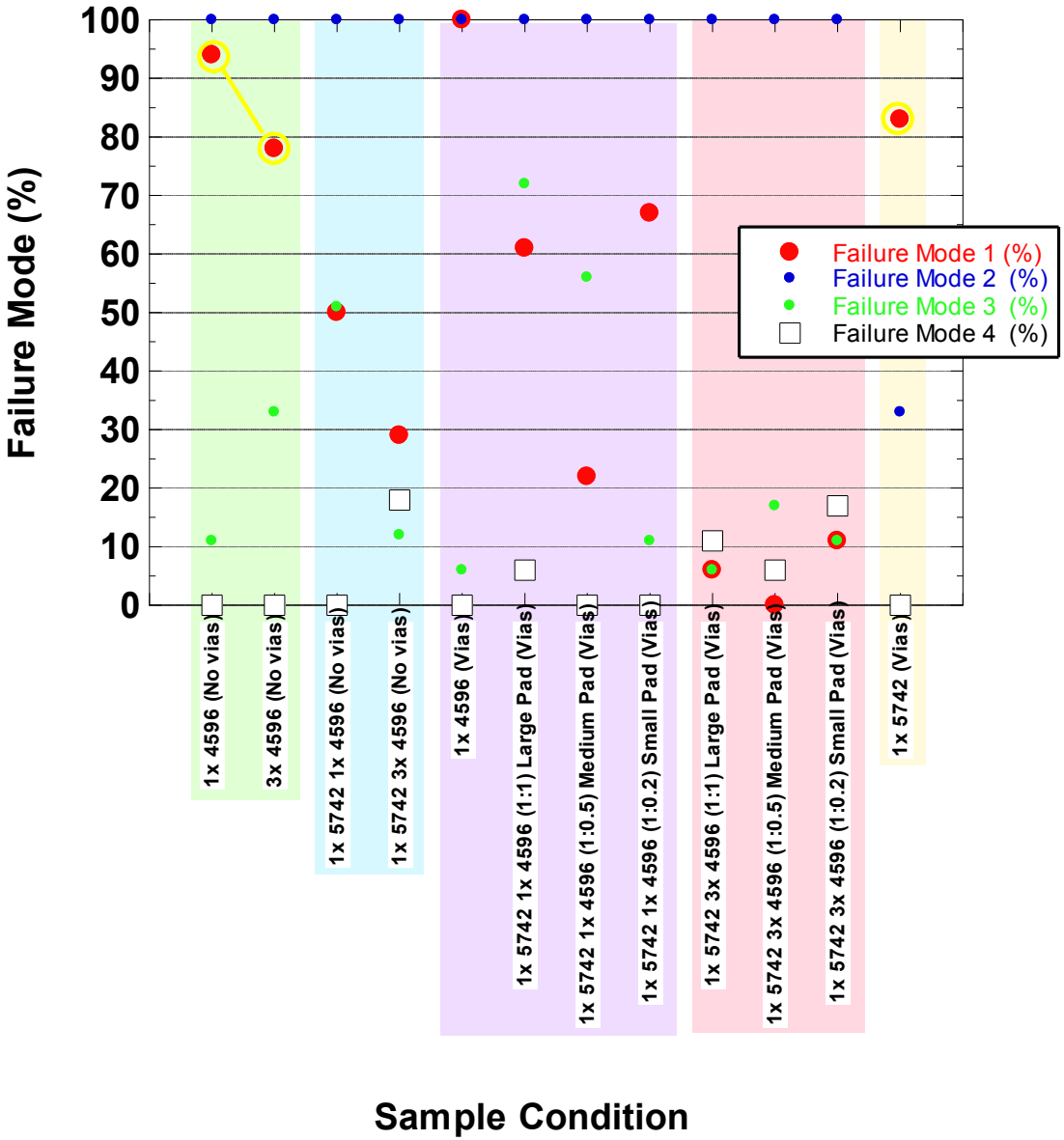
Results and discussion

These failure mode trends were observed:

1. **Changes to the thick film layer indirectly affected the solder/thick film interface.**

2. **The addition of the 1x 5742 layer did not significantly affect the failure mode. Recall: The strength of the 5742 TKN/LTCC interface bond was comparable to that of the 1x 4596 layer.**

3. **Increasing the number of 4596 layers, in the presence of 1x 5742, increased the propensity for TKN/LTCC failures (often with divots).**



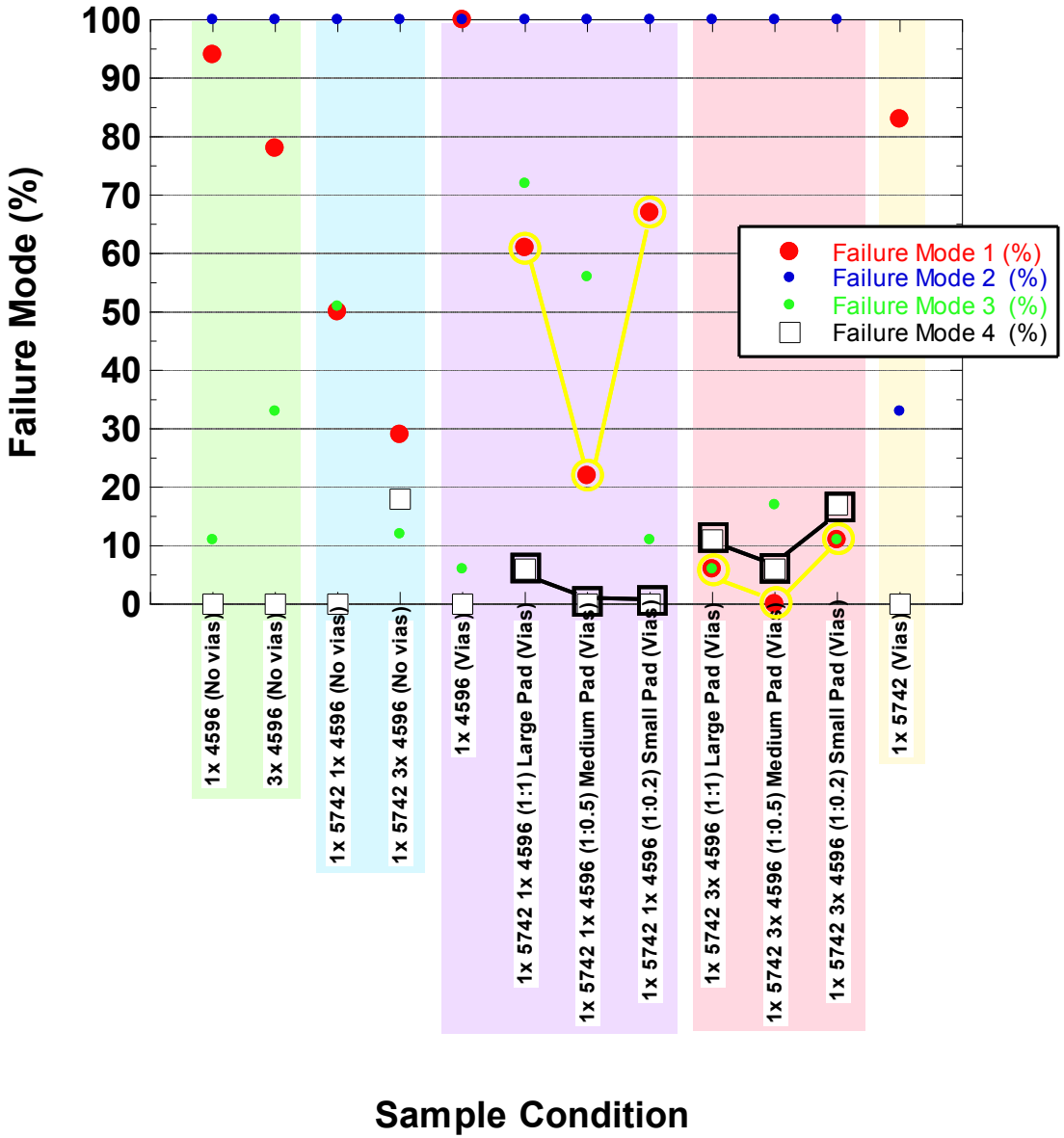
Results and discussion

Failure modes *(con't):*

4. **The maximum strength of the [1.0:0.5] footprint ratio was accompanied by:**

   (a) foremost, by improving the strength of the TKN/LTCC interface and …

   (b) secondarily, by improving the strength of the solder/TKN interface.



Results and discussion

The mean strengths of thick film structures having more than two layers were weaker and more likely to show the TKN/LTCC failure mode.

The number of layers corresponded to the number of post-process firing steps.

The graph of pull strength versus number of firing steps indicated that a maximum strength was obtained for between 2 and 3 such steps.

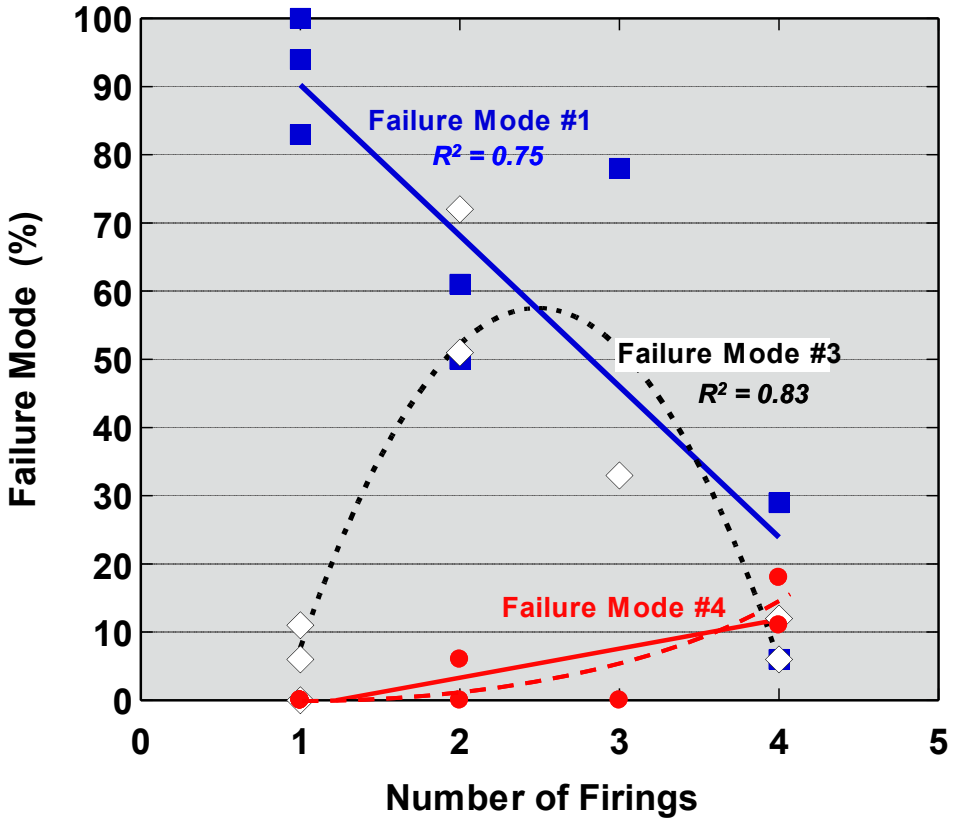
Results and discussion

- The failure modes were analyzed as a function of number of firing steps.

- The bulk solder failure mode (#3) was the "default" mode, between the solder/TKN (#1) and TKN/LTCC (#4) behaviors.

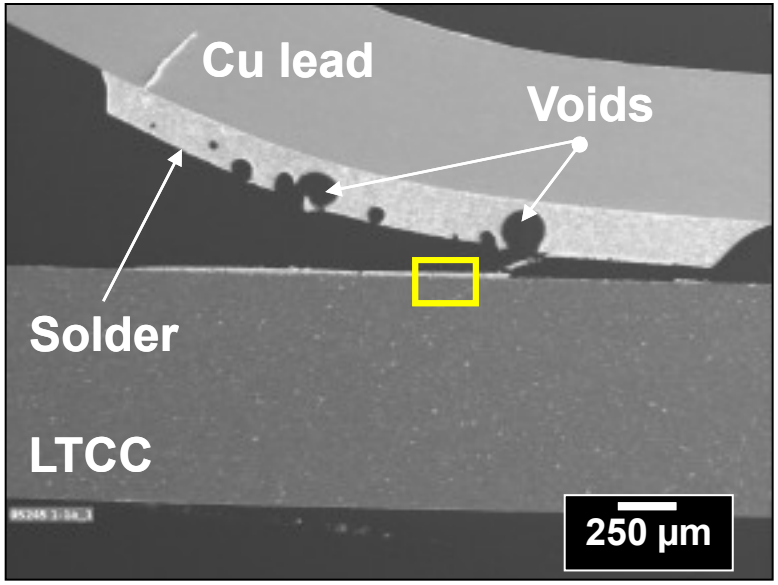
- Introducing the 5742 layer that comprised the 1 → 2 firing step transition, improved the solder/TKN interface strength per the mode #1 trend.

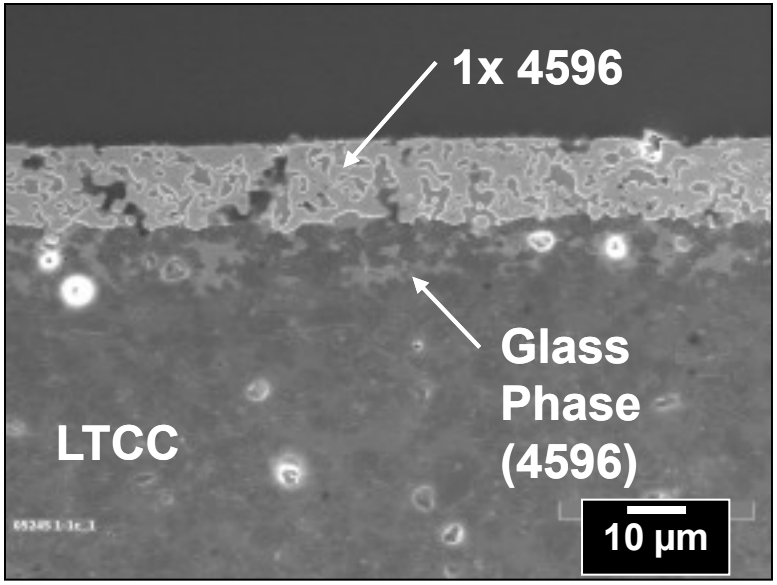
- More than 2 - 3 firing steps decreased the strength of the TKN/LTCC interface per the mode #3 trend.



Results and discussion

Metallographic cross sections provided a more exacting assessment of the failure modes that accompanied the pull strength values.

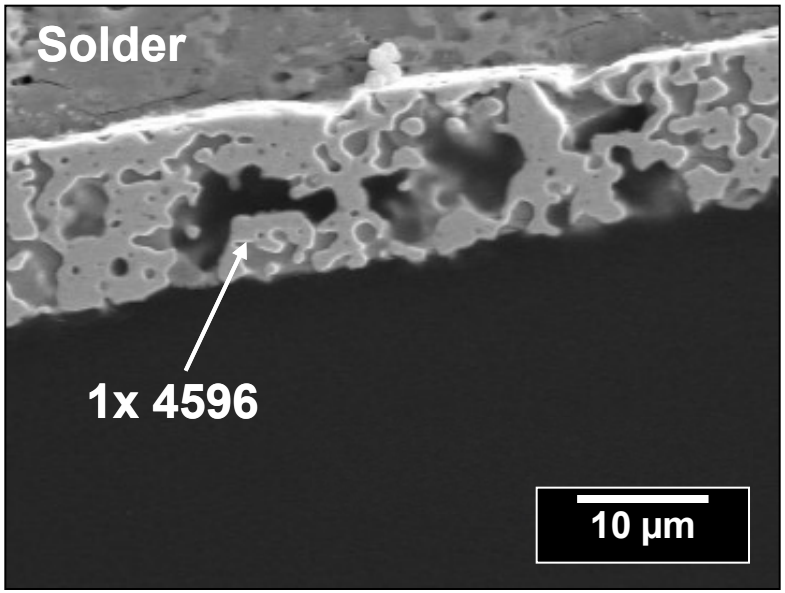




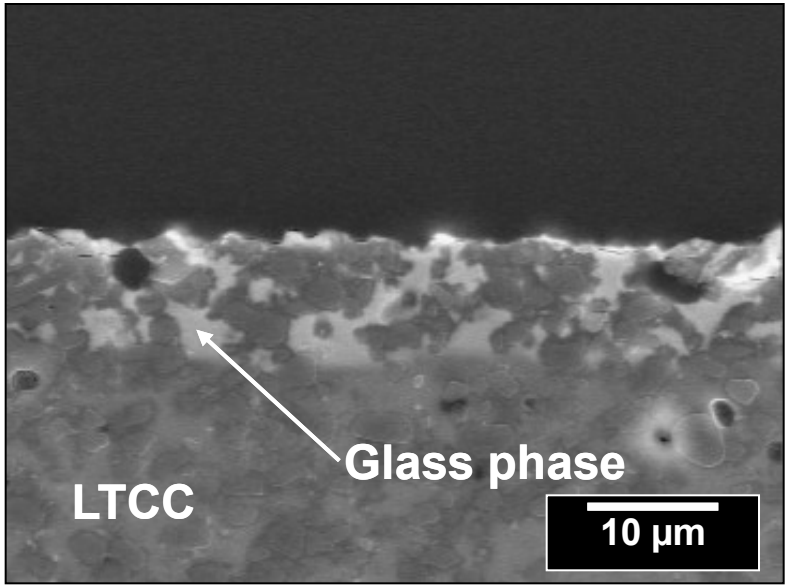
The solder/TKN failure mode (#1) for a 1x 4596 layer (no via).

Results and discussion

The TKN/LTCC failure mode (#4) for a 1x 4596 layer (no via).



The TKN fracture side.



The LTCC fracture side.

The fracture path was isolated to the TKN/glass phase layer interface.

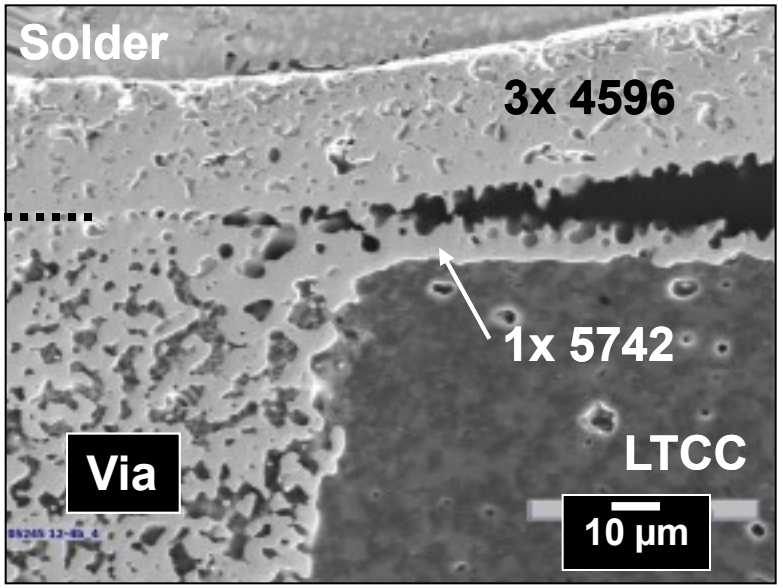
Results and discussion

- **Fracture within the thick film layer was not observable by visual inspection, but was recorded through the cross section analyses.**

- **This failure mode was not very prevalent, observed in the following test cases:**
  - **3x 4596, 1x 5742 (vias, no vias)**
  - **1x 4596, 1x 5742 (no vias)***

- **Failure occurred along the boundary created by the accumulation of 4596 glass phase particles.**

- **The crack was highly ductile.**



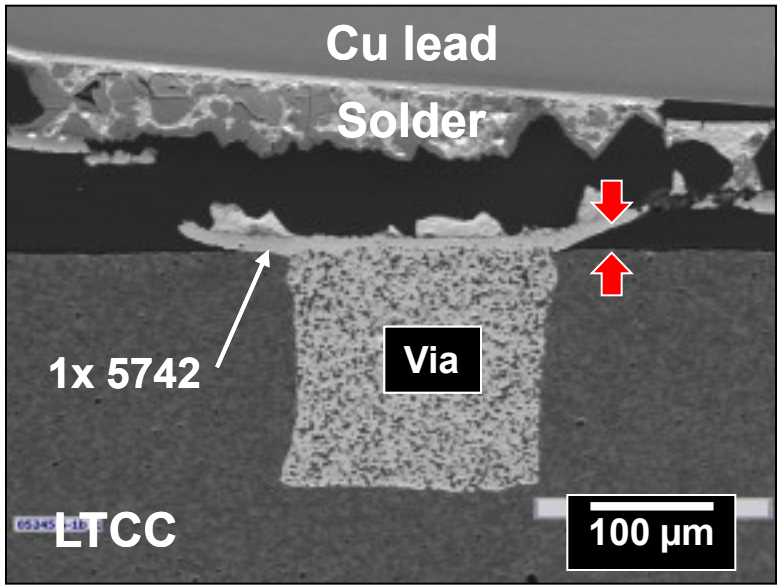
3x 4596, 1x 5742

(There were no via side wall cracks.)

*Very high pull strength case

Results and discussion

- In the case of the 1x 5742 thick film and In-Pb solder joints, the TKN/LTCC failure mode was observed in some samples.
- Adhesion between the 1x 5742 layer and the via fill material was excellent.
- When the 1x or 3x 4596 layer was added to the 1x 5742 layer, the TKN (5742)/LTCC failure mode was observed *very infrequently*.
- This case exemplified the general observation that the vias did not significantly impact the overall mechanical behavior (pull strength or failure mode) of these interconnections.



1x 5742 (In-Pb solder)

Summary

- A study was performed that examined the mechanical properties of solder interconnections made to thick film pads on low-temperature, co-fired ceramic (LTCC) substrates.
  - Thick film materials: DuPont™ 4596 (Au-Pt-Pd)
    DuPont ™ 5742 (Au)
  - Solder materials: 63Sn-37Pb (wt.%) with 4596
    50In-50Pb with 5742
- The experimental variables included:
  1. 1x 5742 barrier layer presence or absence (baseline)
  2. 1x or 3x 4596 layers
  3. Three [4596:1x5742] pad foot print ratios
- The pull strength test technique: “shepherd’s hook (12 mm/min).

Summary

- The interconnections exhibited excellent solderability and void formation that was not consequential to the study conclusions.
- The pull strength values were 3.5 - 4.0 lb, which although being slightly below historical values, also exhibited less data scatter.
- Pull strength was maximized for structures having 2 - 3 firing steps (e.g., 1x 5742, 1x 4596), resulting from the synergistic roles of solder/thick film and thick film/LTCC interface mechanical properties.
- The pad length dimension ratio [4596:5742] of [1.0:0.5] provided the maximum pull strength, accompanied by a minimum occurrence of the thick film/LTCC failure mode.
- The presence of the vias generally did not have a significant, consistent effect on the pull strength of the solder interconnections.