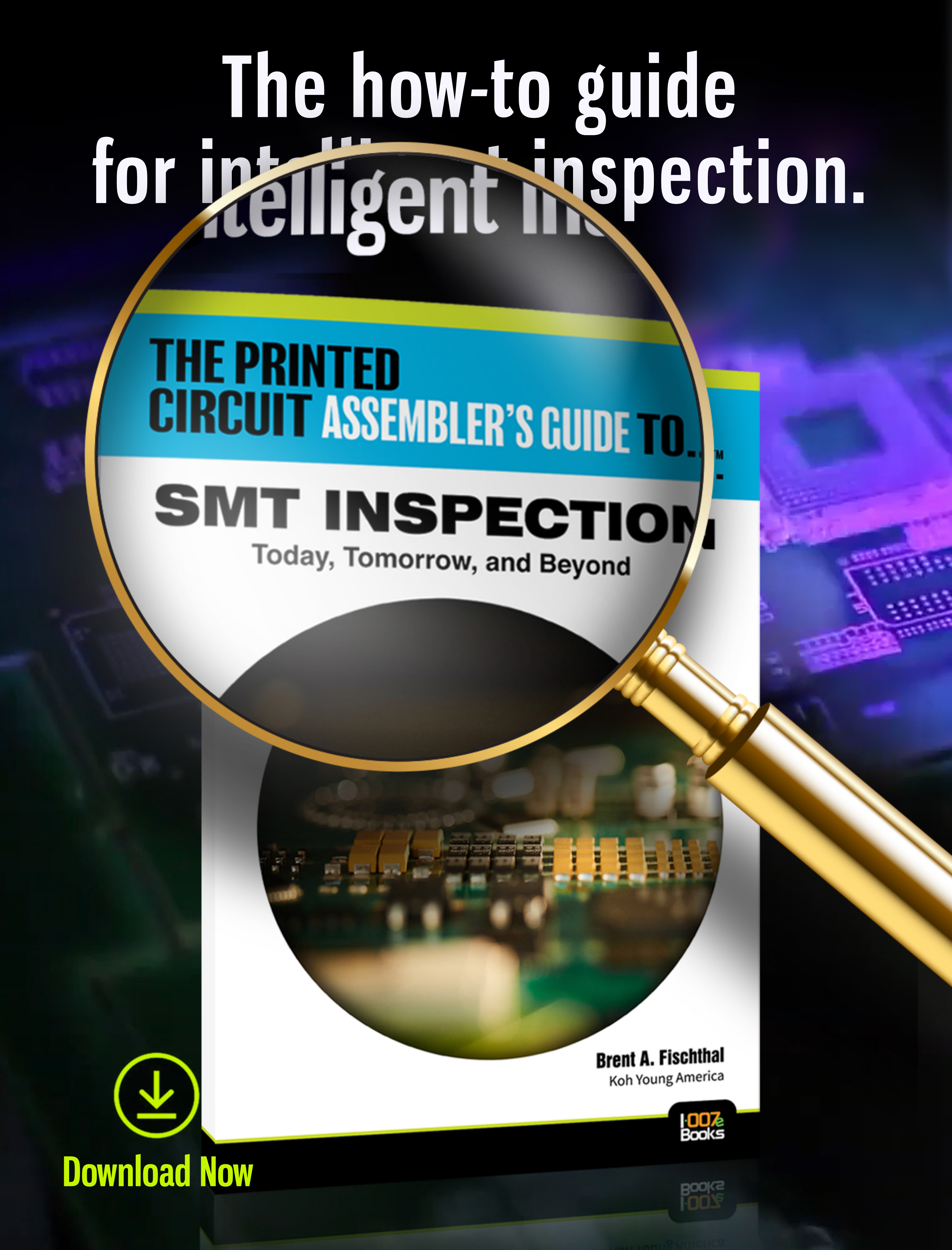
JULY 2021

I-Connect007

SMT007 MAGAZINE

Reliability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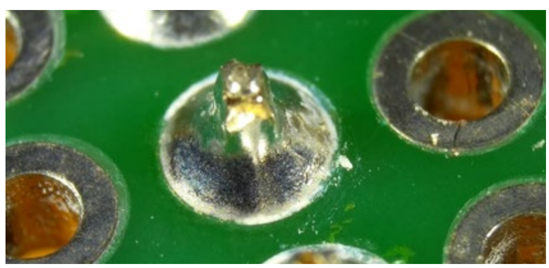
Reliability

In this issue we look at the key contributing factors that affect reliability challenges on your manufacturing floor. We help you run the gamut from specifications and standards to assembly and testing.



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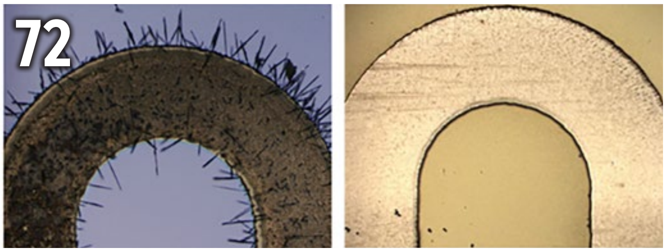

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Nolan's Notes

by Nolan Johnson, I-CONNECT007

A couple weeks ago, I made the three-hour drive from my home in Portland to the city of Bend in central Oregon. It was a weekend getaway with some college buddies, and we did college buddy stuff. We're too mature to go out drinking all night (we did catch some live music, though), but we're not so feeble that we needed afternoon naps either. No, we spent the weekend enjoying the outdoors and the great weather that Bend has to offer.

Not too far out of town is Smith Rock State Park. It's a beautiful place. A rocky butte pokes up out of the high desert floor, and the picturesque Crooked River wiggles around the butte, setting up some lovely scenery. Smith Rock is a world-class rock-climbing destination. Back when I was actively climbing, I'd spend a lot of time there, scaling the routes. We didn't climb, but we hiked the Misery Ridge Trail and watched the climbers do their thing. I certainly could climb again, but as I watched everyone on this day, I was reminded of the one thing I detest about rock climbing: rappelling.

Our cover this month shows a climber mid-rappel. They're descending on the rope, attached to their harness. I had always expected rappelling to be fun. And it is. There's a thrill ride sense that comes with dancing down the rock face as the rope zips through your hands on the descent. But once I'd climbed, using hands and feet, with climbing gear and a climbing partner holding a rope to keep any falls short and safe (instead of life-ending), I found rappelling to be profoundly distressing. I say this because there is no redundancy in the system. When rappelling, you have one point of contact with the rope; the rope, then, has one point of contact with the rocks; your climbing partner is removed from the feedback loop, as is all protection except the one anchor at the top end of your rope. That's it. Any failure at all is often catastrophic. Even world class

Reminiscing about one of my past climbs, behind me, (Smith Rock State Park, Redmond, Oregon).

Along the Misery Ridge trail, hikers get a good view of the Monkey Face pinnacle, (Smith Rock State Park, Redmond, Oregon).

climbers sometimes make a fatal mistake setting up their rappel, or worse yet, rappel right past the bitter end of the rope and into freefall. No wonder then, that in years past, when my climbing buddies and I would visit the climbing gear stores, we'd all eventually gravitate to the case with the rappelling/belaying devices to see if there was anything new to make the descent safer.

As you can imagine, reliability is crucial when rock climbing. And I couldn't help but think of this issue as I walked Smith Rock with my friends. Our current supply chains have become that single point of contact—much like rappelling—rather than a resilient, multiple-choice experience like climbing itself. Our line equipment need not be the best, but it needs to function flawlessly, like climbing gear. Likewise, redundancy means resilience. And if you simply cannot include redundancy, then our processes must be repeatable, reproducible, and downright automatic.

In this issue we look at the key contributing factors that affect reliability challenges on your manufacturing floor. We help you run the gamut from specifications to standards to assembly to testing. And in the process, we bring you a comprehensive pair of discussions with Eric Camden and Muhammad Irfan. We also deliver columns on digital manufacturing, automation, flux cleaning, and process optimization—all facets of improving reliability. And if that weren't enough, we also serve up technical articles on drop shock, benchmarking testing processes, the IPC WP-019 standard, CFX, and developing evaluation tests for conformal coatings. It's a full agenda of reliability components, to be sure.

I'm sure I've "belay-bored" my climbing metaphor by now, but reliability and climbing both are an ever-changing set of problems to solve, constraints to overcome, weak points in the process that must be guarded against, but sometimes leaned on with no other safety net than your process. Whatever happens, come back safe.

We're always happy to hear from you, our readers, with story ideas, topics, questions, comments and even criticisms of our coverage. Here at I-Connect007, our mission is to advance conversation within the industry. Let us know what you're thinking; what you have to say is what makes this a conversation. **SMT007**

Nolan Johnson is managing editor of *SMT007 Magazine*. Nolan brings 30 years of career experience focused almost entirely on electronics design and manufacturing. To contact Johnson, click here.

Cleanliness Behind Many Assembly Challenges

Feature Interview by the I-Connect007 Editorial Team

Eric Camden says nobody knows your board like you do, so it's time for assemblers to start doing their own cleanliness testing and due diligence, and stop relying on outside organizations to determine how clean their boards need to be.

Nolan Johnson: Could you launch us into this conversation with a quick recap on yourself, your background, and a little about the company you work for?

Eric Camden: Officially I'm a lead investigator at Foresite in Kokomo, Indiana. We're a failure analysis and reliability testing laboratory. I've been here 21 years, and I've spent the majority of my time going through other people's processes. I'll see a failure, or they're trying to optimize a process in some sort of way on the assembly side of things; we will analyze that as well as going onsite to look at the equipment and processing parameters, and then determine where optimizations can be made. I've spent a lot of my time on improving reliability for our customers in that way, as well as failure analysis. We are an in-depth failure analysis lab with experience from all corners of the industry, from component packaging to assembly.

Johnson: What seems to be the most urgent or highest visibility issue right now?

Camden: For the past few years, miniaturization has been creeping up and overtaking reliability issues when it comes to chemistries, residues, and similar kinds of failure analysis projects. Cleanliness is still a big problem; it drives a lot of what we do around here, and when we're looking at the changes in the IPC, what they've done with J-STD-001 cleanliness (where they've taken out the 1.56 target number for acceptability on the ROSE testing), it's been replaced with creating your own objective evidence now. WP-019 explains how the Rhino Group came to these conclusions, and

what to put in place instead of accepting that historical number. Cleanliness and reliability go hand in hand, and I don't see it changing any time soon. And when you put miniaturization on top of that you're just compounding your own problems.

Johnson: You were mentioning work with IPC standards to change ROSE testing and so forth. From your perspective, what's going on there?


Eric Camden

Camden: When you think about it on the surface, it seems pretty simple. The ROSE tester, developed by the DoD in the 1970s, was never meant to be acceptance criteria. And when you think about the material sets and the components that were being used at that time, when this go/no-go number was put together and generally accepted by a lot of the manufacturing sector—the boards were full rosin, they were being cleaned. If they were being cleaned, they were being cleaned with Freon. None of the technology has really survived as-is from the 1970s, when that criterion came out.

Over time, regarding miniaturization, as we see less ionics being allowed on the board to function properly in the field, there had to be a better way to determine what test was required for your particular board. The industry is starting to realize that all boards are not made the same. We've all known that, but we've got the failure data to tell everybody that your board is very unique. Once they decided that 1.56 number really was no longer applicable, then it was just taken out. A lot of companies were moving in that direction on their own, as they saw their left hand was holding a report that said they had met certain criteria, and in the right hand was their failure analysis report.

When you see enough of those, you can conclude that maybe this isn't working. That Rhino Team from IPC really gives a lot of power back to the assembler: "If this is my end-use environment, I should probably do this kind of testing." Now, it's more of a guideline: "This is how you come to the conclusion that your boards are clean enough." It's the old question nobody can answer: How clean is clean enough? It depends on your end-use environment, and people are coming to accept that they must stop relying on outside organizations to determine how clean their boards need to be. Now the IPC is backing up that thought by saying, "You need to figure out how clean your boards are." And I think that was the impetus for completely changing section 8 of J-STD-001.

Johnson: If perceptions and requirements for cleaning are changing, and if we're getting into a period where cleanliness is becoming increasingly important, what are the drivers for the assemblers?

Camden: The drivers are that they've recommended objective evidence tests. With surface insulation resistance, it will be a prerequisite for any new product going forward for acceptance (if you're looking at IPC). Surface insulation resistance was really a test that's been agreed upon, and rightfully so. There are a couple of different ways to do it. There are ways to tweak that test and still stay within the spirit of the IPC TM-650 test methods. But they recommend the SIR, and then you can build on that with your own ROSE testing. If you have an acceptable lot of boards through SIR, then you take a lot of boards built with the same materials in the same time frame and do ROSE testing to determine what that number is, based on their equipment.

There was a paper from the mid-'90s that showed ROSE testers serial numbers one, two, three, would come back with different results on three different boards. It really becomes more important for each individual CM to use their equipment on their boards and say, "We're getting repeatable numbers." It doesn't matter if it's one microgram per square inch or if it's a hundred micrograms per square inch, it's what their equipment is measuring in their environment. The SIR drives the dataset that says, "These materials in this process should work for our product."

Take that, along with either some additional ROSE testing or the more advanced ion chromatography testing, to determine how clean your boards are. That creates a benchmark for process monitoring. You can still use your ROSE tester to do cleanliness monitoring. They're not telling you that you can't use it, they're just saying you need a better dataset to determine your acceptability criteria as it's no longer 1.56. You still get to do the same testing for process monitoring, but now you need a better objective evidence dataset before you start doing the test.

Johnson: The ultimate test for reliability is the field failure rate. I would assume the assembler wants to be successful at that metric because that reflects on the assembler.

Camden: Oh, for sure. And in many ways: reputation and bottom line.

Johnson: It puts more of the decision-making power in the hands of the assembler. Does the typical assembler possess the expertise for that?

Camden: The tier ones have that expertise. But from my experience the vast majority of the CMs that we work with are aware of this drive toward the new numbers and are determining it for themselves. They've been proactive to this new objective evidence way of thinking.

Dan Feinberg: Eric, have you seen any recent difference in field failure rates, electrical vs. mechanical? It seems there are more portable circuit devices, which are more susceptible to mechanical problems such as drop shock. Are you seeing any trends?

Camden: Primarily, we see more electrically driven failures, especially when talking about electrical leakage paths. When we talk about failures in long-term and various end-use environments, it's primarily electric. CMs are trying to make their products more robust if they know the device will be portable. They're changing the way they clean their boards.

We don't see many of the mass-produced products around here because it's cheaper just to replace them than troubleshoot them. I would say we still see a fair amount of electrical circuit failures on mobile portable type devices, but I haven't seen an increase in mechanical.

Johnson: Eric, where are you seeing upticks in business?

Camden: We're seeing more failure analysis that may not have been done because of the methods required. Earlier, I was discussing potted samples, and recently we've been seeing a lot of potted assemblies. I think they're being tested instead of just treated as "no trouble found," because of the lack of components. I think there are a lot of issues and people are afraid that they're not going to be able to get BGAs or they are trimming back on anything that could be considered as a failure.

Depotting these parts is a long chemical exposure, very time-consuming, and fairly expensive. Because of the difficulty in getting components right now, people are doing more failure analysis than before to stem any failures on a larger scale. As component scarcity becomes a real issue, they will do some FA (failure analysis) on parts that may have been scrapped before.

Johnson: Is the intent to fix something that failed, and put it back out in the field?

Camden: It could be two-fold. First, I believe it's just to get to the root cause of the failure. That's the most important thing. Figure out if it's something obvious in the process that can be changed or optimized. Once you figure that out, you can potentially save other product from being produced with that set of parameters. Second, once we've depotted a component—if we didn't do any mechanical damage to it—they can use it as a replacement part.

Johnson: It would seem to go together with the increased demand in the quantities of sourced components that automotive is going to require. If you think about it from that perspective, this extra failure analysis work starts making sense.

Camden: Sure. Anytime you can stop a failure from happening in the first place, it's usually worth the investment. Before, if a company saw one or two out of a thousand fall out, they may have just written that off; now they seem to be more likely to go ahead and do the FA work on it.

Anytime you can stop a failure from happening in the first place, it's usually worth the investment.

Barry Matties: Are we going to see more parts reclamation?

Camden: I do believe that's something that we're going to start seeing more of with parts availability. I know that Bob Wettermann has a good column which also appeared in the March 2021 issue of *SMT007 Magazine* about being able to salvage parts. I think that's something that we're going to start seeing more, and we have been asked by certain clients to verify cleanliness of these parts after removal. It's kind of dribs and drabs right now, but I think as this chip shortage keeps happening, the longer it goes on, the longer we're going to see more people trying to recover components.

Matties: It sounds like the shortage is going to be around for a couple of years anyway.

Camden: It really does. Because they're so far behind now, it sounds like it's going to take them a year to catch up and another year to get back to zero.

Happy Holden: We seemed to be okay in terms of supply before the pandemic; it's just that a year and a half later coming out of it, suddenly shortages show up.

Camden: They have worked through all the stock in the warehouse, and then it wasn't being refilled as fast as it was previously. So, it makes sense.

Johnson: What are some of the most common challenges on the floor with respect to better reliability?

Camden: Knowing how to troubleshoot your own process. You can't detect small changes in cleanliness with a ROSE tester. You've got to do localized extractions. You've got to do ion chromatography, and you have to use live product. Often, we see customers qualify the B-52 test board through SIR; they'll even do 596-hour electrochemical migration testing. They'll do some extended testing, and then they'll try to transfer that same recipe and all that material over to their actual product, which is obviously going to be a very different mix of parts, thickness, etc. Fine-tuning that process after coming off the qualification process can be a little troublesome for some com-


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panies. This is because they're using a ROSE tester metric which doesn't detect small pockets of contamination, that doesn't determine which components are the hardest to reflow due to thermal mass, or whatever it might be, and then being unable to fine-tune the process to that one failed area.

I think CMs still struggle transferring the qualification package over to the actual product, just because it's so different.

Johnson: And having the skill set to do that?

Camden: Yes. And there's still the issue with brain drain in the work force. We still see managers cutting the floor staff who have been building boards for a long time. Take that tribal knowledge away and it really becomes lost—until somebody else learns what the problem is and how to fix it. We see so many people move from one company to another, taking that knowledge with them and leaving a void behind.

Johnson: Cleanliness issues are going to affect reliability and build quality in numerous ways. Could you list out a couple for us?

Camden: Yes. It's one of our specialties. When you're building an assembly there are so many opportunities to add contamination; you take these 100 different touchpoints, and if you don't know how to look for each one of them, you can have a failure and never know where it came from. Cleanliness is reliability in terms of operation in the field, and it's just so important.

The first thing you're going to see is electrical leakage; probably half of what we do is "no trouble found" conditions. It's the Florida vs. Arizona conundrum, where 10 of them were sent to Arizona and never had a problem, but 10 of them were sent to Florida and every one of them failed. The availability of the atmospheric moisture in your end-use environment is such a critical parameter when you're manufacturing your board so you know how clean your board needs to be and what levels of residues are allowable.

Sometimes condensation on your board will cause it to fail. You say, "We've got a failure here. Let's send it back to the manufacturer." The manufacturer puts it on their desk, and it doesn't fail. Now, they've got the customer swearing it failed and the CM says, "No way it failed." What we find out is that the board is on that hairy edge of failure. With electrical leakage, you're really lucky if you get a constant failure. That means there's something we can do some testing on to determine exactly what's causing that leakage.

These issues start with electrical leakage, and then if it's allowed to stay in service with this on-again/off-again electrical current, you grow dendrites. Now you've got a hard failure. That's really the second thing, and we're still seeing issues with these electrical leakage paths happening under conformal coating. The boards aren't being prepped in a way that they're ready to take a conformal coat so are still able to absorb moisture. There are so many ways to contaminate the board, but the end result is usually some sort of electrical leakage, unwanted voltage; you could even get EOS from that. There are a lot of different ways to make the board fail with contamination, but it just ends up with electrical issues.

Johnson: Eric, is this a shortcoming of the current cleaning technology?

Camden: The technology is fine. It's just a matter of each individual CM—and the operators within that on that line—knowing how to set up a good wash process in the first place. Understanding how to set up the equipment, how much temperature it needs, belt speeds, and how to optimize a wash process—and then verifying that using different methods of testing, including just standard burn-in type testing where you put your live product in an environmental chamber and see how well you clean.

There's no shortage of cleaning chemistries or equipment. It's a matter of experienced operators and engineers setting up the wash profiles to give themselves the best chance to do the best job possible with that chosen set of materials. I just got back from a customer site, verifying two wash processes; you just make a couple little tweaks on these things, and it can have a huge impact on cleanliness.

Whether you're building a true no-clean process, or you're washing it off, it's just knowing how to get to that cleanliness point.

Johnson: How does someone get the expertise needed to get clean boards?

Camden: The same way my kid learned to ride a bike; you just keep doing it. I mean, you fall off, you hurt yourself, and yet you keep going. If you're lucky enough, you've got a mentor within your facility there. Short of that, there is an abundance of online articles and videos on how to clean a board, and you can join groups like SMTA and IPC.

A lot of people get this experience after they've done it really wrong, and it can be fairly expensive; that's trial by fire right there. There are a lot of different ways to do it depending on how much effort they want to put into it.

Johnson: What does an assembler really need to know right now to make reliability better?

Camden: They need to know that cleanliness and the entire assembly process is important. They need to know that the quality department is something they should never shortchange on. To know how clean your boards need to be at the very last spot before they're shipped out, you need to know how to measure and monitor how clean that board is, and you've got to know how to do all your homework. Like I said, the J standard, the WP-019, is a very good reference for what they need to know to set their cleanliness criteria for their own products. That's the thing they've needed to know all along. Nobody knows your board like you do, so you need to be doing your own cleanliness testing.

I've never been an advocate for a one-size-fits-all. Even as I sit here at a failure analysis lab, we have our own recommended limits that work for most of our customers, but never would I ever say these numbers will absolutely work for your board. We say, "This should work for you, but you've got to do some testing to determine if it will or will not work." Every CM has come to that conclusion, and now they're trying to determine how best to get to it and follow the new IPC guidelines. Contract manufacturers don't follow IPC standards out of the goodness of their heart; the standards are called out in a contract somewhere. The big CMs certainly work with IPC, but they only follow these guidelines because they're asked to by their customers.

Contract manufacturers don't follow IPC standards out of the goodness of their heart; the standards are called out in a contract somewhere.

Johnson: Do you expect to see reliability in the assemblers' environment change over the next three to five years? What's over the horizon?

Camden: I see better in-house testing capabilities for testing live product. I think companies will go to more testing right after manufacturing, and they will test larger lots in an environmental chamber to really put some moisture onto their boards that determines what the quality and reliability is.

I think there will be a better eye on how to qualify live product and not just test boards.

A lot of customers have started the qualification testing, and they'll come right back with live product from a first run and say, "How does this compare to what we did on the test board?" There will be a mindset to be more thorough with your dataset for post-qualification samples to look at actual live product.

Holden: Eric, with the advent of more bottom side termination, the standoff distance is miniscule. As they go to more wafer-level packaging and this miniaturization, especially the standoff, is this potentially causing more issues with contamination or cleanliness? In the past, all the parts were open and easily accessed, but miniaturization in the Z-direction is really taking hold, especially with these bottom terminations where a lot of contract manufacturers talk about voids. For one thing, you can only use an X-ray for that, but the other thing is, what else can be trapped underneath between all those terminations?

I always say QFN sent my first kid to college, and at this rate, it will probably send my second one too.

Camden: Right. I always say QFN sent my first kid to college, and at this rate, it will probably send my second one too. I mean, there's not another component in the industry that has shown more failures than the QFN, and absolutely for the reasons you mentioned. You can have a four-mil stencil, you can print a QFN, and by the time that large thermal ground pad has soldered down, it's sometimes as low as half a mil standoff high. We've done cross-sections that show you're at a half mil standoff height. Now, if you're using a no-clean process, how are you supposed to vent out the gases? And they just don't outgas reliably 100% of the time the way they're supposed to.

They become intermixed there with your rosin or resin component of your no-clean flux, and they just stay active at the perimeter of the pad between the leads and the ground pad. It's that same standoff issue that we see causing problems with an aqueous process, where you're taking that same QFN and now you're trying to wash out all the residues from underneath there, and that same standoff height basically just creates a dam around the edge of that component. And if you're lucky, you'll clean 15–20% out between the outer edge of the perimeter of the QFN going to the middle, but that same luck that lets you clean that much also exposes any of the active parts of your flux that were supposed to be outgassed at the time.

Effectively you're removing a bandage, and we see a lot of issues around here with partially cleaned no-clean flux residues. It basically exposes all the active contaminants that were meant to be bound within the outer shell. It's so difficult to clean or to properly outgas no-clean flux residues from under QFNs that we see failures to this day. I don't believe it slowed down when it comes to the percentage of failures that we see that are attributable straight to QFNs. QFNs and micro BGAs, any of the bottom terminated components as you mentioned, are all showing potential for failure just because they're so difficult to process. This is one of the things that I was saying earlier about having the experience to set up a good wash process. It's knowing, "This is a very difficult-to-clean component. I have to be very mindful of where it goes into my cleaner, what my belt speeds are, because I'm going to need extra time, extra exposure to saponify and deionize water to make sure that this thing gets completely cleaned between part and pad."

QFNs are still a huge pain in the butt in this industry, and I don't know what the answer is. We've seen improvement with some standoff ideas where you actually put some thermal vias in the pads themselves that can help give you a little more standoff. You can design a windowpane for the ground pad instead of one solid pad and increase standoff height. There are a couple of QFN manufacturers I've seen that have gone to an actual windowpane on the component side as well that helps give you a little bit more standoff. I think that when we see better QFN designs that will help increase the standoff height to four mil, somewhere in that neighborhood. You'd like to see 3-5 mils anyway, to help you better outgas those no-clean activators as well as being able to clean them. QFNs and all bottom terminated components are still a huge percentage of failures.

Holden: Because of density and the fact that chipscale packages and wafer-scale packages keep getting denser, with smaller solder balls, which means less and less offset, evolution is going to make that an increasing issue. Especially with IBM announcing two nanometers geometries on their latest set of wafers. All of that will be more IOs, and more ground IOs; things like that add smaller and smaller pitch.

Camden: You are absolutely right, and this is the price they pay. The extra scrutiny they must put on cleanliness, washing it, or whatever it might be—that is the trade-off. They must put a finer eye on reliability. It's certainly not a one-to-one relationship, but the smaller your spacing, the lesser amount of contamination is allowable. And as voltage goes up, that also has a part to play in it. Cleanliness is always important, but as you said, especially Z-height, when the miniaturization goes that way has even more importance to it.

Johnson: Eric, I know I'm oversimplifying with this question, but is no-clean obsolete?

Camden: No, not even close. It's the number one choice for CMs out there. As I mentioned earlier, we see a lot of failures related to partially cleaned no-clean flux that removes that outer shell. I am positive with no data to back it up that this trend of cleaning no-clean flux was made by someone who's never built a board in their life. They said, "Well, it's no-clean flux. So, if we don't get it all, it won't matter. Anything that we can't see won't matter." And it's absolutely the opposite of that. A partially no-clean flux can be just as detrimental to an assembly as water-soluble flux being left after the wash process. You're still looking at open active flux residues that are very hygroscopic, and then it just doesn't take that long with enough moisture and enough voltage to set up that electrical leakage path.

With no-clean, it will be 95 to 5 if it's not already. No-clean is absolutely the wave of the future or the wave of the last 10 years really, but it will continue to dominate outside of certain sectors of the industry. A lot of the DoD still uses water-soluble and then cleans that. Aerospace uses a water-soluble and cleans that for their components, but there's just this mindset that you can partially clean it and it will be okay. People are learning the hard way that this is not the truth, and that goes back to what we were just saying about the washing process with QFNs. Those are the components we see most of our partial cleaning failures with because it's so hard to penetrate that.

I always say that if you're going to wash, use water-soluble. Don't make it any harder on yourself, just make sure you're doing a good job. It's so much easier to clean off the no-clean. You're not trying to break down this rosin or resin material through a two-minute wash process. Being able to properly process no-clean fluxes, whether you're leaving them in place or washing them, is just so critical.

Matties: The demand is still there on a grand scale, that's for sure. Thank you so much for all your time and insight. It's really helpful.

Camden: It was absolutely my pleasure. SMT007

Digital Manufacturing: Just-in-Case or Just-in-Time

SMT Prospects & Perspectives

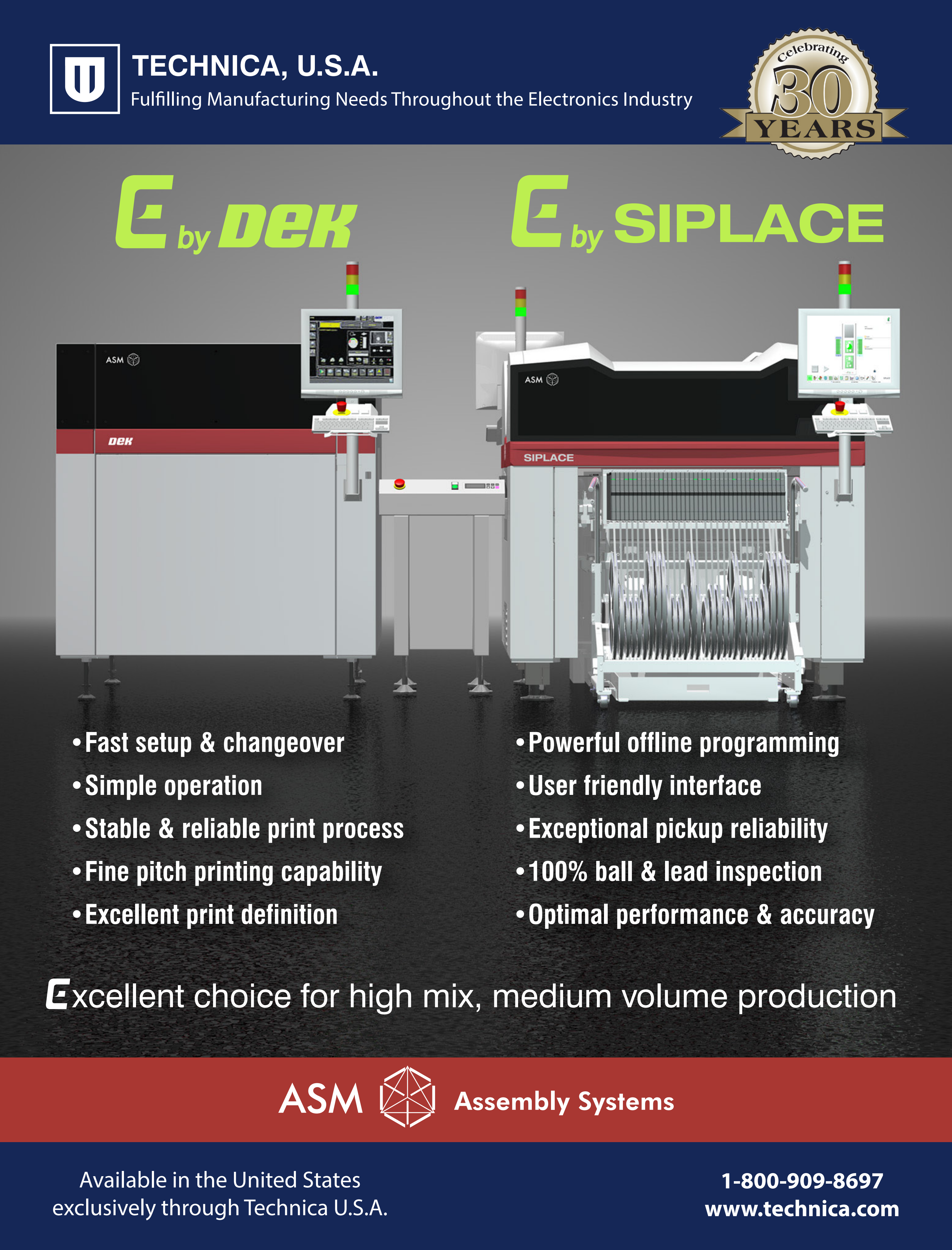
by Dr. Jennie S. Hwang, CEO, H-TECHNOLOGIES GROUP

As the semiconductor chip shortage around the world shows no signs of abating in the imminent future, I was drawn to this headline: "How Toyota Dodged the Chip Shortage" from Bloomberg Businessweek on April 12. It reported the ways and means that led to Toyota's success in weathering the supply chain disruptions. While its rivals are missing the product delivery, the company's past experiences that prompted implementation of its contingency plan have helped it mitigate the impact of today's global chip shortage on the production and delivery of cars in the global marketplace. Vividly, this is a timely business case as well as a use case to ponder.

Under today's dynamic global-macro environment and the emerging digital manufacturing platforms, what will or should change?

Regardless of whether the global chip shortage is a result of pandemic or from unanticipated market supply-demand imbalance, it is warranted to deliberate on solutions to eschew recurring events in the manufacturing sector. One plausible question to ask is, "What are the lessons learned from the success of Toyota's ability to keep its plants humming as other automakers shutter plants?" First, there is value in truly learning from the lesson by effectively taking actions. Toyota's past encounter during the 2011 earthquake-triggered tsunami that wreaked havoc on its production capabilities (including the supply chain disruptions) has brought out its actions in scrupulously examining its supply chain. The company learned the lesson by acting. This time around, the company has benefited tremendously by previous astute actions in implementing a comprehensive system throughout its supply chain.

In deciphering the supply chain strategy and tactics[1], in broad strokes, it boils down to six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key words: visibility, predictivity, identifying, monitoring, communicating, and balancing. These are positioned in the to-do list calling for planning and actions to dodge future supply chain challenges.

Visibility: A crucial question to address is the level of visibility throughout the supply chain. In the intricate supply chain network, knowing the direct suppliers is the starting point, not the end point, to acquire an adequate visibility of the supply chain. Understanding and knowing the second-, third- or even fourth-tier suppliers is also a part of the equation of supply chain management to gain adequate visibility and transparency.

Predictivity: It is not hard to look back to make conclusions, but it is dauntingly demanding to predict the future accurately. However, in supply chain management, what level of predictability is required is a necessary-evil question to tackle. The better the visibility, the more thorough planning, the higher level of predictability can be achieved.

It is not hard to look back to make conclusions, but it is dauntingly demanding to predict the future accurately.

Identifying: To identify a list of key parts for an end-use product is easier said than done; it takes knowledge and effort to make a "right" list. In the Toyota case, the automaker came up with a list of about 1,500 parts it deemed to be necessary to secure alternatives for or to stockpile.

Monitoring: Set a monitoring system in motion that gauges the network of suppliers that produce those key parts to ensure planned delivery from the chain of suppliers—another deliberate and elaborate effort. In tasking, one important question to ask is, "What is the technology employed to monitor the chain of supply?" Timely adopting of evolving technology, to leverage the capabilities of a digital tool to facilitate data acquisition and the flow of digital information in supply chain, is key to an agile operation.

Communicating: The following all play an essential role in the integrity of a supply chain: Effective and efficient communication between the OEM and Tier 1 suppliers; the data flow between the OEM and the Tier 1 suppliers; communication between the Tier 1 suppliers and their network to include Tiers 2, 3, 4; and the feed-back loop.

Balancing: To a manufacturer in producing and delivering a given product, inventory management is just as important as supply chain management because the inventory directly impacts the bottom line of a business. Reducing and minimizing the inventory of a part/component of a given product is an ongoing effort. Questions to address are:

1. Do all strategic raw materials (with sound justification) have alternate source(s)?

2. Do all mission-critical components have alternate source(s)?

3. Which parts/components call for stockpile? For those stockpiled parts/components, what is the "days in inventory" and what is the "dollar inventory" that can be justified?

Synchronizing with the holistic manufacturing strategy, be it supplied locally or globally, the goal is to reach an optimal level of inventory. It is an intricate balancing act to achieve both a secure supply chain and an optimal inventory management, which requires knowledge, know-how, and effort.

Just-in-Time or Just-in-Case

As the global landscape continues to change, the future remains the most precious commodity. Charles F. Kettering, a famed American inventor, and the founder of Delco of General Motors, conveyed it well:

"My interest is in the future, because I am going to spend the rest of my life there."

Looking at the future, the manufacturing infrastructure is becoming more intricate; the swift and timely delivery of products to end-users (customers) is paramount to a viable business.

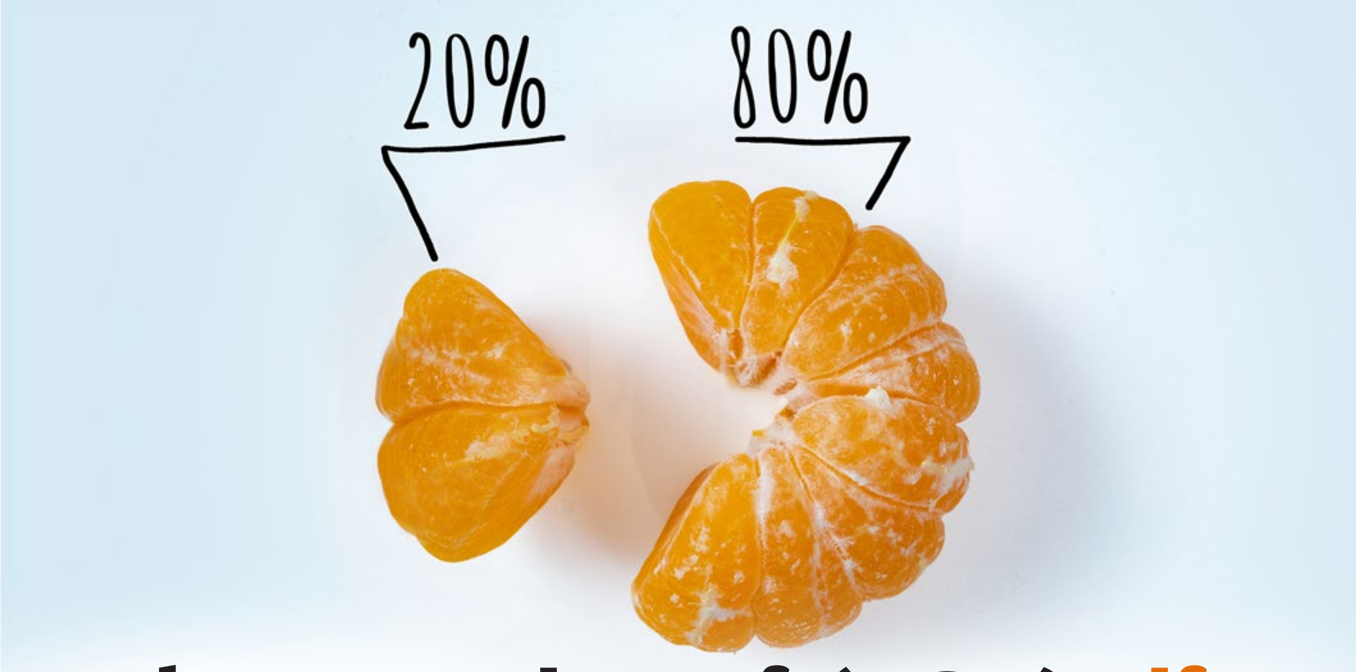
Going forward, under the dynamic global-macro factors and the burgeoning digital manufacturing platforms, the construct that is solely based on just-in-time inventory management as a stand-alone practice could be proven inadequate. Considering both just-in-time and just-in-case appear to be a pragmatic model to operate in the digitized enterprise; perhaps it is a "comforting" approach as well.

It is hoped that this article will spark deeper and wider thoughts and actions about the future supply chain enterprise and its role to business viability, competitiveness, and ultimately the prosperity. **SMT007**

Reference

1. "Rethinking Manufacturing—Bracing and Embracing Post-Pandemic Decade," by Dr. Jennie S. Hwang, *SMT007 Magazine*, pp. 10–16, July 2020.

Dr. Jennie S. Hwang—an international businesswoman and speaker and a business and technology advisor—is a pioneer and long-standing leader to SMT manufacturing since its inception as well as to the development and implementation of lead-free electronics technology. Among her many awards and honors, she was inducted to the International Hall of Fame–Women in Technology, elected to the National Academy of Engineering, named an R&D Star to Watch, and received a YWCA Achievement Award. Having held senior executive positions with Lockheed Martin Corp., Sherwin Williams Co., and SCM Corp., she was the CEO of International Electronic Materials Corp. and is currently CEO of H-Technologies Group, providing business, technology, and manufacturing solutions. She has served on the board of Fortune-500 NYSE companies and civic and university boards; the Commerce Department's Export Council; the National Materials and Manufacturing Board; the NIST Assessment Board; as the chairman of the Assessment Board of DoD Army Research Laboratory and the chairman of the Assessment Board of Army Engineering Centers; and various national panels/committees and international leadership positions. She is the author of 600+ publications and several books and is a speaker and author on trade, business, education, and social issues. Her formal education includes four academic degrees, as well as the Harvard Business School Executive Program and Columbia University Corporate Governance Program. For more information, visit JennieHwang.com. To read past columns or contact Hwang, click here.



The Meaning of (PCB) Life

Feature Article by Bob Neves
MICROTEK CHINA

New products, new designs, but still the age-old question persists, "How long will it live and what will its quality of life be?" Assembled printed circuit boards (PCBAs) are a complex system of materials, components, and interconnections that all need to work as intended for the product to reliably operate during its expected life. All it takes is one piece of that complex system to fail and the product's life span will disappoint.

To manage this disappointment in life—in this case reliability failure—the first step is to categorize the influence that each piece of this complex PCBA system has on the life of the product. In addition, as the PCBA is subjected to very high temperatures during component attachment, the influence that each piece has on life may change before and after the attachment process, so simulation of this attachment process prior to any life prediction testing is vital to understanding the true life expectancy of a PCBA.

Evaluating all the parts and systems in a PCBA system is an overwhelming task to say the least, so I tend to follow the Pareto principle when looking to pare down the list to something more manageable. The Pareto principle roughly states that 80% of consequences come from 20% of the causes. This nugget of wisdom came from Joseph M. Juran who studied the work of Vilfredo Pareto and ultimately published his *Quality Control Handbook* in 1951, which is still used today as a basis for management of quality and quality control.

The next step in the process is identifying the 20% that will cause most of a product's life problems and subsequently focusing efforts on reducing the disappointment in life from these items. Active and passive components, PCBs, subsystems, connectors, wiring harnesses—the list goes on. Once you have identified a set of likely offenders, you will need to decide how to evaluate them for their effect on premature life failure.

Terms like "infant mortality," "fatal anomaly," "long-term reliability," "Weibull analysis," and "latent defects" are thrown around when

speaking about product life. There are also a host of acronyms associated with this branch of faith-based prediction, most of which are so important that they have been bumped up from three- to four-letter acronyms: ESS (environmental stress screening), HATS (highly accelerated thermal shock), HAST (highly accelerated stress testing), HALT (highly accelerated life testing), HASS (highly accelerated stress screening), MTBF (mean time between failure) and burn-in (first on the scene, entrenched before someone came up with an appropriately long acronym). There is a whole branch of palm readers—I mean scientists and engineers—whose job it is to predict the life span of a product. You remember the part in your car, TV, or cellphone that dies a short time after the warranty expires? Well, these wizards (and witches) are the ones who predicted that fortune. How do you think they came up with the warranty terms in the first place?

There is a whole branch of palm readers—I mean scientists and engineers—whose job it is to predict the life span of a product.

How to Deal with the Stresses of Life

"I can't wait years to see if my product will last. Is there any way you can speed that up?" This is a question I hear often and is at the heart of the mystical art of life predictions. The current focus of this faith-based exploration is by using accelerated stress testing to predict product life. The basic premise of this philosophy is that by increasing the amount of stress a product sees, the time of the product's death can be accelerated in measurable increments. The medical profession has been preaching this about us humans for a long time. Correlating the accelerated stresses of life testing to actual non-accelerated life environment is the real challenge. Quantifying the stresses a product will see during its life can be accomplished by thoroughly evaluating the mechanical and environmental conditions experienced during its life and then finding a way to accelerate them without introducing additional factors of life acceleration that do not appear in real-world use.

Mechanical stresses are typically related to the dropping, vibrating, shaking, rattling, and bumping the product is expected to see in the real-world during its life. Environmental stresses involve the atmospheric conditions the product will experience during its intended life (thermal, moisture, light, weather, pressure, etc.). In many cases, the product will generate an environment of its own during operation.

To plan an effective environmental stress screening program that accelerates product life, all the mechanical and environmental conditions that will be present during operation, storage and use of the product must be considered. It is also important to evaluate the non-operational mechanical and environmental stresses that are experienced during a product's birth (assembly, delivery, and set-up) that can be the worst stresses the product will experience during its life.

The GUESS Test

One of the most common types of accelerated life testing I see employed today is the GUESS (grossly un-correlated and exaggerated stress) test. There is much literature thought to exist about the GUESS test, and people recount experiences and data obtained from GUESS testing like they would a UFO abduction experience. Many GUESS tests have their roots in ancient history. Various references to GUESS tests found in literature are usually based upon faith, hearsay, or anecdotal experience rather than science. These tests are usually handed down from one engineer to the next or from company to company without understanding the true impact on product life.

In lieu of expensive GUESS testing, many now utilize the Spock approach to product life assurance. This approach consists of the shipping clerk (or some other duly ordained personnel) raising their right hand, parting their middle two fingers, and speaking the words, "Live long and prosper" just as the product leaves the shipping dock.

Predictions of Life

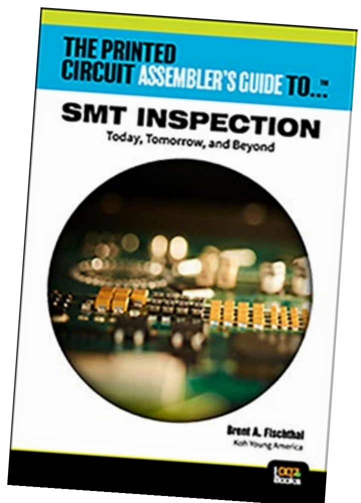
How long will it live? Answering that question when product designs, supply chains, and components used are constantly in flux (pun intended) can cause more stress to the engineers than the product itself and can contribute to a reduction of their life. Taking the time and spending the money to truly understand the factors that affect product life is challenging to say the least. Life predictions, after all, are just that—predictions. Astrologers and Tarot card readers make predictions as well, and it is important to weigh the data obtained from accelerated stress testing accordingly. **SMT007**

Bob Neves is chairman/CTO of Microtek China, and vice chair of the board at IPC.

EXCERPT:

The Printed Circuit Assembler's Guide to... SMT Inspection: Today, Tomorrow, and Beyond

Chapter 5: Advanced Process Control and Inspection



Reliable AOI methods have become powerful, economical complements to traditional test strategies. AOI can be used successfully as a process monitoring tool for measuring printing, placement, and reflow performance. Some advantages include:

Detecting and correcting SMT defects during process monitoring is less expensive than after final test and inspection, where repairs are typically 5 to 10 times more costly.

Detect trends in process behavior, such as placement drift or incorrect mounting, earlier in the overall process. Without early inspection, more boards with the same defect could be rejected during functional test and final inspection.

Identify missing, skewed, or misplaced components with incorrect polarity earlier in the assembly process when component placement is verified before reflowing.

Yet, a single inspection system has limitations, especially when there is limited or no communication with the balance of the line. In this setup, it simply cannot optimize a printed circuit board assembly process. Equipment suppliers must cooperate to achieve communication for a zero-defect future. M2M connectivity can optimize the process by exchanging real-time SPI and AOI measurement data with other machines in the production line. This real-time feedback includes measurement data such as offset, volume, height, area, and warnings to other systems, while analyzing trends to optimize the process and identify trends. The connected systems can automatically define correlations between the processes.

To read the rest of this chapter and more, download *The Printed Circuit Assembler's Guide to SMT Inspection* free here.

Hands-off Manufacturing

Smart Factory Insights

Feature Column by Michael Ford, AEGIS SOFTWARE

Assuming perfect manufacturing engineering and reliable process, then product reliability issues are always caused by variation, whether as the result of a simple operational mistake by a person, the wear of a mechanical component on a machine, deviations in material characteristics, or simply a change in the environment. The use of automation has not eliminated causes of unreliability, nor defects, which ironically continues to drive the need for humans to be hands-on, even as part of SMT operations. There is clearly something missing, so cue our digital twin.

With successful manufacturing automation, people are there for their brains, not for their hands. If we were to put a red dot on everything that we touched in manufacturing, whether through necessity, we would quickly have a factory that looked like it had contracted measles. Success can be measured by reducing the number of human touches that need to be made to the product, materials, tools, or machines themselves. This rule applies to assembly itself as well as dealing with exceptions that happen. How then to keep our brains focused while keeping fingers on keyboards and away from danger and still creating world-class process and product reliability?

With each innovation of hardware within manufacturing, we lose first-hand sight of both routine and non-routine events that occur, which include abnormalities and trends that negatively impact reliability and quality. Automation only includes the sensors it needs, assuming other factors are taken care of elsewhere, and unless pushed, typically only shares the minimum of information. When humans were all over the manufacturing line, we were

aware of surroundings, seeing issues developing out of the corner of our eyes, that we would remember and address. Without the ability to use our eyes, another form of visibility is needed. We need to gather data. The history of gathering and trusting data from manufacturing has been fraught with challenges—thankfully now being resolved through the increased use of the plug-and-play IPC-CFX standard, which drives IIoT data exchange across the whole shop floor. Of course, data is not visibility; it must be contextualized through the IIoT-based MES layer, which builds event information based on disparate data trails, together with known configuration information, material conditions, work-order perspectives, etc., to create the live digital twin of the manufacturing operation. This visibility is our digital peripheral vision without us interacting directly.

Without the ability to use our eyes, another form of visibility is needed. We need to gather data.

It's not incorrect to say that the method to improve reliability is to be data-driven, but is very much a simplification. Raw data, proprietary data, and even IPC-CFX are not solutions in themselves, including measurements and inspections. Any data that is gathered must be processed in some way in order to create value. Machine learning famously processes raw machine data measurements to refine and improve the operation. This is incorrect; value comes from the interpretation of results, by another party, such that the determination of whether an escape is really a defect or not, for example the result of an inspection by AOI. Qualification and contextualization bring the value. SMT line closed-loop solutions are another example, where software provides qualification of variation in inspection data coming from one or more machines, then applying corrections and compensation to other machines to keep variation under control. However, it is incorrect to believe that the value of such solutions comes solely from the raw data. Every data point is contextualized by analytic software, based on such things as the dimensions of the PCB, the use of different nozzles for different materials, etc. The type of correction is based on the knowledge of the product, work-order, and materials which do, of course, change. A difference in the material vendor, representing variation potentially in the size, shape, or features of that material, could lead to the closed-loop software making a false call. Holistically, further information needs ultimately to come from MES to understand the complete context of the operation.

These two simple examples illustrate the use of contextualized data to make decisions that impact reliability; in other words, preventing defects from occurring not only during manufacturing, but out into the market. Using trend analysis and refinement in the understanding of the threat that variation represents, a whole slew of hands-on actions is prevented that, in a defect-ridden process, compound quality risk geometrically. There are many other areas where hands-off, data-driven manufacturing ensures that no "out of control" condition is reached to the extent that human action is required. Six Sigma is the leading example of a statistical tool that detects in real-time whether a complex series of data points will remain within control limits, or whether there is a chance that the limits could be exceeded in the near future. Six Sigma is therefore a good engine to be used for "AI-based" monitoring. The problem again is that, as with the case of raw data, the use of Six Sigma is only a means to an end, a tool that needs to be used, with algorithms needed that enable it to be effective for use.

The Active Rules Engine is a great way to think about an AI application that resides within the MES solution, and that is responsible for automatically monitoring a great many contextualized trends, making decisions, and raising alarms, much in the same way as our peripheral vision and thoughts did in the past. Some decisions, such as in the case of SMT line closed-loops, lead to decisions that are executed without the need for any human involvement, becoming more common as we learn how to use our digital-twin visibility more effectively. Some potential decisions, however, need to be referred up to humans, who are now able to manage manufacturing operations much more effectively from their screens, seeing the holistic visibility of the problem, contextualized within the entire operation, rather than having to be physically out on the lines. Such challenges include bottlenecks in the flow of the process, the removal of a suspect material, absence of material or tools, or a potential premature failure of a machine part. Being able to recognize the issue and create a solution avoids the initial quality impact of a defect, as well as avoiding most of the consequences of any failure, all from the comfort of your armchair. Reducing the number of defects found in manufacturing indicates the reduction of market reliability issues.

Now that the contextualized data has taken us so far, there is one more step that we can reliably take to promote hands-off manufacturing. There are likely to be various digital solutions in operation on the shopfloor, which, just like machines, will each do fundamentally different things, and most likely, will come from different suppliers with different core-focused areas of expertise. Take for example, the use of AMR (autonomous mobile robots), a technology that is very useful in executing decisions made by our Active Rules Engine, as well as those escalated to humans. AMR fleet management is dependent on knowing the live status of manufacturing completions and requirements, both routine and exceptional. This can easily be orchestrated through MES in which the Active Rules Engine is based, with the AMR fleet manager driving the detailed specific AMR flow and task management, as they cover material transportation, setup and teardown of materials and tools, product transfers, and tool management, as well as bringing feeders, nozzles, heads, and stencils, etc., in and out of production for routine maintenance. IIoT-based interoperability between shop-floor solutions is essential in allowing automation to work effectively, with the minimum of manual intervention, no matter what challenges appear, leading potentially to the elusive SMT cleanroom, lights-out operation.

Reducing the number of defects found in manufacturing indicates the reduction of market reliability issues.

Hands-off manufacturing, by addressing causes and effects of variation in the digital domain, with necessary mechanical activities moved outside of the production area where possible, means that the manufacturing physical and digital twin succeed in levels of reliability and quality that no human nor automated solution could ever achieve unaided. **SMT007**

Michael Ford is the senior director of emerging industry strategy for Aegis Software. To read past columns or contact Ford, click here.

Ductility is Your Greatest 'Alloy:' Avoiding Drop Shock Failures

Feature Article by Ranjit Pandher
MACDERMID ALPHA ELECTRONICS SOLUTIONS

The drop shock reliability of solder joints has become a major issue for the electronic industry not only because of the ever-increasing popularity of portable electronics and the widespread use of lead-free solders, but also in ensuring high first-pass yield during handling in a production environment. Most of the commonly recommended lead-free solders are high tin (Sn) alloys which play a critical role in reliability of lead-free solder joints as high Sn alloys have relatively higher strength and modulus. Further, even though metallurgically, it is the Sn in the solder alloys that principally participates in the solder joint formation, details of the intermetallic compound (IMC) layers formed with tin-lead (SnPb) and Pb-free alloys are different. The markedly different process conditions for SnPb and Pb-free alloys also bear on solder joint quality.

Brittle failure of solder joints in drop shock occurs at or in the interfacial IMC layer(s). This is due to the inherent brittle nature of the IMC, defects within or at IMC interfaces, or transfer of stress to the interfaces as a result of the low ductility of the bulk solder.

In developing improved performance alloys, MacDermid Alpha has addressed both issues—improved ductility, and modification and control of the intermetallic layer. A broad range of base alloy compositions together with selected micro-alloying additions to SnAgCu alloys have been evaluated with the objective of controlling bulk alloy mechanical properties and the diffusion processes operating in the formation and growth of the intermetallic interfacial layer(s).

The alloy additives generally act as diffusion modifiers slowing interdiffusion rate between substrates and solder thereby reducing IMC thickness or the propensity for void formation. Alternatively, additions can be made that act as diffusion compensators. It should be noted that the level of the micro-additions does not measurably modify the bulk mechanical properties of the base alloys. Our results show that dramatic improvements in the solder joint reliability, as demonstrated by high-

speed ball pull and drop shock tests, can be achieved. Devices have highlighted the need for good drop shock reliability, and it is in this arena that SAC305 and other relatively high Ag SAC alloys have significant shortfalls. The root cause of the poor high strain rate response of SAC305-like alloys, relative to eutectic SnPb, lies in the bulk alloy properties. Most Pb-free solders are high Sn alloys with up to 5%Ag and 1% Cu. These alloys have a relatively higher strength and modulus and lower acoustic impedance and, therefore, under conditions of drop shock, more readily transfer stress to the solder-substrate interface. The intermetallic compounds (IMC) formed during soldering are of low ductility and it is this interface that exhibits brittle failure in mechanical testing.

A large number of alloys have been evaluated and discussed in literature as alternatives to high Ag SAC alloys for BGA and CSP dependent devices. The prominent factor addressed is bulk alloy properties. The effect of the higher strength at the expense of drop shock performance in high Sn alloys can be minimized through the selection of low Ag alloys. At lower Ag there is less Ag3Sn IMC in the bulk alloy with concomitant reduction in mechanical strength. The shear strength for the SAC family of alloys is shown in Figure 1, which highlights the lower Ag alloys' advantage in potentially absorbing the effect of high strain rate deformation due to mishandling of devices during manufacturing operations. The use of lower silver alloys to enhance mechanical strength will directly impact the reliability of assemblies in both a production environment as well as in general consumer handling in use. **SMT007**

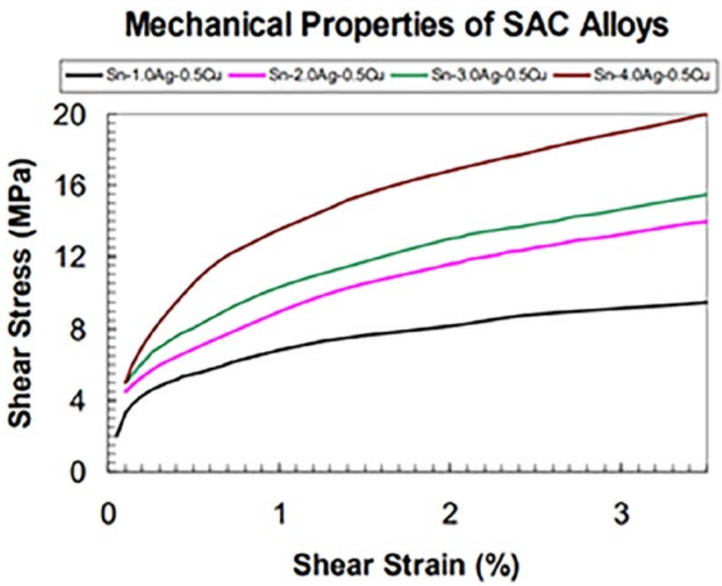


Figure 1: Mechanical properties of SAC alloy.

Ranjit Pandher is a senior manager, LED and Semiconductor, MacDermid Alpha Electronics Solutions.

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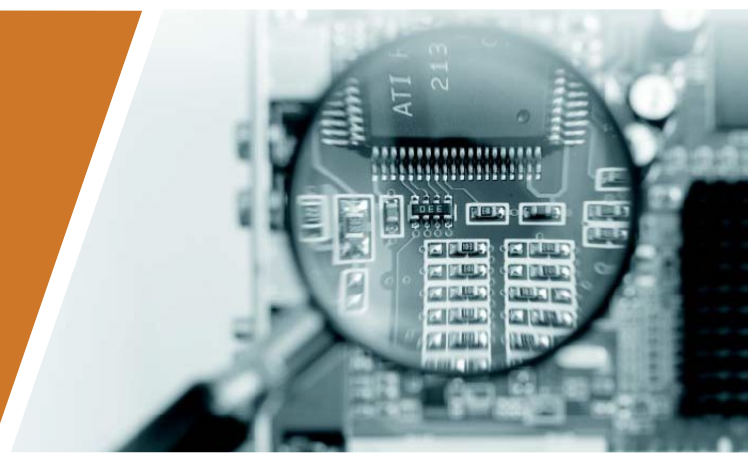

Flux and Cleaning—How Clean Is Clean? Part 1

SMT Solver

Feature Column by Ray Prasad, RAY PRASAD CONSULTANCY GROUP

The subjects of flux and cleaning are interrelated; one cannot be discussed without the other. The selection of fluxes and cleaning processes plays a critical role in the manufacturing yield and product reliability of electronic assemblies. Once soldering is accomplished, any corrosive material left on the surface must be completely removed after soldering.

In this column, I discuss various types of fluxes and why we use them, followed by various types of cleaning materials and processes. In my next column, I will discuss cleanliness requirements to know whether the boards have been cleaned enough to meet their functional requirements for their intended applications.

Why Do We Use Flux?

We use flux to be able to join two metallic surfaces. Joining is done by welding, brazing, or soldering. They are essentially the same except they are done at different temperatures. In all these three joining processes, we use flux to remove oxides so that a strong bond between the mating surfaces can be accomplished. The key difference among these processes is that there is no need for cleaning after welding and brazing. But when it comes to electronic assemblies, cleaning is a critical process. You are not done after the joining processes until you remove the residues. Otherwise, field failures are almost certain depending on what components and flux types are being used.

The common metallic surfaces for joining in the soldering process are copper and tin. Like most metals, tin and copper have the natural tendency to oxidize. However, to accomplish intermetallic bonds between them, you need to get rid of oxides. Flux helps provide a fresh clean surface to accomplish the intermetallic bond between copper and tin (it is the same for both tin-lead and lead-free) to achieve a reliable solder joint.


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Fluxes do a few other things at soldering temperatures. They reduce the surface tension of solder causing it to spread and promote wetting, which in turn makes it possible to form strong and reliable solder joints. In addition, they protect solder from further oxidation during soldering. For additional oxidation protection, at times we also use nitrogen. But nitrogen plays no role in the formation of intermetallic bond while it is essential for intermetallic bond.

Consequences of Using Flux

We need flux but there is a downside to using it. As we just discussed, we need flux to accomplish good solder joints. However, once we are done with soldering, what to do with those flux residues? Do we leave them on the board or get rid of them? The answer is: it depends. You can leave them alone or you must remove them depending on how harmful those residues are.

The types of flux residues or contaminants that require cleaning are determined primarily by the type of flux used. Halides, oxides, and various other contaminants are introduced during storage and handling as well. The use of aggressive fluxes makes soldering easier even if components and boards are slightly oxidized and contaminated.

The cleaning process to be used is selected based on type of flux, types of contaminants, and type of assembly. For example, mixed assemblies using both SMT and through-hole components may need one cleaning process after reflow soldering and another one after wave soldering, but a two-sided full SMT assembly may need only one cleaning process after the second side is reflowed.

When no-clean fluxes are used, boards may not require cleaning. In no-clean fluxes, chemicals such as carboxylic acids activate and perform their deoxidizing function, then burn off and leave no active chemicals on the surface. But no-clean fluxes require perfect surfaces to solder. Otherwise, solder defects will be too high.

Types of Fluxes

There are four major types of fluxes and each one further subdivides into six different categories. In other words, we have 24 different types of fluxes to choose from. However, the last category, IN (inorganic flux), is not used in the electronics industry since they are too aggressive for electronics products. In effect we have only 18 types of fluxes to choose from instead of a total of 24—still a daunting task. Please see Table 1 for a quick summary of all 24 different categories of fluxes.

The major four categories of fluxes are: rosin (RO), resin (RE), organic (OR), and inorganic (IN). Each flux type has three activity levels to choose from (low, medium, and high). These levels—L, M, and H—come with or without halides. When you do the math, there are a total of 24 different flux categories to choose from. Fluxes without halides have 0 at the end of their designations, while fluxes with halides have 1 at the end. For example, rosin flux without halide will be called ROL0 and rosin flux with halide will be called ROL1. These designations repeat for RE, OR, and IN as well. Halides in L1, M1 and H1 are less than 0.5%, 0.5 to 2%, and more than 2%, respectively. The activity of the halide-free fluxes comes from naturally occurring acids. The higher the flux activity, the better the soldering results. However, more active fluxes must be cleaned properly to prevent corrosion in the field. No-clean fluxes can be RO or RE with or without halides. But OR fluxes must be without halides (ORL0) to be classified as no-clean.

Due to high activity levels, inorganic (IN) fluxes, commonly used by a plumber, are not used in the electronics industry.

Types of Cleaning Materials and Processes

It is generally thought that cleaning surface mount assemblies is very difficult because, for example, stand-off heights between the surface mount components and the board are small, creating a tight gap that may entrap flux

Flux Type Symbol	Flux Material of Composition	Symbol	Flux Activity Level (%Halide)	Flux Type
A B C D E F	ROSIN	RO	Low (0%) Low (<0.5%) Moderate (0%) Moderate (0.5–2.0%) High (0%) High (>2.0%)	L0 L1 M0 M1 H1
G H I J K L	RESIN	RE	Low (0%) Low (<0.5%) Moderate (0%) Moderate (0.5–2.0%) High (0%) High (>2.0%)	L0 L1 M0 M1 H0 H1
M N O P Q R S	ORGANIC	OA*	Low (0%) Low (<0.5%) Moderate (0%) Moderate (0.5–2.0%) High (0%) High (>2.0%)	L0 L1 M0 M1 H0 H1
T U V W X Y	INORGANIC	IN	Low (0%) Low (<0.5%) Moderate (0%) Moderate (0.5–2.0%) High (0%) High (>2.0%)	L0 L1 M0 M1 H0 H1

* Organic acid flux is also referred to as OR

Table 1: Flux classification based on material composition and halide content.
(Source: Ray Prasad, *Surface Mount Technology, Principles and Practice,* second edition, Table 13.1)

and make it hard to remove during cleaning. Indeed, if proper care is taken in selecting the cleaning processes and equipment, and if the soldering and cleaning processes are properly controlled, cleaning surface mount assemblies should not be an issue even when aggressive fluxes are used. It does need to be emphasized, however, that good process control is essential when using aggressive water-soluble fluxes.

The selection of a cleaning process depends upon the type of flux being used. See Table 2 for a quick summary of cleaning processes for different types of fluxes.

Rosin and resin fluxes can be cleaned by various types of solvents such as organic solvents or aqueous and semi-aqueous solvents. When cleaned by aqueous solvents, additives are needed. If no-clean fluxes are to be cleaned (sometimes they are), they can also be cleaned with these solvents, although at times, special formulations may be required. Water soluble fluxes can be cleaned with water with and without additives.

The cleaning process selected may use solvents or deionized (DI) water or a combination of these two processes. In the past, the commonly used solvents were CFCs (chlorofluorocarbons) such as Freon but they were banned decades ago due to environmental concerns. The industry has had no choice but to

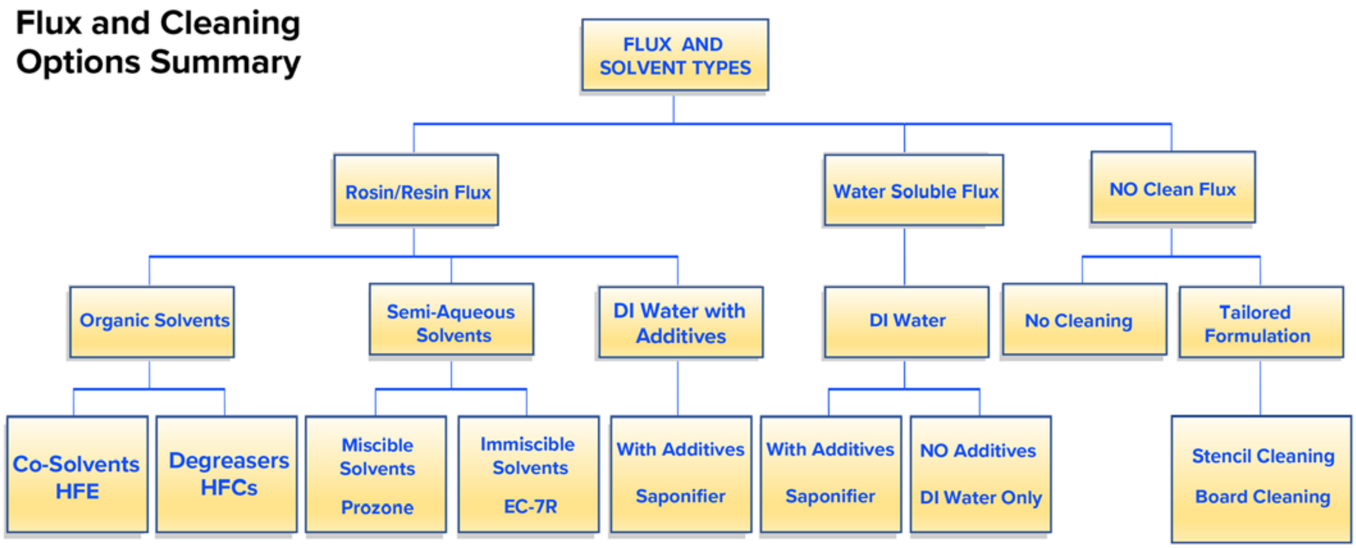


Table 2: Cleaning solvents for different types of fluxes.
(Source: Ray Prasad, *Surface Mount Technology, Principles and Practice, 2nd Edition*, Table 13.5)

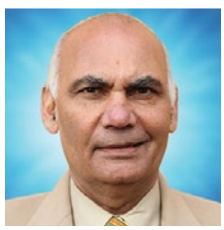
use either an alternative solvent or water-soluble fluxes and pastes for cleaning or to move on to a "no-clean" process by using low residue or no-clean fluxes and pastes.

Current technology using no-clean or low-residue fluxes is eliminating the need for cleaning. However, the use of no-clean flux requires a clean work environment and a culture change that not only affects the user but their suppliers as well. In addition, the use of no-clean fluxes may require a controlled soldering atmosphere to provide a process window compatible with their lower activity.

The use of no-clean fluxes is increasing due to the environmental concerns of using fluxes that require cleaning and the disposal of used solvents containing lead. But we also need to keep in mind that no-clean flux is not as active as other types of flux and hence the soldering results may be less than desired unless adequate steps are taken not only internally at the company but also by component and board suppliers.

Conclusion

No matter what fluxes, cleaning materials, or processes are used, they all need to meet the same requirements. When using more active fluxes, cleaning should be done with appropriate solvents to remove any contaminants that can cause field failures due to dendritic growth and corrosion. But how do you know when it is clean enough? If you asked a similar question about solder joints causing reliability problems in the field, it would be easier to answer because the accept/reject criteria in J-STD-001 and IPC 610 is well established. But it is not that simple when it comes to deciding how clean is clean even though the requirements are established in these two standards. We will discuss cleaning requirements in our next column. Stay tuned. **SMT007**



Ray Prasad is the president of Ray Prasad Consultancy Group and author of the textbook *Surface Mount Technology: Principles and Practice*. Prasad is also an inductee to the IPC Hall of Fame—the highest honor in the electronics industry—and has decades of experience in all areas of SMT, including his leadership roles implementing SMT at Boeing and Intel; helping OEM and EMS clients across the globe set up strong, internal, self-sustaining SMT infrastructure; and teaching on-site, in-depth SMT classes. He can be reached at smtsolver@rayprasasd.com and regularly offers in-depth SMT classes. Details about classes can be found at rayprasad.com. To read past columns or contact Prasad, click here.

Feature Article by Graham Naisbitt
GEN3

There are a multitude of electronic circuit assembly manufacturers, high volume/low product mix to low volume/high product mix. Only you will know where you are in that definition.

Either way, the removal of the discredited ROSE test using an accept/reject criteria of 1.56 µg/cm^2 is causing mayhem in the industry. Today, the non-negotiable requirement is to produce objective evidence.

Once the production process (material set) has been characterised, the user needs to have a fast, reliable, and repeatable test that will identify any ionically detectable changes in the final assembled product. Note: Such tested assemblies need to be assessed as suitable for shipment.

The new Process Ionic Contamination Test (PICT) [1] does precisely that.

- Fast: Less than 15 minutes
- Sensitive: At the same level as ion chromatography, but without the spectrum
- Repeatable: Proven acceptability to Six Sigma levels

The SIR "process characterisation of a material set" is best defined in a new Test Method: IEC 61189-5-502 published earlier in 2021.

Where Can SIR Be Used?

SIR can be used for process validation, process verification, and process or material characterisation.

SIR testing is usually done by process material manufacturers to qualify their material to meet certain standards requirements such as solder flux, coatings, resists, and more, in isolation to all other materials.

In the case of a process "material set" characterisation, we are using a representative

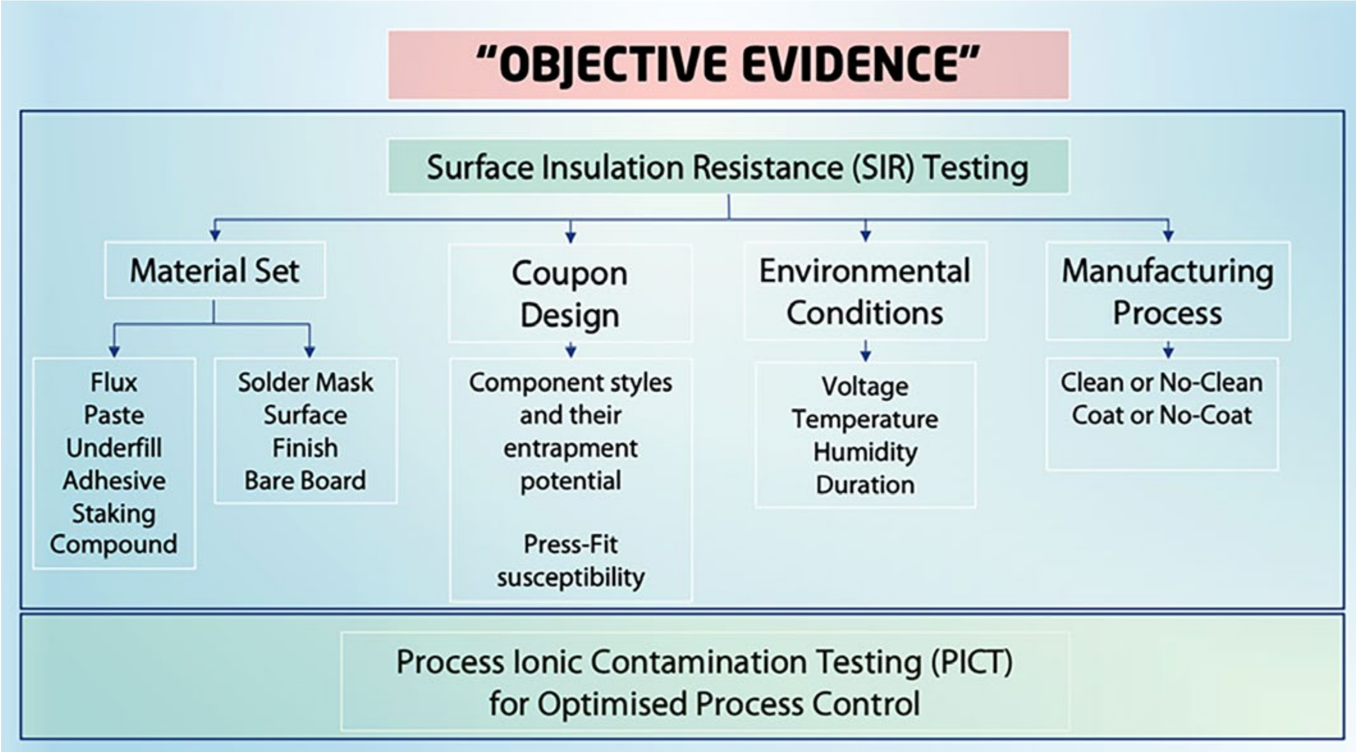


Figure 1: SIR testing.

example of the intended end-product, fully assembled. The examination is to determine electrochemical compatibility between solder mask/resist, solder flux, paste or wire, underfills, adhesives, staking compounds cleaning processes, conformal coatings, etc.

The test standard employs the IPC B-52 that has been evolved from the original research carried out by the NPL. Copies of the NPL research papers have been uploaded to the IPC Works 5-32b website with a free download. The IPC B52 coupon, also known as the IEC TB57, was developed using a selection of dummy components that represent "worst case" process residue entrapment sites.

This is not a test that we would recommend for process qualification. It would be an impossible task to include a full complement of the components in use today, as much because they must be true dummy components with no internal dies or connections.

We are often asked, "Can SIR testing can be used as a process control tool?" and, "Can it be run for less than 168 hours?" As a major equipment vendor of SIR test instruments that trace its origins back to the mid-1970s, GEN3 is very much in favour of this idea.

However, and in specific regard to high-volume/low-mix manufacturers, it is unrealistic. SIR testing is neither fast nor simple, and we have too many instances of failures by customers not respecting the many and varied "procedures" that need to be catered for. Equally, WIP (work in progress) will mostly prohibit such an approach.

In addition, many no-clean fluxes today exhibit ECM failure beyond 500 hours in service. This suggests that the test duration presently called out in IEC 61189-5-502 and IPC 9202, might need to be extended from 168 hours to 500 or even 1,000 hours.

To achieve acceptable "objective evidence," SIR is recognised by the IPC as the primary technique. It (SIR) doesn't care what is present that might be causing a failure, it is simply an examination of whether the representative sample (IPC B-52 or other) exhibits acceptable electro-chemical reliability data, irrespective of being ionic or non-ionic.

Conversely, the other techniques are essential in determining what is present that is causing the problem identified by SIR. That is why the overall "toolbox" of test methods is crucial in helping to predict circuit reliability. Such further examination is best described as a "toolbox" of various test techniques, the most common of which, is ion chromatography or FTIR.

In conclusion, users must demand their material supplier to provide the SIR data used to qualify their product. Then select your preferred material set and run an evaluation to the IEC 61189-5-502. If unacceptable data is found, it will be necessary to run ion chromatography and/or FTIR to determine what might be causing a problem.

The recommended procedure would be to test a B-52 sample extracted at each individual process stage, starting with bare copper. In this way, it is possible to identify at which process step the SIR data changed and endeavour to find alternative materials or equipment adjustments. **SMT007**

References

1. "Process Control of Ionic Contamination Achieving 6-Sigma Criteria in the Assembly of Electronic Circuits," P. Eckold, M. Routley, L. Henneken, G. Naisbitt, R. Fritsch, U. Welzel, published at IPC APEX EXPO Conference and Exhibition 2017. Also refer to IPC WP-019B for more information.

Graham Naisbitt is president of GEN3. He is a member of IEC TC91 WG2, WG3 & WG10, is a maintenance leader for a number of published documents having to do with cleanliness, and is on numerous IPC subcommittees and task groups on solderability and cleaning. Naisbitt is also the author of *The Printed Circuit Assembler's Guide to Process Validation.*

Developing Drones to Address Pandemic-related Challenges in Scandinavia

The onset of the COVID-19 pandemic spurred an immediate need to develop new, innovative systems in supply chains and infrastructure. And for three Norwegian graduate students enrolled in the MIT Professional Education Advanced Study Program (ASP), spring 2020 was the moment when technology, innovation, and preparation met opportunity.

Lars Erik Matsson Fagernæs, Bernhard Paus Græsdal, and Herman Øie Kolden were all students at the Norwegian University of Science and Technology (NTNU) but only met after they arrived on the MIT campus for their ASP in 2019.

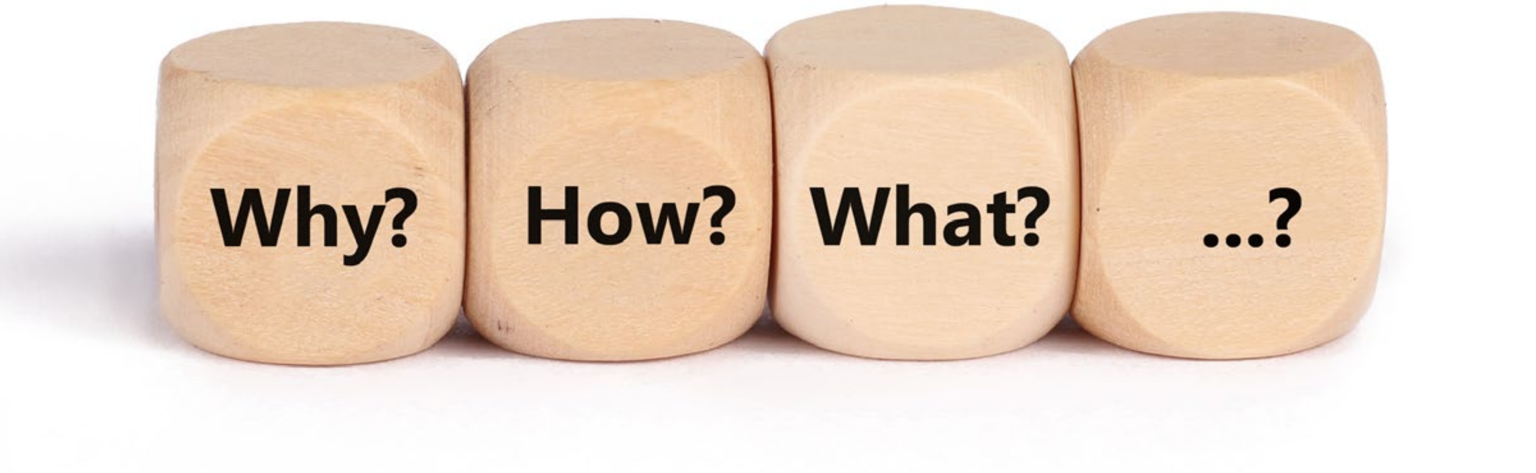
The friends had already been working on a drone-related project and pivoted to the idea of making a drone to transport biological samples. They chose a fixed-wing quadcopter design that combines vertical takeoff and landing with efficient long-distance travel.

Their prototype drones were built at MIT and tested in the Johnson Athletic Center around its running track. They found inspiration in the work of MIT professors like Russ Tedrake, director of the Center for Robotics at the Computer Science and Artificial Intelligence Laboratory (CSAIL) and a professor of electrical engineering and computer science.

In building their drone, Fagernæs, Græsdal, and Kolden had to overcome a number of technical issues, including icing, vibrations, and variable temperatures. Evolving EU drone regulations necessitated building redundant systems and a parachute in case of malfunction. However, the biggest challenge was the distance they needed to fly, 120 kilometers from start to end. An autonomous flight of that length had never been completed in Scandinavia before.

"People thought we were crazy," Fagernæs recalls. "But we were lucky enough to speak to the right people at the hospital who were desperate for a solution, and they decided to give us a chance. So, we have been working ever since, day and night."

(Source: MIT News)



Knowledge Continuity in Manufacturing

Feature Article by Ben Gumpert
LOCKHEED MARTIN

"Why do we do it that way?" "Because we always have."

Those can be some of the most dreaded words on the manufacturing floor. It means that someone decided at one point to do things a certain way, and you don't know whether it's a critical aspect of the assembly process, or just another roadblock to improvement. Knowledge is a significant asset to manufacturing; it is critical for manufacturing a reliable product, and effectively managing tribal knowledge is more important than ever as people change roles often. Not only does it require effort to bring new people up to speed, but it is also difficult for those who are moving on to convey everything they've done ("Why did they make that change?").

This tribal knowledge concerning the how and why of an assembly process is not unique to one group; it includes knowledge held by all roles in manufacturing, such as assemblers, engineers, and quality assurance. It can be an assembly-specific item about target conditions, methods that make the process easier or more consistent, or what tooling to use and how. Even documented requirements can be affected, with variations in the interpretation of standards or engineering requirements. Consistency in the manufacturing process is key to identifying problems, whether it's a rash of acceptance test failures or long-term reliability trends. The fewer variables that need to be considered, the more confident one can be about impacts of those variables. Although it is desirable to maximize flexibility for the process, it must be done without compromising consistency and quality, which lead to reliability.

What is Your Process?

Most groups use a variety of methods to capture tribal information. Work instructions can be the most obvious and are often used as corrective action when problems surface. Adding detailed instructions can be helpful, but too much can have the opposite effect, as an assembler may stop reading when they think they get the point. Pictures and videos can convey a great amount of information quickly, but key points may need to be emphasized, and changes to the design may drive the need for frequent updates.

In many cases, the buddy system is often used because it's easy; the new person is taught by the old. This method is the definition of tribal knowledge and has the obvious disadvantages of losing information in the relay, not to mention that this is also an effective method of passing on bad habits along with good.

Training programs require extra effort to develop and are best for standard processes and procedures. The more formal the training, the more difficult it typically is to maintain. Less formal training (on-the-job training or training checklists) can be much more flexible, but they are also more likely to deteriorate or not be used.

Mistake proofing is always a good option, which essentially builds the knowledge into the process. There needs to be a way to keep changes from being made when the reason for the process isn't clear.

A 'Lessons Learned' Library

All these methods of maintaining and transferring tribal knowledge have their advantages and disadvantages, so an effective manufacturing environment will use a variety of these based on the type of work being done, the process requirements, or the mixture of people and products. Lots of tribal knowledge is about problems, defects, or symptoms that aren't part of the normal "process." These are often lost to a "lessons learned" database. The main problem with this type of resource is that people don't look for things when they don't know what to look for. So, a lessons learned library is best for troubleshooting issues after the fact and not for preventing mistakes in the future.

Establish a 'Just Ask' Culture

Having the right culture is key to driving knowledge transfer. Encourage people in all roles to ask about the abnormal. Make it easy to ask, "Is this ok?" Knowing who to ask is usually what makes this successful, and providing basic, simple training can enable this. Since many people will take a long time to become proficient in a subject, it's more important that they understand some basics, and then know who to reach out to for additional information when the time comes. Subject matter experts should be relied on and made easily accessible. The use of internal or external forums to communicate and ask questions helps reach a broad audience and can return multiple pieces of information quickly.

Don't Let New Trends Disrupt

New trends in the manufacturing domain can disrupt tribal knowledge as well. Agility is important, but there needs to be a balance to check that process changes or improvements are not just reactionary. When process improvements are developed (informally or formally) they should be reviewed and documented in a way that will be useful to someone looking back later.

Trends toward automation and the use of digital models down to the assembly level bring up new challenges, as some of the lessons learned will now need to be built into the model and not just maintained by the production team. This is not just a sharing of knowledge between peers, but a transfer of knowledge between roles, which can be a new form of transfer for many.

Tribal knowledge is a significant asset for the manufacturing team. The information it represents often means the difference between good and bad product, and can have a major impact on the reliability of a process. The transfer, documenting, disseminating, and development of this knowledge needs to be intentionally built into the methods and culture of the manufacturing team. That way, when the question "Why do we do it that way?" is asked, the answer is: "Let me show you." **SMT007**

Ben Gumpert is a manufacturing engineer at Lockheed Martin.

Cleaning of 'No Clean' Fluxes in PCB Rework

Knocking Down the Bone Pile

Feature Column by Bob Wettermann, BEST INC.

The original intention of a "no clean" solder was to eliminate the post PCB assembly cleaning process while still not risking any performance or long-term reliability degradation. Some industry surveys indicate that about one-half of assemblers using no-clean flux chemistries clean the PCB after assembly. Many times, the first look or inspection of a reworked solder joint is the aesthetic appeal defined by the cleanliness inspection criteria found in IPC-A-610 (Section 10.6). Due to uneven heating from the rework process, corrosive no-clean flux activators may not be completely encapsulated with activated flux. This means the activators are on the exposed circuits and are likely to cause corrosion and dendritic growth, thereby negatively impacting reliability.

In PCB rework, a no-clean flux (Figure 1) is active when spread out on the board and the

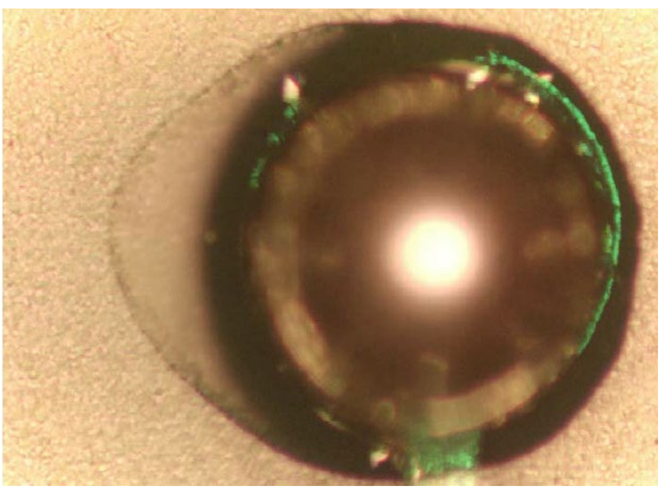


Figure 1: No clean flux residue around through-hole pad.

only way that that residue becomes safe to leave on the board is when it is properly activated via a temperature reflow cycle. That requires all the flux, even that spilling over to neighboring devices and not being subject to a reflow cycle, to be cleaned off the PCB. Hand solder and rework methods that do not sufficiently control flux volume are going to leave dangerous residues such as chlorides and weak organic acids which may, in turn, impact the performance or reliability of the solder joints.

There are several ways to mitigate the problems associated with rework and the associated flux residues left behind:

1. Limit the volume of flux applied to the rework area. More flux means that there is a greater likelihood of non-benign residue being left on the board.
2. Proper training on flux and flux residue removal for any hand assembly or rework technician. This training should include the method of cleaning, the method of rinsing, as well as the disposal of any remnant solution. The training on "when to use" what cleaning solution is also important.
3. Proper training on the importance of activating the flux during rework.

Cleaning the flux post rework is defined in Procedure 2.2.1 of the IPC 7711/7721 "Rework and Repair of Printed Circuit Assemblies." The procedure defines that up to 10 ml of clean-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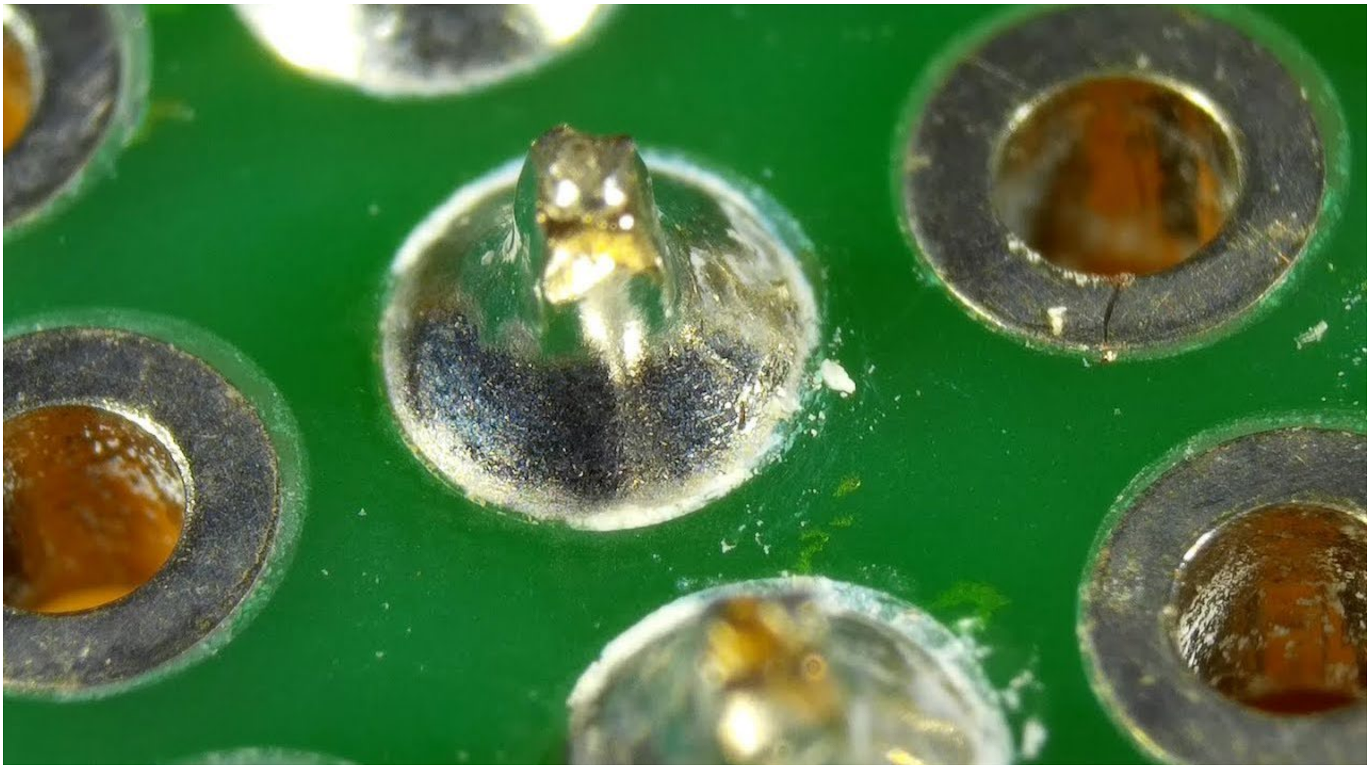


Figure 2: White residue around solder joint.

ing solution for four square inches of affected area can be used to clean the reworked area. A clean, soft-bristled brush is then used to scrub the area followed by an isopropyl alcohol rinse. This is an important step as soiled brushes may bring unwanted debris and flux residue to the to-be-cleaned area. Any excess and leftover IPA from the rinsing process should then be cleaned with a lint-free cloth. Then the cleaning process inspection occurs per the agreed upon inspection criteria. Other cleaning processes can be used if agreed upon between the builder and the end customer.

For PCB rework, even for a "no clean" flux formulation, the area around a solder joint area post reflow should be cleaned. The idea of a no residue or no-clean flux is a misnomer. Instead, the flux should be described as low residue. These residues, along with other contaminants from the rework area such as airborne contaminants, human skin, tool debris, etc. need to be removed. There are numerous reasons to clean an electronics assembly post rework, namely to:

- Allow for better inspection/better cosmetic appearance around the solder joint
- Promote the surface for better coating adhesion
- Allow for testing to be done where required
- Prevent electrical problems (noise or capacitive coupling)
- Eliminate a longer-term reliability or corrosion problem

As PCB density increases, an understanding of the impact of cleaning becomes more challenging. Premature failure or improper component functionality is site specific and, therefore, a localized testing means of cleanliness is crucial. A localized ionic contamination measuring method using an extraction technique in the area of interest has become more acceptable to measuring the contaminants left behind after PCB rework. Gone are the days of the ROSE testing which measures the ionic contaminants on the entire assembly.

There are several benefits to cleaning the low residue no-clean flux. One of the benefits is to ensure that any underfill or replacement conformal coating will be properly adhered to the PCB. Any residue left behind may outgas and impact adhesion. The right defluxing process and saponifier is used to facilitate better inspection and enhanced cosmetic appearance. A defluxing process is a cleaning process in that everything is cleaned. Contaminant species from board fabrication (like feeder tape residue), component fabrication residues, assembly residues, and human handling residues all are cleaned off in a cleaning process. All of these may cause performance issues and their resultant removal mitigates this risk.

While the cleaning of the flux holds some distinct advantages, there are several disadvantages to cleaning a no-clean flux after rework. Since DI water alone cannot be used to clean off the residue, a saponifier chemistry will need to be used and, therefore, extra expense added in terms of chemicals, cleaning equipment (if not already on site) as well as chemical disposal. By not properly cleaning all of this off, you can end up with active flux on the board and be in a worse position with respect to the reliability of the assembly. These and other drawbacks need to be considered when contemplating the necessity for a post-rework cleaning process.

The choice of the cleaning agent is important. It needs to match the residue and cleaning process. Dissolution of the residue at a fast rate is critical. Equally critical is the cleaning method's ability to deliver the cleaning agent to the no-clean residues.

Reliable hardware is more challenging to build due to component size miniaturization, bottom termination devices, shortened distance between conductors, and higher pin-out devices in a small footprint. These factors require that there is no entrapped flux residue and that the board is properly cleaned post rework. **SMT007**

Bob Wettermann is the principal of BEST Inc., a contract rework and repair facility in Chicago. For more information, contact info@solder.net. To read past columns or contact Wettermann, click here.

Astronomers Pinpoint When Cosmic Dawn Occurred

Cosmic dawn, when stars formed for the first time, occurred 250 million to 350 million years after the beginning of the universe, according to a new study led by researchers from the University of Cambridge and University College London (UCL).

The study, published in the Monthly Notices of the Royal Astronomical Society, suggests that the NASA James Webb Space Telescope (JWST), scheduled to launch in November 2021, will be sensitive enough to observe the birth of galaxies directly.

The UK-led research team examined six of the most distant galaxies currently known, whose light has taken most of the universe's lifetime to reach us. They found that the distance of these galaxies away from Earth corresponded to a "look back" time of more than 13 billion years ago, when the universe was only 550 million years old.

Analysing images from the Hubble and Spitzer Space Telescopes, the researchers calculated the age of these galaxies as ranging from 200 to 300 million years, allowing an estimate of when their stars first formed.

"Theorists speculate that the universe was a dark place for the first few hundred million years, before the first stars and galaxies formed," said lead author Dr Nicolas Laporte from Cambridge's Institute of Astronomy. "Witnessing the moment when the universe was first bathed in starlight is a major quest in astronomy.

"Our observations indicate that cosmic dawn occurred between 250 and 350 million years after the beginning of the universe, and, at the time of their formation, galaxies such as the ones we studied would have been sufficiently luminous to be seen with the James Webb Space Telescope."

(Source: University of Cambridge)

MilAero007 Highlights

Survey: Reasons U.S. Electronics Manufacturers May Exit Defense Market ▶

In a new IPC industry survey and report, 24% of electronic manufacturers say the costs and burdens of compliance with the Cybersecurity Maturity Model Certification (CMMC) may force them out of the U.S. Department of Defense's (DoD) supply chain.

Summit Interconnect Acquires Eagle Electronics ▶

Summit Interconnect, Inc. is pleased to announce the acquisition of Eagle Electronics, Inc. Established in 1979 and located in Schaumburg, Illinois, Eagle is one of North America's leading providers of advanced prototype printed circuit boards.

Increasing Productivity Through Training ▶

Too often when we think of training our manufacturing workforce, we focus on the shop floor. We need to cast a wider gaze. Quality, engineering, sales and marketing, logistics, and even accounting/finance are all part of the process that starts with a business plan and culminates with your trinket in the hands of your happy customer.

Raytheon, GLOBALFOUNDRIES Partner to Accelerate 5G Wireless Connectivity ▶

Raytheon Technologies and GLOBALFOUNDRIES will collaborate to develop and commercialize a new gallium nitride on silicon (GaN-on-Si) semiconductor that will enable game-changing radio frequency performance for 5G and 6G mobile and wireless infrastructure applications.

Fortify, Rogers to Develop 3D Printed Dielectric Material Systems for RF Devices ▶

Fortify, a Boston-based 3D printing startup, and Rogers Corporation, a global leader in engineered materials for advanced connectivity and power electronics, announced their partnership to enable additive manufacturing of low-loss dielectric materials for radio frequency (RF) devices and electronics.

Curtiss-Wright Selected by Lockheed Martin to Upgrade U.S. Navy Computers ▶

Curtiss-Wright's technology leadership in Modular Open-Systems Approach-based rugged commercial off-the-shelf modules tapped for U.S. Navy MH-60R/S Seahawk helicopter in response to cyber-attacks.

Defense Speak Interpreted: The U.S. Has a Space Force—JEDI Knights Next? ▶

Does the U.S. Department of Defense's JEDI contract mean it's going into a *Star Wars* production? Sorry, not this time. Sorting out the good guys and bad guys in this cloud computing scenario.

Satnav, Connectivity Network for the Moon Explored by Inmarsat ▶

Inmarsat, the world leader in global, mobile satellite communications, will be a key member of a new consortium led by Telespazio to study the development of a satellite navigation and communications network that supports future missions to the Moon.

IPC-WP-019: The How-to Behind the Cleanliness Requirements in IPC J-STD-001G

Feature Article by Debora Obitz
IPC

IPC-WP-019, "An Overview on Global Change in Ionic Cleanliness Requirements," was initially released in August 2017. This document, a white paper, was released to help the industry understand new cleanliness requirements in the G revision of IPC J-STD-001 Requirements for Soldered Electrical and Electronic Assemblies.

Leading up to that time, for many years, vast facets of the industry utilized a requirement of 1.56 $\mu g/cm^2$ NaCl to determine acceptable cleanliness of printed circuit assemblies. This was conducted using Resistivity of Solvent Extract (ROSE) testing per IPC-TM-650, method 2.3.25.

With the complexity of assemblies increasing and flux chemistries and cleaning solutions changing, the ROSE test—originally developed in the 1970s as a process control method for rosin-based fluxes—was not an adequate test for acceptable levels of ionic residues on the majority of the new flux chemistries. Many datasheets indicate that the new flux chemistries cannot be brought into solution with alcohol or water. The ROSE test is based on spraying/immersing the board into a 75% alcohol/25% deionized water solution. From this information, science tells us that the ROSE test is inadequate in these situations.

A different method or combination of methods for establishing cleanliness of an assembly is needed to provide "objective evidence." That knowledge and understanding led to a small group of dedicated volunteers who named themselves the "Rhino Team" to look at the requirements of IPC J-STD-001 and make recommendations for change. This team included technical subject matter experts from aerospace, materials, automotive, and commercial companies.

Over the course of several years and presentations to the IPC J-STD-001 task group, new cleanliness requirements were beginning to emerge. The task group determined that a qualified manufacturing process was required for manufacturers of Class 2 and Class 3 products.

The task group quickly realized that industry needed a technical explanation of the requirements and guidance to help with implementation. The task group directed the Rhino Team to develop a white paper before the requirements were put into IPC J-STD-001. After two years of work, there was consensus approval of IPC-WP-019. Unlike a standard, IPC-WP-019 provides the additional explanations, clarifications, knowledge, and/or guidance on the subject of cleaning requirements in preparation for incorporating those cleaning requirements in IPC J-STD-001.

IPC-WP-019 takes the reader through an explanation of cleanliness requirements within Chapter 8 of IPC J-STD-001G. Scenarios are provided to assist the reader with examples of how the requirements can be implemented, and additional references available for guidance.

Eleven months after the release of the original IPC-WP-019, a revision of the white paper was released that aligned to the new cleanliness requirements forming the basis of IPC J-STD-001G Amendment 1. Because of the importance of cleanliness of electronic assemblies, IPC J-STD-001G Amendment 1 would introduce the new cleanliness requirements to industry, and IPC-WP-019A would be there to help companies that wanted to begin implementation.

In 2020, IPC J-STD-001H was released. The revision of this document included changes to the cleanliness section, including additional information on what supporting objective evidence is required when qualifying a manufacturing cleaning process. Supporting objective evidence is test data demonstrating that the performance of the product is not adversely affected in the service environment of Class 2 and Class 3 products. This may include test data from surface insulation resistance (SIR) testing, possibly in combination with ion chromatography (IC), historical evidence demonstrating that residues have not caused failures in service, and electrical testing with power on during extremes of temperature and humidity which represent the end-use environment. These changes prompted the Rhino Team to further revise IPC-WP-019 to ensure the explanations and support to industry would remain current.

Today, IPC-WP-019B continues to support the industry and provide the explanations and information needed to assist companies using the cleanliness requirements of IPC J-STD-001H. It's the how-to behind the requirements.

For more information or to purchase IPC-WP-019B, visit IPC.org. **SMT007**

Debora Obitz is manager of IPC Technical Programs.

Electronics Industry News and Market Highlights

Siemens Acquires proFPGA Product Family from PRO DESIGN ▶

Building on the recent announcement of its next-generation Veloce hardware-assisted verification system for integrated circuits (ICs), Siemens Digital Industries Software has signed an agreement with Germany-based PRO DESIGN Electronic GmbH to acquire its proFPGA product family of Field Programmable Gate Array (FPGA) desktop prototyping technologies.

Hitachi Establishes New Semiconductor Engineering Facility in Portland, U.S. ▶

Hitachi High-Tech Corporation and Hitachi High-Tech Group company, Hitachi High-Tech America, Inc., announce the establishment of Hitachi's Center of Excellence in Portland, a new centralized facility for semiconductor engineering in Hillsboro, Oregon.

Henkel Invests in Innovation Center in Shanghai ▶

Henkel announced the construction of a new Adhesive Technologies Innovation Center in Shanghai. With an investment of more than 60 million Euro (RMB 500 million), the state-of-the-art facility will transform Henkel's current Zhangjiang site into an Innovation Center for China and Asia-Pacific.

Driving in the Snow is a Team Effort for AI Sensors ▶

Nobody likes driving in a blizzard, including autonomous vehicles. To make self-driving cars safer on snowy roads, engineers look at the problem from the car's point of view.

North American Semiconductor Equipment Industry Posts April 2021 Billings ▶

North America-based semiconductor equipment manufacturers posted $3.41 billion in billings worldwide in April 2021 (three-month average basis), according to the April Equipment Market Data Subscription (EMDS) Billings Report published by SEMI.

Cutting the 'Key' to an Unhackable 5G Network ▶

Scientists from Heriot-Watt University have secured six-figure funding from Innovate-UK on a project led by BT to develop a practical quantum key distribution (QKD) transmitter and receiver modules for short range terrestrial applications.

PTT, Foxconn Announce Venture on Electric Vehicle Production Platform ▶

H.E. General Prayut Chan-o-cha, Prime Minister of Thailand, presided over the Virtual Signing Ceremony of a Memorandum of Understanding (MoU) for a Development and Manufacturing EV project in Thailand between PTT Public Company Limited, the largest publicly listed conglomerate in Thailand and Hon Hai Technology Group (Foxconn), the leading global technological solution provider.

Cadence Accelerates Cloud Hyperscale Infrastructure ▶

Cadence Design Systems, Inc. announced immediate availability of Cadence® IP supporting the PCI Express® (PCIe®) 5.0 specification on TSMC N5 process technology.

Get Your Industry 4.0 Here! IPC-CFX Momentum Builds

Article by David Bergman
IPC

Do you hear that?

That buzzing sound.

Yeah, me too.

Is it a hive of bees? No. I know a thing or two about bees. That's no bee buzzing.

That buzzing is the industry embracing and running with IPC-CFX.

- An industry that views the clean pipe of data that IPC-CFX provides against the clogged pipes of other machine communications protocols
- An industry that demands the highest level of security for its data and factories
- An industry that knows it can get more value out of a standardized, open communication protocol that is managed by—you guessed it—industry

Those of us who have been actively involved in the development of IPC-CFX and IPC-2591 from the beginning always knew the standard would be a breath of fresh air for industry. It was just a matter of time. That time is definitely upon us, and IPC is prepared to meet the challenge to ensure any company's successful implementation of IPC-CFX.

As an industry organization, IPC has the unique opportunity to align some of its core programs and support models to ensure industry's success in implementing and getting the full value from IPC-CFX. So last year we got to work launching IPC-CFX solutions around education, support, and qualification, all of which tie into the heartbeat of our organization: standards. In this case, it is IPC-2591 and the 2-17 Connected Factory Initiative Subcommittee and IPC-CFX A-Team which maintain the standard.

Here's a rundown of what IPC is providing industry.

Getting What You Pay For

When you buy a piece of equipment that your vendor says is IPC-CFX ready, is it? For the first two years of industry integration of IPC-CFX, that question received subjective responses. What one vendor considered to

be IPC-CFX-ready did not match what other vendors—or more importantly, the EMS and OEM customers—understood as being IPC-CFX ready.

This caused some pain points in industry, as some EMS companies, after buying equipment touted as being IPC-CFX compliant only to find when they plugged it into their line, saw only some base IPC-CFX message sets ("Are You There?") were supported. Recognizing this as a hurdle to IPC-CFX adoption, the 2-17 Subcommittee addressed this with the most significant update to IPC-2591 to date in the release of version 1.3 of the standard.

IPC-2591, Version 1.3 sets minimum mandatory IPC-CFX message topics—or groupings of IPC-CFX messages—that a particular type of equipment must be able to send and receive to meet the standard. These requirements draw a clear line in the sand regarding what it means when an equipment vendor states a particular model is IPC-CFX compliant.

These requirements draw a clear line in the sand regarding what it means when an equipment vendor states a particular model is IPC-CFX compliant.

To fully support the subcommittee's establishment of these IPC-2591 requirements, IPC released the IPC-CFX Self-Validation System and IPC-CFX-2591 Qualified Products List (QPL). As the first of its kind in our industry, the Self-Validation System is a standardized, virtual testbed for any vendor to test and troubleshoot IPC-CFX endpoints (equipment models).

Once a vendor has determined that their models can support the mandatory IPC-CFX topics for their piece of equipment, they can run the equipment through a third-party virtual audit. The virtual audit acts as another IPC-CFX endpoint to verify the equipment can send and receive the applicable messages. If the equipment vendor has done their homework using the Self-Validation System, their piece of equipment should quickly pass the virtual audit and receive an instant listing on the IPC-CFX-2591 QPL.

In addition to the mandatory topics required for QPL listing, vendors also can demonstrate additional capabilities by testing optional messages they would like to have included in their QPL profile. As an equipment vendor, think of these as the add-ons when you're selling a car. Sure, my pick-and-place customer needs Core Communications, WIP Tracking and Basic Recipe Validation, but I know for a fact that their data analytics teams and Factory of the Future planning will also find value in Remote Recipe Management, Material Blocking and Station Locking. Any pick-and-place equipment provider can add these optional messages to their virtual audit to demonstrate that their particular model will meet your needs.

For the EMS and OEM companies, IPC-2591 is now not just a standard; it is a shopping catalog. You understand your IPC-CFX implementation plans, so by using the standard, you can run through the list of optional topics for each piece of equipment and ask your vendors if they will support those and when you will be able to find their models on the QPL.

In just a few short months, there are 12 models on the IPC-CFX-2591 QPL, and there are dozens more in the pipeline. In fact, one major equipment vendor has even committed to every single one of its models on the QPL.

If you are an EMS or OEM company looking to add IPC-CFX to your shop floor now or in the future be sure you reference a trusted source for IPC-CFX equipment in the IPC-CFX-2591 QPL. To learn more and to access the QPL list, go to https://www.ipc.org/ipc-cfx-2591-qualified-products-list-qpl. If you don't see your vendors there, ask when they will be on the QPL.

If you are a vendor who wants to demonstrate your IPC-CFX capabilities to industry, contact TamaraSites@ipc.org for more information.

What about My Old Stuff? A Focus on Legacy Equipment

So, the IPC-CFX-2591 QPL works for new equipment I plan on buying down the line, but what if I want to begin implementing IPC-CFX now?

You are not the first to ask this question. We have had discussions with many OEM and EMS companies who want to integrate IPC-CFX now rather than wait for equipment swap-outs. They want to immediately gain benefits from the clean, data-rich messaging stream for SPC, data analysis, quality improvement, and the many other things IPC-CFX can offer. They also want to have an IPC-CFX line in place for when they do buy new IPC-CFX equipment; it's plug and play.

To shine a spotlight on IPC-CFX implementations for legacy equipment on shop floors, IPC has started collecting support declarations from equipment vendors. On these declarations, vendors indicate which equipment they will (or can) support with IPC-CFX and how they can support—add-on hardware or direct implementation. For some companies, they can provide IPC-CFX support for equipment more than 10 years old.

The following vendors comprise the early short list of those with support declarations:

- Acculogic
- ASM Assembly Systems
- Creative Electron, Inc.
- CyberOptics
- Ersa GmbH
- Europlacer
- FlexLink Systems Inc.
- Heller
- JUKI Automation Systems Corporation
- Koh Young Technology
- Nordson Asymtek
- OK International
- PARMI
- Pillarhouse International Ltd.
- PVA
- SJ INNOTECH
- SPEA Automatic Test Equipment
- SYNEO LLC
- TE Connectivity
- Test Research, Inc.
- ViTrox Technologies Sdn. Bhd.
- YJ Link Co., Ltd

We will update this list as vendors continue to submit declarations, so stay tuned for updates. If you are an EMS or OEM using vendors you don't see on the list, ask them to submit their IPC-CFX legacy support declaration, using the form on the web page.

Want to Get Smart about CFX?

Earlier this year, we unveiled the first in a series of on-demand IPC-CFX education using IPC's EDGE education platform. The CFX 100 course is a set of five 15-minute modules that are intended to take any person from little to no understanding of IPC-CFX to knowing how to have your equipment send and receive its first set of IPC-CFX messages.

To date, more than 200 people have registered for this course, with more than half of those coming from EMS and OEM companies.

You can view details about the CFX 100 series, including free access to IPC-CFX 101, here. In the months ahead, we will roll out the next series of education topics, which take a much deeper technical dive into IPC-CFX topics relevant to all IPC-CFX users. Additional courses will focus on specific equipment types, from pick and place to AOI, ICT, FCT, and other test equipment.

IPC also provides free webinars for industry to provide firsthand insight into utilization of

IPC-CFX from subject matter experts in the field. Our next webinar, scheduled for July 15, will demonstrate how IPC-CFX can be used to support smart factory enablement in security-critical applications, utilizing its AMQP security protocol and standardized message sets.

Register for this free webinar at https://www.ipc.org/event/factory-future-webinar-series-smart-industry-40-enablement-security-critical-applications.

Yo, a Little Help?

Even though we have the education in place and are seeing multiple vendors successfully integrating IPC-CFX into their equipment, we recognize some companies will need a little additional help for their successful IPC-CFX implementations. IPC-CFX Engineering Support Service can provide assistance from coding questions and code review to guidance on the IPC-CFX topics and messages your equipment will need for your customers to achieve their IPC-CFX shop floor plans.

You can learn more at https://www.ipc.org/ipc-cfx-engineering-support-services.

IPC-CFX is a Keystone of IPC's Factory of the Future Thrust

Although this may seem like a lot of activity in a short period of time, there is no rest when it comes to IPC-CFX. Based on the activity we have seen in industry in the last six to nine months, we fully expect 2021 to be a breakout year for IPC-CFX, and we're setting the stage to support current and future needs.

We are forming new task groups under the 2-17 Subcommittee to home in on specific machine types or important topic areas under IPC-CFX. We will challenge these groups to define what they want IPC-CFX to be in the next three to five years to help the subcommittee focus its efforts to ensure IPC-CFX will meet industry needs.

The subcommittee also will continue to expand IPC-CFX to ensure any piece of equipment that is involved in the manufacture of electronics can be supported by the standard, including AGVs/AMRs and fleet management systems, as well as back end of line equipment such as mechanical assembly. The subcommittee will also continue to collaborate with Hermes and IPC-2581 groups for better alignment of the standards. Their goal is to release IPC-2591, version 1.4 by end of year.

We also will continue to work with industry to help to close the gaps for IPC-CFX implementation on existing shop floor lines. In addition to gathering support declarations from vendors, we are also keeping a pulse on other activities in this area which could bear fruit for legacy lines, such as industry-developed solutions for Raspberry Pi devices.

IPC will also soon release next levels of on-demand education on IPC EDGE and is planning for additional webinars later this year to focus on hot topics around IPC-CFX.

All this is in addition to continuing to support the growing pipeline of equipment vendors accessing the Self-Validation System and adding their models on the IPC-CFX-2591 QPL.

A lot will happen between now and the next time you hear from me, so if you want to stay on top of all these activities—or influence the next generation of messages in IPC-CFX—join the 2-17 Subcommittee. To sign up for the subcommittee and to have your company listed on our IPC-CFX Supporters page at https://www.ipc.org/join-ipc-cfx-committee-member-supporter-or-partner, or visit ipc.org. **SMT007**

David Bergman is IPC vice president of standards and technology.

Supplier Highlights

Dynamic Source Manufacturing Selects MIRTEC 3D AOI ▶

MIRTEC is pleased to announce that Dynamic Source Manufacturing, Inc. has selected MIRTEC's MV-6 OMNI 3D AOI machine to meet their high-quality manufacturing standards.

CyberOptics Receives Order Valued at $4.2 Million for Mini LED Inspection and Metrology ▶

CyberOptics Corporation, a leading global developer and manufacturer of high precision 3D sensing technology solutions, announced that it has received a new follow-on order valued at approximately $4.2 million for its SQ3000™ Multi-Function systems for mini LED inspection and metrology.

Murray Percival Co. Upgrades Bennett Pump to Ersa VERSAFLOW ▶

The Murray Percival Company, a leading supplier to the Midwest's electronics industry, announced the sale of a Kurtz Ersa VERSAFLOW 3/35 to Bennett Pump.

MacDermid Alpha Experts Present on Low Temperature Solder Solutions at Virtual Technical Conferences ▶

MacDermid Alpha Electronics Solutions, leaders in innovative electronic interconnect technologies, presented papers on low temperature solder technology and solutions at two virtual conferences, the Electronic Components and Technology Conference (ECTC) on June 7, and at the Low Temperaure Soldering (LTS) Conference 2021 on June 16.

Rehm's PWI Monitoring Tool—Perfect Profiling, Monitoring of Soldering Process ▶

The new ProMetrics monitoring tool from Rehm Thermal Systems offers optimal control and top quality when soldering electronic assemblies.

Prototype Electronics Continues Expansion With Identical Second Placement Machine ▶

Despite the pandemic, Piddlehinton-based Prototype Electronics Ltd. has invested in a second iineo pick-and-place machine from Europlacer.

Bob Bouchard Named Director of Sales–Americas for BTU International ▶

BTU International, Inc., a leading supplier of advanced thermal processing equipment for the electronics manufacturing market, announced the promotion of Bob Bouchard to director of sales–Americas.

METCAL Announces Patent Pending Software Upgrades to GT Series Soldering Systems ▶

METCAL, a leader in benchtop soldering systems, announces patent pending software updates for their newly launched GT90 and GT120 Soldering Systems.

Essemtec Expands into Puerto Rico with APT ▶

Essemtec, the Swiss manufacturer of production systems for electronic assembly and packaging, announced that it has hired Advanced Process Technologies (APT) Inc. as its manufacturers' representative.

SMT Process Optimization

Maggie Benson's Journey

by Ronald C. Lasky, INDIUM CORPORATION.

(Editor's note: Indium Corporation's Ron Lasky continues this series of columns about Maggie Benson, a fictional character, to demonstrate continuous improvement and education in SMT assembly.)

Professor Patty Coleman of Ivy University (IU) was excited to see her two best former students, Maggie and John, to help them develop a continuous improvement plan for Benson Electronics (BE). Since both Maggie and John were captains of IU's student golf teams, Patty suggested that they might want to play nine holes first. Truth be told, Patty also needed the break; she had been working too hard and golf was one of her favorite pastimes. In fact, both Patty and her husband Rob were top notch golfers. Annika Sörenstam had even encouraged Patty to become a professional golfer, but Patty decided against it.

On the other end of the phone, Maggie Benson was delighted by the invitation; she had another chance to try and beat Professor Coleman at golf. She had played with her about five times in the past and lost every time.

On the golf course, a short time later...

Patty just couldn't help herself; she always wanted to win at golf, and she now found herself one stroke behind Maggie going into the last hole. It wasn't that she was playing poorly; she was one under par, but Maggie was two under. The last hole was a 510-yard par 5. Maggie hit first—a beautiful 260-yard drive right down the middle.

"Nice drive, Maggie," Patty remarked.

Maggie is 5 feet 9 inches tall and 145 pounds. She hit that drive as hard as she could.

Patty got up and smoked a 275-yard drive, considerably farther than Maggie's. Both women drove the ball farther than LPGA pros.

"Why can't I hit it farther than Professor C?" Maggie thought. "I'm two inches taller and 15 pounds heavier."

Maggie hit her second shot five yards short of the green and Patty's was just off the green hole high, 30 feet away. Maggie was savoring a potential victory, or at least a tie, when she chipped up about eight feet from the hole.

However, Patty chipped it in the hole for an eagle 3. Maggie would now need to sink her 8-footer for a tie.

When the ball lipped out, Maggie almost swooned. "Foiled again," she thought to herself.

John didn't have any better luck: he shot a 1-under par round, but was crushed by Rob's 4-under par.

"Professor Coleman, I don't think I will ever be able to beat you," Maggie groaned.

"You will someday, Maggie. And remember: it's 'Patty,'" Patty said.

"Yes, Professor Coleman," Maggie responded.

They all burst into laughter.

Patty was a hardworking and dedicated mother, wife, and professor. She cared deeply about her current and former students, but she just couldn't help herself; she always wanted to win, and she couldn't help but revel in her small victory.

After golfing, they retired to the Simon Pearce restaurant for lunch to discuss Maggie and John's improvement plans for Benson Electronics, and to share the details of Maggie and John's engagement and emerald ring.

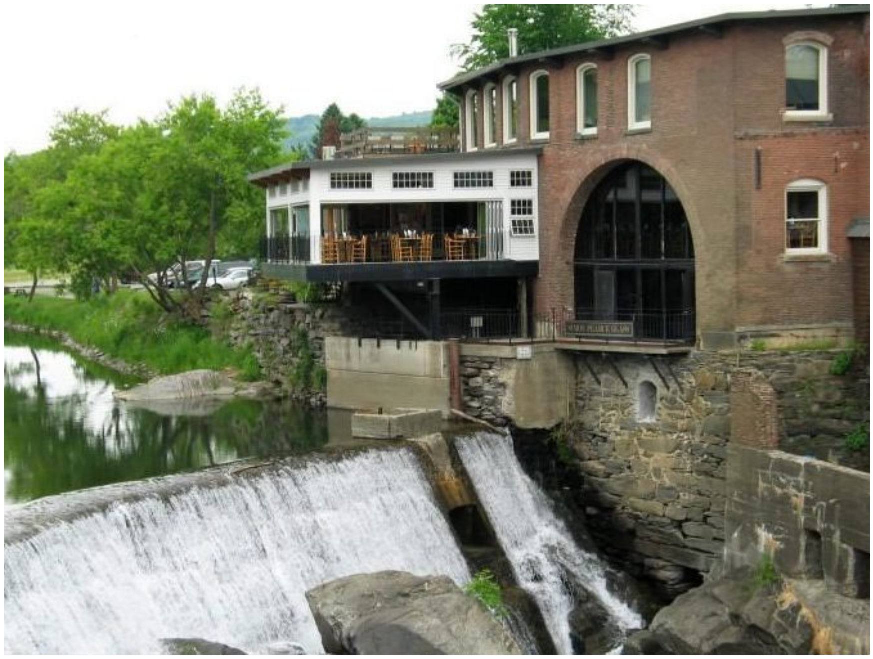


Figure 1: An image of the Simon Pearce Restaurant. (Source: roadfood.com.)

Two days later...

Maggie and John gave everyone at Benson Electronics an SMT-101 test. Expecting some concern from the employees, they held an all-employee meeting to explain that the test was to help them understand what type of training was needed. They mentioned to the employees that all training would be paid as overtime and staff would receive time-and-a-half pay. The workers could also opt out of the test and would be in the "SMT Trainee" section of the workshops; 50% of the workers opted for this choice.

As Fred Clinton said, "Better to not take the test and be thought a big dummy than to take it and remove all doubt."

In general, the staff was happy for the opportunity to get paid training. In addition, it was important to Maggie and John that all the operators learned how to program and run every machine, as there were times in the past when the few operators who knew how to run the stencil printer were out sick and the lines stopped.

Within weeks, much cross training on machines was accomplished and morale was very high. Numerous employees stopped Maggie or John and thanked them for these chances for self-improvement. On two occasions, workers stopped Maggie to thank her, and they burst into tears and gave her a hug. Neither saw that Maggie had tears in her eyes, too.

Maggie, John, and John's friend, Frank Emory, had spent scores of hours working out a continuous improvement plan. Frank was mainly responsible for optimizing the business processes while Maggie and John would manage the operational processes. They agreed that quick turnaround time, customer satisfaction, high operational efficiency, profitability, and employee morale where their top concerns. The tools would use Lean Six Sigma approaches. A common Lean Six Sigma acronym is DMAIC, which is defined as:

- Define
- Measure
- Analyze
- Improve
- Control

As they were discussing their high-level improvement plan, Frank chimed in, "Hey, you guys, you're the experts in SMT process optimization, but I have to tell you: BE's line uptime stinks.[1] This is so fundamental to all that we want to accomplish that we need to address it before we do anything else."

Both Maggie and John knew Frank was right, but John finally asked, "Frank, how did you come to that conclusion?"

"I've been here every day now for weeks," Frank responded. "Whenever I walk past the shop floor, I make a note in my smartphone if a line is up or not. What do you think the uptime is?"

Maggie groaned, "Don't tell me it is less than 20%."

"I get about 15%," Frank said.

Maggie and John both looked crestfallen.

"Hey, the good news is the business is doing OK right now, and we can easily make it a lot better by getting the uptime to more than 35%," Frank said.

Maggie and John both nodded in agreement.

What will the trio do to get the uptime to at least 35%? Stay tuned to find out.

I imagine some readers are chuckling at the largesse of Maggie and John, thinking that it would be difficult to be so generous in today's business climate. Yet, they understand the Law of Exponential Profits (LoEP). (Okay, I made this term up.)

Here is an explanation of the LoEP by a simple example. Suppose a small company like Benson Electronics has $10 million in sales per year, 3% ($300,000) profit, and $700,000 in business expenses, such as labor, rent, depreciation, utilities, etc. Since they are assembling electronics, a low value add but high return on assets business, about $9 million of the cost of their sales is in purchased material such as components, PWBs, etc. Let us assume they increase their productivity by 10%; they will now have $11 million in sales. However, their business expenses increase hardly at all. Labor, rent, and depreciation do not increase, whereas utilities increase only marginally. So, their business expenses might go from $700,000 to $740,000. Therefore, profit is now $360,000 (10% of $11 million—$740,000). Hence, if productivity increases 10%, profits increase 20% ($360K vs. $300K). **SMT007**

References

1. Uptime is simply the percentage of time the line is running during production hours. Surprisingly, 35% is very good. I get these values from the scores of factories that I have visited worldwide. If anyone claims to have 70% or more uptime, please invite me to visit.

Ronald C. Lasky is an instructional professor of engineering for the Thayer School of Engineering at Dartmouth College, and senior technologist at Indium Corporation. Image of Maggie Benson by Sophie Morvan. To read past columns, or contact Lasky, click here.

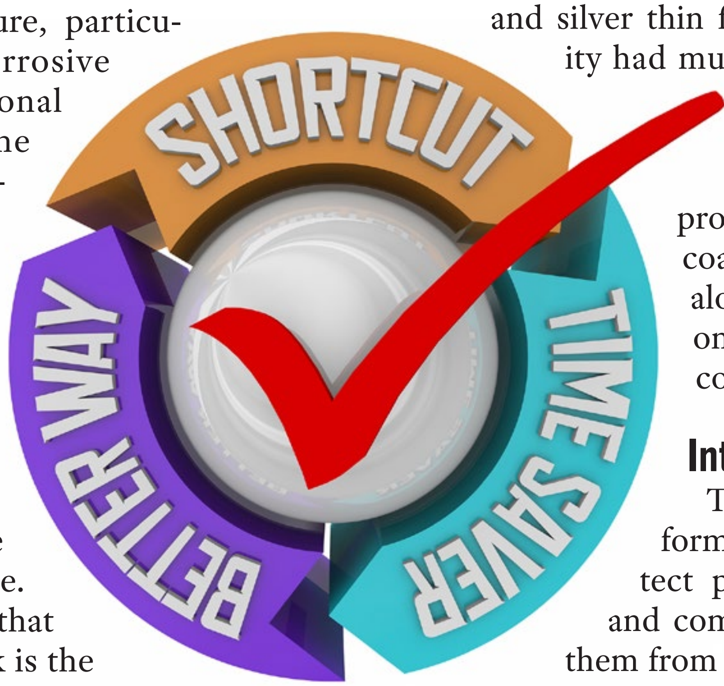
Conformal Coating Evaluation Test Development

Article by Prabjit Singh and Larry Palmer, IBM CORPORATION; **Chen Xu, Jason Keeping, Marko Pudas; Mei Ming Khaw, Kok Lieh Tan,** KEYSIGHT; **Mike Huang, Ruby Lin,** WISTRON CORPORATION; **Haley Fu,** iNEMI

Abstract

The purpose of conformal coatings is to protect printed circuit boards and components mounted on them from the deleterious effects of moisture, particulate matter, and corrosive gases. The conventional method of testing the effectiveness of conformal coatings is to expose the conformally coated hardware to a corrosive environment for ex-tended periods of time lasting many months and determining the mean time to failure. A quicker method that takes less than a week is the subject of this paper.

In this method the corrosion rates of conformally coated thin films of copper and silver, exposed to a sulfur gas environment, are used to characterize conformal coatings. This paper describes the test chamber design and setup and investigates how the temperature and humidity impact the corrosion rates of conformally coated copper and silver thin films compared to uncoated films. Performances of acrylic, silicone, and atomic layer deposition (ALD) conformal coatings were studied as a function of temperature and relative humidity. The test temperatures were 40°C and 50°C and the relative humidity levels were 15%, 31%, and 75%. Temperature affected the corrosion rates of conformally coated copper and silver thin films. Relative humidity had much less effect on corrosion rates. Significant differences in corrosion protection provided by the three coatings will be reported along with a discussion on the optimum test conditions.



Introduction

The purpose of conformal coatings is to protect printed circuit boards and components mounted on them from the deleterious effects of corrosive environments that can have high concentrations of gases such as sulfur dioxide, hydrogen sulfide, free sulfur, chlorine, oxides of nitrogen, and ozone. Particulate matter with low deliquescent relative humidity (DRH) can electrically short circuit features with potential differences across them

by forming low resistance bridges (electrical short circuits) when the relative humidity in the air is above the DRH of the particulate matter. As data centers proliferate worldwide into geographies with high levels of pollution and high relative humidity, the use of conformal coatings becomes necessary especially for mission-critical and military hardware [1-5]. Another factor making conformal coatings necessary is the decreasing feature sizes of components. With decreasing feature gaps that dust particles and corrosion product particles can more readily bridge, conformal coatings need serious design considerations.

Commercially available conformal coatings cover a wide range of price, ease of application, and effectiveness in protecting the underlying metal from corrosion. The industry standard means of evaluating conformal coatings is to apply them to the actual hardware and determine the mean time to failure of the coated hardware. This means of testing is very inconvenient and slow. Even where the corrosion of the coated components can be monitored, such as in the case of surface-mount resistors, it can take more than a year to evaluate a coating and that too under very limited conditions of temperature, humidity and environmental corrosivity [5-7].

A convenient way of evaluating conformal coatings is to coat thin films of copper and silver and to monitor the corrosion rates of the coated thin films while subjected to corrosive and humid environments [8,9]. Effective conformal coatings protect the underlying metal well. The paper gives a detailed description of the proposed test method for characterizing conformal coatings. The test method was evaluated at four temperature-humidity conditions on three different coatings (acrylic, silicone and ALD). A somewhat modified version of the iNEMI flowers of sulfur (FoS) chamber was used as the environmental chamber [10-13].

Experimental Procedure and Results

The test vehicle used for evaluating conformal coatings consisted of a serpentine thin film of copper or silver, 800 nm thick, sputtered on oxidized silicon die 15x15 mm. The die was glued to a prototype printed circuit board (PCB). One end of each of four L-shaped connector pins were soldered to the PCB and the other ends were joined using silver epoxy to 4-point contact pads of the serpentine thin film. The silver epoxy we chose required 140°C bake for one hour in flowing nitrogen gas. Nitrogen gas blanket avoids oxidation of the metal thin film. The L-shaped pins soldered ends were further connected to a receptable connector also soldered to the PCB. A schematic cross section of the serpentine thin-film test vehicle is shown in Figure 1 along with a photograph of the thin-film setup.

The thin-film setups were conformally coated with the coatings under test. Fine wire, 50 mm-diameter, T-type thermocouples were

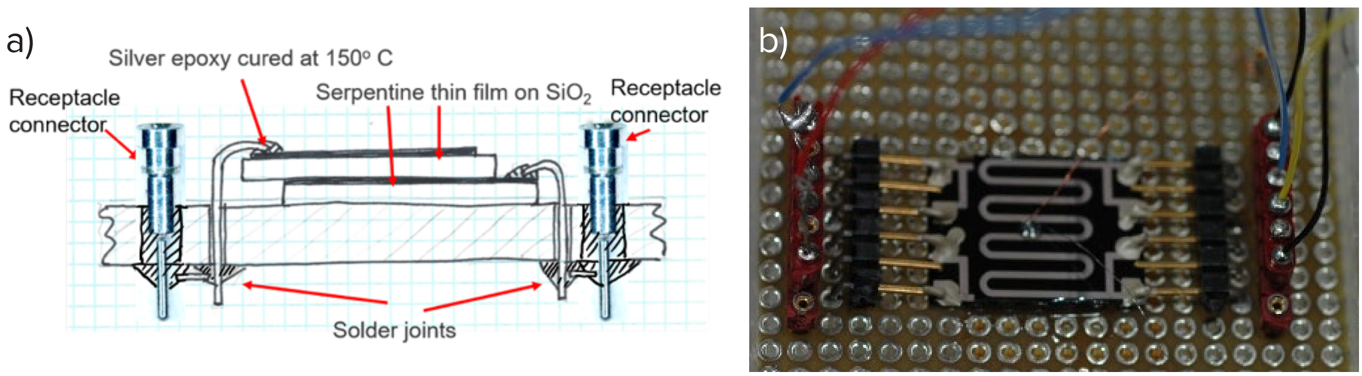


Figure 1: a) Serpentine thin-film setup. In earlier works the bottom thin films were to heat the top film; b) In this work the bottom films were not used.

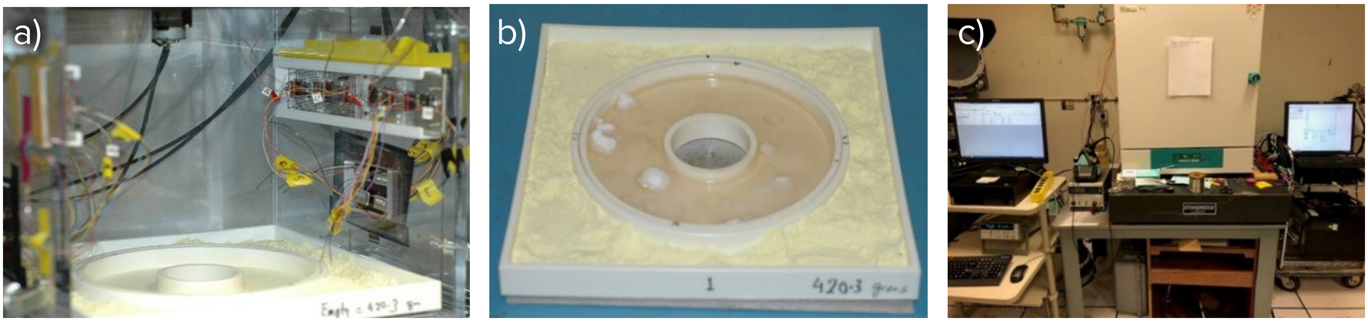


Figure 2: Flowers of sulfur chamber with the thin-film setup: a) Inside view of flowers of the sulfur chamber; b) sulfur and saturated salt trays; c) overall view.

glued on top of the conformal coatings in spaces between the serpentine thin films. The conformally coated thin-film setups were hung on the side walls of a modified iNEMI flowers of sulfur (FoS) chamber [10-13] and electrically connected to potentiostats through appropriate electrical feedthroughs. The modified iNEMI FoS chamber is shown in Figure 2. The changes made to the chamber were the removal of the paddle wheel and the household bleach. As a result, there was no forced air circulation and no chlorine gas in the chamber. The corrosive gas in the chamber consisted only of sulfur vapor. The sulfur concentration was 0.15 ppm when the chamber was at 40°C and 0.3 ppm when the chamber was at 50°C [14]. The relative humidity in the chamber was controlled at 15% using $ZnCl_2$ saturated salt solution, at 31% using $MgCl_2$ saturated salt solution, or at 75% using NaCl saturated salt solution. The chamber air was not mechanically circulated as it had been in past projects on creep corrosion testing [10-13].

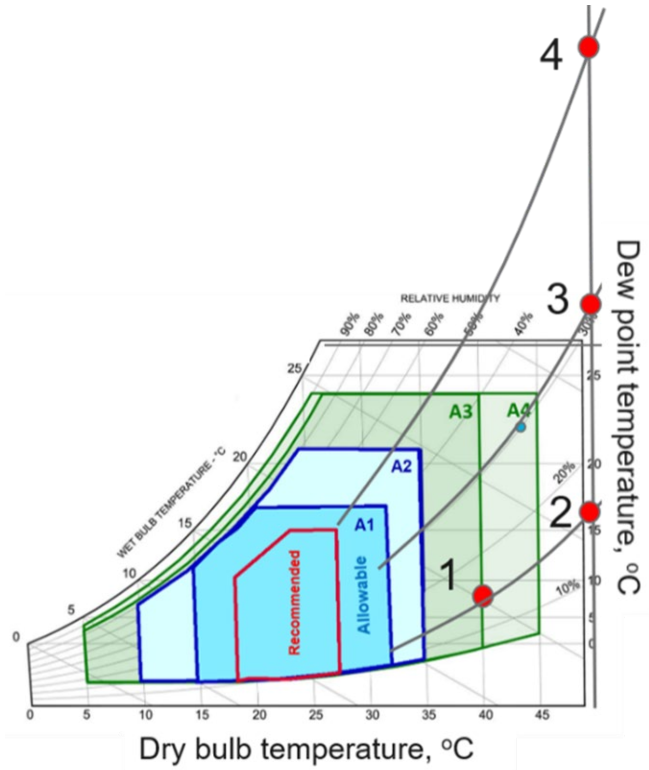


Figure 3: Psychrometric chart showing the four temperature-humidity test conditions.

The resistances of the thin films were measured using potentiostats to pump known values of currents through the thin films and measuring the voltage drops across them. Thin film temperatures were monitored using thermocouples attached to a data logger. Resistance and temperature readings were taken simultaneously every 10 minutes over the 5.32-day period of each test.

Three conformal coatings were tested: acrylic coating 39-45 mm thick; silicone coating 100 mm thick; and atomic level deposition (ALD) coating 0.1 mm thick. ALD coatings are ultra-thin (1-200 nm), stochiometric, dense, and highly uniform in thickness. ALD process is performed in a vacuum reactor at relatively low temperatures typically 80-300°C depending on the material deposited and the substrate thermal budget. To characterize/evaluate the conformal coatings, the corrosion rates of the coated thin films were measured and compared with uncoated (bare) thin films.

Duration, days	Current, mA	Nominal film temperature, °C
0–1.85	100	42
1.85–3	200	52
3–4.16	300	64
4.16–5.32	100	42

Table 1: Electrical and temperature test conditions for the FoS chamber at 40°C.

Four tests were run with the chamber under the conditions shown on the psychometric chart of Figure 3: (1) 15% relative humidity, 40°C; (2) 15% relative humidity, 50°C; (3) 31% relative humidity, 50°C; and (4) 75% relative humidity, 50°C. As mentioned earlier, the humidity was maintained using saturated salt solutions. The durations of various electrical and temperature conditions are listed in Table 1.

Testing involved test periods at various temperatures and even though the intent was to keep temperature constant during each test period, rise in film resistance with time increased film temperature accordingly. The effect of temperature was compensated, as shown below, by calculating the value of resistance that would be if the film were cooled to temperature, T_o.

$$R(t,T) = R(t,T_0)\left[1+\alpha(T-T_0)\right]$$

$$R(t,T_0) = \frac{R(t,T)}{1+\alpha(T-T_0)}$$

The temperature compensated (corrected) resistance, $R(t,T_o)$, can then be used to calculate the film thickness using the following relation:

$$th(t) = \frac{R(t=0,T_0)}{R(t,T_0)}\, th(t=0)$$

The temperature coefficients of electrical resistance, a, of copper and silver thin films were determined as illustrated in Figure 4. The very high electrical resistivity of the corrosion product allowed us to neglect the effect of the parallel resistance path of the corrosion product.

The sulfur concentration and the relative humidity were fixed by the chamber temperature and by the choice of the saturated salt solution, respectively. An indirect means of determining the air composition is by measuring its corrosivity towards copper and silver foils inserted through narrow slots into the front door of the chamber and exposed to the chamber environment, typically for a day. The total thickness of the corrosion products per day was determined using coulometric reduction [15]. Corrosion rates of the copper and silver foils on a per day basis are shown in Figure 5. The effect of the chamber temperature is clear: 40°C chamber environment is less corrosive than 50°C environment. On the other

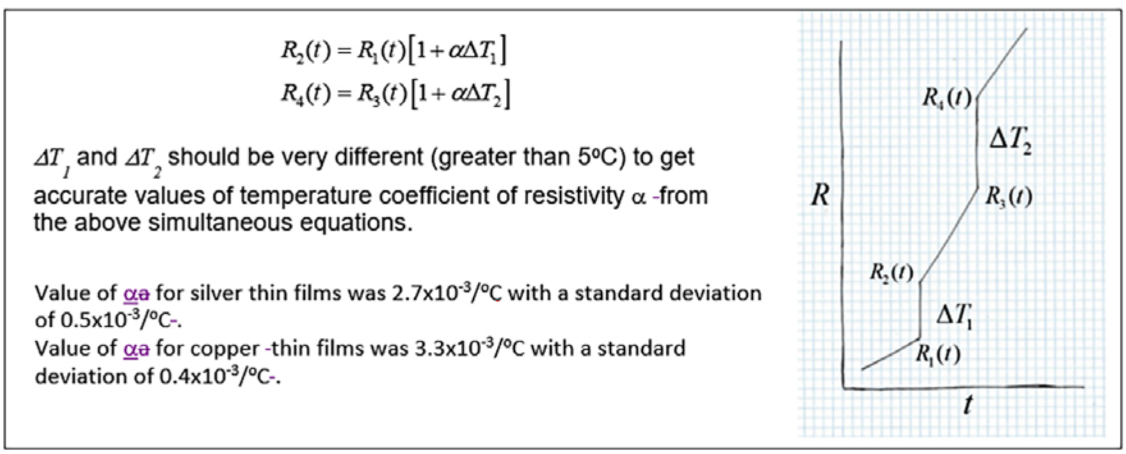


Figure 4: Method for determining the value of temperature coefficient of resistance α.

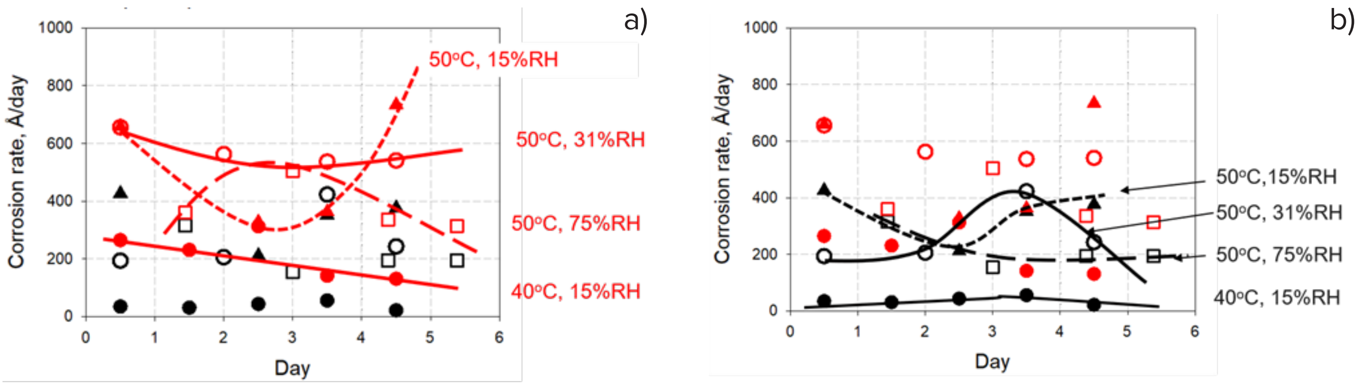


Figure 5: Corrosion rates of a) copper foils and b) silver foils in FoS chamber. Typical time of exposure of foils was one day. Coulometric reduction was used to determine total corrosion product thickness [15].

hand, higher relative humidity makes the air less corrosive. At higher humidity, the sulfur concentration in the chamber decreases because of sulfur vapor absorption by surfaces with higher amounts of adsorbed moisture. Lower sulfur concentration makes the air less corrosive.

As already mentioned, we determined the corrosion rates of conformally coated copper and silver serpentine thin films. The coatings tested were acrylic, silicone and ALD. Silicone coating provided the least protection to the underlying films; ALD coating provided the best protection. Test results of copper thin films covered with these two coatings and of bare copper thin film are shown in Figures 6-10. Figure 6 shows the temperature profiles of the test specimens over the 5.32-day test. Figure 7 shows the uncorrected resistance of the thin films measured using 4-point probe and a potentiostat. The data in Figures 6 and 7 provide enough information to determine the temperature coefficient of electrical resistivity of the thin films. From these figures, the temperature-compensated (corrected) resistance profiles, shown in Figure 8, can be obtained. From Figure 8, we can calculate the extent of copper corrosion as a function of time as shown in Figure 9. This copper corrosion refers to the copper thickness lost to corrosion, whereas the corrosion rates of Figure 5 refer to the total thickness of the corrosion products growing on the copper foils. The total thickness of copper corrosion products growing on a copper foil is twice the thickness of the copper thickness lost to corrosion. From the slopes of the plots in Figure 9, we

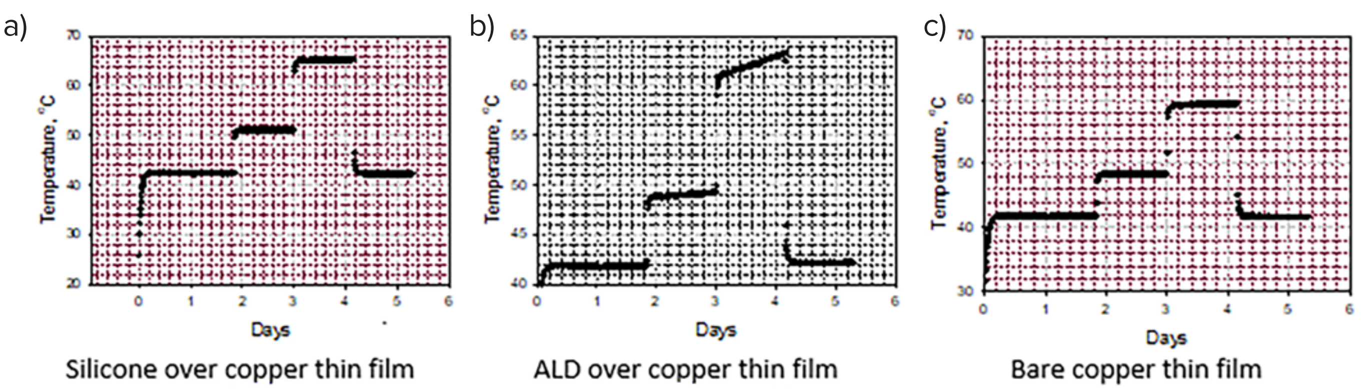


Figure 6: Temperature of copper thin films as a function of time in FoS chamber at 40°C and 15% relative humidity.

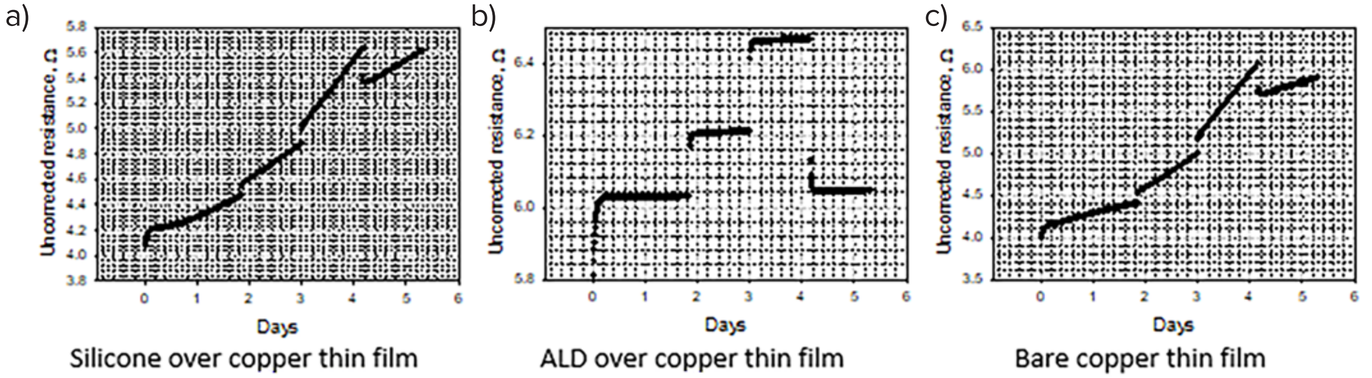


Figure 7: Uncorrected resistance of copper thin films as a function of time at various thin film temperatures in FoS chamber at 40°C and 15% relative humidity. The nominal thin film temperature was 42°C for 0–1.85 days; 52°C for 1.85–3 days; 64°C for 3–4.16 days and 42°C for 4.16–5.32 days. A) Silicone over copper thin film; b) ALD over copper thin film; c) bare copper thin film.

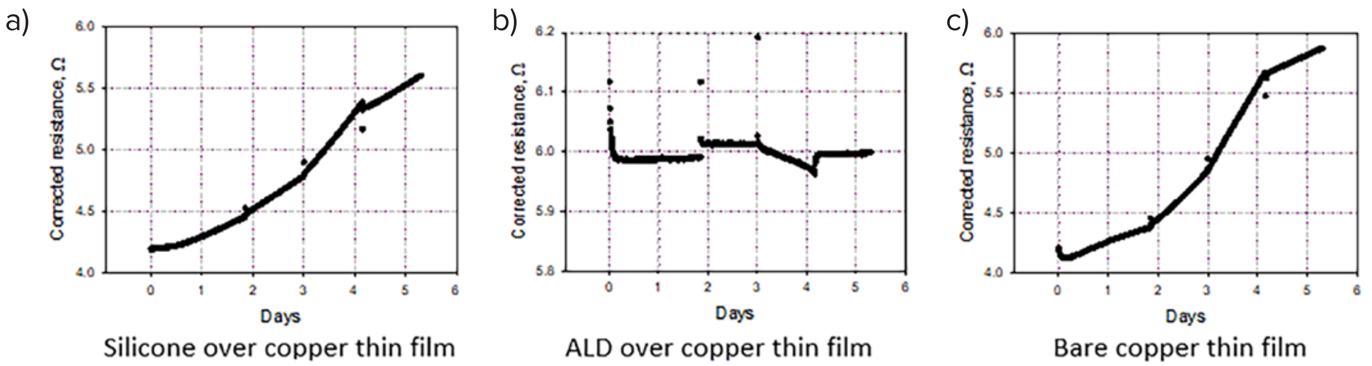


Figure 8: Corrected resistance of copper thin films as a function of time in FoS chamber at 40°C and 15% relative humidity. The nominal thin film temperature was 42°C for 0–1.85 days; 52°C for 1.85–3 days; 64°C for 3–4.16 days and 42°C for 4.16–5.32 days.

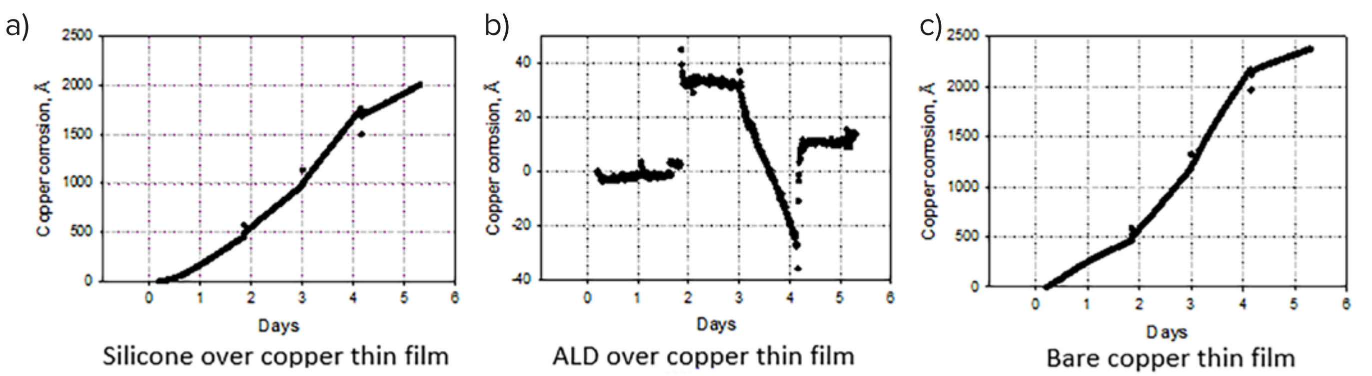


Figure 9: Extent of copper thin film corrosion as a function of time in FoS chamber at 40°C and 15% relative humidity. The nominal thin film temperature was 42°C for 0–1.85 days; 52°C for 1.85–3 days; 64°C for 3–4.16 days and 42°C for 4.16–5.32 days.

can obtain the rates of copper corrosion as a function of temperature and plot them in an Arrhenius fashion as in Figure 10. The corrosion rates of copper and silver films under the ALD coating were within the limits of the experimental error and therefore could not be measured in Figure 9 and therefore could not be plotted in Figure 10.

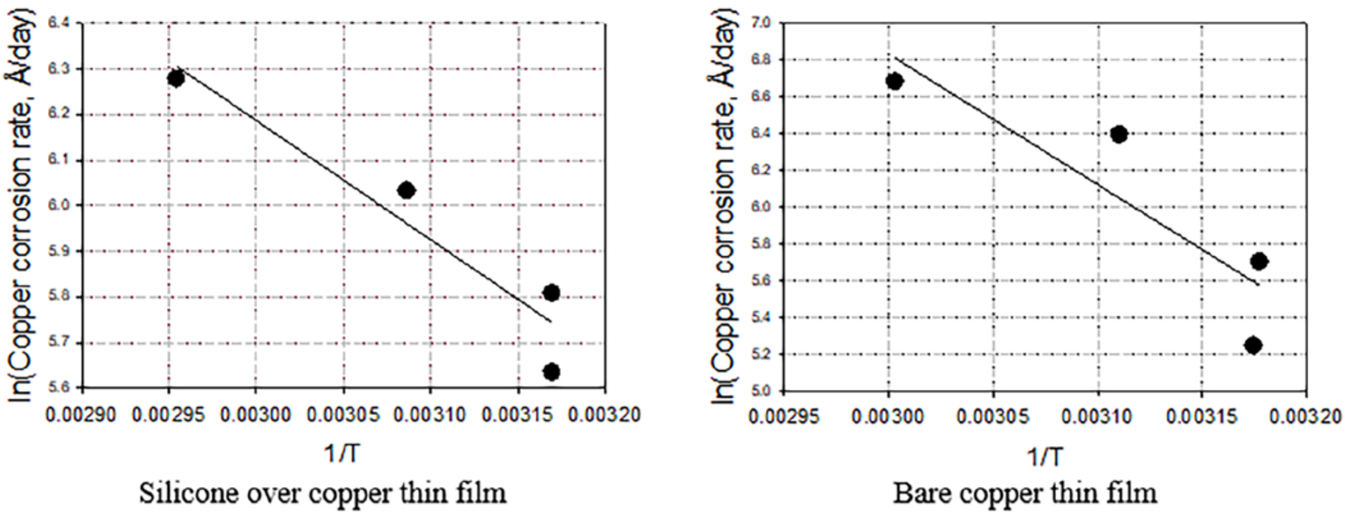


Figure 10: Arrhenius plot of copper thin film corrosion rates in FoS chamber at 40°C and 15% relative humidity.

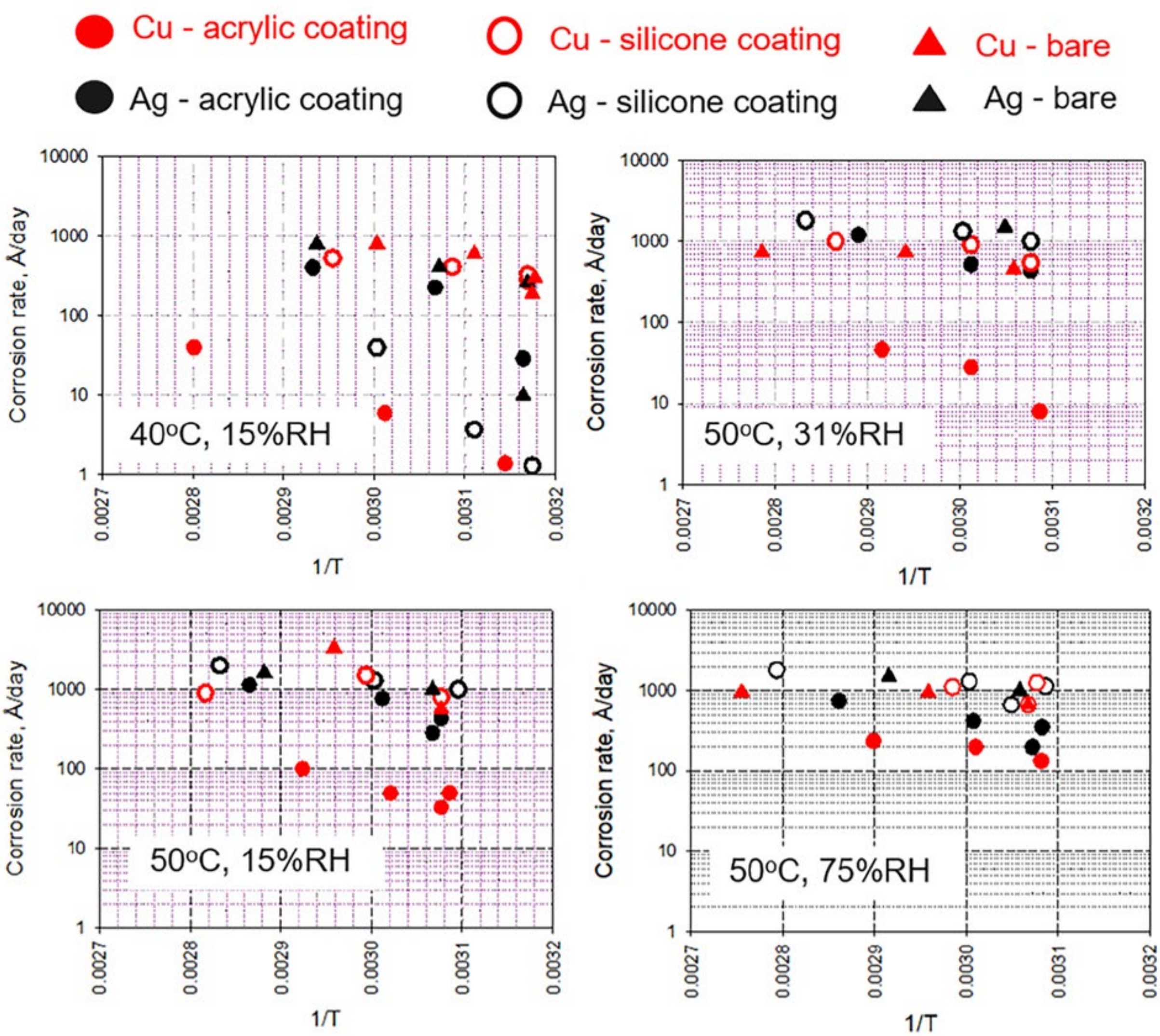


Figure 11: Summary of corrosion rates of bare copper and silver serpentine thin films and thin films coated with acrylic or silicone. ALD-coated thin film corrosion rates are not included in these plots because their corrosion rates were within the limits of the experimental error.

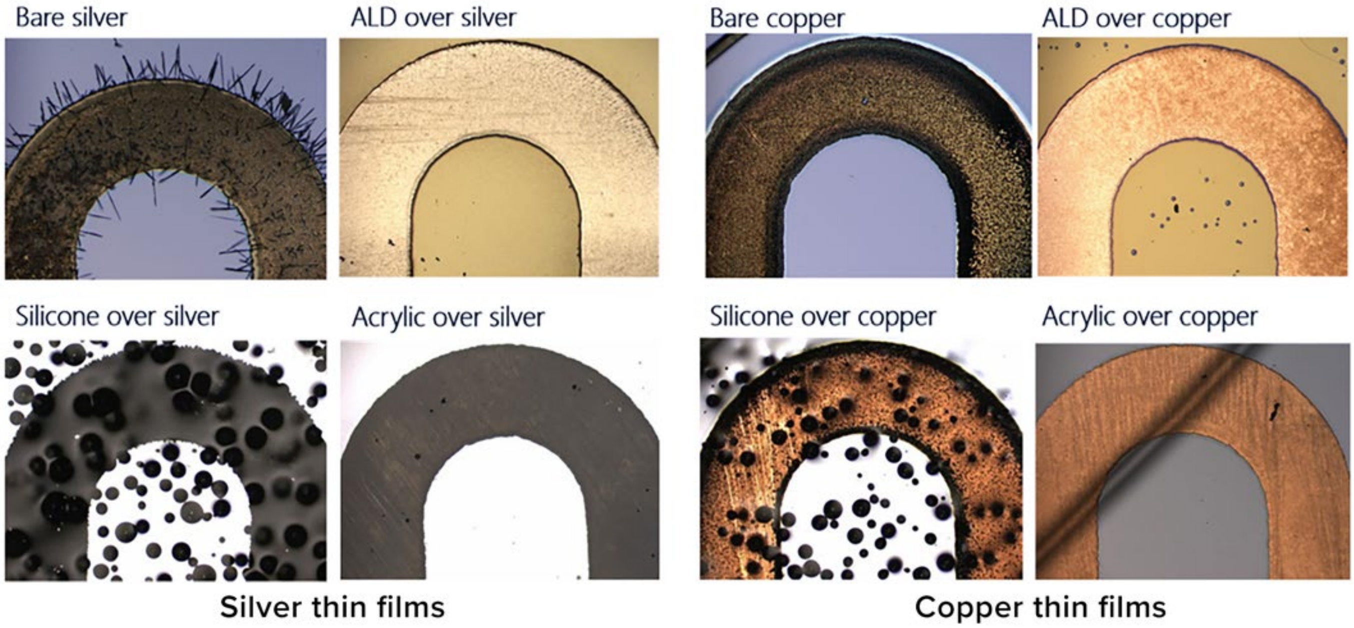


Figure 12: Photographs of serpentine thin films after the 5.32-day test at 50°C and 31% relative humidity.

Figure 11 summarizes the corrosion rates of bare (uncoated) copper and silver serpentine thin films and the corrosion rates of thin films coated with acrylic or silicone. Atomic level deposition (ALD) coated thin film corrosion rates were not included because their corrosion rates were within the limits of the experimental error.

Discussion

Figure 11 summarizes the corrosion rates of copper and silver serpentine thin films coated with acrylic or silicone and compares them to corrosion rates of bare (uncoated) copper and silver films. Atomic level deposition (ALD) coated thin film corrosion rates were not included because their corrosion rates were too low; they were within the limits of the experimental error.

Acrylic coating protected copper thin films from corrosion to some extent. In 40°C FoS environment, the corrosion rate of acrylic-coated copper was two orders of magnitude less compared to bare copper. Increasing the FoS environment temperature to 50°C increased the acrylic coated copper thin film corrosion rate by approximately an order of magnitude. Of the three humidity test conditions (15, 31 and 75%), the highest corrosion rate of acrylic-coated copper was at 75% relative humidity. Acrylic coating did not protect the underlying silver thin films. An increase in temperature from 40 to 50°C did increase the silver corrosion rate somewhat.

Silicone coating provided no corrosion protection to the underlying copper thin films. At 40°C and 15% relative humidity, silicone coating provided some corrosion protection to silver thin films. At 50°C, silicone coating provided no corrosion protection to the underlying silver thin film, over the whole range of relative humidity tested.

Figure 12 gives visual qualitative evidence of the extent of the underlying metal corrosion in agreement with the metal corrosion rates plotted in Figure 11. The ALD coatings clearly provided excellent corrosion protection to the underlying Cu and Ag films. Acrylic coating protected copper but not silver, in agreement with Figure 11. Silicone did not protect Cu or Ag films, again in agreement with Figure 11. Another interesting observation is that Ag_2S whiskers grew on the bare silver thin films and that these whiskers were prevented from growing by the three conformal coatings.

Predicting field performance often requires accelerated testing involving higher temperatures and harsher environments to shorten the test times to convenient durations. A downside of harsher conditions is that they may unduly overstress the hardware thus changing the failure mechanism from one occurring in the field. A better approach is to keep the test conditions close to or the same as the field conditions and to shorten the test time by improving the sensitivity of detection of the hardware degradation. The latter approach was taken in this paper by characterizing conformal coatings based on the corrosion rates of coated thin films that can be measured with down to +/-1 nm sensitivity. As a result, there is no need to accelerate the test conditions. This and earlier studies indicate that the environmental conditions in a flowers of sulfur chamber at 40°C are adequate for testing conformal coatings [8,9]. In this study, the chamber air was not mechanically stirred. In future studies, we will study the role of gentle mechanical stirring of the air in the flowers of sulfur chamber.

A downside of harsher conditions is that they may unduly overstress the hardware thus changing the failure mechanism from one occurring in the field.

Conclusions

The study provides additional evidence that conformal coatings can be evaluated by the degree of corrosion protection they provide to the coated copper and silver films. The corrosion rates of metal thin films can be very effectively and accurately measured by the 4-point technique and by taking in to account the effect of temperature on film electrical resistance. The film temperature must be measured using a thermocouple with fine wires. The film electrical resistance corrected for temperature is inversely proportional to the film thickness remaining. The rate of decrease of remaining film thickness is the corrosion rate of the film and is used to characterize the corrosion protection provided by the conformal coating. Test environmental conditions in a modified iNEMI flowers of sulfur chamber at 40°C are aggressive enough for the conformal coating testing. The advantage of not using too aggressive conditions is that the degradation mechanism in the test is the same as that in the field. SMT007

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Karl's Tech Talk

Visiting Photochemical Machining

Karl Dietz
1941–2020

Article by Karl Dietz

Editor's note: This article was originally published by Karl Dietz as a column in 1998 and is being reprinted here with prior permission from the author.

Allow me to digress a little in this column from the theme of fine line printed wiring boards to the world of photochemical machining or "chemical milling." Some readers may consider this a rather obscure topic. However, this industry is worth studying since it has advanced technologies which it shares with PWB fabrication. This "niche technology," as the German title[1] implies, deals with very demanding precision requirements and fine geometries. During a recent visit to photochemical machining shops, I have seen more 2-3 mil (50-75 micron) feature work than in any "high tech" PWB shop.

Photochemical machining has steadily expanded into electronic packaging. Examples are lead frames[2], EMI shielding, and flexible circuits that require etching or plating of circuits as well as etching of Kapton® polyimide layers. This industry is using materials familiar to PWB fabricators, such as photoresists, developers, etchants, and strippers. Process equipment may be identical to PWB fabrication, but you might find more tank processing than conveyorized spraying, and there are industry-specific process alterations, such as "barrel" plating.

A 1996 survey of photochemical machining companies[3] showed that most of them had annual sales revenues in the range of $1-5 million (1997 survey: $1-10 million), which is quite low compared to PWB fabricators. For lack of volume and standardization, these niche businesses were barely in a position to drive the development of equipment, processes, or chemicals to serve their needs, but had to adopt and tailor offerings from suppliers of other, larger industries. It is therefore no surprise to find that owners of photochemical machining shops are colorful personalities who love to tinker and invent.

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2/3 of electronic industry companies have difficulty finding production workers.[1]

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[1] IPC. (2017). Findings on the Skills Gap in U.S. Electronics Manufacturing.

When it comes to photoresist applications in this industry one could be led to believe[4-6] that resists, specifically developed for photochemical machining, are widely in use but this has not been my experience. Most resists used in photochemical machining are also found in PWB shops. That is not to say that you will not find exotic resist species in this niche industry, even resist dinosaurs such as close cousins of what used to be Kodak's KPR.

Performance criteria for chemical milling photoresists are in many ways more demanding than those of PWB fabricators; there is a plethora of different substrates such as Alloy 42, beryllium copper, iron-nickel alloys, molybdenum, tungsten, Invar, and many more. The etching chemistries and etch conditions, which the resist must survive, are brutal. In addition to the more benign cupric chloride and the mainstream ferric chloride, you find mixtures of hydrofluoric and nitric acid which embrittle the resist, as well as very highly alkaline solutions of potassium ferrocyanide, which act like strippers on aqueous processable resists.

The etching chemistries and etch conditions, which the resist must survive, are brutal.

Resist Features

There are certain resist features which are highly valued by the photochemical milling industry:

- Good adhesion to a variety of metal substrates through aggressive etching or plating cycles. Since most surfaces are quite smooth and don't offer much mechanical interlocking at the resist metal interface, the chemical adhesion of the resist has to be very good.
- Resist flexibility/ductility. In some applications, the work piece is bent after resist lamination, and the resist has to follow the contours of the new shape without delaminating. It was also desirable that any resist overhang resulting from under-etch will not break off during processing and cause contamination.
- Conformation/flow. Many resist applications involve lamination over contoured surfaces, comparable to secondary imaging with solder mask over a circuitized surface, an application that requires good resist flow and conformation.
- "Thin" resist. The issue here is etching uniformity. Resist thickness affects the etch rate in narrow channels because it adds to the aspect ratio of the etch channel and impedes the fluid dynamics of etchant replenishment. Conversely, isolated resist features allow free etchant attack from both sides. The result is an image-pattern-dependent etch rate difference. Both can be minimized with thin resist.
- Clean stripping/no residual stain. Many photochemically machined products are decorative in nature, so a stained surface becomes a functional defect, not just a "cosmetic" nuisance. In this context it becomes apparent why this industry has a preference for a resist with a bleach-out ("photo-fugitive") image after exposure. Such bleaching upon exposure prevents dye staining on the surface of the etched metal. It also allows visual inspection of the metal feature under the protective resist coating.

Surface Preparation

Machine oils are the most common surface contaminant in this industry. Strongly alkaline cleaners at elevated temperatures (60°C) have proven to be very effective in removing surface oils. Alkaline cleaning is followed by a water rinse, an acid rinse, another water rinse, and a drying step. A "water break test" can be employed to judge the completeness of the cleaning step: a sheet of water across the surface will break up in water beads within less than thirty seconds if hydrophobic organics are present on the surface.

Electrochemical cleaning is commonly used to remove residual traces of contaminants. Depending on the type of metal, the surface is either cleaned anodically or cathodically.

Some metal surfaces, such as steel, can absorb hydrogen, especially during cathodic cleaning, which can lead to metallurgical defects. To drive off hydrogen, it is common practice to prebake the material for about 10 minutes at 120°C before resist lamination. This baking step has little to do with resist adhesion, except that it could generate surface oxides which might interfere with dry film adhesion.

Occasionally, "conversion coatings" are applied to the metal surface prior to resist lamination to enhance resist adhesion and etch quality. The following list gives examples. Compatibility with the resist should be evaluated in the selection of a specific conversion coating:

- Aluminum: Proprietary solutions from a variety of chemical suppliers
- Magnesium: 2-3% phosphoric acid at room temperature for about 30 seconds, followed by a rinse
- Nickel: 2-3% phosphoric acid at 70-80°C for 2-4 minutes, followed by a rinse
- Stainless Steel: 20% nitric acid at 65-70°C, followed by rinsing. Alternatively, heat to 260°C for 5 minutes and cool to room temperature
- Steel and Ni/Fe Alloys: 25% phosphoric acid at 70-80°C long enough to lightly phosphatize the alloy providing a slightly matte or dull finish
- Zinc: 2% phosphoric acid for 2-3 minutes at room temperature

Surface cleaning methods vary from metal to metal. Aluminum is typically degreased with an alkaline cleaner, followed by a sodium hydroxide microetch and an "etching smut" removal with nitric acid. This method is not applicable to anodized aluminum. Chromium finishes are cleaned with warm alkaline cleaners. Strong acid cleaning or reverse-current cleaning will attack this surface finish. Copper alloys and brass cleaning is similar to that practiced in PWB fabrication, but microetching or mechanical roughening may not be acceptable on all work pieces. Gold is normally alkali cleaned, followed by an acid dip to neutralize the surface. Stainless steel is cleaned with a hot alkaline cleaner, followed by acid (see above). Kovar/Alloy 42 can be cleaned in a similar fashion. Magnesium is degreased with a mild alkaline cleaner, rinsed, and dried. Pumice can be used if a matte finish is acceptable. Nickel is cleaned similarly, often followed by an acid "surface activation" step. Silver is pumiced for good resist adhesion if a matte surface is acceptable; otherwise use an alkaline soak cleaner followed by acid neutralization.

Surface cleaning methods vary from metal to metal.

Lamination of Dry Film Resists

Manual hot roll laminators are much more common than automatic sheet laminators. Specific lamination conditions are provided by the resist product data sheet. Wet lamination has been tried successfully to improve resist adhesion and conformation to stainless steel surfaces.

Development/ Etching/Stripping

These process steps are often done in tanks because of the small size of the work piece, small batch sizes, and the use of a variety of different chemistries which makes it impractical to set up conveyorized spray units for all these unit operations. Occasionally, environmental and health concerns dictate the use of tanks to avoid aerosols of chemicals such as HF in vented air due to spray action. I have seen resist development in tanks and in vertical or horizontal conveyorized spray units. Some tanks and vertical developers are relics from the era of solvent resist processing and give only marginal results with modern aqueous processable resists.

Control of the Production Environment

About cleanroom environment, temperature and humidity control, the effort is commensurate with the need for a particular end-use. One shop I visited has standards that exceed what is common in PWB fabrication in order to meet very stringent medical and aerospace requirements.

In summary, the photochemical machining industry is practicing and advancing PWB technologies as it is growing its product mix in the arena of advanced electronic packaging components with fine features and tight tolerances. This industry's traditional flexibility in handling a variety of products in small lot sizes with short lead times should be a real asset in the electronics arena. **SMT007**

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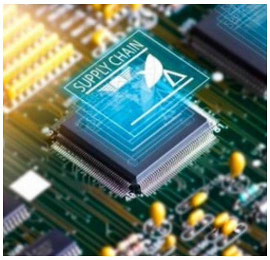
Dr. Karl Dietz had decades of experience in the chemical and electronic industries, and a well-known expert in material and process technology for printed circuit boards and substrates. He was an author and a columnist on PCB topics, as well. Karl passed away in 2020; he will be missed.

1 X-Rayted Files: Genius, Evil, or Evil Genius? ▶


Bill Cardoso

Apple dominates its market in many ways. Is this genius for the consumer, or does it effectively rule out any competition? Columnist Bill Cardoso debates its merits—and disadvantages for other players.

2 Industry CEOs Urge Action to Improve Electronics Manufacturing Ecosystem ▶



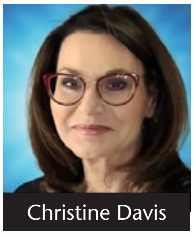
More than 50 CEOs urged Commerce Secretary Gina Raimondo to take concrete steps to address challenges confronting the entire U.S. electronics supply chain.

3 Why You Should Get Involved in IPC Standards Development ▶


Chris Jorgenson

From a business perspective, involvement in IPC standards is incredibly important. Usage of IPC's globally accepted standards creates a level playing field in the electronics supply chain. The playing field, however, is only as level as the participants who are involved in the development of a standard.

4 Her Voice: Protect the Family Jewels ▶


Christine Davis

There are many lessons to be learned in working with the bank to secure your business. Christine Davis shares some important truths about protecting your personal assets.

5 IPC Committees as an Emerging Engineer ▸


Jonathon Vermillion

We are extremely fortunate to have some of the industry leaders participating in our committees. We also try to make the documents easier to understand with simple wording, so it's easier to be translated and used globally.

6 TIM: Thermal Interface Material in Power Electronics ▸


Jeff Brandman

The omnipresent trend in power electronics for higher performance in smaller spaces requires a quick, effective, and cost-efficient heat transfer, within and out of, highly compact power modules. A well-designed, heat management concept from the beginning of a new design guarantees a longer lifetime of the electronic components and, by that, higher quality of the whole electronic power module.

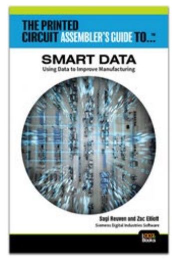
7 Omega EMS Acquires TeckQuest, Forms Subsidiary: Omega Green Power Corp (OGPC) ▸

OGPC is located within the facilities of Omega EMS in San Jose, Calif., and will leverage the existing Omega EMS expansive infrastructure and service platform which includes product design, materials and manufacturing solutions, and forward/reverse logistics flows.

8 SMTA Provides Spanish Language Support for Online Assembly Process Training ▸

The SMTA is proud to announce that most 101-level online training courses on assembly processes are currently available with captions for English and Spanish languages.

9 Excerpt: The Printed Circuit Assembler's Guide to... Smart Data ▸



IoT applications are gathering huge amounts of real-time, shop-floor data constantly but collecting data simply is not enough—it needs to be used intelligently. Analytics is the application of statistics and other mathematical tools to business data to assess and improve practices.

10 Jabil Selects Cogiscan for SMT Machine Connectivity to Accelerate Digital Transformation Strategy ▸

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Location: Portland, Oregon or USA (remote)

Job Number: 242982

Seeking a technology communications change maker! Siemens Digital Industries Software is looking for a content creator for its embedded software group. The ideal candidate for the Brand Marketing coordinator/writing strategist position will work closely with engineers and managers to write, edit and produce compelling technology marketing content (magazine articles, blogs, technology papers, multi-media, customer success stories and promotional materials). Do you possess creative energy and enjoy storytelling with an energetic team?

Requirements:

- Strong writing and editing skills
- Education and/or experience in technology, science, journalism and/or English
- A technical background or experience (such as a BS or an associate's degree in engineering or computer science) is preferred
- 1-3 years of experience in writing about technology solutions
- Basic knowledge of online publications, digital platforms and social media is useful to meet project specifications in a fast-paced environment
- Ability to research and collect data, repurpose existing materials, collaborate with subject matter experts, and translate technical information into compelling marketing communications content that engage audiences

Creative materials will be used globally, in a high-energy environment, supporting the world's leading industrial software company.

apply now

Career Opportunities

FirstPageSage

Technical Writer
(Full-time, Remote)

SEO company seeking a technical writer in the area of PCB design & manufacturing. We provide Search Engine Optimization and Thought Leadership services for well-managed, ethical companies. Our team produces high-level content for companies who are leaders in their industry. We are seeking writers who are well-rounded researchers with a particular interest in electrical engineering and impeccable writing skills.

Ideal candidates are seasoned writers with practical experience in electronic systems development in one or more of the following areas:

- Circuit simulation
- Schematic capture
- PCB layout
- Design analysis
- PCB fabrication
- PCB assembly
- PCB testing

Qualifications:

- Technical writing experience with a proven track record of independent research and content development. Experience in data sheet, report, or white-paper writing preferred.
- Electronic technician or engineering degree, ideally in electrical engineering, computer science, or mechanical engineering.
- Industry experience in PCB design, testing, or manufacturing.
- Punctuality, professionalism, and excellent time management skills.
- A reliable internet connection and computer

Salary & Benefits:

This is a full-time telecommuting position with a starting salary range of $62,000 to $68,000 annually. Benefits PTO, sick time, 401K, health and dental coverage, and more!

To see the full job description and apply, please click the link below.

apply now

Innovative Circuits, Inc.

Real Quality Is Innovative!

Multiple Positions

Innovative Circuits, a quick-turn, high mix, low-volume PCB manufacturer located in Alpharetta, Georgia, is growing and looking for talented individuals to join the team.

Front End Engineering Manager
Oversee CAM, programming/production engineering and quoting departments. Ideal candidates will have 15 years' experience working in a printed circuit board front-end department with flex and rigid flex circuit board construction.

Process Engineer
Responsible for the implementation and maintenance of chemical and/or mechanical processes used to produce flex circuits, rigid flex and rigid printed circuit boards.

Third Shift Production Manager
Oversee third shift productions workers, product schedule and reporting.

Wet Lab Tech
Perform all lab analysis using burettes, pipettes, pH/ion meters, atomic absorption spectrophotometer, laboratory balance, hydrometers, hull cells, CVS, and all other lab-related equipment.

CAM Operator
Inspect, modify, and contribute to the initial development of producing flex circuits, rigid flex and rigid printed circuit boards based upon customer requirements and data files.

Quality Inspector
Responsible for verifying that the product meets customer requirements prior to shipping.

Wastewater Technician
Operate, monitor, maintain and troubleshoot the wastewater treatment facility and its processes.

Production Worker
Machine operator and light chemistry in a PCB manufacturing environment.

Please visit the link below to view our opportunities and apply.

apply now

Career Opportunities

MivaTek Global

Product Manager

MivaTek Global is preparing for a major market and product offering expansion. Miva's new NG3 and DART technologies have been released to expand the capabilities of Miva's industry-leading LED DMD direct write systems in PCB and Microelectronics. MivaTek Global is looking for a technology leader that can be involved guiding this major development.

The product manager role will serve as liaison between the external market and the internal design team. Leadership level involvement in the direction of new and existing products will require a diverse skill set. Key role functions include:

- **Sales Support:** Recommend customer solutions through adaptions to Miva products
- **Design:** Be the voice of the customer for new product development
- **Quality:** Verify and standardize product performance testing and implementation
- **Training:** Conduct virtual and on-site training
- **Travel:** Product testing at customer and factory locations

Use your 8 plus years of experience in either the PCB or Microelectronic industry to make a difference with the leader in LED DMD direct imaging technology. Direct imaging, CAM, AOI, or drilling experience is a plus but not required.

For consideration, send your resume to N.Hogan@MivaTek.Global. For more information on the company see www.MivaTek.Global or www.Mivatec.com.

apply now

MivaTek Global

Field Service Technician

MivaTek Global is focused on providing a quality customer service experience to our current and future customers in the printed circuit board and microelectronic industries. We are looking for bright and talented people who share that mindset and are energized by hard work who are looking to be part of our continued growth.

Do you enjoy diagnosing machines and processes to determine how to solve our customers' challenges? Your 5 years working with direct imaging machinery, capital equipment, or PCBs will be leveraged as you support our customers in the field and from your home office. Each day is different, you may be:

- Installing a direct imaging machine
- Diagnosing customer issues from both your home office and customer site
- Upgrading a used machine
- Performing preventive maintenance
- Providing virtual and on-site training
- Updating documentation

Do you have 3 years' experience working with direct imaging or capital equipment? Enjoy travel? Want to make a difference to our customers? Send your resume to N.Hogan@MivaTek.Global for consideration.

More About Us

MivaTek Global is a distributor of Miva Technologies' imaging systems. We currently have 55 installations in the Americas and have machine installations in China, Singapore, Korea, and India.

apply now

Career Opportunities

Sheldahl®

A Flex Company

Sheldahl, a leading provider of flexible interconnect products and electronic materials, is seeking candidates to join their diverse and skilled team.

We are looking for people who demonstrate:

- Intense collaboration
- Passionate customer focus
- Thoughtful, fast, disciplined execution
- Tenacious commitment to continuous improvement
- Relentless drive to win

Positions in America include:

Project Manager – Northfield, MN
Candidate will provide timely cost estimation and project budget definition, be responsible for maintaining customer relations, participate in meetings, etc.

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Program Manager – Specialty Films
Candidate will work with our Specialty Films in the Aerospace, Medical, and Commercial Aviation markets providing timely cost estimation and project budget definition, maintaining customer relations, participate in meetings, etc.

apply now

Business Development Manager – North America
Candidate will provide leadership in the planning, design and implementation of customers' specific business plans and will provide vision, penetration strategies and tactics to executive managers in order to develop and drive external and internal senior-level relationships.

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Sheldahl®

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Sheldahl, a leading provider of flexible interconnect products and electronic materials, is seeking candidates to join their diverse and skilled team.

We are looking for people who demonstrate:

- Intense collaboration
- Passionate customer focus
- Thoughtful, fast, disciplined execution
- Tenacious commitment to continuous improvement
- Relentless drive to win

Positions in Europe include:

Business Development Manager — France
Seeking out-of-the-box thinkers to help us take the ordinary to the extraordinary by cultivating current customer relationships and developing new business opportunities with our European team, based in France.

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Business Development Manager — Germany
Seeking out-of-the-box thinkers to help us take the ordinary to the extraordinary by cultivating current customer relationships and developing new business opportunities with our European team, based in Germany.

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Career Opportunities

Career Opportunities

Career Opportunities

Now Hiring

Director of Process Engineering

A successful and growing printed circuit board manufacturer in Orange County, CA, has an opening for a director of process engineering.

Job Summary:

The director of process engineering leads all engineering activities to produce quality products and meet cost objectives. Responsible for the overall management, direction, and coordination of the engineering processes within the plant.

Duties and Responsibilities:

- Ensures that process engineering meets the business needs of the company as they relate to capabilities, processes, technologies, and capacity.
- Stays current with related manufacturing trends. Develops and enforces a culture of strong engineering discipline, including robust process definition, testing prior to production implementation, change management processes, clear manufacturing instructions, statistical process monitoring and control, proactive error proofing, etc.
- Provides guidance to process engineers in the development of process control plans and the application of advanced quality tools.
- Ensures metrics are in place to monitor performance against the goals and takes appropriate corrective actions as required. Ensures that structured problem-solving techniques are used and that adequate validation is performed for any issues being address or changes being made. Develops and validates new processes prior to incorporating them into the manufacturing operations.
- Strong communication skills to establish priorities, work schedules, allocate resources, complete required information to customers, support quality system, enforce company policies and procedures, and utilize resources to provide the greatest efficiency to meet production objectives.

Education and Experience:

- Master's degree in chemical engineering or engineering is preferred.
- 10+ years process engineering experience in an electronics manufacturing environment, including 5 years in the PCB or similar manufacturing environment.
- 7+ years of process engineering management experience, including 5 years of experience with direct responsibility for meeting production throughput and quality goals.

apply now

Now Hiring

Process Engineering Manager

A successful and growing printed circuit board manufacturer in Orange County, CA, has an opening for a process engineering manager.

Job Summary:

The process engineering manager coordinates all engineering activities to produce quality products and meet cost objectives. Responsible for the overall management, direction, and coordination of the engineering team and leading this team to meet product requirements in support of the production plan.

Duties and Responsibilities:

- Ensures that process engineering meets the business needs of the company as they relate to capabilities, processes, technologies, and capacity.
- Stays current with related manufacturing trends. Develops and enforces a culture of strong engineering discipline, including robust process definition, testing prior to production implementation, change management processes, clear manufacturing instructions, statistical process monitoring and control, proactive error proofing, etc.
- Ensures metrics are in place to monitor performance against the goals and takes appropriate corrective actions as required. Ensures that structured problem-solving techniques are used and that adequate validation is performed for any issues being address or changes being made. Develops and validates new processes prior to incorporating into the manufacturing operations

Education and Experience:

- Bachelor's degree in chemical engineering or engineering is preferred.
- 7+ years process engineering experience in an electronics manufacturing environment, including 3 years in the PCB or similar manufacturing environment.
- 5+ years of process engineering management experience, including 3 years of experience with direct responsibility for meeting production throughput and quality goals.

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Career Opportunities

LENTHOR ENGINEERING
MAKING THINGS FLEXIBLE IN A RIGID WORLD®

Sales Account Manager

Sales Account Management at Lenthor Engineering is a direct sales position responsible for creating and growing a base of customers that purchase flexible and rigid flexible printed circuits. The account manager is in charge of finding customers, qualifying the customer to Lenthor Engineering and promoting Lenthor Engineering's capabilities to the customer. Leads are sometimes referred to the account manager from marketing resources including trade shows, advertising, industry referrals and website hits. Experience with military printed circuit boards (PCBs) is a definite plus.

Responsibilities

- Marketing research to identify target customers
- Identifying the person(s) responsible for purchasing flexible circuits
- Exploring the customer's needs that fit our capabilities in terms of:
  - Market and product
  - Circuit types used
  - Competitive influences
  - Philosophies and finance
  - Quoting and closing orders
  - Providing ongoing service to the customer
  - Develop long-term customer strategies to increase business

Qualifications

- 5-10 years of proven work experience
- Excellent technical skills

Salary negotiable and dependent on experience. Full range of benefits.

Lenthor Engineering, Inc. is a leader in flex and rigid-flex PWB design, fabrication and assembly with over 30 years of experience meeting and exceeding our customers' expectations.

Contact Oscar Akbar at: hr@lenthor.com

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LENTHOR ENGINEERING
MAKING THINGS FLEXIBLE IN A RIGID WORLD®

Senior Process Engineer

Job Description

Responsible for developing and optimizing Lenthor's manufacturing processes from start up to implementation, reducing cost, improving sustainability and continuous improvement.

Position Duties

- Senior process engineer's role is to monitor process performance through tracking and enhance through continuous improvement initiatives. Process engineer implements continuous improvement programs to drive up yields.
- Participate in the evaluation of processes, new equipment, facility improvements and procedures.
- Improve process capability, yields, costs and production volume while maintaining safety and improving quality standards.
- Work with customers in developing cost-effective production processes.
- Engage suppliers in quality improvements and process control issues as required.
- Generate process control plan for manufacturing processes, and identify opportunities for capability or process improvement.
- Participate in FMEA activities as required.
- Create detailed plans for IQ, OQ, PQ and maintain validated status as required.
- Participate in existing change control mechanisms such as ECOs and PCRs.
- Perform defect reduction analysis and activities.

Qualifications

- BS degree in engineering
- 5-10 years of proven work experience
- Excellent technical skills

Salary negotiable and dependent on experience. Full range of benefits.

Lenthor Engineering, Inc. is the leader in Flex and Rigid-Flex PWB design, fabrication and assembly with over 30 years of experience meeting and exceeding our customers' expectations.

Contact Oscar Akbar at: hr@lenthor.com

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Career Opportunities

Career Opportunities

BLACKFOX
Premier Training & Certification

IPC Instructor

Longmont, CO; Phoenix, AZ; U.S.-based remote

Independent contractor, possible full-time employment

Job Description

This position is responsible for delivering effective electronics manufacturing training, including IPC Certification, to students from the electronics manufacturing industry. IPC instructors primarily train and certify operators, inspectors, engineers, and other trainers to one of six IPC Certification Programs: IPC-A-600, IPC-A-610, IPC/WHMA-A-620, IPC J-STD-001, IPC 7711/7721, and IPC-6012.

IPC instructors will conduct training at one of our public training centers or will travel directly to the customer's facility. A candidate's close proximity to Longmont, CO, or Phoenix, AZ, is a plus. Several IPC Certification Courses can be taught remotely and require no travel.

Qualifications

Candidates must have a minimum of five years of electronics manufacturing experience. This experience can include printed circuit board fabrication, circuit board assembly, and/or wire and cable harness assembly. Soldering experience of through-hole and/or surface-mount components is highly preferred.

Candidate must have IPC training experience, either currently or in the past. A current and valid certified IPC trainer certificate holder is highly preferred.

Applicants must have the ability to work with little to no supervision and make appropriate and professional decisions.

Send resumes to Sharon Montana-Beard at sharonm@blackfox.com.

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APCT
Passion | Commitment | Trust

APCT, Printed Circuit Board Solutions: Opportunities Await

APCT, a leading manufacturer of printed circuit boards, has experienced rapid growth over the past year and has multiple opportunities for highly skilled individuals looking to join a progressive and growing company. APCT is always eager to speak with professionals who understand the value of hard work, quality craftsmanship, and being part of a culture that not only serves the customer but one another.

APCT currently has opportunities in Santa Clara, CA; Orange County, CA; Anaheim, CA; Wallingford, CT; and Austin, TX. Positions available range from manufacturing to quality control, sales, and finance.

We invite you to read about APCT at APCT.com and encourage you to understand our core values of passion, commitment, and trust. If you can embrace these principles and what they entail, then you may be a great match to join our team! Peruse the opportunities by clicking the link below.

Thank you, and we look forward to hearing from you soon.

apply now

Career Opportunities

Pre-CAM Engineer

Illinois-based PCB fabricator Eagle Electronics is seeking a pre-CAM engineer specific to the printed circuit board manufacturing industry. The pre-CAM Engineer will facilitate creation of the job shop travelers used in the manufacturing process. Candidate will have a minimum of two years of pre-CAM experience and have a minimum education level of an associate degree. This is a first-shift position at our Schaumburg, Illinois, facility. This is not a remote or offsite position.

If interested, please submit your resume to HR@eagle-elec.com indicating 'Pre-CAM Engineer' in the subject line.

apply now

Process Engineer

We are also seeking a process engineer with experience specific to the printed circuit board manufacturing industry. The process engineer will be assigned to specific processes within the manufacturing plant and be given ownership of those processes. The expectation is to make improvements, track and quantify process data, and add new capabilities where applicable. The right candidate will have a minimum of two years of process engineering experience, and a minimum education of bachelor's degree in an engineering field (chemical engineering preferred but not required). This is a first shift position at our Schaumburg, Illinois, facility. This is not a remote or offsite position.

If interested, please submit your resume to HR@eagle-elec.com indicating 'Process Engineer' in the subject line.

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TRAIN. WORK SMARTER. SUCCEED.

Become a Certified IPC Master Instructor

Opportunities are available in Canada, New England, California, and Chicago. If you love teaching people, choosing the classes and times you want to work, and basically being your own boss, this may be the career for you. EPTAC Corporation is the leading provider of electronics training and IPC certification and we are looking for instructors that have a passion for working with people to develop their skills and knowledge. If you have a background in electronics manufacturing and enthusiasm for education, drop us a line or send us your resume. We would love to chat with you. Ability to travel required. IPC-7711/7721 or IPC-A-620 CIT certification a big plus.

Qualifications and skills

- A love of teaching and enthusiasm to help others learn
- Background in electronics manufacturing
- Soldering and/or electronics/cable assembly experience
- IPC certification a plus, but will certify the right candidate

Benefits

- Ability to operate from home. No required in-office schedule
- Flexible schedule. Control your own schedule
- IRA retirement matching contributions after one year of service
- Training and certifications provided and maintained by EPTAC

apply now

Career Opportunities

U.S. CIRCUIT

Sales Representatives (Specific Territories)

Escondido-based printed circuit fabricator U.S. Circuit is looking to hire sales representatives in the following territories:

- Florida
- Denver
- Washington
- Los Angeles

Experience:

- Candidates must have previous PCB sales experience.

Compensation:

- 7% commission

Contact Mike Fariba for more information.

mfariba@uscircuit.com

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YOUR JOB AD HERE

For information, please contact:
BARB HOCKADAY
barb@iconnect007.com
+1 916.365.1727 (PACIFIC)

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CREATIVE TECHNOLOGIST: **BRYSON MATTIES**

COVER: **SHELLY STEIN**

COVER IMAGE: **ADOBE STOCK** © **EDB3_16**

SMT007 MAGAZINE

SMT007 MAGAZINE®
is published by BR Publishing, Inc.,
942 Windemere Dr. NW, Salem, OR 97304

July 2021, Volume 36, Number 7
SMT007 MAGAZINE is published monthly,
by BR Publishing, Inc.

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