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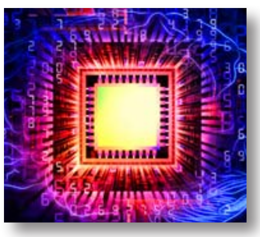
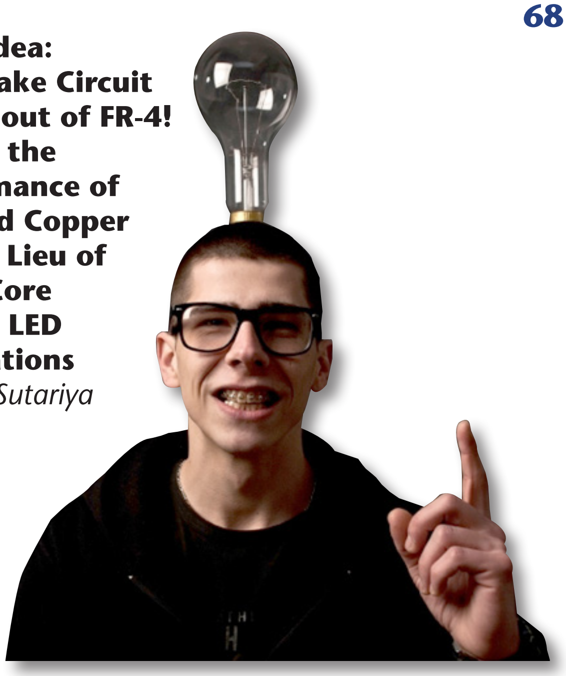
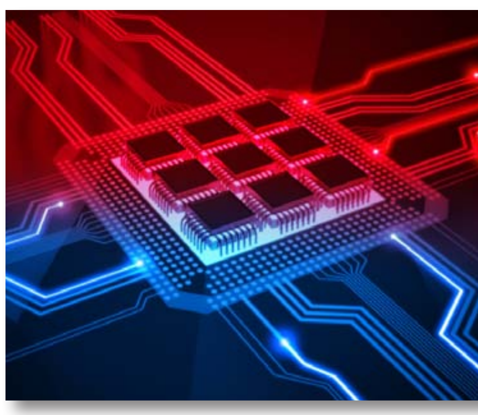
THERMAL MANAGEMENT

Electronics manufacturers learned long ago that it's much safer to be proactive with thermal issues throughout the product development process rather than face such issues when it's too late. So why do thermal issues still get the "Rodney Dangerfield" treatment?







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THE WAY I SEE IT

Chasing Our Tails

by Ray Rasmussen
I-CONNECT007

SUMMARY: The IPC conference on tin whiskers drew a who's who of the high-reliability world, eager to learn the latest and greatest around this complex and sometimes perplexing issue.

Although I'm not old enough to remember those early days when solders were made mostly of tin (it was easy to work with and had a low melting point), it was back then when the engineers of the day were looking into product failures. They started to notice the presence of what looked to be small metal hairs growing between metal solder pads. These hairs were causing short circuits. The problem seemed to be solved by adding lead, which prevents the growth of the hairs.

First discovered in the early 1950s and solved a few years later, the tin whiskers issue seemed to be more of a hiccup rather than the crisis it's becoming today. The subsequent 50 years were virtually whisker-free, and electronics found their way into just about every product in one form or another.

Then, not long ago, we decided to *unsolve* the problem and let the pesky whiskers out of their box with the introduction of lead-free solders (more tin, no lead).

So, here we are again, looking for solutions to this problem we solved over half a century ago. It's a good thing for conference promoters, associations, engineers, and materials and equipment suppliers who are all working to develop solutions to this perplexing problem, again. It's good for the press, too; there is a lot going on, and lots to write about.

Chasing Our Tails

From the outside looking in, it's pretty easy to be critical of the efforts around this issue at a conference like this one. Since I'm not caught up in it, maybe I can help bring some perspective to this effort. To me, it looks like we're chasing our tails.

As I mentioned, the conference was well attended, which should tell you something about the magnitude of the problem. The audience was comprised of many companies that need high-reliability electronics for military applications, which, in some cases, need to last for decades, literally ready to fly off at a moment's notice to attack an adversary overseas. There were many military suppliers in attendance, along with a few OEMs from the medical and automotive communities who face similar issues with reliability and longevity.

Here are a few of the companies in attendance: Celestica, Cessna, DDi (now Viasystems), Delphi, Draeger Medical, DRS, EADS, Fugitsu, Goodrich, Honeywell Aerospace, L-3, Lockheed Martin, Molex, Moog, Murrietta Circuits, NASA, NPL, Northrup Grumman, Philips Healthcare, Raytheon, Robert Bosch, Rockwell Collins, Texas Instruments, U.S. Army, Uyemura, along with many others (95 in total). As you can see from the list, only a few materials suppliers, a couple of board fabricators, and one EMS provider were present. Interesting. I thought this would have been a great place to tout one's technical savvy or introduce new, exciting materials that solve the tin whisker problem. No TTM, no Endicott Interconnect, no Sparton, no Flextronics or Sanmina. Where were the solder suppliers or the conformal coating


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CHASING OUR TAILS *continues*

suppliers? Those two groups of suppliers' materials were the topic of discussion in most of the presentations. Did they avoid the conference on purpose, eager to avoid the tough questions that would have been posed by a crowd of engineers who are on the hot seat to come up with a solution?

The more complex a solution is to a problem, the more likely that problem will recur. Smarter people than me have figured that out over the years, hence the sayings like KISS (keep it simple, stupid) and something that goes like this: "If all things are equal, the simplest solution is the best."

From my view in the "cheap seats," this is a complicated mess which will only get worse. You see, the rules around lead-free, which have pushed the industry to remove the solution to the problem, since there isn't a drop-in replacement, has resulted in dozens of variations of new solders and dozens more on the drawing board. The reason for the many solder alternatives is that they all have shortcomings. None of them work the way leaded solder has for such a long time.

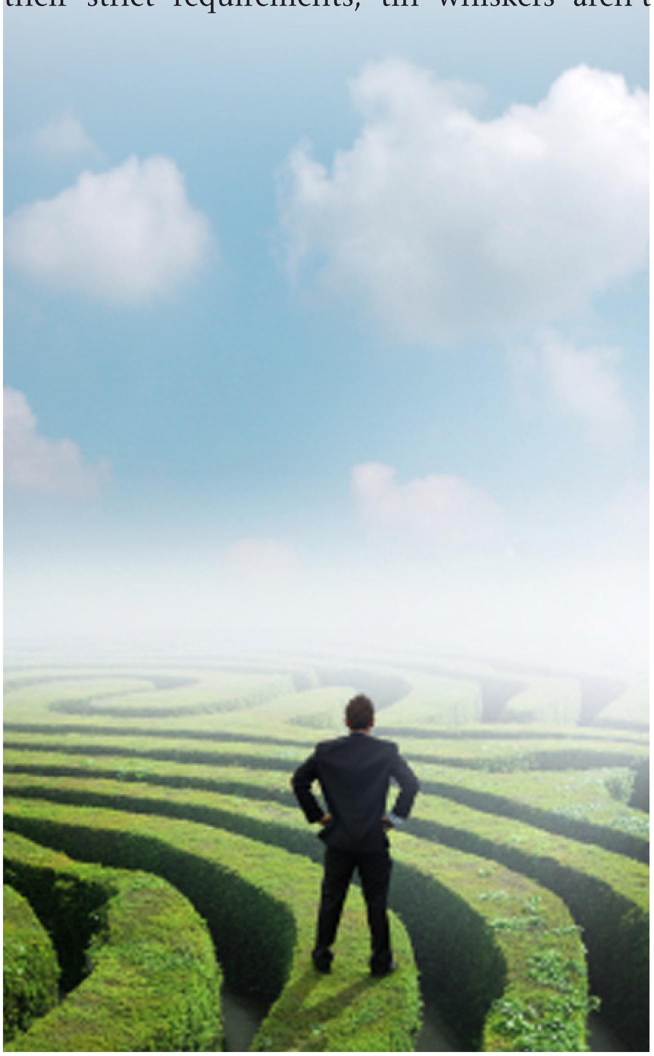
In addition, these new solders melt at substantially higher temperatures, sending ripples through the entire industry as suppliers have had to develop new materials to handle the higher temperatures. As a result, we have issues with copper dissolution, assembly issues with bottom-side terminations, and pad cratering, to name a few. On top of all that, things are shrinking. Everyone wants to do more, much more, in a lot less space. The shrinking dimensions will require new materials, which will have to be compatible with everything else.

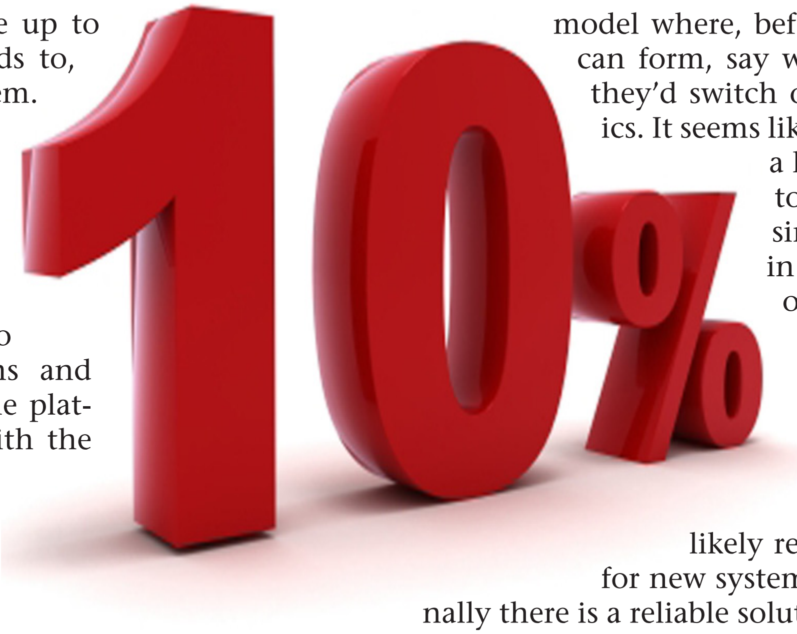
Now, with all the variables added to the process (new materials, new problems creeping up all the time, known problems without solutions, etc.) it seems to me that we're getting nowhere fast. We're all hoping for that magic bullet (like the lead bullet that solved the problem the first time). Maybe someone will develop that perfect replacement and we can put this one behind us. Let's hope so.

Can We Find Our Way Out?

It's the process, stupid! That was basically the message in a presentation from Werner Huegel of Bosch. They've been working on this issue since the early 2000s, knowing they wouldn't be exempt from RoHS and wanting to ensure reliable products for their customers. As Huegel pointed out, Bosch products can be found in every car on the planet, so they have quite a bit at stake. Reliability is critical for them and their customers. Although many suppliers in the crowd were pleased to hear about Bosch's progress, the jury's still out for most of them. Bosch's four or five years of data is encouraging (whisker-free with their processes), but the Mil/Aero guys have a requirement for 100% uptime over 30 years.

To dial in their lead-free processes, they focused on the root cause of whiskers and claimed basically to have solved the issue as a result of tight process controls around plating of the component leads. If their suppliers follow their strict requirements, tin whiskers aren't





an issue. If that's done up to spec, the problem tends to, well, not be a problem. When asked for some more specifics about the Bosch process, Huegel declined to divulge any of their secrets, but he did think it would be possible to share his specifications and audit info regarding the plating on components with the audience.

The other highlight for me was a presentation from Russell Hallman of Y-12 National Security Complex, who recently started working on the whiskers problem. He and his team are taking a fundamental approach to the problem and really looking deeply into the composition of the metals. It's not necessarily new, but they did come up with an interesting approach. They found that they could manipulate the grain structure of SAC solders using magnets. It seems to have an interesting effect on formation of whiskers. As we saw in several of the presentations, the grain structure seems to make all the difference as to whether whiskers will form or not.

The 10% Solution

Although exempt from RoHS and lead-free, the Mil/Aero guys are struggling to get the lead materials and components they need to avoid the pesky and sometimes deadly conductive metal hairs that crash billion dollar systems. Representing less than 10% of the industry, and subject to the whims of the more dominant sectors like consumer electronics, they know lead is dead. They have to figure out how to work in a lead-free world, or… not?

A couple of interesting ideas were bandied about, such as whether the Mil/Aero guys would leave the COTS (consumer off the shelf) market and move back to proprietary models to ensure long-term life and reliability of their systems. Another idea, which might be altogether better, would be a planned obsolescence model where, before the whiskers can form, say within five years, they'd switch out the electronics. It seems like there would be a lot of advantages to this solution since great leaps in technology can occur with each cycle, allowing these systems to take advantage of the latest and greatest technology, likely reducing the need for new systems. Plus, when finally there is a reliable solution, they can go back to their long-term legacy mentality, but I doubt they will. Once they get used to it, they'll want to upgrade systems on a regular basis.

S.A.F.E. (Solderless Assembly for Electronics)

What I didn't see during the two-day conference was a new look at how we're doing things. To really get on top of these issues, we likely have to reinvent the way we're building electronics. I would have expected some serious discussions around new approaches to manufacturing. If you lay out where we need to go with our electronic systems, we are going to have a very hard time getting there with what we're currently doing. We're pushing a wet noodle. We have to change the way we do things if we want a different result.

My good friend Joe Fjelstad and I have had many conversations about these alternatives. And although I don't pretend to know what Joe knows, what he says seems to make a lot of sense. And, since many of Joe's patents (hundreds, I believe) are actual products working in the field, he does know what he's talking about. He isn't just an idea guy, but someone who knows how to build useful, innovative products.

I was talking to Joe after the conference and he pointed out that he's given private presentations on the Occam Process to some of the folks in attendance at the conference. He's actually visited their factories and sat down face-to-face

CHASING OUR TAILS *continues*

with their engineering teams, without result. I don't think it's just a case of someone trying to protect their turf; they're so focused on solving today's problems that they don't have the bandwidth to take on something like Occam. Additionally, most were already complaining about constrained budgets just to work on the projects around whiskers. I'm sure that getting money for something like Occam which, granted, needs a lot of development dollars and years of study to prove long-term reliability, would seem like an almost impossible task to them.

It may be the right thing to do, but the high-reliability guys are just going to have to wait until they start hitting some technical walls that can't be climbed. The pain isn't quite high enough yet. Once the pain threshold is exceeded they'll be able to break loose some funding for the R&D needed. At that point, it will be a crisis, but that's usually what it takes to get the right people aligned with the resources necessary to solve a complex problem.

From what I can see out there, it's the commercial market that will bring something like Occam to market sooner. It will be because Occam solves some technical or cost hurdle, which Joe is certain can happen. Again, the Mil/Aero and medical guys won't hit the wall as soon as, say, Apple suppliers, who are relentlessly being driven to double or triple performance every year.

After two days of listening to some of the biggest companies talk about what they're doing to get on top of this issue, it seems to me that if there is a light at the end of the tunnel, it's most likely a train. All I see going forward are more and more meetings like this one, doubling in attendance each year as this issue begins to creep (pun intended) into mainstream electronics. It's been nearly six years since RoHS took effect, which seems to be about the time tin whiskers began to do their damage. Over the next few years, things should begin to unravel.

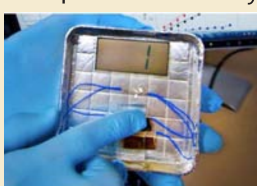
At that point, we'll have some decisions to make. **SMT**

Ray Rasmussen is the publisher and chief editor for I-Connect007 Publications. He has worked in the industry since 1978 and is the former publisher and chief editor of *CircuiTree Magazine.* Contact Rasmussen here.

Berkeley Lab Scientists Generate Electricity From Viruses

Imagine charging your phone as you walk, thanks to a paper-thin generator embedded in the sole of your shoe. This futuristic scenario is now a little closer to reality. Scientists from the U.S. DoE's Lawrence Berkeley National Laboratory (Berkeley Lab) have developed a way to generate power using harmless viruses that convert mechanical energy into electricity.

The scientists tested their approach by creating a generator that produces enough current to operate a small liquid-crystal display. It works by tapping a finger on a postage stamp-sized electrode coated with specially engineered viruses. The viruses convert the force of the tap into an electric charge.



Their generator is the first to produce electricity by harnessing the piezoelectric properties of a biological material. Piezoelectricity is the accumulation of a charge in a solid in response to mechanical stress.

The milestone could lead to tiny devices that harvest electrical energy from the vibrations of everyday tasks such as shutting a door or climbing stairs.

It also points to a simpler way to make microelectronic devices. That's because the viruses arrange themselves into an orderly film that enables the generator to work. Self-assembly is a much sought after goal in the finicky world of nanotechnology.

Scientists fabricated a virus-based piezoelectric energy generator and created the conditions for genetically-engineered viruses to spontaneously organize into a multilayered film. This film was then sandwiched between two gold-plated electrodes, which were connected by wires to a liquid-crystal display.

When pressure is applied to the generator, it produces up to six nanoamperes of current and 400 millivolts of potential. That's enough current to flash the number "1" on the display, and about a quarter the voltage of a triple A battery.

SMT PERSPECTIVES AND PROSPECTS

100 Points on Lead-Free Performance and Reliability, Part 1

by Dr. Jennie S. Hwang, *CEO*
H-TECHNOLOGIES GROUP

SUMMARY: In this month's column, the first of a two-part series, Dr. Hwang takes a wide, sweeping look at the history, timeline, highlights, and future projections for lead-free manufacturing.

After more than a decade of lead-free manufacturing, millions of products have been produced and put to use across many industry sectors and for people in all walks of life. What is the track record for lead-free electronics?

In a holistic view, this two-part column lays out the landscape in 100 points by taking into consideration manufacturability, reliability, and future trajectory. Each of the summary points will not be discussed or elaborated. However, inquiries about any of the points for scientific base, rationale, and further discussion are welcome.

1. From a supply chain perspective, lead-free electronics primarily comprises three parts: Solder joint, PCB surface finish, and components. All three components need to be lead-free for the final product to be lead-free.

2. Globally, many patents on lead-free solders have been issued, yet only a small percentage of those patents have actually worked on a commercial scale.

3. Technically, the design of a "robust" lead-free solder is an intricate task.

4. An intricate solder composition should not be translated to instability or lack of the required stability in application.

5. Metallurgical alloying, microstructure, and micro-structural evolution under an anticipated service environment are critical to the technical base.

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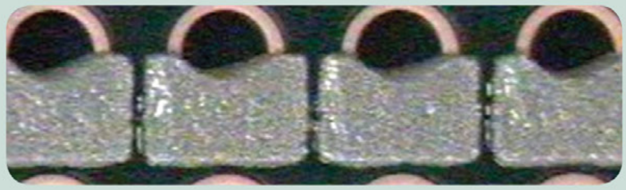

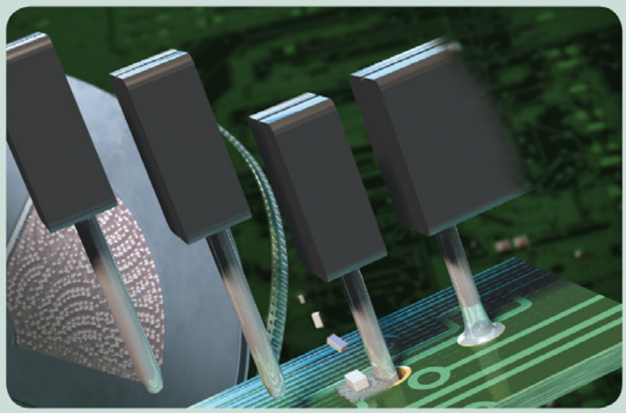

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100 POINTS ON LEAD-FREE PERFORMANCE AND RELIABILITY, PART 1 *continues*

6. For obvious scientific reasons, the greatest technical challenge comes when designing alloy compositions with a melting temperature (liquidus) less than 210°C without incorporating a high percentage of Mg, Zn Bi, In, and other low-melting elements.

7. R&D work in lead-free solder commenced long before the RoHS regulatory mandate.

8. Since inaction of the EU's initiative, RoHS has gone global.

9. Japan is a pioneer in practice.

10. Solder alloy selection in lead-free manufacturing is critical to the quality and reliability of lead-free electronic products.

11. A working solder composition is dictated by the existing SMT establishment.

12. A working solder composition should be dictated by the performance need for a specific application.

13. Several choices of solder joint alloys are available.

14. Several choices of PCB surface finishes are available.

15. Several choices of lead-free components are available, albeit with some limitations.

16. The PCB assembly process must work with all components for a specific design.

17. Constraints in the heat tolerance of components and the PCB bare board exist.

18. The choice of solder alloy drives the reflow processing temperature required.

19. The choice of solder alloy drives the wave pot temperature required.

20. The alloy drives process temperature and impacts reliability on both process and material fronts.

21. The main SMT operation modules (printing solder paste, pick-and-place, reflow, wave, inspection, testing, etc.) remain essentially the same as in SnPb production.

22. When a problem or defect occurs, the ability to separate SMT manufacturing issues from those induced or aggravated by lead-free is a prerequisite to obtaining an effective solution.

23. Production defects are often attributed to lead-free (SAC system).

24. No surprises in production results occur with the SAC system judging from the fundamentals and technical anticipation.

25. Production yield is in sync with the best practices in SMT manufacturing.

26. Practicing the assured compatibility between material and process is a prerequisite for high-yield, low-defect production.

27. Understanding the basics of compatibility in the material system is a prerequisite in implementing lead-free electronics.

28. Designing a compatible material system is a prerequisite for product reliability.

29. Contrary to perception, Bi is a relatively safer element than other metals often used in electronics.

30. If used properly, Bi and In can be beneficial to the properties and performance of solder alloys (lead-free or SnPb).

31. The manufacturing process is key to solder joint integrity by keeping two basics in mind: Solid bonding zone and well-formed microstructure.

32. The manufacturing process is key to an assembly's reliability—minimizing the co-planarity problem, heat-induced damages, and preventing defects, etc.

33. Commonalties and differences exist between SnPb and lead-free concerning production issues.

34. A high percentage of problems/defects that separate SnPb from lead-free are induced by the higher process temperature required for SAC solders.

35. A cardinal rule for rework: "Do it right at the first time." (Particularly for lead-free.)

36. Integrate manufacturing know-how and solder joint integrity to achieve quality and high yield.

37. Integrate manufacturing know-how and solder alloy intrinsic properties to achieve product reliability.

38. Reliability depends not only on the as-received (as-designed) materials and components, but also on the process that puts them together.

39. Reliability assessment requires the integration of material, process, testing, and data analysis while meeting fundamental principles.

40. Pay attention to not only obtaining test data, but also to data interpretation and integration.

41. Reliability assessment takes more than accelerated temperature cycling (ATC) tests.

42. One set of ATC testing does not necessarily translate into reliability. Circumspection in drawing conclusions is warranted.

43. Reliability assessment takes more than hard data—especially when the field data is scarce or nonexistent.

44. Extrapolation, experiences/knowledge, and meeting fundamental principles should be part of the equation in reliability assessment.

45. Reliability, a relative term, is to minimize probability of failure.

46. Tests can only verify reliability.

47. Meeting fundamental principles is key to long-term product reliability performance.

48. A life prediction model alone does not guarantee reliability.

49. Materials science principles work wonders—the observed phenomena and performance coincide with the teachings of materials science and metallurgical engineering.

50. No surprises observed thus far.

My next column, appearing in July, will continue with the remaining points of interest in lead-free manufacturing. **SMT**

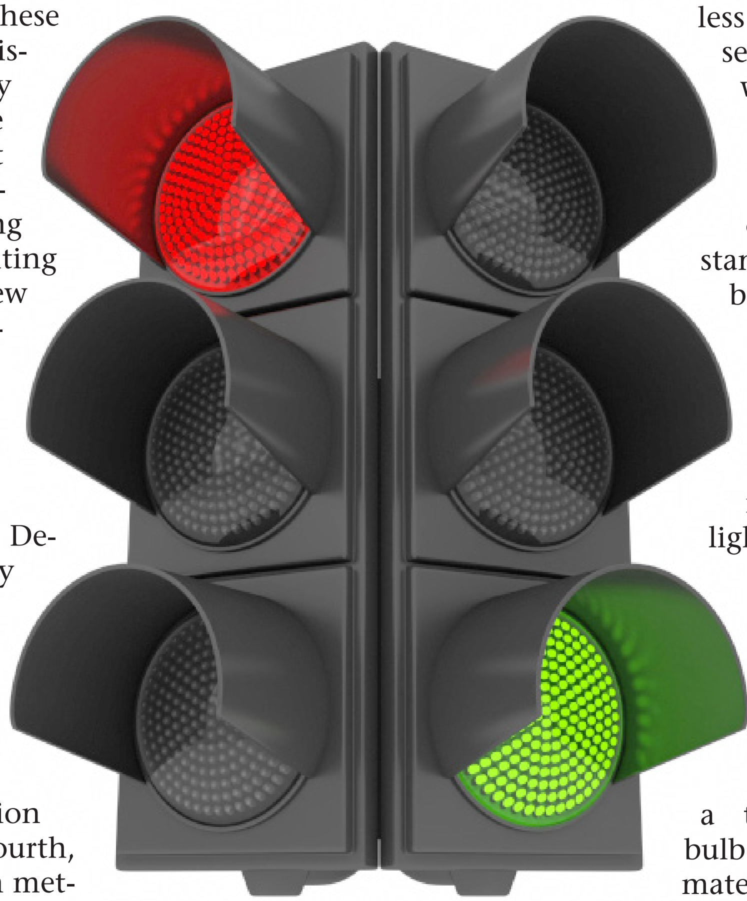
Dr. Hwang, a pioneer and long-standing contributor to SMT manufacturing since its inception as well as to the lead-free development, has helped improve production yield and solved challenging reliability issues. Among her many awards and honors, she has been inducted into the WIT International Hall of Fame, elected to the National Academy of Engineering and named an R&D Stars to Watch. Having held senior executive positions with Lockheed Martin Corporation, Sherwin Williams Co., SCM Corporation and IEM Corporation, she is currently CEO of H-Technologies Group providing business, technology and manufacturing solutions. She is a member of the U.S. Commerce Department's Export Council, and serves on the board of Fortune 500 NYSE companies and civic and university boards. She is the author of 300+ publications and several textbooks and an international speaker and author on trade, business, education and social issues. Contact her at (216) 577-3284; e-mail JennieHwang@aol.com.

Thermal Management for LEDs

by Anita LaFond
CONSTRUCTIVE COMMUNICATION, INC.

SUMMARY: The United States Department of Energy estimates that switching to LED lighting over the next 20 years could save $120 million in energy costs, reduce electricity consumption for lighting by one-fourth, and avoid 246 million metric tons of carbon. With this in mind, manufacturers are eager to meet the demand for energy-efficient LED designs and are looking for ways to make packages more cost efficient.

In the continuing quest for energy-efficient lighting products, light-emitting diodes (LEDs) offer many advantages such as low-energy consumption, long service life, and compact size. These beneficial characteristics make LEDs very popular with fixture designers who want to expand into the lucrative and burgeoning energy-efficient lighting market. And with new federal energy standards coming into effect this year, LED light bulbs are becoming more prevalent.



The United States Department of Energy (DoE) estimates that switching to LEDs lighting over the next 20 years could save $120 million in energy costs, reduce electricity consumption for lighting by one-fourth, and avoid 246 million metric tons of carbon. LEDs, therefore, have the promising capability to significantly reduce lighting energy use and impact climate change solutions in the U.S.

Switching to LEDs

In January 2012, the first phase of the Energy Independence and Security Act of 2007 (EISA) went into effect. The "Energy Bill" is an energy policy intended to make better use of our nation's resources and help the U.S. become more energy independent. Part of the law sets energy efficiency standards for light bulbs.

Under the new law, screw-based light bulbs must use fewer watts for a similar lumen output. Common household light bulbs that traditionally used between 40 and 100 watts must be redesigned to use at least 27% less energy by 2014. The second part of the law, which will go into effect in 2020, requires most light bulbs to be 60 to 70% more efficient than current standard incandescent bulbs. Many LEDs can meet this requirement today, and the industry is poised to provide viable, cost-efficient alternatives to standard lighting products.

As a substitute for incandescent lighting, compact fluorescent lighting (CFL) has also become more popular. Compared to a typical incandescent bulb (which lasts approximately 1,000 hours), a

CFL has a life expectancy of nearly 8,000 hours. These statistics, though, are "dim" in comparison to an LED bulb with its life span of 30,000 to 50,000 hours. CFLs, however, contain mercury, a toxic substance that makes disposal a potentially hazardous situation. LEDs contain no toxic materials, while offering high-quality illumination that is superior to incandescents and CFLs.

Managing Excess Heat

Manufacturers are eager to meet the demand for energy-efficient LED designs and are looking for methods to make LED packages more cost efficient. Thermal management is one of the most important aspects of successful LED systems design. LEDs convert only 20 to 30% of their electric power into visible light. The remainder of the light is converted to heat that must be conducted away from the LED die.

Excess heat is an unwanted by-product of LED design because it reduces light output and shortens the life span of the LED bulb. Therefore, managing thermal output to dissipate heat is crucial to maximizing an LED's performance potential. This is especially important for high-power/high-brightness LED applications such as streetlamps, traffic lights, and automotive head lights where long operating life is essential.

"Thermal management is one of the most important aspects of successful LED systems design."

In a typical LED configuration, the LED module is soldered to a metal-core printed circuit board (MCPCB) or a ceramic substrate, and bonded to a heatsink. The heatsink, made of thermally conductive material, dissipates heat away from the LED bulb into the atmosphere. With less heat contained in the LED package, the bulb can run cooler, resulting in a brighter light output and longer life time.

While the MCPCB configuration is widely used in the LED industry, it does not efficiently manage heat conductivity and can be expensive to produce due to high material costs. High-thermal conductive dielectric materials, such as aluminum nitride, are expensive; and cheaper ceramics, such as alumina, offer lower thermal conductivity.

As an alternative to more expensive materials or lesser performing materials, aluminum is gaining popularity as conductive material for LED packages. Although aluminum is less expensive and offers good thermal conductivity, it requires an insulation layer on the substrate.

Less Heat, More Light

According to Mitsuru Kondo, global LED project manager for Heraeus Precious Metals' Thick Film Division, thermal management really is the key to good LED design. "The LED light is relatively cool; it is the LED die itself that generates excessive heat and it is this heat that must be dissipated into the substrate," Kondo said. "The more heat you can dissipate into the substrate, the longer life will be generated from the LED light."

Long life expectancy is one of the LED advantages that is of particular interest to municipalities looking to save money and maintenance time on streetlight purchases. For example, in a typical streetlight outfitted with incandescent or fluorescent bulbs, the bulbs must be changed every six months to one year. Contrast this with an LED streetlamp fixture where the bulbs will last from three to four years. Less time spent maintaining streetlamps translates into immediate cost savings.

"LEDs really are on-trend for the general buying public, too," Kondo said. "The electrical energy savings makes LEDs a viable replacement for incandescent or fluorescent lighting, especially with the government directives mandating changes in the standard light bulb industry. Through mass production techniques and competition among suppliers, LEDs can be made less expensively. This will bring the prices down, making them more appealing to the average consumer."

Effective thermal management, therefore, is a crucial component for the growth of the LED industry. "Keeping the temperature low in an LED package is essential for optimal LED functionality," noted Kondo. "By lowering the temperature of an LED, the life expectancy of the LED can be more than doubled and overall costs can be lowered, and that will make LEDs much more attractive to the consumer."

Although LEDS are currently more expensive to purchase, the long life expectancy makes them a worthwhile investment. An LED that costs $30 can last for up to three years, while a $5 incandescent bulb has to be changed every five to six months. The total cost of LED ownership is cheaper and electrical costs are less expensive, along with the time savings in not having to change bulbs as frequently. LED manufacturers are working to get their costs down, so that the price of LEDs can be lowered also.

Successful Design

Four areas of thermal management are important to LED designers: Increased LED life, higher output of lumens, reduced heatsink size, and less LED chips. Effective heat dissipation helps to keep the temperature of LEDs lower which in turn improves brightness and life span. The ability to use less expensive substrates, such as aluminum, can also help to lower the overall cost of LEDs.

"If you can reduce the temperature by just 10°C, you can double the life of an LED," explained Kondo. "Lumen power can be increased and designers can reduce the number of LEDs needed without restricting performance. If you can reduce the amount of LEDs needed, while still producing the same output, you save money on the overall design cost."

For example, Celcion, a thick-film materials system offered by Heraeus, allows LED designers to build circuits directly onto aluminum substrates, eliminating the need for thermal interface materials. The insulated aluminum materials system takes the same form, fit, and function as traditional MCPCBs, but operates cooler—as much as 10°C cooler. Thermal connectivity is increased and costs are decreased.

MCPCB's require large heat spreading layers to dissipate heat. This increases the overall size of the substrate, and consequently the size of the heatsink, which is expensive. With the Celcion system, the circuit is constructed directly on the heatsink, reducing the thermal interfaces between the LED and the heatsink. This enables the designer to eliminate the large heat spreaders, and thereby reduce the size of the overall substrate.

One of the materials in the Celcion material set is a silver paste that is used in place of a heat spreader, and allows printing directly on the aluminum substrate or the heatsink. Heatsink size can be reduced while lowering the temperature of the LED chip.

"With Celcion, designers can reduce the amount of LED chips needed in a lamp configuration," said Kondo. "The temperature can be lowered, so that more power can be applied to get more lumens. If a design uses 10 LEDs, you can get the same or better light output by using only six LEDs. This translates into design cost savings and more efficient thermal management."

According to the EISA, LED bulbs have the potential to last up to 22 years and can save up to 75% or more in energy costs. However, the initial cost is currently more expensive than other alternatives. As manufacturing costs decrease through better thermal management techniques, LEDs are expected to increase in performance and become more affordable. Effective thermal management is the key to making a brighter future for LEDs. **SMT**

Anita LaFond is Senior Editorial Manager at Constructive Communication, Inc. with more than 30 years of experience as a business journalist in the manufacturing industry.

Video Interview

Board-Level Defects Examined

by Real Time with... IPC APEX EXPO 2012

Dr. Jennie S. Hwang discusses key issues related to board-level defects, such as pad cratering, conductive anode filament formation (CAF), and solderability defects. Dr. Hwang also notes that lead-free assembly has placed significant stress on printed wiring board assemblies and discusses packaging trends such as BTC.

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Samsung Presents New Graphene Device Structure

One issue with graphene is that, unlike conventional semiconducting materials, current cannot be switched off because it is semi-metallic. This has become the key issue in realizing graphene transistors. Both on and off flow of current is required in a transistor to represent "1" and "0" of digital signals.

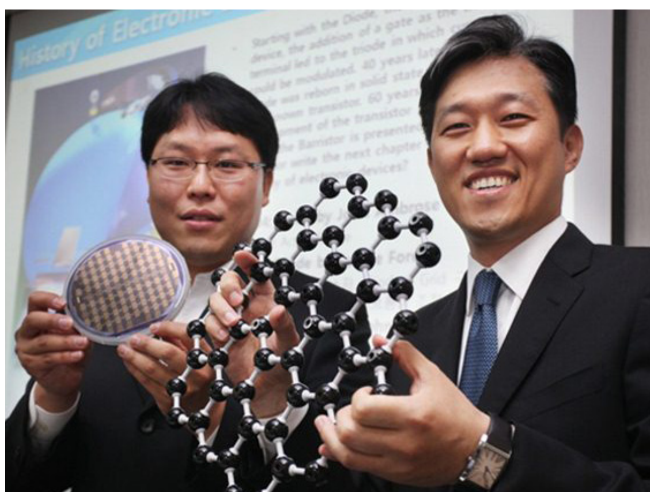
By re-engineering the basic operating principles of digital switches, Samsung Advanced Institute of Technology has developed a device that can switch off the current in graphene without degrading its mobility. The demonstrated graphene-silicon Schottky barrier can switch current on or off by controlling the height of the barrier. The new device was named Barristor, after its barrier-controllable feature.

In addition, to expand the research into the possibility of logic device applications, the most basic logic gate (inverter) and logic circuits (half-adder) were fabricated, and basic operation (adding) was demonstrated. Samsung Advanced Institute of Technology owns nine major patents related to the structure and the operating method of the Graphene Barristor.

As demonstrated in this research, the institute has solved the most difficult problem in graphene device research and has opened the door to new directions for future studies. This breakthrough continues to keep Samsung Advanced Institute of Technology at the forefront of graphene-related industries.

The Schottky Barrier is named after a German physicist Walter H Schottky and is a potential (energy) barrier formed at a metal-semiconductor interface. It prevents an electric charge to flow from metal to silicon.

Generally, metal-semiconductor junction would have fixed work function and Schottky barrier height, but as for graphene, Schottky barrier height can be controlled through the work function.



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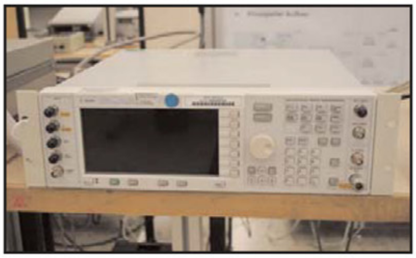



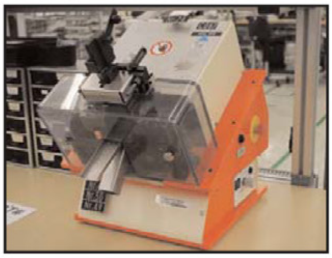


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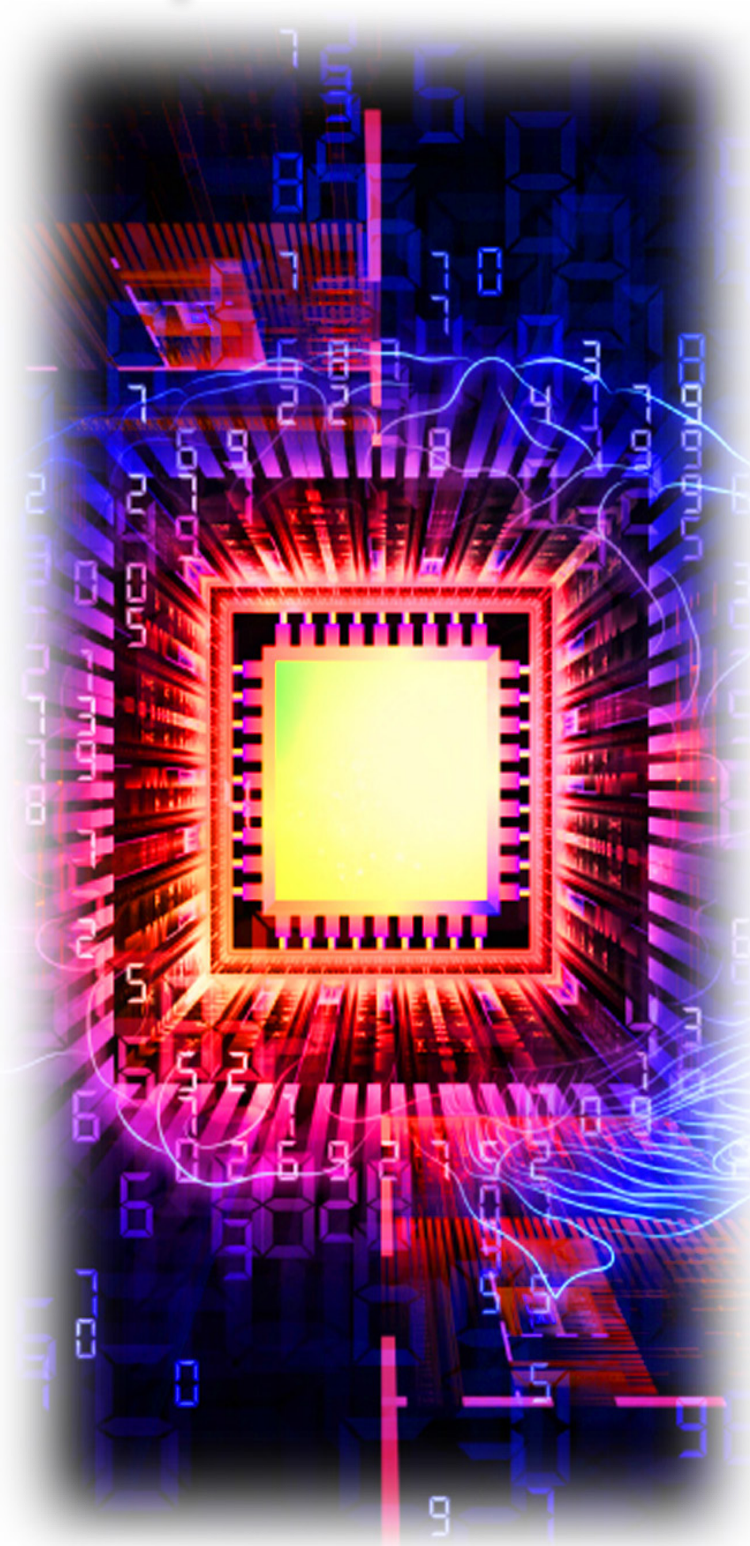
THERMAL CYCLE RELIABILITY STUDY: Vapor Phase BGA Solder Joints



by Ward Gatza
AGILENT TECHNOLOGIES, INC.
and Tom Evans
THOMAS C. EVANS CONSULTING

SUMMARY: The following paper discusses the reliability of vapor-phase-processed BGA solder joints and the appropriate vacuum soldering options for each.

This paper was presented originally at the IPC APEX EXPO 2012 Technical Conference and published in the Proceedings of the IPC APEX EXPO 2012 Technical Conference.

Authors' Note: Prior to committing production boards to vapor phase soldering, we performed an evaluation to assess reliability and evaluate the vacuum soldering option. The reliability of vapor-phase-processed BGA solder joints, with and without vacuum applied, was evaluated by means of a test vehicle circuit board assembly. The test vehicle was designed with daisy chain nets through multiple solder joints. These were designed with all of the solder balls in a chain having a similar distance from neutral point, so this factor could be part of the reliability assessment. The boards were temperature cycled for 8,250 cycles of -5°C to 95°C, by which time all of the outermost daisy chains had failed. The number of cycles-to-failure was analyzed using Weibull plots and characteristic life was calculated.

While convection reflow is the standard method for the surface mount process, thermal variation is always present across a large board; and smaller temperature margins are found within the tighter process window for lead-free soldering. It can be difficult to achieve minimum temperatures in highly-dense areas without over-heating less dense areas on the same printed circuit assembly (PCA). Vapor phase

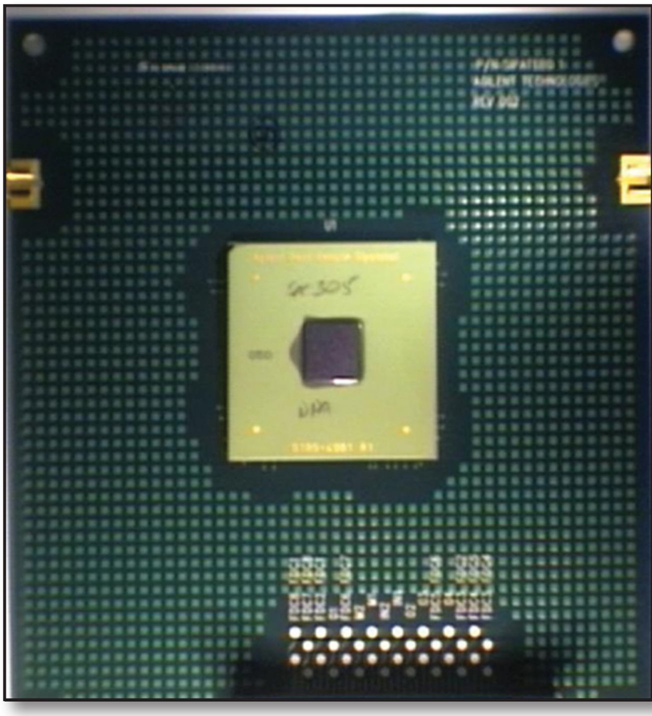


Figure 1: The test vehicle board.

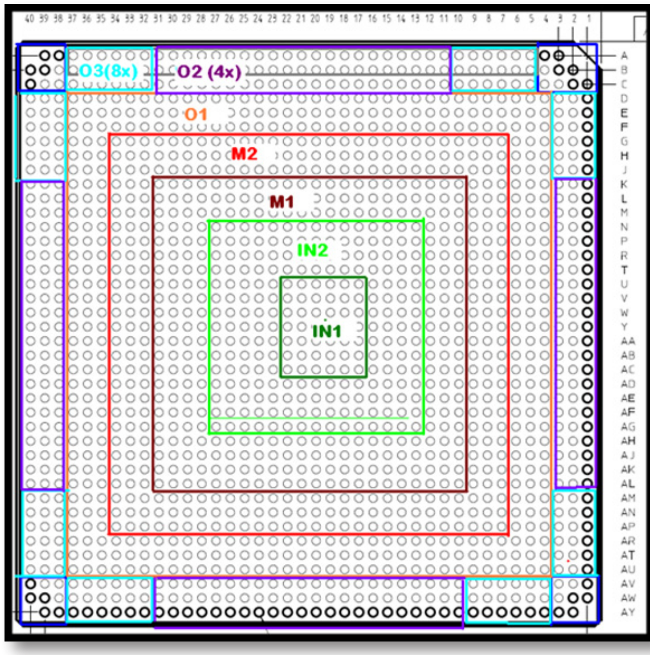


Figure 2: The continuity circuit layout.

reflow provides an advantage in limiting the maximum temperature on the PCA to the vapor temperature of the heating fluid. Vacuum applied in the vapor phase process allows for reduction in the amount of voiding. The reliability of vapor phase with and without vacuum is not well known and the objective of this study was to evaluate this area of interest.

The Test Vehicle

The test vehicle board was designed to hold a single BGA, as seen in Figure 1, for the purpose of evaluating a number of material or process options.

The PCB and BGA were designed to have eight daisy chain continuity circuits for resistance measurement testing. A diagram of the continuity circuit layout is shown in Figure 2.

All solder balls within the named areas are included in the daisy chain circuit. O4, O3, and O2 include the outermost three rows and columns. O4 is comprised of three of the four corner areas. The fourth corner area was not used in this study because it is part of an independent, high-frequency circuit. M2 and M1 include the next six rows and columns heading inward. IN2 and IN1 are two daisy chains covering the inner 16 rows and columns in the center of the BGA package.

The BGA in this experiment is a 40 mm x 40 mm full array configuration. It is 1.5 mm thick and constructed of multilayer ceramic with a high CTE of 12.3 ppm/°C. The PCB is eight layers, 62 mils thick, and made of high Tg laminate with a CTE of 13 to 14 ppm/°C.

BGA die size (mm)	10.6 x 10.6 x 0.635
BGA substrate (mm)	41 x 41 x 1.5
BGA solder pad dia. (mm)	0.600 (NSMD)
BGA solder pad metallization	ENIG (0.1 - 0.5um Au over 3.0 – 7.0um Ni)
BGA solder ball pitch (mm)	1.0
BGA solder ball array	40 x 40, 1594 connections
SAC305 s/b dia. (mm)	0.650
PCB material	8 layer ISOLA PCL-370HR 1 oz copper
PCB size (mm)	127 x 140 x 1.57
PCB surface finish	Immersion Ag
PCB solder pad dia. (mm)	0.609 (NSMD)

Table 1: Test vehicle definition.

THERMAL CYCLE RELIABILITY STUDY *continues*

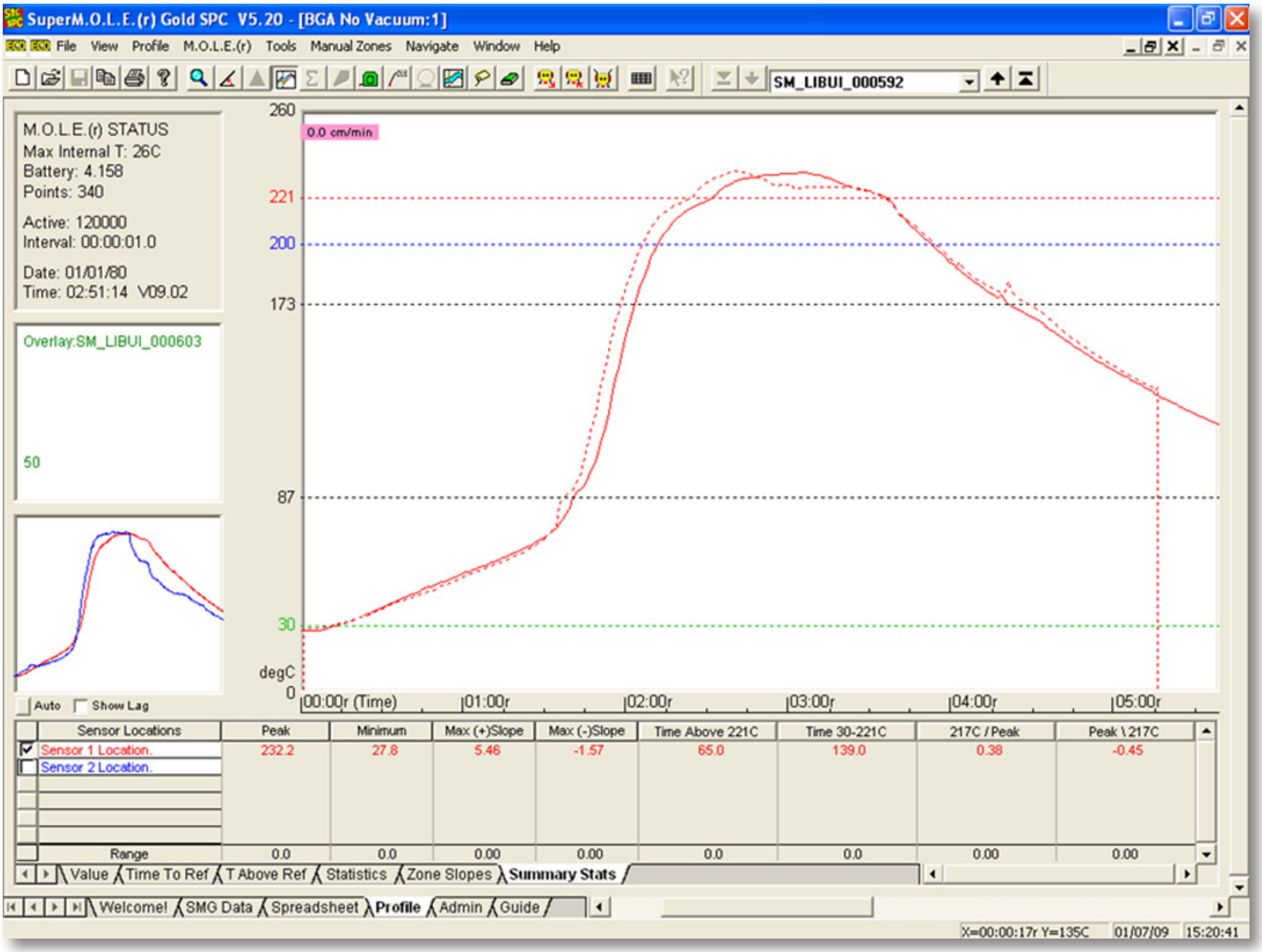


Figure 3: Overlapping solder profiles for vacuum (dashed line) and no-vacuum settings.

Nine test vehicle boards were assembled: Four in a vapor phase oven with the vacuum option turned off, four in a vapor phase oven with the vacuum turned on, and one in a standard convection reflow oven as a control sample. The vacuum option is available for the purpose of reducing voids in solder joints. The vacuum is pulled during reflow causing gas trapped within the molten solder to expand and break through the surface of the solder. Then air pressure is returned to the chamber and residual voids shrink to a smaller size.

Figure 3 shows overlapping solder profiles for vacuum (dashed line) and no-vacuum settings. The profile with vacuum has a slightly longer time above liquidus, 72 seconds versus 65, as the board is held in the vacuum chamber under IR heaters to keep it molten.

This reliability evaluation was performed as the initial investigation of vapor phase soldering and the vacuum process parameters were not optimized. X-ray inspection showed numerous small voids in the solder balls of all boards, with the vapor phase soldered BGAs having noticeably more voids than the convection soldered board. Boards soldered with the vacuum process had some solder bridging between adjacent solder balls. One sample board had enough short circuits due to bridging to exclude it from subsequent thermal cycling.

Thermal Cycling

Electrical resistance measurements of the daisy chain circuits in each sample part were recorded prior to thermal cycling and at 250 cycle intervals. Temperature cycling was performed

THERMAL CYCLE RELIABILITY STUDY *continues*

DC net	O4	O3	O2	O1	M2	M1	IN2	IN1
No-Vac 1	4250	5000	5750	7250	7750	7750	-	7750
No-Vac 2	5000	5000	6250	8250	-	-	-	-
No-Vac 3	4500	5750	7250	-	-	-	-	8250
No-Vac 4	4500	5000	6750	7500	-	8250	8250	8250
Vac 1	3750	5000	6000	7250	-	-	7750	8250
Vac 2	4500	5000	6250	7750	8250	8250	-	8250
Vac 3	4250	5000	6250	7750	8250	-	8250	-
Convection	4500	5750	6750	8250	8250	-	8250	8250

Note: '-'indicates daisy chain net did not fail.

Table 2: Number of thermal cycles to failure (>10% resistance change).

for 8,250 cycles, from -5°C to +95°C for the majority of cycles. A dual chamber machine was used with each chamber set permanently to one of the temperature limits. The rack of boards was moved quickly between chambers every 15 minutes.

Daisy chain circuit failure at each interval was defined as an increase in measured resistance of more than 10%. Table 2 shows the measurement cycle in which each daisy chain became a failure. Solder joints that were farthest from the center of the substrate longest distance

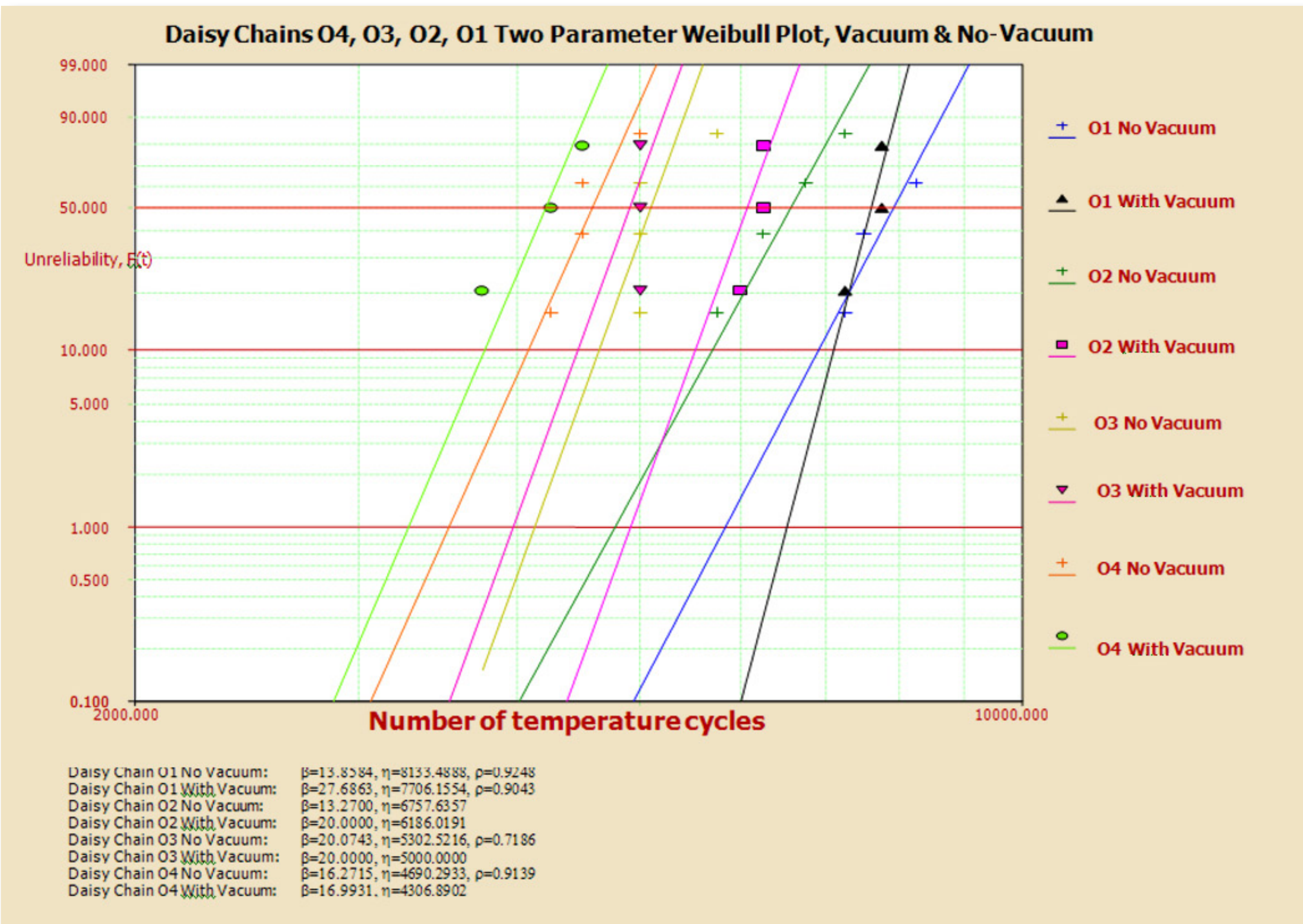


Figure 4: Weibull plot of vacuum versus no-vacuum on the four outermost daisy chain nets.

from the neutral point (DNP) were observed to be the earliest failures. The eight daisy chain circuits per sample part are listed in the table in order of longest to shortest DNP: O4 (corners), O3, O2, O1, M2, M1, IN2, and IN1.

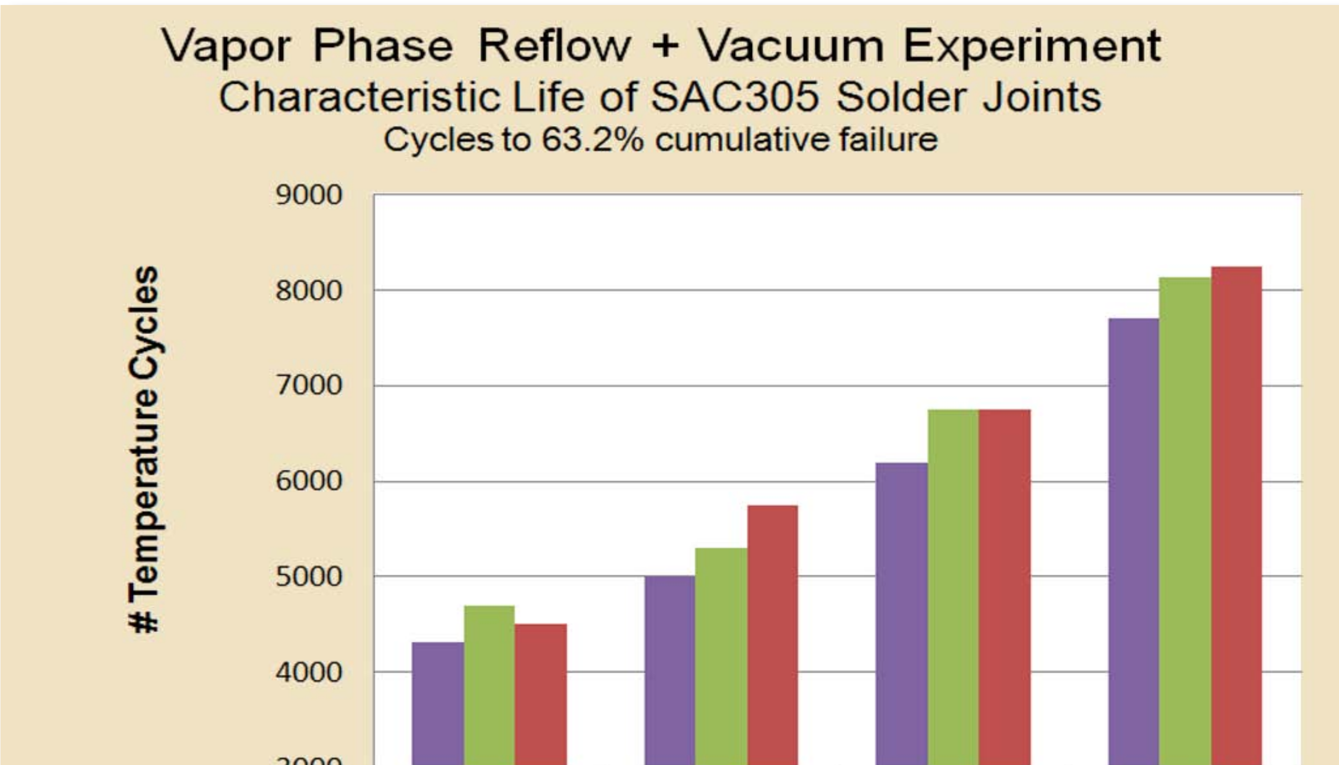
Figure 4 has a Weibull plot of vacuum versus no-vacuum on the four outermost daisy chain nets. The four innermost (shortest DNP) daisy chain nets had few failures, and are not shown.

From the Weibull plot, Eta (h) values [characteristic life—number of cycles to failure with 63.2% probability of failure] for each daisy chain net are used in Figure 5 to directly compare vacuum and no-vacuum sample types.

Characteristic life data from this experiment demonstrates that SAC305 solder joints made with vapor phase reflow and vacuum processing have slightly less temperature cycling reliability. The one sample of standard convection reflow is also included as a single data point (not characteristic life), and appears to have the highest reliability in this particular dataset.

Several factors are important to consider when using this dataset and any of the Weibull probability analyses in the report. The dataset may limit the ability to draw significant conclusions or make statistical comparisons between different processes. Factors that limit statistical analysis include:

- Right censored (suspended) sample data: Daisy chain nets on some samples did not fail at 8,250 cycles.
- Interval censored sample failure data: Groups of sample daisy chain net failures at 250 temperature cycle intervals, not individual sample daisy chain net failures at a specific number of temperature cycles.
- Small sample size: Some regression correlations were not possible.



	O4	O3	O2	O1
VACUUM (n=3)	4307	5000	6186	7706
NO VACUUM (n=4)	4690	5303	6758	8133
Std. Reflow (n=1)	4500	5750	6750	8250

Figure 5: Comparison of vacuum and no-vacuum sample types.

As a result of these factors, there is a wide range of Beta (β - slope) values and low regression coefficients (ρ).

Reliability Comparison

To further understand the experimental results, another reliability analysis was performed. Characteristic life was analyzed for daisy chain circuits in all eight test vehicle samples, regardless of sample type (vacuum, no-vacuum, or convection reflow). The new Weibull probability analysis combines daisy chain net O4, then O3, then O2…ending with IN2, to be representative of the reliability of SAC305 solder joints with the same DNP for all samples.

A Weibull plot for seven of the eight combined daisy chain nets is shown in Figure 6. The innermost daisy chain net, IN1, did not have enough failures to generate non-deterministic Weibull statistics.

Distance from Neutral Point

As expected, the characteristic life of the daisy chain nets decreases as their distance from the center of the BGA increases. The outer daisy chain nets failed in order. However, on some boards, certain inner and middle daisy chains failed by the end of test even though other inner and middle chains still had not. The longest distance of all of the solder balls in the daisy chain circuit from the neutral point is plotted in Figure 7. Plotted on the same graph is the calculated characteristic life.

The graph shows that the longest DNP for circuit O1 is actually longer than that for O2: 24.1 mm versus 22.1 mm. However, the O2 net failed first. This is because the O2 daisy chain includes solder balls along the outer rows of the BGA which makes them more vulnerable to the stress once the corner balls in the O4 circuits have failed.

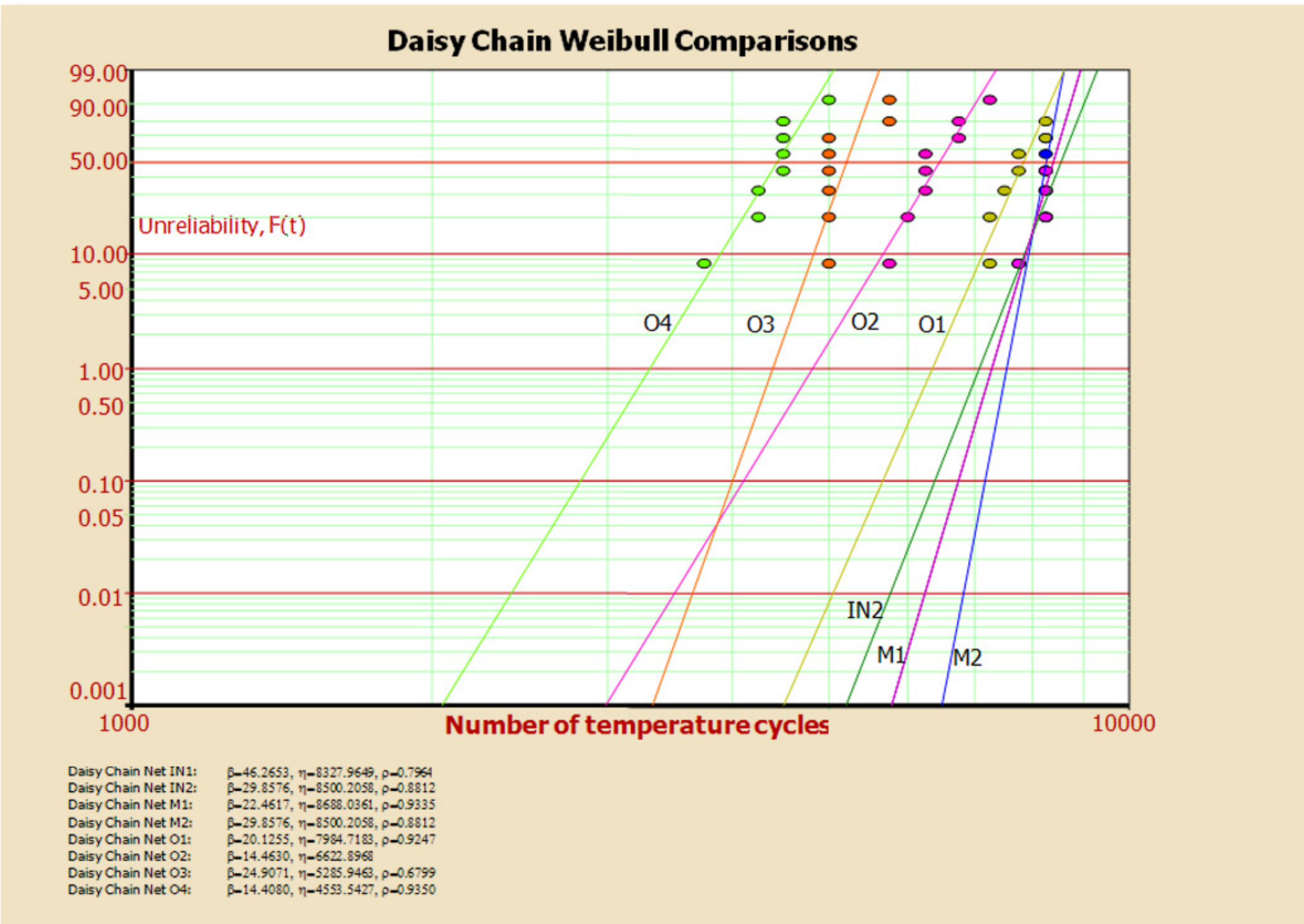


Figure 6: Weibull plot for seven of the eight combined daisy chain nets.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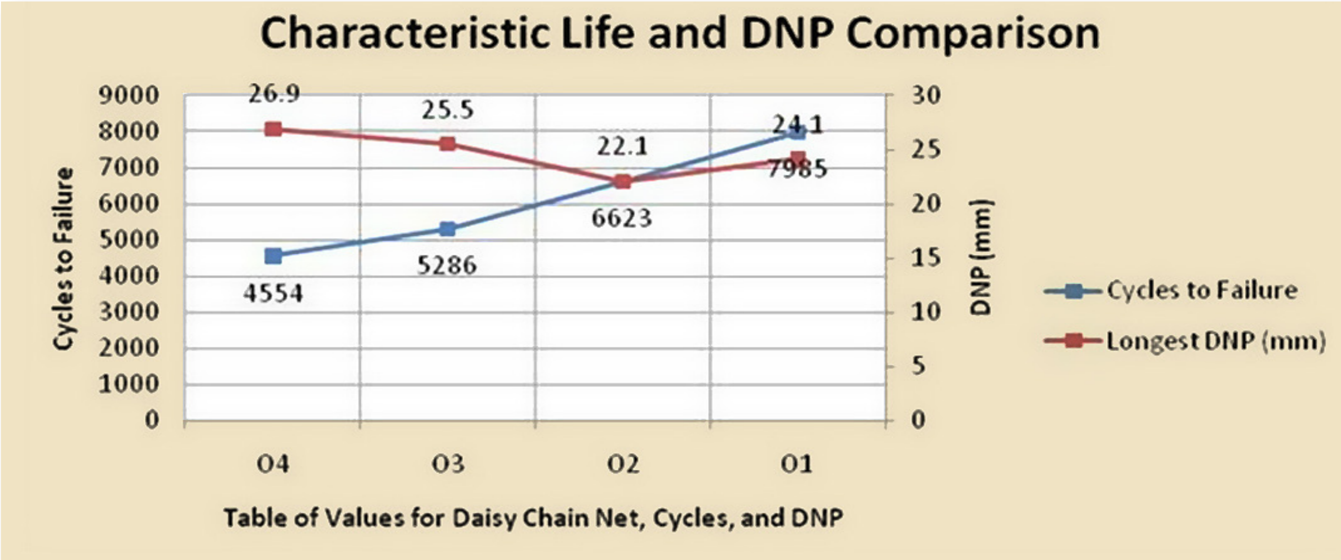

Figure 7: Distance plot of all solder balls in the daisy chain circuit from the neutral point.

Cross-Section

One part was cross-sectioned to observe the nature of the interconnect failure. An example failed solder ball is shown in an SEM image in Figure 8. The break is through the bulk solder and at the intermetallic interface to the BGA substrate. This is the typical fracture seen on other solder balls. Some fracturing was also observed in the bulk solder down near the PCB interface, but none of these were found to have propagated too far.

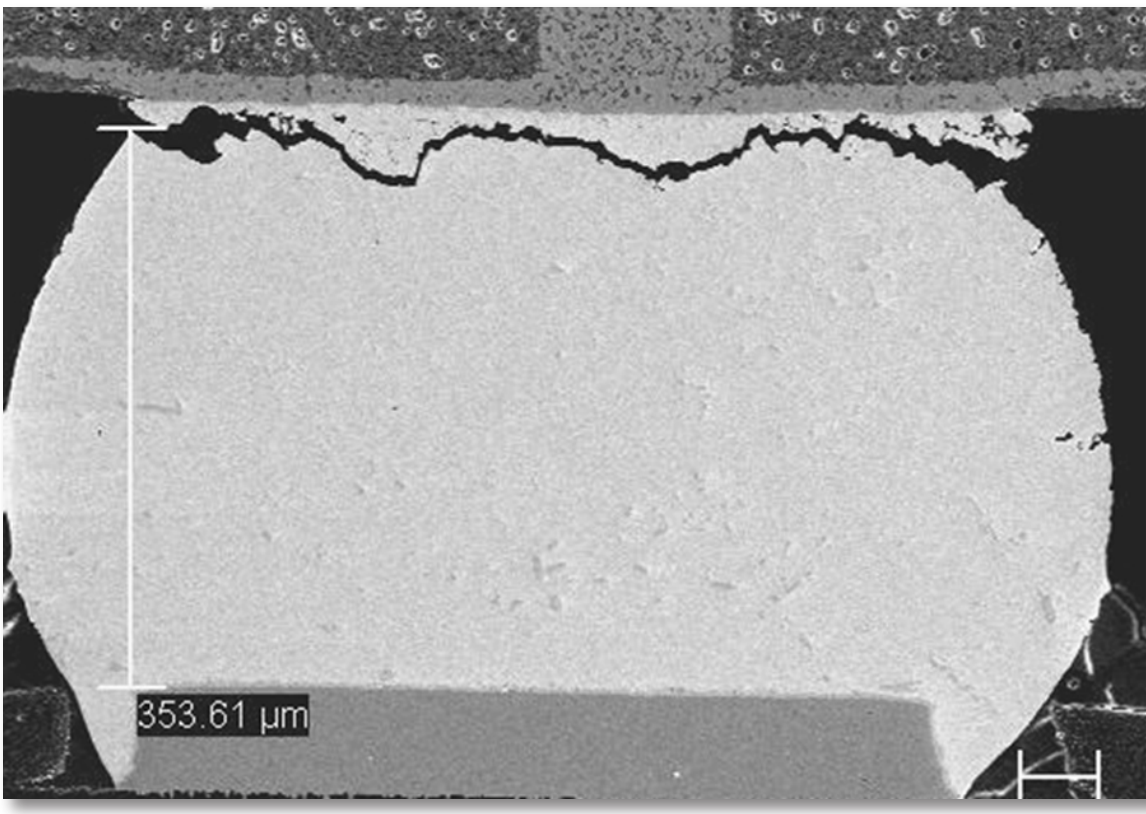

Figure 8: Example of a failed solder ball as seen under an SEM.

Conclusions

Referring to Figure 4, the sample sizes were not large enough to show that the characteristic life is statistically different between the different reflow methods. The reason is that the 90% confidence bounds surrounding Weibull plot lines for the vacuum process and no-vacuum process results overlap, and therefore don't show statistically significant differences. What can be stated is that the differences are consistent for each reflow method across four outermost daisy chain nets as shown in Figure 5, and have the appearance of indicating realistic values expected for larger sample sizes. The reason for the vacuum soldered board showing shorter apparent characteristic life than the other samples isn't fully understood yet, but it is not suspected to be caused by the slightly longer time-above-liquidus in the profile. This difference appears negligible and the values are well within recommended limits. Further destructive analyses of the solder joints may shed some light on this.

There is an instance of a statistically significant difference in two populations within this dataset. Vapor phase no-vacuum daisy chain net O3 has a characteristic life of 5,303 cycles and a DNP of 25.5 mm. For the same boards, net O4 has a characteristic life of 4,690 cycles and a DNP of 26.9 mm. At a 90% confidence level, the O3 sample data represents a population with characteristic life that is not part of the population represented by O4 sample data. The longer characteristic life of O3 is therefore attributed to a shorter DNP. **SMT**

Acknowledgements

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In appreciation for the solder processing of the circuit boards: Venture Manufacturing Services Inc.

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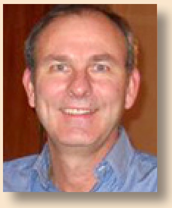
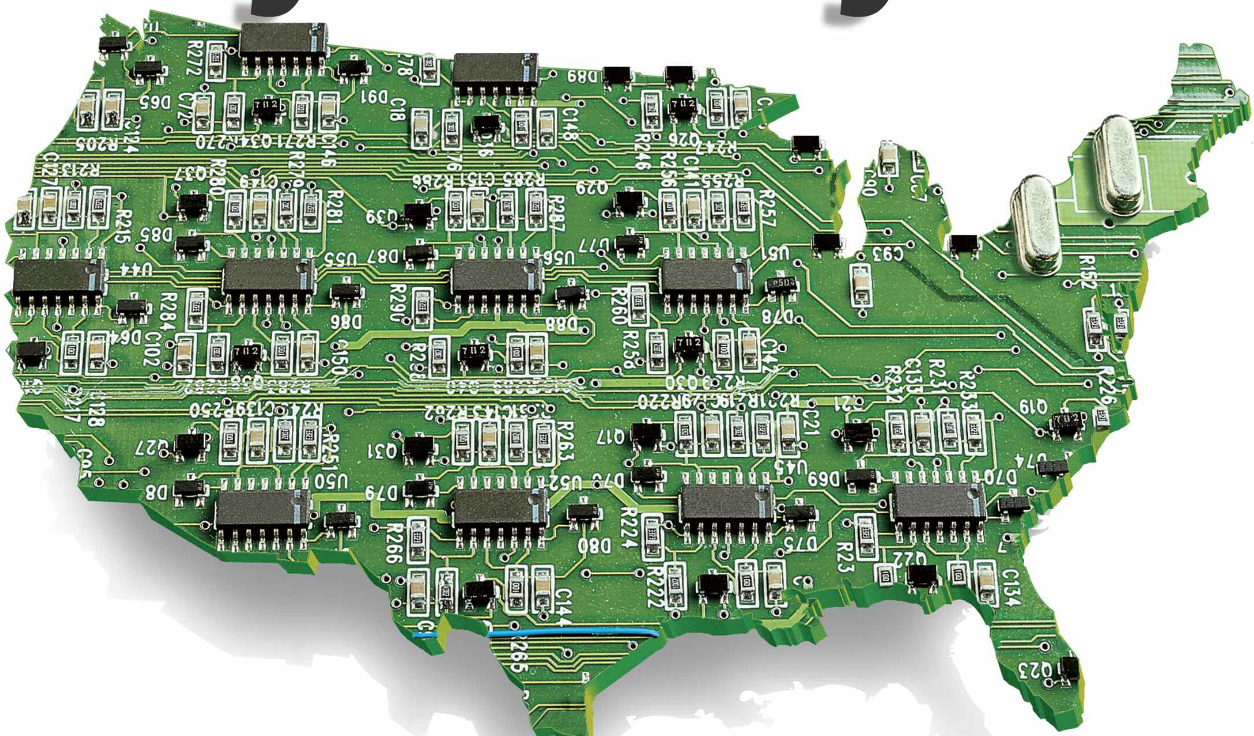


Ward Gatza began his career as an electronic design engineer with GE Aerospace in Philadelphia and eventually moved to Colorado Springs. After several years as development lead for silicon micro-machined crash sensor products at Ford Microelectronics, Ward joined Agilent Technologies, Inc. In his role as PCA and PCB materials engineer, he supports new product introduction of Agilent oscilloscope, logic, and protocol analysis products. For the past several years he has introduced new products utilizing vapor phase soldering systems.

Starting with thick film hybrid technology in the '70s, Tom Evans has been involved with a very broad range of packaging, sensor, MEMS, and optical technologies. Consulting on new technology, with start-ups and major companies alike, is a constant challenge and learning opportunity that continues to excite him. Now consulting for Agilent Technologies, he is responsible for setting up ASIC reliability engineering and RoHS compliance.



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SUMMARY: In 2009, author Yash Sutariya consulted Clemens Lasance, a thermal management guru, who began teaching the ways of the (thermal) force. Now, Yash is curious: Are brand-name thermal dielectrics on metal core printed circuit boards more effective than traditional FR-4 PCBs with Cu-plated vias?

"Life can be much broader once you discover one simple fact: Everything around you that you call life was made up by people that were no smarter than you and you can change it." – Steve Jobs

Like the rest of the industry, I was swept up by the high-powered marketing campaigns promoting the performance benefits of cutting-edge dielectrics for LED PCBs. Not to mention I thought it was kind of cool making a PCB from a sheet of metal. Appealing to total cost of ownership, the wave informed us that the dielectric's reliability performance justified the higher (purchase) cost. The wave had seemingly short-circuited that part of my brain responsible for basic physics. As a result, when the current bragged about a thermal conductivity of 2-3 W/m K, I was inhibited from realizing that this was less than 1/100 that of copper's thermal conductivity (400 W/m K).

In 2009, I consulted a thermal management guru who began teaching me the ways of the (thermal) force. Now, like Sid the Science Kid, I just have to know: Are brand-name thermal dielectrics on metal core printed circuit boards (MCPCBs) more effective than traditional FR-4 PCBs with Cu-plated vias?

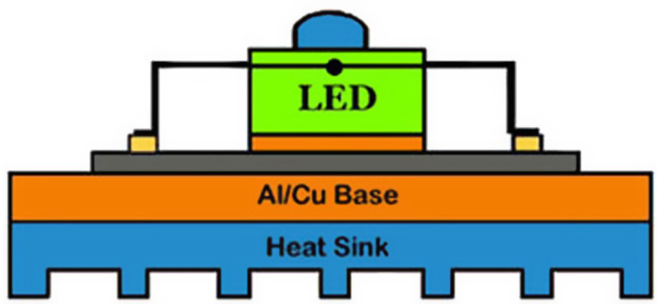


Figure 1: MCPCBs for LEDs.

PCBs for LED Thermal Management: The Basic Mechanism

The mechanism by which a thermally conductive PCB material works is fairly simple. The base of the LED component is soldered to a center pad of the component footprint. This center pad is not electrically connected to any of the other features. Its sole purpose is to provide a conduit for heat to be drawn away from the LED, increasing the light output as well as life of the product. MCPCBs in their simplest form consist of a circuit layer, a thermally conductive dielectric layer, and a metal substrate (most commonly aluminum). Once the PCB is assembled it is typically mounted to a heatsink with a thermal interface material (TIM).

PCBs for LED Thermal Management: The Basic Problems

MCPCB materials have numerous issues associated with them. First and foremost is the lack of an industry specification. As our past webinars have discussed, this results in a wide array of potential issues to the designer—primarily incorrect specifications that leave the end customer open to failures. Further, the MCPCB material can run up to 10 times the cost of standard FR-4, eroding the full potential savings of moving from incandescent to LED lighting.

This is where the lightning bolt struck me: By drilling and plating multiple vias into the heatsink pad of the LED component footprint and using traditional FR-4 two-layer plated-through-hole technology, could I create a PCB that rivals the thermal performance of metal-clad materials that cost up to 10 times that of standard FR-4 materials?

Being a novice in thermal calculations, I called on my trusted advisor, Clemens Lasance, who is principal scientist emeritus at Philips Research. A good portion of his career was dedicated to solving the challenge of thermal management electronic parts and systems. From the very beginning, Clemens was skeptical of vendors' claims pertaining to thermal conductivity requirements for the MCPCB in relation to thermal performance. In fact, he claimed that the MCPCB is the last element to attack in a chain that includes TIMs, heat sinks, convections, and the LED itself.

His reply was quick and simple:

When heat spreading is at stake, analytical solutions and approximate equations can only be used in limited cases where the designer is dealing with one- or two-layer problems with one-sided heat transfer and one source. Fortunately, many practical cases fall into this category, such as an FR-4 board with a copper top layer or metal core PCBs with a dielectric and a metal layer. For all other situations—for example when dealing with double-sided heat transfer, or multiple sources, or more than two layers, or when vias are applied, or when layers consist of more than one material, or for which the boundary conditions cannot be considered uniform—the problem becomes intractable from an approximate analytical point of view and we have to rely on computer codes.

It should be stressed that using analytical solutions, including the 1D series resistance network, has its main merits in getting insight, hence is second-to-none from an educational point of view. However, when accuracy is at stake in the final design stages, the recommended approach for solving real-life problems is in using a 3D conduction solver.

In principle, all finite volume/finite element, etc., codes can be used that solve the 3D heat diffusion equation. In practice, only those user-friendly codes are recommended that enable a designer to get results in a couple of hours or so. Some popular CFD codes dedicated to thermal management of electronic systems (FloTHERM, 6SigmaET, Icepak) used in conduction-only mode are examples of such a code.

For a fair comparison between an FR-4 board with copper layers at both sides provided with vias and an MCPCB board there is no other way than to use a 3D conduction solver. Of course experiments also can do the job, but to explore a range of parameters such as interface materials, heat sinks, convection modes, a choice of vias, copper layer thickness etc., the time gained by using numerical simulations is substantial. Estimated order of magnitude: One day for numerical simulation; one month to prepare and perform the tests. [1, 2]

Okay, so now we know we're on the right track. I asked Clemens to break out the Crayola 64-pack and draw me a picture so I could understand the concept. He did better: He created a 50,000-cell numerical model to analyze the various constructions I was discussing with him. The explanations behind these formulae and units of measurements can be found in Clemens' paper "Two-Layer Heat Spreading Revisited," presented at SemiTherm, March 2012, in San Jose, California [3].

We suggested comparing the following constructions:

- MCPCB;
- One-layer FR-4; and
- Two-layer FR-4 with vias under LED heatsink/slug.

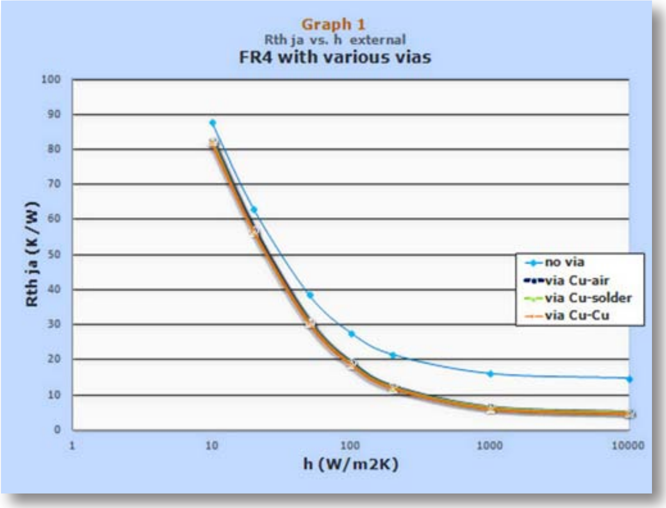
The basic assumptions used in the modeling were:

- LED with slug. The thermal resistance of the slug is orders of magnitude smaller than the one of the leads; hence, all power is delivered thru the slug.
- The LED is not modeled except for the slug; hence, all thermal resistances are from slug to ambient.
- All circular entities (slug, vias) are represented by squares with the same effective area.
- The heat sink is represented by a base connected to the PCB via a TIM; the fins are represented by an effective external heat transfer coefficient.
- Area allocated to a single LED is 25*25 mm.
- External h: h=10 W/m2K means free convection, no heat sink. h=100 means heat sink with area extension of factor of 10. h=1,000 is forced convection and h=10,000 liquid cooling.

We first wanted to compare the FR-4 constructions. In addition to the standard plated through vias, we thought to model vias that are filled with solder, as well as vias that are pure copper filled for comparison purposes.

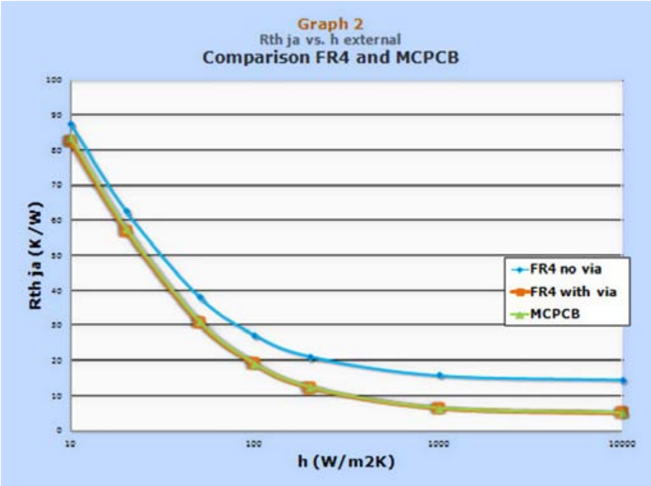
Author's Note: Clemens made his comments in regard to the following graphs:

The following graphs are based upon an analysis using FloTHERM in conduction-only mode (hence not solving the Navier-Stokes equations), applying quarter symmetry to a model consisting of both layouts with the LED slug as the power source and an heat sink base of 2 mm coupled with an interface material to the PCB in question.



Conclusion

Almost no difference can be found in the thermal performance of a standard via versus vias filled with solder or copper. This makes sense considering the very high thermal conductivity of copper. There is, however, a huge difference between an FR-4 board that has no vias and one that has plated through vias. Knowing this baseline data, we then plotted the thermal performance of the FR-4 boards against that of a traditional MCPCB that has a thermal resistance of approximately 0.09°C in^2/W.



Conclusion

Almost no difference can be found in the thermal performance of a PTH FR-4 board and a MCPCB across a wide range of convection methods (h).

For years we have been pushing the idea that plated vias having >100x the thermal conductivity of thermally conductive dielectrics should be a viable alternative. We now have mathematical proof of concept.

FR-4 Thermal Vias Versus Thermally Dielectric MCPCBs: An Empirical Study

Now that we are armed with the confidence of having our theory proven correct via formulae, it made sense to run out and purchase a thermal imaging unit and create LED PCB test vehicles.

The following test vehicles were created:

- Aluminum core with copper pour;
- Aluminum core without copper pour;
- Two-layer copper pour (both sides);
- Two-layer copper pour (bottom);
- One-layer copper pour; and
- One-layer no copper pour.

The copper pours are comprised of 1-inch square areas of solid copper pour. Figures 2 and 3 are screen shots of both examples.

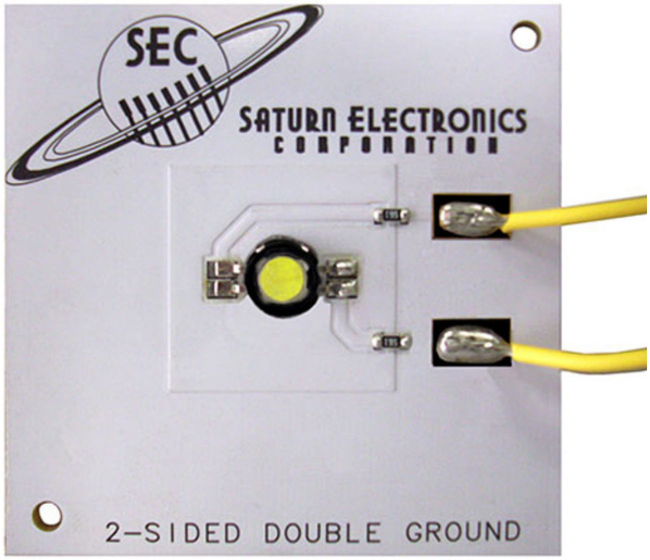


Figure 4: Test vehicle.

For the two-layer designs we duplicated the 1-inch top surface copper pour on the bottom layer. The intent was to have the heat from the LED base travel through the vias, and then spread across the bottom copper pour.

After allowing a one-hour burn-in to reach normal operating temperature, we took thermal images from a top vantage point of each LED test vehicle. The thermal imager also allows us to take temperature readings from the hottest

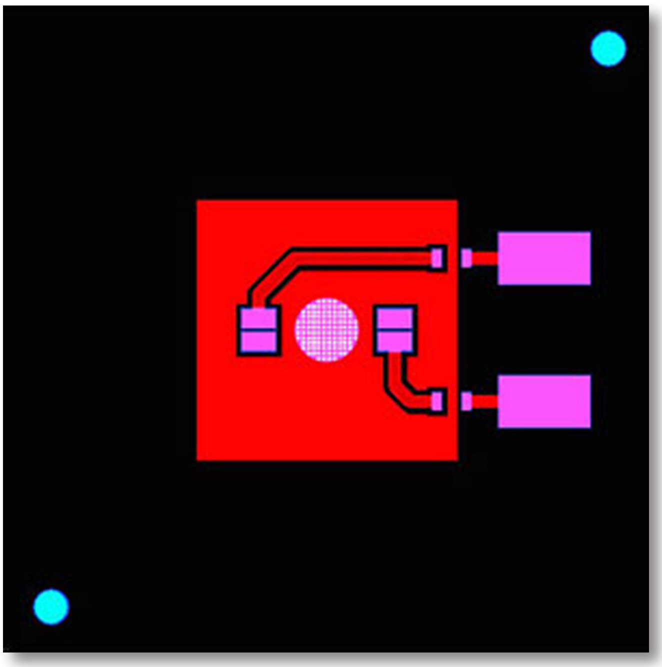


Figure 2: LED PCB with copper pour.

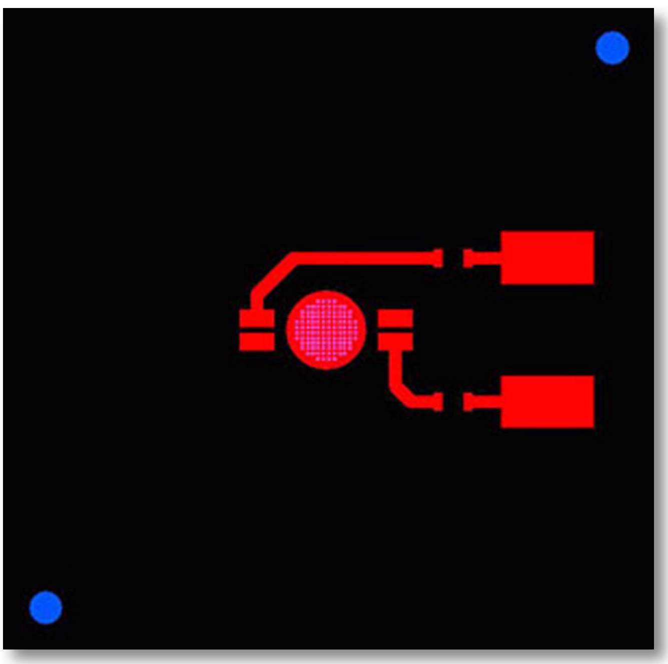


Figure 3: LED PCB without copper pour.

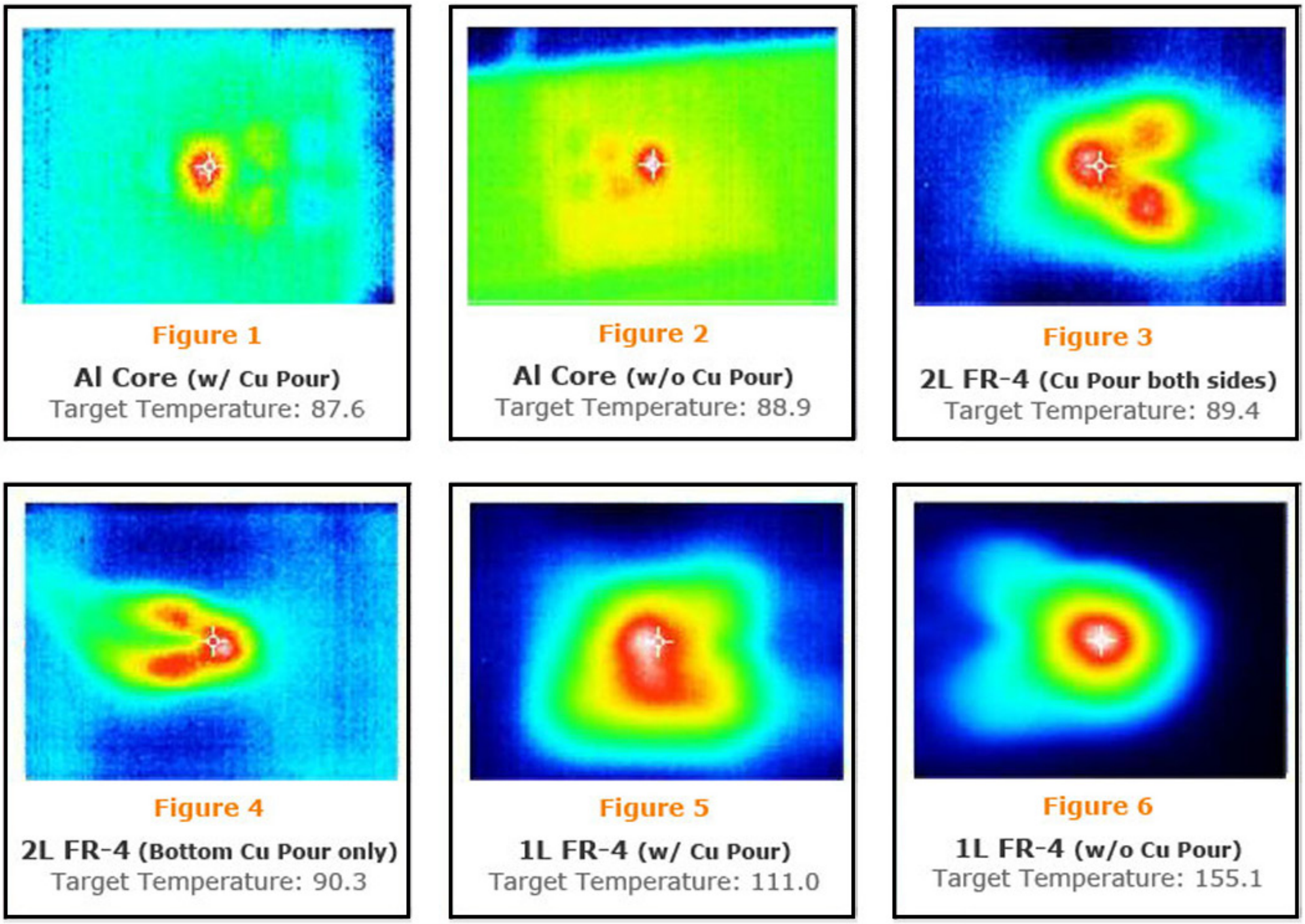
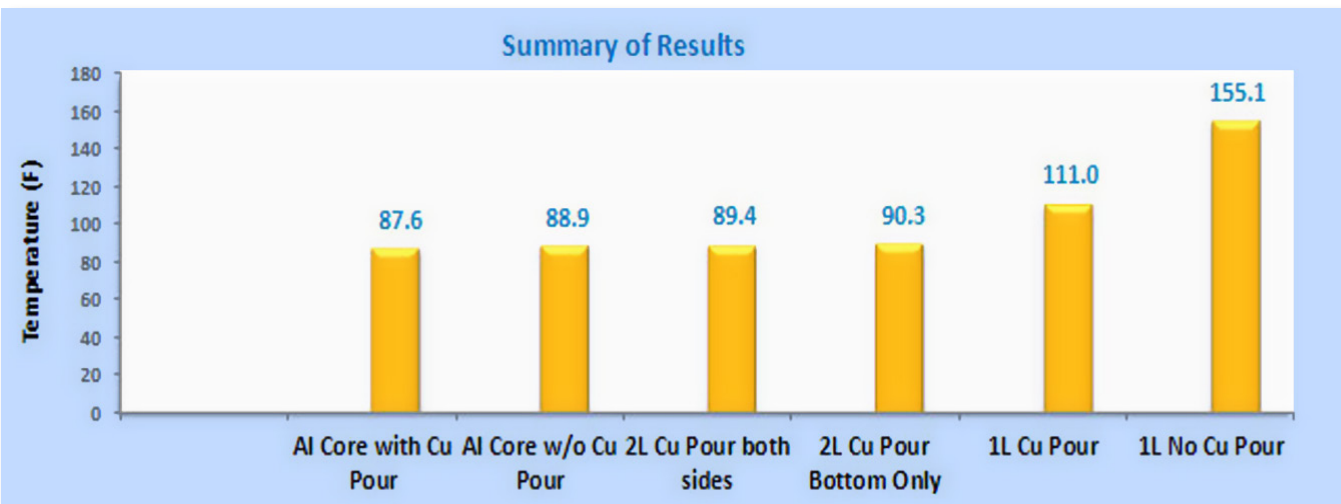


Figure 5: PCB thermal images from test vehicles.

point, namely the LED itself. The theory is that the heat measured from the top side is heat that has not been conveyed to the heatsink via the thermally conductive dielectric (in the case of the MCPCB) or the PTH (in the case of the two-layer FR-4 boards) (Figure 5).



Graph 3: Graphical summary.

Graphical Summary

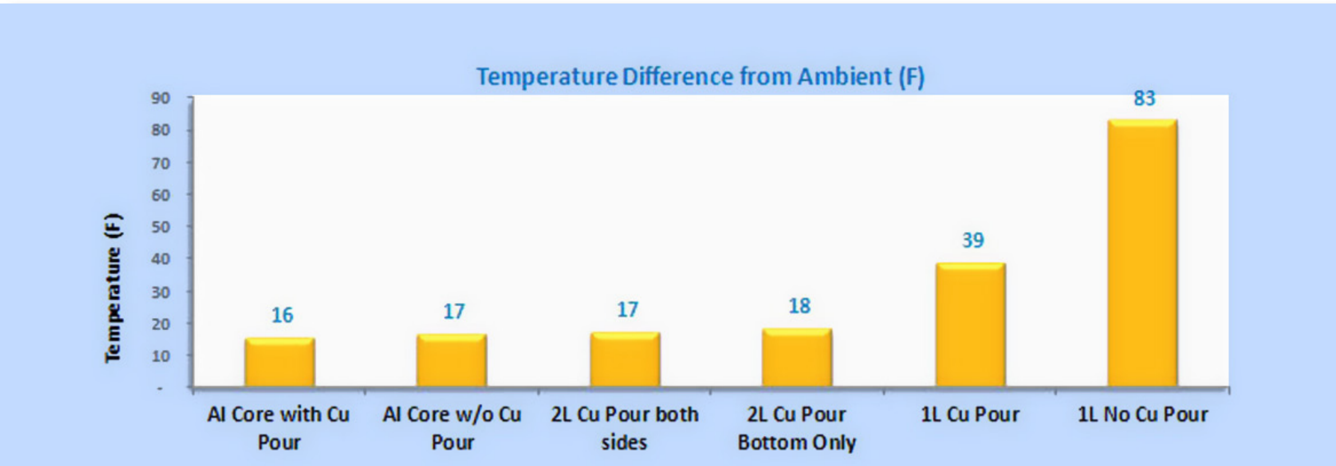
The values in the chart represent surface temperature measurements only. However, it is more critical to calculate the temperature rise from ambient to glean the true performance of the thermal stackup, as shown in Graph 4.

FR-4 Thermal Vias Versus Thermally Dielectric MCPCBs: A (Cost) Benefit Calculation

When considering alternative solutions, it's always important to know what exactly will be the benefit. For the bean counters, it boils down to the money saved. If we can assume that a particular design will perform the same between an MCPCB design and a plated via FR-4, can I save enough from a cost standpoint to compensate for additional testing and UL-related costs associated with converting my product over? Let's see (Graph 5).

Conclusion

Our test results demonstrate that FR-4 PCBs with Cu-plated vias achieve thermal transfer roughly equivalent to that of metal core PCBs with thermally-conductive material. Please note



Graph 4

Characteristic	MCPCB	2L FR-4 PTH
Size	10.82" x 1.79"	10.82" x 1.79"
No. on 18"x24" Panel	18	18
Final Finish	SN100CL	SN100CL
EAU	25,000	25,000
Piece Price	$6.37	$2.65
Annualized Spend	$159,173	$66,322
Percent Difference		-58%
Annualized Savings		$92,851

Graph 5: **Values will not calculate exactly due to rounding in the piece price.*

that the results are specifically for this set of constraints including number of vias, LED type, and choice of MCPCB. Any designer wishing to convert their MCPCB design to use FR-4 with plated vias should not only contact a thermal management consultant for part-specific calculations, but also perform physical tests as we have done here. Should you need, Clemens Lasance can be contacted at lasance@onsnet.nu.

From a cost standpoint, the potential savings are substantial. The raw material savings alone more than compensate for the added processing steps required to create a two-layer plated through PCB. Further, it is difficult to find a supplier that is UL certified to a particular MCPCB material; conversely, using FR-4 technology allows the end user to add a great deal of competition to the supply base…as most PCB fabricators are already UL-certified to use FR-4 materials. **SMT**

References

1. Lasance, Clemens, "Heat spreading: not a trivial problem," Electronics Cooling, Vol. 14, pp. 24-30, May, 2008.

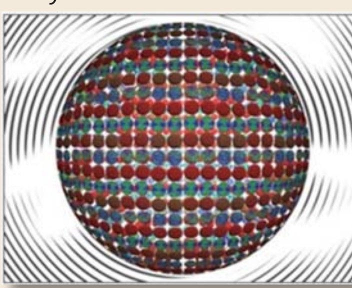
2. Lasance Clemens, "How to Estimate Heat Spreading Effects in Practice," Journal of Electronics Packaging, 132, 031004, 2010.

3. Lasance Clemens, "Two-layer heat spreading revisited," Proceedings, SEMITHERM, March 28, 2012, San Jose, California.

Yash Sutariya is vice president of Corporate Strategy at Saturn Electronics Corporation (SEC) and owner/president of Saturn Flex Systems, Inc. Since joining the team, SEC has successfully navigated from a low-mix, high-volume automotive supplier to a high-mix, medium- to high-volume diversified supplier. As a result of the company's transformation, manufacturing capabilities now range from quick-turn prototypes to scheduled volume production while attending a broad cross-section of industries to include industrial controls, telecommunications, aerospace and power supply industries.

Liquid Crystal Behavior Portends New Materials

Liquid crystals, the state of matter that makes possible the flat screen technology now commonly used in televisions and computers, may have new technological tricks in store. An international team of researchers led by University of Wisconsin-Madison Professor of Chemical and Biological Engineering Juan J. de Pablo reports the results of a computational study that shows liquid crystals, manipulated at the smallest scale, can unexpectedly induce the molecules they interact with to self-organize in ways that could lead to entirely new classes of materials with new properties.



Liquid crystals exhibit the order of a solid crystal but flow like a liquid. Used in combination with polarizers, optical filters and electric fields, liquid crystals underlie the pixels that make sharp pictures on thin computer or television displays. Liquid crystal displays alone are a multi-billion dollar industry.

The new study modeled the behavior of thousands of rod-shaped liquid crystal molecules packed into nano-sized liquid droplets. It showed that the confined molecules self organize as the droplets are cooled. "At elevated temperatures, the droplets are disordered and the liquid is isotropic," de Pablo explains. "As you cool them down, they become ordered and form a liquid crystal phase. The liquid crystallinity within the droplets, surprisingly, induces water and other molecules at the interface of the droplets, known as surfactants, to organize into ordered nanodomains. This is a behavior that was not known."

In the absence of a liquid crystal, the molecules at the interface of the droplet adopt a homogeneous distribution. In the presence of a liquid crystal, however, they form an ordered nanostructure.

Top Ten Most-Read Supplier/ New Product Highlights

Koh Young Achieves Delivery Milestone for AOI System

The company, a leading supplier of 3D SPI, AOI, and advanced automated inspection equipment, announces the delivery of their 3,000th in-line system, a Zenith 3D automatic optical inspection system, to Hitachi Mito Works, one of the main Japanese factories of Hitachi, Ltd., a leading global electronics company.

Henkel Develops Materials for High Power Electronics

Advances in power electronics are key to a sustainable energy future: Semiconductor power devices such as insulated gate bipolar transistors (IGBTs) deliver the high switching speeds which are critical for energy efficiency in electric cars, trains, and other industrial applications.

Sanmina-SCI Enhances NPI Function with JTAG Systems

JTAG Technologies has announced that Sanmina-SCI, a leading manufacturing solutions company making the world's most complex and valuable optical, electronic, and mechanical products, will be using JTAG's boundary scan tools for prototype testing at its Haukipudas Oy facility.

Manncorp Offers SMT Assembly Equipment Discount

Manncorp is anticipating a record number of first-time visitors and customers to its new e-commerce website thanks to an across-the-board 12% price reduction, in effect through June 30, 2012.

Nordson YESTECH Unveiled Dual Technology AOI Approach at NEPCON China 2012

Nordson YESTECH's complete line of automated optical inspection (AOI) solutions offer a unique technology approach, providing both image-based and algorithm-based inspection techniques. The company showcased this new technology during NEPCON China 2012.

ALeader Vision Technology Nets SMT China Vision Award

ALeader Vision Technology's newest ALD700 in-line AOI has won the 6th SMT China Award for Automated Optical Inspection.

Manncorp Equipment Highlight of ACI Assembly Training

The company has installed an SMT equipment line at American Competitive Institute that is being used for both actual PCB assembly in-house and as a training facility for "Boot Camp" teaching programs. This line was chosen for its flexibility in performing high-mix assembly with long- or short-run capability.

Asteelflash and Adetel Form Joint Venture

Asteelflash Group and Adetel Group will be forming a joint venture contracting company to offer a comprehensive package ranging from product design to turnkey manufacturing.

NexJet System: The Next Step in Jetting Technology

Nordson ASYMTEK, a leader in fluid dispensing, coating, and jetting technologies, announces the new, patent-pending, NexJet™ System, a significant advancement representing the next step in jetting technology.

Essemtec Unveils Fourth Generation ePlace Software

Fourth generation ePlace software makes operating an SMD pick-and-place machine easier while saving time and money. Due to Windows 7 and an SQL database, the system is simpler to integrate as well. ePlace 4.0 is the most modern graphical user-machine interface from Essemtec. Currently, various SMD placement machines are compatible with ePlace, including Paraquda and Cobra.

From Beer Fridges to Laptops, Thermal Simulation Improves Product Design

by Robin Bornoff
MENTOR GRAPHICS CORPORATION

***SUMMARY:** At first glance laptops may not have much in common with a mini-fridge, but because author Robin Bornoff had access to a beer fridge that wasn't working properly, he thought it might be a good idea to find out why. The design lessons learned can be applied to many other electronic products.*

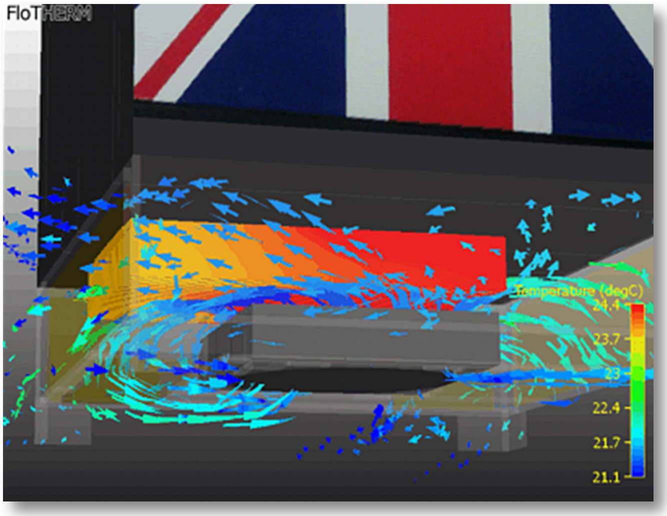
Thermal simulation can be used to help create better products—everything from laptops to beer fridges. While refrigerator design is not normally on the top of everyone's priority list, whether in the office or college dorm, a well-running mini-fridge can be crucial to motivation levels. Because I had access to a beer fridge that wasn't working properly, I thought it might be a good idea to understand why. Besides, the design lessons learned from it can be applied to many other electronic products.

The mini-fridge works by having a thermoelectric cooler (TEC) pump heat from inside the fridge down to a heatsink, using the Peltier effect. A fan then blows cold air over the heatsink so that the heat is convected away from vents in the lower part of the fridge. The heat flow should ensure the space inside the mini-fridge remains at a low, controlled temperature. This approach is less noisy than the classic evaporator/condenser cycle used in most domestic fridge/freezers; although it's somewhat less reliable.

A situation like this is a perfect case for computational fluid dynamics (CFD) simulation software. First, I measured the main constituent parts of the fridge and created a 3D representation in FloTHERM CFD software in just over an hour. Then I had to find the characteristic information for the TEC and the fan. Such objects are not modeled explicitly per se; instead, a "compact modeling methodology" is applied in which their key physical behavior is retained but the exact physics of their operations isn't modeled.

I used parameters such as the current required to pump a certain number of watts against a temperature difference at two (hot side) temperatures as input for the FloTHERM TEC SmartPart object (this particular TEC was not available in the installed libraries). I also used the fan curve that relates to the pressure drop over the fan to the amount of air that it can shift.

As a matter of physics, I expected the air within the fridge to be cold. Here are the surface temperatures on the inside of the fridge, with the side of the fridge hidden for clarity:



Unfortunately, by all accounts this specific model looks to be a really cheap and nasty mini-fridge, not at all providing a uniformly cool interior. The TEC cools a little coldplate at the bottom of the inside of the fridge, which sucks heat away from the air in the lower portion of the fridge; however, as hot air rises, the cold air simply stays at the bottom so only the bottom half of the mini-fridge is cold.

For the fan to be designed effectively, it would need to induce cool air from around the underside of the fridge and blow it onto the heatsink. The air would heat up, and the vents would be arranged so that this warmed air would vent back into the room. One thing you definitely wouldn't want is for the warm air to recirculate back into the underside intake of the fan to be blown back into the heatsink.

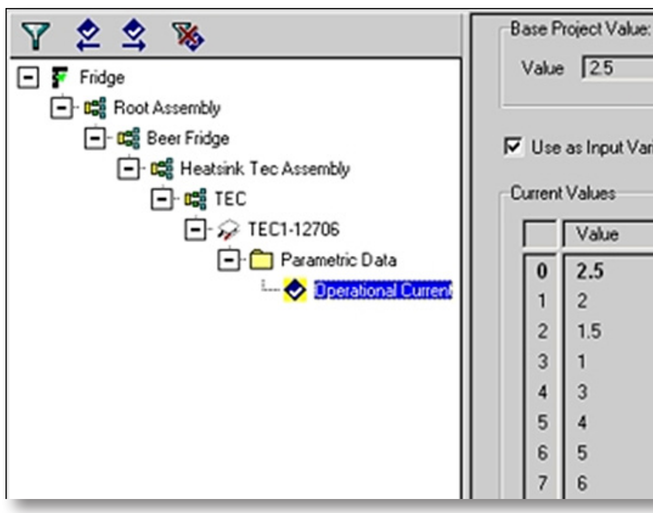
Going back to the TEC, I had to make an assumption about the current for which it was set to operate. For this model, I guessed 2.5A. TEC performance is very sensitive to the current, and an optimal TEC operating would no doubt improve its performance.

TEC Effects on Beer-Cooling Performance

Mini-fridges that use TECs to pump the heat from inside are quiet, but they are also about six times less efficient, requiring much more power to keep the fridge at an optimum temperature for beer. But if you're just trying to cool a small space that doesn't require that much cooling work, then what's a factor of six? And, of course, a TEC-based fridge is much more portable than its hissing, shuddering, bigger counterpart.

A TEC works by passing an electrical current through a chain of semiconductor PN pairs that result in an imposed temperature difference between the two ceramic sandwiched sides of the TEC—resulting in a net flow of heat pumped through. It's like the conductive equivalent of an air-moving fan that takes electrical power and spins a motor with blades on it, which then induces air flow through it. If you supply too little operational current, the TEC doesn't pump enough heat. If you supply too much, then its pumping performance degrades because of the increased Joule (self-) heating that occurs within.

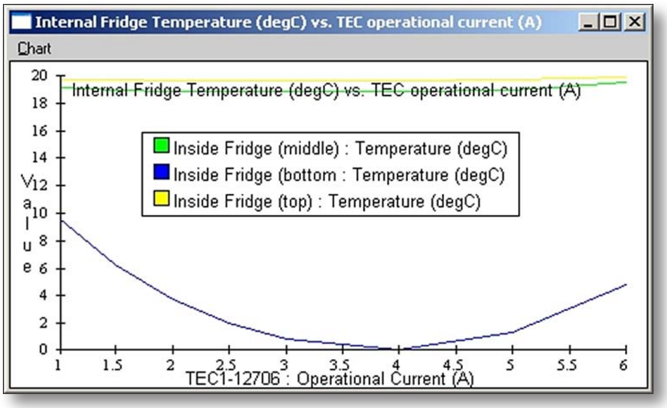
I used FloTHERM to investigate the relationship between the TEC's operational current and the resulting air temperature distribution within the fridge. It has an application window called the Command Center. This window allows for just about any parameter of a FloTHERM model to be varied and for the results of the subsequent scenario of variations to be presented back to the user. In this case, I varied the TEC operational current between 1 and 6A. Here's what that set-up looks like in the software:



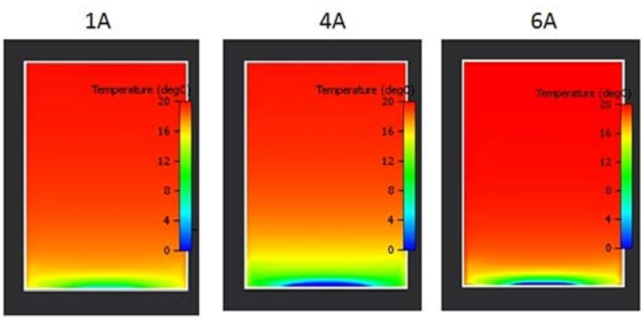
One click of the GO button and the software solves all these variants and then presents the results back. One of the simplest ways to

FROM BEER FRIDGES TO LAPTOPS *continues*

inspect the results is to note "monitor point" temperatures, temperatures at defined points in the model; in this case, inside the fridge right at the bottom, in the middle, and at the top:

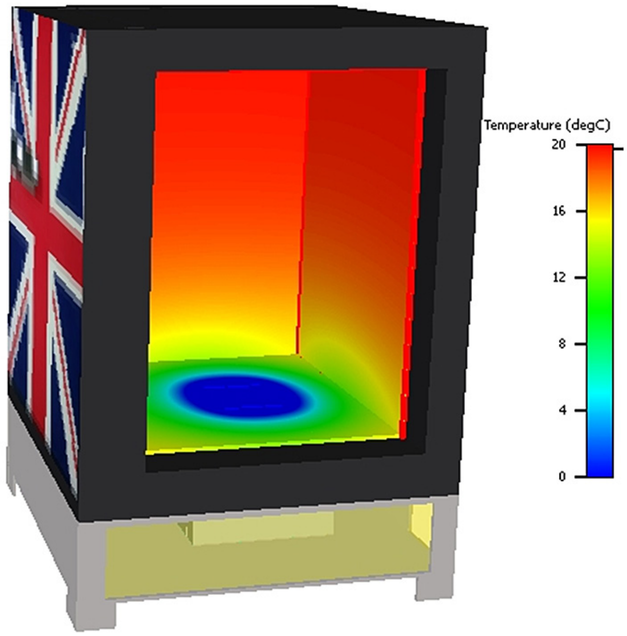


The TEC performs best at about 4A; this is when the temperature at the bottom of the fridge is lowest. Currents below or above 4A result in a degradation of performance. It's interesting that the middle and top of the fridge are always warm—too warm. Let's dive down and look at the temperature:



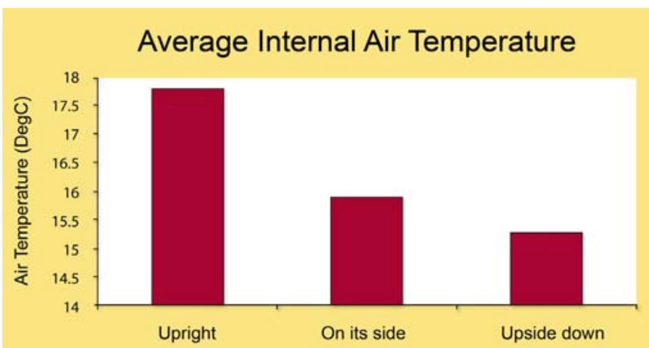
The colder air at 4A at the bottom of the fridge just sits there because of stable stratification. There is no way for the cold to reach the top of the fridge; so the top of the fridge remains too warm (unless you're a real ale drinker).

How would you get the cold to better spread around the inside of the fridge? How about stocking it full of beer so that the cold can conduct up through it all, or maybe turn the fridge upside down to get the cool air to dump down and spin the air inside the fridge around? Testing the mini-fridge with beer in it upside down would be the logical next step. The door is tightly closed so why not? This would tell me whether the potential beer cooling is in any way affected.



As shown previously, the TEC only cools a small metal plate on the bottom face of the inside of the fridge. Air next to the plate is going to be the coldest inside the fridge, getting warmer the further away from the plate it gets. With the fridge upright and the cold plate on the bottom of the inside of the fridge, the cold air just sits at the bottom with the warmer air stagnating above it. Once the fridge is on its side or upside down, the air cooled by the plate dumps down to the bottom of the fridge mixing things up inside.

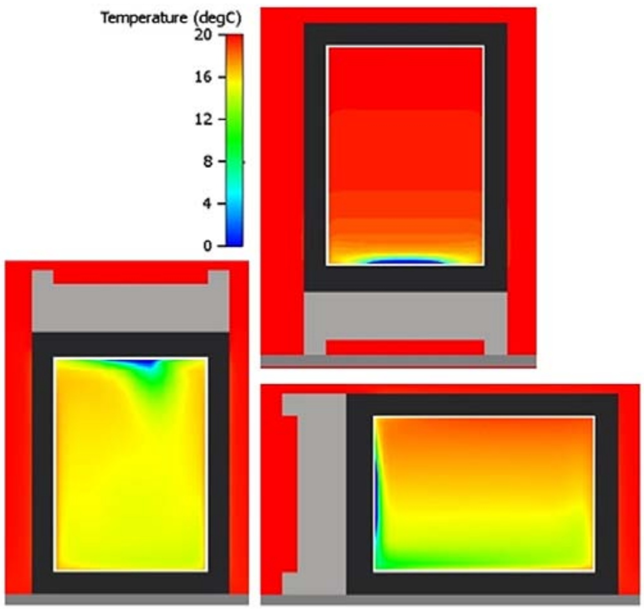
The main effect of this is to reduce the average air temperature. After a couple of assembly rotations and subsequent simulations, the following chart shows the effect of the rotations.

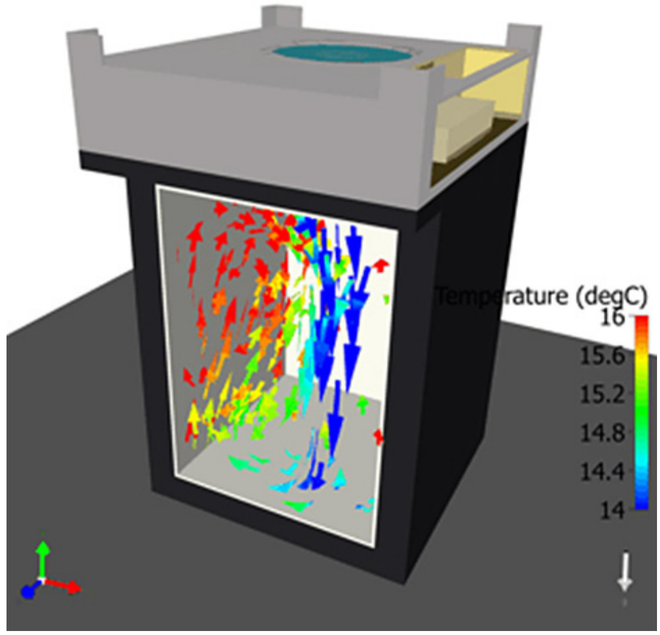


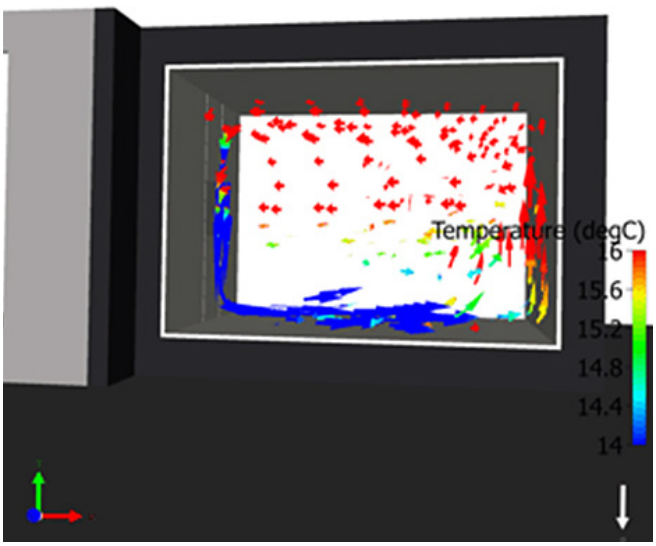
An empty mini-fridge just doesn't get that cold.

In a little more detail, here are the predicted temperature variations within the fridge:

FROM BEER FRIDGES TO LAPTOPS *continues*







The mixing effects of the cold dumping air can be seen when the airflow inside the fridge is animated. (I reduced the temperature range to go from 14 to 16°C, blue = < 14, red = > 16 to clearly show the hot air rising and the cold air sinking; the speeds are not to scale.)

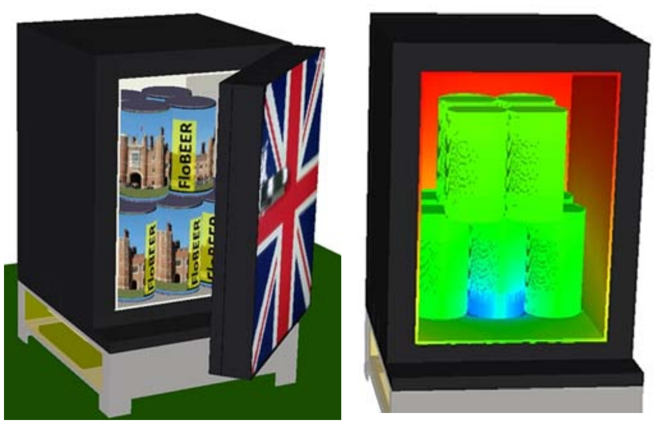
Most people would intuitively know that putting a radiator on the ceiling would not be the best way to heat a room. However, there is more to product design than thermal considerations. Simplicity that leads to a reduction in manufacturing costs is a big one. The structural instability of having the heatsink and fan on the top of the mini fridge might increase the risk of litigation. My conclusion is that mini-fridges are not designed to be empty. Stock it full of beer cans and you might think it would not get any colder. Think again…

Introducing: FloBEER

I modeled a can of beer in FloTHERM as a solid cylinder with a thermal conductivity representative of the (stationary) liquid surrounded by a thin sheet of metal. I came up with a value of 5 W/mK.

I stocked 13 of these virtual cans in the simulated mini fridge, closed the door, and observed.

Compared to the average temperature of about 18°C when the fridge was empty, the average temperature when the beer is in the fridge went down to 13.6°C, with the average temperature of the beer decreasing to 10.1°C. Not all cans are equal, so unsurprisingly the can sitting



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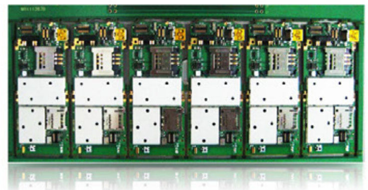

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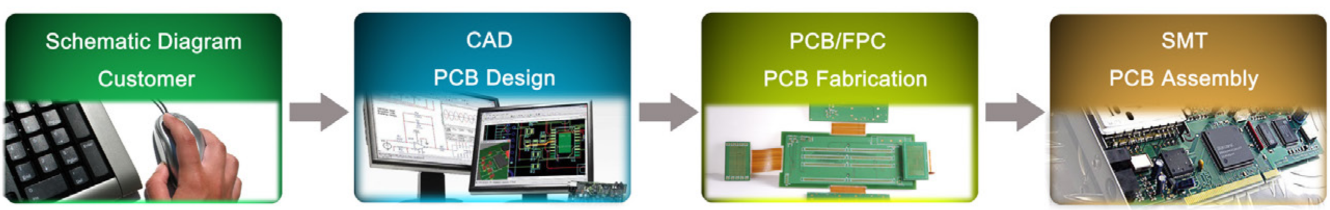

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DESIGN - FABRICATION - ASSEMBLY

FROM BEER FRIDGES TO LAPTOPS *continues*

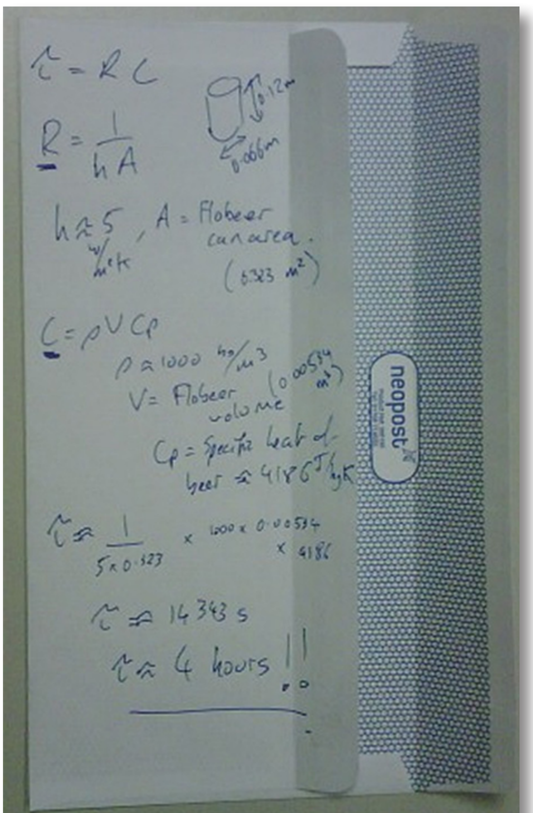
on top of the cold plate is the coldest (shown here by hiding the three cans at the front):

Getting the cold to conduct up and through the cans inside proved to be a far more effective method of moving the cold air from the TEC up, into, and around the fridge. Even moving air is no match for the conductive ability of beer.

Time for a FloBEER

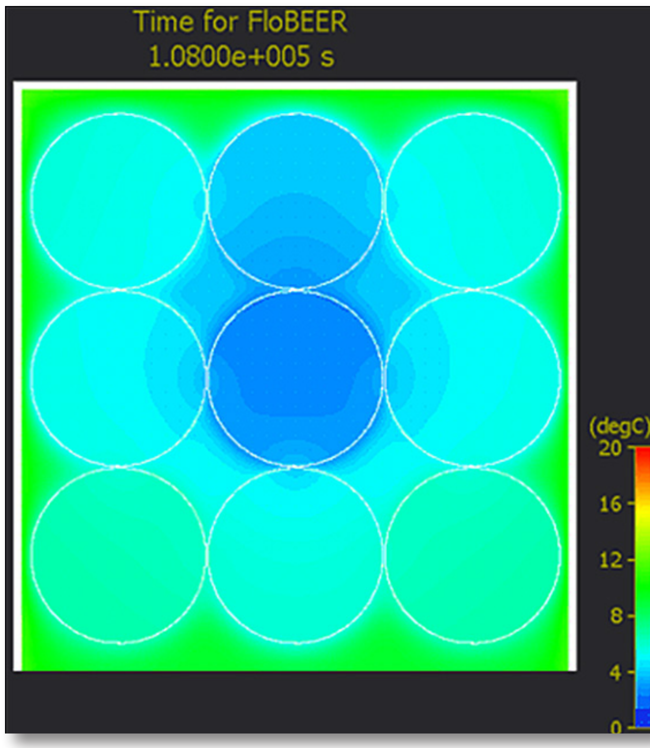
All good things come to those who wait. For beer, this entails a tradeoff between anticipation and satisfaction. A transient thermal simulation will tell you how long, and how evenly, the beer cools down.

A time constant is a resistance multiplied by a capacitance. I made a back-of-the-envelope estimation as to how long it would take warm beer, placed in a cold environment, to achieve its cool temperature. Thermal resistance = 1/heat transfer coefficient x area; a thermal capacitance = density x volume x specific heat; a time constant = thermal resistance x thermal capacitance. The time constant is the time it takes for the beer to cool down to about two-thirds of the way to minimum. Here's the envelope:



When doing a transient simulation, you have to define for how long you wish to predict the behavior of the system. Using the back-of–the-envelope calculations helps set an initial guess for this duration. The rest is simply a matter of waiting for the software to crunch through the simulating. The end-product is a series of predictions of the full 3D temperature distribution at many points in time (time steps). This information can be animated to show how the cold penetrates the cans.

I found that there's a bit of a cold bias towards the rear of the fridge, away from the door, which means that either the bottom-middle or bottom-rear beer would be the best to grab first. Remember to move the remaining cans to fill the hole just left, and turn either to the envelope or FloTHERM if you want to estimate or simulate (respectively) how long you should take to drink the current one until the next one has cooled further down to acceptable levels.



Design is the process of making a plan for the construction of an object or a product. Whether you subscribe to the rational- or action-centric model of the design process, some form of iteration and adaption is used to arrive at a design that is fit for production. Trying an idea, seeing it fail, finding out why, and trying a better idea next is the essence of design success.

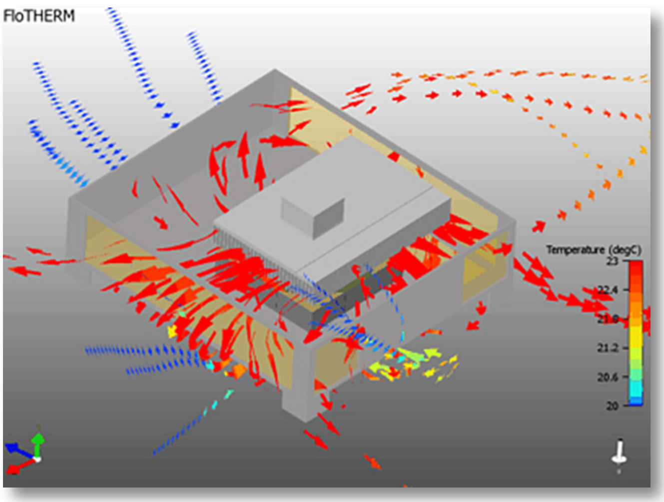
Let's keep that in mind for the mini-fridge design. Testing a physical prototype with smoke-flow visualization before a commitment to manufacture would have shown that the venting arrangement and configuration of the fan and heatsink are not optimal. The TEC would work better if the heat that it sucks out of the fridge is effectively removed from the system when it's passed to the heatsink, then the fan blows cool air over the heatsink, and the resulting hot air is evacuated to the room. The room would warm up (a little), leading you to desire a beer to quench your thirst, which is a nice symbiotic symmetry.

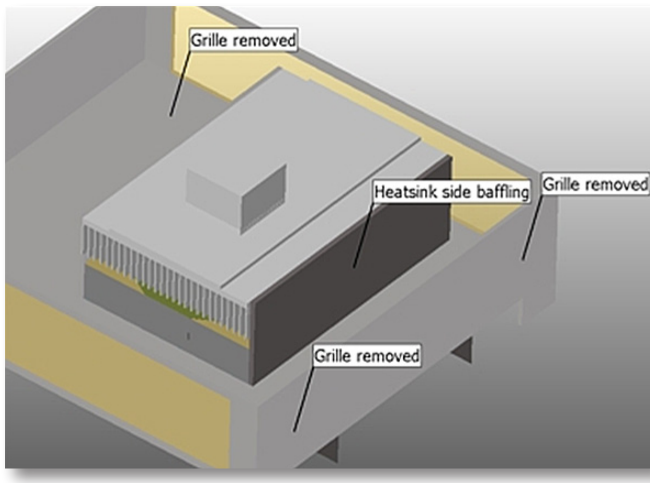
The resulting flow fields of the simulation shown above, with the moving air arrows colored by temperature (red is hot) and the fridge enclosure itself hidden for clarity, show that the hot air issuing from the heatsink is sucked back down under the unit and back into the fan. Far from nice cool air being blown on to the heatsink, it's actually heating itself (well... not being cooled). In addition, some of the air blown onto the heatsink does not move down the extruded fin channels as it should; instead it smacks into the fins and promptly goes sideways through the gap between the heatsink and the fan—wasted air.

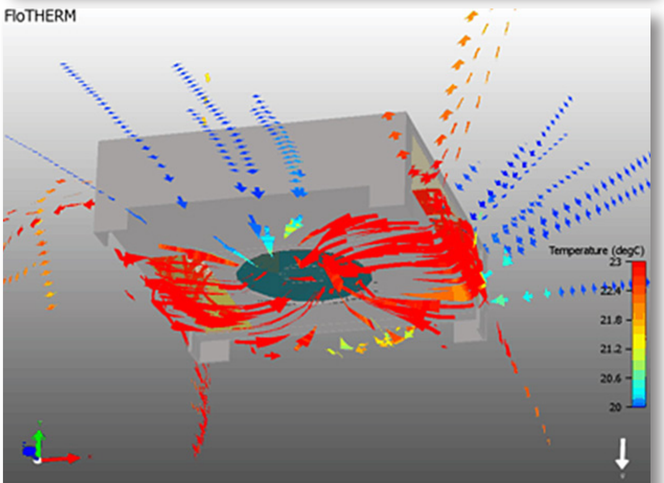
Baffles and Bottlenecks

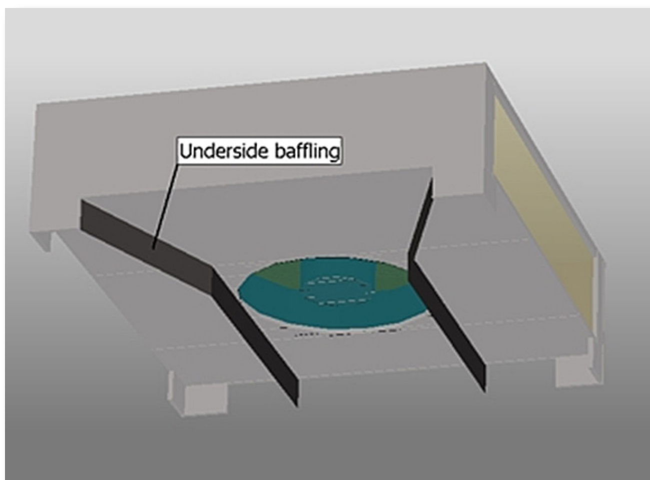
Now that I have identified these deficiencies, I can propose a design alteration. Baffling would ensure that only cool room air is sucked into the fan, the fan pushes air through the heatsink fins channels and the resulting hot air leaves the system, never to be re-ingested (see below):

Now that the air flow is better managed, let's turn our attention to the heatsink. Heatsinks don't magically sink the heat out of existence; they are area extenders. With a little

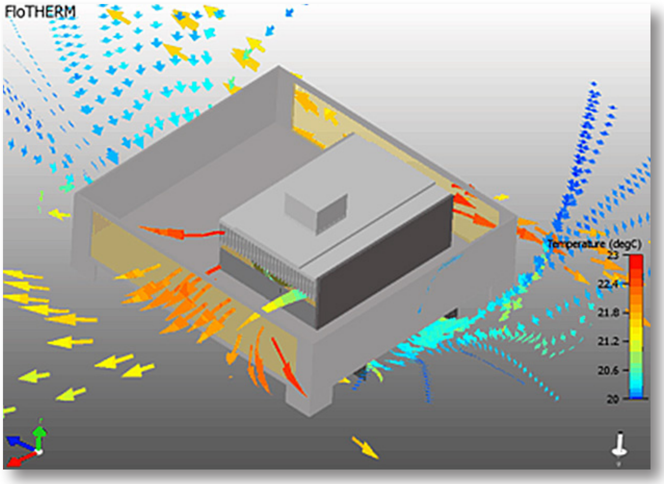


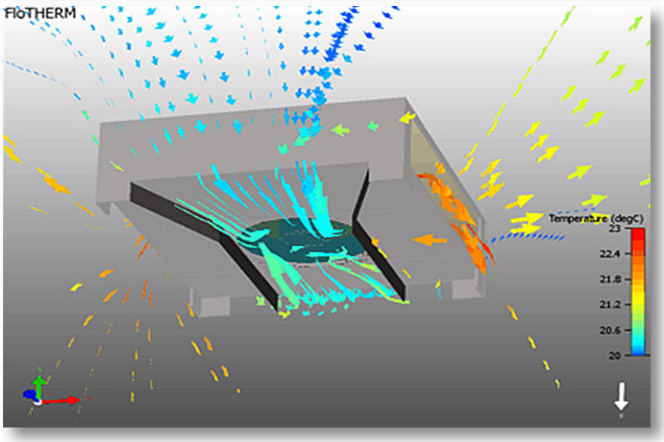






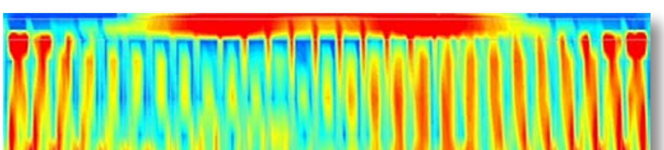
FROM BEER FRIDGES TO LAPTOPS *continues*



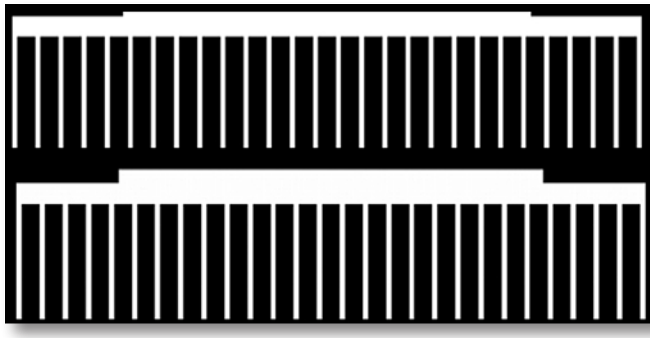


more solid thermal resistance in the form of more aluminum, the heat can be passed to the air over a much larger surface area resulting in more effective cooling. For heatsink design, the number of fins, fin thickness, fin spacing, heatsink length, etc., are all interrelated parameters. Let's just look at the heatsink base thickness.

Using FloTHERM, we can visualize where thermal bottlenecks exist in a design. From a heatsinking perspective, a good design is one where the bottlenecks are as uniform as possible; that is, heat finds it equally easy to pass through all parts of the metal on its way to the air. Looking at the distribution of BN on a plane through the heatsink, we can see where it builds up in the central portion of the heatsink base:



We could use a material with a higher thermal conductivity, or make the cross-sectional area the heat passes through larger to relieve a bottleneck. The latter choice is much less costly, so I increased the base thickness in the middle portion:



All well and good, but how would I determine the effectiveness of the baffling and heatsink design modifications? If the system is working more efficiently, then the TEC would require less power to maintain the mini-fridge at the same temperature as before. In my opinion, this is a better metric than just making the fridge colder; if was any colder, the beer would start to freeze! Making the above two changes, the TEC requires only 3.2A (down from 4A) and pulls 23 W (down from 37 W). The difference in the ratios of current reduction and consumed power reduction is determined by the temperature-dependent self-heating effects in the TEC, which is all handled automatically by FloTHERM. So I conclude that designing a mini beer fridge via this method would ultimately result in 35% energy savings. **SMT**

Robin Bornoff earned a mechanical engineering degree from Brunel University in 1992 followed by a Ph.D. in 1995 for CFD research. He then joined Mentor Graphics Corporation, Mechanical Analysis Division (formerly Flomerics Ltd.) as an application and support engineer, specializing in the application of CFD to electronics cooling and the design of the built environment. He is now the Product Marketing Manager responsible for the FloTHERM and FloVENT software.

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PCB: An Important Piece of the Puzzle in LED Thermal Management

by Kris Vasoya
SINKPAD CORPORATION

SUMMARY: *Thermal management is critical to the long life of LEDs used in solid state lighting (SSL). This paper demonstrates where PCBs stand in the chain of LED thermal management, types of PCBs used, and their effectiveness on reducing LED junction temperature.*

Although LED light sources are more energy-efficient than incandescent, there are many critical differences. One major difference is the way heat is generated and dissipated into the environment. An LED's P-N junction, made of semiconductor material, is located between the anode (+) and the cathode (-). Under electrical power, movement of electrons across the P-N junction releases energy and the emission of photons, located in the ultraviolet band that is beyond the visible spectrum of the human eye. However, when the photon hits a phosphor coating on the lens of the LED, it excites and causes the phosphor to emit light in our visible spectrum.

What is Heat and How Do We Manage It?

Heat is energy. Energy, by the law of physics, can be transformed, but never disappears. Because of this, rather than cooling, we need to think of thermal management in terms of moving heat energy away from the P-N junction to a remote location. This process is called heat transfer or thermal transfer. Heat transfer can happen by combination of three phenomenons: Thermal conduction, thermal convection and thermal radiation.

Thermal conduction is a mode of transfer of heat energy within and between bodies of matter due to a temperature gradient; basically, the transfer of thermal energy from one molecule to the next. There is no physical movement associated with conduction; it is an exchange of molecular energy. Heat spontaneously tends to flow from a body at a higher temperature to a body at a lower temperature in effort to equalize thermal differences.

Thermal convection is the collective movement of ensembles of molecules within fluids such as liquids and gases. Thermal convection should be thought of as a fluid process.

Thermal radiation is electromagnetic radiation generated by the thermal motion of charged particles in matter. All matter with a temperature greater than absolute zero emits thermal radiation.

Though LEDs are much more efficient than any traditional light technology, the light efficiency of these chips are up to 20 to 30% greater, depending on the semiconductor material, current they are running at, and the cooling system's efficiency. Despite the high-efficiency of LEDs, approximately 70 to 80% of the electrical power input is converted to heat.

LEDs hardly radiate any heat into the environment. This means that all of the heat generated by LEDs must be conducted away from the source by physical means. If the heat is not conducted away from the source, and the LEDs get too hot, the phosphor converting photon light to visible light cannot function properly and may be permanently damaged, causing the light to change to an unacceptable color (color shift), which affects the overall quality of light output and longevity of the LED. Furthermore, too much heat will limit the lifetime of the LEDs. Ensure that the product selected has appropriate heat sinking to avoid color shift and shortened lifespan.

Selecting the Right Thermal Solution

To avoid LED thermal runaway and permanent damage, excellent heat conduction must be taken into account throughout the entire LED system. An LED system includes LED package (chip), substrate or PCB, thermal interface material (TIM) located between PCB and heatsink, and the heatsink itself.

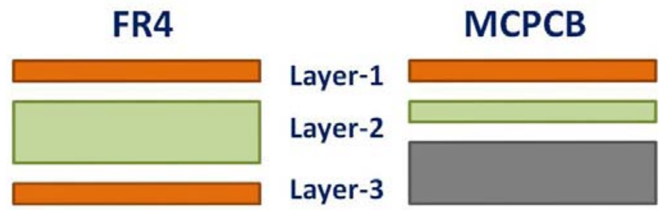

Figure 1: Sectional view of a PCB used in LED application.

For this article I will focus on to PCB (or substrate) portion of the LED system. The overall goal is to achieve low thermal resistance. LEDs at the package level already have pre-defined structure and associated thermal resistance designed by the package manufacturer. After a LED package, a PCB is second in line within the conduction thermal path. It is important to analyze and understand PCB structure, material and thermal property to optimize conduction heat transfer.

Figure 1 is a sectional view of a most-common PCB used in the LED application. Basically, it is a three-layer structure: Top, middle and bottom. The top layer is a circuit layer, the middle layer is a dielectric layer and bottom layer is either a thin copper layer (FR-4 PCB) or thick metal layer (metal core PCB, or MCPCB). LEDs are mounted onto the top circuit layer.

Selecting the Right PCB with the Least Thermal Resistance

The PCB is one of the important pieces of the puzzle when it comes to optimizing LED thermal management. Several types of PCBs may be considered for the LED application, depending on how much heat dissipation is required. Metal core PCBs and standard FR-4 PCBs with thermal vias are commonly used to dissipate heat from a LED, which is surface mounted to a PCB.

Therefore, the board is the first level of thermal dissipation after the LED chip itself. For many of the low power LEDs, ordinary FR-4 substrate with thermal vias provides acceptable performance. But for medium- to high-power LEDs, FR-4 substrate is not good enough and

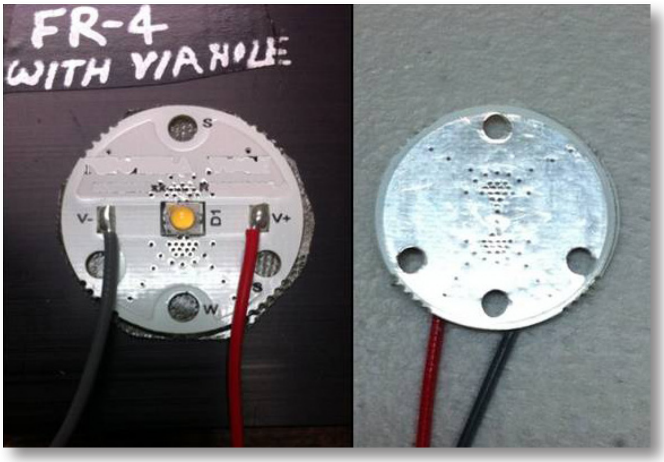

Figure 2: FR-4 PCB with thermal via.

more often, an MCPCB is used. MCPCBs (often called aluminum PCBs) use a thermally conductive dielectric layer (Figure 1) with base metal aluminum or copper.

Substantial advances have occurred in recent years in the field of MCPCB. With the prospect for high growth in LEDs, many companies are trying to develop the best thermal substrate solutions and market them for LED applications. A handful of new MCPCB material manufacturers exist and many are just entering the market, but all are offering a simple variation of two things: Thermal conductivity of the dielectric and dielectric thickness. Focus has been on how to improve thermal performance of an existing dielectric material.

Table 1 shows various thermally-conductive dielectrics available in the market. Thermal conductivity values range from 1.0-4.0 W/m.K, and typical thickness of these dielectrics are 70um to 150um. Based on our evaluation of various MCPCB materials, we discovered one important fact: Thermal conductivity and the thickness of the dielectric might look comparable on a data sheet, but they do not perform in the same way when it comes to transferring heat from the LED.

It is fair to say the key to the performance of the MCPCB lies in its dielectric layer. Even though thermally conductive dielectric has higher thermal performance compared to standard dielectric material it is still the weakest link in the conduction thermal path of the MCPCB. Is there a way to eliminate dielectric thermal resistance completely from the thermal path?

Metal Post MCPCB: Direct Thermal Path Solution

LED manufacturers are continuously pressing the envelope towards miniaturization of LED packages. This allows Luminair manufacturers to design more LEDs in a smaller space, i.e., high-heat flux. The goal is to achieve rapid heat spreading directly below the LED. There are two types of thermal management in solid state lighting (SSL)—active thermal management (active cooling) and passive thermal management (passive cooling).

Active cooling is used where passive cooling cannot move heat at a high enough rate to support thermal management needs of a given device. Also, there are disadvantages to active cooling in SSLs. Few, if any, active cooling devices are proven to match the 100,000-plus hours expected of a SSL product. Additionally, the noise they introduce and the power they consume is undesirable.

Thus, passive cooling is clearly preferable when sufficient heat exchange can be facilitated without the need for active cooling. Passive thermal management relies on the thermody-

THERMALLY CONDUCTIVE DIELECTRICS

- ✓ Arlon 92ML – 2.0W/m.k
- ✓ Bergquist – 2.2-3.0W/m.k
- ✓ Doosan – 2.0W/m.k
- ✓ Denka Hit Plate – 2.0-8.0 W/m.k
- ✓ DuPont CoolLam – Polyimide based – 0.80W/m.k
- ✓ ITEQ- IT859 GTA – 2.0W/m.k
- ✓ Laird Technology HKA – 3.0W/m.k
- ✓ Polytronics – 2.7W/m.k
- ✓ Sekisui – 2.0W/m.k
- ✓ Ventec - VT 4A1 – 1.6W/m.k

Table 1: A list of the various thermally-conductive dielectrics available.

Figure 3: MCPCB.


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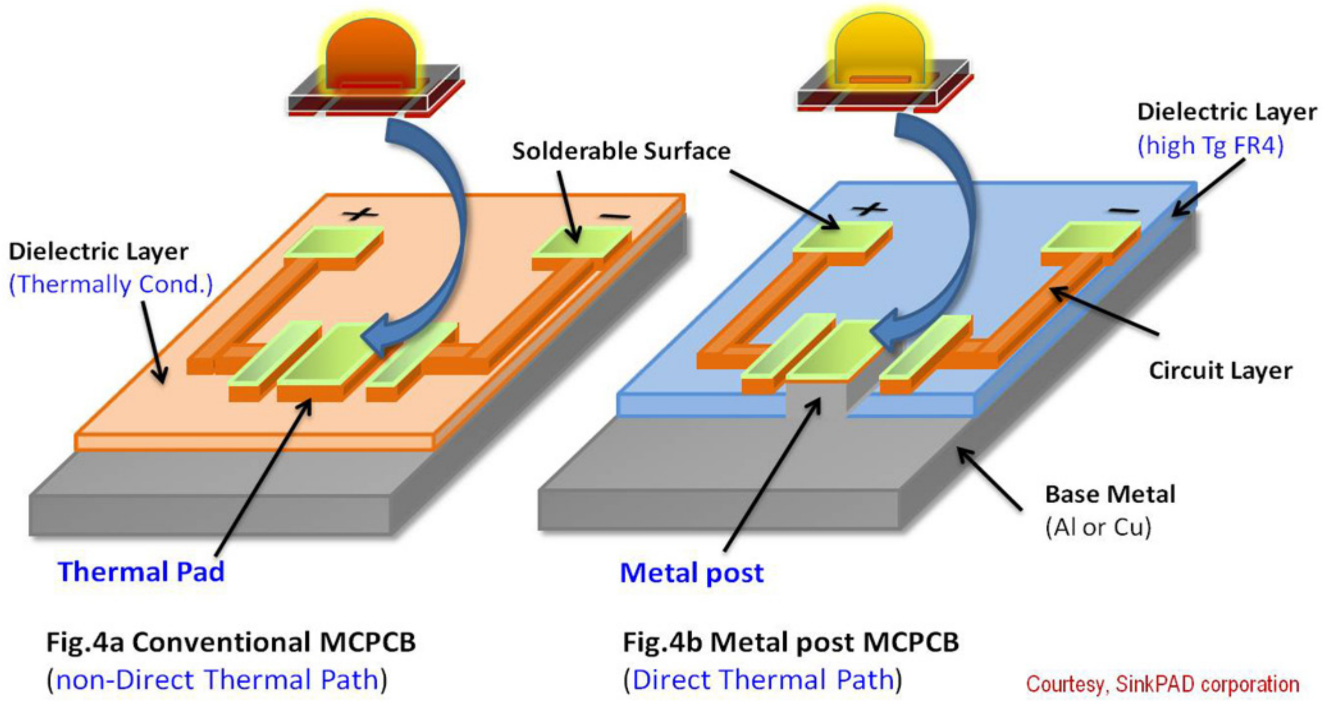


Figure 4: Traditional MCPCB and metal post MCPCB.

namics of conduction and convection, without an introduction of additional energy to enhance thermal transfer. Heat conduction starts at the junction, and the heat-energy travels through a series of components to end at the convection surface. A goal of the SSL design engineer is to adjoin these components in a manner that maximizes the thermal conductivity between the junction and the convection surface. How is the best passive thermal path achieved? It can be done by reducing the number of materials in the thermal pathways to a minimum (i.e., reduce interfacial thermal resistance) and by using higher thermally-conductive materials.

As described in a Figure 4, a localized metal-post approach can take traditional MCPCB to the next level by eliminating the use of a dielectric completely from a thermal path. This creates 100% metal-to-metal contact between the thermal pad of an LED chip and the base metal of an innovative MCPCB.

Test Data and Conclusion

In this test setup, a Nichia N219 LED was mounted onto three different types of PCBs to measure its ability to dissipate heat: a) FR-4 PCB with thermal vias; b) MCPCB; and c) metal post MCPCB. Figure 5a shows the infrared picture displaying the thermal dispersion pattern between the three types of PCB after the LED has been powered for 25 minutes. As is easily observable from this picture, the FR-4 PCB has higher thermal resistance than the metal core PCB, which has higher thermal resistance than the metal post MCPCB.

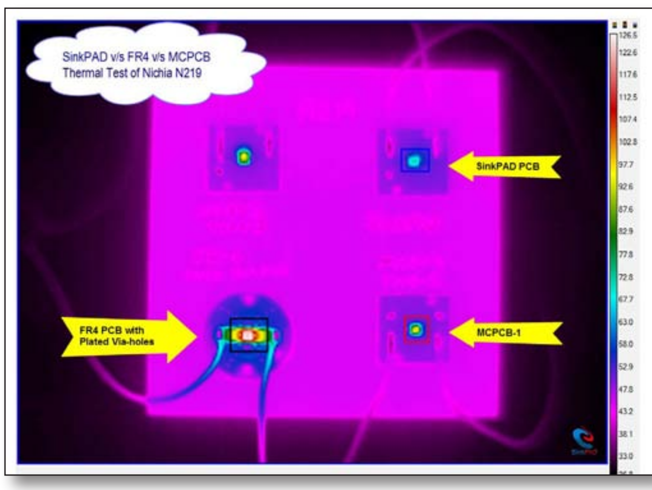
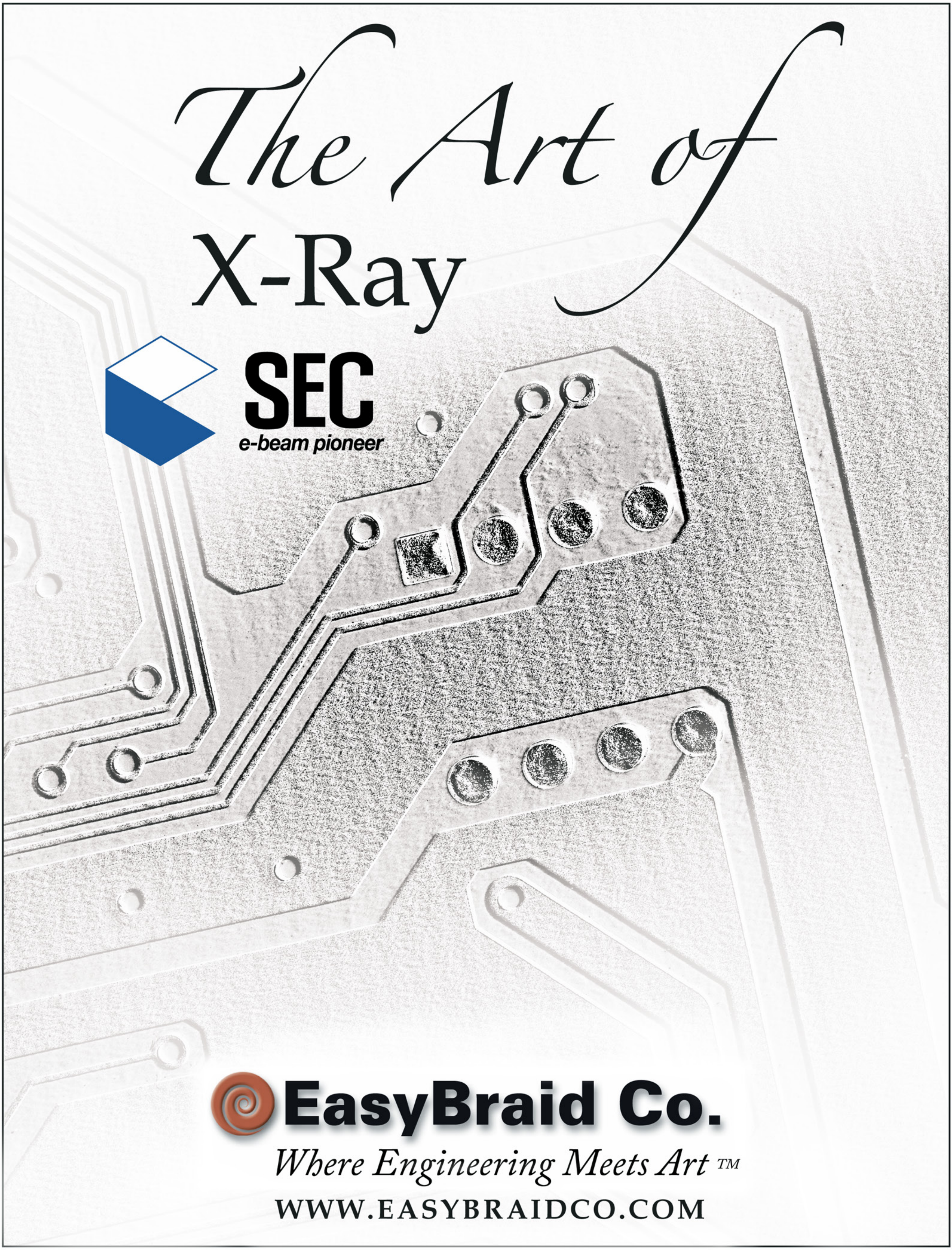


Figure 5a: Infrared thermal image of; a) an LED mounted on an FR-4 PCB with thermal via; b) MCPCB; and c) SinkPAD MCPCB.



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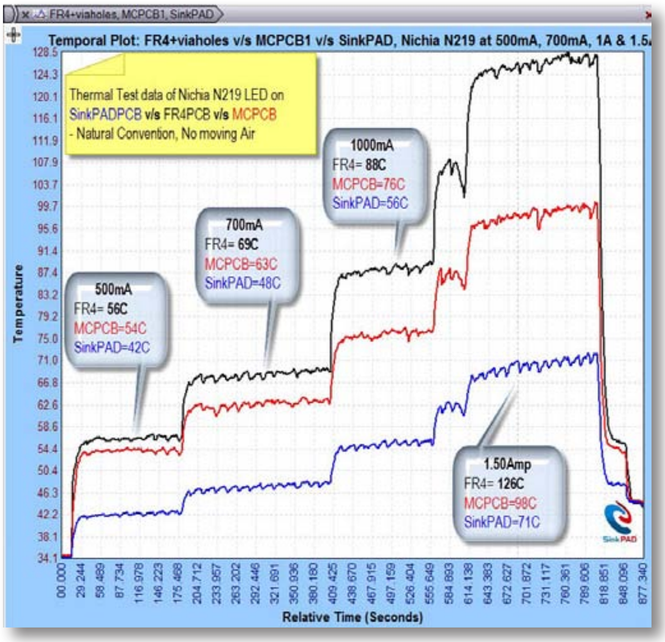


Figure 5b: Time versus temperature plot of: a) an LED mounted on FR-4 PCB with thermal via; b) MCPCB; and c) SinkPAD MCPCB, running at 500mA, 700mA, 1000mA, and 1500mA current.

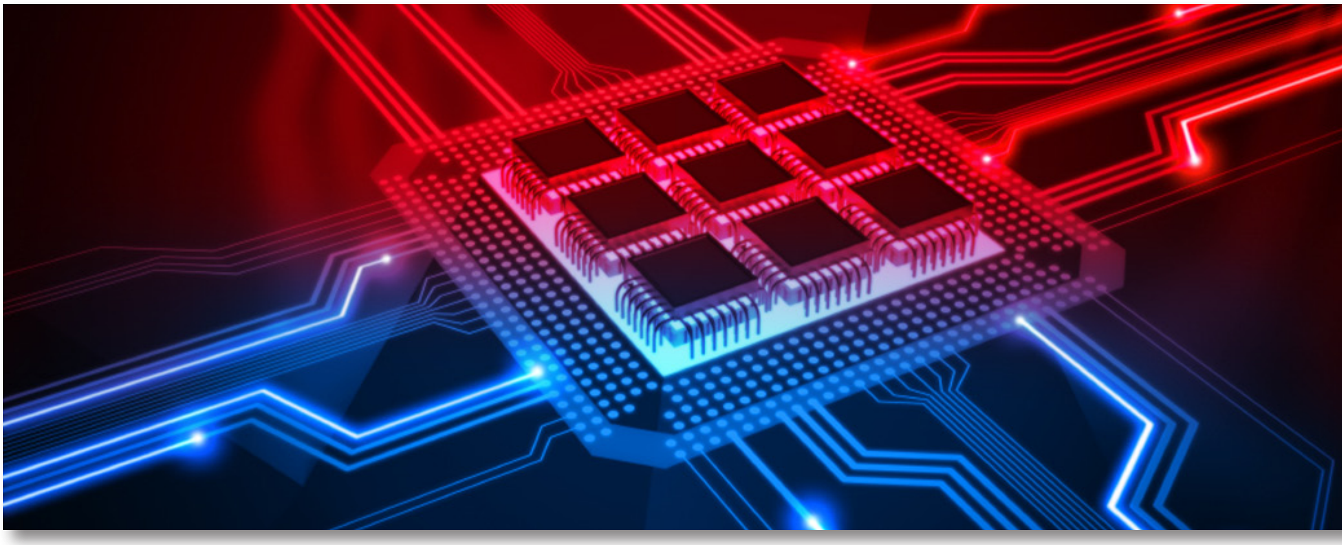
Conclusion

Due to the higher thermal resistance of the FR-4 PCB, it is primarily used for low-power LED applications where high heat dissipation is not required. The MCPCB has much lower thermal resistance than FR-4 and can be used for medium- to high-power LED applications. An improved version of MCPCB can be appropriate for high-power LED or high-heat flux applications.

When it comes to LED thermal management, the type of PCB used truly matters. **SMT**

Kris Vasoya is a founder and CTO of SinkPAD Corporation. He works on new processes and materials solutions and technologies to enhance the thermal performance of traditional PCBs. He invented carbon composite-based thermal management technology for the complex multilayer PCB and has been awarded more than dozen patents worldwide.

COOLING FROM DOWN UNDER: Thermally-Conductive Underfill



by Larry Wang and Paul Hough
LORD CORPORATION

SUMMARY: This paper, presented at last month's International Microelectronics and Packaging Society Symposium, describes the key challenges in developing underfill technologies imposed by package geometries and performance requirements. Such demands on underfills require innovative formulation design using novel polymeric materials and specially-selected fillers.

Abstract

The industry trend toward reduced feature size and faster operating speed has generated increased demand for flip-chip devices. Flip-chip technology enables design flexibility and offers many benefits, but, at the same time, the devices are susceptible to thermal and mechanical stresses and require the use of an underfill to achieve the desired reliability. In addition, advances in the device design to "pack in" more power and functions often impose more demands on underfills.

In many cases the cooling capabilities of these advanced packages still limit device performance, especially when there is limited space for conventional heat dissipation techniques, such as thermal greases, heat sink, and/or fan. To address the issue of thermal dissipation in flip-chip applications, LORD Corporation has developed a thermally-conductive underfill which combines the processing properties and reliability improvement from a traditional underfill with a thermal conductivity of 1.2 W/mK. The thermally conductive underfill is ideal for flip-chip applications where there is limited space for traditional heat dissipation techniques and/or in hermetic packages where no air movement is available to cool the device.

This paper describes the key challenges in developing underfill technologies imposed by package geometries and performance requirements. These demands on underfills require innovative formulation design using novel polymeric materials and specially-selected fillers. We will discuss the design of a non-anhydride underfill with low viscosity, small particle size filler, fast flow, and high reliability.

Introduction

Continued advances in flip-chip design and technology have made flip-chip devices more versatile and multi-functional. It has allowed

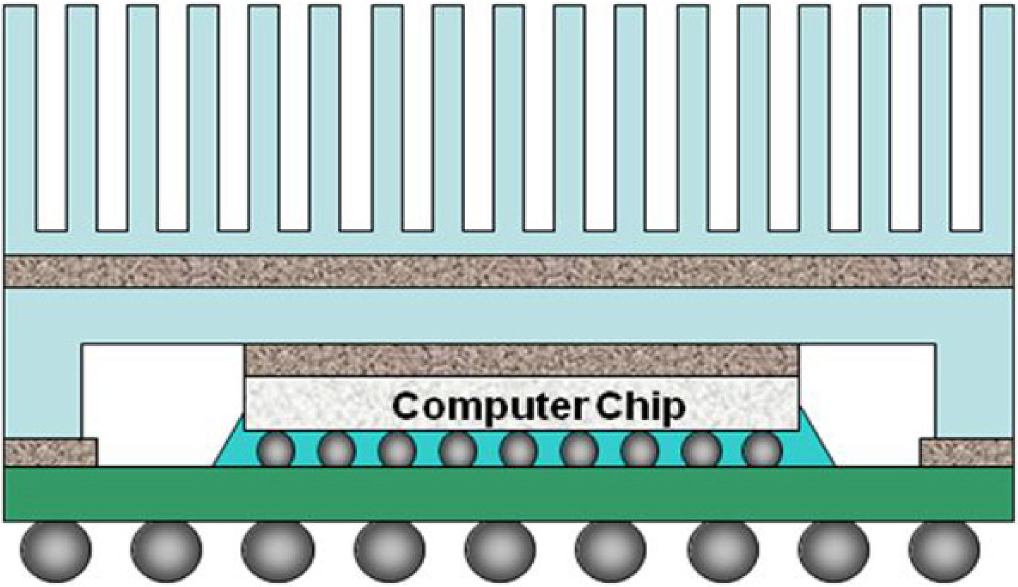


Figure 1: Heat dissipation and thermal management become challenging in a confined space.

penetration into many different applications with various restrictions and performance requirements. All of these FC devices still require an underfill to achieve desired reliability, but each is unique by itself to fit the specific requirements and restrictions. Thus it creates challenges for material suppliers to formulate different underfills for different device types. When the flip chips are designed with increased functionality, and more power is packed into the ever-smaller form factors, heat dissipation and thermal management become challenging, especially in a confined space.

In a conventional design, when heat dissipation is needed, several levels of thermal interface material (TIM) may be used to conduct the heat away through the top of a flip chip to the ambient air. However, in a confined space, not only is there no space available on top of the chip, but no air movement to dissipate heat from the top. In this situation, cooling from down and under the chip becomes the only viable solution in terms of thermal management.

In response to the market need, LORD Corporation has developed a unique underfill with high thermal conductivity while also satisfying other demanding requirements for processing and performance. A better thermal solution allows the chip to run at a cooler temperature for efficiency or to design more power and functions into the chip.

Current work shows that ME-543 demonstrates low viscosity, good flow, minimum keep-out zone, and low creep. The cured flip-chip device exhibits lower chip temperature and excellent reliability performance compared to a conventional underfill, indicating the desired heat dissipation benefits.

Experiments

In this section we describe the methodology that is used to study the uncured and cured state properties of an underfill encapsulant. The uncured properties of an underfill encapsulant dictate its processing characteristics during flip-chip assembly whereas the cured properties of the underfill determine its ultimate performance and the reliability of the flip-chip device.

Figure 2: Little space is available and air flow is restricted—cooling from down and under the chip is the only solution.

Property	ME-543
Resin	Epoxy
Curing agents	Amine
Fillers	Ceramic
Filler loading, weight %	60-70%
Particle size, average, microns	5
Viscosity, Pa.s @25°C	21.0
Viscosity, Pa.s @90°C	0.20
Flow time, seconds @ 90°C	
12.70 mm x 6.35 mm	8
12.70 mm x 12.70 mm	35
12.70 mm x 25.40 mm	116
Gel time, 150 °C	4 min
Cure condition*	165 °C
	15 minutes
Cure profile, by DSC	
Onset, °C	118
Peak, °C	130
Enthalpy, J/g	172
Thermal Conductivity, W/mK	1.2
TGA, Temp @1% wt loss, °C	340
Tg (by TMA), °C	135
CTE, ppm/°C (<Tg)	27
CTE, ppm/°C (>Tg)	95
Elastic modulus (25 °C), GPa	5.5
Elastic modulus (250 °C), GPa	0.43

Table 1: Characteristic properties of thermally-conductive underfill ME-543.

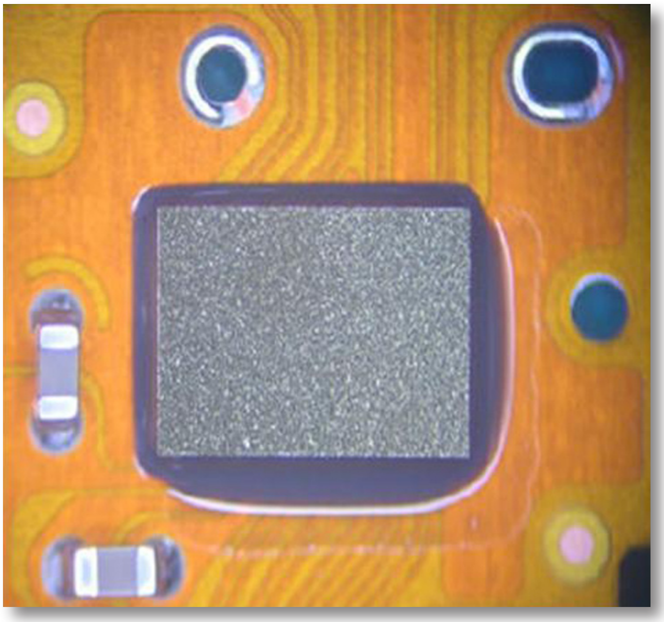


Figure 3: The underfill features minimal unwanted flow away from the flip chip.

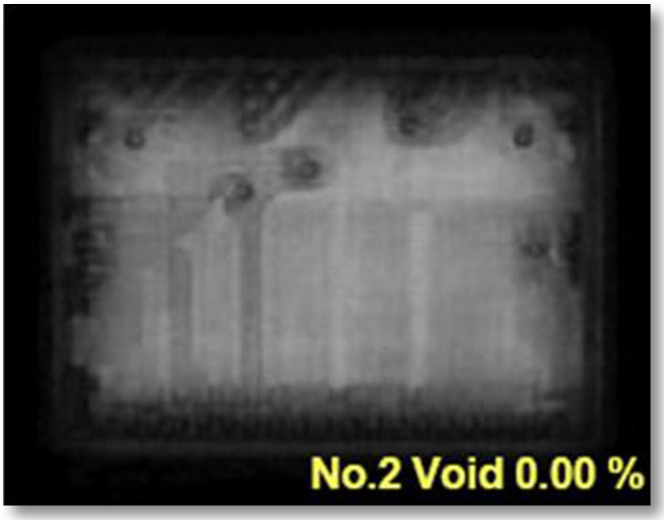


Figure 4: X-ray shows a void-free product.

Underfill viscosity is measured with a parallel plate rheometer at 25°C and at 90°C and underfill flow is studied by a simulated method using a glass slide over an appropriate substrate.

The curing behavior and cured properties of ME-543 are measured by DSC, TMA, DMA, and DSC and the thermal conductivity is measured by laser flash method using a sample disc of 1 mm thickness.

Results and Discussions

Underfill Properties

Table 1 summarizes the characteristic properties of LORD ME-543 underfill. The underfill is based on non-anhydride cure chemistry rather than the traditional epoxy/anhydride chemistry. This gives the material better reliability performance in addition to being easy to process and more environmentally friendly.

As seen in Table 1, the underfill viscosity may not appear to be the lowest at 25°C, but it drops rapidly as the temperature increases. This allows for faster processing and better flow at application temperatures, typically 90°C to 110°C, which is confirmed by the fast flow time in the simulated underfill flow test.

Underfill Application and Processing

ME-543 has been evaluated extensively in customer line trials on various devices and configurations. It was found to have good dispensing and flow behavior using both jetting dispenser and positive displacement machines. Furthermore, the viscosity profile and formulation design of the product make it convenient to control the keep-out zone and creep, which means the underfill will have minimal unwanted flow away from the flip-chip or climb over to the top of the die. This allows customers to use it on boards that have densely populated components, and for flip-chips that have strict requirements for a clean top of the die.

In addition to easy dispensing and flow, ME-543 is also capable of fast cure and void-free coverage, as examined by CSAM and X-ray.

Underfill Reliability in Flip-Chip Devices

The reliability testing of ME-543 was carried out by a major electronic OEM and its CEM partners. The product provided desirable thermal dissipation through the underfill layer as measured by the Theta-JA temperature. Additionally, the product exhibits excellent reliability results in this customer-specific flip-chip device. The underfill successfully passed, among many reliability measures, the thermal cycling test from -55°C to 125°C for 3,000 cycles with zero failure. The inspections by CSAM, X-ray, cross-section, and flat-section of test devices after 3,000 cycles confirmed that the underfill has provided sufficient protection to the flip chip and its solder joints and there were no defects or signs of failure.

Conclusions

LORD has developed a new underfill material with novel non-anhydride curing chemistry and high thermal conductivity. We have presented here the material properties, processing characteristics, and the reliability performance of the thermally-conductive underfill. The underfill provides fast flow into fine gap for small- to medium-size flip chips, and showed to have minimal keep-out zone and creep. The results from reliability studies indicate that the underfill provides excellent protection of the chip and solder joints after long thermal cycles, high humidity, and other reliability tests. **SMT**

Editor's Note: This paper was originally presented at the International Microelectronics and Packaging Society Symposium in May 2012.

Larry Wang, Ph.D., staff scientist, Electronic Materials Research and Development, is responsible for the development and commercialization of new materials for the electronics market. With expertise in various areas including conductive materials, adhesives, underfills, potting, and encapsulants, he also leads technical support to Marketing and Sales for the LORD electronics business. Having worked for the company for 11 years, Wang has more than 20 years of combined industrial experience focused on adhesives, coatings, and potting encapsulants for the electronics industry.

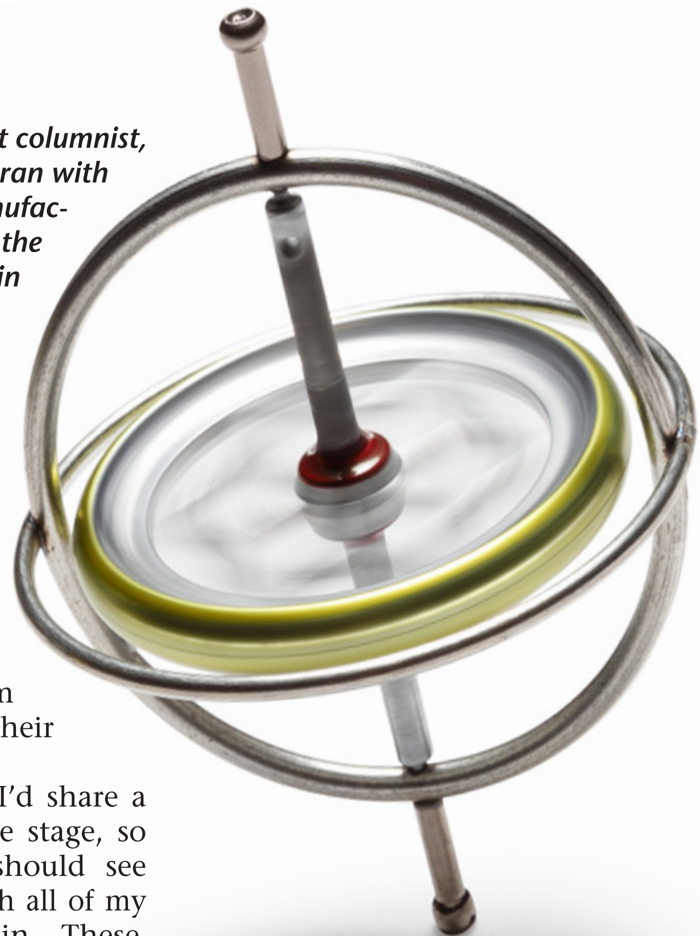
Paul Hough, European Technology Manager, Electronic Materials, LORD Germany GmbH, is responsible for evaluation of new projects, supporting product implementation, expanding market presence, and technical service for the European electronics market. He spent nine years in product development, focusing on encapsulation and thermally conductive material development. Hough has spent the past five years as the Technology Leader in the expansion of LORD Electronic Materials in Europe.

PROCESS CONTROL

What's the Spin?

by Bill Loving
SCANCAD INTERNATIONAL, INC.

SUMMARY: SMT Magazine's newest columnist, ScanCAD's Bill Loving, an industry veteran with nearly 40 years' experience with manufacturing systems and process flow, sets the stage this month for what's to come in future issues.



It's always about the "spin." We all have filters that shape our belief systems, our way of looking at the world. Naturally, every column or article represents a crystallization or snapshot of the writer's spin at that moment in time. Link a number of these together and you begin to see a theme... you begin to see where the authors are coming from based on what they've shared. Their "spin" becomes obvious.

As a new columnist, I thought I'd share a bit about my spin up front—set the stage, so to speak. If I'm successful, you should see common threads that weave through all of my columns that align with this spin. These threads include:

- Entrepreneurship;
- A global perspective;
- Risk taking;
- Collaborative versus competitive;
- Motivation;
- Business as a positive influence in our world;
- Smiling, fun, humor, and lightening up;
- Keeping things simple;
- Sustainable;
- Weighted toward electronics manufacturing, yet crossing the industry;
- Values-based;
- Respect for the individual.

The fabric woven from these threads feature a pattern or spin that comes from growing up on a ranch in the mountains of Colorado and being educated as a mechanical engineer. My hobbies include racing catamarans, spelunking, scuba diving, skiing, biking, hiking, climbing, golfing, and traveling and enjoying every continent with my wife and children while supporting a company.

I have nearly 40 years of experience with manufacturing systems and process flow, over 24 years of which involved CEO positions in public and private global companies. The industries supported were mainly electronics manufacturing with some forays into transportation (trucks, trains, and airplanes), electric utilities (generation, transmission, and distribution), telecom, and plastics.

WHAT'S THE SPIN? *continues*

Why is this new column titled *Process Control?* My belief is that it's all in the process. You've heard it before: Input - process - output. Simple. All of work, all of life comes down to inputs - processes - outputs. The process is your personal value-add to the equation. It's where you leave your own fingerprints… it's why we're here. For work, it's what you're paid to do. If you are passionate about your process, it's what brings you back each day. It's in the only "place and space" that you can be at any given time. We only live, breathe, and process in the present moment.

How you control your process determines your productivity, your happiness, your satisfaction, and the output of your work and personal life. The goal of this column is to bring you interesting ideas that may be incorporated into your present process. With luck, ideas that simulate, motivate, and act as a catalyst for change in your life.

In future columns, expect to see the following topics:

- Inspection versus measurement: Two different animals.
- Paperless work instructions: What are the options?
- Legacy product reverse engineering: How to keep the old systems running.
- Why IPC-2581? Is it needed?
- BGA inspection: Human versus machine.
- Tweak a stencil for every job lot of bare PCBs...why not?
- Can temporary workers really perform complex work reliably?
- Will your process documentation pass the language audit?
- How to maintain traceability even when using subcontractors. It's easier than you think!
- Personal health and well-being made easy.
- Organizational health and well-being.
- Who's really the boss?
- The unwritten goal of every company.
- Automating employee training and certification.
- Ten secrets to successful software design.
- And much more.

There you have it: A few clues on my "spin" and a blueprint for a new column based on process control. The path should take us to some interesting places together. Who knows? It might even change our lives! **SMT**

William (Bill) Loving is president and CEO of ScanCAD International, Inc., a global provider of process control tools for the electronics industry with distribution and support networks supporting customers in 46 countries. Having founded the company in 1990 with extensive electronics manufacturing industry experience with IBM and OZO Diversified Automation, and a bachelor's of science in mechanical engineering, Loving focuses his energy on customer-oriented technical applied technology. His responsibilities include focusing ScanCAD's product leadership in support of today's dynamic global manufacturing challenges.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Top Ten Most-Read Mil/Aero007 Highlights

Prognostics of Electronic Interconnect

NPL is launching a new collaborative project aimed at finding data on the Remaining Useful Life of assemblies. Interconnects in electronic assemblies have well recognised wear-out properties. However, interconnect performance is affected by specific materials and processes during manufacture, which can significantly alter lifetimes from the physics-of-failure models.

Kemet Rockwell Collins' Top Supplier for 2012

Rockwell Collins has named Kemet Electronics Corporation, a leader in capacitance technologies, as the President's Award winner for 2012. The top honor was presented at the Rockwell Collins Annual Supplier Conference, which took place May 1, 2012.

Sanmina-SCI, Thales Deliver New APAR System

"We are proud to be part of the successful delivery of the latest generation APAR system and to see our microwave design and custom manufacturing expertise being applied to Thales' leading-edge T/R modules and Switch Matrix solutions," said John Pokinko of Sanmina-SCI.

Flextronics' U.S. Facilities Achieve AS9100C Certification

Three of Flextronics' U.S. facilities—Charlotte, North Carolina; Austin, Texas; and Milpitas, California—have separately received certification under the AS9100C aerospace and defense quality standard. The certifications were awarded by TUV SUD America Inc. after extensive third-party audits at all three facilities.

Northstar Discusses Market Outlook, Strategies

Northstar Electronics, Inc., which previously signed a Letter of Intent to acquire Echotec Sonar Corporation, announces that Echotec and Northstar have just given an exclusive interview about the sector, the company, and its strategy.

Nortech Aerospace System Nets AS9100:2009 (Rev C)

"This important certification demonstrates our commitment to continuous improvement throughout our entire operation," says Michelle Risius, quality manager at Aerospace Systems, a division of Nortech Systems located in Blue Earth, Minnesota.

Ducommun LaBarge Posts Q1 Sales Increase

The DLT segment reported net sales for the first quarter of 2012 of $110.1 million, compared with $27.3 million in the first quarter of 2011, reflecting sales of $84.4 million from the acquisition of LaBarge.

Sparton, USSI JV Secures Contract for Sonobuoys

Sparton Corporation and USSI announce the award of subcontracts valued at $13.9 million from their ERAPSCO/SonobuoyTech Systems joint venture, for the manufacture of multiple passive and active sonobuoys in support of international end-user exercises and training.

OSI Secures $2 Million Order for Electronic Sub-Assemblies

OSI Electronics, a business within its OSI Systems, Inc.'s Optoelectronics and Manufacturing division, has received an order of approximately $2 million for electronic sub-assemblies from a major provider of secure identification-based solutions.

Orbit's VP & COO Bruce Reissman to Step Down

Orbit International Corporation has announced that the company and its Executive Vice President and Chief Operating Officer Bruce Reissman, have come to a mutual understanding in which Reissman will be stepping down from these positions as of July 31, 2012, and his employment agreement will not be renewed beyond that date.

More Mil/Aero News

TOP TEN

Most-Read News Highlights from SMTonline this Month

① Flat Demand Weakens Sanmina-SCI's Q2 Results

"As we expected, our second quarter continued to be challenged by relatively flat demand across most of our markets and a decline in the multimedia segment," stated Jure Sola, chairman and CEO. "Based on our outlook for the third quarter and feedback from customers, we remain encouraged that we should see improvements in the second half of the calendar year."

② John Mitchell Begins Tenure as IPC President and CEO

New IPC President and CEO John Mitchell began his first week on the job at the association that, 55 years ago, helped a newly-formed printed wiring board industry gain acceptance, strength, and visibility. Mitchell says that his mandate from the Board is to help IPC grow internationally and to serve its members worldwide with excellence.

③ Report: EMS Market to Reach $671.7B by 2018

GIA announces the release of a comprehensive global report on the "Electronic Contract Manufacturing Services" market. The global market for electronic contract manufacturing Services is projected to reach US $671.7 billion by the year 2018.

④ Seven Engineers Earn SMTA Certification

The SMTA proudly announces seven engineers recently received SMTA Certification for SMT Processes at a certification event held March 28-30, 2012, at Logic PD Corporate Office in Eden Prairie, Minnesota. The SMTA Certification program is unique as it recognizes and certifies the entire SMT assembly process at an engineering level.

5 Sanmina-SCI's Suzhou Plant Strengthens Medical Capability

"Earning the ISO 13485 certification shows our commitment to produce the highest quality devices for the medical market," said Seamus Grady, senior vice president, Medical Division of Sanmina-SCI.

6 Benchmark Recovers From Thai Flood; Revenue Rises

"We are extremely pleased with the improvement in the operating margin this quarter. Our margin increase was achieved through revenue growth driven by new program ramps, the Thailand recovery and the diligent focus of our global operations team," said Gayla J. Delly, president and CEO.

7 Probe's Q4 Revenue Soars to 57% Growth

Probe Manufacturing, Inc. has reported 57% revenue growth for its fourth quarter 2011 and 62% revenue growth for the year ended December 31, 2011, compared to the fiscal year 2010.

8 HEI Posts Sales Drop in Q1

Sales for the first quarter were $9.1 million as compared to $9.7 million for the first quarter of 2011. The company generated net loss of ($157,000) for the first quarter of 2012 compared to net income of $185,000 for the same period in 2011.

9 Q1 EMS M&A Activity Represents Steady Recovery

Nine completed EMS transactions occurred in the first quarter of 2012. The transactions represent continued steady recovery in recent M&A activity from a low point in Q3 2011. The continued economic and credit market improvements combined with the general market need to deploy cash is driving further M&A.

10 Celestica's Q1 Results within Guidance

"Celestica delivered a solid first quarter with strong operational execution and cash performance, despite an overall weak demand environment," said Craig Muhlhauser, president and CEO. "Consistent with our strategy, we continued to invest to support the growth of existing and new customers and we made further progress on our revenue diversification."

THE SALES CYCLE

China: From the Inside

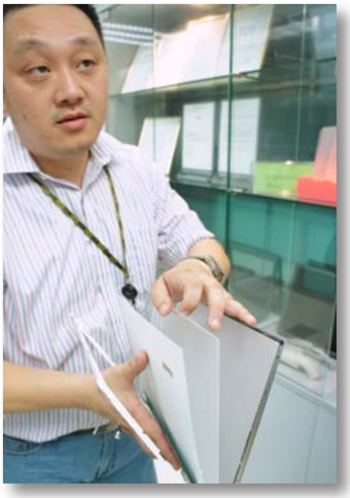
by Barry Matties
I-CONNECT007

SUMMARY: One aspect of Chinese manufacturing so often called into question is working conditions. During a recent visit to China, I-Connect007 publisher Barry Matties sat down for an in-depth interview with Hamed El-Abd, president of WKK Distribution. When he broached the topic, Hamed invited him to tour his company's factory in Guangdong.

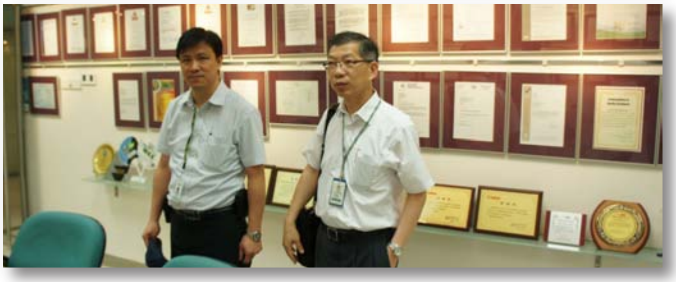
In past columns I have written about the economic war with China and the trap we have set for ourselves. But the battle isn't just for low-cost products being produced and shipped back to America, it is also for access to the very large and fast-growing domestic market in China. As suppliers to PCB fabricators and assemblers worked to gain market share in China, they faced many challenges, including cultural issues, infrastructure, employees, language, kickbacks, corruption, and others. The most common approach to overcoming these challenges was to ink a deal with a large distributor. One well-known distributor is WKK Distribution (WKKD).

WKKD is part of Wong's Kong King Group (WKK), which has been serving the global markets for nearly 35 years. WKKD distributes many products to the PCB fabrication and assembly market from suppliers around the world. Products include both consumables, such as P. Kay Metal's MS2®, and equipment from manufacturers like Multiline and ECD. If you have ever visited the WKKD booth at an industry trade show in China, you understand the company's depth of coverage. One thing that has changed, due to market demands in recent years, is WKKD's approach to the distribution market. Not only is the company representing and selling the equipment of its principals, but WKKD is now manufacturing several lines for its principals as well.

One issue debated over the years is the ability of the Chinese to produce high-quality equipment. Hamed El-Abd, president of WKKD, will be the first to explain that they—the Chinese—can, and WKKD now offers several lines to prove that fact. That being said, we all know the high-quality standard the Japanese demand, and to now see some of Yamaha's equipment being produced by WKK Donguang Manufacturing certainly speaks to the capabilities of the Chinese and WKK.



CHINA: FROM THE INSIDE *continues*



The other side of Chinese manufacturing so often called into question is working conditions. During a recent visit I sat down for an in-depth interview about China with Hamed, and when I broached this issue he invited me to tour his company's factory in Guangdong. With all of the ongoing news coverage of working conditions at other EMS companies in that region, I decided to go have a look at what was going on at WKK.

Though WKK is small in comparison to Foxconn, the company's facility is still much like a small city, with an infrastructure that includes a power-generation facility, fire station, health clinic, barber shop, food store, library, and a restaurant that feeds more than 5,000 employees daily. Aside from that, recreation facilities include basketball courts, roller rinks, a movie theater, and other amenities for employee comfort. Granted, this is not a resort, but for many employees it is a very comfortable environment compared to their lives before WKK. WKK employs thousands of people and also offers dormitories that house nearly 5,000 of those workers.

Upon our arrival, we were first taken to a special security area where we signed in and

were asked to wash our hands. This procedure was first implemented when SARS was rampant in China several years ago. A factory could easily be brought to its knees if a contagious disease such as SARS were introduced into the workforce. After the sign-in process, we made our way into the main lobby for a very warm welcome.

The tour began with a walk though the engineering, quality, and admin offices—all what you would expect: People at desks working at their computers and such. From there we moved into the manufacturing areas, though some areas were off-limits due to confidentiality agreements. The areas we were able to tour included plastics fabrication, dry film processing, some assembly, extruding processing, and the equipment manufacturing area. In each area, the manager greeted us and gave us detailed explanations of their processes and answered our questions. The pride of each person was very apparent.

I asked our tour guides Stephen To, general manager of New Product Development, and Johnson Fok, general manager of WKK Donguang Manufacturing, about the employees' work hours and compensation. They ex-

CHINA: FROM THE INSIDE *continues*

plained that a typical day is comparable to the work schedule in America. The worker is paid at least the minimum wage, which is set by the local government; I think it is approximately RMB 1,800 or US $250 per month. That doesn't sound like much, and by our standard it isn't, but in that region of the world it seems to be a competitive wage. If an employee works overtime, he can earn time and a half.

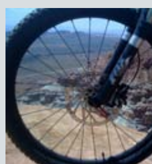
One thing I kept hearing throughout the tour is how committed Senta Wong, chairman and CEO of Wong's Kong King Group, is to the employees. (Read our in-depth interview with Mr. Wong here.) His goal is to take great care of the people and make sure they are happy in their jobs; this substantially reduces employee turnover, which improves overall product quality. Perhaps this is a unique approach in China, but as we toured the factory, there was evidence of this philosophy everywhere. During our tour we were invited to lunch at the company's dining facility and I was quite impressed with the quality of the food.

To help keep meal costs down, not all of the food is purchased from local suppliers. Some is actually produced in-house, such as the tofu. We toured the bean curd processing area. Here the soybeans are processed into tofu. Not only does this help keep costs down, but it also increases the quality of the food served. Food

CHINA: FROM THE INSIDE *continues*

costs can easily get out of control when you are feeding 5,000+ people daily. Another measure to help reduce costs can be found in the food serving process. Three lines are available to employees, based on how hungry they are—from "not too hungry" to "very hungry." By controlling portions based on appetite, waste is reduced.

As the pressures to increase human standards in China continue, it looks like WKK is well ahead of the curve and may be a model for others. I do realize there are other companies in China that are the polar opposite of what WKK has created and that is the image the news media paints for the world. It's just nice to know that there are companies in China that do understand the value of their employees and work to provide an exceptional working environment. It may not be perfect, but at least they're trying. **SMT**



Barry Matties is the publisher of the I-Connect007 family of publications. He started in PCB manufacturing in the early 1980s and in 1987 became a founder of *CircuiTree Magazine,* which sold nearly 13 years later as the leading industry publication. In the early 2000s, Barry and longtime business partner Ray Rasmussen joined forces again and acquired PCB007 and launched the I-Connect007 family of publications. Later, in July 2010, *SMT Magazine* and SMT China was also acquired by I-Connect007. With his proven successful business development and leadership skills, Barry now produces this column relating over 25 years of successful business experience, including business, marketing and selling strategies that really work. Contact Barry here.

Contents

EVENTS

For the IPC's Calendar of Events, click here.

For the SMTA Calendar of Events, click here.

For the iNEMI Calendar, click here.

For a complete listing of events, check out *SMT Magazine's* full events calendar here.

Upper Midwest Expo and Tech Forum
June 7, 2012
Minneapolis, Minnesota

IEEE ICC 2012
June 10-15, 2012
Ottawa, Canada

2012 Symposia on VLSI Technology and Circuits
June 12-14, 2012
Honolulu, Hawaii

NEPCON Malaysia
June 12-14, 2012
Penang, Malaysia

IPC International Conference on Flexible Circuits
June 12-14, 2012
Irvine, California

JPCA Show 2012
June 13-15, 2012
Tokyo, Japan

Intersolar 2012
June 13-15, 2012
New Munich Trade Fair Centre, Germany

National Electronics Week: North Africa 2012
June 13-14, 2012
Utica Tunis, North Africa

NEPCON West China 2012
June 19-21, 2012
Chengdu, China

PCIM Asia
June 19-21, 2012
Shanghai China

Webtorial: PWB Reliability
June 19 & 26, 2012

DMS
June 20-22, 2012
Tokyo Big Sight, Japan

MEDICAL TECHNOLOGY EXPO
June 20-22, 2012
Tokyo Big Sight, Japan

Counterfeit Electronic Parts and Electronic Supply Chain Symposium
June 26-28, 2012
College Park, Maryland

43rd International Annual Conference
June 26-29, 2012
Karlsruhe, Germany

ASQED Microelectronic Olympiad
July 9, 2012
Bayan Lepas, Malaysia

Ohio Valley Expo and Tech Forum
July 12, 2012
Independence, Ohio

Future Horizons Semiconductor Industry Forecast Seminar
July 17, 2012
London, England

PUBLISHER: **BARRY MATTIES**
barry@iconnect007.com

PUBLISHER: **RAY RASMUSSEN**
(916) 294-7147; ray@iconnect007.com

SALES MANAGER: **BARB HOCKADAY**
(916) 608-0660; barb@iconnect007.com

EDITORIAL:
GROUP EDITORIAL DIRECTOR: **RAY RASMUSSEN**
(916) 294-7147; ray@iconnect007.com

MANAGING EDITOR: **HOLLY COLLINS**
(252) 288-2751; holly@iconnect007.com

TECHNICAL EDITOR: **PETE STARKEY**
+44 (0) 1455 293333; pete@iconnect007.com

MAGAZINE PRODUCTION CREW:
PRODUCTION MANAGER: **SHELLY STEIN**
shelly@iconnect007.com
MAGAZINE LAYOUT: **RON MEOGROSSI**
AD DESIGN: **SHELLY STEIN, BRYSON MATTIES**
INNOVATIVE TECHNOLOGY: **BRYSON MATTIES**
COVER ART: **SHELLY STEIN, BRYSON MATTIES**

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ADVERTISERS INDEX

Next Month in SMT Magazine

Companies are dealing more and more with advanced packages: Chip-scale packages, BGAs, stacked chips, through-silicon vias—the list goes on and on. Next month, we tackle the subject with an array of articles on advanced packaging in the July issue of *SMT Magazine.*

The issue features content from the best in the industry, including articles from **TT electronics; NexLogic Technologies; SEMI; ZESTRON;** and columns from **Dr. Jennie Hwang; Chris Torrioni; Bill Loving;** and Editors **Ray Rasmussen** and **Barry Matties.**

If you're not yet a subscriber, don't miss out! Click here to receive *SMT Magazine* in your inbox each month.

See you in July!