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HIGH TEMPERATURE PCBs & SOLDERABLE SURFACE FINISHES

NPL / SMART HARSH ENVIRONMENT SEMINAR
July 2014

DENNIS PRICE

MERLIN CIRCUIT TECHNOLOGY LTD.

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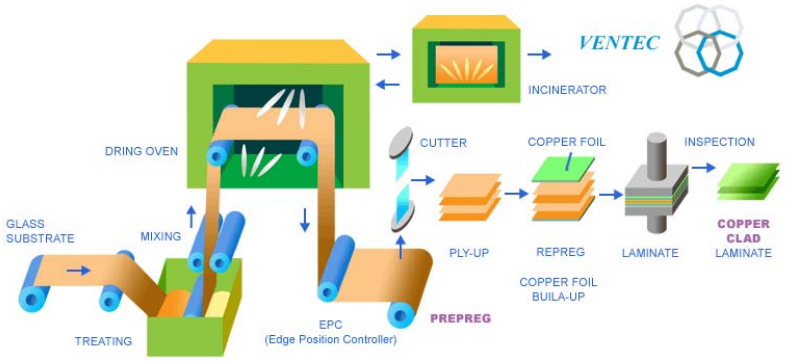
Laminate Manufacture



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Laminate Construction

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Laminate Suitability

- Application suitability of laminates is based on consideration of the following parameters:
  - **Tg – Glass transition temperature.**
  - **Td – Decomposition temperature.**
  - **Z axis expansion.**
  - **Maximum working temperature (U.L.).**
  - **I.S.T performance.**
  - **T260 and T288 performance.**
  - **Solder float survivability.**
  - **Thermal cycling performance.**
  - **CAF Resistance.**
  - **Moisture Absorption.**

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Laminate Properties

Property	Definition	Issue
Glass Transition Temperature, Tg	Thermodynamic change in polymer from a relatively rigid, glassy state, to a softened, more deformable state.	Several properties change as the Tg is exceeded, including the rate at which a material expands versus temperature. Modulus also decreases significantly as Tg is exceeded.
Z-Axis Expansion	Change in physical dimension (in Z-axis) as a function of temperature, expressed as a 'coefficient of thermal expansion' (CTE) or percentage expansion over a temperature range.	CTE values above Tg are much higher than below Tg. Expansion induces stress on plated vias. The higher temperatures of lead-free assembly result in more total expansion for a given material. Several mature lead-free compatible materials incorporate inorganic fillers that reduce CTE values.
Decomposition Temperature, Td	Measures weight loss from resin degradation as a function of temperature. Td is typically defined as the point at which 5% of the original mass is lost to decomposition, but other levels can also be reported, e.g. 1%, 2%, or 'onset'.	Resin decomposition can result in adhesion loss and delamination. A 5% level of decomposition is severe, and intermediate levels are important for assessing reliability since peak temperatures in lead-free assembly can reach onset points of decomposition. A high Td by the 5% definition does not guarantee performance. Conversely, a low Td by the 5% definition is not necessarily bad if the onset temperature of decomposition is high enough.

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Laminate Properties

Property	Definition	Issue
Moisture Absorption	Tendency of a material to absorb moisture from the surrounding environment. Can be assessed by more than one method, including water soak or in an increased pressure & humidity environment.	Vapor pressure of water is much higher at lead-free assembly temperatures. Absorbed moisture can volatilize during thermal cycling and cause voiding or delamination. PWBs that initially pass lead-free assembly testing may exhibit defects after storage in an uncontrolled environment, as a result of moisture absorption. This should be considered when evaluating materials and PWB designs.
Time to Delamination	While not a fundamental property, measures the time for delamination to occur at a specific temperature, e.g. 260°C (T260) or 288°C (T288).	Related to decomposition temperature and adhesion between material components. Thermal expansion and moisture absorption can also influence results. In multilayer PWBs, the treatment of the internal copper surfaces is also critical.

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Glass Transition Temperature, Tg

- Definition:
  - A second order thermodynamic change from a glassy solid to an amorphous solid
- Test Methods (all give somewhat different values)
  - Differential Scanning Calorimetry (DSC)
    - Measures rate of heat absorption
  - Thermal Mechanical Analysis (TMA)
    - Measures expansion rate
  - Dynamic Mechanical Analysis (DMA)
    - Measures modulus
- What happens as Tg is exceeded?
  - Rapid increase in z-axis expansion
  - Rapid loss of mechanical performance

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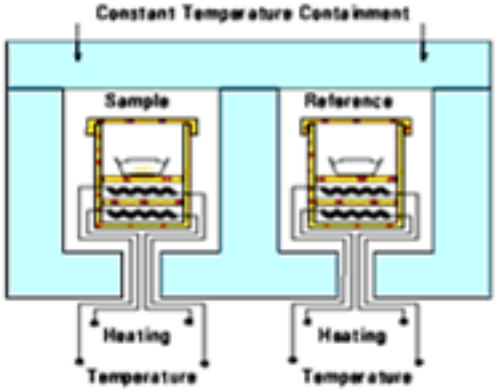
Differential Scanning Calorimeter



DSC measures the difference between heat taken in (endotherm) or heat given out (exotherm) by the sample relative to the reference (normally aluminium).

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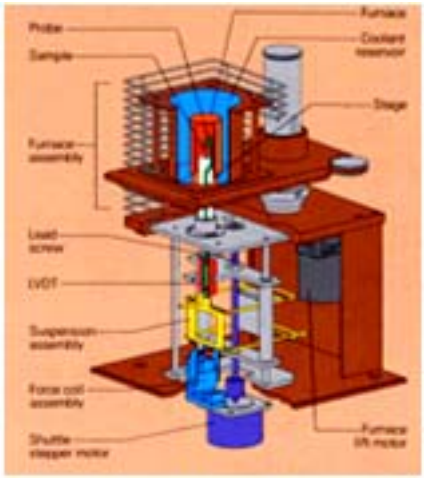
Thermo Mechanical Analyser



The equipment measures the displacement of the probe during a thermal excursion.

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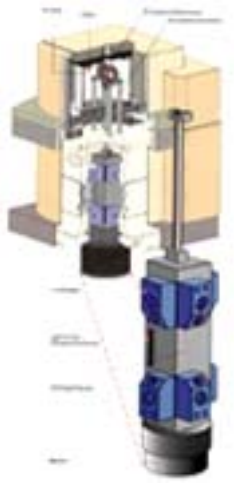
Dynamic Mechanical Analyser



Foils & thin laminates

Fibres

This equipment measures the in mechanical properties during rotational stress and temperature.

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Tg Measurement Comparisons

Test Item	Condition	Unit	Results				
			IT155G	IT200D	GETEK	FR408	N4000-13
Dk(R/C=52%)	1 GHz	—	4.3	3.8	3.9	3.9	3.8
Df(R/C=52%)	1 GHz	—	0.009	0.009	0.009	0.012	0.01
Tg	DMA	℃	175	201	185	199	236
Tg	DSC	℃	160	192	175	187	208
Tg	TMA	℃	150	182	150	165	197
CTE(Z)	TMA(50-260℃)	%	3.2	2.7	4.5	2.9	2.9
Delamination Test	TMA(260℃)	min	>60	>60	>60	> 60	> 60
Solder Float	288℃	min	>5	>5	>5	>5	>5
Water Absorption	PCT, 1hr	%	0.24	0.35	0.16	0.33	0.36
Chemical Resistance	$NH_3/HBF_4/H_2O_2$	%	0.04	0.046	0.05	0.05	0.08
Peel Strength(35μm)	25 ℃	Kgf/cm	>1.4	> 1.4	>1.4	> 1.3	> 1.4

Approximately 20 to 40 degrees C variation on a range of FR4 type materials

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Decomposition Temperature, Td

Definition

The temperature at which a 5% weight loss occurs by thermal gravimetric analysis (TGA)

Test Method

ASTMD3850

IPC-TM-650 2.4.24.6

What happens as the decomposition temperature is exceeded?

Accumulative and irreversible degradation / damage of material due to breakdown of chemical bonds

Lower levels of decomposition, especially when exposed to multiple thermal cycles, can significantly degrade reliability.

The point at which this level of decomposition occurs is critical.

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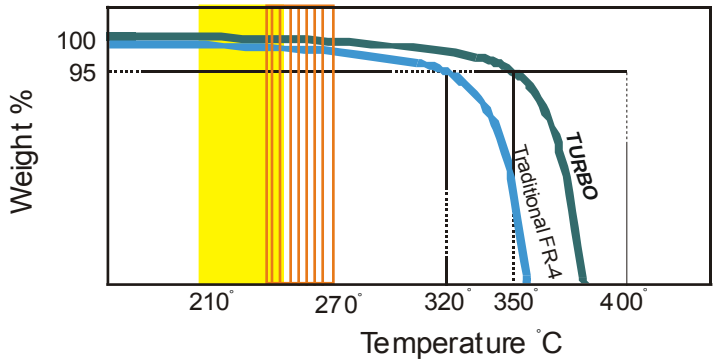
Decomposition Temperature, Td



Lead-free assembly temperatures extend into the region where conventional FR-4 materials begin to decompose. Delaying the onset of decomposition beyond this range is critical.

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Continuous (Maximum) Operating Temperature

Very difficult to quantify – the UL "Relative Thermal Index" (RTI) is an Arrhenius plotting of Time Vs. Temperature for the mathematical extrapolation of data from a four temperature accelerated aging evaluation to a temperature at which the material will operate for 100,000 hours and still retain at least 50% of its original physical or electrical properties.
Typical properties tested by UL are tensile strength, dielectric breakdown resistance etc.

RTI may not represent the PCB designers ultimate material temperature choice but is a good starting point remembering that the rate of any chemical reaction approximately doubles for every 10 degrees C rise.

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Time at Temperature Performance

Definition

- Many ways to measure
- T260/T288 measures time to delamination at specific temperature (i.e. 260°C/288°C)

Test Method

- IPC-TM-650

What happens/What does it mean?

- At the test temperature after some period of time the sample will delaminate
- Longer T260/T288 times indicate better delamination/measles/blister resistance
- Results are dependent on decomposition temperature, component CTE values, inter-laminar adhesion etc.

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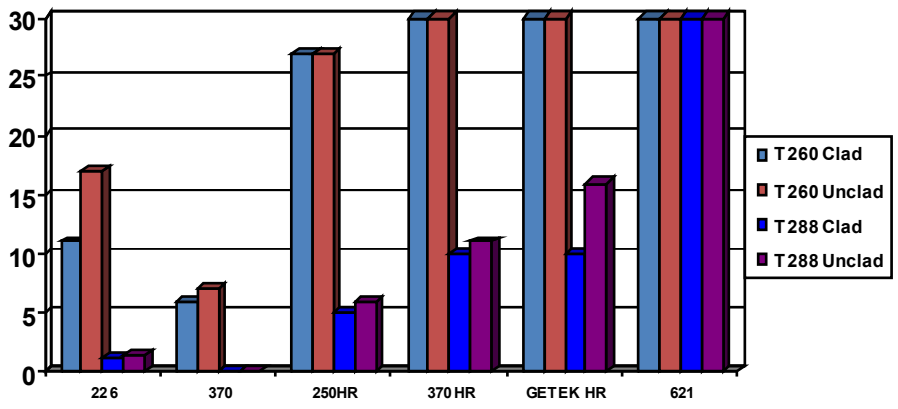
T260/T288 Data



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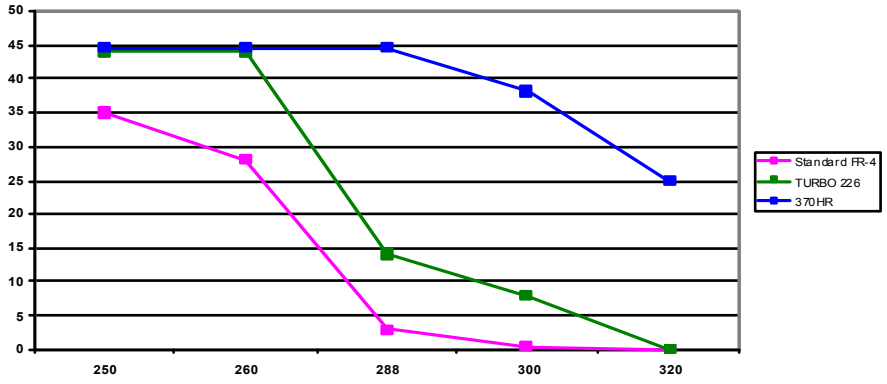
Time to Delamination (TMA Method)



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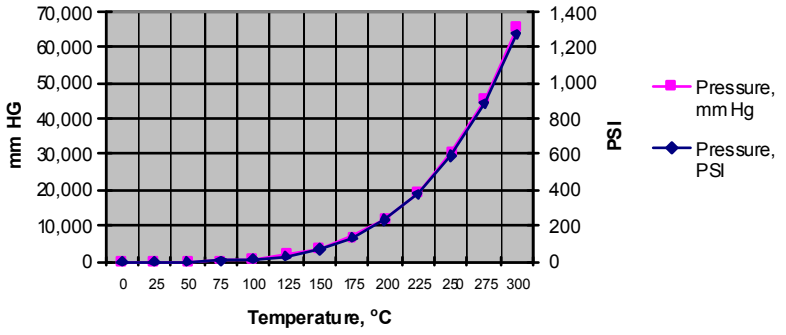
Laminate Moisture Absorption

At 220°C the vapor pressure of water is about 340 psi.
At 230°C the vapor pressure of water is about 400 psi.
At 260°C it increases to approximately 700 psi!



All materials will absorb some level of moisture

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Delamination Due To Moisture

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Laminate Flammability

- UL 796 – Printed Wiring Boards.
- UL 94 – Test for Flammability of Plastic Materials.
- Flammability Classifications:
- 94V-0
- 94V-1
- 94V-2
- Horizontal Burning (HB)

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Flammability Tests Reference Standards

The FTT UL 94 tests for flammability of plastic materials giving a preliminary indication of their suitability for a particular application. The apparatus is supplied as a complete system incorporating all the features necessary for ease of use and safety. It conforms to all five UL 94 horizontal and vertical Bunsen burner tests and associated international standards. These are: -

1. Horizontal Burning Test; UL 94HB (ASTM D 635, ISO 1210, IEC 60695-11-10 or IEC 60707).
2. Vertical Burning Test; UL 94V-0, V-1, or V-2 (ASTM D 3801, IEC 60695-11-10, IEC 60707 or ISO 1210).
3. 500 W (125mm) Vertical Burning Test; 5VA or 5VB (ASTM D 5048, IEC 60695-11-20, IEC 60707 or ISO 9772).
4. Thin Material Vertical Burning Test; VTM-0, VTM-1, or VTM-2 (ASTM D 4804 or ISO 9773).
5. Horizontal Burning Foamed Material Test; HBF, HF-1, or HF-2 (ASTM D 4986 or ISO 9772).
6. Burners (ASTM D 5025, ASTM D 5207, ISO 10093, ISO 10351)

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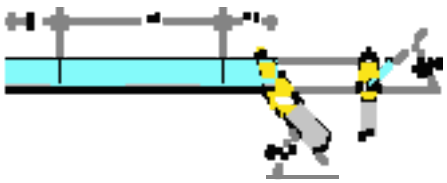
Horizontal Testing (HB) - Method A

Procedure: A specimen is supported in a horizontal position and is tilted at 45°. A flame is applied to the end of the specimen for 30 seconds or until the flame reaches the 1 inch mark. If the specimen continues to burn after the removal of the flame, the time for the specimen to burn between the 1 and 4 inch marks are recorded. If the specimen stops burning before the flame spreads to the 4 inch mark, the time of combustion and damaged length between the two marks is recorded. Three specimens are tested for each thickness.



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Horizontal Flame Test

Horizontal Rating	Requirements
HB	• Specimens must not have a burning rate greater than 1.5 inches/minute for thicknesses between 0.120 and 0.500 inches and 3 inches/minute for thicknesses less than 0.120 inches. • Specimens must stop burning before the flame reaches the 4 inch mark.

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Vertical Testing (V-0, V-1, V-2) - Method B

Procedure: A specimen is supported in a vertical position and a flame is applied to the bottom of the specimen. The flame is applied for ten seconds and then removed until flaming stops at which time the flame is reapplied for another ten seconds and then removed. Two sets of five specimens are tested. The two sets are conditioned under different conditions.

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Vertical Flame Test

Vertical Ratings	Requirements
V-0	• Specimens must not burn with flaming combustion for more than 10 seconds after either test flame application. • Total flaming combustion time must not exceed 50 seconds for each set of 5 specimens. • Specimens must not burn with flaming or glowing combustion up to the specimen holding clamp. • Specimens must not drip flaming particles that ignite the cotton. • No specimen can have glowing combustion remain for longer than 30 seconds after removal of the test flame.
V-1	• Specimens must not burn with flaming combustion for more than 30 seconds after either test flame application. • Total flaming combustion time must not exceed 250 seconds for each set of 5 specimens. • Specimens must not burn with flaming or glowing combustion up to the specimen holding clamp. • Specimens must not drip flaming particles that ignite the cotton. • No specimen can have glowing combustion remain for longer than 60 seconds after removal of the test flame.
V-2	• Specimens must not burn with flaming combustion for more than 30 seconds after either test flame application. • Total flaming combustion time must not exceed 250 seconds for each set of 5 specimens. • Specimens must not burn with flaming or glowing combustion up to the specimen holding clamp. • Specimens can drip flaming particles that ignite the cotton. • No specimen can have glowing combustion remain for longer than 60 seconds after removal of the test flame.

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Laminate CTE Values

Table 4. In-plane CTE of dielectric materials

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

Table 5. Through-plane CTE of dielectric materials

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

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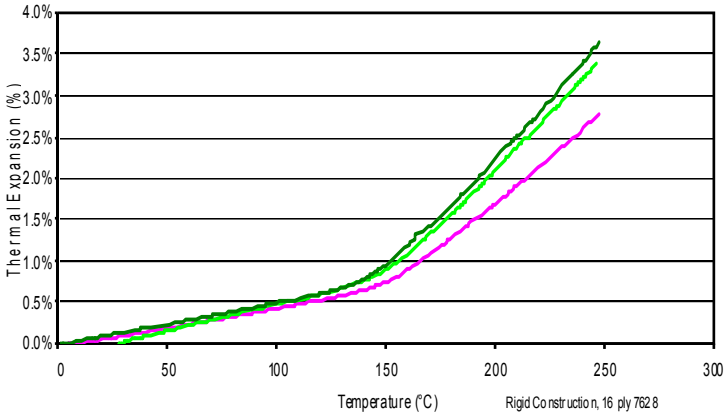
FR4 Z-axis Thermal Expansion Comparison



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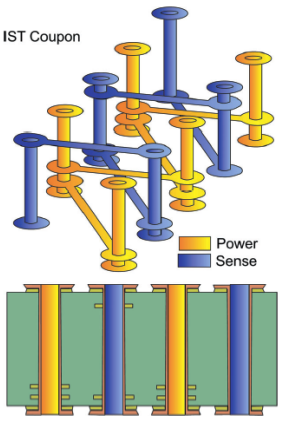
Interconnect Stress Testing (IST)

- IST is an accelerated stress test method
- Creates uniform strain from within substrate
- DC current is used to heat the PTH barrels and forced convection cooling to cycle PTH
- Technique identifies and assesses the severity of post separation and barrel cracks



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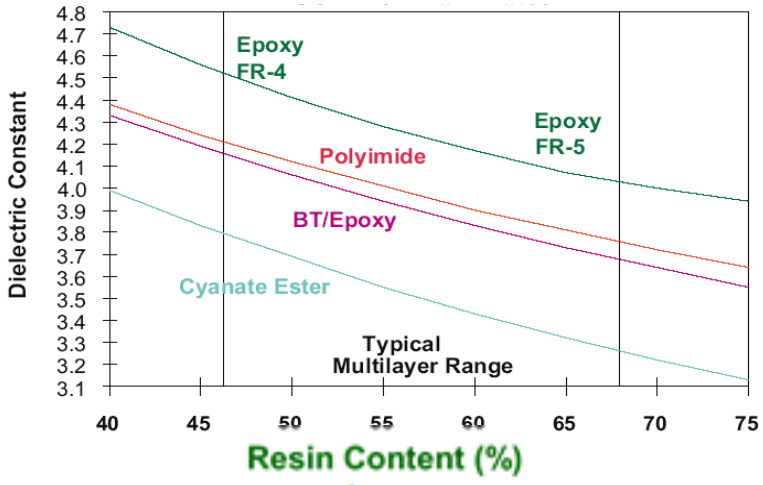
Dk Values Of Typical Rigid Laminate Types



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Thermally Conductive Resins

Product Type		Preliminary IPC Pb-Free Spec (/124)	33N Polyimide UL-94 VO	35N Polyimide UL-94 V1	85N Polyimide UL-94 HB	EP2 Enhanced Polyimide	45N DiCy Epoxy	91ML TC Epoxy	92ML TC Epoxy
Glass Transition (Tg)	°C	>155	250	250	260	250	175	170	170
T260	min	>30	>60	>60	>60	>60	8	>60	>60
T288	min	>15	23	>60	>60	15	0	>30	>15
T300	min	>2	8	11	>60	10	0	>10	>5
Td (initial)	°C		353	363	387	363	299	354	340
Td (5%)	°C	>330	389	407	407	424	311	368	400
$CTE_{z\ (<Tg)}$	ppm/°C	<60	53	51	55	25	50	36	22
$CTE_{z\ (>Tg)}$	ppm/°C	<300	164	158	149	150	185	192	175
$CTE_{z\ (50\text{-}260C)}$	%	3.5	1.2	1.2	1.2	0.65	2.6	2.6	1.8
Thermal Conductivity	W/m-K		0.25	0.25	0.25	0.45	0.25	1.00	2.00

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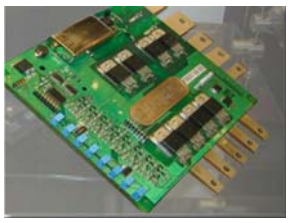
PCB Heat Planes



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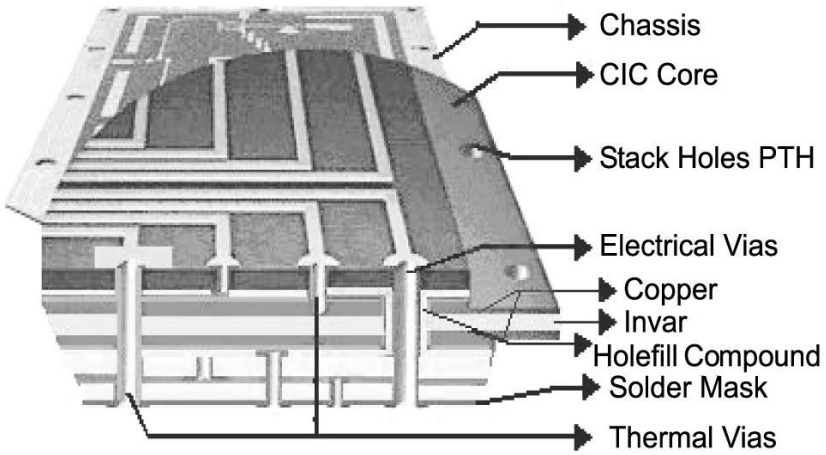
Copper-Invar-Copper Layers



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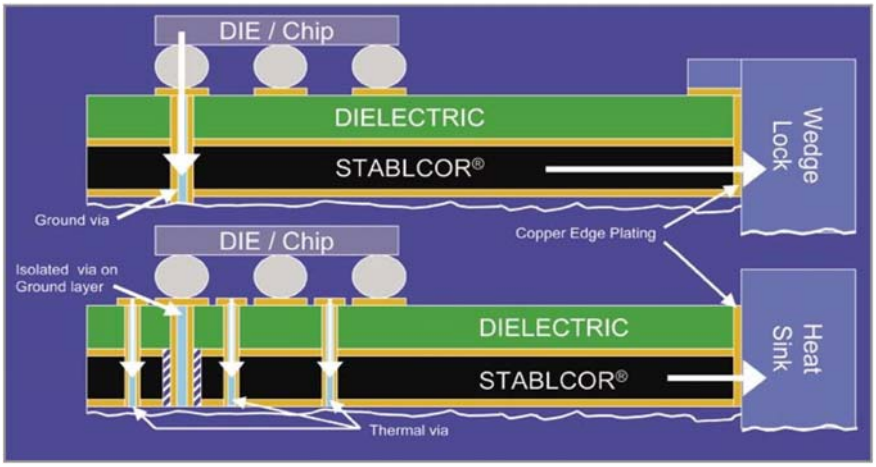
Carbon Cores



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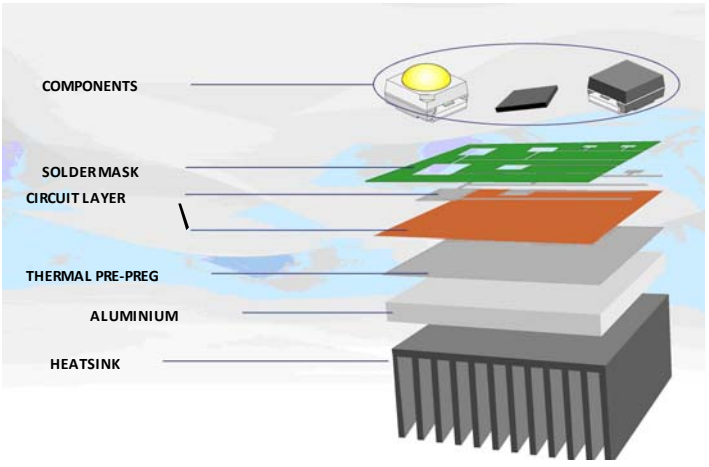
Insulated Metal Substrates (IMS)



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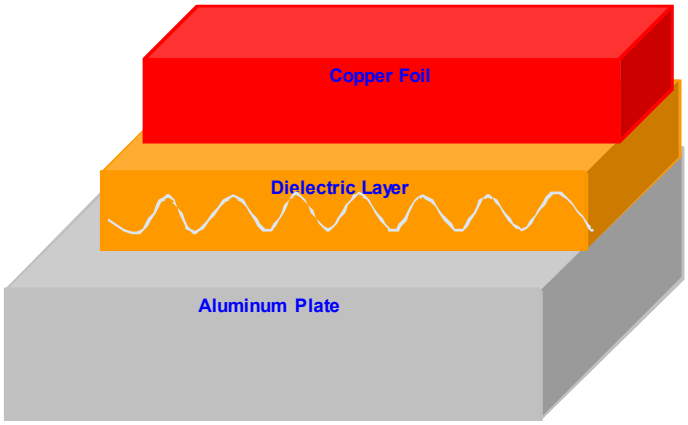
IMS Laminate Construction



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Selection Of IMS Laminate Suppliers

- Laird Technologies, Thermagon, T-Lam
- Bergquist, T-Clad System
- Doosan Corp. DS-44001 & DS-5000
- Asahi, Denka HITT Plate
- Ventec, VT-4B3 etc.

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Typical HF Laminate Properties

Suppliers	Arlon (AR320)	GIL	Rogers	Nelco	GE Electromaterials	Arlon	Isola	Isola
	Taconic (TLC-32)	(MC5, GML1000)	(RO4003, RO4350)	(N-8205)	GETEK ML2000	25N	Gigaver 210	Gigaver 410
Resin/Reinforcement	PTFE/ Woven E-Glass	Polyester/ Woven E-Glass w/Random Core	Thermoset Hydrocarbon/ Ceramic & Woven E-Glass	Cyanate Ester/ Woven E-Glass	PPO Epoxy/ Woven E-Glass	Thermoset Olefin Ceramic & Woven E-Glass	APPE/ Woven E-Glass	APPE/ Woven E-Glass
Dielectric Constant	3.20 (10 GHz)	3.20, 3.05 (10 GHz)	3.38, 3.48 (10 GHz)	3.6 (1 MHz)	4.2 (1 MHz)	3.25 (1 GHz)	3.3 (1 GHz)	3.3 (1 GHz)
Dissipation factor	0.003 (10 GHz)	0.014,0004 (10 GHz)	0.0 022,0.004 (10 GHz)	0.009 (1 MHz)	0.015 (1 MHz)	0.0025 (1 GHz)	0. 005 (1 GHz)	0.004 (1 GHz)
Water Absorption (%)	0.08	0.07, 0.02	0.06, 0.0 6	0.50	0.10	0.08	0 .32	0.21
Flexural Strength (kpsi) Mach	40	28,25	21,31	75	77	-	-	-
Flexural Strength (kpsi) Cross	35	25.5, 25.5	21, 31	60	52	-	-	-
Copper Peel Strength (lb/in)	12.0	6.0, 5.0	4.5, 5.0	8.0	8.0	4.0	7.84- 8.96	11 .76-12.32
Glass Transition Temperature(°C)	NA	140, 135	280, 280	2 40	180	100	> 210	> 200
CTE (ppm/K) Z <Tg />Tg	70	95/ 350, 80/ 4 10	35/ , 50/	65/270	-	70/	80	85
CTEW (ppm/K) XY	9/12	37/35, 40/3 4	11/14, 14 /16	17/17	16/18	17/17	-	-
Specific Gravity (g/cm^3)	2.5	1.71, 1.69	1.77, 1.8 6	1.8	-	1.54	1.6	1.6
Thermal conductivity (W/(m×K))	0.23	0.21, 0.17	0.64, 0.6 2	0.25	0.25	0.45	-	-
UL Flame Rating (94)	V-O	V-O, V-O	None, V-O	V-O	V-O		V-O	V-O
Price Index FR-4	x 5 to 50	x 5 to 10	x 6	x 4	x 1.5	x 5 to 10	x 2 to 3	x 4 to 5

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Sample Isola Lead-Free Laminate Properties

	IS400	DE156	IS410	IS420	IS415	IS500	FR408	IS620	IS640-D	P95	P96 /P97*
Description	150 Tg Filled nondicy	Halogen Free 150 Tg	Phenolic Cured 170 Tg	Phenolic Cured Filled 170 Tg	Non Phenolic, Non Dicy-190 Tg	170 Tg Halogen Free	180 Tg, Low DK Low Loss	215 Tg Low DK, Very Low Loss	Very Low DK very Low Loss	>250 Tg Polyimide HB	>250 Tg Polyimide V-0 /V-1
Applications	Auto & consumer	Halogen Free	High Rel.lead free	Very High Thermal rel.	High Speed, High reliability	High Speed, High rel, halogen free	High Speed Digital apps	Very High Speed Digital Apps.	Very High Speed Digital Apps.	Military/Computers, Down Hole Drilling	Military/Computers,
Lead Free Compatible	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Halogen Free	No	Yes	No	No	No	Yes	No	No	No	No	No
CAF resistant Chemistry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ROHS and WEEE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Thermal Cycling rating IST/TCT HATS	Very High	Very High	High	Very High	Very High	Very High	High	Very High	High	Very High	Very High
Tg-DSC Deg C	150	150	175	170	190	170	180	215	225	>250	>250
X CTE PPm/C Below Tg	13	13	13	13	13	13	13	13	11	14	14
Y CTE PPm/c below Tg	14	14	14	14	14	14	14	14	10	17	17
Z Alpha 1 CTE PPm/C	45	45	60	40	55	50	65	55	NA	55	60
Overall expansion z to 288 Deg C Percent	3.00%	3.00 %	3.50 %	2.80 %	2.90 %	2. 80 %	3 .50 %	2 .80 %	3 .60 %	1.50%	1.50%
Decomposition temp Deg C Onset	330	380	350	340	370	400	360	353	350	416	382
T-260 Minutes	60	60	60	60	60	60	60	60	60	60	60
T-288 Minutes	>5	>5	>15	>15	>20	>15	>15	>15	>10	60	60
Peel Strength lb/inch	>7 .4	>6 .3	>6 .3	>6.3	>6.3	>6.3	>5. 5	>6. 3	>5 .5	>6 .3	>6. 3
Peel Strength N/mm	>1 .3	>1 .1	>1 .1	>1.1	>1.1	>1.1	>1. 1	>1. 1	>1	>1 .1	>1. 1
Dk -2 Ghz	4 .0 0	4 .0 0	4 .0 0	4.0 0	3.9 0	3.9 0	3.6 0	3. 60	3 .0- 3 .6	3.90	3.90
Df-2 Ghz	0 .02 0 0	0 .0 20 0	0 .0 21 0	0 .0 20 0	0 .0 16 0	0 .0 16 0	0 .0 11 0	0 .0 0 80	<.00 4 5	0 .0170	0.0170
Dk-10 Ghz	3 .9 0	3 .9 0	3 .9 0	3.9 0	3.8 0	3.8 0	3.5 5	3. 55	3 .0- 3 .6	3.80	3.80
Df-10 Ghz	0 .02 2 0	0 .0 22 0	0 .0 23 0	0 .0 21 0	0 .0 17 0	0 .0 17 0	0 .0 12 5	0 .0 0 80	<.00 4 5	0 .0200	0.0200
* Only For Europe											

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Maximum Operating Temperature (MOT)

Laminate Type	Tg Range	Td Range	MOT
FR4 (Standard Tg – Dicy cured)	130C to 145C	300C to 320C	105C
FR4 (Mid Tg – Novolac cured)	150C to 165C	320C to 330C	130C
FR4 (High Tg – Novolac cured)	170C to 185C	330C to 350C	130C
FR4 Blends (PPO, APPE etc.)	170C to 220C	330C to 350C	130C
BT Epoxy	175C to 220C	325C to 350C	140C-150C
Hydro Carbon (Ceramic filler)	280C	390C to 425C	115C
Cyanate Ester	240C to 250C	370C to 380C	Various
Polyimide (Glass reinforced)	250C to 260C	380C to 420C	Various
PTFE	N/A	327C M-point	180C
Polyimide Flex (DuPont Kapton)	195C to 220C	380C to 420C	180C-200C

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Most Popular High Temperature Laminate Choice

- **POLYIMIDE: Typical parameters**
  - **Tg – 260C.**
  - **Td – 380C to 420C.**
  - **Z axis expansion – 50 to 55 ppm/degree C.**
  - **In plane expansion – 15 to 19 ppm/degree C.**
  - **ED Copper expansion – 17 to 18 ppm/degree C.**
  - **MOT – (Isola P96) – 210C.**
  - **Thermal conductivity – 0.2 W/mk.**
  - **Moisture Absorption – up to 0.3%.**

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Most Popular High Temperature Laminate Choice

- **POLYIMIDE – Popular types:**
  - **Isola - P96 & P95.**
  - **Arlon – 33N, 35N & 85N.**
  - **Nelco – N7000.**
  - **Ventec - VT-901.**

Known Major Manufacturing Issues:

- **Resin chipping (during NC drill & profile).**
- **Moisture Absorption.**

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Laminate Thermal Cycling Results (Calce)

(TTF = Time To Failure)

DEVICE TTF (cycles/days)	FR4 TTF (Cycles/days)	High Tg FR4 TTF (cycles/days)	Polyimide TTF (cycles/days)
LCCC	77/3	112/5	252/12
Resistor 2512	760/32	1,103/46	2,732/114
PBGA	4,523/188	5,524/230	19,490/2.2 years
Resistor 1210	6,208/259	9,007/1.03 years	22,302/2.5 years
LQPF	13,517/563	39,237/4.48 years	> 30 years

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Ultimate High Temperature Laminate Choice

- **Ceramic:**
  - **LTCC (Low Temperature Co-fired Ceramic) – a multilayer ceramic technology, which possesses the ability to embed the passive elements, such as resistors, capacitors and inductors into a ceramic interconnect package while the active elements are mounted on the outer layers.**
  - **HTCC (High Temperature Co-fired Ceramic) – differs from LTCC by high temperature of 1600C while LTCC uses a temperature of 850C to 950C.**

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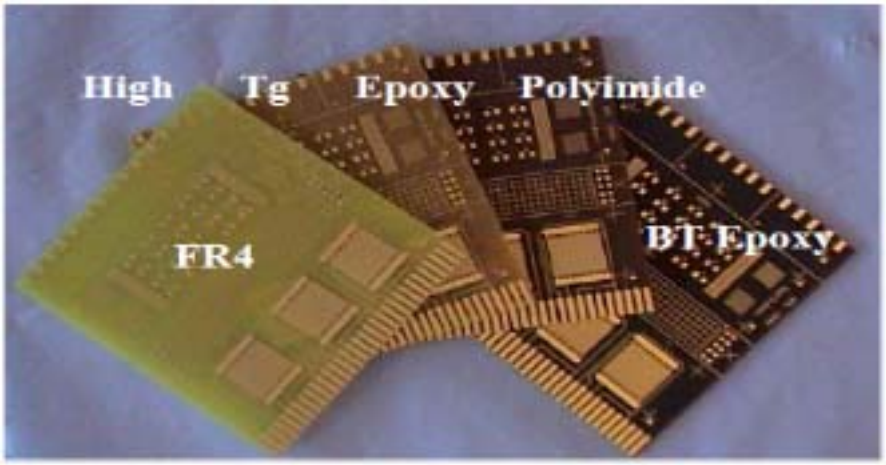
Appearance Of Various Resin Systems



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Solder Masks

Standard solder masks are epoxy based products and will oxidise at prolonged temperatures above 150C – this results in a colour change from the original (usually green) to dark brown.

I am only aware of one Polyimide based solder mask but this is not available in a photoimageable format, has limited technical capability and the Tg is only quoted at 165.8C.

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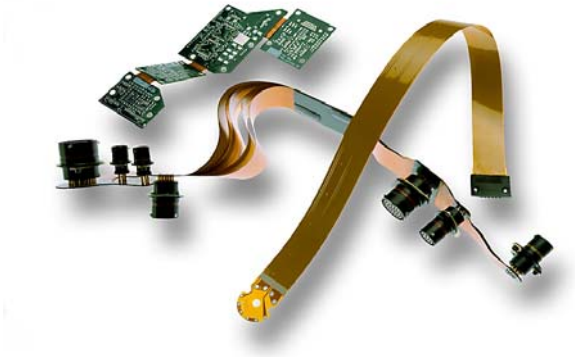
Flexible Base Materials



DuPont Pyralux AP Kapton flexible laminate is UL 94V-0 & UL 796 approved to 180C working temperature.
Some flex designs can operate up to 220C with flex heater circuits occasionally reaching 260C

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PROPERTY	HASL	ENIG, ENIGEG, DIG, ENEPIG, EP,ENEP,	ORGANIC	IMMERSION & ELECTROLESS SILVER, ASIG	IMMERSION TIN
Topography	Not flat	Flat	Flat	Flat	Flat
Solderability/Shelf Life	Very good	Very good	Average	Good	Good (if not subjected to heat)
Assembly Risk Compatibility	Compatible with all flux types	Compatible with most flux types	Compatible with most flux types	Compatible with most flux types	Compatible with most flux types
Detriment to P.C.B. integrity	Thermal shock – especially Lead-free	None	None	None	None
SMT pitch	0.5 mm	Any	Any	Any	Any
Ionic cleanliness	Possibly problematic	Good	Good	Good	Good
Fiducial recognition	Possibly problematic	Excellent	Good	Good	Good
Handling	No special handling	No special handling	Requires care	Requires care	Requires some care
Re-work (Fabricator)	Risky	Not possible	Possible	Possible	Possible
Cost	Medium/low	High	Low	Medium	Medium/low

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ELECTROLESS NICKEL/IMMERSION GOLD (ENIG)

- Electroless Nickel barrier (3.0 – 6.0 microns)
- Thin gold layer absorbed in solder (0.05 – 0.1 microns)
- Aluminium wedge wire bondable
- Flat
- Good shelf life
- Multiple solder operation compatibility
- Solder mask compatibility
- Environmentally unfriendly process
- Carbon key pad compatible
- Black pad issues !

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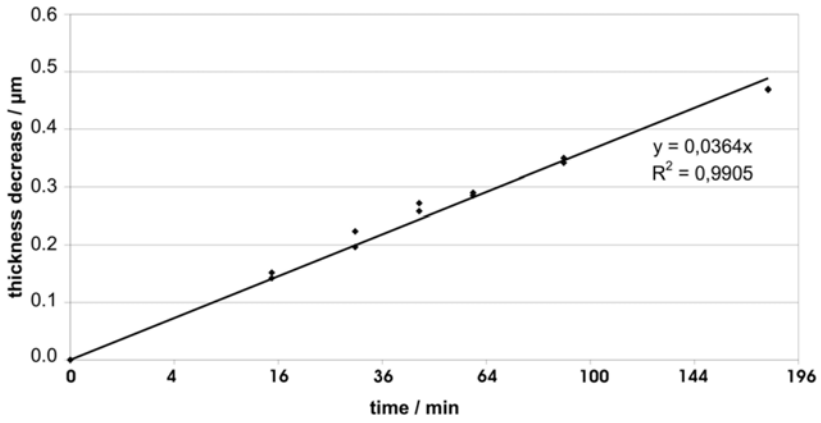

Reduction of pure Tin layer @ 155 degrees C

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THANK YOU FOR YOUR ATTENTION

Further Reading

Everything You Wanted To Know About Laminates … But Were Afraid To Ask.

By Chet Guiles --- ARLON

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