Latest on Lead-Free Capable Materials

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SUMMARY — Advancements in lead-free materials are not necessarily restricted to the materials themselves; they often develop in our knowledge base of the characteristics and performance criteria of the already available library of materials in the marketplace. This is truly the low-hanging fruit.

Advancements in Materials... or in the Way We Think?

It's been over five years since RoHS compliance took hold. Initially, the topic dominated industry conversation as it seemed everyone had an opinion on properly transitioning to compliance. Apparently, this topic ran out of gas — at least from a copper-clad laminate standpoint.

It's time to fire up that engine again and examine some new materials in development as well as a few existing ones that were neglected from the outset — at least from the North American standpoint.

According to Steve Jobs, "You can't connect the dots looking forward; you can only connect them looking backwards." This article will review learned experiences, interpret current methods and analyze developing laminates.

How We Specify Lead-free Capable Laminates

Referencing the IPC-4101 PCB materials standard is the most efficient way to specify raw materials. This automatically aligns your fabrication notes to the latest version of this standard. Below is a summary of the most common lead-free capable laminates, from the IPC-4101 standpoint.

There are six distinct silos here, but I consider there to be three distinct categories. The only thing that distinguishes one material from its corresponding pair is the presence of fillers.

If you've read some of my past pieces, I'm probably going to sound like a broken record. You're actually right, but only because I see the same mistakes being made continually. It's almost as if designers are copying and pasting fab notes from past revisions to current designs, but that's just crazy talk. No one does that...

Initially, most customers reflexively specify "best" materials rather than performance-appropriate ones. After addressing more pressing matters, such as component libraries and new line administrations, they would return to evaluating other grades of materials to enjoy cost savings.

The original goals have been accomplished;

“ Initially, most customers reflexively specify “best” materials rather than performance-appropriate ones. ”

	/99, /124	/101, /121	/126, /129
Resin System			
Primary	Epoxy	Difunctional Epoxy	Epoxy
Secondary 1	Multifunctional Epoxy	Multifunctional Epoxy	Multifunctional Epoxy
Secondary 2	Modified/Non-epoxy (max 5%)	Modified/Non-epoxy (max 5%)	Modified/Non-epoxy (max 5%)
Fillers	99: Inorganic; 124: n/a	101: Inorganic; 121: n/a	126: Inorganic; 129: n/a
T_g	150 C min.	110 C min.	170 C min.
T_d	325 C min.	310 C min.	340 C min.
T260 (min)	30 min	30 min	30 min
T288 (min)	5 min	5 min	15 min
T300 (min)	ABBUS	ABBUS	2 min

Due to fillers, IPC designates 6 distinct silos but we’ve trimmed it down to three by conflating corresponding materials.

Figure 1: IPC 4101.

poor Larry the Lead-Free Laminate Specification, on the other hand, was abandoned faster than the Microsoft Zune.

I’m annoyed when reading articles in which the author’s opinion either outweighs or completely lacks factual evidence (maybe another thing that no one does?), so let’s review some user polls we took on this topic.

Materials are specified in a variety of ways. Only Td addresses the material’s lead-free assembly capabilities; the rest do not. Since this poll was taken a few years ago, we do see more

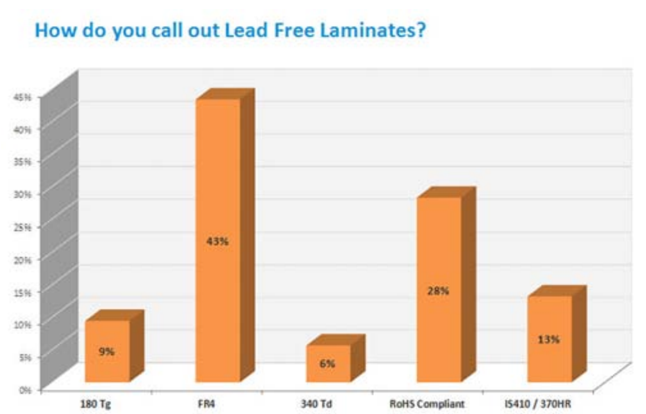

Figure 2: Laminate poll.

notes calling out the IPC-4101/126 or /129 reference, but there’s still work to be done.

Delaminate Already

The industry needs to deal with delamination. While phenolic materials have great thermal properties (Tg > 170°C and Td > 340°C, when conforming to IPC-4101/126 or 129), most are extremely weak in the fundamental areas of moisture absorption and copper-to-laminate adhesion.

Moisture Absorption

Standard 130Tg FR-4 materials typically have a moisture absorption rate of 0.20% when measured using a 0.028” thickness core material. Using the same test vehicle, phenolic materials often measure moisture absorption up to 0.45%. These results no longer appear on data sheets, however, as test vehicles have been altered to 0.059” thickness.

Copper to Laminate Adhesion

Standard 130Tg FR-4 materials generate peel strength results of 8-10 lbs. Holding all parameters equal, phenolic materials generate peel strength results of 3-4 lbs.

Vapor Escape

Material characteristics exacerbate lead-free assembly parameters. Absorbed moisture remains trapped in the PCB until escaping the dielectric from the weakest point in the board, which is typically plated via holes. During standard SnPb assembly at 200°C, the vapor pressure is 225 psi. At lead-free assembly temperatures (250°C), however, the vapor pressure increases to 575 psi.

The Perfect Storm

Combining the increased vapor pressure with phenolic material characteristics of increased moisture absorption and lower adhesion strength creates a perfect storm capable of ruining entire production runs. In fact, the forces here are so strong that often, instead of just blowing vias, entire layers separate from each other forming delamination areas of 1 square inch or greater.

SEC Solution

Mid-Grade Materials

We advocate using mid-grade materials found under IPC 4101/99 and /124. While thermal properties (150°C Tg and 325°C Td.) are lower than /126 or /129, the mechanical characteristics more than compensate (demonstrated in lab tests below). Further, I have yet to find one person in the industry who can give me a formula showing the extra benefits of a 5 or 10 degrees T_d increase. For more detailed information, please view our [Lead-Free Cost Reduction webinar]().

Test data on IPC-4101/99 and /124 materials:

In the final analysis, standardized lab tests and assembly simulation demonstrated that IPC-4101/99 and /124 materials not only outperform /126 and /129 materials regarding moisture absorption and peel strength, but also pass (without a single failure) 6x lead-free reflow at 260°C peak temperature.

Now, Let Me Blow Your Mind...

Commercially, the lead-free transition immediately increased the bare board's cost. For the most part, this cost was magnified in low-tech, low layer-count boards.

In general, the lower the layer count and technology, the higher the percentage cost increase that was incurred on behalf of the

Test Group	Results
Condition	Condition A
Peel Strength Side 1:	11.73 lbs/in.
Peel Strength Side 2:	10.95 lbs/in

Figure 3

Test Group	Results
Percent Weight Loss:	0.20%
Start Temperature:	0 degrees C°
Stop Temperature:	0 degrees C°
Comments:	Moisture Method
Weight Loss % by TGA	% Weight Loss = 0.1717%

Figure 4

Conditioning	As Received
Board Number	14573-1
Material	IS400
Conveyor Speed (cm/min)	48
TC Temp Range	3.4
Time above 217	101
Passes to Fail	6x Pass

Figure 5

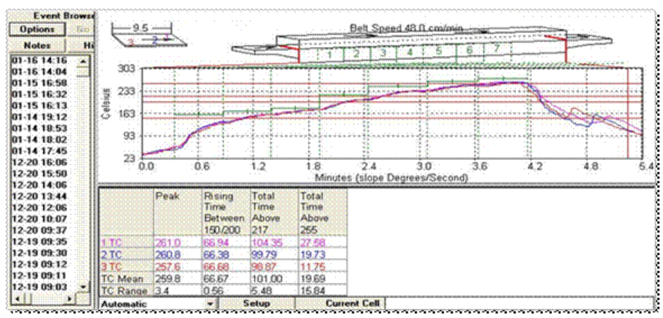

Figure 6

user. This has a great impact since, by volume, 2-8-layer boards account for a high percentage of mainstream PCB purchases.

As an illustration, let's consider a simple 4-layer board priced at domestic high volume.

Characteristic	SnPb Cost	Pb-Free
Base Board Price (10" x 6")	$12.00	$12.00
Final Finish	SnPb HASL: $0	ENIG: $ 4.50
Laminate	/21 FR4: $0	/129 FR4: $ 2.00
Total Cost	$12.00	$16.50
% Increase	0.0% - baseline	54%

Figure 7

Proposing a lead-free alternative buildup with less than 10% net cost added may evoke skepticism; however, here is such a proposal:

Characteristic	SnPb Cost	Pb-Free
Base Board Price (10" x 6")	$12.00	$12.00
Final Finish	SnPb HASL: $0	SN100CL: $ 0.50
Laminate	/21 FR4: $0	/101 or /121 FR4: $ 0.40
Total Cost	$12.00	$12.90
% Increase	0.0% - baseline	7.50%

Figure 8

IPC-4101/101 and /121 laminates have been largely ignored in the North American market, perhaps because they are viewed as too risky for such an extreme process as lead-free assembly.

We commissioned 1000-hour thermal cycling testing between -40°C to +125°C based on the following ramp and dwell rates:

1000-Hr Thermal Cycling Test	
-40°C to +125°C	5 minutes
Time @ +125°C	25 minutes
+125°C to -40°C	5 minutes
Time @ -40°C	25 minutes

Figure 9

The total time for each cycle is one hour, with 1,000 such cycles comprising the total test.

The test vehicle is an 8-layer daisy chain coupon with the following hole-size characteristics:

Drilled Hole Size	Finished Hole Size
8 Mils	6 Mils
10 Mils	8 Mils
12 Mils	10 Mils
14 Mils	12 Mils
16 Mils	14 Mils

Figure 10

The test vehicle was conditioned by processing three times through a lead-free reflow profile and then submitted for thermal cycling. Following is a chart displaying the number of failures by finished via diameter at each measurement interval. Failure is established if the resistance between endpoints of a specific via diameter daisy chain increases more than 10%.

Test Vehicle Failures (marked endpoint)					
FHS	0 hr	336 hr	612 hr	750 Hr	1008 Hr
0.006	0	10	11	11	11
0.008	0	0	2	4	7
0.01	0	0	0	0	0
0.012	0	0	0	0	0
0.014	0	0	0	0	0

Figure 11

Note that the test vehicle was fabricated with little pre-engineering with regard to drilling and desmear parameters. Based on this and the test results, we can easily establish that this material has a wide processing window and that there should be little concern to use this material type down to a 10-mil finished via size for high-reliability applications. The test parameters used were for on-engine applications.

OEMs can determine what cycling temperatures and number of cycles best fit their applications, which may increase or decrease the applicability window of this particular class of materials.

Regardless of the work involved in qualifying this third grouping of materials, the cost

savings could be well worth the added effort of reopening the book of lead-free capable materials in most organizations.

Conclusion

Advancements in lead-free materials are not necessarily restricted to the materials themselves. Rather, they often develop in our knowledge base of the characteristics and performance criteria of the already available library of materials in the marketplace. This is truly the low-hanging fruit. **PCB**

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