METAL MATRIX CAST COMPOSITES

Copper MetGraf™ Composites for Printed Circuit Board Thermal Control

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Innovative Technology and Impact

- Thermal management, CTE control, and mechanical stability are critical for lightweight aerospace/defense printed circuit board (PCB) applications.
- *Current* materials for PCBs such as oxygen-free high purity (OFHC) copper and graphite epoxy-based laminates do not adequately address thermal requirements, reliability, and weight reduction in a single material solution.
- Aerospace and defense platforms currently using PCBs incorporating a variety of thermal core materials include:
  - Phased array radar
  - Missile systems
  - Military avionics, guidance, and targeting systems
  - Satellites and space shuttles
  - Naval shipboard electronics
  - Commercial avionics

Innovative Technology and Impact

- New materials must offer:
  - Higher thermal conductivity -- especially in the Z axis
  - Reduced thickness
  - Reduced weight
  - Adapt directly to existing printed circuit board manufacturing processes.
- A single material solution that can be integrated within a PCB would be a benefit when multiple requirements are needed.
- MMCC is now producing copper-graphite composite thermal cores:
  - Panel dimensions: 30.5cm x 45.7cm (12” x 18”)
  - Available panel thicknesses: 0.25mm – 1.02mm (0.010” to 0.040”)
  - Standard PCB processes, electrolytic copper plating, drilling
  - Production thermal core PCB products have been *qualified by a major defense electronics manufacturer.*

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Innovative Technology and Impact

- Applications include radar, guidance, engine controls, cockpit displays, and targeting systems.
- The materials to be described in this presentation provide:
  - Improved thermal conductivity in all planes;
  - Selective CTE values matched towards silicon, silicon carbide, gallium nitride;
  - Reduced PCB weight.
- The purpose of this presentation is to:
  - Describe new thermal core materials developments;
  - Describe initial PCB manufacturing analysis, using these new thermal cores;
  - Increase market awareness for these new thermal core PCB capabilities for OEMs and PCB manufacturing partners to evaluate as possible solutions.

MMCC
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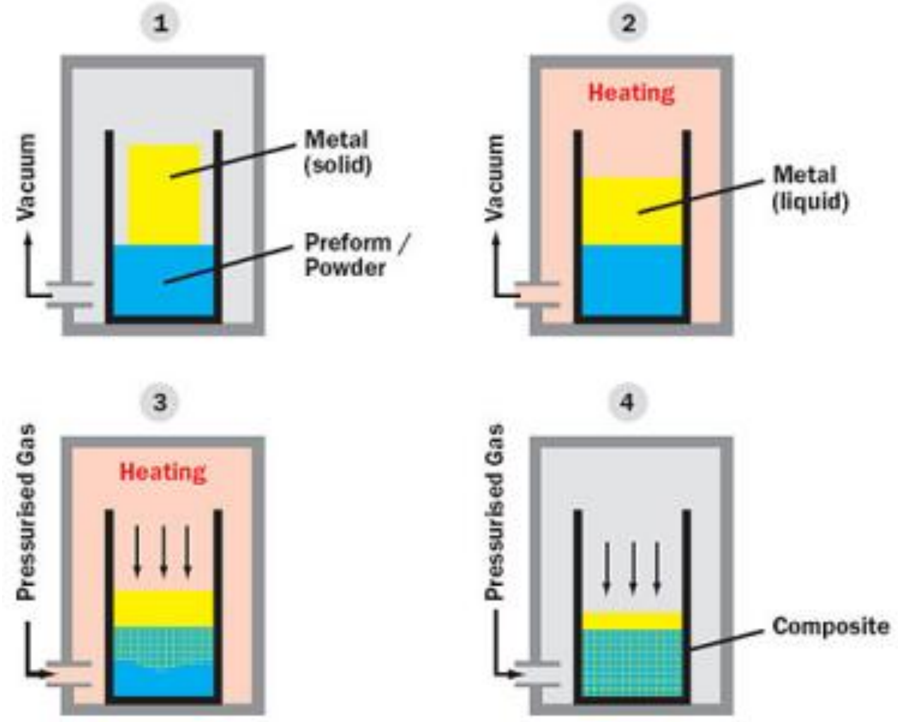
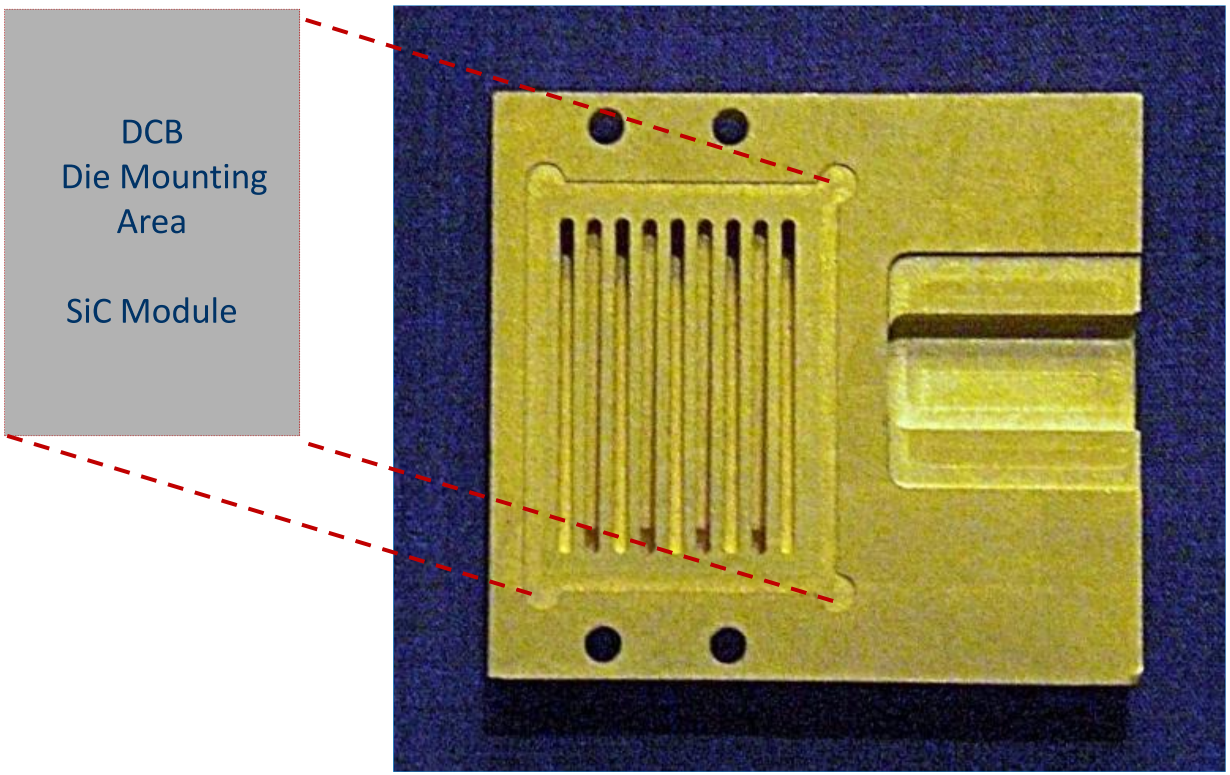
About Metal Matrix Cast Composites LLC

- Founded: 1993
- Founder was formerly director of Inorganic Materials Laboratory at MIT.
- MMCC LLC specializes in:
  Engineered composites for high heat flux thermal management and thermal-structural applications for industry and defense.
- Privately owned
- ISO 9001:2000 Certified
- ITAR Registered
- Patented technologies
- Volume manufacturing capacity
- Headquarters, engineering, and manufacturing: Waltham MA USA

Pressure Infiltration – Core Technology



About Metal Matrix Cast Composites LLC



GE Aviation *Power Overlay Technology SiC Module*
MMCC Liquid Impingement-Cooled CTE-Matched Liquid Cold Plate

Cu MetGraf™ for Passive PCB Thermal Control

Market need:

- Improved thermal core printed circuit board materials with these attributes:
  - Higher power density and heat dissipation capability
  - CTE matched to required semiconductor materials (Si, SIC, GaN)
  - Reduced weight

Technology gaps:

- Lighter-weight, expansion-controlled, high thermal conductivity planar core materials for PCBs
- Printed circuit boards capable of operating at:
  - Higher temperatures
  - Improved CTE values
  - Lower overall weight
  - Greater system reliability

PCB Thermal Control Layer Materials

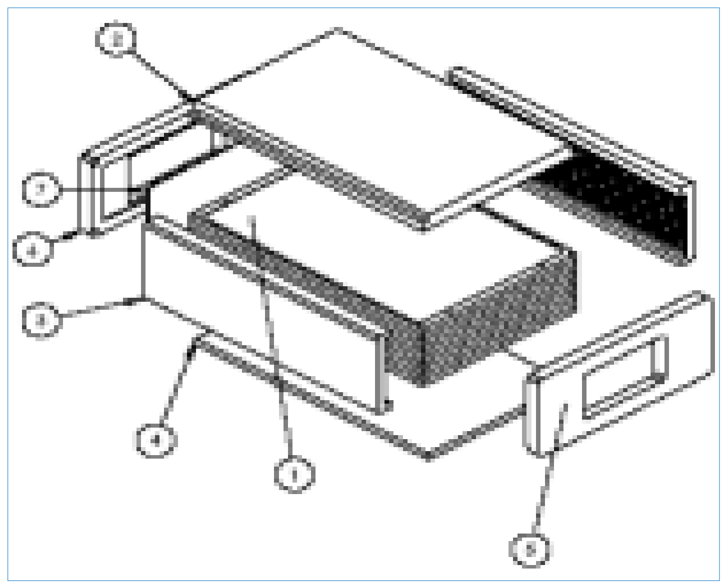
Material	Thermal Conductivity (W/m-°K)	CTE (ppm/°C)
Cu MetGraf 7-300™	XY: 285-300, Z: 210	XY: 7, Z: 16
EPOXY	~ 0.5	~ 55
Graphite/Epoxy (+ 0.5 oz. copper each side)	XY: 175, Z: ~1	XY: 4-6.5, Z: ~55
OFHC Copper	390	17

Cu MetGraf addresses thermal, reliability, and weight reduction in a single material solution for high density multi-layer interconnect PCB assemblies.

Thermal core PCBs using a Cu-MetGraf core meet MIL-P-55110 (IPC-6012).

PCB Thermal Control Layer Manufacturing

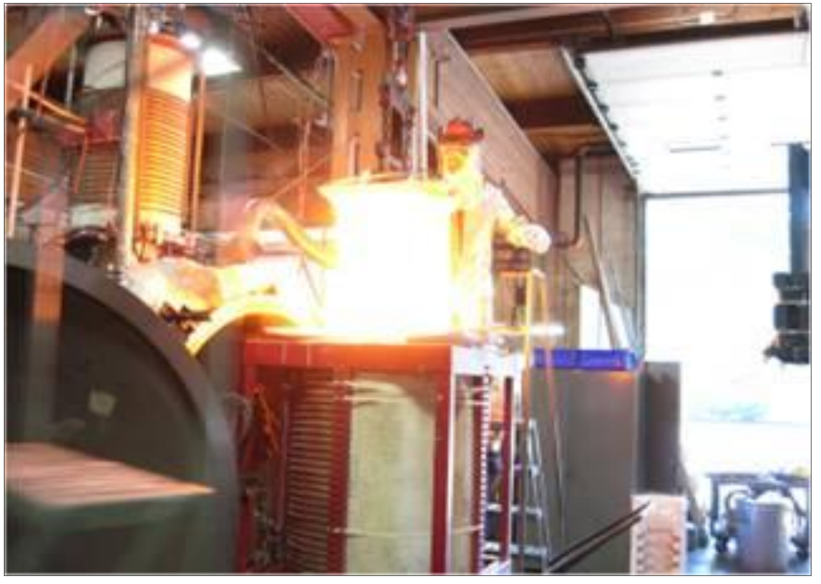
Step 1:* Graphite fibers are pressed into thin panels which are stacked and loaded into a mold assembly.



**   At MMCC*

PCB Thermal Control Layer Manufacturing

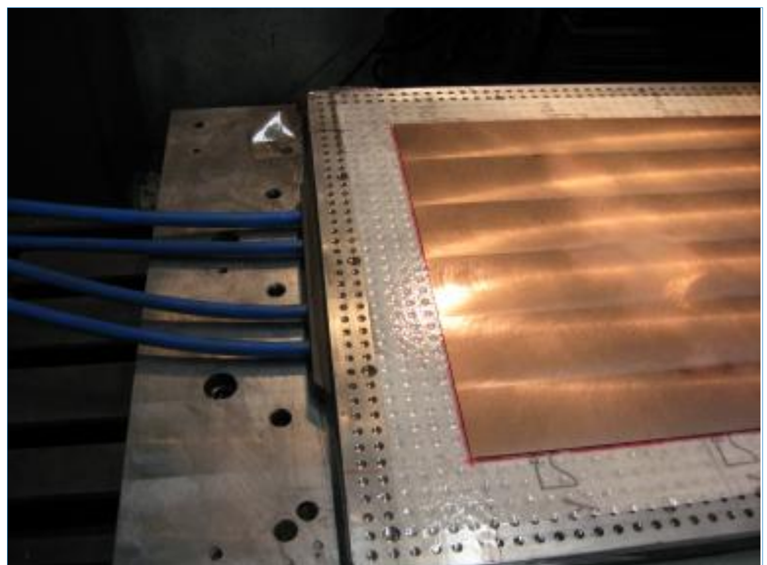
Step 2:* The mold is loaded into a casting vessel and heated under vacuum to the melting point of copper.



** At MMCC*

PCB Thermal Control Layer Manufacturing

Step 3:* The copper graphite sheets are de-molded, machined to the final surface finish and thickness required.



Copper MetGraf™ panel fabrication: 30.5mm x 45.7mm x 0.25mm (12.0” x 18.0” x 0.010”)

***   At MMCC***

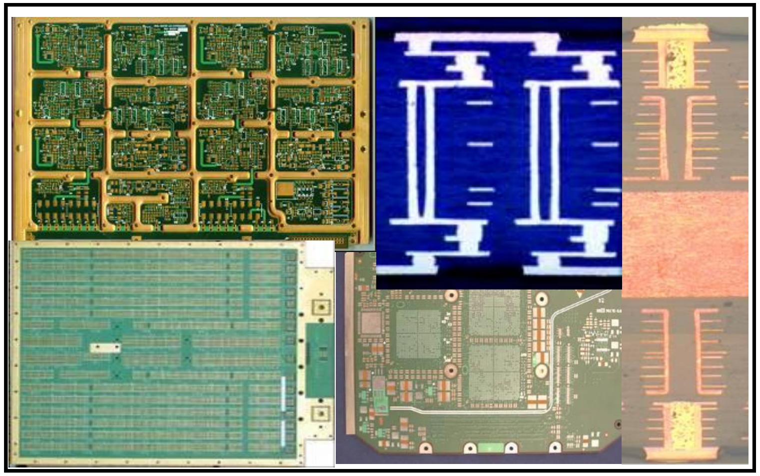
PCB Thermal Control Layer Manufacturing

Step 4:* Electrolytic copper metallization is applied.

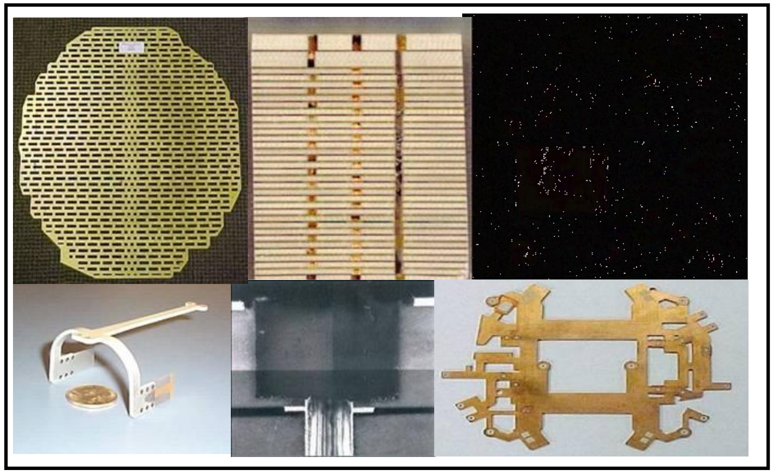
***   At TTM Technologies***

PCB Manufacturing Development

Step 5:* The Copper MetGraf™ thermal core is laminated within the PCB structure and used in various PCB applications.



High Density Interconnect (HDI) PCBs



RF PCBs

TTM Technologies is a manufacturer of an array of high-density interconnect, rigid flex, RF/microwave, and backplane PCBs for military and aerospace applications.

**   At TTM Technologies*

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PCB Manufacturing Development

The following data is provided by MMCC's commercialization partner:

TTM Technologies
Time-To-Market Interconnect Solutions™

Scope

Scope for thermal core PCB production, test, and analysis program:

- Evaluate material performance of MMCC Cu-MetGraf™ as a PCB thermal core material as compared to (current) Stablcor ST325.
- Determine feasibility for incorporating Cu-MetGraf into a PCB board as a thermal core material, using standard PCB processes and chemistry.

MetGraf Phase A – Test Goals

Phase A test goal:

- Copper MetGraf™: Determine MetGraf thermal core panel material compatibility with standard PCB process equipment and chemistry.

MetGraf Phase A – Test Plan

Phase A test plan:

- Panel Size: 22.9cm x 30.5cm (9”x12”)
- Laminate MetGraf material within standard PCB laminate materials
- There were two parts to the lamination process test sample plan:
    1. Laminate the MetGraf material with a balanced stack-up and 4 additional (other) layers;
    2. Laminate MetGraf material with an unbalanced stack-up and 10 additional (other) layers.
- Drill holes: 0.25mm, 0.90mm (.0098”, .0354”) diameter
- Hole preparation: plasma and chemical preparation
- Electroless copper deposition: 0.0013mm (0.00005”) average thickness
- Electroplate copper deposition: 0.025mm (0.001”) average thickness
- Cross-section test samples for hole quality and plating adhesion
- Provide detailed report of findings and recommended improvement plan.

MetGraf Phase A -- Balanced Stack-up

1	Top	1oz
	.010 Core (Nelco -29)	
2		1oz
	Prepreg 3-1080 (Nelco -29)	
	Metgraf Material	
	Prepreg 3-1080 (Nelco -29)	
3		1oz
	.010 Core (Nelco -29)	
4	Bottom	1oz

Overall Thickness: ~ 2.31mm (0.091")

MetGraf Phase A -- Unbalanced Stack-up

1	Top	1 oz
	.010 Core (Nelco -29)	
2		1 oz
	Prepreg 3-1080 (Nelco -29)	
	Metgraf Material	
	Prepreg 3-1080 (Nelco -29)	
3		1 oz
	.010 Core (Nelco -29)	
4		1 oz
	Prepreg 2-1080 (Nelco -29)	
5		1 oz
	.010 Core (Nelco -29)	
6		1 oz
	Prepreg 2-1080 (Nelco -29)	
7		1 oz
	.010 Core (Nelco -29)	
8		1 oz
	Prepreg 2-1080 (Nelco -29)	
9		1 oz
	.010 Core (Nelco -29)	
10	Bottom	1 oz

Overall Thickness: ~ 3.56mm (0.140”)

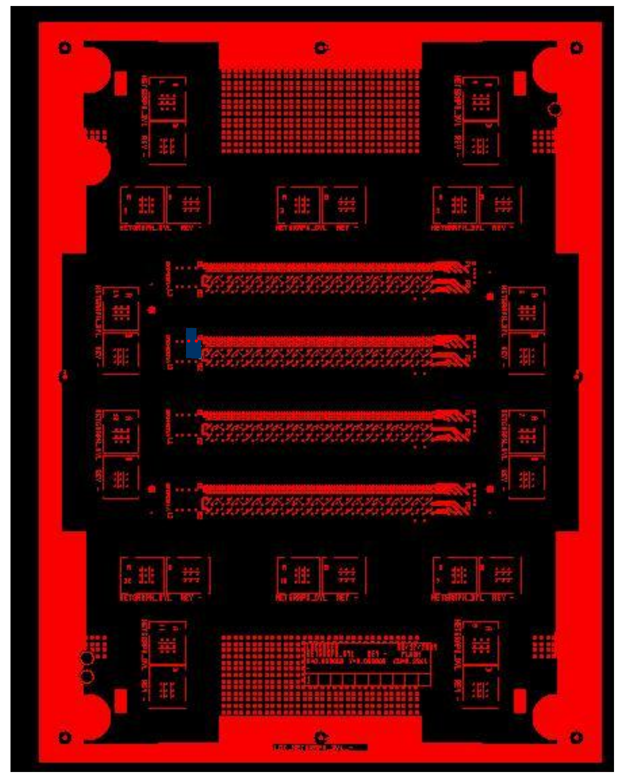
MetGraf Phase A -- Panel Design

IST Design:

- (4) IST Coupons
- 14 A/B Mil coupons
- Drilled hole sizes:

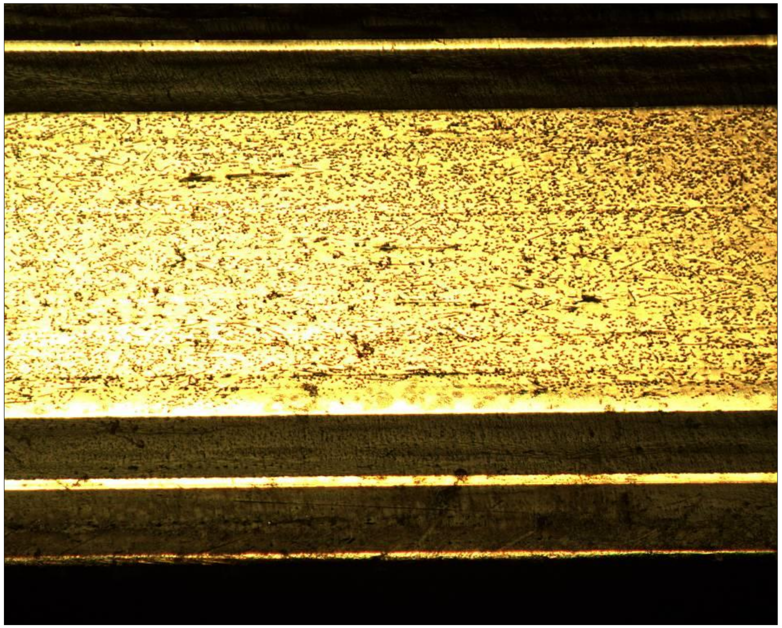
  0.25mm, 0.90mm diameter (.0098”, .0354”)
- Panel size:

  22.9cm x 30.5cm (9.0”x12.0”)
- Internal layers were left as solid copper



MetGraf Phase A -- Lamination Process

4-Layer Balanced Stack-up

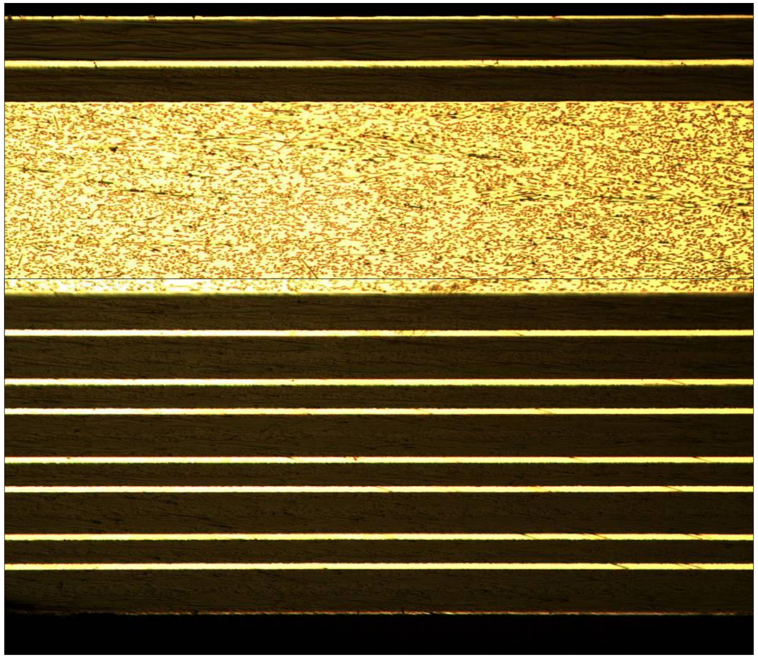


Analysis:

- No issues were noted during the lamination step.

MetGraf Phase A -- Lamination Process

10-Layer Unbalanced Stack-up

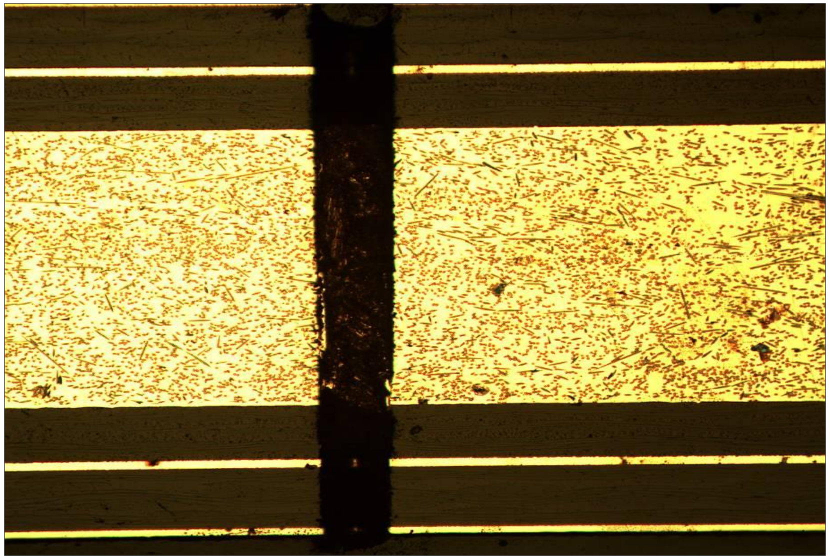


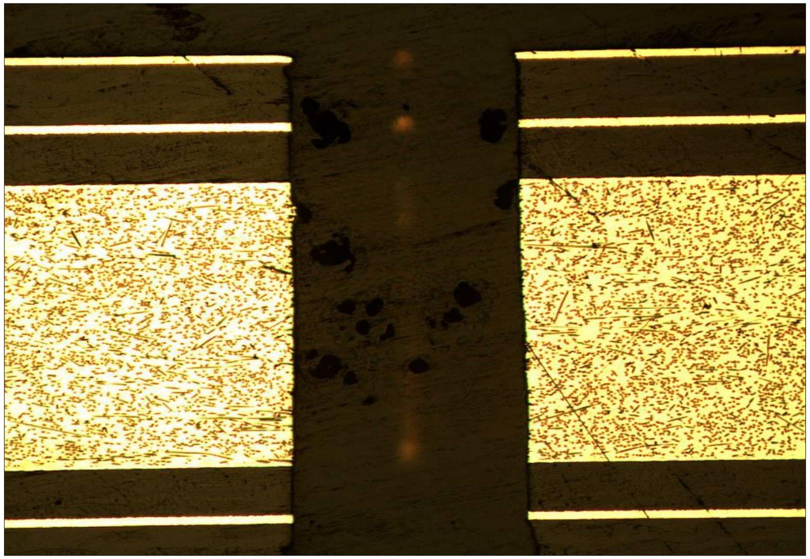
Analysis:

- No issues were noted during the lamination step.
- We could not process through drilling due to the amount of warp.

MetGraf Phase A -- Drill Process

4-Layer Balanced Stack-up





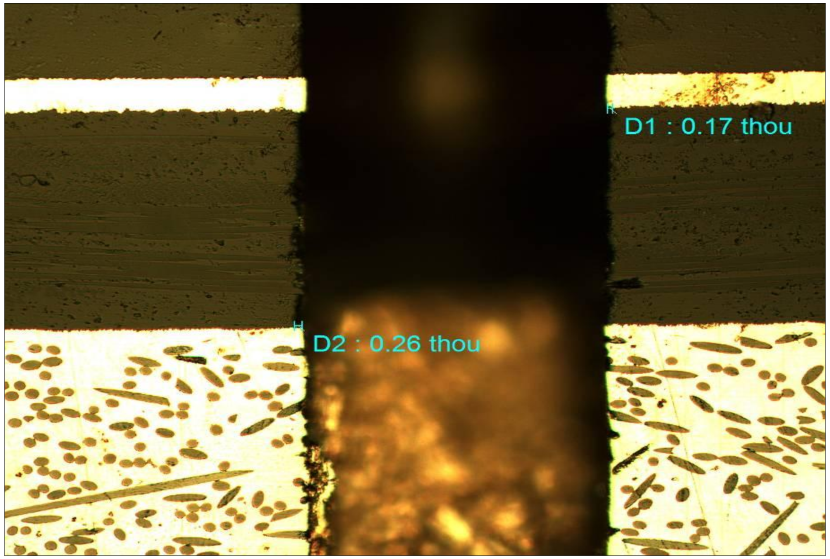
Process Step:

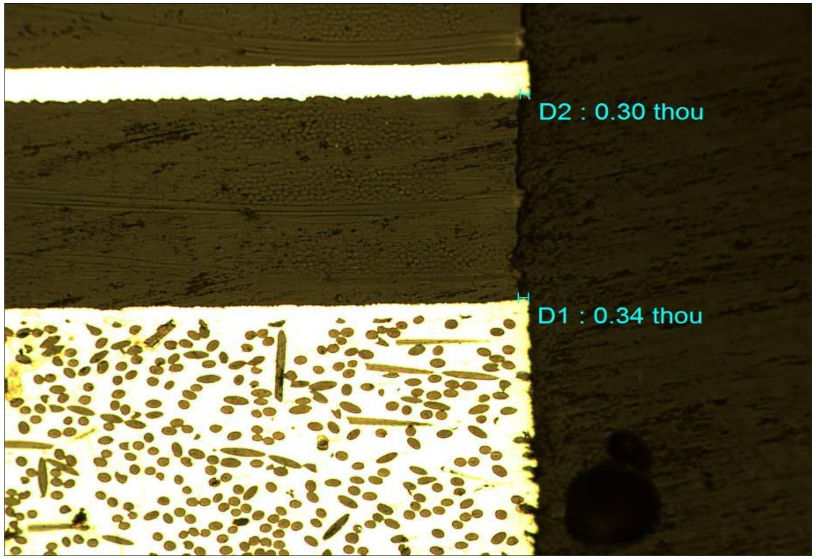
- Drill 0.90mm (0.0354”) and 0.25mm (0.0098”) diameter holes

Analysis:

- Overall hole wall quality is good.

MetGraf Phase A -- Plasma Etchback Process

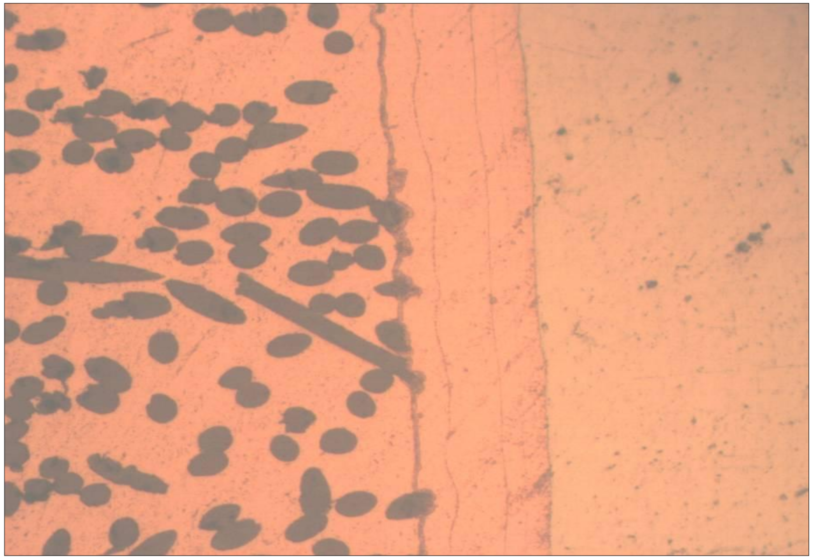




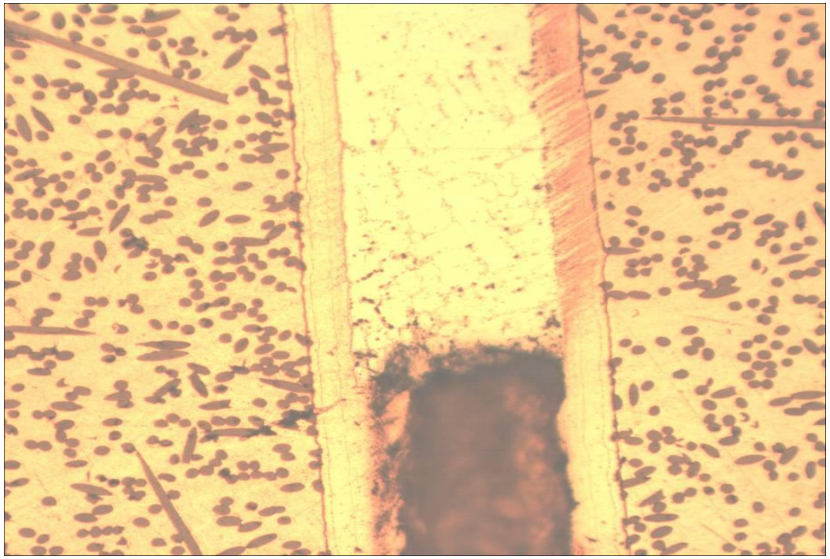
Analysis:

- Plasma desmear cycle has provided 0.0 – 0.008mm (0.0 - 0.0003”) etchback and the remainder of the hole wall is still in good shape.

MetGraf Phase A – Plasma Etchback Only/EC

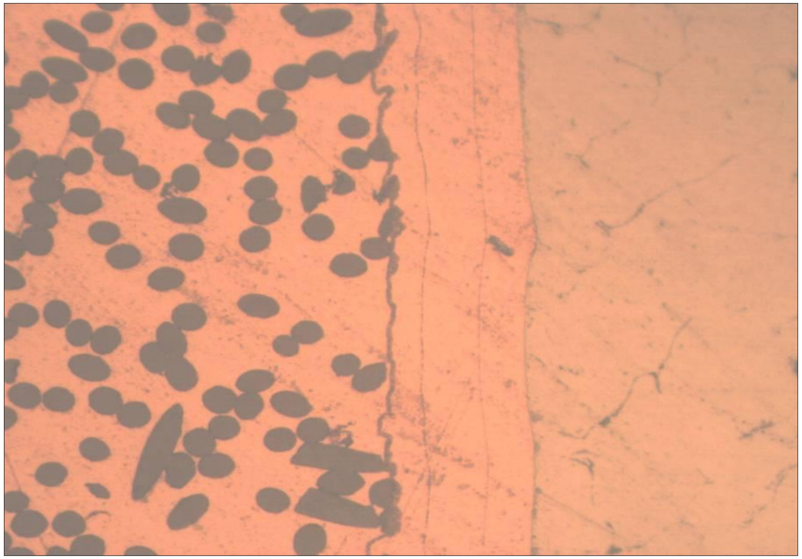


Large hole

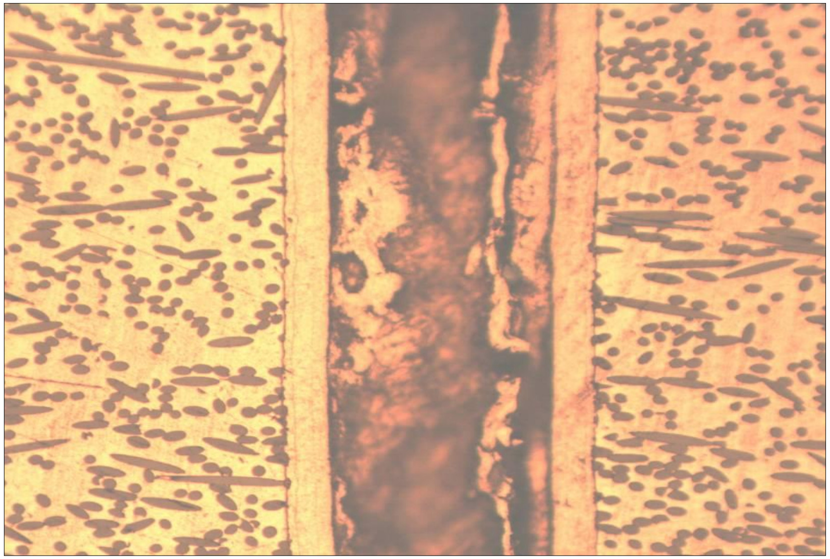


Small hole

MetGraf Phase A – Plasma/Wet Etchback/EC



Large hole

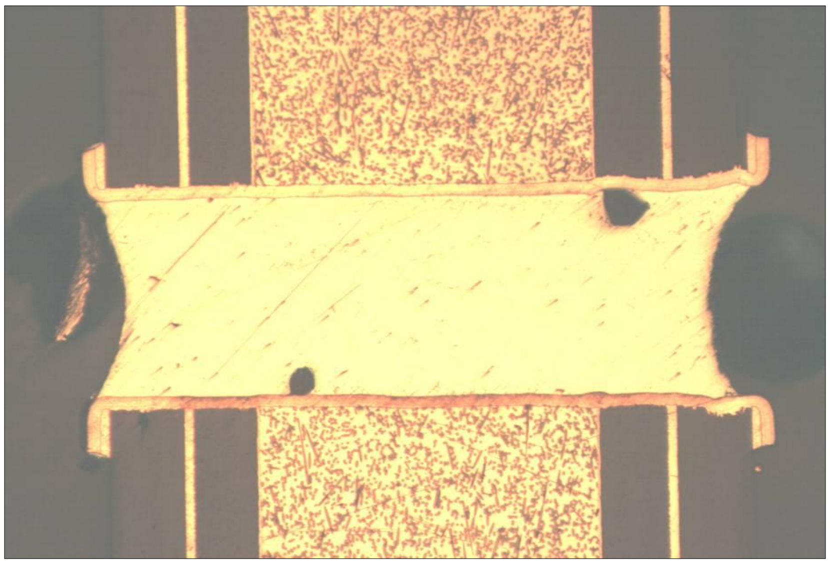


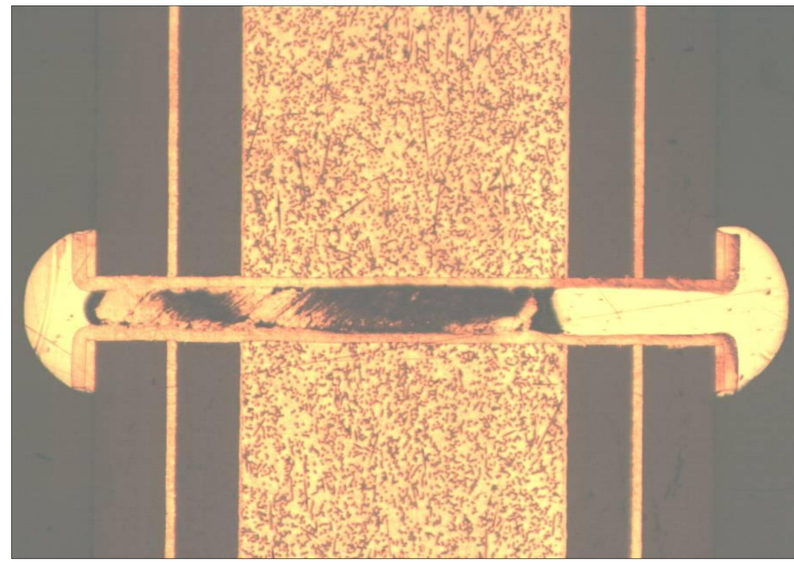
Small hole

Analysis:

- The holes exposed to the additional wet etchback process do not show any negative influence on the MetGraf material.

MetGraf Phase A -- Final Thermal Stress





Process Step:

- Sectioned after 3X thermal stress (550°F/10 seconds)

Analysis:

- Excellent material and copper plating adhesion.

MetGraf Phase A -- Observations

Analysis:

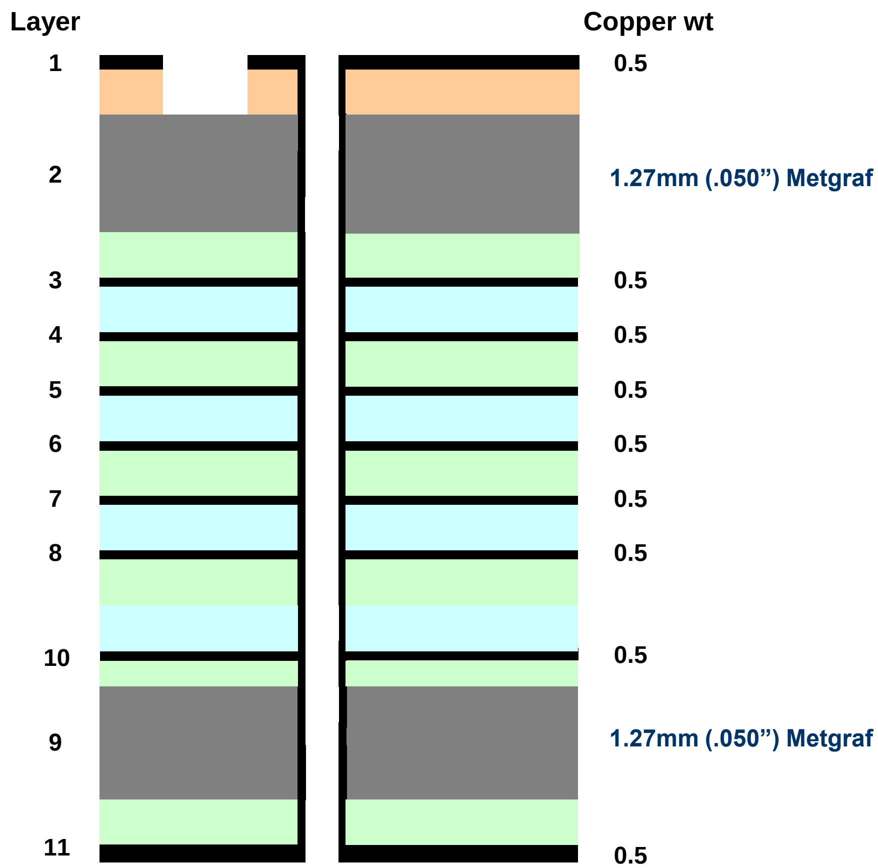
- MetGraf material bonded very well to Nelco-29 epoxy laminate.
- MetGraf material was exposed and evaluated through the entire standard PCB manufacturing process.
- Standard plasma and wet etchback process does not have any negative effect on the MetGraf thermal core materials.
- All cross-sectioned PCB samples were thermally stressed 3x @ 550˚F for 10 seconds and did not exhibit any thermally-related defects
- Overall testing and analysis: Successful.
- Recommendation: Initiate PCB production of samples for Phase B test plan.

MetGraf Phase B -- Test Plan

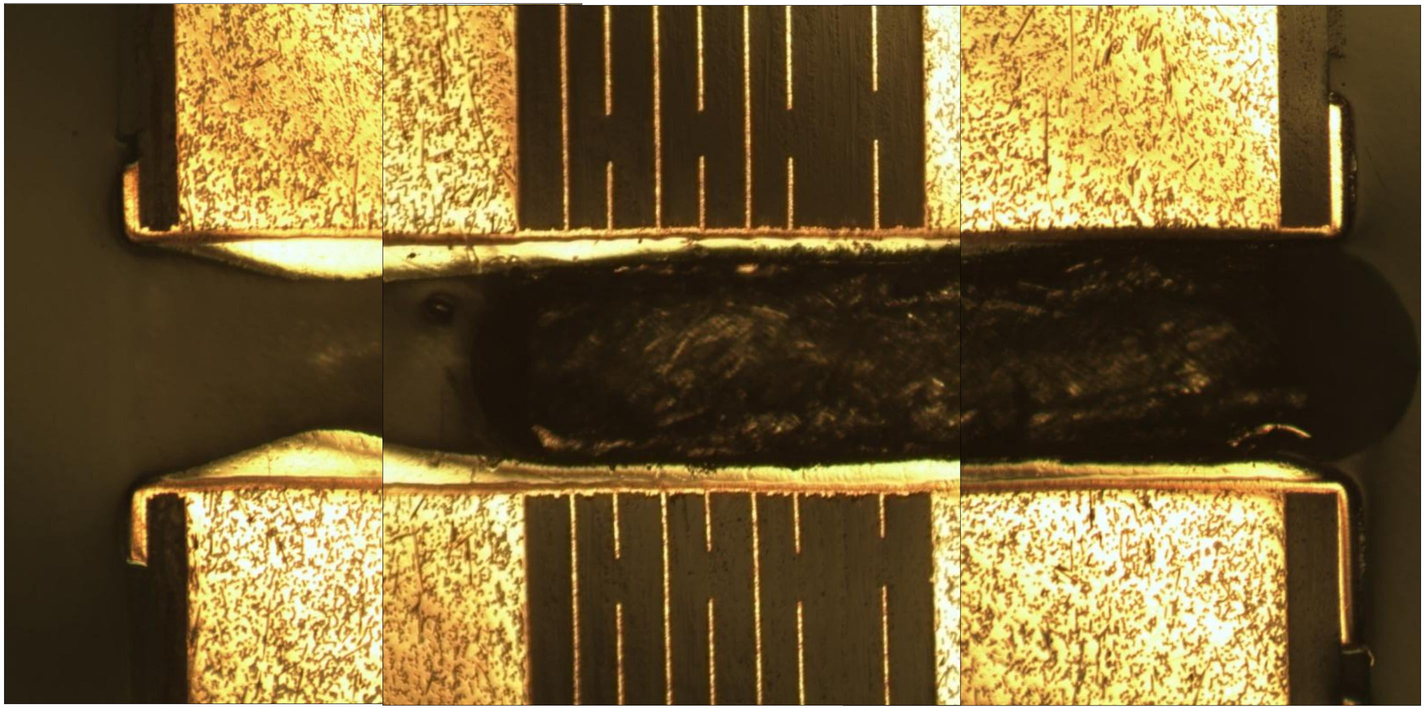
Phase B Test Plan:

- Panel size: 30.5cm x 45.7mm (12.0”x18.0”)
- Drill holes: Only non-plated through-holes in the final assembly.
  - Via will not be drilled.
- Hole preparation: plasma etchback
- Electroless copper deposition: 0.0013mm (0.00005”) average thickness
- Electroplated copper deposition: 0.025mm (0.001”) average thickness
- Cross-section and examine samples for hole quality and plating adhesion.
- Provide detailed report of findings and recommended improvement plan.

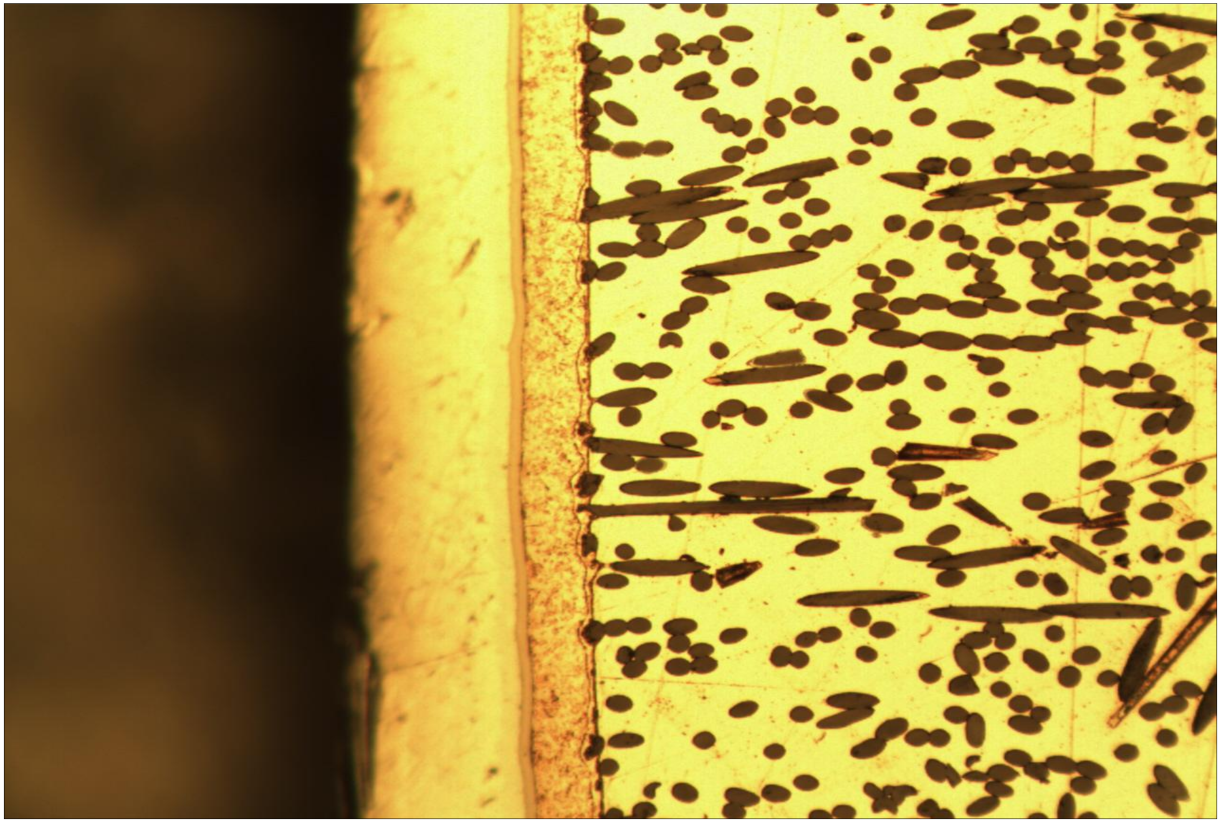
MetGraf Phase B -- Stack up



MetGraf Phase B -- Analysis



MetGraf Phase B -- Analysis



MetGraf Phase B Conclusions

Process Evaluation:

- This phase of testing introduced all layers of MetGraf and other required materials and a portion of the drilled holes through the standard overall PCB manufacturing process.

Analysis:

- This test verified that the MetGraf thermal core materials:
  - Met all process requirements throughout the entire printed circuit board manufacturing process.
  - Provided good thermal verification.

MetGraf Phase B Conclusions

Process Evaluation:

- Thermal core PCB pilot production included RF PCBs with provision for machined cavities for direct solder attach of RF devices directly to exposed Cu-MetGraf thermal core.
- Enables attachment of RF heat sources directly to metallized thermal core, to maximize X-Y heat spreading to conduct heat load to PCB enclosure side walls.
- Enables maximizing Z-direction thermal conductivity.

Cu-MetGraf™ Thermal Core PCBs – Next Steps

Process Development:

- Test and evaluation of finished, fully-populated Cu-MetGraf thermal core PCBs for missile development program applications (2011-2012).
- Cost reduction program for Cu-MetGraf thermal core materials (2012).

Thermal Performance Evaluation:

- Thermal testing of finished, fully-populated Cu-MetGraf thermal core PCBs (2012)

References and Notes

References:

1. A. Pergande, J. Rock, "Advances in Passive PCB Thermal Control", *Proceedings, IEEE 2011 Aerospace Conference,* Big Sky MT USA, March 2011, Manuscript no. 978-1-4244-7351-9/11.
2. D. Saums, DS&A LLC, "Developments in CTE-Matched Thermal Core Printed Circuit Boards", *Electronics Cooling Magazine*, June 2011, pp. 10-11.

Notes:

MetGraf™ 7-300 is a trademark of MMCC Inc., Waltham MA USA

STABLCOR® ST325 is a registered mark of Stablcor Technology Inc., Huntington Beach CA USA

IPC 6012(C) *Qualifications and Performance Specification for Rigid Printed Circuit Boards,* ISBN 1-580986-36-6, April 2010. IPC, Bannockburn IL USA

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