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Lead Free- Basics

Laminate Materials

Matrix USA, Inc.

Fall 2005

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Pb-Free
Driven by EU Directives

WEEE Directive

(Waste Electrical and Electronic Equipment Directive)

Electronic waste recycling & disposal

- Waste collection system established Aug., 2005
- Pay for system & take back waste Jan.,2006

RoHS Directive

(Restriction of Hazardous Substances Directive)

Six Materials Banned

Lead & Select Flame Retardants out by July, 2006

ELV Directive

(End of Life Vehicle)

Design Compliance

- Enact in 2007

Legislation for product shipped into the EU.

After deadline, non-compliant product will be barred.

Non-EU jurisdictions are proposing similar directives: Japan, China, etc.

Non-EU jurisdictions are proposing similar

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Pb-Free Global Implementation

In Europe

In the EU Directive concerning electronics packaging and packaging wastes, it is stipulated that lead contained in packaging must be reduced.

In Japan

In April 1997, the Japanese Ministry of International Trade and Industry set a numerical target for the amount of lead used (by weight) for cars, except for batteries, and later ordered that it be reduced "to half compared to 1996 by the end of 2000 and to one third by 2005". Since manufacturers will be obliged in 2001, according to the law promoting the recycling of household electric appliances, to reclaim all lead used, all household electric appliances manufacturers are working towards the creation of completely lead-free products.

In the United States

Since subsurface water is very commonly used as a source of drinking water, lead has been a big concern. The use of solder for water pipes has already been strictly banned. Additionally, a law concerning lead control in electronic equipment was submitted to Congress in 1990. Development of solder substitutes has rapidly been promoted by manufacturers and in national projects.

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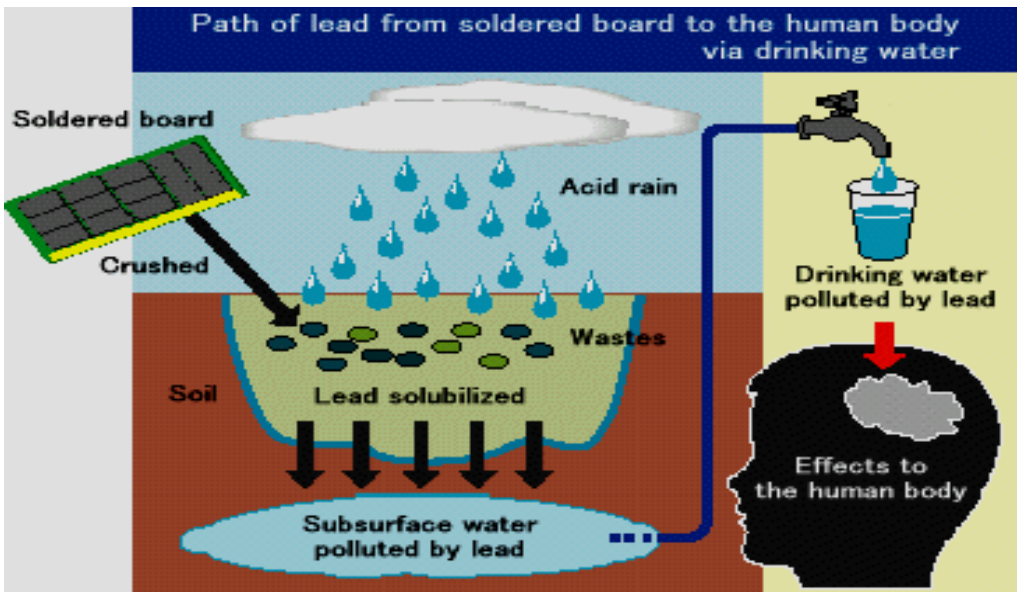
Why Lead Free Legislation?

When soldered (Sn-Pb) circuit boards are scrapped and buried:

1. Acid rain gradually dissolves the Pb out of the solder.
2. The subsurface water then becomes polluted with Pb compounds.
3. The polluted subsurface water is taken into the human body as drinking water.



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Pb Free Defined

Electrical and Electronic products and/or components produced without the intentional use of lead in any raw materials, processing or assembly.

JEDEC & NEMI define lead-free,

"As devices and/or products having no lead intentionally added, with less than **0.2% lead by weight".**

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RoHS Directive

- **Requirements**
  - Seeks to reduce the environmental impact of WEEE by restricting the use of certain hazardous substances during manufacture.
    - Lead (Pb)
    - Mercury (Hg)
    - Cadmium (Cd)
    - Hexavalent Chromium (Cr^{6+})
    - Poly Brominated Biphenyl (PBB)
    - Poly Brominated Diphenyl Ether (PBDE)
  - Restricted Due to Bioreactivity, Carcinogenicity, Chemical Reactivity

- **Timetable**
  - Publication – February 13, 2003
  - Member states Transposition - August 13, 2004
  - Producer Responsibility – August 13 2005
  - Substance Ban (RoHS) – July 1, 2006

Banned Materials Details

- **Lead (Pb)**
  - Used in virtually all solders, electronic components & PWB's.
- **Cadmium (Cd)**
  - Used in batteries (NiCd), plastic stabilizers, plating
- **Mercury (Hg)**
  - Used in some electrical components, batteries, pigments
- **Chromium VI (Cr6+)**
  - Used in dyes, pigments, plating solutions, alloys
- **PBB & PBDE**
  - (Polybrominated-Biphenyls, Polybrominated Diphenylethers)
  - Used as flame retardants in plastics, some PWB's **(not FR4)**

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Pb-Free US Implementation

- **United States**
  - No US Environmental restriction on lead solders for use in electrical and or electronic assemblies, has been implemented to date.
  - California has adopted the EU RoHS protocol, which will go into affect in January, 2007.
  - Several other states have bills pending to adopt the EU RoHS protocol.
- **IPC Position**
  - The IPC has taken a very active role in educating the PCB Industry on the requirements and implementation of EU RoHS protocol, and has developed aggressive programs towards qualifying alternative alloys to meet the new guidelines.
- **Industry Progress**
  - The major OEMs, EMS, PCB Fabricators and Material Supplier are all working toward support of these new environmental standards.
  - Some Technology Sectors have exemption from compliance to these standards until 2010 or beyond.
    - Servers, Routers, Military
  - Many of those companies intend to implement these requirements, recognizing the environmental impact and complexity of integrating Pb-Free Component Compliance.

Pb-Free Influence on Assembly, PCBs & Materials

- **Alternative “Pb-free” Solder Solutions**
- **Pb-Free: Product Implementation**
- **Pb-Free: Potential Impact on Fabrication, Assembly and Reliability**

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Alternative "Pb-free" Solder Solutions

No direct drop in replacement exists for Sn/Pb.

- All recommended alternatives require higher soldering temperatures:
- Current front runner alloy is Sn/Ag/Cu (Tin/Silver/Copper) (SAC)
- Melting point 30°C higher than existing solder (approx. 217°C)
- Assembly temperatures required will exceed temperature limits of current component and board materials
- Development in new component materials/assembly methods

Pb-Free Solder Alloys

Desired Critical Attributes

- **Comparable cost**
- **Similar melting point**
- **Low toxicity**
- **Fully recyclable**
- **Good wetting characteristics**
- **Good mechanical properties (strength, ductility)**
- **Good physical properties (CTE, thermal conductivity)**
- **Comparable reliability**
- **Acceptable rework/repair**

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Pb-Free: Potential Impact

Critical aspects for Fabrication, Assembly & End-User

- **Cost:**
  - Most of the Pb-Free alloys are more expensive than current tin-lead solder (2 – 5X).
- **Thermal Impact:**
  - The leading Pb-Free alloys require higher reflow temperatures, which translates to higher energy costs, and longer cycle time (reduced productivity).
  - Higher reflow temperatures will force changes in base materials, components and may also require new equipment.
- **Narrow Process Windows:**
  - New and tighter process control guidelines will be required to produce high quality parts with the new alloys.
  - Component and board warpage may be a concern.
- **Unknown Long Term Stability:**
  - Intermetallic formation between Pb-Free solder and metallization on chips, connectors or substrates.
  - Solder Bond Reliability.
  - Rework
- **New Solder Material Properties:**
  - Increased component insertion pressure, may effect PCB performance.
  - Design Guidelines.

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RoHS Compliance Impact on PWB's

- **Thermal**
  - Boards must be able to withstand peak reflow temperatures in excess of 250°C from 215°C.
  - Multilayer Applications May See From 6 to 10 Solder/Heat Cycles.
    - Manufacturing – Multiple Lamination Cycles.
    - Multiple Reflow Cycles.
    - Multiple Rework Cycles.
  - PWB's are Exposed to Longer Process Dwell time at peak temperature.
  - Higher temperatures mean greater stress during manufacturing, so new materials must be proven compatible, and reliable once assembled
- **New Laminate Specifications Required for Material Compatibility.**
  - Thermal Decomposition.
- **New Tests Required to Certify Satisfactory Lead Free Performance.**
  - Time-to-Delamination "T-288" (IPC TM-650 2.4.24.1)
  - Temperature - of - Decomposition "TD" (ASTM D3850)
  - IST testing with 3X & 6X reflow cycle preconditioning at 260°C, to simulate manufacturing conditions.
- **PWB's will have to be equivalent or better in all respects, despite a more stressful manufacturing environment!**

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Key Pb-Free Material Attributes

What Does Pb-Free Mean for Laminate?

- RoHS Compliant.
  - Almost all Laminate is RoHS Compliant (Does not contain 6 Named Compounds)
- Pb-Free Process Capable.
  - Able to Withstand New Higher Temperature Requirements for Lead Free Solders.

Pb-Free Process Capable Critical Material Properties

- Time to Delamination, T-260C, T-288C
- Thermal Decomposition
- IST
- CTE
- Tg - Glass Transition Temperature
  - “Tg No longer King”

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Key Pb-Free
Process Capable Material Attributes

- **Time to Delamination, T-260/T-288 (TMA) –Base material or PWB Test to determine the time in minutes the sample can withstand the specified test temperature before a catastrophic failure (Delamination) occurs.**
  - Analysis of the failed sample you can determine the specific mode of failure (resin to copper, resin to reinforcement, resin to oxide).

- **Thermal Decomposition Temperature – (Td)"Thermogravimetric Analysis" (TGA) measures the actual chemical and physical degradation of the base resin, based on a measurement of sample mass vs. temperature.**
  - Td is calculated based on 5% weight loss of the sample. \
  - Similar resin systems having the same Tg, can have significantly different Td.
  - Td is now recognized as an important tool in determine the performance and overall reliability of materials.

- **Internal Stress Test – (IST) PCB test using a daisy chain pattern of plated through holes (10 – 14 layer PCB), with an applied electrical current to the network to heat the entire sample to 150C, then cooling to ambient. This represents one cycle. The resistance is constantly measured, with a 10% drop in plated hole resistance constituting failure.**
  - The cycles to failure can provide an indication of PCB reliability.
  - IST results are influenced by base materials and PCB processing.

- **Important Note! - The combination of Td ,Tg, and CTE values for a given resin system can provide significant insight into the performance of that material for Pb-Free applications.**
  - No Longer Does one Specific Test Such as Tg determine overall thermal Performance.

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Key Pb-Free
Process Capable Material Attributes-2

- **CTE (Coefficient of Thermal Expansion) – Dimensional change of materials as a function of temperature.**
  - All FR-4 materials will expand with thermal excursion. Measurement of this expansion is referred to as (CTE)
  - Expansion rates below Tg range from 45 -60ppm, while expansion above Tg can exceed 300ppm.
  - Values are presented in either ppm or %.

- **Thermal Mechanical Analysis (TMA) Measures dimensional changes as a function of temperature. This technique allows for calculation of both Tg and CTE.**
  - "Extrapolating the linear portions of a TMA curve to the point at which they intersect provides a measure of the Tg".
  - "The slopes of the linear portions of the curve above and below the Tg represent the respective rates of thermal expansion CTE". (CTE ą1: "50C – 150C", CTE ą2: "150C – 250C)
  - **Important Note:** A critical point for consideration is; A material with a higher Tg will delay the increase in CTE through thermal excursion for that resin system, but total expansion can be significantly different for each material type.

- **Expansion of the entire assembly during reflow and assembly will be drastically increased with the introduction of Pb-Free solders and the corresponding requirement for higher peak temperatures and extended time above the Tg of the materials.**

- **Control of CTE values for base materials will be critical.**

Key Pb-Free
Process Capable Material Attributes-3

Tg – (Glass Transition Temperature) –

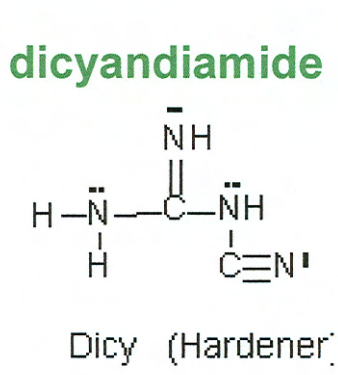
- Temperature at which the materials changes from a semi-rigid to a softened state.
- Tg can be determined using several methods, DSC, DMA & TMA.
- (TMA) Thermal Mechanical Analysis Measures dimensional changes as a function of temperature. This technique allows for calculation of both Tg and CTE.
- (DSC) "Differential Scanning Calorimeter - Measures heat flows and temperatures associated with phase transitions.
  - The DSC is typically used for determining cure via glass transition temperatures measurements on epoxy systems.
- (DMA) "Dynamic Mechanical Analysis" measures mechanical properties as a function of time, temperature, frequency, stress, and combinations of these attributes.

Note: All Three Test Methods Above Will Yield Slightly Different Tg Test Results.

- Generally Tg Results will Rank as Follows DMA > DSC > TMA.

What does Phenolic Mean?

- **Dicy and Phenolic Refer to Curing Method for FR4 Epoxy Resin.**
  - Phenolic also Referred to as “Novalac”
- **Most of Today’s FR4 Epoxy Laminate is cured with Dicyandiamide (Dicy).**
- **Dicyandiamide is Hygroscopic. i.e. a Substance that attracts Moisture from Atmosphere.**
  - Moisture can Affect Final Cure (Tg).
  - Moisture is Retained in Final Cured PWB.
  - Moisture is Bad for Finished Board and Solder Process (Delamination)
- **Phenolic Cured FR4 Reduce Moisture Absorption.**
  - Improve Cure and Therefore Final Thermal Performance.
  - Reduce Moisture Content in Finished Board Improving Solderability.
- **The Best Pb-Free FR4 Epoxy Multilayer Materials on the Market are Phenolic Cured.**
- **Specialty Pb-Free High Speed – Low Loss Materials May not be “phenolic” cured.**
  - Megtron Plus
- **Matsushita R-1755 is a Phenolic Cured Laminate Material.**



Who Defines Pb-Free?

- **OEM**
  - With Help of Assembler.
- **Specs are Individually Set.**
  - Design and Application Specific.
  - End-Use Solder Specific.
  - Example: How Many Solder/Heat Cycles will Finished Board See. (# of Lamination Cycles, HASL, Wave Solder, Rework, etc.)
- **No Generic Spec. Developed Yet.**
- **Guidelines are Forming.**
  - Thermal Decomposition is Key.
  - CTE
  - T260, T288, IST, and CAF Testing Prominent.
  - Tg is No Longer Sole Determining Characteristic.
- **Next Six Months Should Generate Generic Guidelines**
  - IPC 4101B
  - New Laminate Slash Sheets for RoHS Compliant Materials.
    - Slash 99
    - Slash 121
    - Slash 124

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Proposed IPC Specifications

IPC 4101B – New Slash Sheets Proposed.

- 4101B /99 – Filled Non – Dicy.
- 4101B /121- RoHS – Dicy.
- 4101B /124 – RoHS Non - Dicy.

- **Requirements:**
  - T260 > 30 Min.
  - T288 > 5 Min.
  - Td > 330C
  - CAF and IST Spec also Proposed.

What about Lead Free Double – Sided?

- **Phenolic Use in Doubled Sided Applications is Rare.**
- **Standard 170Tg Materials Work Well.**
  - Minimal Thermal Excursions.
    - 1X – 3X Most
  - Low Value Content of Finished Part.
    - Part Fails…Throw Away.
- **HF Materials May be Future:**
  - Typical Tg 155C
  - Td – 340-350C.
- **Matrix USA Evaluating Option for Double-Sided Pb-Free.**
  - 170Tg KB 6167 Available Today
  - 155Tg KB 6162 Halogen Free Available Q1 2006.
  - 175Tg Panasonic R1755 “Phenolic” Available Q1 2006.
- **Options Downside: Cost – Approx 40-50% Premium.**

Panasonic
Pb-Free Process Capable Materials

- **All Panasonic Laminate Materials meet RoHS Specifications.**
  - R-1755
    - Hi-Performance FR-4 Laminate and Prepreg.
    - Properties and Performance.
  - MEGTRON Plus
    - High Speed/Low Loss Laminate and Prepreg.
    - Properties and Performance.

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1755 Critical Properties

Test Element	Value	Test Method	Units	FR4 170 Tg	1755
Dk (RC=53%)	1 GHz	IPC-TM 650		4.22	4.24
Df (RC=53%)	1 GHz	IPC-TM 650		0.017	0.018
Tg		TMA DSC	℃ ℃	165 170	170 175
CTE	Z – a1 Z – a2	TMA	ppm ppm	60 265	50 240 (3.2%)
Thermal Decomposition		TGA	℃	310	364
Time to Delam	T-260℃ T-288℃	TMA	mins.	20 2	100 60
IST	Condition 3 X 260 ℃	PWB, Inc.	cycles	> 150	> 500
Solder Float		IPC-TM 650	N floats to failure	4 X	10 X
HAST		IPC-TM 650	Hours	> 120	> 500

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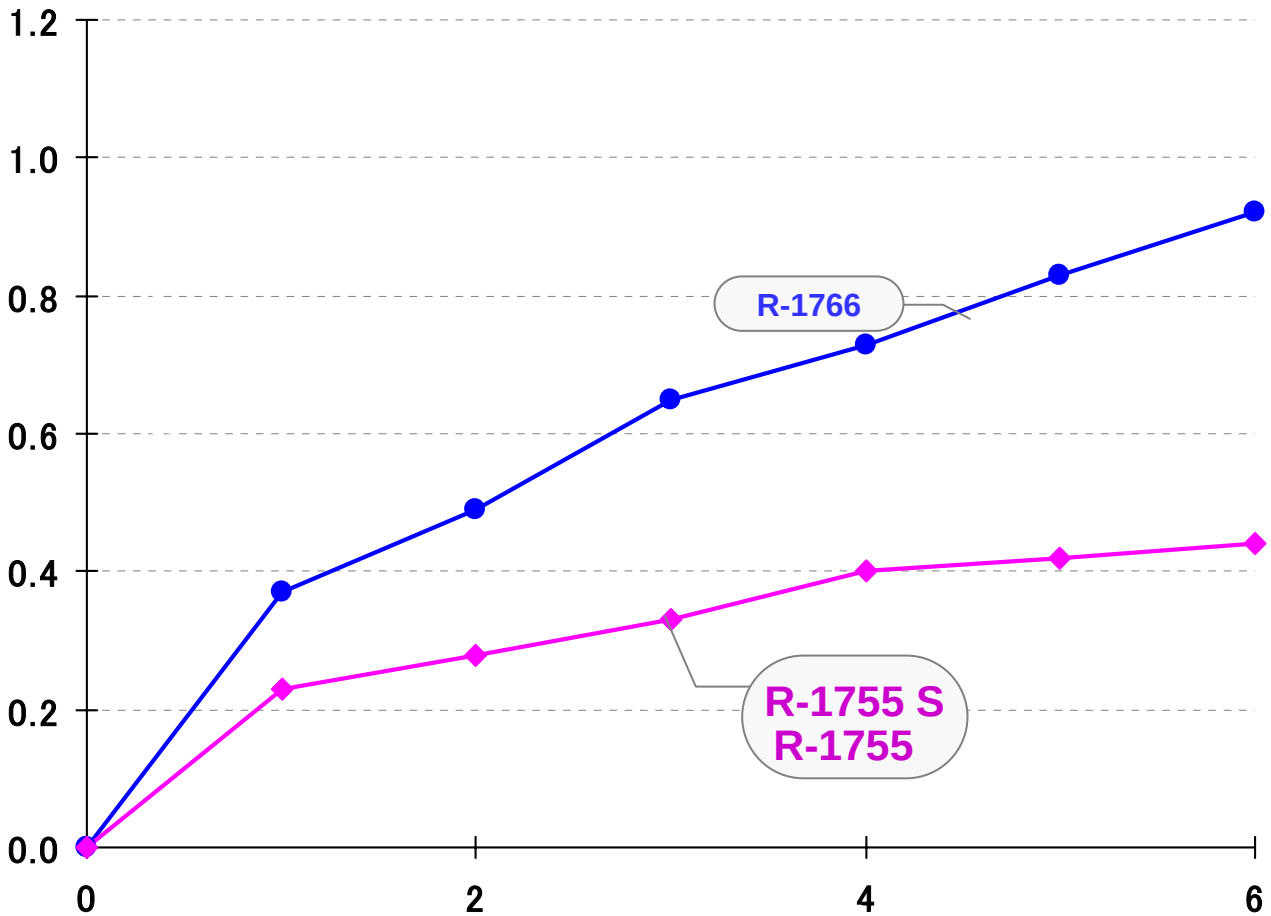
Moisture Absorption is Key



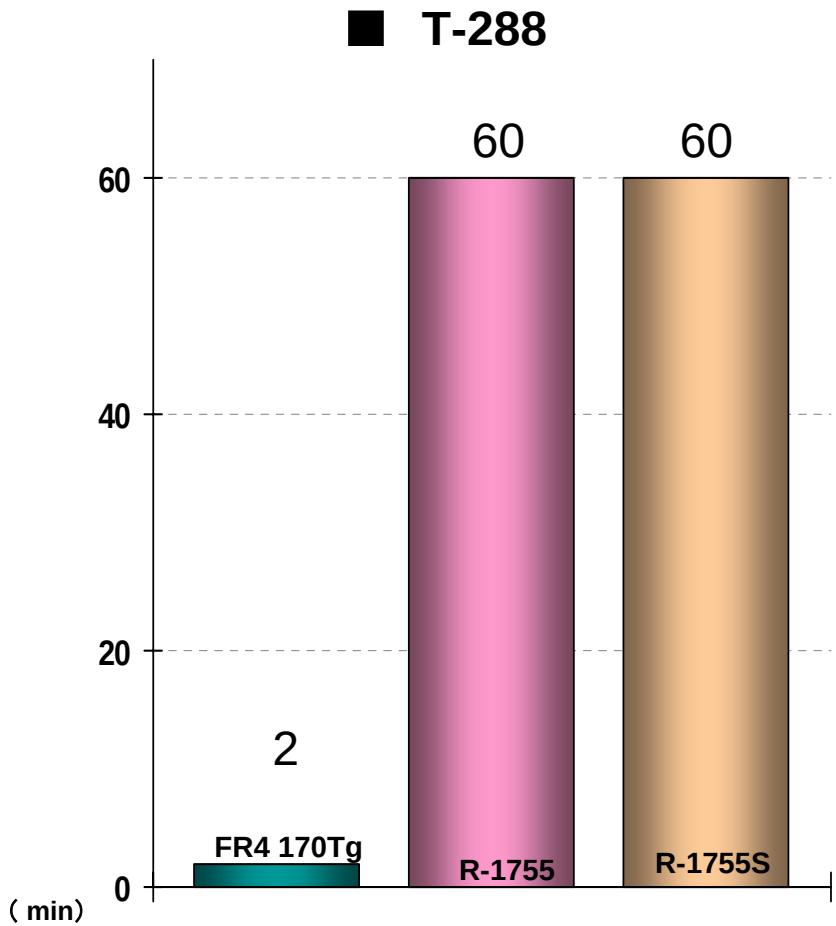
The above data is obtained from actual test samples. Results may vary

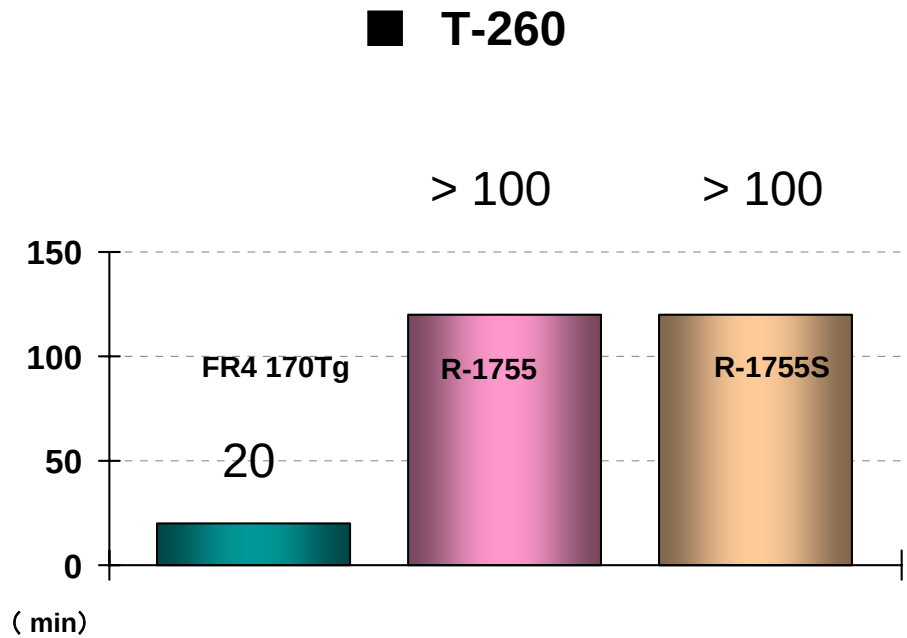
■ Test Condition

PCT 121℃
100%RH

thickness：1.0mm

Thermal Reliability





The above data was obtained from actual tested materials. Results may vary.

MEGTRON Plus Critical Properties

Test Element	Value	Test Method	Units	MEGTRON	MEGTRON *Plus*
Dk	**1 GHz**	**IPC-TM 650**		3.75	**3.79**
Df	**1 GHz**	**IPC-TM 650**		0.0103	**0.0089**
Tg		**TMA** **DMA**	℃ ℃	172 185	175 190
CTE	**Z – a1** **Z – a2**	**TMA**	**ppm** **ppm**	60 270	**52** **245 (3.3%)**
Thermal Decomposition		**TGA**	℃	315	**324**
Time to Delam	**T-260**℃ **T-288**℃	**TMA**	**mins.**	30 4	**40** **10**
IST	**Condition** **3 X 260 ℃**	**PWB, Inc.**	**cycles**	> 300	**> 400**
Solder Float		**IPC-TM 650**	**N floats to failure**	6 X	**8 X**
HAST		**IPC-TM 650**	**Hours**	➢300	**> 450**

24 Layers Multilayer Circuit Board

Test Item		MEGTRON PLUS	MEGTRON
Solder float 10 seconds	288C - 6 x	Good	No Good - Delam
	260C - 6 x	Good	Good
Temperature Cycle -65C ⇔ 125C		1000 cycle Passed	> 100 cycle Passed

PWB Fabricator Pb-Free
Compliance Requirements

- **Qualify a Suitable Pb-Free Laminate Material.**
  - Panasonic R-1755, Megtron Plus.
- **Qualify a Suitable Pb-Free Final Finish.**
  - Electroless Nickel Gold
  - Immersion Tin
  - Immersion Silver
- **Convert HASL Operation to Pb-Free Alternative.**
  - New Equipment Required.
  - Tin Copper Alloy Solder Replacement.

Panasonic as First Choice Pb-Free Laminate

- **Comprehensive Line.**
  - Hi Performance FR4 – R-1755.
  - Volume High Speed Low Loss Materials – Megtron Plus.
  - High Tech High Speed Low Loss Materials – Megtron 5, Megtron 6.
- **R-1755 – Major OEM's First Choice for Pb-Free Laminate.**
  - Ranked #1 in Thermal, CAF and IST Performance.
  - "Plug and Play" Compatible with Standard 170Tg Manufacturing Processes.
  - Competitively Priced.
  - Available Throughout North America from Matrix and Matrix Distributors.
- **Proven Quality**
  - Manufactured by the World's Largest PWB Laminate Manufacturer in 10 Global Plants.
- **Proven Technology**
  - Matsushita has Provided Global Leadership in Technology Development for Printed Circuit Materials.
- **RoHS Compliant – All Panasonic Materials Meet EU RoHS Requirements.**

R-1755 Competitive Advantages

- CAF Resistant
  - Best in Class – IBM
  - No Failures at Fabricators to Date.
- IST
  - At Times >1,500 cycles.
  - Top of the Class
- Resin Flow
  - Fills Heavy Copper Designs.
  - 15% Better Flow Than Comparative Dicy Designs.
  - Filled Materials Have Reduced Flow.
- No Cure Advance
  - Does NOT Continue to Cure After Initial Material Cure Cycle.
  - No Embrittlement.
  - Optimized for Sequential Lamination.
- Transmission Loss
  - All Phenolic Cured Laminates Have Greater Transmission Loss Than Dicy Materials.
  - Fillers Increase Loss, R-1755 does Not Have Filler.

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Summary

- **Lead Free is Here to Stay.**
- **Time is Running Out For Qualification.**
  - July 2006 Deadline.
- **Future Proof Your Operation.**
  - Qualify R-1755 and Megtron Plus.

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