

New Reinforcement Material can Solve Heat and Co-Efficient of Thermal Expansion Challenges of the Printed Circuit Board and IC Substrate

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Abstract

Printed Circuit Boards (PCB) and IC Substrates are the essential building blocks of electronics. As the technology moves rapidly into the future, the electronics industry faces issues with hot spots, solder joint stresses and Co-efficient of Thermal Expansion (CTE) mismatch in a PCB and IC substrates. The most popular material used in the PCB industry is glass fiber based composite material. It delivers great electrical properties but has minimal thermal and mechanical properties. As more functionality is required from a single device, the PCB is getting denser and has a very high heat load per unit area. Also, the speed of the electronics is becoming more critical. This means it is necessary to have the shortest electrical path between silicon and the PCB. This requires eliminating long wire bonds and moving to the Flip Chip types of packages. Flip chip type packages have more functionality and faster speed but also have very low CTE compare to traditional PCB material. Thus it is necessary to have a low CTE printed circuit board in order to keep solder joints intact with such low CTE packages. There are currently several materials available in the market to address thermal and CTE challenges but each material has its own advantages and limitations. For example, heavy copper is often used for thermal management with a thermal conductivity up to 385 W/m.K. But it has a higher CTE (17 to 20 ppm/C) and high density (8.9 g/cc) and is not easy to drill for the smaller holes required for HDI PCBs. Thus, heavy copper has the ability to do thermal management at the sacrifice of weight, CTE and limited to non-HDI technologies. On other hand, CIC has ability to deliver lower CTE but again CIC is very heavy and hard to drill for smaller vias. Other material non woven Aramid can deliver low CTE but does not have good thermal conductivity. It also has a very high Z-axis expansion and is sensitive to the moisture absorption. Thus all above materials can address one issue but are limited in other areas.

The ideal solution for the challenges would be a material that has the ability to do thermal management, CTE control and provide increase rigidity with no additional weight. Thus, it is necessary to think outside the box and find a material that can address multiple issues at once. If you look at carbon fiber, it has very unique thermal and mechanical (CTE and Stiffness) properties but it is not a dielectric fiber unlike glass fiber. If we manage to use carbon fiber along with the glass fiber, we can address electrical, thermal and mechanical aspect of the functionality required by the industry. This presentation will address: (1) Details of the carbon fiber, (2) Carbon fiber composite types and shapes necessary for the PCB and Substrate, (3) How to make the electrical conductivity of the carbon fiber a plus point as opposed to a hurdle, (4) What needs to be done to use it successfully, (5) How it can address thermal and CTE challenges, (6) Basic understanding of manufacturability: (6a) Compatibility with FR4, Polyimide and other materials, (6b) Effect of feature sizes, scaling, drilling, routing and (6c) DFM through CAM. If carbon fiber could be used as reinforcement material instead of glass fiber (only in few layers) it could bring following benefits to the circuit board:

- Enable efficient conduction cooling
- Create a thermal path from hot IC Chips to the frame or chassis
- Allow the PCB to act as Heat Spreader and/or Heat sink
- Control the CTE of a PCB to match with Components such as Ceramic BGA (CBGA), Ceramic Column Grid Array (CCGA), Flip Chip (FC), and Chip on Board (COB) etc.
- Deliver additional stiffness
- Give a higher stiffness to weight ratio increasing shock and vibration reliability
- Provide a thermal management material that does not add weight to the product

Introduction

The evolution of electronics is now reaching the threshold of design capability. The Printed Circuit Board (PCB), the ground base of all electronics, is reaching limitations due to the material functionality. High Density Interconnect (HDI) PCBs are faced by high signal frequency, signal speed, thermal, and Co-Efficient of Thermal Expansion (CTE) issues. Traditional dielectric materials have very good electrical properties such as very low dielectric constant, low loss, high frequency and high speed characteristics. There are other materials to address thermal and CTE issues. These materials may

have the capability to solve one issue while sacrificing in other areas. For example, Heavy Copper has the ability to manage the thermal issues on a PCB, but has limitations in CTE control, high density (thus weight) as well as manufacturing limitations. Non-Woven aramid materials have the ability to control CTE, but have limitations in thermal management, more than double z-axis expansion, and also have a tendency to be moisture absorbent.

Table 1: Thermal, CTE, Rigidity, and Density properties of the various PCB Materials

Thermal Management, CTE Control, Stiffener Materials Comparison				
MATERIAL	Thermal Conductivity (W/m.K)	IN-PLANE CTE (ppm/C)	Tensile Modulus (Msi)	Density (g/cc)
Low Modulus Carbon Fiber	8 to 12	-0.41	30 to 35	1.7 to 1.8
High Modulus Carbon Fiber	300 to 325	-1.5	100 to 114	2.1 to 2.2
Copper Clad Carbon Composite	X & Y: 75 to 175*	3 to 6	10 to 25	1.65 to 1.7
Heavy Copper	385 to 400	17 to 19	12 to 16	8.9
Copper-Invar-copper (CIC)	20 to 30	5 to 6	18 to 19	9.9
Copper-Molybdenum-Copper (CMC)	180 to 220	6 to 8	N/A	9.8 to 10
Non woven Aramid Composite	0.2 to 0.3	9 to 12	2 to 2.1	1.25 to 1.3
Copper C11000 full hard	385 to 400	17	6.4	8.9
aluminum 5052	150	25	3.76	2.7
Aluminum 6061 T6	150	25	3.75	2.7
*Theoretical Calculated Values				

Section I: Thermal Transfer Rates of Raw Materials, Method of Use and its Limitations

There are several types of materials used for thermal management in a Printed Circuit Boards or semiconductor substrate. Some of them are thick copper or other metals, metal alloys and carbon composite materials. Each possesses its own unique property of thermal conductivity. Some of these materials can also contribute to the Co-efficient of Thermal Expansion (CTE) and provide stiffness and weight benefits in addition to the thermal conductivity.

Common thermal management materials used in a printed circuit boards today are metals like copper, copper invar copper (CIC), Copper Molybdenum Copper (CMC) and Aluminum. Thermal conductivity of copper ranges from 385-400W/m.k, CIC ranges from 20-30W/m.k, CMC ranges from 180-220W/m.k and aluminum has ~150W/m.k. Normally metals are isotropic thermal conductors. Thick metal layers are used as an integral layer of a printed circuit board, usually as one thick layer of metal in the center of the PCB. The Metal layer is located at center of the PCB which is quite far (deep) from the heat generating chips located at the surface of the PCB. Most designers place heavy copper in the center of the board, so as not to create the expansion problems near the surface. The trouble with heavy copper/metal in the center is that it creates a much longer thermal path (thus high thermal resistance) for the heat to travel from the chip to metal core located at the center of the stack-up. Thus, there are several layers of dielectric (non-thermally conductive) materials between hot chips and thick metal layer, high thermal resistance. Therefore, even though copper/metal could have a very high thermal conductivity its effective thermal conductivity of the metal core drops due to the higher thermal resistance between the heat source and thermal material within the PCB. In addition, the isotropic nature of the metal tends to spread heat around in a circular pattern from the heat generating IC and does not utilize entire PCB area for efficient cooling. Another limitation that designer face is the thick metal layer limits their ability to have fine features and limits connectivity of signals from one side of the metal core to the other side. This reduces their ability to use the thick metal layer for thermal management in HDI (high density interconnect) designs..

The thermal transfer rate of the raw material of a Carbon composite, at the raw fiber level, can range from 8-325W/mK depending on the material selected. Carbon composite laminate is a fibrous composite. It is used as plane layers, preferably in a ground plane in the “stack-up” of a printed circuit board or substrate. These can be easily processed and easily placed in the second layer from the surface of the PCB. Multiple layers can be strategically placed throughout the PCB in symmetric manner in order to increase heat capacity. The thermal conductivity of this composite is directional (non isotropic) driven by the carbon fiber throughout the entire plane, thus enabling the PCB to act as a heat spreader. The composite laminate acts like a heavy copper layer without high expansion and weight premiums that a designer experiences while using heavy copper. Carbon composites are easy to drill through, which could be advantageous to HDI designs. Designer can have fine features and can connect all the necessary signals from one side of the composite layer to the other side without any limitations.

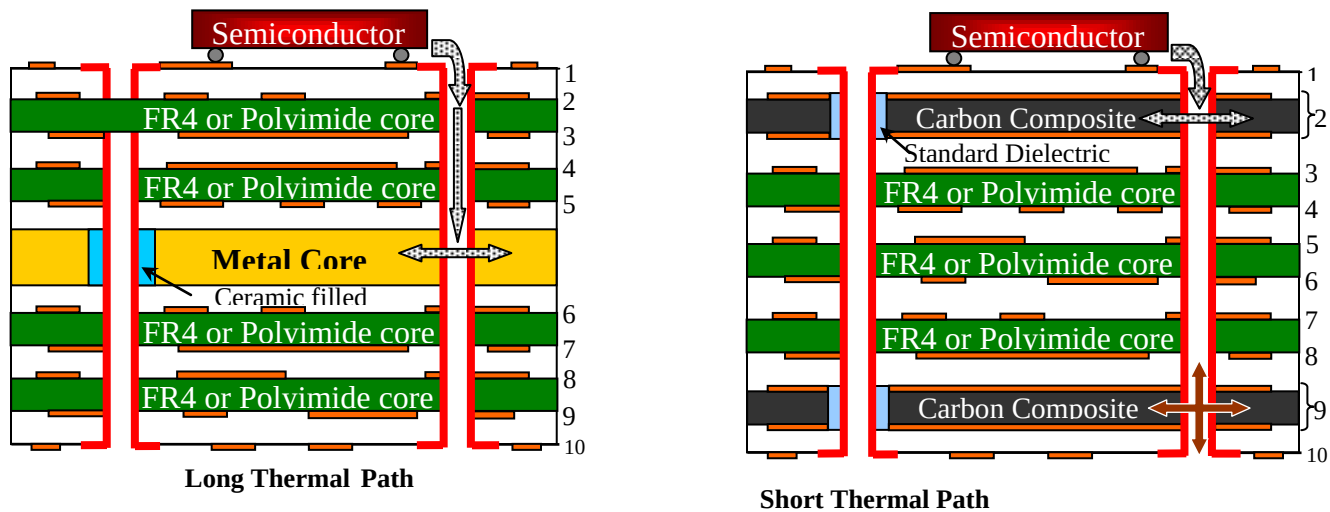


Figure 1: Thermal Path from heat source (IC) to the thermal plane

In Carbon embedded PCBs, heat will travel through the ground vias and thermal vias, then travel through very thin dielectric layer before reaching to the carbon composite layer, thus embarking on a much shorter thermal path (low thermal resistance). Also, heat can conduct through thin dielectric layer directly to the composite layer located at layer-2 (next to the surface layer). Once the heat reaches the composite layer it travels quickly, in an anisotropic nature, to any structure of the board that is heat absorbing such as a wedge lock, chassis, frame or heat sink. Additionally with the added carbon in the PCB the board acts like a heat spreader, thus, channeling the heat away from the IC's.

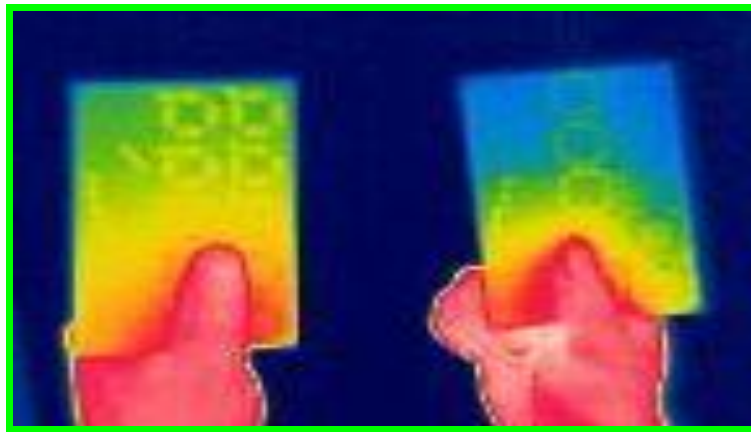


Figure 2: Thermal performance comparisons of carbon composite PCB to standard PCB, transferring body heat

A limitation of carbon composite material in a printed circuit board is that it is an electrically conductive material, such as copper/metal. Copper can be patterned using chemical etching process but carbon composites are not compatible to the chemical etching process to pattern the circuit. Thus know how is required in order to successfully incorporate the composite material within the printed circuit board stack-up. The good news is that manufacturer does not require any capital investment in equipments to process this material.

SECTION II: Beyond Thermal, Additional Benefits of Carbon Composites

Carbon fibers have some great properties besides thermal conductivity such as negative co-efficient of thermal expansion (CTE), high tensile modulus (thus stiffness) and low density (thus weight). Composites made from these carbon fibers bring unique benefits to the circuit industry beyond thermal benefit.

Coefficient of Thermal Expansion (CTE) Properties

Most of the printed circuit board materials are made from glass fiber composite (also known as organic materials) with different resin systems. Glass fiber based PCB composite materials have in-plane CTE ranging from +16.0 to

+20.0ppm/°C. Carbon fibers have very low to negative CTE, (-0.41 to -1.5 ppm/°C). So, composite made using carbon fibers have very low in-plane CTE (+2.0 to +6.0ppm/°C).

Throughout the last few decades, wire bonds were used between the die and the organic substrate to absorb the expansion mismatch, and then leads were added to carry the signals to the board. This process works effectively for expansion mismatch, but not for high signal speeds. As the world demands increased power and speeds in all areas of electronics, faster interconnect and packaging methods had to be invented, thus giving birth to the flip-chip, Ceramic Ball Grid Array (CBGA), Chip Scale Package (CSP) and Multi Chip Packages (MCP) of today. Plastic, Ceramic and flip-chip packages have become the mainstream in electronic packaging technology. Plastic packages expand during thermal cycling at a rate of 16-20ppm/C, Ceramic packages at 6-8ppm/C and flip-chip at 2.5-4ppm/C. Plastic packages can be mounted reliably onto standard printed circuit board because of matching CTE but mounting low CTE ceramic and flip chip packages on a high CTE printed circuit board causes tremendous stress at solder joint and leads to solder joint failure. With high I/O count chips such as ASIC,, processing devices, and memory chips the ability to place the bare die on an organic Printed Circuit Board directly is hampered by shear stress caused by expansion mismatch at the tiny bump connections. The higher the connection counts on a chip and the smaller the connection pads, the harder it is to attach and adhere to a radically expanding substrate or board. Thus, to mount a low CTE, high I/O packages reliably on a printed circuit board one is required to have low CTE printed circuit board. A user can take low CTE carbon composite laminate and embed it into PCB layer stack-up. This will tailor the surface CTE of a standard Printed Circuit Board from 4ppm/C to 12 ppm/C, enabling closer CTE match with ceramic or flip-chip packages.

CTE Case Study: 14layer Thermount PCB v/s 14layer FR4 with two layers of a carbon composite

Non-woven Aramid (also known as Thermount) material was very popular for its low CTE properties. Many defense and medical electronics were using aramid material to reduce co-efficient of thermal expansion of a printed circuit board. About a year ago due to limited availability of an aramid fibers production of aramid composite material was discontinued. There was a CTE study done on an aramid based 14 layer printed circuit board and a FR4 with two layers of a carbon fiber composite. Fig.3 shows cross-sectional stack-up of a 14 layer aramid PCB. Fig.4 shows equivalent cross-sectional stack-up of a 14 layer FR4 & Carbon composite PCB.

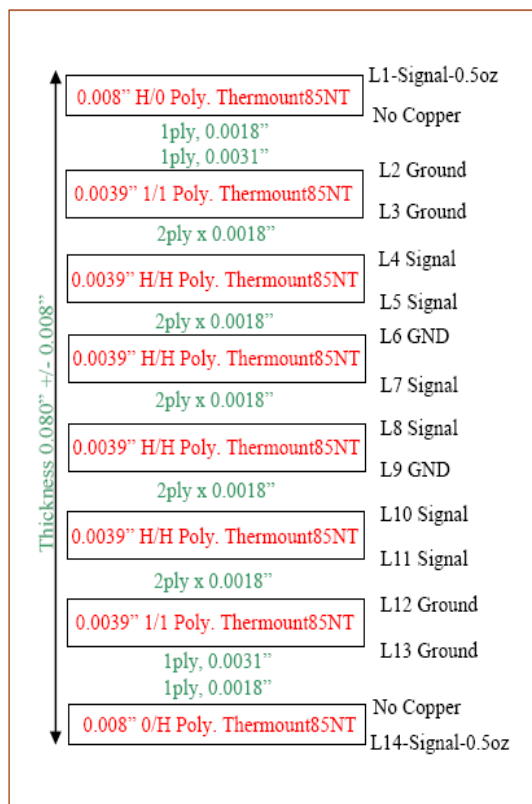


Fig. 3, 14-layer non-woven aramid PCB

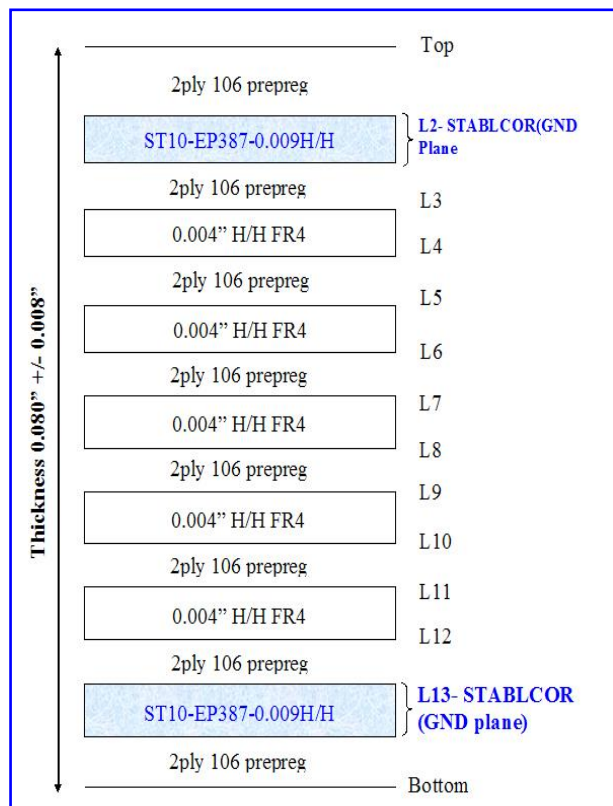


Fig. 4, 14-FR4 with two layers of carbon composite PCB

Fig.5 shows In-plane CTE of a 14 layer aramid PCB. As you can see, in-plane CTE ranges from 10.3 to 12.1 ppm/C from temperature -50°C to +150°C whereas the CTE of the same design manufactured with FR4 and two carbon composite layers measures 10.9 to 12.5 ppm/C from temperature -50°C to +150°C, Fig.6. As you can see CTE between two different material

set is very comparable. Thus, designers can use carbon composites within a multilayer printed circuit board to tailor the surface CTE. There are three main factors that affect the surface CTE. (1) volumetric ratio of the carbon composite versus rest of the material, (2) distance of the carbon composite layer from the surface and (3) type of the carbon composite.

In addition the FR4 hybrid PCB does not have the Z-axis expansion an aramid board has. The hybrid board is not as moisture sensitive as the aramid board. And the carbon composite makes the PCB thermally conductive and more rigid at higher temperature.

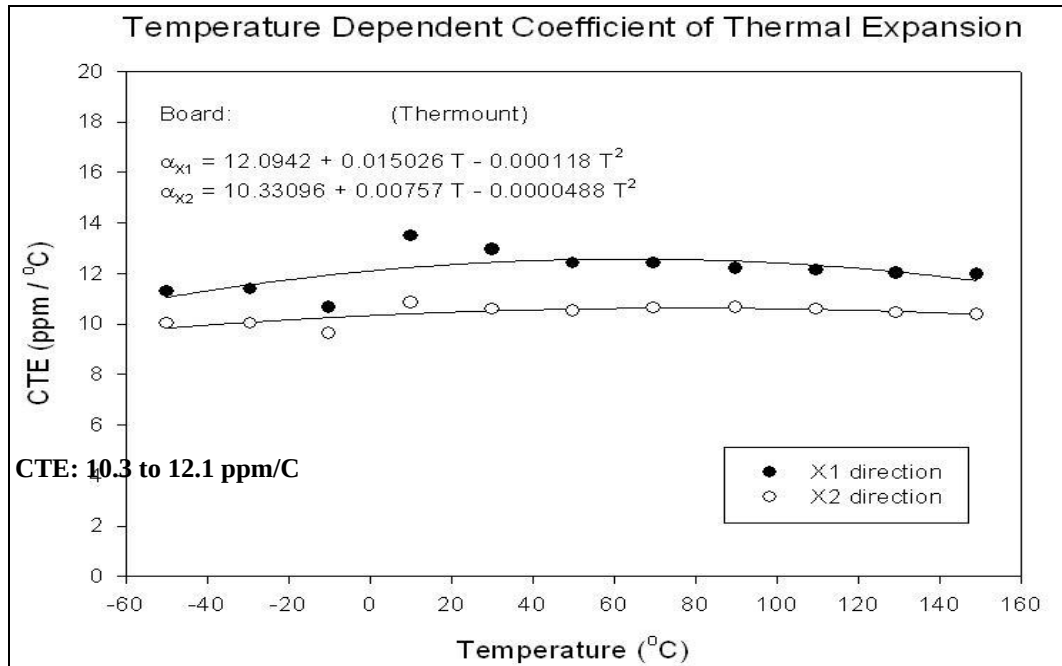


Fig. 5 In-Plane CTE graph of a 14-layer Thermount Printed Circuit Board

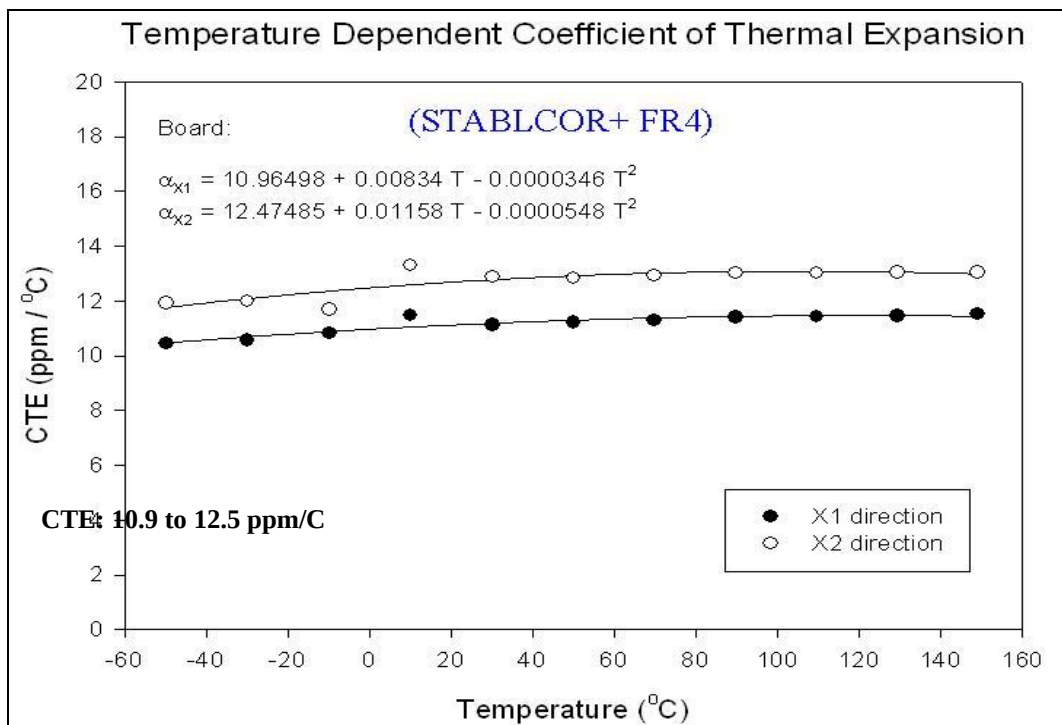


Fig. 6 In-Plane CTE graph of a 14-layer FR4+Carbon Composite Hybrid Printed Circuit Board

Tensile Modulus (Stiffness / Rigidity)

Tensile modulus of the carbon fiber ranges from 34-114msi (million pounds per square inch). The tensile modulus of the carbon composite ranges from 10-25msi whereas the tensile modulus of glass fiber is about 10-12msi and of glass composite 3.5-4.5msi. Thus carbon is a magnitude higher than glass composite material as shown in property chart of Table1. When carbon composites are embedded in an FR4 or Polyimide board, the stiffness increases up to 3 times depending on the volume and type of the carbon composite vs. the volume of the dielectric material in the board.

A study was done to measure stiffness improvement using two layers of a carbon composite layers within an 8-layer, 0.060” (1.52mm) thick printed circuit board. Fig. 7A, 7B and 7C shows cross-sectional stack-ups of the test samples. All samples were laminated at the same time and kept at constant 60mil thickness. A three point bend test was performed by Accolade Engineering Solutions (lab in Irvine). Deflection amount was kept constant to 10mm and different load were measured to achieve the pre-determined deflection. Deflection versus load on all three samples was measured and recorded as shown in Fig.7D and Table2. A 26% carbon composite volume showed a 154% stiffness improvement.

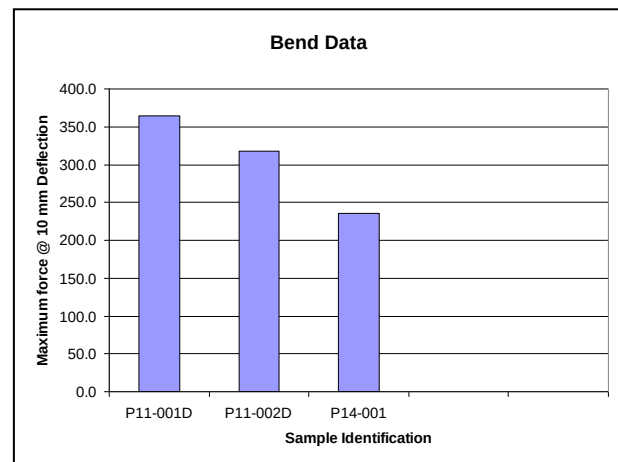
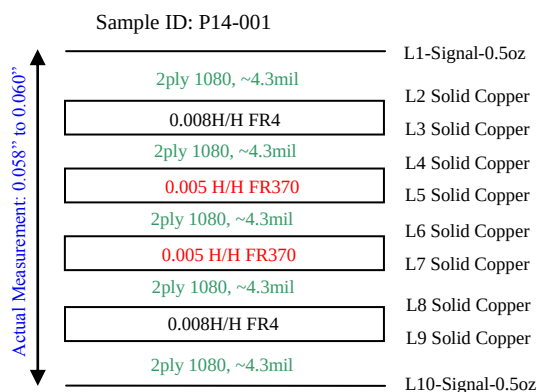
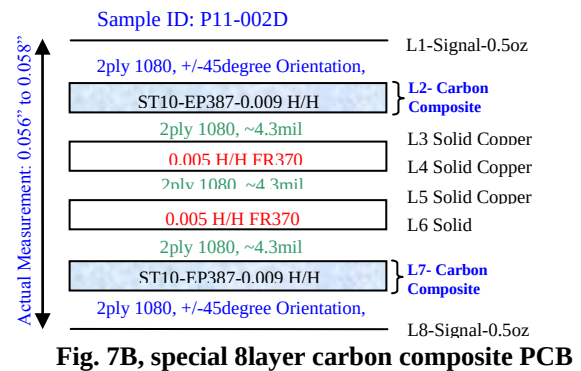
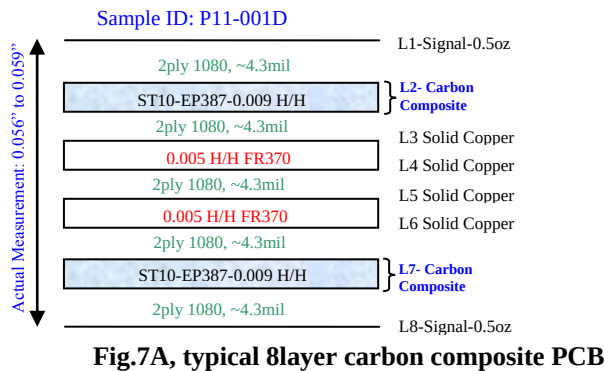


Table: 2, Stiffness Improvement data at 10mm constant deflection

Sample Identification	Maximum force @ 5mm (N)	Force(N)/mm	Stiffness Improvement (%)
P11-001D	363.9	37.6	154.2
P11-002D	317.9	31.69	134.7
P14-001	236.0	23.3	-

Density (Weight)

The density of the carbon fiber can range from 1.7 to 2.2 g/cc. When fiber is combined with resin the composite density can be range from 1.65 to 1.70g/cc. Density of other thermal management material such as copper (8.9g/cc) and CIC (9.9g/cc) are substantially heavier than the carbon composite. In space applications where weight adds a premium cost to the project the replacement of CIC or Heavy Copper is very attractive.

Stiffness to Weight Ratio

As can be seen from the property chart, Carbon composites deliver substantially higher stiffness to weight ratio compare to other thermal material. This increases substantially the shock and vibration reliability of the electronics. This could be advantageous for the mobile and aerospace electronics industries.

Further information can be found by visiting www.stablc.com or by calling (877) STABLCOR

NEW COMPOSITE MATERIAL CAN ADDRESS THERMAL & CTE MISMATCH CHALLENGES OF THE PCBs

**Presented at:
IPC Printed circuit Expo, Apex and Designers summit 2008**

**April 3-2008, Las Vegas
Speaker: Kris Vasoya, Chief Technology Officer
STABLCOR Inc.**

Outline

- ✧ **Electronics Challenges**
- ✧ **Today's Material and it's limitations**
- ✧ **Comparisons of thermal management technologies**
- ✧ **Material that can address Thermal, CTE, Stiffness and Weight challenges – Carbon Composite**
- ✧ **How to use Carbon Composite in a PCB**
- ✧ **Benefits of the Carbon Composite in a PCB**
- ✧ **Test Data / Case studies**
- ✧ **Design Guidelines**
- ✧ **Conclusion**

Challenges of the Electronics

The electronics Industry today is facing challenges such
as

HOT SPOT

CTE mismatch,

solder joint stress,

thermal fatigue failure

shock and vibration issues,

“SMALLER, FASTER, STRONGER”

PCB material & It's limitations (Dielectric)

DIELECTRIC MATERIAL	Thermal Conductivity (W/m.K)	IN-PLANE CTE (ppm/C)	Tensile Modulus (Msi)	Density (g/cc)
FR-4/E-glass	0.3 to 0.4	16 to 20	3.5 to 4.5	1.6-1.8
Polyimide/E-glass	0.2 to 0.4	15 to 19	3.5 to 4.5	1.5-1.7
Aramid/Epoxy	0.2 to 0.3	9 to 12	2 to 2.1	1.25-1.3
PTFE Ceramic (RO3000)	0.5 to 0.66	17	0.30	2.1-3.0
Non-PTFE Ceramic (R4000)	0.6 to 0.65	12 to 16	1.6 to 3.9	1.8-1.86

Current Material & It's limitations

- ❖ **ELECTRICAL Property- Very Good**
- ❖ **THERMAL Property – Poor**
- ❖ **MECHANICAL Property – Poor**
 - ❖ **Rigidity**
 - ❖ **Co-efficient of Thermal Expansion (CTE)**

Thermal Management Technologies

❖ Ceramic (DBC)

- ❖ Aluminum Oxide (Al_2O_3) – 24W/m.K, CTE 7.5ppm/C
- ❖ Aluminum Nitride (AlN) – 180W/m.K, CTE 4.1ppm/C
- ❖ Beryllium Oxide (BeO) – 260W/m.K, CTE 8.5ppm/C

❖ Pros

- ❖ Good Thermal Conductivity
- ❖ Good for High Power Chip
- ❖ Low CTE

❖ Cons

- ❖ Very Brittle material
- ❖ Very difficult to process
- ❖ Very small panel size (5"x7")
- ❖ Limited to Single sided PCB
- ❖ Limited to low density PCB
- ❖ smallest feature 20/15mil L/S

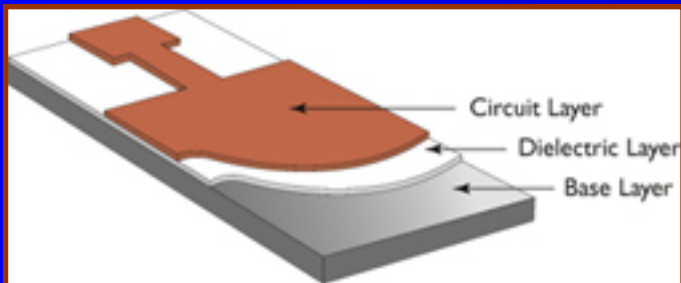
Thermal Management Technologies

❖ Insulated Metal Substrate (IMS)

- ❖ Thermal Clad (Bergquist) – Base metal 0.031” to 0.250”
- ❖ T-Lam / T-Preg – Base metal Aluminum or Copper, 0.031” to 0.250”

❖ Pros

- ❖ Good for single and double sided PCB



❖ Cons

- ❖ Can not have components on both sides
- ❖ less effective for multilayer
- ❖ Very heavy & Bulky to handle

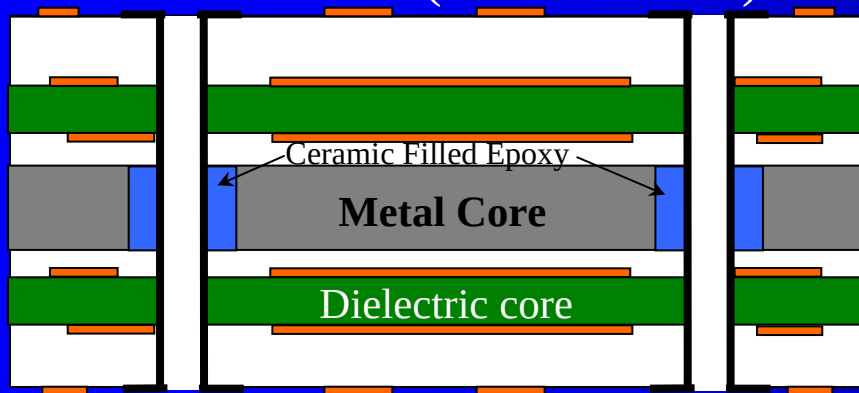
Thermal Management Technologies

❖ Thick Metal & Metal Alloys

- ❖ Copper-Invar-Copper (CIC) – 30W/m.K, 5-6 CTE ppm/C
- ❖ Copper-Moly-Copper (CMC) – 180-220W/m.K, 6-8CTE ppm/C
- ❖ Thick Copper (Cu) – 385W/m.K, CTE 17-20ppm/C

❖ Pros

- ❖ Good Thermal Conductivity
- ❖ Good for High Power Chip
- ❖ Low CTE (some material)



❖ Cons

- ❖ Heavy
- ❖ Higher CTE (some cases)
- ❖ Less effective for HDI PCB
- ❖ Limited to low layer count
- ❖ Limited to low density PCB
- ❖ Higher weight/stiffness ratio

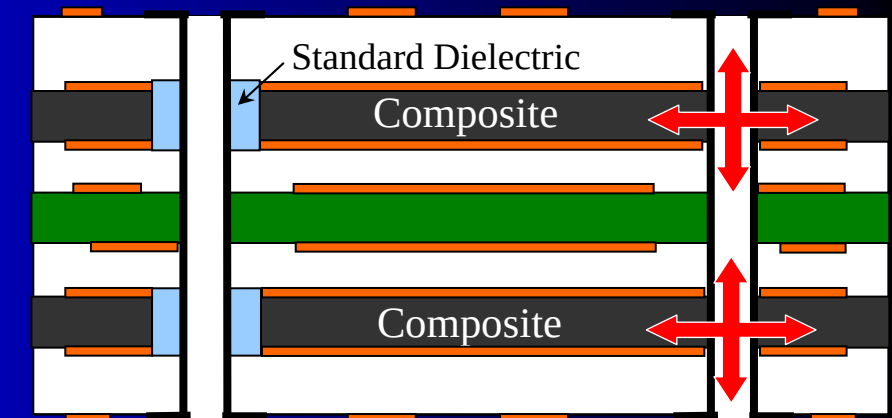
Thermal Management Technologies

❖ Carbon Composite in a PCB

- ❖ 75-175W/m.K, CTE ~2to6 ppm/C
- ❖ Density 1.70g/cc (Weight)
- ❖ Tensile Modulus 10-25msi

❖ Pros

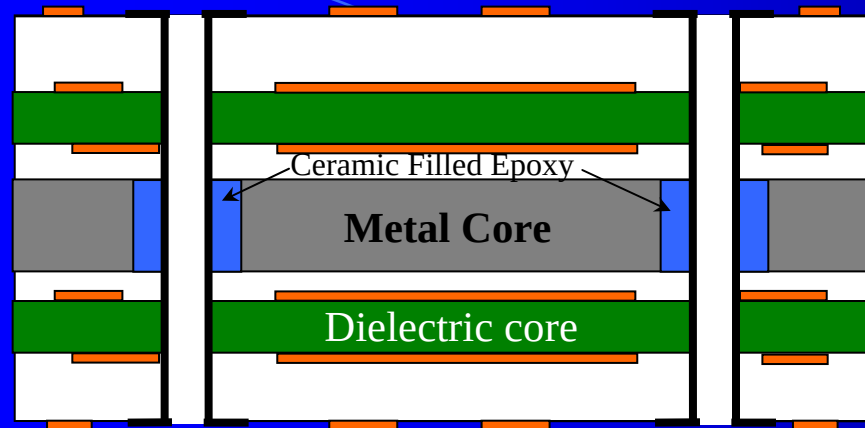
- ❖ Good lateral Thermal Conductivity
- ❖ Less Thermal Resistance
- ❖ Can be used in HDI
- ❖ Low In-plane CTE
- ❖ no weight penalty over FR4
- ❖ Higher stiffness/weight ratio



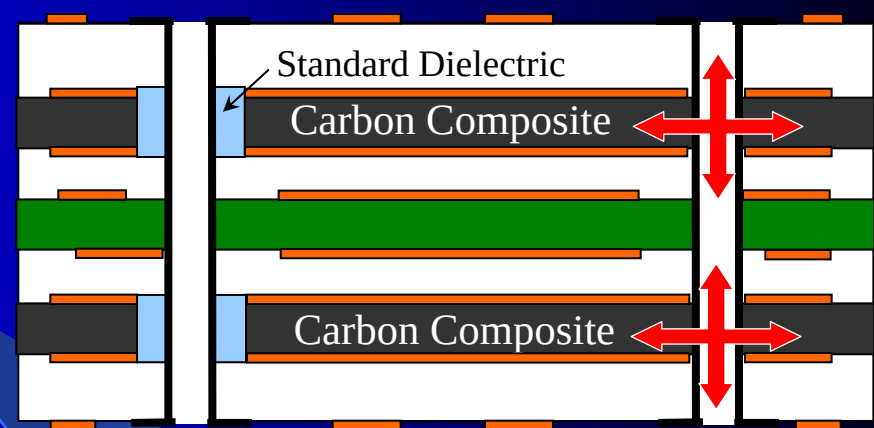
❖ Cons

- ❖ New material in the market
- ❖ It is an electrically conductive
- ❖ In some cases it adds thickness to the finished PCB
- ❖ Carbon remains exposed at the edges of the PCB

Metal Core Construction



STABLCOR Construction



❖ Limitations using metal core

- ❖ Heavy weight
- ❖ High thermal resistance
- ❖ can not be used in HDI designs effectively
- ❖ difficult to drill small PTH
- ❖ Requires special filling

❖ Benefits over metal core

- ❖ Light weight
- ❖ less thermal resistance
- ❖ can be used in HDI designs
- ❖ Does not require additional lamination
- ❖ directional heat transfer

Property Comparison at Fiber level

Properties	Glass Fiber	Carbon Fiber
Thermal Conductivity (W/m.k)	0.3 to 0.4	8 to 325
Tensile Modulus (msi)	10 to 12	34 to 114
CTE (ppm/C)	5 to 6	-0.5 to -1.15
Density (g/cc)	2.4 to 2.5	1.76 to 2.2
Dielectric constant (Dk)	4.3	13+
	Dielectric material	Electrically Conductive

Carbon Composite Material Property

COPPER CLAD CARBON COMPOSITE

Thermal, Low CTE, Stiff and Light Weight Material

E.CONDUCTIVE MATERIAL	Thermal Conductivity (W/m.K)	CTE (ppm/C)	Tensile Modulus (Msi)	Density (g/cc)
FR-4/E-glass	0.3 to 0.4	16 to 20	3.5 to 4.5	1.6-1.8
Polyimide/E-glass	0.2 to 0.4	15 to 19	3.5 to 4.5	1.5-1.7
Low Modulus Carbon Fiber	8 to 12	-0.41	30 to 35	1.7 to 1.8
High Modulus Carbon Fiber	300-325	-1.5	100 to 114	2.1 to 2.2
Carbon Composite-Unclad (XY)	ST10~ 2* ST325~82*	ST10~4.5to6 ST325~1to3	ST10~ 9 ST325~ 24	1.6 to 1.65
Carbon Composite-with 1oz Cu clad (XY)	ST10~ 75* ST325~175*	ST10~5to7 ST325~2to4	ST10~ 10 ST325~ 25	1.65 to 1.7

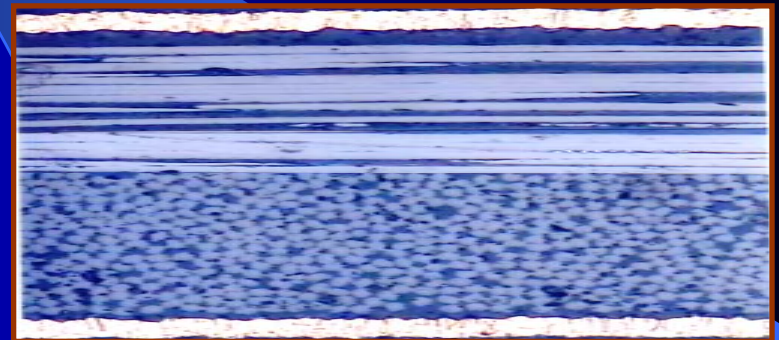
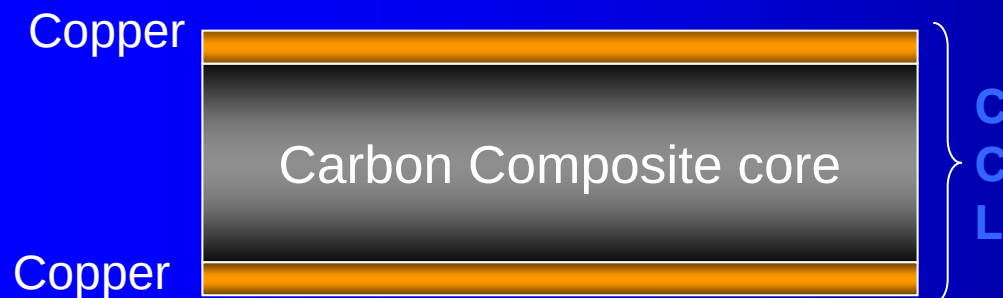
* Theoretical calculated In-Plane values based on volume & Thermal conductivity of the composite materials

Thermal & Thermo-mechanical material

Carbon Composite Material can address THERMAL, CTE, RIGIDITY and WEIGHT Challenges in Printed Circuit Boards and Substrate

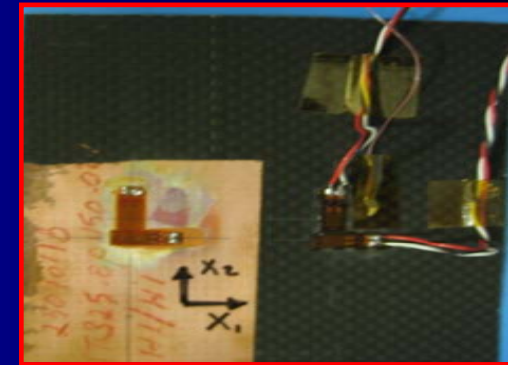
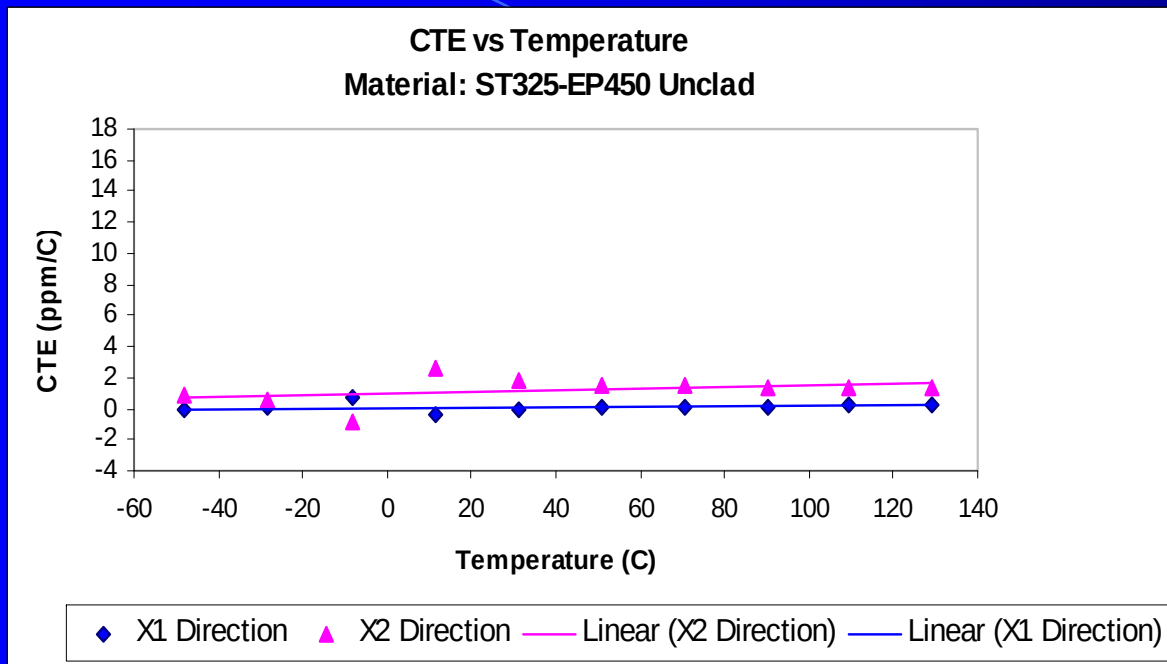
What is Carbon Composite Material?

- ❖ **It is a Carbon fiber-resin matrix**
- ❖ **A thermally & Electrically Conductive Composite Material**
 - ❑ It has very good In-plane Thermal Conductivity
 - ❑ It has low In-plane CTE (3-6 ppm/C)
 - ❑ It can be used as a plane layer, Preferably GND plane



CTE – Carbon Composite Material

❖ In-Plane CTE

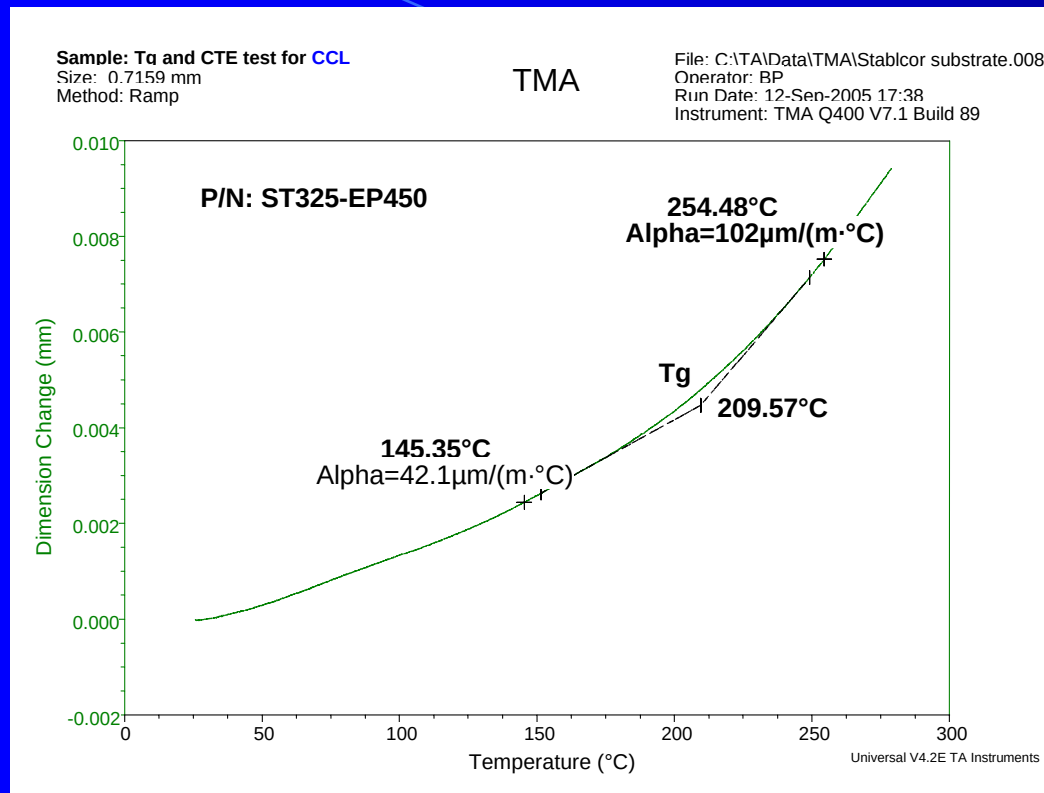


DIELECTRIC MATERIAL	In Plane CTE (ppm/C)
FR-4 / E-glass	16 to 20
Polyimide/E-glass	15 to 19
Non Woven Aramid/Epoxy	9 to 12
PTFE Ceramic (RO3000)	17.00
Non-PTFE Ceramic (RO4000)	12 to 16

Composite CTE (0-3 ppm) over
Temp. range of -50C to +130C

CTE – Carbon Composite Material

Through Plane CTE



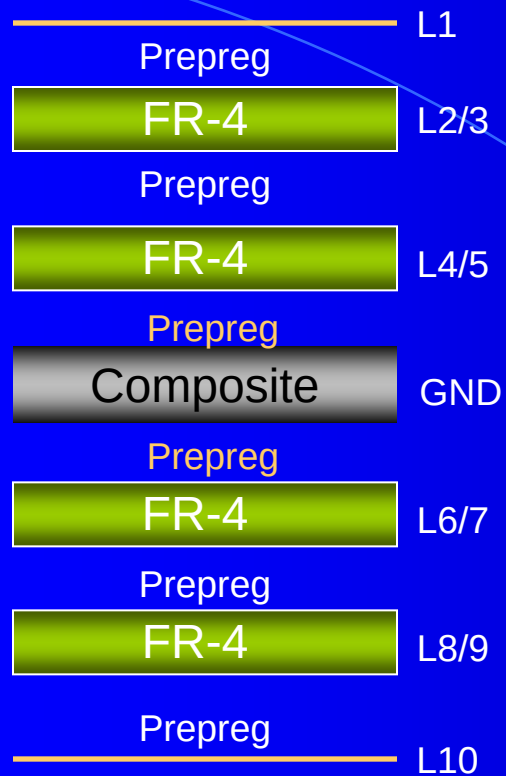
Z-axis CTE measurement by TMA method

Run number	Z-CTE before Tg (ppm/°C)	Tg (°C)
1	42.1	209.57
2	34.8	201.87

DIELECTRIC MATERIAL	Through Plane CTE (ppm/C)
FR-4/E-glass	55 to 60
Polyimide/E-glass	50 to 55
Non Woven Aramid/Epoxy	110 to 120
PTFE Ceramic (RO3000)	25 to 40
Non-PTFE Ceramic (RO4000)	50 to 55

How is Composite used in a PCB?

(<0.035") PCB/Substrate



1-CORE

(<0.093") PCB



2-CORE

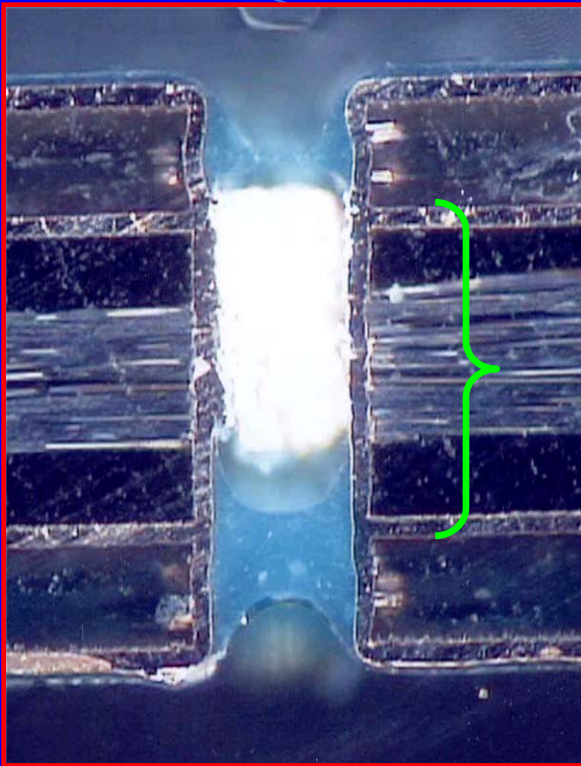
(>0.093") PCB



3-CORE

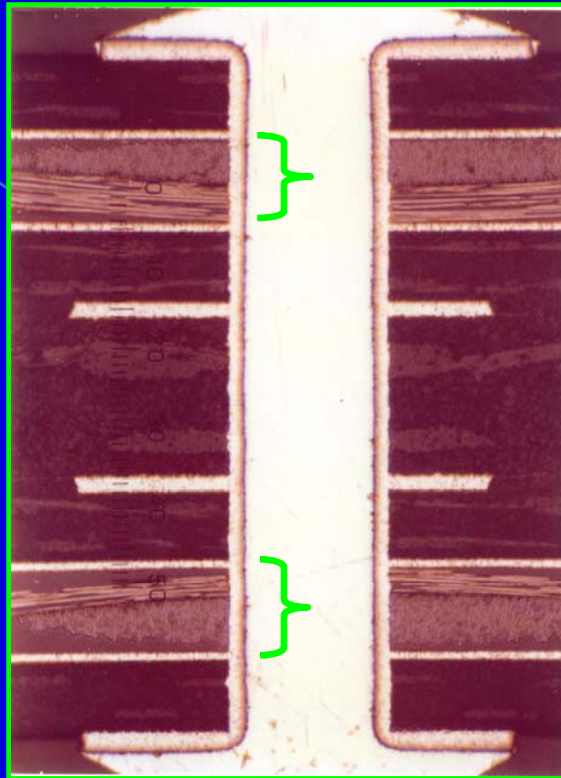
CROSS SECTIONS

3-layer PCB



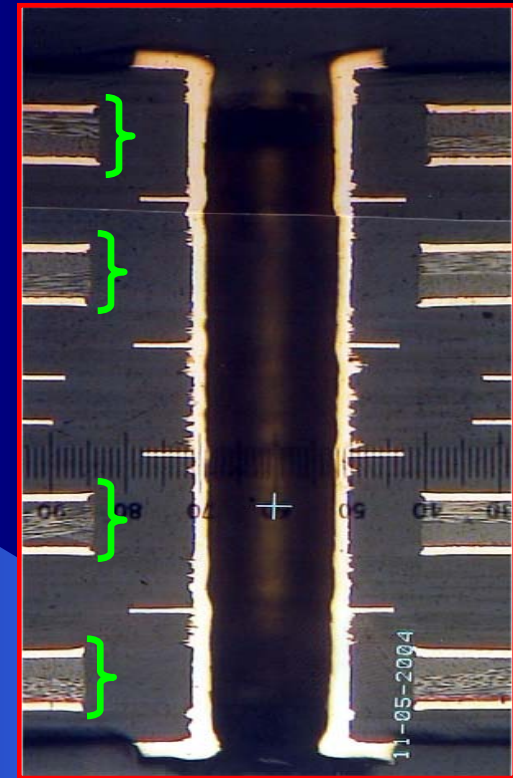
1-CORE

6-layer PCB



2-CORE

12-layer PCB



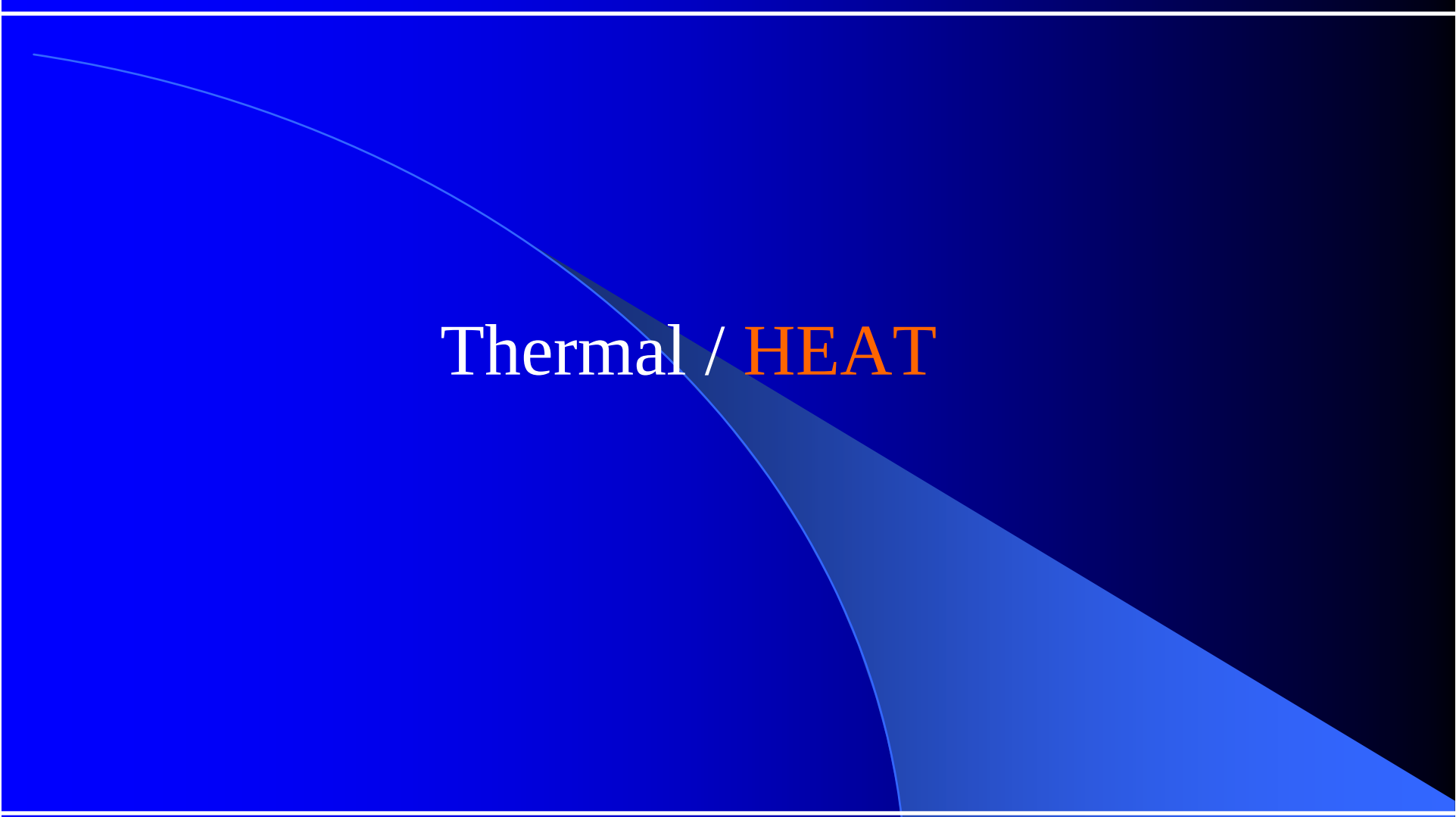
4-CORE

The Benefits Of Composite in a PCB / Substrate

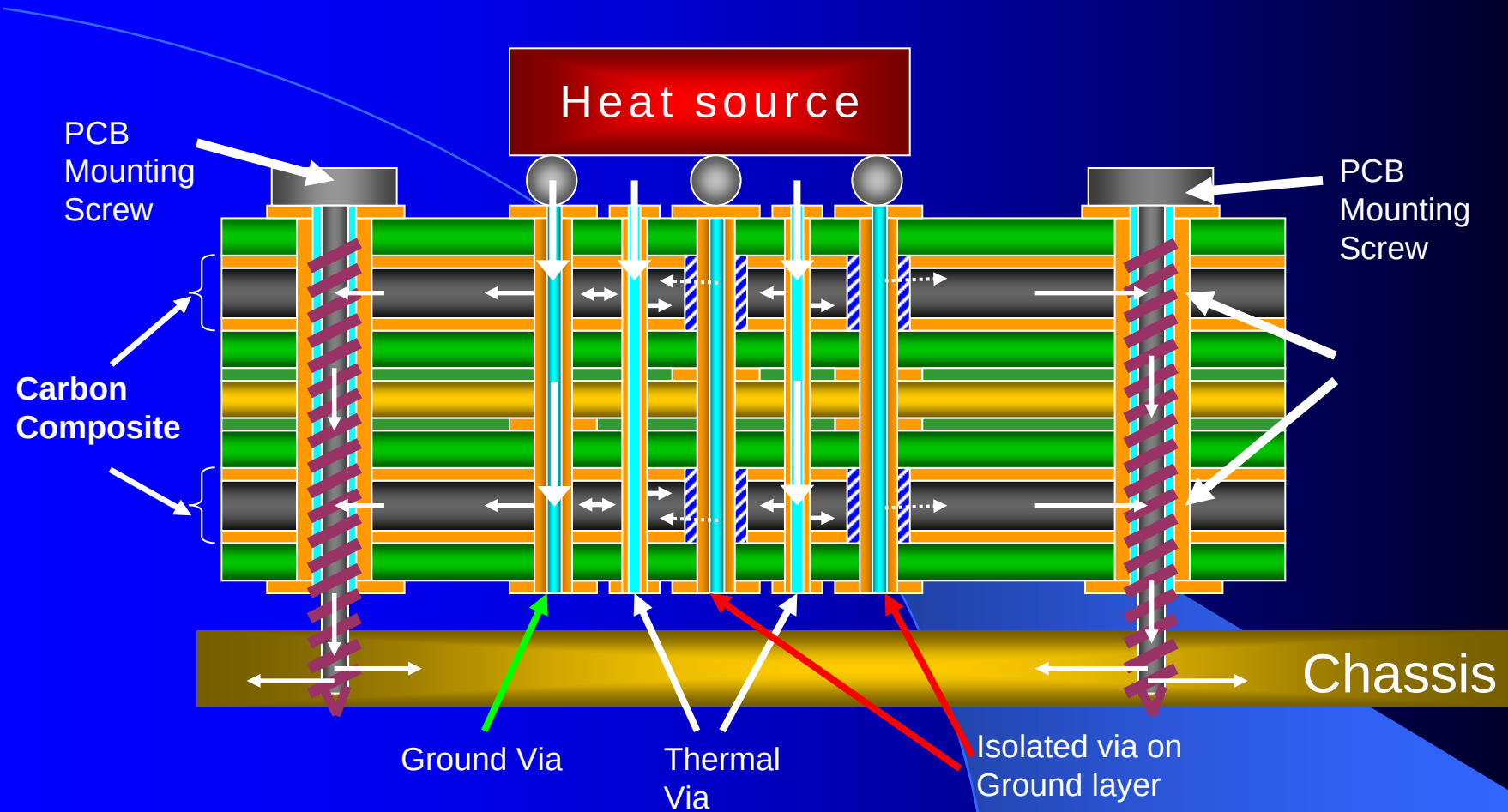
- ❖ Thermal
- ❖ CTE (Co-efficient of Thermal Expansion)
- ❖ Rigidity / Stiffness
- ❖ Density / Weight

CARBON IN A PCB

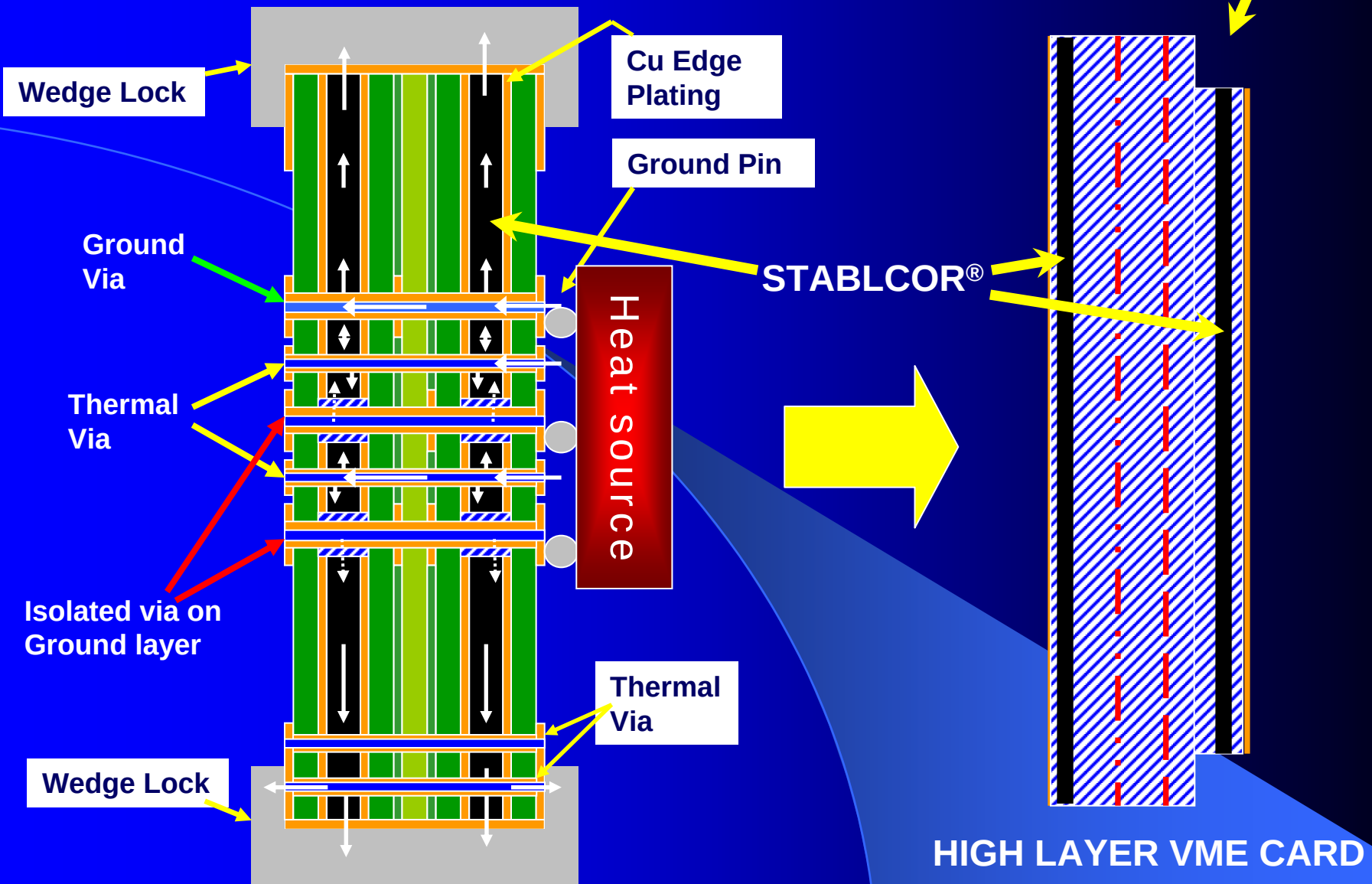
Thermal / HEAT



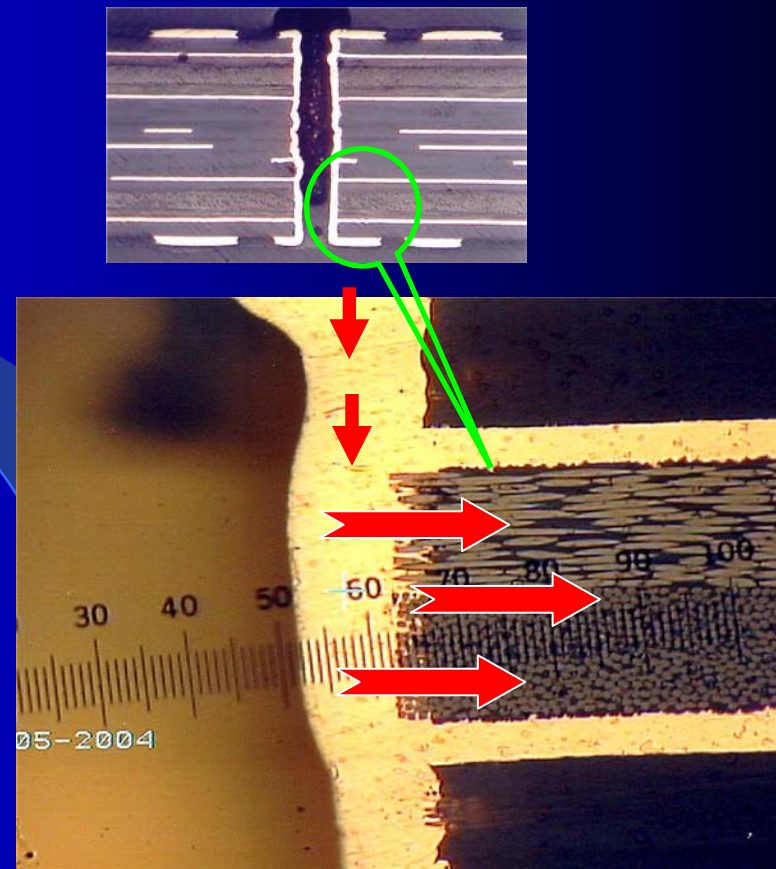
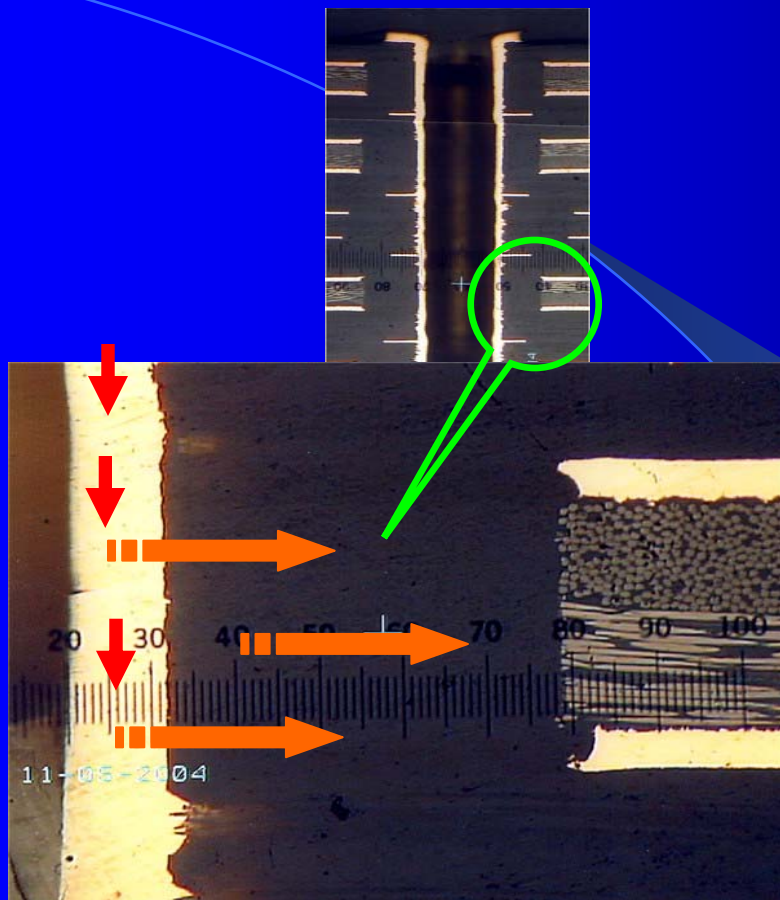
PCB Thermal Path - Schematic



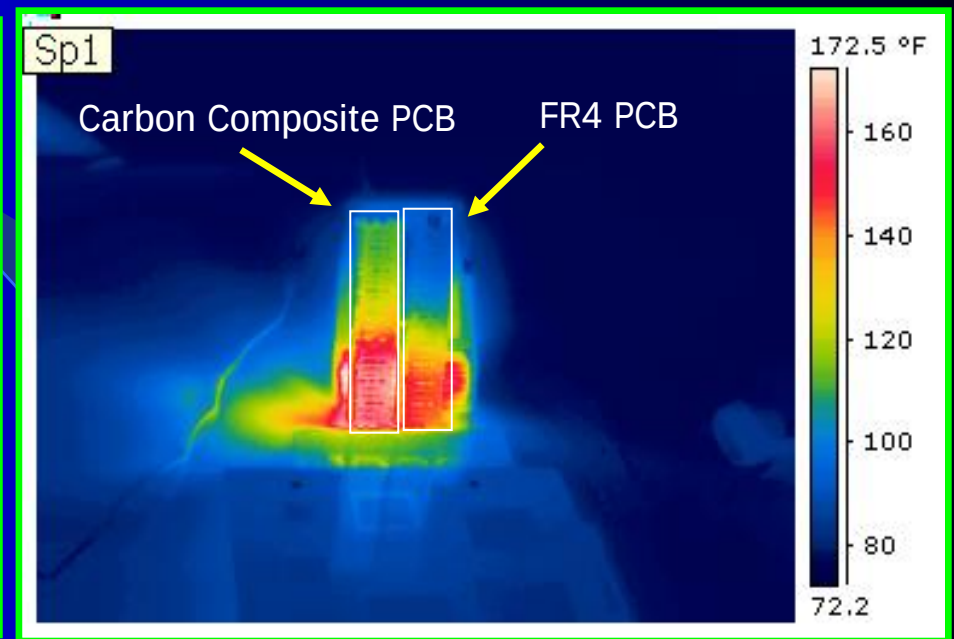
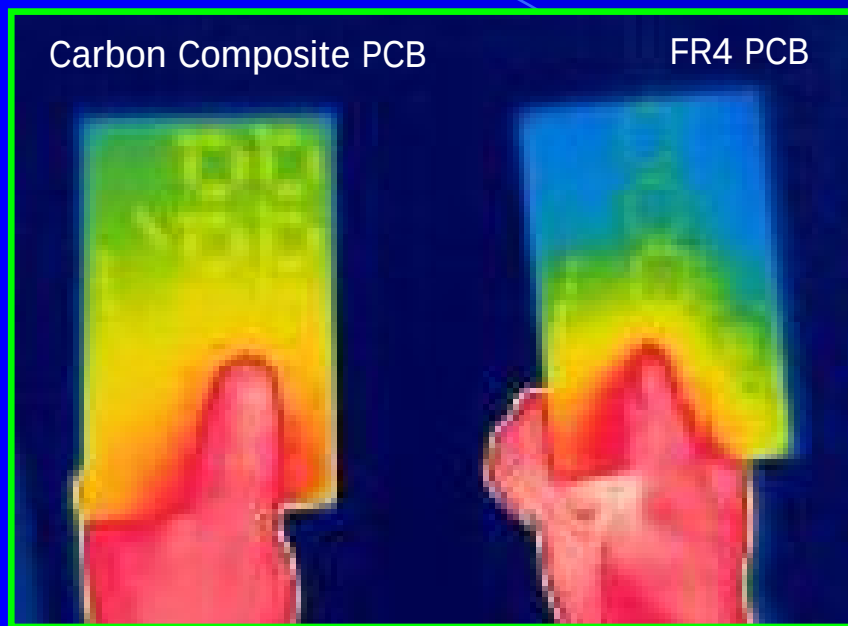
VME - Wedge Lock



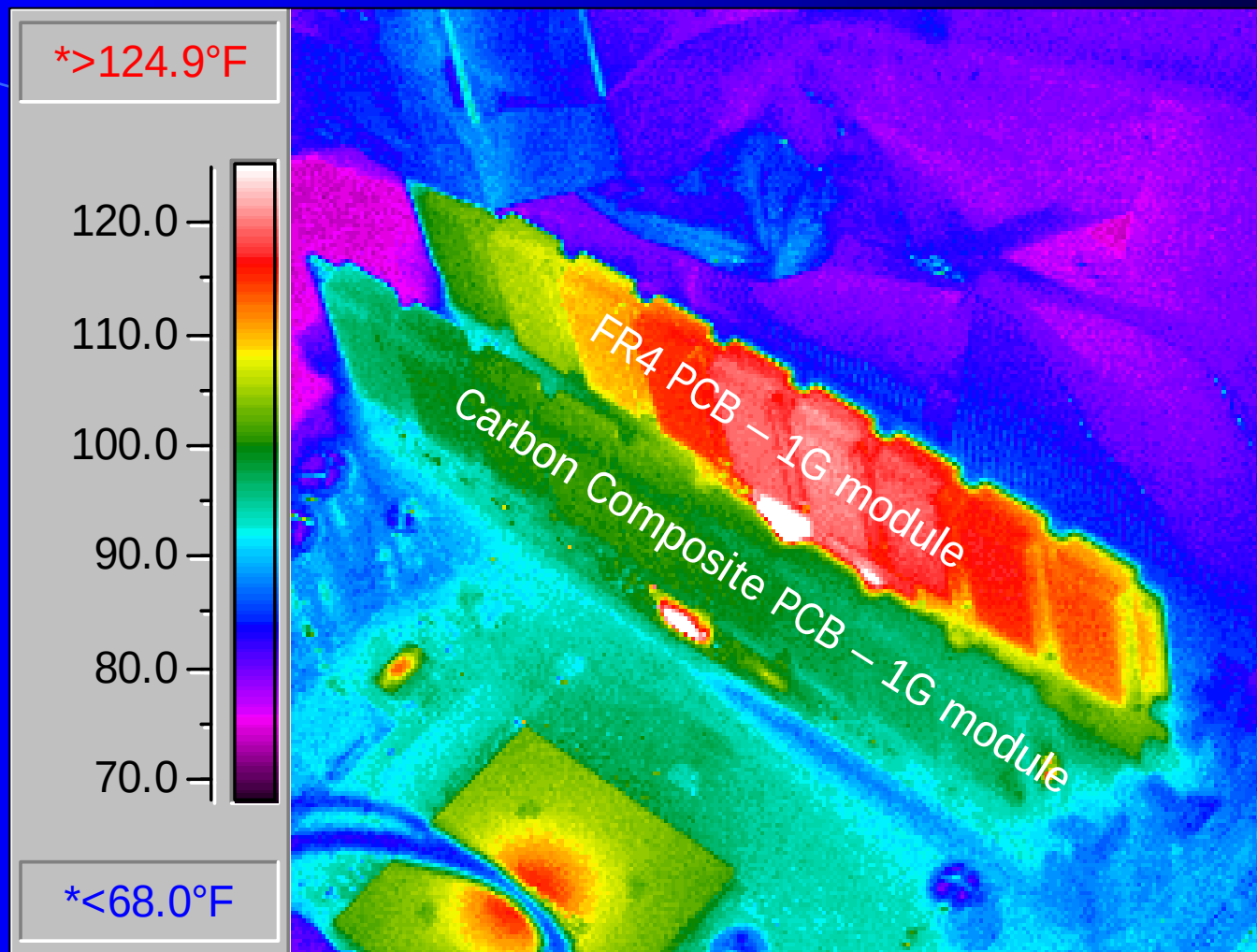
THERMAL PATH



PCB acts as HEAT SPREADER



THERMAL – PRODUCT LEVEL



THERMAL SIMULATION SOFTWARE

Material is listed in these software library

1. Ansys Inc. (TAS PCB Software)

David Rosato

Ph: (978) 772-3800

David.rosato@ansys.com

Canonsburg, PA 15317

2. Fluent Inc. (Icepak Software)

Dan Scharpf

Ph: (603) 643-2600 x 617

dfs@fluent.com

New Hampshire 03766

3. Flomerics (Flotherm Software)

Sherman Ikemoto

Ph: (512) 420-9273 x 203

Sherman.Ikemoto@flowmerics.com

Vista, California 92083

CARBON IN A PCB

Co-efficient of Thermal Expansion

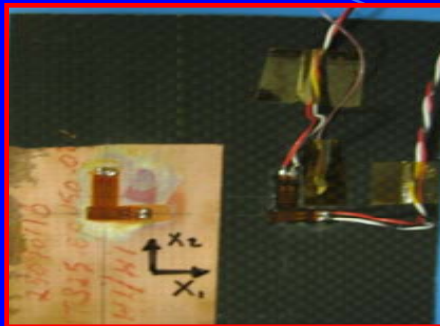
CTE Associated with Package Type

❖ IC PACKAGE TYPE

- ❖ Organic Packages (CTE: 16-19ppm/C)
- ❖ Ceramic Packages (CTE: 6-8ppm/C)
- ❖ Flip Chip, DDA, WLP (2-4ppm/C)



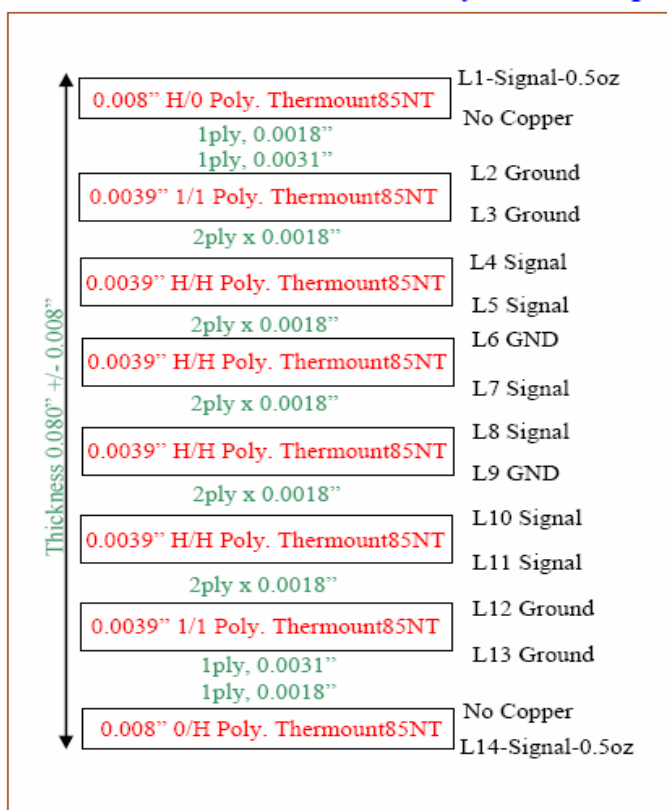
CTE – Carbon Composite Material



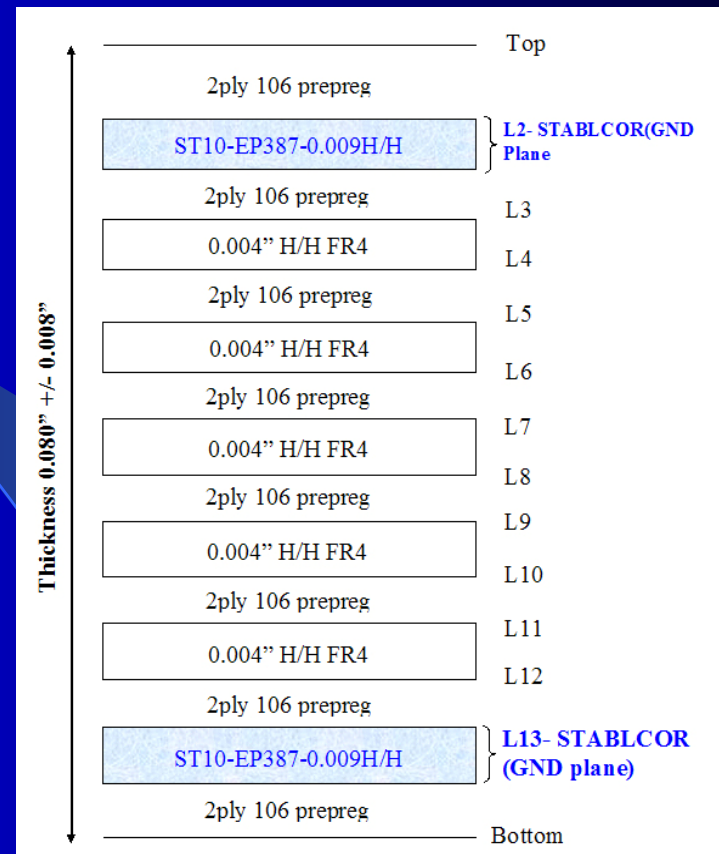
Sample	CTE, α_x ($\times 10^{-6} 1/^{\circ}\text{C}$)	CTE, α_y ($\times 10^{-6} 1/^{\circ}\text{C}$)
ST10-EP387-0.006 0/0	4.88	6.28
ST10-EP387-0.009 0/0	5.85	6.48
ST325-EP387-0.008 0/0	0.25	1.8
ST325-EP387-0.010 0/0	0.91	1.6

Thermount vs. Carbon Composite PCB CTE

85NT THERMOUNT PCB Layer Stack-up



14-Layer, 80mil Thick, 85NT Thermount PCB

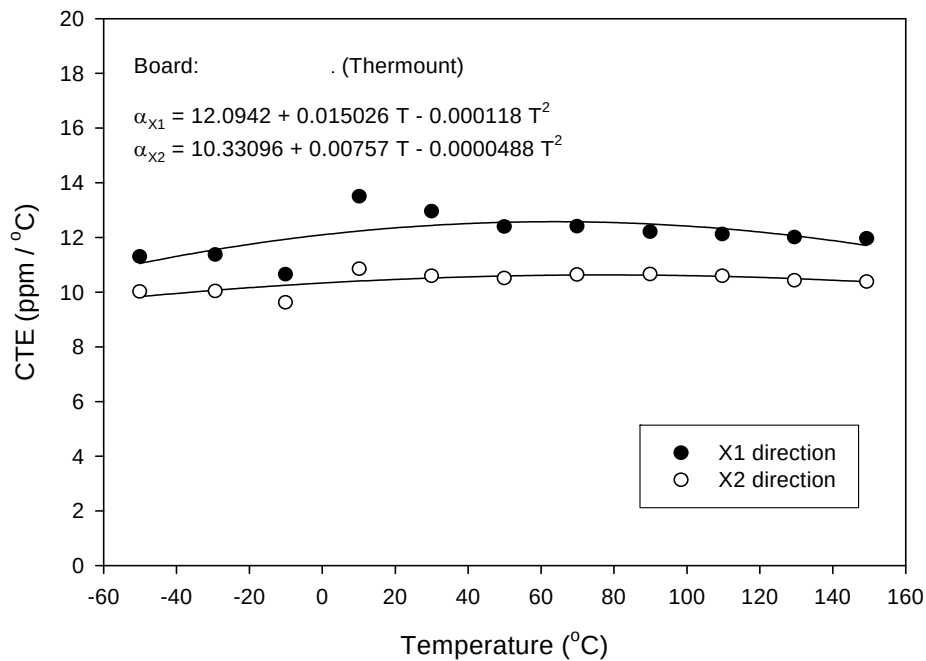


14-Layer, 80mil Thick, FR4+Composite PCB

Thermount vs. Carbon Composite PCB CTE

14-Layer, 80mil Thick, 85NT Thermount PCB

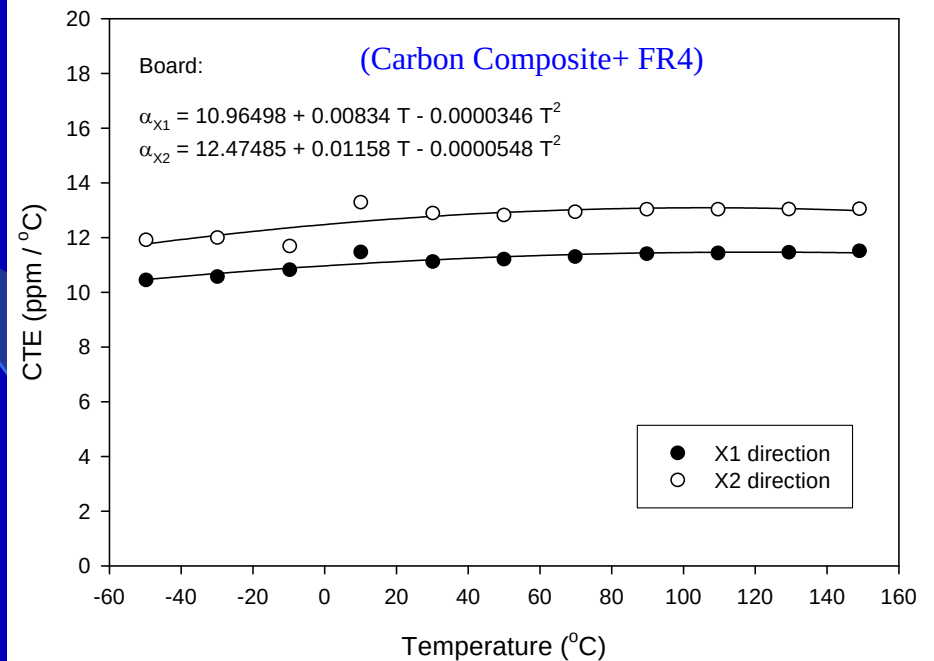
Temperature Dependent Coefficient of Thermal Expansion



10.3 to 12.1ppm/C

14-Layer, 80mil Thick, FR4+Composite PCB

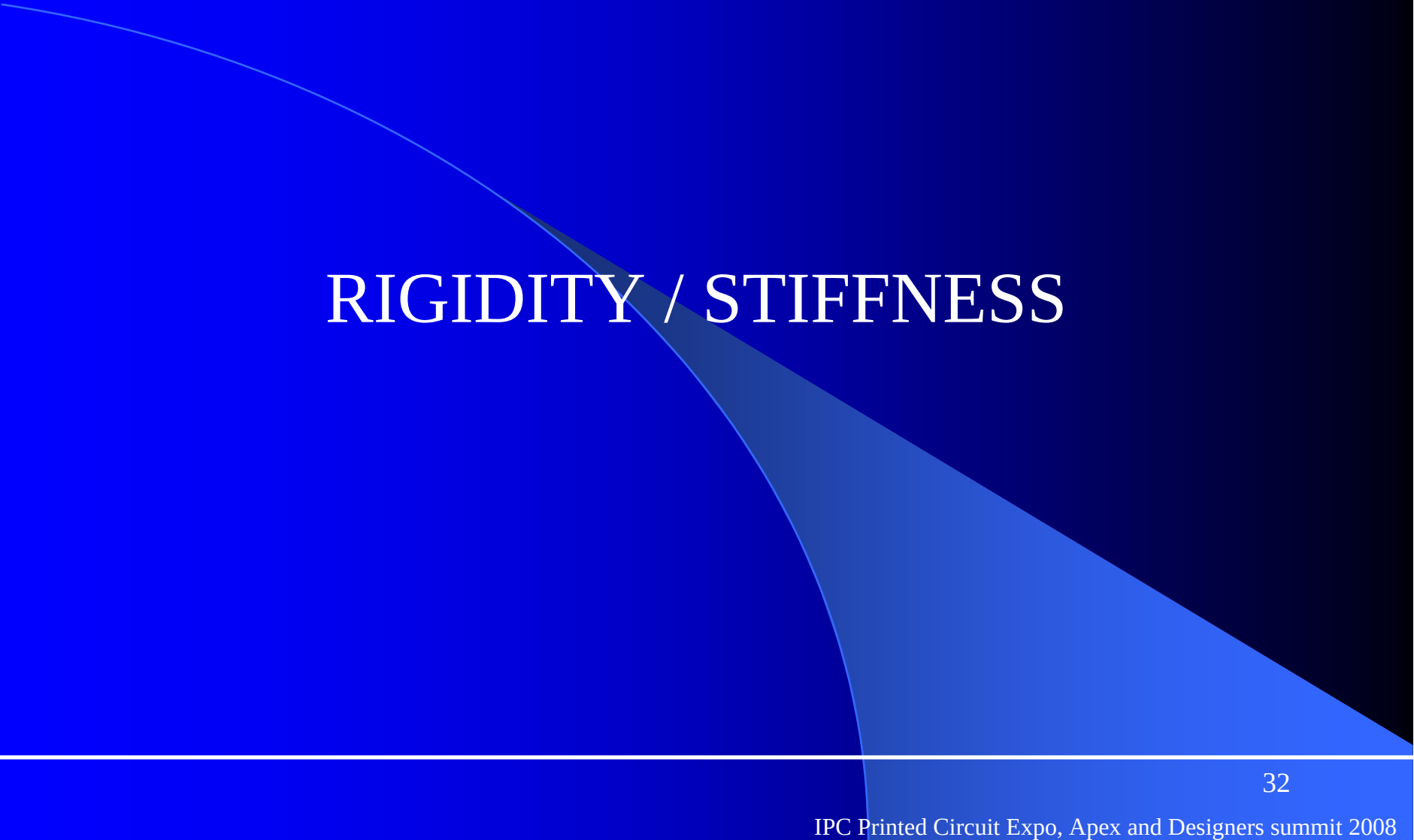
Temperature Dependent Coefficient of Thermal Expansion



10.9 to 12.4ppm/C

CARBON IN A PCB

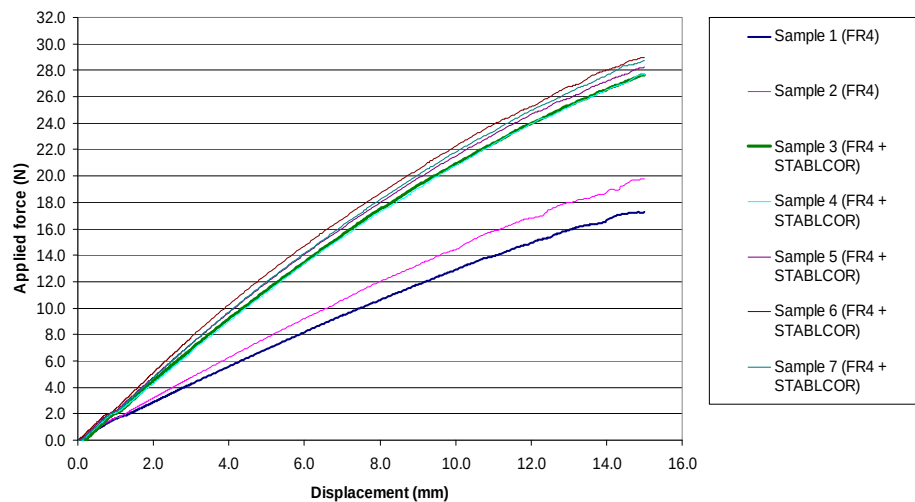
RIGIDITY / STIFFNESS



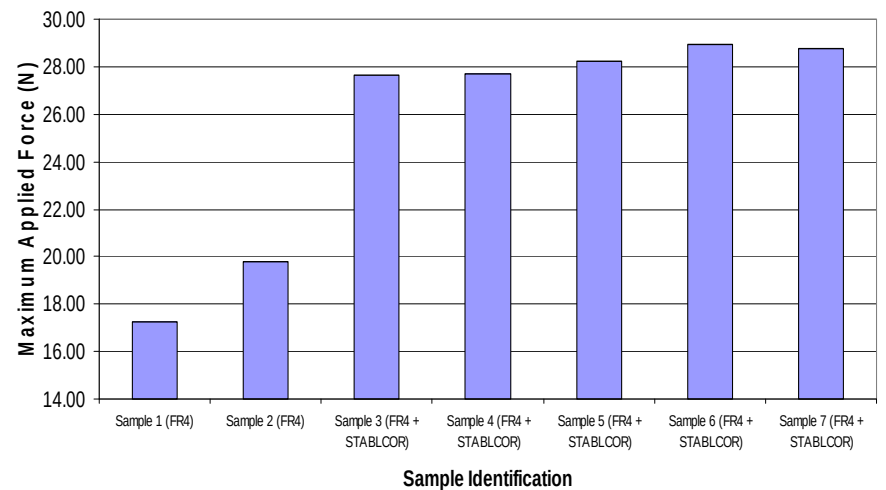
Rigidity / Stiffness

❖ Rigidity of Composite PCB v/s FR4 PCB at Room Temp

Printed Wiring Board Bend Data



Maximum Force at 15mm Deflection



This result shows the Carbon Composite PCB is ~ **66.6 %** stiffer than the FR4 test samples

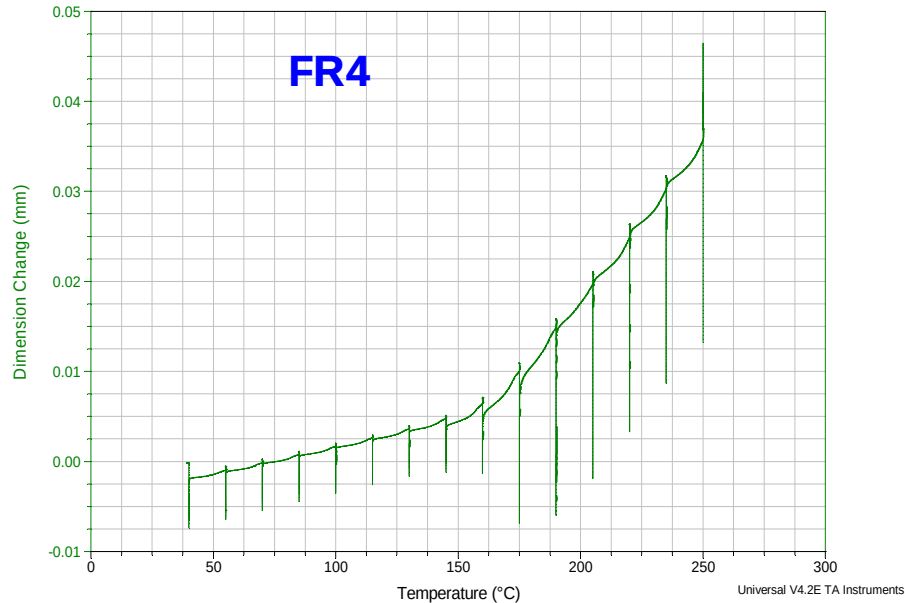
Rigidity / Stiffness

❖ Bend Test Over Temperature Range (40°C to 250°C)

Sample: PCB
Size: 3.0000 mm
Method: Force Ramp
Comment: Bend Test at various temperatures

TMA

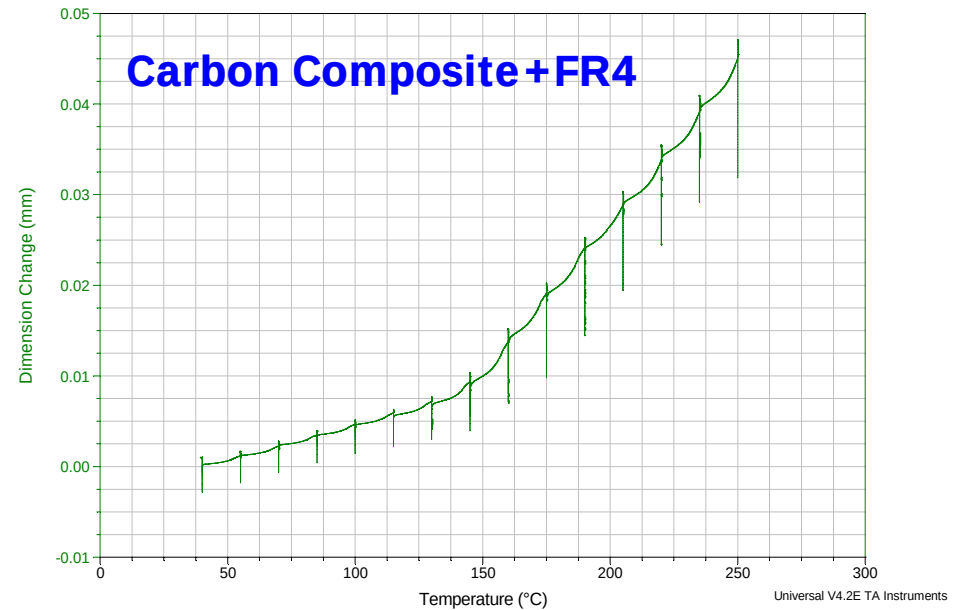
File: C:\TAData\TMA\3 pt bend VLP FR4.003
Operator: BP
Run Date: 07-Sep-2005 23:19
Instrument: TMA Q400 V7.1 Build 89



Sample: PCB
Size: 3.0000 mm
Method: Force Ramp
Comment: Bend Test at various temperatures

TMA

File: C:\...TMA\3 pt bend VLP Stablcor.002
Operator: BP
Run Date: 06-Sep-2005 19:55
Instrument: TMA Q400 V7.1 Build 89



Length of vertical lines represent the amount of Deflection

WEIGHT

Material (Laminate)	Density gm/cm3
FR4	1.80
Polyimide	1.70
Carbon Composite (w/o Cu)	1.65
Aluminum	2.7
Copper	8.92
Copper Invar Copper	9.9

Current Supply Chain

Factory: Millbury, Massachusetts, USA



54,000 sq.ft facility

Lewcott / Carbon Core
Laminates (Composite material
manufacturer / Distributor)

Qualified PCB Manufacturer

- Dynamic Details Inc
- Hunter Technologies
- North Texas Circuit Board
- Murrietta Circuits
- Winonics
- Cosmotronic
- Cirtech
- Unicircuit
- Harbor Electronics / ECT
- TTM Technologies
- ** ELTEK - Israel
- ** CIREP – France
- ** Stevenage Circuit - UK
- ** Graphic PLC - UK

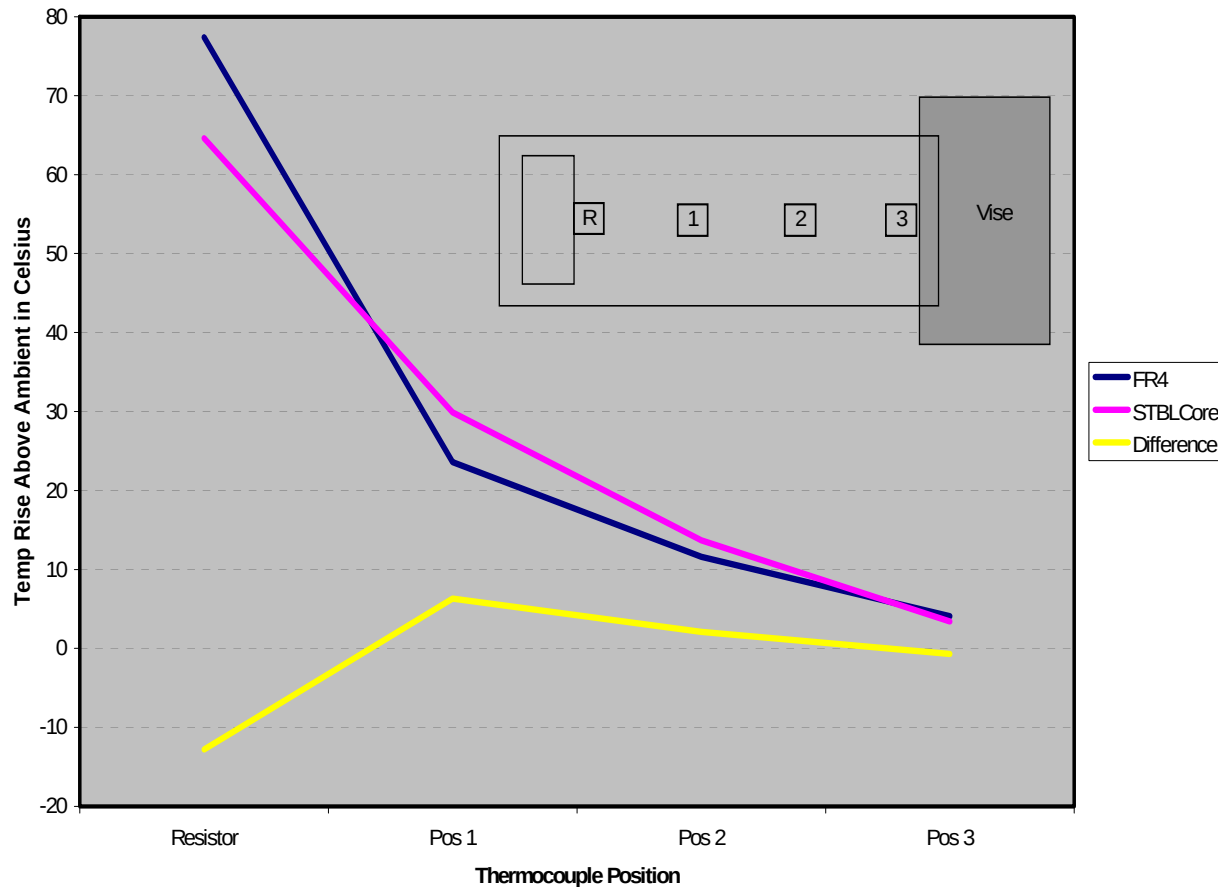
End User / CUSTOMER

CASE STUDY

CASE STUDY

CASE STUDY - THERMAL

Heat Dissipation of PWB Materials with End Clamped in Vise



The superior thermal conductivity is evident from the reduced temperature at the resistor. The power resistor was set up to heat up to about 100°C (ambient was about 24°C during the test), which required slightly over 6W into the resistor. Keeping the resistor power constant, **the COMPOSITE material lowered the resistor temperature by 12.8°C**. The thermal resistivity of the resistor to ambient was **12.6°C/W with the FR-4** and **10.6°C/W with the COMPOSITE** indicating a **2.0W or 19% improvement in power handling capability** with this configuration.

CASE STUDY

JPL Study for Multifunctional Spacecraft Structure

Multi-Functional Spacecraft Structures Using Advanced Printed Wiring Board Materials

Principal Investigator: Donald Schatzel, Section 374
Kevin Watson, Section 345, Carissa Tudryn, 374, Donald Hunter, 374



Inside View



Cross-Section of a Board
with 4-Layers of CCL



Outside/Side View

Base Length = 10"

Benefits to NASA and JPL :

- Significant mass and volume reduction is attained by incorporating electrical signal paths into the mechanical structure.
- Reduced risk due to more efficient integrated thermal paths.
- Favorable material properties that exhibit low thermal coefficient of expansion that will increase mission life in extreme environments.
- Major reduction in cable and connector mass.
- Enhanced material properties for existing flight circuit board applications.



Engineering Model next
to Rover Camera Mast

Project Objectives:

- Develop and demonstrate a low mass electromechanical integrated spacecraft sub-system that incorporates functional electronics within the sub-systems structural elements.
- Leverage advanced printed circuit board lamination technology into the design and fabrication of structural geometries.
- Design, fabricate and assemble simple structural elements & incorporate electronic circuitry (traces, vias) with pad geometries to allow placement of discrete devices, micro Ball Grid Arrays and Chip-On-Board devices.
- Leverage the inherent material strength properties of a carbon core laminate (CCL) weave.
- Compare the strength and stiffness of test articles with CCL to metallic structures.
- Demonstrate electrical functionality of test articles with CCL under load.

FUTURE APPLICATIONS:



Rover Camera

Multifunctional Spacecraft
Structure Rover Camera



Micro-Satellite



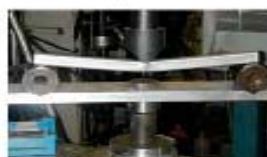
Payload Instruments



CCL 3-pt Bend Test



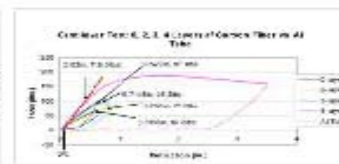
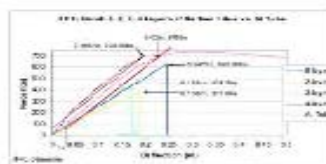
CCL Cantilever Test



Al 3-pt Bend Test



Al Cantilever Test



FY06 Results:

- The optimum strength to weight and stiffness is obtained using 2-layers of CCL.
- Two layers of CCL has the lowest weight compared to 0 and 3-layer beams with the same thickness (0.062" +/- 0.008").
- The practical limit for PCB layer thickness (0.062" to 0.125") is 4-layers of CCL for maximum strength and minimum weight.
- Greater than 4-layers of CCL would result in an undesirable weight penalty.
- For beams with CCL, the force of fracture through the electronic traces and beam structure increased as the number of layers of CCL increased.
- For Aluminum beams, yielding or the onset of plastic deformation occurs prior to failure.
- The graphs on the left depict the maximum force and deflection prior to failure. The Aluminum yielding is defined at 2% offset value (determined by the beam cross-section-ASTM F 1575-33).
- Results from the 3-point bend tests demonstrated the 4-layers of CCL exhibited a 4% higher strength than the Aluminum beam test article.
- Results from the cantilever bend tests demonstrated the Aluminum beam had the highest strength overall by a minimum of 17%.

CASE STUDY – Solar Panel, low CTE & Rigidity



❖ MATCHED CTE

Eliminates thermal induced stress on the triple junction solar cells. Initial thermal cycle testing has shown no damage to solar cells due to **matching thermal expansion**

❖ AUTOMATED PRODUCTION

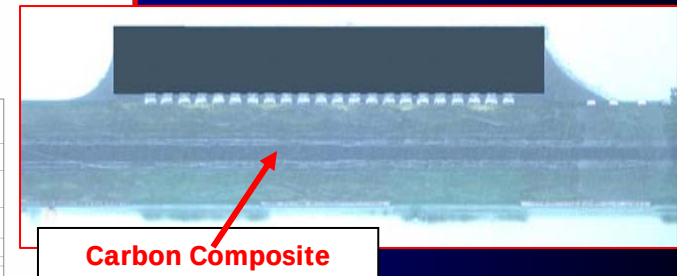
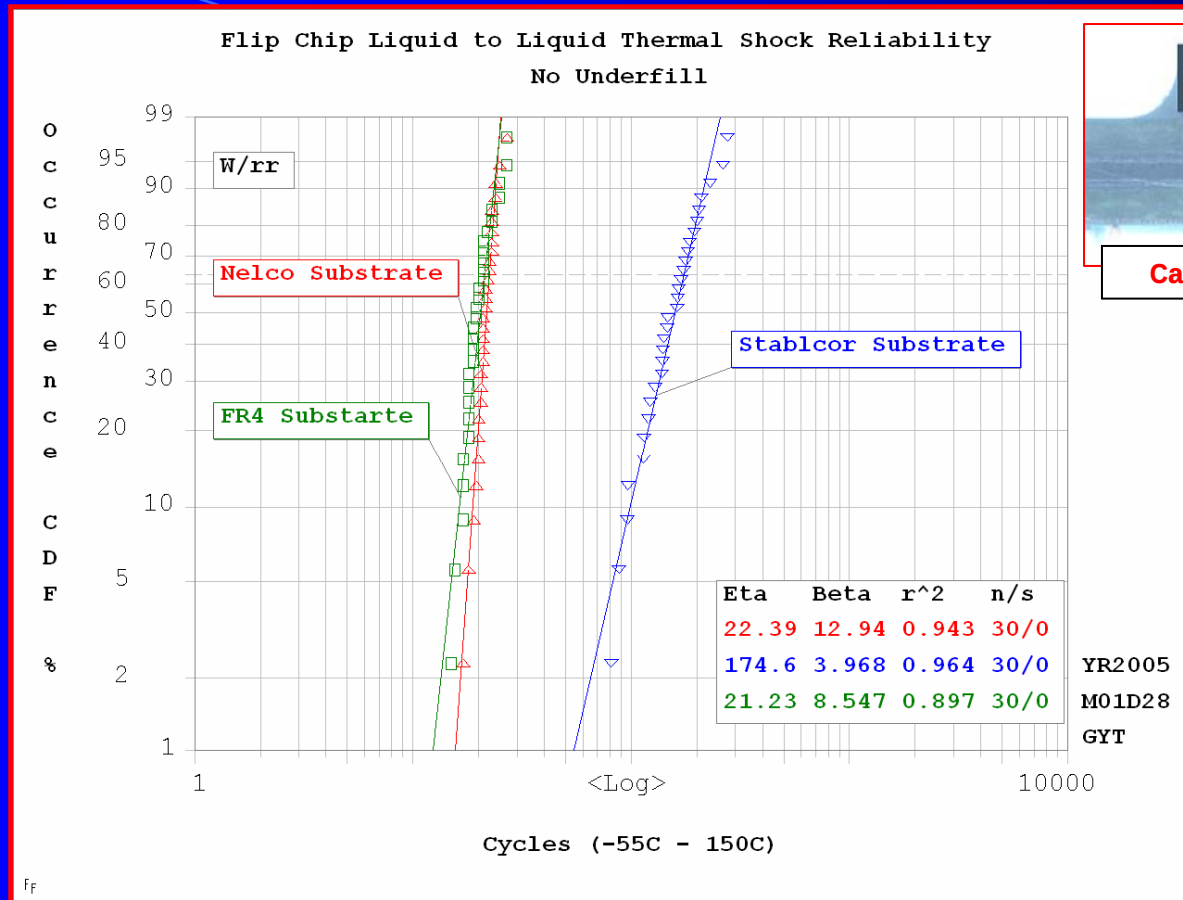
Reduces cost in large volume production compared with traditional attachment methods

❖ RUGGED

The rigidity of the CCL substrates **reduces costs** by eliminating need for additional supports to meet shock and vibration requirements

CASE STUDY – Flip Chip RELIABILITY

❖ Liquid to Liquid Thermal Shock Reliability

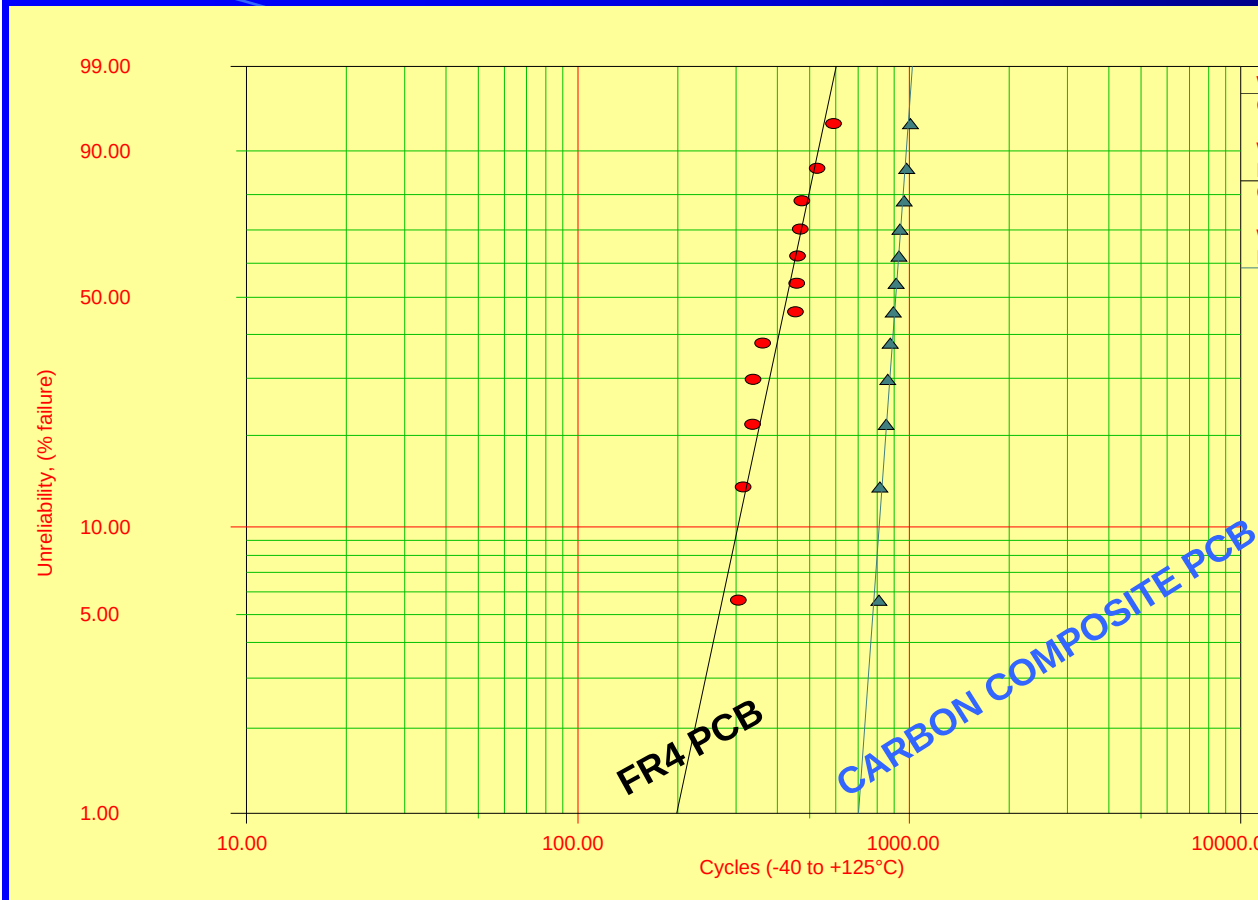


❖ With no underfill, the characteristic (63.2%) life of the FR-4/NELCO is about 20 cycles . The COMPOSITE board is about 173 cycles

❖ For no underfill test, the chips on COMPOSITE substrate remain attached at 353 cycles. Most of the chips detached from the other test boards at 353 cycles

CASE STUDY – Ceramic BGA Reliability

❖ Thermal Cycle Reliability



0.093" Thick PCB

FR4 0.005 h/h	L1
2ply 44N106	L2
ST325-EP387-0.008H/H	L3- CARBON (GND plane)
2ply 44N106	L4
FR4 0.005 h/h	L5
1ply 2313	L6
FR4 0.005 h/h	L7
1 ply 2313	L8
FR4 0.005 h/h	L9
1ply 2313	L10
FR4 0.005 h/h	L11
2ply 44N106	L12- CARBON (GND plane)
ST325-EP387-0.008H/H	L13
2ply 44N106	L14
FR4 0.005 h/h	

The characteristic life of the CBGA on the CARBON COMPOSITE PWB is roughly 2X better than FR4 PWB

DESIGN GUIDELINES

DESIGN GUIDELINES

DESIGN GUIDELINES

CARBON COMPOSITE Laminate

.....is an.....

Electrically Conductive Material

DESIGN GUIDELINES

Thus,.....

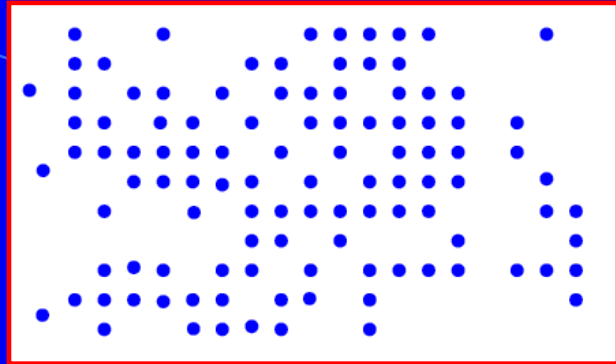
**It is used as a PLANE layer,
preferably GROUND plane layer
within a multilayer PCB**

BEST WAY TO USE COMPOSITE MATERIAL?

- ❖ USE AS A GROUND PLANE
- ❖ USE ALL COMPOSITE LAYERS AS SAME GROUND
- ❖ DO NOT USE AS SPLIT GROUND PLANE
- ❖ DO NOT USE AS A POWER PLANE
- ❖ DO NOT USE AS A MIX PLANE LAYER

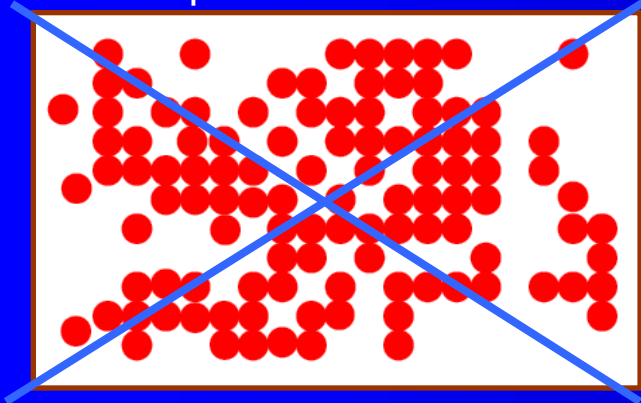
OPTIMIZE CLEARANCE PAD SIZES ON GND Plane

Plated Through Hole (PTH) pattern

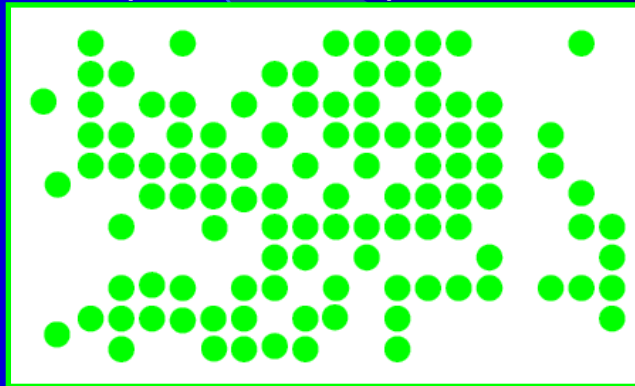


Rule to optimize anti-pad size:
PTH size + 20mil (minimum)
PTH size + 28mil (maximum)
** stay towards minimum side

Anti-pad size "TOO BIG"



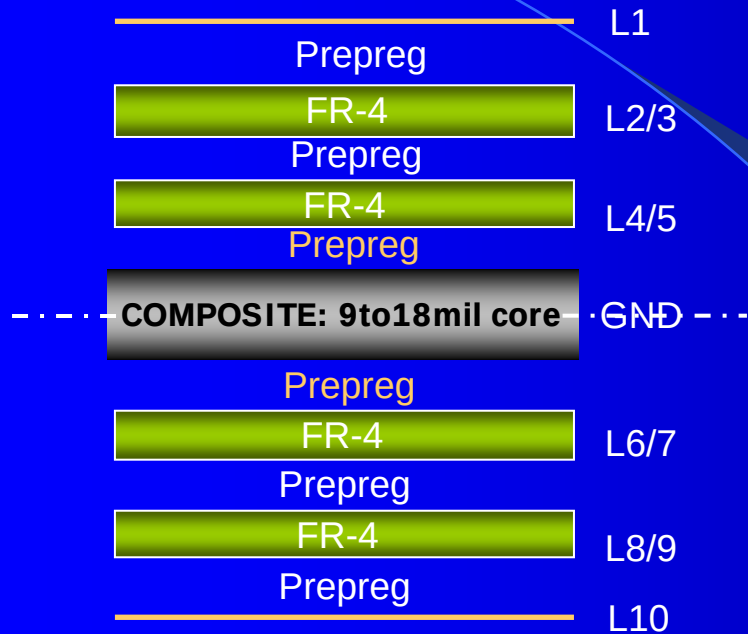
Optimized Anti-pad sizes



DESIGNER MUST OPTIMIZE ANTI-PAD SIZES ON A COMPOSITE GROUND PLANE DATA

Proposed stack-up to Optimize RIGIDITY Benefit

❖ Non-Optimized Stack-up for Rigidity



COMPOSITE along the Neutral Axis

❖ Optimized Stack-up for Rigidity

- ❖ Principle: Use COMPOSITE layers away from Neutral Axis
- ❖ Two thin COMPOSITE layers as arranged below would give higher stiffness than single thick core in a center



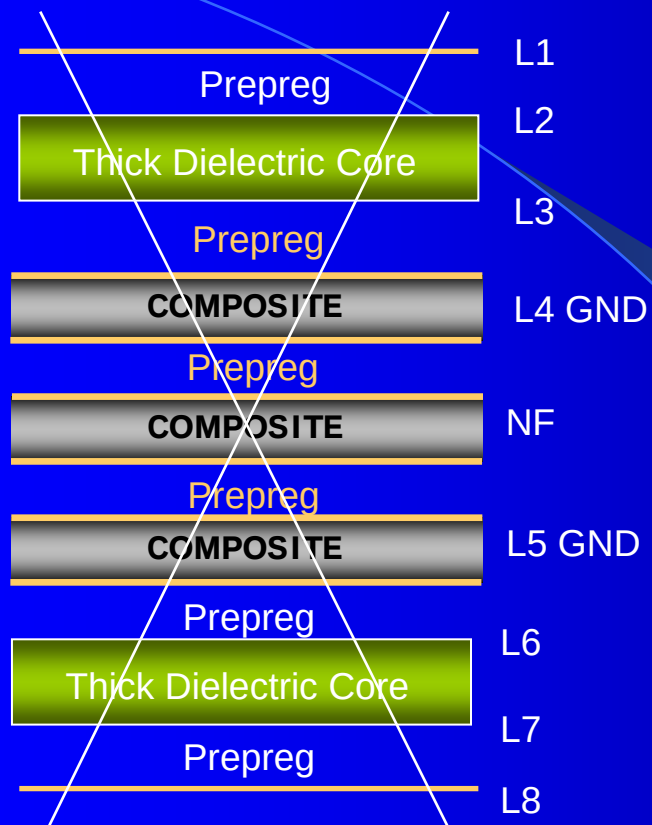
COMPOSITE near the surface and away from the Neutral Axis

Do's & Don'ts

Do's and Don'ts

Do's & Don't

Don't



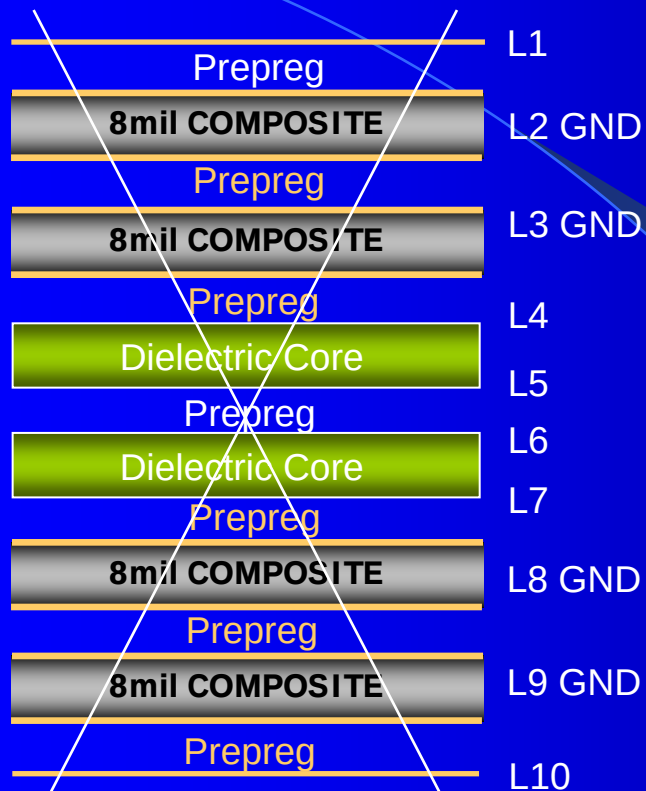
Do's



DISTRIBUTE THE COMPOSITE MATERIAL ACROSS THE THICKNESS OF A PCB

Do's & Don't

Don't



Do's

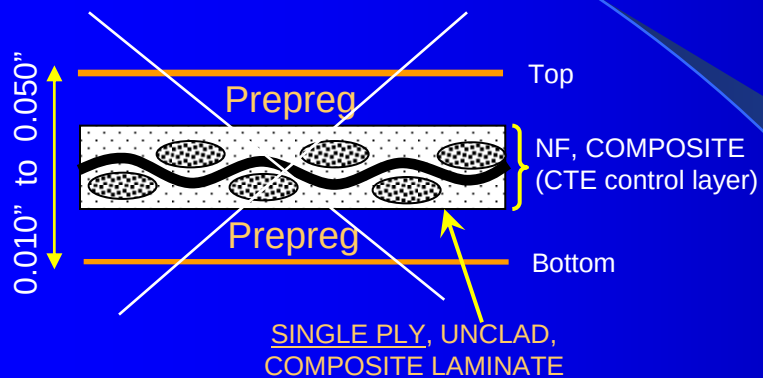


USE THICK CORE INSTEAD OF USING TWO THIN CORE NEXT TO EACH OTHER

Do's & Don't

Don'ts

SINGLE CORE, SINGLE PLY STACK-UP

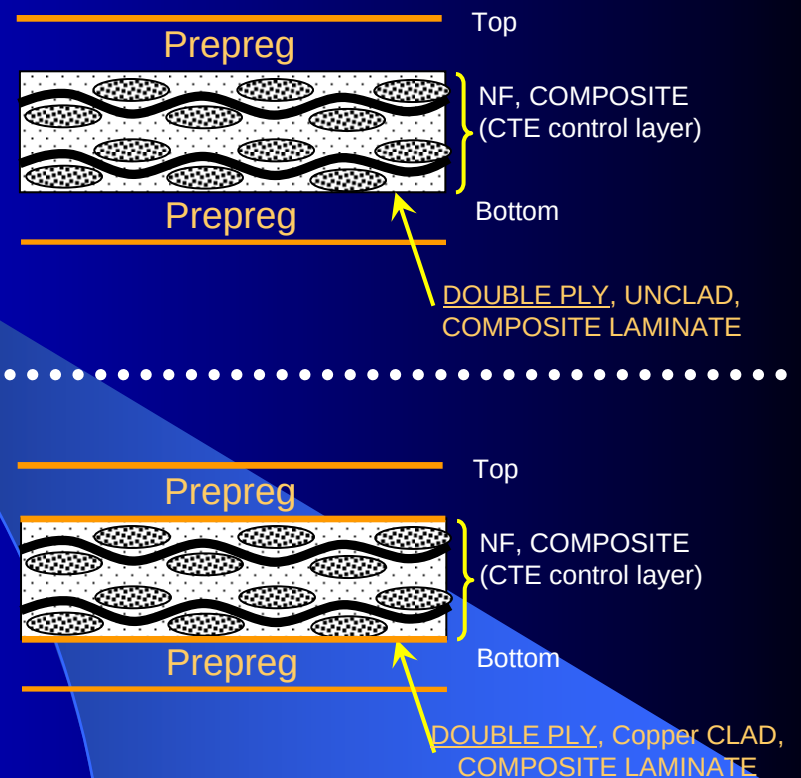


❖ "Single ply" COMPOSITE in a "Single Core, Thin PCB" stack-up will cause "warpage". That is why it is recommended to use "Double ply" COMPOSITE in a "Single Core, thin PCB"

DO NOT USE "SINGLE PLY" COMPOSITE IF THERE IS ONLY ONE CORE STACK-UP

Do's

SINGLE CORE, DOUBLE PLY STACK-UP



LIMITATIONS

- ❖ IT IS NOT A DIELECTRIC MATERIAL
- ❖ IN SOME CASES IT CAN INCREASE FINISH PCB THICKNESS
- ❖ CARBON COMPOSITE WILL BE EXPOSED AROUND THE PERIMETER OF THE FINISHED PCB
- ❖ YOU CAN ONLY HAVE “DIRECT TIE” TYPE CONNECTION WITH COMPOSITE, NO THERMAL RELIEF
- ❖ IT IS NOT RECOMMENDED TO USE HOT AIR SOLDER LEVEL (HASL) SURFACE FINISH

CONCLUSION

Operates Cooler

- ❖ Reduces Hot Spot
- ❖ PCB acts as a Heat Sink
- ❖ Reduces Thermal Stress on Components

Matches CTE

- ❖ Attach Ceramic packages more reliably
- ❖ Attach Flip Chip more reliably

Stiffness

- ❖ Prevents Warpage
- ❖ Increased Yields for Component Placement

All above benefits at almost no weight premium

Benefits for lead free PCBA processing
lower reflow oven temperatures

THANK YOU