I-Connect007

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PCB007 MAGAZINE

THE FOUR PILLARS OF MANUFACTURING


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PCB007 MAGAZINE

The Four Pillars of Manufacturing

We identified four manufacturing pillars: revenue, supply chain, workforce, and technology. In this issue, we examine these four pillars as strategies that affect the manufacturing floor. But in the process, something interesting emerged: the pillars don't stand on their own.

FEATURES:

FEATURE COLUMNS:

Edited by Happy Holden

PCB007 MAGAZINE

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The Four Pillars of Manufacturing

Nolan's Notes

by Nolan Johnson, I-CONNECT007

Last month, we looked at leadership, which was a philosophy-based theme, yet we focused on discussions and examples that are pertinent to our industry. The truth is that leadership is the foundation of a successful business. With leadership in place, the pillars of manufacturing can stand on a solid platform.

For this issue, we identified four pillars: revenue, supply chain, workforce and technology. Our goal was to examine these four pillars as strategies that affect what happens on the manufacturing floor. As we discussed these pillars with our experts, something interesting emerged: The pillars don't stand on their own. Rather, they're intertwined.

This became clear when I talked with Happy Holden. Happy was adamant that to make all four pillars function properly in your business, you first need to benchmark your business and then create a roadmap. According to Happy, the roadmap identifies the specific functions required from all four pillars. Furthermore, Happy maintains the opinion that each pillar supports the others. As you read along in our conversation, you'll see that he's right.

I also spoke with Tim Rodgers on costs and expenses. Tim quickly leveled his sights on the supply chain. He made the point that proper supply chain management influences not only cost containment, but also business optimization. In our conversation, Tim made a number of points regarding the current and future state of the supply chain or supply web. I got the sense that taking a holistic approach to procurement exerts a strong influence on sales, marketing, engineering, and manufacturing. Tim's points were backed up, in part, by iNEMI's recent Electronics Goes Green Conference that went virtual (read the report on the conference by Pete Starkey here), wherein materials regulations, data

collection in the supply chain, and increasing materials recycling content were among the top five high-priority gaps identified in the move toward environmental sustainability.

There were so many directions we could have taken with respect to manufacturing technology, but we focused on just one for this issue: inkjet technology. Garrett Harding from MicroCraft talks about advances in inkjet applications in PCB fabrication. Of course, it struck me that from an equipment supplier's point of view, their revenue pillar enabled their customer's technology pillar, expenses pillar, and even their labor pillar. Ultimately, those three changes should and could improve the customer's sales numbers as well. Not on its own, which Happy had already reminded me, the equipment needs to be in alignment with an overall business improvement roadmap.

The ongoing challenge with staffing and labor gets attention in a conversation with Blackfox. Al Dill and the team discuss the ROI equation for training. Employers continue with the struggle to find trained (or trainable) staff for production. Interestingly, it doesn't stop there. I've spoken to more than one senior director or owner who has lamented that experienced senior-level technical folks simply cannot be found in the U.S., forcing these employers to look overseas for candidates. That shortage of critical knowledge will have a throttling effect on industry growth. The insight from Blackfox, therefore, is of extreme strategic importance to maintaining key staffing skill sets. After all, skilled staff make for efficient operations, lower costs, and increased profitability.

This brings us full circle to our conversation with Happy Holden. The roadmap holds all the pillars together. The pillars may stand on their own, but when connected and supported by the foundation of leadership, and stitched together by the capstone of the roadmap, the pillars become stronger together than when they are separate.

As always, we strive to move the conversation of the industry forward. We welcome your feedback, responses, comments, and submissions. We're here to bring together the meaningful topics in PCB manufacturing. We welcome your feedback! Better yet, let us know what you'd like to submit to the conversation. **PCB007**

Nolan Johnson is managing editor of *PCB007 Magazine*. Nolan brings 30 years of career experience focused almost entirely on electronics design and manufacturing.
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The Pillar Roadmap

Feature Interview by Nolan Johnson
I-CONNECT007

As I spoke with Happy Holden about the four pillars of manufacturing, it became clear that they don't stand on their own; they are intertwined. Happy pulls from his experience at Hewlett-Packard as he discusses benchmarking your capabilities, the competition, and market forces. He then turns that into a technology roadmap, which further drives the other pillars. Happy is adamant that to make all four pillars function properly in your business, you first need to benchmark your business and then create a roadmap. He says the roadmap identifies the specific functions required from the four pillars, and how each pillar supports the others.

Nolan Johnson: We're examining the four pillars of manufacturing from a strategic level. I know that you will have comments on all four of the pillars: sales and revenue, technology, labor and skill set, and cost supply chain. But let's start by concentrating on the technology and equipment portion. There is a lot of potential innovation just over the horizon for plating and PCB fabrication. How do you strategize for that in this current day and age?

Happy Holden: I always come back to the basics. First, where does a company sit in a competitive position? That usually happens by benchmarking. Are you where you want to be, and is your position going to create a profit margin for a competitive advantage that you can build on? This competitive advantage will support your current customers and bring future customers. Take an honest look at where you are. Are your competitive positions and strengths there for survival?

To stay in business and grow profits, do your research. Do you want to jump in with everybody else—such as an area dominated by Asia or those that have a lot of capital equipment—or do you want to jump to a growing area that requires specialization, in which you have a chance of bouncing to the top and gaining the profit margin you want? Once you determine your strategic visions, then you develop a roadmap. Now, how much will the roadmap cost? How much sales growth do you need at particular profit margins to support that roadmap? Next, your salespeople

must present this vision—this is who we are, this is our strength, and this is the direction we feel matches your product development growth and needs, etc.

Most companies can't afford to build a brand-new greenfield plant, but it can have some strengths, weaknesses to improve on, and incrementally, you can get to that position that you're comfortable with. This industry changes so fast, so you need to do this exercise every three to four years. Electronics, products, and semiconductors change so much. Just look at heterogeneous integration. That particular roadmap goes out to 2035 because the semiconductor companies are going to spend billions of dollars. To support this electronics industry, you have to support how that will be implemented in terms of OEMs' products.

Electronics, products, and semiconductors change so much. Just look at heterogeneous integration.

Johnson: I'm hearing the advice to pick your niche, make a strategic decision on what you're going to specialize in, how you're going to present yourself out there in the marketplace, and then roadmap.

Holden: To benchmark, you need to address what your strengths and weaknesses are and the advantages of each. With those traits outlined, then you can create a roadmap to enhance your advantages, plug holes, and minimize your weaknesses—what we call tactical planning and strategic planning.

Johnson: Let's talk about how—at the strategic level first—one should approach acquiring equipment. In benchmarking, you found out what your capabilities were and identified some gaps that will require some new capital investment. What's next?

Holden: You look at what the investment is going to cost in terms of the profitability to support that investment over the next couple of years. If you don't, then you step back and say, "Why aren't my profits higher?" And by that time, it may come down to talking about waste. Are your yields 99%? If not, what are they? If you raise your yield 10%, how much does that add to the profitability to support the roadmap? Are there other ways to increase productivity, such as materials? Most of the time, it comes down to yield. The biggest loss is what we can't ship.

Johnson: That almost sounds like that's a preparatory step for doing your roadmap: Looking at the actual performance you're getting out of your current processes.

Holden: I hope that would be part of the current assessment of strengths, weaknesses, and advantages. If one of your competitive advantages is that you have much higher yields than everybody else in the industry, that's important. If you have much higher quality, there are fewer returns. That total cost of quality for you is lower, and you know how to show that to customers in terms of the sales pitch. Everybody can say, "We have top quality," but you need to boil that down into figures or numbers to demonstrate it to future clients.

I went to the HP sales school. The company knew they had the highest-priced equipment, yet they survived with record growth and profits. Part of it was that in the sales school, we didn't compete on price. If we reduced to compete on price, we were at the bottom end of the very intelligent customers. They taught us how to sell on the total system cost, the total cost to quality, and the reliability of a product. HP was always successful, even though they had the highest-priced solution. They had the best solution for whatever the mission might have been.

Sitting through the same sales training that the rest of the people sat through was an eye-opener about how HP designed products and sold them. HP had 52 product divisions, including a sales division, and no product division got to sell its product. They invented the product, then designed, built, and manufactured it. Then, the sales division sold it worldwide. The interface to the customers was always the same, no matter what product line they sold. They were a separate organization not controlled by the Divisional people who invented the product. They were engineers but professionally trained in selling and at the right level, in the right moment.

Also, everyone spent two or three years in sales support engineering before they got promoted to sales. In the sales office, a new engineer would come in, and for a couple of years, they would be the technical support. They were in the field before they moved up to being a salesperson.

Happy Holden

Johnson: HP is a large organization that turned out to be very successful at selling technology. A few companies that I've worked for have modeled their sales organizations after HP. Many of the people who set up those sales organizations brought prior experience at HP with them. Those sales teams were very successful. Does that model still fit when you're a $20-million-a-year PCB fabricator in North America, for example?

Holden: Some of the basic principles do. As long as you sell a competitive product that has quality and reliability, then it's there. If you don't have quality and reliability, then you're forced to compete on cost, and there are so many people. It will be beaten down to really low margins. If you have low margins, then you don't necessarily have a lot to invest in the future with.

Johnson: It becomes a downward spiral.

Holden: The HP model worked until the end of my career, and then it utterly failed when I got into the software business side of HP. We went down in flames a number of times because the volume of the sales was such a paradigm shift from selling voltmeters, hardware, and computers. When we trained people to sell software and software solutions, it went poorly because they couldn't adapt the hardware model to a software model. We wasted hundreds of millions of dollars of investment—including a career I had invested five to seven years of my life into—and I had to find another job inside of HP. We looked at our potential customers and the computers they used. One-third used HP computers, one-third used DEC VAX computers, and one-third used IBM computers. We had to sell to all of them.

We created software such that it didn't matter what computer they had. We gave them the version that would sit on top of a VAX or IBM because no customer was going to change all of their hardware, IT resources, support, etc. But the sales vice president would not allow anybody to sell HP software if it did not run on an HP computer. We went blue in the face trying to convince him that that's not the software sales model. That limited us to one-third of the market rather than the full market. If we were only focused on one-third of the market, we weren't going to be profitable enough in the long-run compared to our competitors; they were going to allow their software to run on any of the major systems. There was so much momentum and investment put in just to abandon it and use HP software.

Johnson: But there's also the long-range game, meaning that once they ran HP software, they were more likely to choose HP hardware when it came time to upgrade.

Holden: That's what we told him, but no. He would not allow his people to sell something that enhanced the competitors' computers. He was looking at it the wrong way. If they paid for our software, he shouldn't worry about what computer it runs on. He insisted that they have to switch to HP. He destroyed hundreds of millions of dollars, and my division head dissolved the division. Rather than have a profitable future, they cut our losses, dissolved the engine, and got out of the software business.

Unfortunately, I had to tell a bunch of customers that we were discontinuing the software they had bought from us, but HP in Japan would not obsolete the product. They continued to enhance the product and support it only in Japan. They could not face going to their customers and telling them, "Remember all that good stuff we told you and how great we said it would be? We're going out of business and leaving you high and dry." They weren't going to fall on their sword over that.

To the rest of the world, we told people, "We're dropping out." We didn't want to tell them why we were dropping out. When that VP retired and somebody came in who understood, HP started being successful in the software business. Until that time, we invested money, didn't do so well, threw it all away, and started over.

When the board of directors looked at HP's singular focus, and things became too complicated, they chopped it up. In 2000, they created Agilent. That move took away all the business costs of HP's test and measurement products and put in a separate, totally new company. We were getting to have so many products with so many divisions that all the products were being funneled through that one sales organization. It was really difficult to manage the complexity, and it was easier to form a company with its own board of directors and infrastructure.

Johnson: It sounds like the moral of that story is "pick your niche." If you find out that your niche is too large, spin off a company to work on that particular niche.

Holden: They didn't have to buy anything; they already had it. But they spun the niche off so that the people in charge who were planning and managing day-to-day activity knew their customers, their competitive advantage, and how to build it. Being spread out too thin doesn't give the proper amount of time and focus on them. For HP, the computer and networking products were getting all the focus, and the board of directors complained they spent 5% of their time on test and measurement and 95% of their time on computer and networking issues. That wasn't fair to the whole of measurement and test. Measurement and test needed their own board of directors that was 100% focused on those customers, not 5% focused.

Johnson: That example certainly works as well in a smaller business in fabrication, too.

Holden: The fun thing about printed circuits is we never seem to obsolete anything, even over the last 60 years, but we keep adding new stuff all the time. In printed circuits, you could get spread too thin by trying to be a job shop for everybody, and you don't do anything really well because you are so diverse.

Johnson: Isn't the risk that you are betting your company and your company's future on that specific area of specialization that you choose? That's a scary proposition. You could pick well and create a very successful space for yourself competitively, or you could pick a technology that looks like it has promise, doesn't get adopted, and then you're stuck in a backwater. Those are some risks to try to manage. How does one approach that?

Holden: At first, HP just dropped the business. Later, they got a little smarter. They said, "We have the top technological solution. The only reason that we can't be successful is we don't

have the right selling strategy." Toward the end, when HP was faced with that, it spun the company off and became a major stockholder in an autonomous legal entity company, where it could make up its own rules. That proved successful. You couldn't change HP for one reason or another. The company didn't throw away what they had. They spun it, gave it a new name, and let them continue to work on their core competencies not hindered by company history. That proved to be successful with Agilent and HP.

If you look at some of these most successful companies, they are former HP product managers. If their product didn't get the approval of HP, but they were sure it was going to be successful, they asked if they could take the product and make it under their own name or a new name. HP said, "Sure, because you're going to sell it." Many times, these projects were personally financed by HP. People thought these entrepreneurs were creating companies that competed against HP, not knowing they were HP products that the company decided not to sell for one reason or the other.

I saw that over and over again because I worked on the prototypes. HP decided not to go into that business because it didn't match our test, measurement, or computer core competencies. For example, a project manager I worked with at HP asked if he could form his own company using a prototype and got their blessing. They learned not to throw stuff away but to rebrand it or repackage it, put another name on it, and then keep its vintage a secret. People didn't realize that it was an HP technology with a different brown wrapper around it and a different name.

Johnson: For any PCB fabrication company looking to expand and grow, is it better to aim for a smaller specialty niche that's high profit, or go for larger volume and narrower margins?

Holden: It depends on how good you are at your financial connection with banks or investors because if you're going to go volume, you're going to need money. If you want to get close to your product and customer, then staying smaller-focused is better. If you have trouble, hire people who are smarter than you are, who do this for a living, to help you find out which path is best for you. How many years do you want to work? Is this a family business, or is this going to become a corporation? What are the long-term goals?

You have to do it fast. This is a really fast-moving industry, and the technologies keep cropping up. Look at VeCS, for example. It potentially offers higher density and lower cost. That's the kind of thing that we'd look at. We'd say, "Is this what I need to compete with the big companies that have lasers? I don't have money for all these laser drills. With this technology, I can do the same kind of density as them without buying laser drills and have higher reliability, etc."

Johnson: Part of your benchmarking process is figuring out what you can't do. If you want to get into higher density work, but you don't necessarily have the tools nor the investment and capital for tools, then working with an alternative that can be done with a lot of the existing mechanical tools is an incremental step into higher-margin product.

Holden: That's what I mean by benchmarking or technology awareness. Have you kept your head up to see what's going on? If you haven't, talk to an expert who has. Who's the best at crystal ball gazing in terms of what electronics are going to do in the future?

Johnson: Before you start the roadmap, not only do you need to benchmark your capabilities, but you also need to analyze the technologies to know the emerging technologies to pay attention to. Your decision may be to stand pat with exactly what you're doing, or you may decide to step into some new technologies and add new capabilities. Then, you can roadmap it.

Holden: If your self-assessment is that your yield loss is 80% due to scratches and handling errors, then you realize, "I have to minimize handling. Should I buy conveyors? Is this a matter of retraining people? Should I install inexpensive pieces of plastic between the panels? What is a handling error, and should I simplify my process?" One North American company has 40% fewer processes to make the same multilayer than everybody else in the world. That is a great way to improve productivity, yield, space utilization, chemistry, water, etc.

Take an honest look at these four pillars on a scale from 1-10 for this pillar, and ask, "Where am I? Am I near a one or a 10?" The higher your performance on each pillar, probably the better your margins and the return on assets and return on time, etc. I'm a big believer in metrics and measures of performance. Again, look at the four pillars, rate them on a 1–10 scale on the pillars, and then rank them.

Consider how your main competitors rank as well. If I'm losing orders to other companies, then rank them on the four pillars. That's what we famously called our radar diagram. It looks like radar, but each axis coming out of the center is a different pillar of performance. There's where you are, where your competitors are, and where your roadmap says you should be. That gives you a visual clue that your roadmap has to run along this path.

Johnson: Let's pivot for a minute. As a fabricator, I've gone through the process. I have my roadmap. It's a working document, and I know it's going to evolve over time. I'm working to reposition my company and be more competitive. I have to start getting tactical. How do I use my roadmap as a tool for getting the equipment that I need?

Holden: Within the roadmap is the needs, efforts that it takes for implementation, along with the resources. As you detail elements of the roadmap, if it involves capital equipment, not only do you go to places like SMTA-I, IPC APEX EXPO, productronica, and CPCA, but you walk the aisles and have a list of what you need in terms of equipment and how you can afford to pay. You have specific questions and look to see what's available or what's close to what you need. Talk to the people and tell them, "I need this. Your machine is almost there. Is it possible to make a modification? Here's why."

Johnson: As you map out the workflow, you also have to work on the technology roadmap as you talk to equipment suppliers.

Holden: You have to benchmark and look at the best practices and solutions. That information drives new hardware equipment. Features on PCBs keep getting smaller and smaller, and there's only so much you can do with the equipment. Eventually, you have to make a radical change, which keeps coming back to money. For the life of me, I can't figure out why there's an endless supply of money available for PCB equipment in Asia, but not in North America.

For the life of me, I can't figure out why there's an endless supply of money available for PCB equipment in Asia, but not in North America.

Johnson: If you're using it right, the roadmap becomes a tool that you can use to talk to your financiers, bank, and investors.

Holden: Do I need new engineers to have this equipment or this new process? Do I need to upscale my existing engineers by sending them to some industry classes? One of the classes HP sent me to in New Jersey was a three-day course on liquid-liquid extraction. I came back and developed our etchant recovery and regeneration scheme, which we patented. I wouldn't have done it if HP hadn't sent me to a postgraduate course on liquid extraction.

Johnson: The roadmap also helps drive one of the other pillars: your staffing, skill set, and the expertise that you put on your team. It gives you a chance to plan and staff with the people you need when you need them.

At this point, we've discovered that the roadmap helps with technology and equipment from the manufacturing floor. We've discussed that the roadmap also helps you drive your staffing and skill set. We've previously discussed that your roadmap becomes a key part of the story that your salespeople tell your customers about why they want to have a long-term relationship with you.

Holden: An important thing for both management and sales is forming partnerships with customers so that the customers share their product roadmap. You can look at what they think is going to make them successful, and then step back—which is what you'd call quality function deployment. QFD needs to develop, which is the voice of the customer. If your sales and management teams are listening to your customers, and they want to grow and be successful, they're going to have new ideas about products. How does the PCB and assembly support the need for that technology? Using a technique like QFD, you can take their product and algorithmically turn it into board or assembly performance. HP found nothing better than QFD at interpreting your customer's goals into a process, as well as your manufacturing goals, and how to translate them.

If your sales and management teams are listening to your customers, and they want to grow and be successful, they're going to have new ideas about products.

Johnson: We touched on this when we discussed yield as a source for increased profit margin, but the one pillar we haven't talked about in great detail yet with regard to the benchmarking and roadmapping process is costs and supply chain.

Holden: Companies that recycle chemicals and water have an enormous advantage in terms of cost. Rather than throwing good chemicals away and paying money to have them destroyed in waste treatment, consider recycling and regenerating chemicals, as well as recycling water. The only other important direct material in PCB fabrication is the laminate. You get the copper for free when you buy the laminate because you etch the copper off that, and that's pure copper. If you can take it, recover it, and put it back in the plating bath, you've just gained a lot in cost reduction!

Johnson: Regardless of where my technology roadmap takes me in the quest for new capabilities, as a manufacturer I should pay attention to the chemical side of my business and ensure it's as efficient as possible.

Holden: The fundamentals are about all the things that you buy, and what happens next. Do you have to pay to get rid of them? For example, you pay to get rid of laminate because it's shipped as your product. But if you buy dry film or photoresist, you put it down and then take it off. You have to buy it, apply it, throw it away, and treat it. Costs and yields are going to jump out at you. The biggest piece of the pie is waste, not just in terms of yield; there is other waste because you have to buy photoresist and then throw it away.

One change could be not to throw anything away; instead, you could take a neutral dried effluent cake to the landfill. It's not toxic and it doesn't emit water. You may have to buy water if you run things at a higher temperature, and there's evaporation, but no more than anything else is consumed. The only thing that would leave the factory would be the product and the dried cake that you don't have to pay for; it would just go to the dump.

It's about looking at costs and finding opportunities. And the less cost you have, if you have the right product characteristics, then you have a selling price and the difference is your margin. That's how to be profitable.

Johnson: Even if you're not ready to increase your sophistication, there is still room to work on waste management on your manufacturing equipment roadmap. There's a profit there. Once the effluent portion of your manufacturing process has been optimized, then turn your attention to increasing your sophistication, including your technologies and capabilities. But everybody should ensure that they're paying attention to their effluent management and optimizing that.

Holden: You can build anywhere in the world you want because you don't make any waste. They're all connected, and some pillars may be stronger than others.

Johnson: A technology roadmap is a blueprint for how you build each individual pillar and make your pillars work together.

Holden: Most of these concepts are highlighted in key Harvard Business Review articles on competitive advantage, roadmap, and quality function deployment. Sometimes, you go to smart people and find that the answer may lie in another industry in terms of how they approached it.

Johnson: Very true. Thanks for your time, Happy.

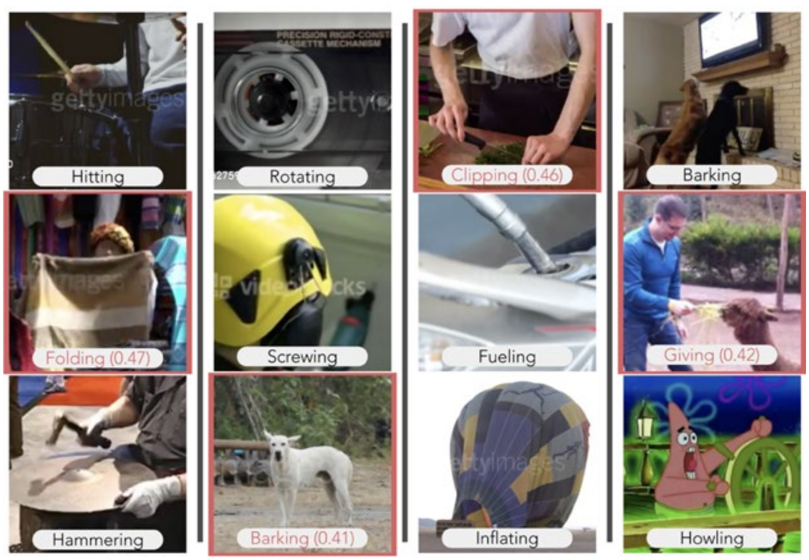
Holden: Thank you. PCB007

Toward a Machine Learning Model That Can Reason About Everyday Actions

Organizing the world into abstract categories does not come easily to computers, but in recent years, researchers have inched closer by training machine learning models on words and images infused with structural information about the world and how objects, animals, and actions relate. In a new study at the European Conference on Computer Vision, researchers unveiled a hybrid language-vision model that can compare and contrast a set of dynamic events captured on video to tease out the high-level concepts connecting them.

Their model did as well as or better than humans at two types of visual reasoning tasks, picking the video that conceptually best completes the set and the video that doesn't fit. Shown videos of a dog barking and a man howling beside his dog, for example, the model completed the set by picking the crying baby from a set of five videos. Researchers replicated their results on two datasets for training AI systems in action recognition: MIT's Multi-Moments in Time and DeepMind's Kinetics.

"We show that you can build abstraction into an AI system to perform ordinary visual reasoning tasks close to a human level," says the study's senior author Aude Oliva, a senior research scientist at MIT, co-director of the MIT Quest for Intelligence and MIT director of the MIT-IBM Watson AI Lab. "A model that can recognize abstract events will give more accurate, logical predictions and be more useful for decision-making." (Source: MIT News)



Adopting Inkjet Technology Results in Cost Savings

Feature Interview by the I-Connect007 Editorial Team

Barry Matties and Nolan Johnson spoke with Garrett Harding, regional sales manager at MicroCraft, about the four pillars of manufacturing, including technology on the manufacturing floor. Harding explains the current interest in inkjet technology and where it fits into the manufacturing process for PCBs, as well as trends, benefits, and more.

Barry Matties: Garrett, would you be so kind as to give us a little bit of a background on you and your company?

Garrett Harding: I've been with MicroCraft for almost three years, and I manage sales in North America, along with Jim Praechter, our West Coast sales rep. Previously, I worked in the automotive and printing industries. My expertise led to this position, and this is my first time in the PCB industry. So far, it has been a great experience. My customers take great pride in what they do and are very passionate about technology. It's an exciting field to work in.

Matties: It's great to see that you're there, bringing all your technology. Has your background always been in sales and marketing?

Harding: I have worked in sales and in HR, but the common thread is that I've always worked with Japanese companies since graduating university. I lived in Japan for seven years, and I speak Japanese, which is how I ended up finding MicroCraft.

Matties: I know that we're talking about inkjet today, but MicroCraft offers a range of technology. Tell us about that.

Harding: MicroCraft was established almost 50 years ago, in 1972. From 1972 to 1993, they manufactured electronic devices like audio equipment and moved into more sophisticated control devices for ships and other military equipment. In 1994, MicroCraft released its first EMMA Series flying probe testers, which was a major turning point for MicroCraft. Since then, grid testers and other types of testing equipment have mostly been phased out. Some are still in use, but very few new grid testers are being purchased these days. In 2002, MicroCraft introduced its first inkjet printers. At that time, they were mostly used to inkjet legend and etch resist inks for industries in and outside the PCB industry.

Garrett Harding

In 2016, we established an ink subsidiary for the development of solder mask inks. Last year, we purchased a software company, Infinite Graphics, out of Minnesota. We had worked with that company for over 20 years, developing features for our testers as well as our printers. They wrote software to convert Gerber, ODB++, and other common industry formats into test and print data. When we found out they were selling the company, we were pretty much first in line to purchase, and that transition has gone very well for us. We're able to focus more on developing advanced features for our testers, such as testing 5G boards and back drill defects, as well as developing new printer features to improve the ease of data preparation and improve print quality.

Matties: What trends do you see in inkjet technology?

Harding: You may know that inkjet printing of legend in the PCB market is fairly mature. If a board shop doesn't have a legend printer, they probably should, just like a flying probe tester. Now that inkjetting legend has been widely adopted, the industry is moving into a second chapter of inkjet, which includes other inks like solder mask and conductive inks. The trend of additive manufacturing is here to stay, and to be a truly additive shop means that you must utilize inkjet in multiple ways.

Matties: Do you see that the fabricators are having an easy time getting the inkjet process adopted by their customers, or is that a challenge?

Harding: It depends on the type of fabricator. If they're doing military jobs, in my experience, some fabricators have spent well over a year getting that printer qualified or accepted by their customers. But other than that, it's so commonplace now that legend is not a big issue because most inks now meet all the requirements, including IPC, UL, and even outgas.

Matties: Do you feel like there are any lingering misunderstandings or myths about legend print that still need to be resolved?

Harding: The issue of satellites, or ink spattering, has been mitigated. With the advances in print strategies and print head technology, we have found ways to virtually eliminate this issue. Another issue was speed. Originally, everything solder mask was very slow due to printing with a single print head. This is because you need to build it up in very fine layers. Since that is an issue, everyone has addressed that by adding heads, including us.

Other than that, there were some performance issues with inks originally. We know that there was a manufacturer in the past who had sold a number of machines on the market, and their customers had to use the ink that they provided. It turned out that ink was not a good performer for multiple types of plating, as well as it had issues with nozzle clogging. Since then, better inks have come out on the market that have addressed those issues.

Matties: In terms of inks, how many suppliers are you working with? Most of them are now in that realm of jetting.

Harding: We work with the main three: Agfa, Electra, and Taiyo. We have multiple installs with each of these companies. Most recently, we installed a two-ink system with Electra solder mask and legend in Europe. We're ink agnostic because our main goal is to sell printers first. Therefore, we allow our customers to choose which ink they would like, and we can offer our inks as well.

We produce ink in a variety of colors, whereas the main solder mask manufacturers are, for the most part, focused on green. Because we have the ability to rapidly tweak our machine and our ink on demand, we're able to innovate quite a bit faster on both the equipment and ink side.

Matties: When companies look at their technology strategy, do they come to you as a supplier for the testing and look at complete strategies, or do they typically come in with just a piecemeal approach?

Harding: I would say a piecemeal approach is common, but in some cases, they want to make sweeping changes to their factory floor. For example, some customers want to change just their legend or solder mask processes and others want to change their whole surface prep and plating processes as well.

Matties: Do you do a process audit before they even know if they're well-suited for this?

Harding: Absolutely. For solder mask, we need to understand their surface prep, plating, and their current solder mask process to decide whether it makes sense to move to inkjet. If it does make sense, then we can make a recommendation to get the best results and then prove this with testing. On the other hand, most customers don't want to change multiple areas of their factory just to accommodate inkjet, so we can also recommend different surface prep products or methods to pair with their existing equipment to achieve optimal results.

Matties: Is there a lot of interest in this?

Harding: There's a very large interest. We're headquartered in Japan, and we have a new facility there. That facility has a dedicated floor for the sole purpose of doing inkjet benchmarks. It has six to 10 printers at any given time for testing. Fabricators and OEMs from all over the world send their boards there. Currently, there is a two-month wait to do a benchmark, and it is first come, first serve.

In addition to an overwhelming number of benchmarks, we have five installs currently in the U.S. jetting solder mask: three are R&D or captive shop type of facilities doing low-production numbers but high-tech work, and then two recent, well-known high-volume PCB fabricators printing solder mask.

For solder mask, we need to understand their surface prep, plating, and their current solder mask process to decide whether it makes sense to move to inkjet.

Nolan Johnson: What's driving the customers to be looking now? It sounds like this is a relatively new occurrence in your sales funnel.

Harding: There has been a great interest even before I started at MicroCraft, but now the quality and speed are there to be considered by mid- to high-volume shops. As I just mentioned, two large-volume production PCB customers purchased this year, and even more are in production in Asia and Europe.

For fabricators, the main drivers are reduction of equipment, labor, electricity, and factory floorspace, which all amount to significant cost and time savings. When you remove the steps involved in the traditional mask process (coating, tack drying, developing, etc.), then you reduce the margin for error in each of these steps. Moreover, the eco-friendliness of inkjet can be a major driver, too. States have different laws and costs associated with removing waste chemicals, and inkjet produces virtually no waste.

For OEMs, it's the potential applications and the possibility of more easily bringing PCB manufacturing in house. If OEMs can bring it in-house, then they can more closely control the process, quickly innovate and, most importantly, keep their technology secret.

States have different laws and costs associated with removing waste chemicals, and inkjet produces virtually no waste.

Matties: Are fabricators challenging their customers to buy into this or approve this as a process? For a fabricator's customer, there is no obvious advantage for them, right? Why would a customer be motivated to spec inkjet versus just ordering a board with traditional because they're not gaining any cost savings, are they?

Harding: Fabricators are already presenting our panels to their customers for evaluation, as well as evaluating the feasibility for themselves. As it gets more widely adopted, the cost savings will be significant.

Matties: Who gets the cost savings? Are the fabricators passing that on or trying to recoup profit?

Harding: One would expect them to pass their savings onto the customer in good faith and to be more competitive in the market. Also, OEMs are often interested in fabricators who are keeping up with technology. But you can also make a case where OEMs are demanding features only achievable by inkjetting legend like serialization for improved traceability. You can do this with solder mask as well; you can have traceability built into the solder mask layer to reduce handling and errors, etc.

Matties: My point is that it's an easy sell for the fabricators due to the value. As you start outlining the steps that they would eliminate, it's significant. There's a quick return on investment, but their customers—the OEMs—have to go through an approval process. Any time a process changes, that change creates doubt, risk, or variables.

Harding: I agree, but as it becomes more commonplace and the understanding that the inks perform exactly the same as traditional LDI or LPI masks, then it will be less of an issue. We have had fabricators reach out to do multiple tests just to send samples to their customers for evaluation and had very positive results.

Matties: When you're selling, are you out selling to the OEMs as much as you are to the fabricators?

Harding: We have quite a bit of business with OEMs. We have some printers that allow them to experiment with inks and build prototypes in-house before they send out their order to large PCB manufacturers. But the bulk of our business is still with fabricators.

Matties: Would you want them to spec your ink as well?

Harding: Of course, but if they are only interested in a specific ink, then we accommodate that.

Matties: What challenges do you meet when you're marketing to the OEMs? What are they looking for?

Harding: They're mainly looking for quality and reliability. We're working with an OEM in

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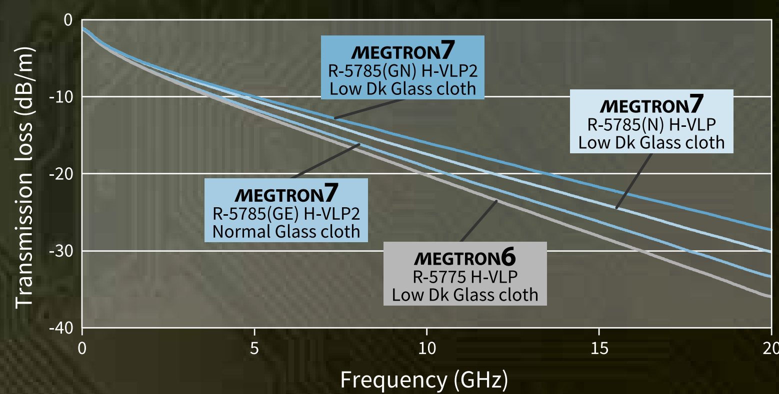
Trace thickness(t)	18μm
Dielectric thickness(h)	300μm
Copper thickness	18μm
Inner treatment	No-surface treatment
Core	0.15mm (#1078 x 2ply)
Prepreg	0.15mm (#1078 x 2ply)
Line length	1000mm
Impedance	50Ω



The above data are typical values and not guaranteed values.

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the U.S. right now, and we've been doing testing for them for over a year. Not because of poor results, but they say, "What about this? Can we do this application with the mask? Can we do conductive ink? Can we do solder mask? Can we do etch resist?" They're looking at it as a complete solution and, once they check off all the areas, they're willing to purchase more machines and bring production in-house completely.

Matties: In terms of tech tolerances, is jetting a better approach for the finer features?

Currently, other equipment, like direct imagers, produce finer features, but as print head technology improves, we may see a point in the coming years where inkjetting is indistinguishable from other methods.

Harding: It really depends on the process that the customer is currently doing. I see this when some of our customers send us their boards with the mask layer data, and that data clearly shows they are not applying solder mask in between tight pads. This is most likely because their current equipment has issues with registration. That is one of the other strengths of inkjet. We then alter the data and print between the pads to show the customer the improvements they can offer to their customers.

Currently, other equipment, like direct imagers, produce finer features, but as print head technology improves, we may see a point in the coming years where inkjetting is indistinguishable from other methods.

Matties: Are there companies using both methods where they may do some part of the board as traditional and then jet another area of the board?

Harding: We have an install in the U.S. doing just that. They're using solder mask in some innovative ways other than just the main mask layer. I can't give too much information, but they are selectively jetting in areas that their film process struggles with. Customers are finding new ways to use it that we never considered, and having multiple uses makes a better case for widespread adoption.

Matties: It's interesting, and I'm surprised that it's taking so long to catch on.

Harding: As you mentioned, there are companies that have legacy requirements, and they haven't changed in two decades or longer. But once the major fabricators implement it, then the smaller fabricators will follow suit. This will lead to an overall market shift.

Matties: There's a real need for an educational process because not only would they perhaps save some dollars through their fabricators—though that's not a guarantee—but you can also change the thickness of your mask in certain areas. You don't need to apply so much material.

Harding: Right. And you don't have to worry about stripping off ink that you didn't necessarily want to strip off because you're only printing where you want it. That's a benefit as well.

Matties: It's fascinating to me that it's taking such a long time to find its way into the mainstream, but I understand the barriers. For the OEMs, they wind up with the board with solder mask on it, and they order it, regardless. There has to be a greater incentive for them to spec this in, and dollars may be part of it, but only if it's being passed on, and I'm not so sure that happens.

Harding: In the future, fabricators can use various ways to market the cost savings and advanced features of inkjettable mask to OEMs, and OEMs can do more testing to show that inkjettable mask does meet or exceed their previously used inks.

Johnson: I have a bit of a marketing background, and one of the things we would look to create was a "compelling event." What's the most common compelling event you run into wherein the fabricator says, "We have to get serious about solder mask jetting because of XYZ," and what are compelling events for your customers?

Harding: That's a tough one. More and more, board manufacturers are making increasingly complicated boards, which require—as you mentioned—various thicknesses of mask, which increases production steps tenfold by going back and forth. This is just another reason added to the previously mentioned time and cost savings.

I don't know if there has been a singular compelling event just yet, but the benefits are clear. In the future, we could see OEMs start demanding inkjet because its superior qualities or environmental regulations become so stringent that inkjet seems to be the only way to comply with those regulations.

Matties: There has to be customer support to do it, though. You don't just go in and do this because you're going to be running dual processes in any case. It has to be driven by the customer or their sales department who sells this process to their customers; otherwise, they rely on you to help educate the OEM.

Johnson: It's a chicken and egg problem, isn't it? OEMs stick to traditional processes; otherwise, they need to revalidate. Then, you have fabricators who would like to increase their margins, reduce their waste, and be more flexible, but they need customer demand to justify buying the equipment. That leaves you sitting right in the middle.

Harding: It's a tough place to be, believe me.

Matties: How is business in Japan?

Harding: We're doing much better than even in 2019. The interest in inkjet has really ramped up in the past year or so.

We're doing much better than even in 2019. The interest in inkjet has really ramped up in the past year or so.

Matties: Flying probes was a large area for you. Do you still see a lot of business in the flying probe sector?

Harding: Absolutely. We see a lot of interest in automating that process even more than it already is. We are also investing heavily in what's coming for 5G, so we have introduced some new testers that can do very high-frequency testing. The split of business is currently about 60% testing and 40% inkjet, but our inkjet business is creeping up on about half. It's a big change from when I started.

Matties: When you talk about the flying probe for 5G, what testing strategies or technologies does a board fabricator need to have? Does their existing technology already cover the requirements?

Harding: Fabricators are being required to test not only the coupons on the board but to test the actual board. This is a major pain point for them because it is time-consuming to do so by hand, so we have found a way to automate this process. We have also developed new unobtrusive methods to test for backdrill defects. There is great interest from both OEMs and fabricators.

Johnson: I wanted to pivot a bit and talk about the digital factory and where you fit in, especially with respect to testers feeding data into the whole digital factory approach. Assemblers seem to have done a much better job stepping into digital factory capabilities than the fabricators have. What do you see as you talk to your customers about digital factories?

Harding: The interest in automating processes with autoloaders, and unloaders—as well as being able to scan a barcode and run the test automatically is a big interest. To do that, you need to change not just the testing process, but the customer must also consider all their other processes leading up to that as well. Automation is a huge topic of discussion. We work with some robotic handling companies, and we have some installs with our printers as well as our testers with robotic arms. We're very focused on that at the moment.

Matties: Is there a big drive from your customers in that conversation, or is it something that you have to carry to them?

Harding: For larger fabricators, there is a big drive for it because it's hard to hire people. If the operator can stack 50 or 100 panels, run the job, and walk away to run some other equipment, the value or ROI of that one employee is much higher.

Matties: There are two parts to that, though. One is you can have loaders and unloaders and robotic arms, and that's an important part of mechanizing your manufacturing process. But when we talk about automating the process itself, where the machines are adjusting based on the work coming through via an etcher or plater or whatever it happens to be, we see more of that in the assembly side than we are in the PCB sector, with the exception of Green-Source Fabrication.

Harding: We also have software options just for that. For example, if you have multiple testers, they can all link up and talk to each other. You can plan production numbers for each tester to maximize productivity. This software is very popular in Asia with customers that have 10, 15, or more of our testers on the floor. However, a lot of our North American customers have one or two testers, and they're not always running, or they only run the morning shift. These customers do less than 100 boards a day.

Johnson: In a more production-oriented environment, it sounds like your product portfolio allows for a seamless flow of data. You're printing the legend on the spot and serializing the boards; that's one of the reasons to use an inkjet printer for legend. You can put some identifiers on the board, which then are usable in testing to know which board you're dealing with, then keeping the traceability through manufacturing, and you have that all tied together with your complete portfolio of product. Is that an area of active R&D for you?

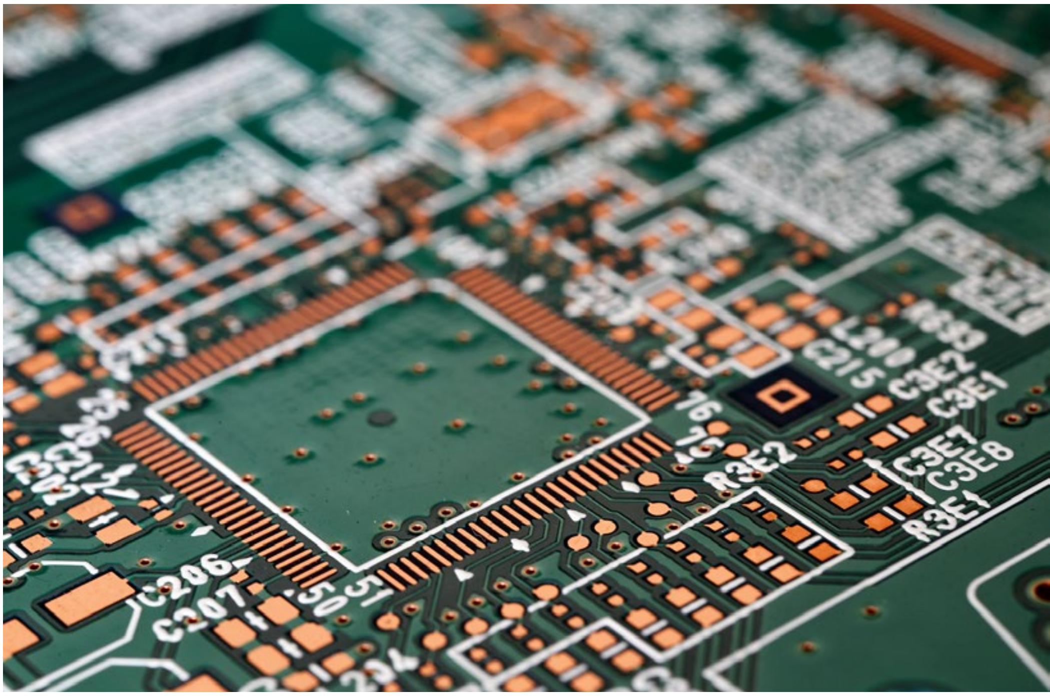
Harding: Yes. We have features that link our printers and testers so that, for a bad part, the printer will X out a sub-panel, and the tester will know not to test that sub-panel. Operators will also know not to populate or ship that panel.

I mentioned that we purchased Infinite Graphics; they're a CAD/CAM software company that wrote a software suite of tools known by the flagship product "ParCAM/EXT," and we now develop and sell it directly. This suite of products directly supports us in data prep for test files for our EMMAs and also for our CraftPix printers. We're working on several projects right now to enhance our ability to drive our testers and printers in more efficient, productive, and useful ways such that they can talk to each other using the data from all industry CAM software products.

Matties: You're doing some great things, Garrett. Any print head updates?

Harding: We now support two new types of print heads, and these print heads jet a very small droplet size. Previously, our standard threshold for solder dam was about 3 mils, and these new print heads achieve a sub-2-

mil solder dam or line width. That level of improvement is huge. We'll be releasing models with those print heads in the near future. We're in the third generation of our solder mask inks and still working hard to improve them. We also have a new eight-head printer for maximum throughput. It can print solder mask on a standard panel in under a minute. Lastly, we have released a new sophisticated in-line autoloader and unloader, which works with all our models.



Matties: Are those only for jetting, or do you provide inks for other applications?

Harding: That's a good question. They're for jetting only. We only produce jettable solder mask inks for flex and for rigid, and those are available in green, red, black, blue, and white for LED applications. With white, you can use it as a legend; it can be very versatile that way.

Johnson: You were talking about scalloping as being a challenge for finer features. Is that primarily a mechanical issue or a solder mask ink issue? Is that something you approach with print head engineering, or by formulating your solder mask to behave differently?

Harding: It's a combination of those two plus proper UV application on the ink. If the UV is too strong, you will pin in the ink too soon, and then you get stronger scalloping. Inkjettable inks are much thinner than traditional masks, so the condition of the surface is important. Overall, we've found ways to combat those issues with different print strategies or by improving the surface itself.

When a droplet lands, there's no way to cure it and not produce a slightly rounded edge. It's not an issue of functionality. The board will function exactly the same, but it's an issue of customer approval. A customer might say "What's with this?" or "What's wrong with the solder mask?" if It's not perfectly straight, but keep in mind nobody says that about inkjetted legend anymore and we expect that look to be more accepted and in time we hope to eliminate the scalloping altogether.

Johnson: It's much clearer now. Great explanation; I appreciate that.

Matties: This has been very good. I look forward to our next discussion because we really want to drive this conversation to the OEMs. Thank you for all your insights. I'm glad to hear you're enjoying this industry. I've been in it for over 35 years now, and there's a lot of good people in this industry.

Harding: I totally agree.

Matties: Thank you very much.

Harding: Thank you for your time. **PCB007**

THE BUILDING BLOCKS OF TRAINING

Feature Interview by Nolan Johnson
I-CONNECT007

I sat down with the Blackfox team to discuss training strategies as a key part of staffing a manufacturing facility. Al Dill, Sharon Montana-Beard, Jahr Turchan, and Jamie Noland provide guidance on why training is increasingly important, why management should be proactive about skills training, and how current pandemic complications only increase the need for training while simultaneously making training more challenging to deliver.

Nolan Johnson: Welcome, everyone! Can you each give a quick introduction?

Al Dill: I'm the president and CEO of Blackfox Training. I'm the original founder. I've been with Blackfox since 1996, and I am proud to be here.

Sharon Montana-Beard: I'm vice president and director of sales and operations, and I've been here since 1998. The company is doing great, so I'm still glad to be here.

Jahr Turchan: I'm the director of veteran affairs and advanced manufacturing programs. I've been working in an advisory capacity to Blackfox for a couple of years now, but I've been full time with Blackfox since February of this year.

Jamie Noland: I handle marketing, I'm the IT manager and a master IPC Trainer for Blackfox. I've been here for about 13 years. I sit on all of the IPC training committees for the different programs that train and certify people. I also serve as the chair and vice-chair of a few committees as well.

Johnson: Our topic is training and how it contributes to the four pillars of manufacturing at a strategic level. It's well known in the industry that we have widespread shortages of skilled labor, and training will be necessary to fill these job openings, not to mention generally improving the skill sets on the manufacturing floor to implement the company's technology roadmap. How do manufacturers plan for this?

Montana-Beard: First, you must identify what skills are going to be needed, whether they're entry-level, advanced, or expert. You also need a good instructional designer that can develop these training programs and dissect it into

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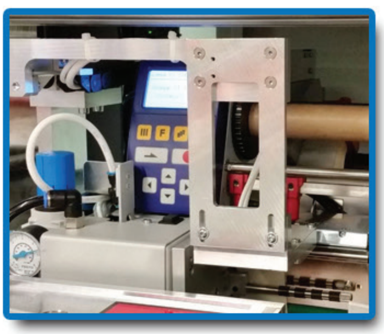

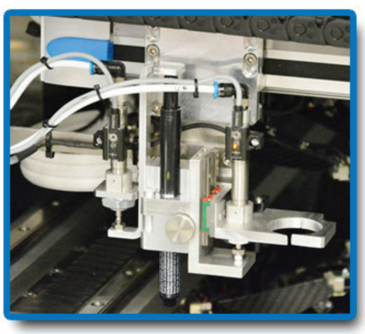

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some smaller pieces of learning. If it's training for a machine, identify who programs it, who sets it up, and who operates it. There are three different levels of training, and you need to do a full investigation before you jump in.

Noland: As far as what we do and who we listen to when deciding what's going to be included in training programs, committees are comprised of many different members from various facets of manufacturing. Their jobs range from those who are directly on the floor to upper management and internal trainers. We try to stay current as far as manufacturing techniques, smaller size components, and different methods of soldering, manufacturing, and cabling. Then, we include that in the training materials as best we can. Usually, training tends to be five years behind what's in the real world. It's a constant battle to keep up. But it helps having so many people on these committees who are vocal about changes and updates to the program.


Jamie Noland

Dill: I also want to touch briefly on some of the new technology and equipment. With the labor shortages and some of the challenges we have—not just because of COVID-19—we see a lot more equipment and robotics going forward. The skill set for the permanent workforce will require higher-tech skills in robotics and programming machines and less hands-on stuff.

Going back to Sharon's point about understanding what the skills are, skill matrices and other tools are required to map out what's required for some of the newer equipment and technology. Then, companies can drive that back toward your training system and your training providers, whether internal, external, or both. Technology is in a new phase that's going to dictate a lot of the skill set at that level.

Johnson: Do you see requests to move the training toward programming and engineering functions? I'm assuming the smart factory environment might create that need.

Dill: It's more about what I read and hear from others. Many executive-level folks are planning and budgeting for new technology. Unfortunately, executives sometimes forget about the human side of skill sets and what some of the skill requirements are to make this work together. It's important to keep that in mind when we're going through our planning to make sure that we are prepared. One of the initiatives assigned to Jahr is to look at these newer technologies and requirements that some of our manufacturers need. This is not to say there isn't still going to be hands-on training; it may be delivered a little bit differently than in the past, or in conjunction with some of the newer techniques. We see a shift toward more automation at this point.

Turchan: From a more general manufacturing perspective—not just the electronics manufacturing, but all manufacturing skill sets combined—I have seen from a number of companies that see around the corner and try to predict where manufacturing is going, as well as where those efficiencies can be earned. Some of them focus on mechatronics-type skills for Industry 4.0 and the smart factory, knowing that they have to change over and take a new approach with smarter employees. Some of them are very active in upscaling their current workforce because they know that the more that their employees know, the more efficient they can be, and the more they can adapt to the rapidly changing environment.

Johnson: How much time should management set aside to build the manufacturing staff's skill set? The machinery has been purchased and is scheduled to arrive on the floor. Employees will need to be ready to run it when that equipment arrives. How do you sync those two schedules?

Montana-Beard: Once the equipment is there, you want the people to be receptive. They should already understand that it's not going to take their job; instead, it's going to expand their knowledge and job. There's always going to be that human element. Once you've established that idea—the importance and the value of it—you have people with their heads straight and willing to take on something new.

I spent years on the manufacturing floor, and if they don't understand why, then they don't see the value. I don't care if it's a new tool for a great big system, you bring in something new and have to learn it. Be patient with it, and be sure to ask a lot of questions. They need to really understand it, put their arms around it, and take care of that machine. They need to feel that they have the right training and education so that they know to ask the right questions.

Johnson: I hear a pretty strong interrelationship between manufacturing, human resources, and the executive team. There are slightly different perspectives that trainers need to manage.

Montana-Beard: My experience and my opinion is you get buy-in, and then you have open minds. That way, the training cycle or process will go a lot smoother, and they will take ownership of what they're going to be doing.

Noland: I've been personally involved in many new implementations of newer technologies: different inspection techniques, X-ray, CT, monography, the introduction of lead-free technologies and processes, etc. The main thing is you explain that this is a machine or a technique that's not designed to take your job but to make your job easier. It's designed to make the quality better, and it still requires humans.

The verification of quality is still 100% human-based. Even if you have a machine inspecting visually or magnetically for quality, it still takes a human to run that machine and interpret the results. It also requires someone to build and program the machine. There's still a lot of that human interaction and requirements. Ensuring that the employees know that is key when implementing new technology.


Jahr Turchan

Turchan: You have to get employee buy-in and educate them that this doesn't eliminate any need for any human capital, but that it's an advancement of the company. And when the company advances, so do employees. When that executive team makes the decision to continually train and upskill their employees, the employees will be more receptive to that new technology as it arrives because they'll feel invested in it. That makes them more secure in that company. When advancements come, they are set to pivot to something different or better.

Johnson: In my experience at a previous employer, I was working in the training department, and it was interesting to notice how some customers approached operator training, especially troubleshooting and preventative maintenance, as an afterthought until they started having issues. Is training now a well-established and necessary prerequisite to getting the equipment running?

Dill: Unfortunately, in a lot of companies, what drives training is pain. That pain may have to reach all the way to the executive level sometimes. The first pains they may see could be poor workmanship, a loss of profit, customers, or employees, etc. Typically, that is when we get involved unless there is a compliance issue. We do a lot of training for compliance, and that's where a lot of the IPC certification comes in. But much of the skill-based stuff that we train, such as quality systems, is driven by pain. We have to start by first understanding what caused their pain and then help rectify that by developing courses around that. It's not true of every company, but that's often what ignites the flame.

Johnson: There can be a reactionary approach, even in the most planning-oriented companies. Can you see a difference when you talk to a customer between those who have a clear vision of the roadmap and those that are more reactionary?

Dill: Definitely. If I'm meeting with the company's top executives, there might be HR folks, training managers, etc. What I see most often is a lack of communications internally and a commitment that does not reach all the way to the top. The HR folks and training managers are serious about developing a comprehensive training plan and sticking to it, but that message is not always supported at the top until that pain arises again. Then, the arrows point back down again, and management says, "Fix it." It depends on internal buy-in and a top-down commitment to make sure this happens and that all your people have the opportunity to do the job right.


Al Dill

One of your questions was, "Who's the customer here?" In my opinion, the customer is the customer. The customer is your company's customer. We're all in this to make sure that we deliver good products and services on time. The end-users suffer if that doesn't happen. I've been at the executive level in some larger companies, and I'll admit that I've been guilty of that, too: "Just get that product out. Let's get our quantities built and make sure we're on schedule," and then all of a sudden, you get it right in the butt when your quality suffers or your profitability goes down because you're not building a great product or your services aren't where they need to be. It's a top-down commitment. We see more and more of that as companies and executives are learning. But it's still a challenge out there.

Montana-Beard: There are things that human resources need to do. For example, with a new employee, what do they need to know? When they join the production floor, they should be ready. It's not the floor supervisor's job to teach them about time clocks, benefits, the location of the nurse's station, ISO compliance, etc. I could name 20 things that a new employee needs to know before they come to the production floor.

Johnson: If you're a manufacturing firm, everybody's there to support the manufacturing process. Training is an investment, so there needs to be a return on investment for the training process. From an executive perspective, it often seems that the measure is how long the employee stays with the job. It's the length of service that pays back the training investment. How do you talk to your customer about the value or ROI of training programs?

Dill: It's an art to understand how to accurately calculate return on your investment for training. There are so many different factors along with that. There's a basic formula, where your net profit change is divided by your training, but that doesn't cover everything. There's no exact formula to calculate ROI. It's a combination of a lot of different factors.

For example, a few years ago, a company came to us and said, "Apparently, we have some training problems that we need to fix to be able to positively affect some of these key factors. One of those factors is our turnover. We have so much turnover right now—about 200%. We think a lack of training is the cause." They also looked at some other factors, such as quality. But the bottom line, in that case, was there were key elements missing in training. Morale becomes a big factor because when people aren't prepared, and they become frustrated, they end up leaving, which leads to high turnover.

Years ago, when I was on the floor at one of our larger customers, they were using a staffing firm for a lot of their employees. The staffing agency was responsible for making sure they were prepared before the new employees took a post on the floor. I happened to be in there watching some SMT equipment when the shift changed. The second shift folks came in, and this young fellow walked up to one of the machines. The previous operator welcomed him, said, "Have a good night," and left.

It turned out that was the gentleman's first night on the job. He looked at that operating manual, closed it, and walked out the door. I followed him because I was curious and said, "Where are you going?" He said, "I don't know

how to run this machine. I'm afraid that I'm going to do damage, trying to run it. They told me there was an operating manual, but I don't understand it." That's the kind of stuff that we used to see.

Johnson: And that was only exacerbated by the fact that there aren't enough people to fill the jobs in the first place. For your more proactive customers, how do they calculate ROI? How do they justify this investment to make sure that they know whether they're an indirect profit center and creating revenue or a cost?

Turchan: From some of the executives that I've spoken with recently, the forward-thinking ones don't seem to be concerned about the ROI. They know that they need to invest in their employees to stay relevant, current and profitable. They've accepted that it is a need that must be addressed.

Johnson: That's not an area that they're going to micromanage. Have the dynamics in 2020, such as the pandemic and supply chain, changed the strategic planning for the customers you're talking to about training? Has that caused them to shift their plans?

Montana-Beard: They're trying to get more work done with fewer employees. Companies are still hiring, just not as robustly as they were before, and cross-training has become essential to cover all of the different jobs that need to be done. I've also heard about some quality issues with people that have been doing the same job for a while, but there are also new quality issues as they learn new skills. We're doing one-day and two-day workshops. With the existing workers on a soldering operation, we'll have one of our master trainers work with them for a day or two.


Sharon Montana-Beard

Before, some of this may have just been put to the side. The thought was, "We're so busy; otherwise, that'll just go away." This pandemic has affected many things, but in manufacturing, they still require training. They try to get production out under the same protection protocols as we all are. We're now doing the same class for three smaller groups, where we used to have just one group.

We have an instructor going to a customer soon, and I emailed my customer contact a couple of times. I've worked with him for years, but he wasn't replying. Then, I received an email from a stranger in the company, informing me that my contact was out on medical leave. That started the process all over again.

Johnson: That takes us right back to your initial point, Sharon. There's a lot of cross-training happening because people are going to need to step in for each other when the unexpected occurs.

Noland: When I talk with some of my students and contacts, I notice that if a company has a little bit of a slowdown right now due to supply chain issues or other disruptions, a lot of them are taking that slowdown opportunity to get their workforce trained. It's a good time because time is absolutely money. And one of the hardest things to do is get a student off of a production floor to attend a class. That's lost production and lost revenues. But it's a perfect opportunity to get some training and certification completed, take care of some compliance issues and remedial training, too. As Sharon said, cross-training is occurring, making employees more valuable so that they can flip around and do multiple tasks or jobs.

Montana-Beard: We're gaining new customers internationally because we offer online training now. I recently sold a class to one of our customers simply because everybody was working at home. He said, "This would be a good time to get them caught up with some training."

Dill: Manufacturers need to take advantage of any downtime that they have. They want and expect some type of just-in-time training or training that's available very quickly without a lot of expenses in travel and employee absence tied to it. The more we can provide them with training systems that are readily available and utilize our training expertise and competencies, the more they'll appreciate that. Being able to jump off during an hour of downtime, tap into even an LMS-type learning situation, pick up a course, and learn how to operate a machine will be very valuable. That's going to be a trend, not just because of COVID-19, but because our new environment is going to require a lot more of that as a training solution.

Turchan: Hopefully, later this year, we'll launch an e-learning platform marketed toward all manufacturers—not just the electronics industry—with a library of about 550 skills and different technical competencies; everything from toolmaking to Six Sigma, Lean manufacturing, safety, engineering drawings, automation, CNC, and soft skills to compliment that. Hopefully, employers can see the value that employees with stronger soft skills are also more efficient employees. Obviously, a more efficient employee adds to your bottom line.

Montana-Beard: There are so many questions unanswered. How do we move forward? Will we be open in two weeks? What if there's a COVID-19 outbreak within our company? How do we plan for a requirement that an entire department has to disappear for two weeks? We could do this now, but can we do it next week? How do you plan and react as quickly as the environment changes?

Johnson: It's a challenge to stick to your roadmap when the geography is constantly changing underneath you. We are all flexing together to meet the new challenges.

Turchan: From a supply and demand planning perspective, especially in electronics manufacturing, we need to be more agile and reactive. We don't know what the next shift is going to be. I'm hoping that manufacturers are more forward-thinking about training their employees and providing a way for their employees to get more upskilled to increase their internal value.

Johnson: Thanks, everyone. This has been an enlightening conversation.

Dill: Thanks for all your time, Nolan. PCB007

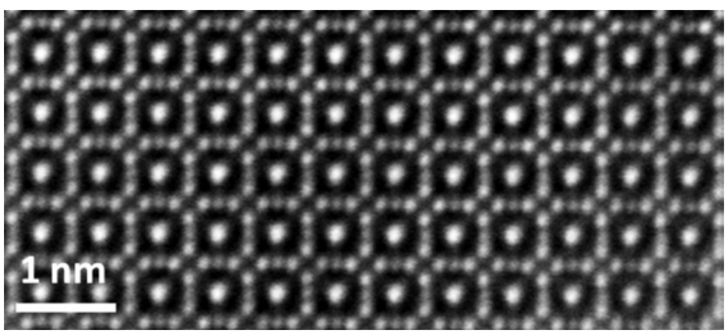
Tiny Circuits, Long Distances: Smaller Light Processing Devices for Fiber-Optic Communication

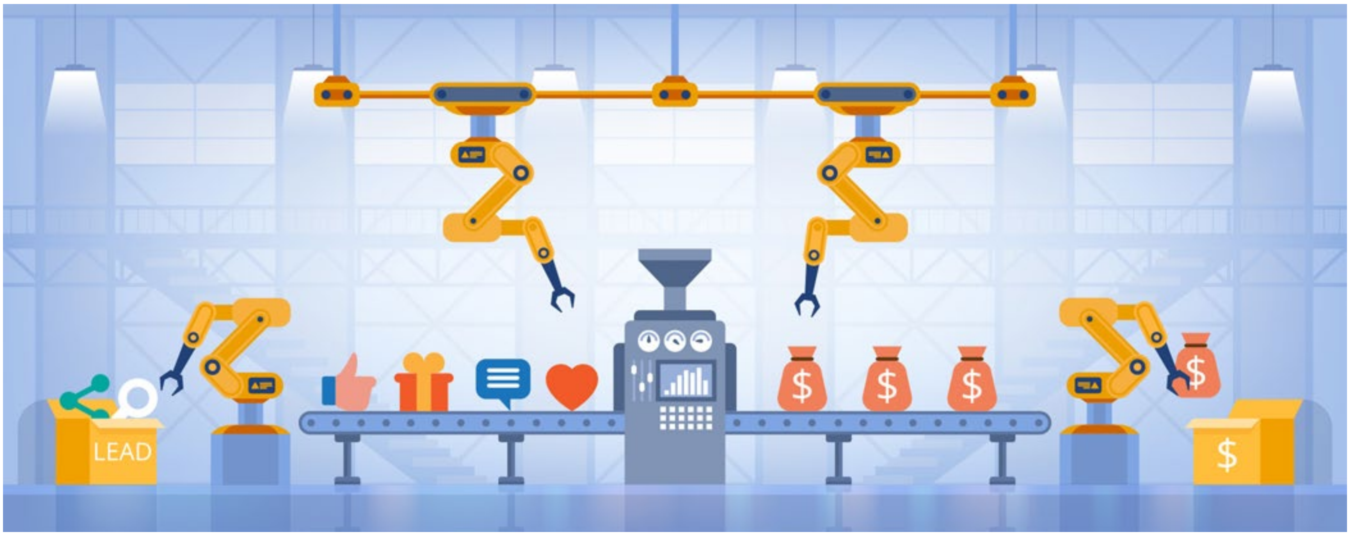
Researchers at Michigan Technological University (MTU) have mapped a noise-reducing magneto-optical response that occurs in fiber-optic communications, opening the door for new materials technologies.

Optical signals produced by laser sources are extensively used in fiber-optic communications, which work by pulsing information packaged as light through cables, even at great distances, from a transmitter to a receiver. Through this technology, it is possible to transmit telephone conversations, internet messages, and cable television images. The great advantage of this technology over electrical signal transmission is its bandwidth—namely, the amount of information that can be broadcast.

New research from a collaboration between MTU and Argonne National Laboratory further improves optical signal processing, which could lead to the fabrication of even smaller fiber-optic devices.

(Source: MTU)





How to Create a Powerful Revenue Engine

Feature by Dan Beaulieu
D.B. MANAGEMENT

No matter what you use for technology, supply chain, operations, or labor, nothing happens without the customer. As Peter Drucker famously said, "There is only one purpose of a business: To create a customer." With that in mind, it should be no surprise that the most important pillars of manufacturing are—drum roll, please—sales and marketing. These beget revenue. But how do you accumulate those customers, and how do you sell your products to them so that you will get to the revenue—the engine that powers all organizations?

Deciding What and Who

First, decide what you are selling. What is your technology? What product do you manufacture? In the PCB business, this consists of three sectors: technology, service, and market. What do you make, and what services do you provide? Then, determine who wants what you are selling. In short, who should you sell to, and why do they need what you have to offer?

Marketing and Selling Your Products

Next, examine how you will market and sell your products to that particular market because there is no selling without marketing. As I have said many times, selling is like fishing with a pole, a hook, and a worm and hoping that a fish will come along and bite; marketing, on the other hand, is getting the fish to jump into the boat.

You must market your products. The best way to is to demonstrate that your company produces the best technological PCBs in that market by filling the vacuum of leadership at the very top of every marketplace. You must develop your reputation and brand as being the industry's experts when it comes to that particular technology.

PCBs can include high-tech rigid boards, flex and rigid-flex boards, heavy-copper boards, thermal boards, metal-backed boards, or any number of other technologies. The point is that whatever technology, market, or service your company addresses, you must gain a true—or at least perceived—leadership position. This is done through marketing.

Developing a Marketing Plan

Over the years, I have helped a number of companies become known as industry leader through strategic marketing. Here is a snapshot of how to do it.

Your marketing plan should have messaging designed to position your company as a true expert when it comes to the technology you are selling and the market you are addressing.

This will involve an implementation plan for producing the following marketing materials to establish your expert brand.

Marketing Message

Your marketing message is how you will position your company as the experts in the field and will serve as the backbone for all of your other marketing. The message must be clear, consistent, easy to understand, and—most of all—memorable.

Content

All your content has to be valuable and strictly on message. Your content, as well as its distribution, is the key to getting your message of expertise out to the marketplace. Here are four examples.

1. Columns and Articles

When it comes to establishing a reputation as an expert, nothing works better than a regular column or article series. It not only provides you with a forum to broadcast your knowledge base, but it elevates the author of that column and associates you as a true expert of your technology.

2. White Papers

White papers are always effective, especially when they are presented at trade shows, exhibitions, or virtual events. They are longer and generally more technical than columns, and they demonstrate your knowledge of a specific aspect of your technology.

3. Technical Bulletins and Newsletters

If technical bulletins and newsletters are sent out consistently—at least once a month—this will help you create a true following or "tribe" of the right people because they consistently read about your expertise. This creates a database of interested potential customers, which is what your marketing efforts are all about.

4. Webinars

Webinars have—more or less—replaced lunch-and-learns in this time of COVID-19. The companies I work with have had tremendous results by offering one-hour webinars on a particular facet of their technology. This is another great way to establish your company's leadership and expertise when it comes to the technology you are selling.

Sales: Turn Your Leads Into Gold

Now that you have done all that great marketing, all that's left is to turn them into sales—or, as I like to say, turn them into gold!

Train Your Salespeople

Make sure you train your salespeople well. Be diligent about this. Most salespeople think they can "wing" themselves to success, but they can't. They must be well-versed in talking about your technology. Then, they will be able to handle some of the questions they will get from the leads of your marketing efforts. Here are five things that salespeople must do to turn their leads into gold.

1. Complete the Lead

Sometimes not all the information is provided. A good salesperson will know how to get the complete information for a given contact. This might mean using LinkedIn or searching with Google. But no matter how you do it, if you are a good salesperson, you will conduct research until you get the right contact's name, email address, and phone number.

Be careful: Anyone who complains about having to do this is calling themselves out as a poor salesperson.

2. Research the Company

Once you have the right contact information, you have to find out everything you can about that target company from its history to what they build and what market they are in. With all the information available today, there is no reason not to learn anything about the companies you are targeting.

Be careful: Anyone who says they cannot find anything about the company is calling themselves out as a poor salesperson.

3. Warm up the Cold Call

With email, snail-mail, and social media, there are a number of ways to make sure that when you place the call to the target customer, they already know who you are. Reach out to them via mail, or write a comprehensive and interesting series of short newsletters to your complete lead list.

My favorite thing to do is to send them a letter with your real signature in one of those $3 post office express letters that look important. And whatever you do, always write out the address by hand. Who can resist opening a hand-addressed FedEx-looking envelope? It will sit on their desk, screaming to be opened.

Follow these suggestions, and the target account will know you who you are.

Be careful: Anyone who lists all the reasons these methods will not work is calling themselves out as a poor salesperson.

4. Prepare the Right Message

Chances are very good that you will get voicemail. Be prepared for this. Come up with a provocative message to get the person to call you back. There are many books with advice on how to create the right message and turn voicemails into opportunities. Buy one and read it. It will be worth your time and effort.

Be careful: Anyone who says that cold calling does not and will not work anymore is calling themselves out as a poor salesperson.

5. Follow Up

If you are still not getting anywhere, send the person a personal letter and an engraved invitation. Better yet, and as scary as this may seem, do a live cold call. Walk into the lobby, ask for them, and if they are too busy to see you, leave a beautifully-engraved invitation.

Make sure that the invitation includes an attractive offer to do business with you, such as a discount off the first order or something similar that fits your particular needs. Surveys indicate that it costs over $10,000 to get a new customer, so you can certainly discount a few hundred dollars to shortcut the process. Do it!

Be careful: Anyone who nixes this idea based on the 2% of their customers who cannot take a discount gift, while the other 98% of their customers will take it, is calling themselves out as a poor salesperson.

Conclusion

By following my plan as outlined, your company will establish expert technology leadership in your marketplace. Not only will your customer know you, but will want to do business with you. After all, you're the experts when it comes to your technology.

And remember those fish? By doing all of these things, you will have thousands of fish jumping into your boat. This will result in successful sales calls, growth, and new customer acquisition, as well as lead to more sales and revenue, which is what you wanted all along. PCB007

Dan Beaulieu is president of D.B. Management Group and an I-Connect007 columnist.

Mechanization vs. Systemization

by Nolan Johnson, I-CONNECT007

In his book, *Automation and Advanced Procedures in PCB Fabrication*, Happy Holden characterizes the relationship between mechanization and systemization. The following excerpt from chapter one puts the two methodologies into perspective—a critical distinction to make when updating your manufacturing technologies.

A Working Definition of Automation

In a working context, automation means more than just automatic machinery. Machinery implies mechanization. Automation also means the system information directs and controls people, materials, and machines, also known as systemization. Therefore, automation is made up of two components, like a vector: mechanization (material flow) and systemization (information flow), Figure 1.

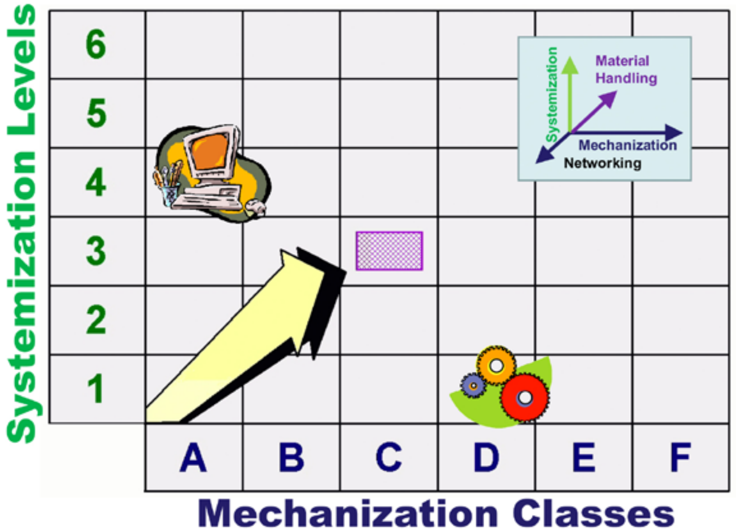


Figure 1: The automation vector is defined as systemization and mechanization, including material handling and networking between work centers.

Mechanization Classes

Mechanization can be divided into six classes that indicate the amount of sophistication of machines and machine interactions with humans, Table 1. The classes are rated based on the percent of the work done by machines.

Systemization Levels

Similarly, systemization can be divided into six levels that indicate the amount and sophistication of blueprints, information, data, scheduling, and control that take place, Table 2. Each level has an increasing percentage of machine/computer content handling the information required to fabricate, schedule, test, or move a product.

To learn more about automation techniques in PCB manufacturing, download your free copy here and visit I-007eBooks.com to download other educational titles. PCB007

	Mechanization Class	% Mechanized*
1	Manual	0%
2	Semi-manual	10–25%
3	Machine-assisted	25–50%
4	Human-assisted	50–75%
5	Semi-automatic	75–99%
6	Fully automatic	100%

*Total machine time / human time + machine time

Table 1: Mechanization classes.

	Mechanization Levels	% Collected by Sensors or Computers*
1	Manual information collection distribution	0%
2	Batch computer/human collection distribution	10–24%
3	Online computer/human collection distribution	25–49%
4	Real-time computer/machine interface	50–74%
5	Dedicated supervisory control	75–99%
6	Fully automatic gateway/network control	100%

*Total machine time / human time + computer time

Table 2: Systemization levels.

Pillars of Mil-Aero Technology and Revenue

From the Hill

Feature Column by Mike Hill, MIL-Q-CONSULTING LLC

The military-aerospace (mil-aero) electronics business is always in constant flux as new methodologies, like AI and space, create the know-how for new PWB designs. In addition, as the number of threats in the world seems to be rising, the need for more unmanned solutions drives more and more electronics. In this column, I have tried to capture some of the most unusual old and new design ideas to support the notion that mil-aero revenue will continue to increase.

Older Military Technology That Changed Your World

To start, Noah Caldwell with *Mic* assembled a great overview article [1] that provides "a quick run-down of 11 of the DoD's most famous and influential products." Here, I share just the highlights. These products not only survived the transition from wartime to peace but also thrived in the consumer market.

1. **Walkie-talkies:** It's no wonder the nickname "handie-talkie" never caught on.
2. **Super glue:** Kids and adults alike—beware.
3. **Duct tape:** Was actually originally called "duck tape," among a variety of other names.
4. **Silly putty:** Similar to the invention of the adhesive now used with Post-It Notes, silly putty was originally supposed to be something else entirely.
5. **Early GPS technology:** Think of satellites that transmitted locational data.
6. **Digital photography:** "Steven Sasson of Eastman Kodak discovered a way to use a sensor (instead of film) to collect light and a means of storing the information numerically."
7. **Virtual reality:** Started as an experimental project where a car drove down every road in Aspen, Colorado.
8. **The EpiPen:** A must-have item to treat severe allergic reactions.
9. **The early internet:** Began with J. C. R. Licklider's conceptual framework.
10. **The deep web:** Also called the darknet or dark web, "the software that enabled such activity was created by the U.S. Navy and patented in 1998."
11. **Nuclear energy:** "May be the most unsurprising item on this list, but it's certainly one of the most important."

U.S. Signal Corps Radio

PHOTO: FLYGVAPENMUSEUM

New Technology

These four new mil-aero technologies provide a window into the future for any company that wants a piece of history.

1. Smart Bombs Moving to Thinking Bombs

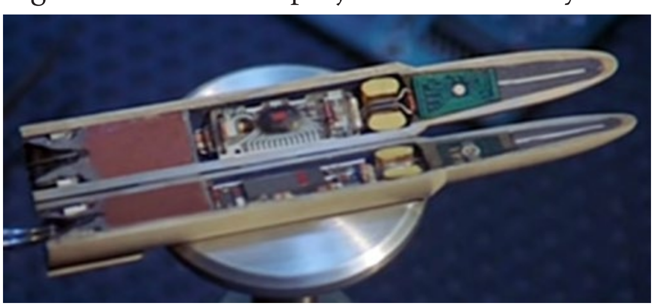
According to Kyle Mizokami, a writer from *Popular Mechanics* [2]:

"Here's how Golden Horde would work: A pair of jet fighters might target a set of concrete aircraft shelters at an enemy airbase. The first fighter targets four shelters with four CSDB-1s, destroying two. The second fighter, flying right behind the first, releases its CSDB-1s while the first jet's weapons are already in the air. The second fighter's bombs receive data that two of the shelters are destroyed. The second flight of bombs, consulting Golden Horde's playbook, reassigns the bombs in flight to destroy the remaining shelters…In the past, weapons were called 'smart weapons' due to their use of onboard maps, lasers, or GPS data to find their targets. Golden Horde, however, takes things a step further by actually making decisions."

2. Self-Steering Bullets

Richard Sammon, senior associate editor for *Kiplinger* [3], explains how self-steering bullets could work.

"Packed with tiny sensors, a 0.50-caliber bullet under development can change course rapidly in midair, potentially giving even a mediocre shooter sniper-like accuracy, with the ability to hit moving targets with ease. Plus, while the cost of these advanced rounds is still unknown, they are sure to be cheaper than the rocket-propelled missiles whose role they could sometimes fill. DARPA, which is working on the EXACTO project with military contractor Teledyne Technologies and ammunition maker Orbital ATK, is keeping mum on exactly how the bullet changes its flight path. A competing effort from the Department of Energy's Sandia Labs uses a laser to indicate the target while small fins on the bullet (also 0.50-caliber) steer it in flight."



Source: DARPA

3. Laser Cannons

In the same article [2], Sammon details laser cannons:

"The iconic science-fiction weapon is closer than ever to reality. The Navy's testing of its laser weapon system aboard the USS Ponce in the Persian Gulf went swimmingly, and the Navy expects to deploy even larger laser weapons aboard ships to protect them from threats such as small attack boats and drones. Meanwhile, on land, Boeing and the Army are working on a truck-mounted laser that can zap incoming threats such as mortar shells or drones. This program has the catchy name HEL MD, for High-Energy Laser Mobile Demonstrator. Competitor Lockheed Martin is also looking for a piece of the Defense Department's ray gun business with its ATHENA system. One of the many benefits of lasers is that they can repeatedly fire for minimal cost—just the diesel to power the truck-mounted generator that provides the bursts of energy the laser concentrates downrange."

4. Wearable Coronavirus Symptom Detectors

Here is an invention the world could use. Matthew Cox, a defense reporter with Military.com [4], details how "U.S. Army medical officials want the defense industry to create wearable monitors to detect whether service members are displaying symptoms of the novel coronavirus."

"Army Medical Research and Development Command recently invited defense firms to submit proposals for a $25 million effort to design prototypes of a wearable diagnostic capability for 'pre-/very early symptomatic detection of COVID-19 infection,' according to a recent request for project proposals issued through the Medical Technology Enterprise Consortium (MTEC). 'There is a dire and urgent need for the development of rapid, accurate wearable diagnostics to identify and isolate pre-symptomatic COVID-19 cases and ... prevent the spread of the virus,' the solicitation states."

Summary

As we use some of these technologies in our everyday life, it's easy to create emotional ties to the mil-aero revenue stream. PWB fabricators that want to be part of history have a revenue stream from products that might have contracts for a decade or more and, like challenging new technology, should consider certification to MIL-PRF-31032 (printed wiring board requirements for the DoD). **PCB007**

References

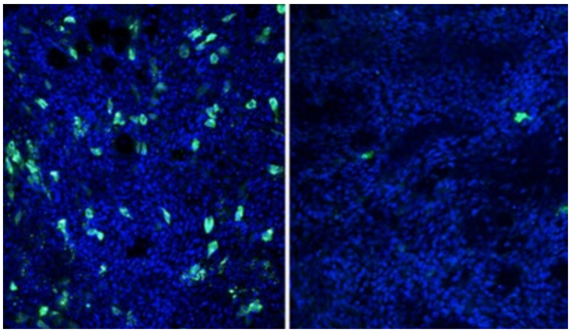
1. N. Caldwell, "11 Incredible Products That Were Really Invented by the U.S. Military," *Mic*, March 31, 2014.
2. K. Mizokami, "The Air Force Is Moving From Smart Bombs to Thinking Bombs," *Popular Mechanics*, July 15, 2020.
3. R. Sammon, "8 Amazing New Military Technologies," *Kiplinger*, December 29, 2016.
4. M. Cox, "Army Wants Wearable Coronavirus Symptom Detector for Soldiers," Military.com, May 11, 2020.

Mike Hill is president of MIL-Q-Consulting LLC. He has been in the PWB fabrication industry for over 40 years. During that time, he participated in specification writing for both IPC and the military. Past employers include ViaSystems, Colonial Circuits, and DDi. To read past columns or contact Hill, click here or email Milqconsulting@outlook.com.

Portable MRI Can Detect Brain Abnormalities at Bedside

A new portable MRI device detected specific brain abnormalities in 29 of 30 patients taken to Yale New Haven Hospital's neuroscience intensive care unit after presenting with symptoms of stroke and other neurological disorders, according to a new study published in the journal *JAMA Neurology*.

The research is the first known attempt to deploy a mobile, bedside, magnetic resonance brain-imaging device, which promises to provide an immediate diagnosis to doctors in virtually any setting with a standard electrical supply.



"Brain-imaging is key to acute care neurology and is a critical determinant of making the correct diagnosis and identifying the optimal treatment option," said Yale's Kevin Sheth, professor of neurology and neurosurgery and co-corresponding author of the new study.

Using the portable MRI device, researchers from Yale found evidence of ischemic stroke, hemorrhagic stroke, subarachnoid hemorrhage, traumatic brain injury, and brain tumors in patients presenting with neurological symptoms at Yale New Haven Hospital.

The portable device could be used by doctors in poor countries, rural areas, or even in ambulances to differentiate between stroke symptoms caused by a brain bleed or blood clot. This information is crucial in determining the course of treatment.

The cost of the portable MRI device is expected to be a fraction of traditional MRI machines, which use extremely strong magnets and can only be used in specially designed rooms.

(Source: Yale News)

MilAero007 Highlights

Understanding MIL-PRF-31032, Part 2 ▶

In Part 2 of this series on understanding the military PCB performance standard MIL-PRF-31032, Anaya Vardya explains how the first step in the process is to develop a quality management plan.

Summit Interconnect Adds John Vaughan to Lead Strategic Market Initiatives ▶

Summit Interconnect Inc. is pleased to announce the addition of PCB and EMS industry veteran John Vaughan as vice president of strategic markets.

TT Electronics Receives Grant From Innovate UK ▶

TT Electronics, a global provider of engineered electronics for performance-critical applications, announced it would receive Innovate UK funding for furthering innovation in the nation's civil aerospace industry. These funds have been awarded to participants in the Aerospace Electric Propulsion Equipment, Controls & Machines Project led by Safran.

Lenthor Engineering Announces Mid-Year 2020 Financial Results ▶

Lenthor Engineering Inc.—a California-based designer, manufacturer, and assembler of rigid-flex and flex PCBs—announced its 2020 mid-year financial results.

BAE Systems Honors Graphic PLC With Supplier Award ▶

Graphic PLC announced it won an award for exceptional performance and contributions to supply chain success in 2019 for BAE Systems' Electronic Systems sector. Graphic PLC was selected from a pool of more than 2,200 suppliers that worked with the sector in 2019.

iNEMI 2019 Roadmap Webinar Review: Aerospace and Defence Products ▶

The iNEMI Roadmap is recognised as a valuable tool for defining the state-of-the-art in the electronics industry, identifying emerging and disruptive technologies, and setting industry R&D priorities over the next 10 years. Pete Starkey provides an overview of iNEMI's latest in a series of webinars highlighting the roadmap's assessments of evolving product requirements, manufacturing infrastructure issues, and technological needs and gaps.

Just Ask Joe: The Land Warrior Project ▶

First, we asked you to send in your questions for Happy Holden. Now, it's Joe Fjelstad's turn! In this segment, Joe provides an update on the Land Warrior Project.

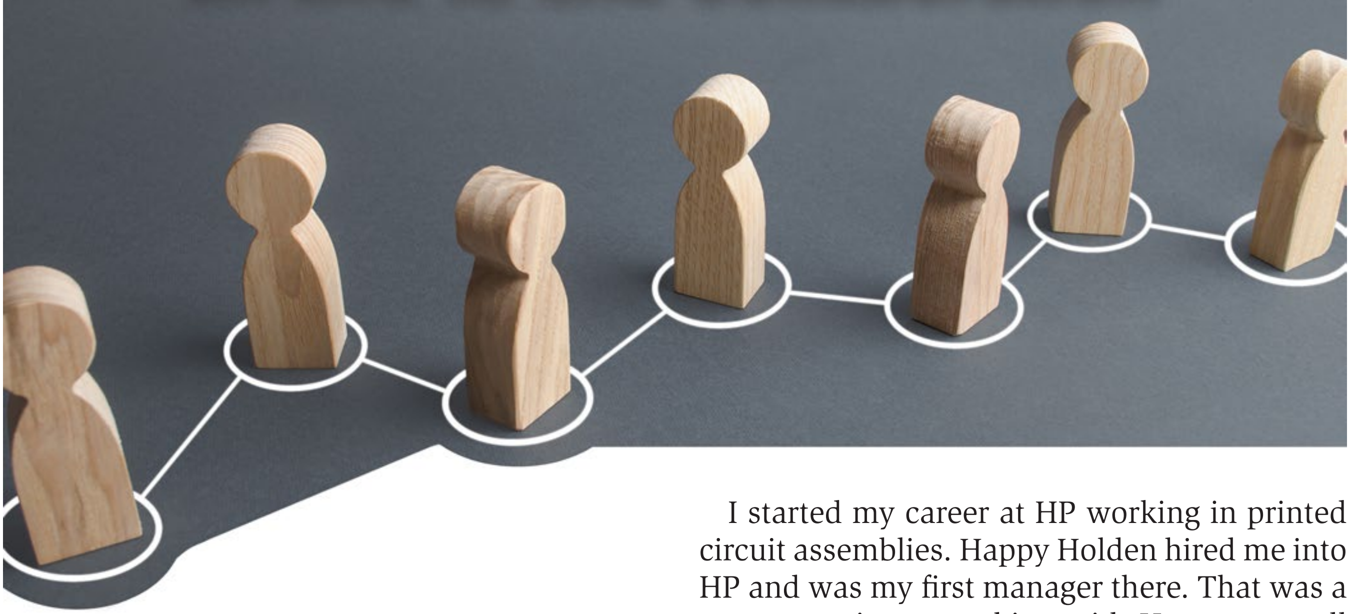
U.S. Defense, Air Force Invite Hackers to Reimagine How Space Systems Are Secured ▶

The U.S. Department of the Air Force and Department of Defense are changing the way they approach building secure and resilient space systems by inviting the global security research community to hone their space domain hacking skills in an open and collaborative environment.

Lockheed Martin, USC Build Smart CubeSats, La Jument ▶

Lockheed Martin is building mission payloads for a Space Engineering Research Center at the University of Southern California Information Sciences Institute small satellite program called La Jument, which enhances artificial intelligence and machine learning space technologies.

The Fabrication Supply Chain Is an End-to-End Collaboration



Feature Interview by Nolan Johnson
I-CONNECT007

Cost containment always sounds like the best option, but Tim Rodgers, Ph.D., a faculty instructor at two universities in Colorado, explains that in proper supply chain management, you also have to consider how it influences business optimization. In this interview, Rodgers discusses costs and expenses, as well as taking a holistic approach to procurement during the pandemic and beyond.

Nolan Johnson: Tim, please introduce yourself to the readers.

Tim Rodgers: I had a 30+ year career working in places like Hewlett-Packard and Eastman Kodak. I also spent two years working in China for Foxconn. Some of your readers may know Foxconn as one of the world's largest contract manufacturers. I've had a chance to work on both sides of the supply chain, as a buyer and on the procurement side, which gives me a unique perspective.

I started my career at HP working in printed circuit assemblies. Happy Holden hired me into HP and was my first manager there. That was a great experience working with Happy, as well as getting to know Clyde Coombs and some of the other demi-gods in the world of printed circuits. Way back in the distant past, HP actually manufactured their own bare boards, printed circuits, and printed circuit assemblies.

Now, I teach as a faculty instructor at both Colorado State University in Fort Collins and at the University of Colorado in Boulder, where I'm also an associate department chair. One of my classes at both universities is supply chain management, and it's still quite a passion of mine.

Johnson: Looking at the supply chain and how it fits into the costs and expenses for running a business, where do we get started in talking about this?

Rodgers: Everybody has suppliers, whether it's hardware, software, or engineering talent. Good supply chain management is by far the biggest contributor when it comes to cost. It comes down to asking questions like, "Are we using standard components, or are we using unique, specialized components that have higher cost?

Tim Rogers

Are we buying from suppliers that can produce in large quantities and achieve economies of scale, giving us lower prices? Or are we buying from suppliers that are pretty low-volume suppliers, where prices might be a little bit higher? Are we actively working with our suppliers to find ways to reduce cost and improve quality, or are we just buying stuff from a catalog?" That contributes to cost as well.

Supply chain management was getting a lot of attention even before the current pandemic because it creates a huge opportunity to impact both the cost and quality of our products. It also impacts performance. Companies that identify good suppliers improve the performance of their products because their suppliers may have access to technology or technical capabilities that the company is unaware of. Your supplier can enable you to achieve higher performance. It's not just about cost or quality; it's also about achieving higher levels of performance, and I encourage companies to take a hard look at their current suppliers and ask whether these suppliers will help them achieve their quality, cost, and performance goals.

Johnson: Let's walk through this systematically. You started with cost savings. Your suppliers are providing outsourcing for some of your processes. When you were at HP, much was manufactured in-house, and we have absolutely shifted away from that. One of the motivations for that shift was cost savings. If you can use a supplier on a project-based, as-needed basis rather than having a sunk cost, there should be cost savings, but does that still hold true?

Rodgers: It depends on the specific thing you're buying. There are a lot of companies that have brought production of certain critical components in-house, and there are a couple of reasons for it. If you really feel that the source of your competitive advantage as a hardware producer—assuming that you have a hardware product of some kind—is some specific technical capability, the only way you can really maintain that competitive advantage is to produce that component or subsystem internally. In other words, if you're buying the same component or commodity that everybody else is buying, how is that going to help you achieve a competitive advantage?

That makes sense for things like resistors and capacitors. These are basically commodity components. But if your product depends on the performance of a custom ASIC of some kind, then maybe the right thing for you to do is to produce that ASIC in-house as much as possible. You may use a fab of some kind to produce the ASIC, but the in-house design provides you with a competitive advantage. I encourage companies to look at everything they buy and consider whether those components really contribute to their competitive advantage as a hardware producer. Does it help your product compete more effectively, or is that not a source of competitive advantage? If not, then you're better off buying from a low-cost supplier because, in most cases, that will save you money.

Keep in mind that anything you produce in-house will probably be in lower volumes. You'll have a lot of capital equipment, expenses, and investments to support that internal production, which means your pricing will be higher. Now, you may be willing to pay more money to produce this in-house because it gives you a competitive advantage. That's a discussion that I'd like to see design, R&D, and new product development teams have with their procurement organizations. What commodities can we buy on the open market to save money, and what commodities or components should we be producing in-house?

Johnson: That's a great perspective for OEMs and assembly houses. Let's talk specifically about PCB fabrication; where is the trade-off there?

Rodgers: I've been a little bit out of the printed circuit manufacturing game for a while, so I don't know whether there are any OEMs producing their own bare boards. I'd be surprised if anybody is still doing that kind of work.

Johnson: That seems to be on the horizon. The environmental liability and cost increases all became a burden and moved fabrication overseas, for the most part. Now, we can see some large-scale shifts in the supply chain again. China is increasingly proactive about being green and very assertive about making sure that fabs are not polluting. That, along with China emerging as more of a first-world country, changes the economics of the cost structure.

Rodgers: We're starting to see people looking for even lower-cost locations—not just for bare boards, but for assemblies as well. This isn't just driven by tariffs; it's also driven by the chase for lower-cost labor. We see companies going to places like Vietnam or other areas in Southeast Asia. Mexico is starting to look attractive again, too. In most cases, the labor costs are still higher in Mexico than in China, but the gap between those is getting smaller and smaller.

Johnson: Right, one of the pillars involves labor costs and expenses. Then, there is expertise. We need to go where the expertise is. Currently, that may not be in the U.S.

Rodgers: That's a very good point. Again, I'm not sure how many companies are still building bare boards. There might be some prototype shops building pretty small quantities, but this is expensive equipment—lamination, drilling, and electroplating—that most people have been getting out of over the years.

Johnson: There are a few new facilities in North America. One lighting manufacturer brought its board fabrication back from China by building an in-house facility in New England. They built themselves a private facility, and it was so effective that they built a new one that is essentially lights-out, fully automated, with most of their processes in a horizontal approach.

Rodgers: At those low volumes, it might make sense to produce it in-house because of the costs; these offshore factories are typically set up for high volume. If you're running a low volume business, you have your own internal capability. At that point, the costs start to look more similar; the cost-to-outsource versus the cost to go in-house. If you're doing a lot of prototyping, having a small facility in-house and shortening that communication loop between your design team and the production of new components can be extremely valuable and can pay for itself.

Johnson: We're starting to see co-op shops over the horizon, where a handful of companies may partner together to build a facility, then cost-share the operations.

If you're in a business that needs to respond quickly to changes in your market, you need a responsive supply chain.

Rodgers: Something we haven't talked about yet is time to market. If you're in a business that needs to respond quickly to changes in your market, you need a responsive supply chain. You may not be able to afford to have your components coming on a ship all the way across the Pacific Ocean. If you're making red ones today, and your customer wants blue ones tomorrow, it may be worth it to have a responsive supplier onshore, like the cooperative approach that you were describing. It's certainly a higher cost, but it provides the responsiveness that you need. We shouldn't overlook the fact that sometimes it's worth it to spend more money.

Johnson: It boils down to the end-to-end cost. If I'm a job shop PCB facility in the U.S., how do I approach my supply chain? It's not exactly the components and chips and ASICs that affect me; it's a different set of raw materials that I'm using.

Rodgers: Bare boards are basically custom components. Whether they're designed in-house or by somebody else, they must be consistent with a schematic by your designers. I suspect a lot of companies are still designing their own. Some are probably outsourcing even that part of the operation, working with the dedicated design team at the fab shop. But the components on that board is where you might be able to save a lot of money.

One of my first responsibilities at HP back in the 1980s was working on a design for manufacturability manual. We wanted to put a DFM manual in the hands of our printed circuit designers to help them with their decision-making process. Is it better to add more layers, or is it better to have finer lines and spaces? Which one adds more cost? Finer lines and spaces typically mean yield loss due to opens and shorts, but more layers lead to higher material cost. You should look for a fab shop that can support you in DFM decision-making, knows their own production processes, understands where the yield losses are, and what the contributors are to the overall cost. You want to have a partner who can work with you on circuit design to help you lay out your bare board in a way that minimizes your costs but still maintains the level of performance you're looking for.

Johnson: That makes sense, except that in the industry right now, even the PCB fabricators tend to push board fab into a commodity service. A common refrain is, "Bring me your design when it's finished, and I'll tell you what it will cost." As we move forward, there needs to be more engineering consulting in the process. The decision and selection of your fabricator shouldn't be when your design is done, and you've accidentally built in a whole bunch of cost additions, but early in the design so they can collaborate along the way, making sure that the design team makes appropriate trade-offs.

Rodgers: Absolutely. It will save you more money in the long run. I always advocate for a close relationship between hardware designers and your procurement or purchasing team. There needs to be a collaboration between those two groups within your organization. We don't want the procurement people always looking for the lowest quote. Sometimes, it's a question about the total cost of ownership. You get better results in the long run by working with a supplier that has the engineering capability to work with your hardware designers to create a lower-cost product and can collaborate in that process.

I suspect your readers are outsourcing the design work as well. Maybe they provide a schematic, and then somebody else creates the Gerber files that are necessary to actually drive the production of the circuit boards. We can't just look at this in isolation. There has to be a marriage between the technical solution needs and cost opportunities.

Unfortunately, in many companies, the procurement and engineering parts of the organization aren't cooperating or collaborating. In some ways, they're at odds. The procurement people are being measured on how much they can drive costs down, but the engineering part of the organization is being measured on how well it can drive performance up, and those are often in conflict with each other.

Johnson: Can you share an example of a company that has either a great experience with that collaboration or an abysmal one?

Rodgers: In Colorado, there's a division of a company that makes controllers used for flow meters and other devices like that. They do a really nice job of integrating and getting the engineers who develop new products to work with the supply chain team and procurement team. It's not just looking at current products, either. When they think about future designs and products, they want to make sure their suppliers have the capabilities that they need for the future.

In some cases, that means working with their existing suppliers to improve their capa-

bilities. Other times, it's identifying new suppliers not currently in their supply base, but always ensuring that when the time comes and these new designs come to market, suppliers can meet their needs.

Johnson: The decision point for making sure that procurement and engineering are working together is senior management?

Rodgers: That's where they come together. We want a clear message from senior management that these teams need to work together and that they will be measured on their collaborative performance. Their performance measures are not in conflict with each other. The procurement team is not there just to do the bidding and finding the cheapest suppliers to squeeze them on the price. Their job is to enable the hardware team to achieve whatever level of price performance that they're looking for. That starts higher up in the organization.

Johnson: I'm now imagining that as a PCB fabricator, I'm working more closely with an engineering team and helping them understand how to make their design the lowest cost and highest yield for them. As a fabricator, what's in it for me?

Rodgers: That's a great question and it comes up a lot. Isn't it in my best interest to promote the higher cost solution, especially if it means higher profit for me? I would suggest that if you want future business from a customer, then having a team-based approach will create more value for your customer. That's more valuable to the hardware OEM and will win you more loyalty in the long run. Even if you're a small OEM, you still may have something of value to a supplier that would incentivize them to want to work with you as a team instead of just in a transactional relationship.

Johnson: That is a fundamental shift. We need to move away from being strictly transactional.

Rodgers: I agree. I've had this discussion with a lot of people in supply chain management. If you want to have a transactional relationship with your supplier, where I pay you, and you provide the stuff that I order, you can do that. But don't be surprised if the suppliers don't knock themselves out on your behalf, or if they don't return your phone call right away because it's just a transactional relationship.

I'm not advocating that you have to be close partners and buddy-buddy with all of your suppliers, but everybody has critical components in their systems where assurance of supply, quality, and ongoing engineering cooperation are important. I encourage supply chain managers to identify what those critical components are, and then invest in more of a partnership relationship instead of treating it as an arm's length transactional relationship.

Johnson: That argument you just made screams PCB fabrication.

Rodgers: Again, PCBs are custom components. You can't just buy them off the shelf. If you expect higher levels of performance from your supplier, then you need to spend a little bit of extra time on the relationship. You can't just have an arm's length transactional relationship. Otherwise, you just look like another customer, and why should your supplier knock themselves out?

Johnson: I'm mindful of the PCB fabricators that have a largely e-commerce model. That seems to be pushing pretty strong on the transactional business model.

Rodgers: Let's face it—it's getting a lot harder these days to visit these suppliers. It's just about impossible. Even before the pandemic, it was cost-prohibitive for a lot of folks, so it tends to be more of a virtual relationship, which makes it a lot harder to establish that sense of partnership. But what do you have to offer? Do you have high-volume purchases? If we're working together on this design and can reach an agreement, there are going to be thousands or hundreds of thousands of units that we're going to purchase from you. That's obviously very attractive to your supplier. Are you working in a new kind of market segment that's attractive to this supplier? Are you working with flexible circuits or molded circuits, 3D circuits? This could provide an opportunity for your supplier to develop more expertise that they can then use as a way of attracting additional customers. You may have something to offer in that category.

You shouldn't look at your supplier as just a way of providing the lowest cost option. Smart companies treat their suppliers as an extension of their own internal manufacturing. Yes, they're a different company, and they have other customers, but you should really treat them as an extension of your own internal production. Your suppliers can enable you to achieve higher levels of performance because of the capabilities that they have.

Maybe you talk to a supplier about a basic FR-4 multilayer rigid board, but then you discover that your supplier has other capabilities, like flex circuits or molded circuits—more three-dimensional designs. Now, suddenly, because your supplier has this capability that you didn't really think of before, your engineering team can create a completely different kind of product because of the capability of the supplier.

Johnson: Or, in the case of a PCB fabricator, spending much more time understanding the other materials available from their suppliers.

Rodgers: Does it have to be an FR-4? You might be able to achieve higher levels of electrical or thermal performance by using a different kind of material altogether that you didn't really think about before, but your supplier has experience fabricating boards with those materials, which opens up other possibilities for your design team.

Johnson: What do you see as some of the challenges we'll face in the next year or two?

Rodgers: The tariffs and the pandemic together have caused people to think a lot about the assurance of supply. A lot of companies have been driving their inventories down to very low levels. Lean manufacturing has been extremely popular for a long time, and people get it. It means keeping low inventories and reducing the number of suppliers. Instead of spreading our purchasing out across a wide supply base, we use fewer suppliers and concentrate our purchasing power, thereby allowing us to get better pricing.

The tariffs and the pandemic together have caused people to think a lot about the assurance of supply.

All of that makes sense, but now we're getting hammered over assurance of supply because suddenly our suppliers are located in parts of the world that have political risk—in the case of tariffs, or our inventories have reached such low levels that we can't quickly respond to changes in the supply chain. I just saw an article that said laptop sales had gone unexpectedly through the roof as a result of the pandemic. Companies that thought they were running a pretty mature business—laptops have been around for a long time—suddenly had to figure out how to scale up their supply chain. They didn't have the inventories in components, sub-assemblies, or boards to support the increase in demand.

Now we see two competing trends—one toward lean and lower inventories to reduce cost, and the other toward creating a more resilient, adaptable supply chain that can react quickly to changes in demand. That costs more money, and it's a higher cost supply chain. That might mean having more suppliers or suppliers in different parts of the world. Remember the big tsunami that hit Japan back in 2011? It wiped out a lot of electronics manufacturers and caused companies to wonder whether they should be concentrating their supply chain in just one part of the world. Diversifying adds cost to your supply chain, so how much is that worth?

We'll see companies try to develop a broader supply chain, with more suppliers that are geographically dispersed, but that gravitational pull of lower cost is always going to be there. I predict that it's only going to be a matter of time before we swing back the other way again and reduce the number of suppliers, than trying to concentrate our purchasing in certain parts of the world. Finding the balance is very, very difficult.

Johnson: This pendulum is going to keep on swinging until you can diversify and spread out the entire supply chain. You're going to see problem points somewhere.

Rodgers: Exactly. There's going to be specialization, and that's what has happened with electronics manufacturing in China, particularly in Guangdong province; there's just an incredible concentration of skilled and experienced suppliers. To reproduce that elsewhere is going to be difficult and expensive.

Johnson: What are your thoughts on Blockchain, Tim?

Rodgers: Blockchain is getting a lot of attention. It's great for certain supply chains because it's basically a distributed ledger that allows every step of the supply chain to make entries that are visible. It provides traceability, and it's a great technology, but I would caution not to jump into blockchain without thinking clearly about what problem it would solve for their business. Do they have a business where traceability is important, or where they really need to know exactly what's going on at every step of the supply chain? Blockchain is still a relatively expensive technology, and if you're looking into it, be clear about what problem you're trying to solve before you invest in that technology.

We're seeing examples of companies in the food business that want to make sure that they have traceable supply chains, where they know exactly what the provenance is for the raw materials that go into their products, and whether they are using sustainable practices. It's also a great way of eliminating some of the paperwork in supply chains. But I'm just afraid that people will spend a lot of money on blockchain and not get the results for which they were hoping. Then, blockchain gets a bad rap.

Johnson: In *The 7 Habits of Highly Effective People,* Stephen Covey says, "Begin with the end in mind."

Rodgers: Absolutely. What problem are you trying to solve? Then, seek a solution to that problem. Don't rush and implement something because you think it will magically improve your performance. You have to dig a little bit deeper.

Johnson: It does. Tim, this has been a fantastic conversation. Thank you so much.

Rodgers: You're welcome. **PCB007**

A Path to Successful PCB Fabrication

The PCB Norsemen
Feature Column by Didrik Bech, ELMATICA

In the PCB fabrication process, there can be multiple actors involved, ranging from designers to developers, project leaders, salespeople, business developers, accounting personnel, government officials, and industry associations. How can you ensure that all these actors are cooperating to maximize the positive effects and minimize the negative effects of the pillars of PCB fabrication? It might sound like an insurmountable task, but there is a path that can increase your chances of success.

PCB Fabrication Pillars

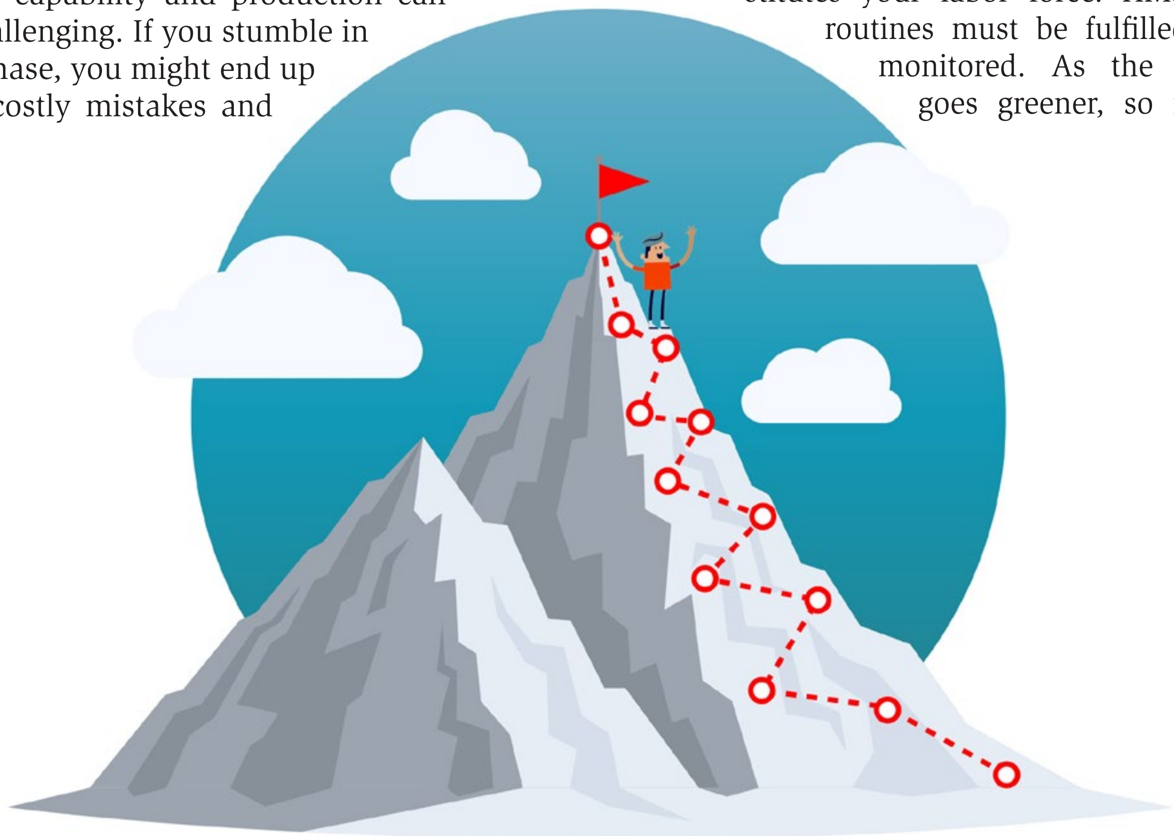
The First Pillar: Technology

PCB capability and production can be challenging. If you stumble in this phase, you might end up with costly mistakes and delays later in the process, so keep your focus and consider the following questions:

- What are the demands for the product?
- What technology is feasible for your demands and design?
- Will the design require flexible, rigid, or rigid-flex printed circuits?
- What PCB laminates are suitable, considering whether the product needs reliability for harsh environments?

The Second and Third Pillars: Labor and Cost

Choosing the right internal team, as well as partners and manufacturers, is vital and constitutes your labor force. HMS and routines must be fulfilled and monitored. As the world goes greener, so is the



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demand for greener production, and environmental certifications. You don't want surprises in your production after release, and you need the right labor force with the knowledge and experience necessary to succeed. There are several examples where well-known market leaders in all industries faced bad PR cases when child labor was identified, or products were withdrawn from the market due to safety or regulatory concerns, or unsafe or unfair labor conditions. These elements can be detrimental for a product or company, and the costs can be shattering.

The Fourth Pillar: Sales

The fourth pillar is no less important. Your product is ready for launch and global distribution, but do you have the right partners to succeed and ramp up or adapt to new market demands? Do you have the necessary insurance or a solid relationship with your logistic partners offering the necessary priority you need? COVID-19 has shown us how brittle a supply chain can be, and we have all learned many lessons; have you taken those into consideration?

The Fifth Pillar: Cybersecurity

The fifth pillar of PCB production should be cybersecurity. Protecting your data and intellectual property rights is a core necessity to allow you to keep your competitors at bay and give you room to further develop your products. Are you working with partners with the necessary equipment and procedures to protect your data?

Six Steps to Success

Understanding the pillars of PCB fabrication without setting it into a proper context may not allow you to fully understand its challenges and opportunities. I see this context by laying a path from the start to the end of the product development process (PDP). It's essential to recognize at which step along the path you should involve the right actors based on the knowledge and expertise that the process requires is essential.

Unfortunately, actors are often brought in too late or at the wrong stage of the PDP, resulting in slower development, increased costs, and a suboptimal product. It is vital that the project leader for every new idea institutes a clear plan, path, timeline, and goals, as well as what to do if you are successful or unsuccessful.

Here are six steps to success, from concept and idea generation to product launch and distribution.

1. Concept and Idea Generation

An idea itself will not end up as a product. When starting a PDP, you need to ask all the important questions. What is possible, cost-effective, legal, smart, and most optimal for your electrical product? What technological solution should you select, and at what price? At this stage, there is a tendency not to involve actors, such as procurement, sales, and accounting. These actors have unique knowledge regarding what technology the market actually is requesting (sales), cost-and-benefit analyses of technological solutions (procurement), and the actual profitability of the potential solution (accounting).

2. Research and Analysis

When the concept is set, research and analysis can begin. Ensure that you have all the actors to help you. The analysis is a key strength during any PDP, and this stage is often underestimated. Resources are spent on a product that the market either did not request (sales) or are labor-intensive and expensive (procurement and accounting). Spend time developing a comprehensive cost, sales, and market analysis. Know your market, and then you will know your product.

3. Design

When all parameters are set, and the analysis is complete, you are ready to start designing. Avoiding costly mistakes in your design

and knowing at an early stage whether the design is optimal or not will ensure that the right manufacturer is selected for your design. Procurement and third-party actors are key during this stage to ensure that the right partners are selected. The costs can vary greatly if you select the wrong manufacturing entity at this stage, as they might lack the optimal technical capability, capacity, or experience with the product you are designing.

Many entities say, "Yes, we can," but do you really know? How can you really find out? My advice is simple: Make sure you have the right knowledge and experience internally or through third-party entities to secure your design and manufacturing selection.

4. Prototype

Building your prototype is one of the most exciting phases during your PDP. Are all parameters covered, and will you meet the deadline? Are the manufacturing entities qualified and audited, and what is their experience with your type of products?

Working diligently in this phase will save you lots of trouble and costs. Select the right manufacturer from the beginning based on the expected sales volume of your product, compliance in relation to environmental standards (IPC, UL, automotive, medical, defense, ROSH, REACH, and numerous others). The cost of requalification is not only expensive and time-consuming, but it can determine whether you are actually allowed to access a market or deliver a bid.

5. Production

When volume production kicks in, you want to make sure you are in good hands. Document your production and audit the manufacturer to secure your delivery. From here on, it is the supply chain management, combined with the market demand for your product, which will determine if your product can be a success.

Seamless production and being able to actively receive feedback from the market to improve your product will allow you to offer a good solution and create the trust that is vital to give your product a good reputation. Thus, your sales and market apparatus is key during this stage in combination with your designers and developers.

6. Launch

Your product is ready for launch and global distribution. Your global delivery platform and experience with documentation, regulations, and compliance should now be set. Having involved all the right actors at the right stage should now ensure that the pillars of PCB production are either stacked in your favor or reduced as much as possible. Get ready and launch.

5 Tips for Improved Product Development

1. Ask the Right Questions

Ask necessary why, how, where, what, and when questions.

2. Do Your Research

Involve an experienced partner to identify challenges, growth potential, and compliance.

3. Do Not Skip Steps When Designing

If PCB design is not your strength, involve someone with the right skills. This will save you from making costly mistakes. The same applies to your choice of manufacturer.

4. Know Where You Produce

Make sure to have a trusted partner for production who offers transparency, documentation, and audited manufacturers.

5. Do Not Forget Documentation

Do not step into the "I forgot documentation" trap. When your product is ready for launch, use a partner with a global delivery platform and experience with documentation, regulations, and compliance. You do not want your product to face trouble at the finishing line. A great idea is not equivalent to a viable one.

Conclusion

There are a lot of technologies to consider, designs to create, costs to be calculated, manufacturers to be selected, and sales quotas to be met. Numerous times, I have seen the unfortunate result of inadequate planning and execution in the early phase of the PDP. Thus, I strongly recommend structuring and spending more time during the first three stages of this process (idea, research and analysis, and design). This will ensure that your PCB manufacturing aspects are in line, handled, and optimized for your future sales. And remember that even though an idea might be great, it does not mean that it is technologically viable, labor optimized at an acceptable market cost, or able to bring in the required sales revenue. **PCB007**

Didrik Bech is the CEO of Elmatica. To read past columns or contact The PCB Norsemen, click here.

Upgraded Cleanroom Facilities Will Give UCLA Advanced Nanofabrication Capabilities

UCLA's high-tech capabilities for creating atomically tiny devices and materials are undergoing a multimillion-dollar upgrade. The enhancements include adding state-of-the-art fabrication equipment to its existing cleanrooms. The changes will allow researchers to build new generations of small devices, such as computer chips that mimic how the brain works, ultra-high-efficiency batteries and solar panels, and even biological sensors for rapid and portable diagnosis.

As part of the upgrade, two existing cleanrooms will merge under a single operation called the UCLA Nanofabrication Laboratory (NanoLab). The upgrades, which began this year, should be complete in 2022. The UCLA NanoLab is available to the campus community, as well as to researchers from other institutions and high-tech companies. Hundreds of businesses have already used UCLA's cleanrooms.

"This joint investment is an important demonstration of a strategic partnership with an impact that will extend across campus and beyond," said Adam Stieg, an associate director of CNSI responsible for the institute's technology centers. "Providing this type of advanced research infrastructure will accelerate the translation of early-stage scientific discoveries into new technologies and knowledge-driven enterprises."

Some of the upgrades will build on UCLA's established excellence in semiconductor lithography, the drawing of patterns onto the silicon wafers that form the foundation of integrated circuits. The new equipment will enhance the campus's capabilities for subsequent steps in the process, depositing functional materials onto the patterns, etching away unneeded parts of the wafers, and analyzing the characteristics of the resulting devices.

This added equipment will enable researchers to work with emerging materials that combine metal with oxygen or nitrogen. Potential applications include greener electrical power and brain-mimicking computer chips.

(Source: UCLA)

Communication Goes Both Ways

Flex Talk

by Tara Dunn, OMNI PCB

The definition of new technology in the PCB industry varies from person to person. I have been chasing new technology for 20 years. Some of it has been new to me, while some of it is new to the industry. First, it was flexible circuit technology, which was not new to the industry but was my first experience in PCB manufacturing. This was followed by rigid-flex and then complex HDI structures, which, again, were not new to the industry but were new to me.

I am also interested in and eager to learn about materials and processes new to the industry. Among those that have caught my eye is a new material from DuPont called Pyralux® GPL Sheet Adhesive. How exciting to think about the possibility of eliminating the bikini-cut adhesive for rigid-flex. And from a process perspective, learning about Averatek's A-SAP™ process, a semi-additive PCB process enabling 15-micron trace and space—how could I not be excited for all of the possibilities that this opens up for PCB design and simplifying complex HDI designs? From a medical application perspective, what about gold traces instead of copper traces applied on polyimide for a simple, biocompatible solution? This just scratches the surface of new materials and processes being introduced to the PCB industry.

What is the best approach when searching out technology new to you but not necessarily new to the industry? Those who read my column regularly can probably guess that my first piece of advice is to work with your fabricator. After all, if your fabricator is working with this technology every day they have a tremendous amount of knowledge built over time and are always happy to share and help guide customers through what can, at times, be a steep learning curve.

Flex and rigid-flex are excellent examples. First, plan a deep dive before starting your first design using flex or rigid-flex construction. On the surface, it may seem that flex is not all that different than a rigid PCB, outside of the obvious benefits to space, weight, and packaging with materials able to bend, fold, and flex. Over the years, I have accumulated so many stories and examples that disprove that assumption. There are the obvious examples of the "flex that didn't flex." The thickness and rigidity of solid copper shielding in the tail area of a rigid-flex can

build up much more quickly than anticipated. In working with your fabricator, they may recommend using "unbonded" layers in the flex area, which eliminates a layer of adhesive between layers and can significantly improve flexibility. Alternatively, they may recommend using crosshatch patterning in the flex area to improve flexibility.

Involving your fabricator early in the design process can also help prevent an approach that, while functional, may add unnecessary complications and expenses. Let me share a real-world example. A fabricator was asked to do a design review of a rigid-flex design being built at a competitor. This design was in production and functioning well, but the fabrication yield was consistently low, increasing costs beyond what the final product could bear.

Involving your fabricator early in the design process can also help prevent an approach that, while functional, may add unnecessary complications and expenses.

In this case, a designer new to rigid-flex had designed the circuit with a flex layer on the outer layer. This particular attribute created a chain reaction in fabrication. Because the flex was on the outer layer, laser cutting the coverlay was required to open the fine-pitch SMT pads. To ensure flexibility, the fabricator also had to use button plating to not introduce additional copper in the flex layers. These two things together forced the fabricator to use a smaller size fabrication panel to ensure proper registration. Each added cost, but together they had an exponential impact on cost.

This was redesigned using a rigid layer for the outer layers and a flex tail between the rigid areas. Although material costs were higher with the added rigid layer, the laser cut coverlay was eliminated, the button plating was eliminated, and the fabricator could use a larger panel size. Yields increased, and the cost to the end-user decreased by over 20%. Again, fabricators can be a valuable source of information when you are learning about new technologies and can help prevent costly mistakes and guide a designer along the learning curve.

Other times, other things are new to the industry as a whole, such as new materials, chemistries, and processes, to name a few. In these situations, it is also important to communicate with your fabricator, but in a slightly different way. Many times, they will be learning right along with a designer. Often, it is the material suppliers or technology developers educating the OEMs, the design community, and the fabricators. When there is a strong benefit for your application, it is important to discuss that with your fabricator so they can more easily understand the market need and timing for the demand from their customers.

One example of this is Averatek's A-SAP™ process. This semi-additive process fits in with subtractive etch processes to enable 25-micron line and space. This technology has been available for a couple of years and is now currently being licensed by four PCB fabrication facilities. Other fabricators are discussing the demand for this technology with their customers and making decisions on when or if it will be implemented. Just as they are happy to help someone new to flex or another technology along the learning curve, they are equally happy to receive feedback from their customers that help them make informed decisions.

Technology, whether new to you or new to the industry, requires communication between both the end-user and the fabricators. A collaborative approach benefits not only the end-user seeking the information but also the fabricator that will be providing the technology. PCB007

Tara Dunn is the president of Omni PCB, a manufacturer's rep firm specializing in the PCB industry. To read past columns or contact Dunn, click here.

Electronics Industry News and Market Highlights

Keysight Technologies, Cambridge Industries Group Accomplish Interoperability Testing of O-RAN Radio Units ▶

Keysight Technologies Inc.—a technology company that helps enterprises, service providers, and governments accelerate innovation to connect and secure the world—announced interoperability development testing (IODT) of O-RAN radio units (O-RUs) in collaboration with Cambridge Industries Group (CIG), an original design manufacturer (ODM), headquartered in Shanghai, China.

NSF Announces MIT-led Institute for Artificial Intelligence and Fundamental Interactions ▶

The U.S. National Science Foundation (NSF) announced an investment of more than $100 million to establish five artificial intelligence institutes, each receiving roughly $20 million over five years. One of these, the NSF AI Institute for Artificial Intelligence and Fundamental Interactions (IAIFI), will be led by MIT's Laboratory for Nuclear Science and become the intellectual home of more than 25 physics and AI senior researchers at MIT and Harvard, and Northeastern and Tufts Universities.

Trend Micro CEO Eva Chen Named to Top 100 Women in Cybersecurity for 2020 ▶

Trend Micro Incorporated, the leader in cloud security, announced its CEO and Co-Founder Eva Chen had been recognized as one of the most influential women in the cybersecurity industry.

Columbia Engineering: Laser Inversion Enables Multi-Materials 3D Printing ▶

Additive manufacturing—or 3D printing—uses digital manufacturing processes to fabricate components that are light, strong, and require no special tooling to produce. Over the past decade, the field has experienced staggering growth, at a rate of more than 20% per year, printing pieces that range from aircraft components and car parts to medical and dental implants out of metals and engineering polymers.

Eliminating Latency in Next-Gen WiFi 6E Devices ▶

The product utilizes a novel proprietary ceramic material in a low temperature co-fired ceramic (LTCC) manufacturing process designed to improve performance similar to high-Q standards' performance. The high-Q factor is a unitless numerical value that represents the performance of an RF component.

DuPont's Bryan Barton Named Kavli Foundation Emerging Leader in Chemistry Lecturer ▶

Bryan Barton, Ph.D., was selected to present The Kavli Foundation Emerging Leader in Chemistry Lecture at the American Chemical Society (ACS) Fall 2020 Virtual Meeting and Expo. The meeting took place on August 17–20 with the theme of "Moving Chemistry From Bench to Market."

Ibeo, ams Solid-State LiDAR Technology Used by Great Wall Motor to Enable Autonomous Driving Vehicles ▶

ams, a worldwide supplier of high-performance sensor solutions, and Ibeo Automotive Systems GmbH, the German specialist and the global technology leader for automotive LiDAR sensor technology and the associated software, confirm that ams vertical cavity surface-emitting laser (VCSEL) technology is a core component of Ibeo's newly-developed solid-state LiDAR solution.

A Process Engineer's Guide to Interconnect Defects

Trouble in Your Tank

by Michael Carano, RBP CHEMICAL TECHNOLOGY

Introduction

For those associated with PCB fabrication, one of the biggest nightmares is the infamous interconnect defect (ICD). Essentially, an ICD is a separation of the plating from the interconnect foil. The industry typically classifies this defect into four categories. Type 1 describes the situation where the electroless copper separates from the inner layer copper face. Of course, there are other types of separation that can be encountered.

It is well known that the electrolytic copper may separate from the electroless copper, but the electroless copper remains on the interconnect. This situation is referred to as Type 2 ICD. Whereas Type 1 references the electroless copper separating from the inner connect post or inner plane, there is a third type where the electroless copper deposit separates from itself. This is more like a cohesive failure within the deposit. Type 3 is very difficult to detect and requires excellent micro-sectioning and polishing techniques to properly detect and troubleshoot the root cause. Finally, one defect you may encounter is the fourth type of ICD, D-Sep.

Type 1

A type 1 ICD occurs due to a number of factors. First and foremost, an extremely high rate of deposition introduces internal stress into the electroless deposit. When the deposit is highly stressed, most thermal excursions will cause the copper deposit to separate from the inner layer post. The separation can be as little as a hairline fracture to small separations along the face of the post. One solution to mitigating a Type 1 ICD is to slow down the rate of copper deposition. Also, it prevents over-catalyzation (excessive palladium at the interconnect face) and reduces operating temperatures.

D-Sep

D-sep is also a separation of the electroless copper deposit from the interconnect. However, unlike a Type 1 ICD, which occurs after a thermal excursion (solder shock, assembly, etc.), D-sep occurs without any thermal stress (Figure 1). D-sep is caused by excessive stress in the deposit, allowing the separation that resembles the letter "D," hence the name. Other possible root causes relate to the interruption of the plating mechanism that leads to a misoriented grain structure of the copper deposit,

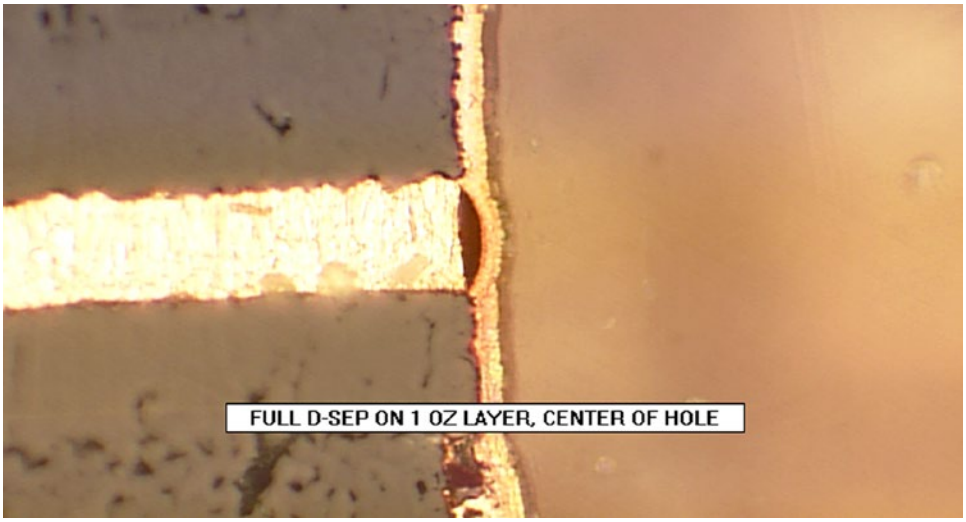

Figure 1: D-sep.

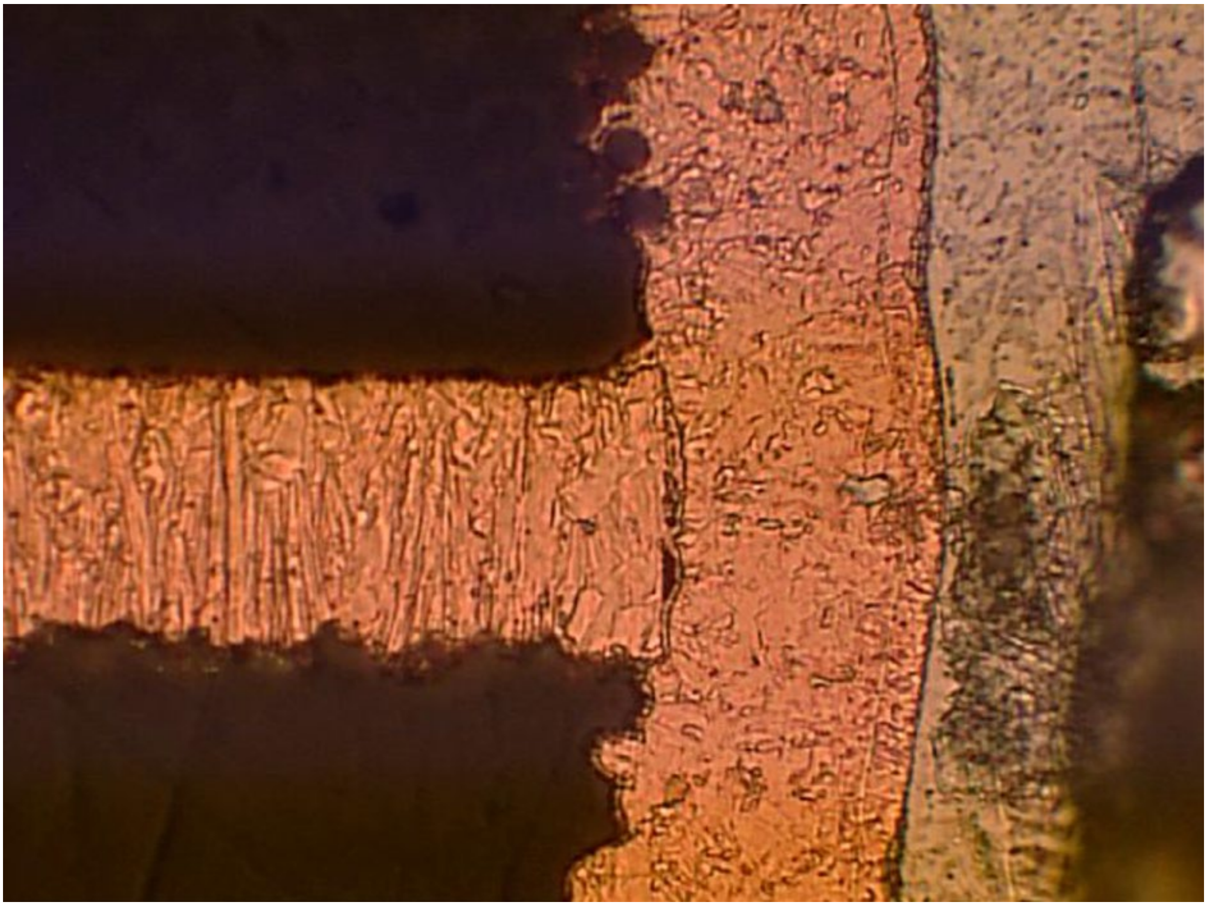

Figure 2: Type 1 ICD.

whereas with a Type 1 ICD, a thermal excursion is required to cause the separation of the electroless copper from the post (Figure 2).

One can easily surmise that a Type 1 ICD and D-sep are the result of a highly stressed copper deposit. However, there are several other potential causes of these issues that must be considered. Deposit stress can be introduced in a variety of ways.

Since D-sep occurs without the application of a thermal excursion, a skilled troubleshooter would look at the following areas. This exercise includes both chemical and mechanical parameters related to the electroless copper process. The main cause of D-sep can be summarized as a change in the deposition conditions of the copper deposit. This is not due to drill smear remaining on the interconnect post. The change in key chemical parameters, including the hydroxide concentration, solution specific gravity, and solution temperature are outlined as follows:

1. **Low caustic level:** Depleting the caustic stops the plating reaction.
2. **High specific gravity:** By-product components are produced that have an inhibiting effect on the chemical plating, most notably sodium sulfate and sodium formate.
3. **Vibration:** Vibration removes air bubbles that may be trapped in the hole as it enters the tank. Hydrogen gas is produced during the reaction and needs to be removed from the holes.
4. **The temperature of electroless:** Higher temperature increases the plating rate. If solution is not transferred fast enough, the reaction stops.

As the following reaction shows, the electroless copper plating solution ages over time with the buildup of formate, carbonate, and chloride as by-products. These by-products are measured with specific gravity but are not individually differentiated. Chloride increases linearly with the consumption of cupric chloride. Carbonate is formed as carbon dioxide from the air reacts with sodium hydroxide in the bath. Assuming air flow is constant, carbonate will build linearly. Formate also tends to grow linearly at low levels through several reactions:

1. $2HCHO + OH^- \rightarrow CH_3OH + HCOO^-$ (Cannizzaro reaction)
2. $2Cu(II)(chel) + HCHO + 5OH^- \rightarrow Cu_2O + HCOO^- + 3H_2O + 2(chel)$
3. $2HCHO + OH^- \rightarrow HCOO^- + H_2$

Formate and other by-products contribute to the increase in specific gravity, which reduces plating rates. With this situation, one can find the occurrence of D-sep.

Some ways to prevent D-sep include:

- If D-sep occurs, raise the caustic level in the electroless copper solution to 9.5 g/L
- Lower the operating temperature of the copper plating solution
- Reduce the specific gravity of the bath
- Increase the ability of the solution to flow through the holes
  - Increase vibration
  - Increase solution movement
  - Ensure proper rack agitation
  - Open up the spacing between boards

Other areas that will help include:

- Increase rinsing to clean the holes
- Raise the temperature of the rinse water
- Increase the pH of the rinse before electroless
- Ensure desmear is giving a clean hole and not dragging any chemistry down the line

Conclusion

As a process engineer, one must be able to discern the difference between a Type 1 ICD and D-sep for the simple reason that the root causes are different. Thus, the troubleshooting exercise will require one looks at different areas of the fabrication process to properly solve the ICD. **PCB007**

Michael Carano is VP of technology and business development for RBP Chemical Technology. To read past columns or contact Carano, click here.

Wireless Device Makes Clean Fuel From Sunlight, CO_2, and Water

The device, developed by a team from the University of Cambridge, is a significant step toward artificial photosynthesis, based on an advanced photosheet technology, and converts sunlight, carbon dioxide, and water into oxygen and formic acid—a storable fuel that can be used directly or converted into hydrogen.

The results, reported in the journal *Nature Energy,* are a new method for the conversion of carbon dioxide into clean fuels. The wireless device could be scaled up and used on energy farms similar to solar farms, producing clean fuel using sunlight and water.

Harvesting solar energy to convert carbon dioxide into fuel is a promising way to reduce carbon emissions and transition away from fossil fuels. However, it is challenging to produce these clean fuels without unwanted by-products.

"It has been difficult to achieve artificial photosynthesis with a high degree of selectivity so that you're converting as much of the sunlight as possible into the fuel you want rather than be left with a lot of waste," said first author Dr. Qian Wang from Cambridge's Department of Chemistry.

"We were surprised how well it worked in terms of its selectivity. It produced almost no by-products," said Wang. "Sometimes, things don't work as well as you expected, but this was a rare case where it actually worked better."

(Source: University of Cambridge)

ENIG: Corrosion and Learning From Failures

Article by Britta Schafsteller, Gustavo Ramos, Mario Rosin, Sebastian Weissbrod, and Timo Schlosser
ATOTECH DEUTSCHLAND GMBH

Abstract

The electroless nickel/immersion gold (ENIG) finish is one of the most mature final finishes accepted in the market for decades. As the nature of the gold deposition is an immersion reaction, the dissolution of nickel and the risk of extensive nickel corrosion is process immanent. Under standard conditions, this does not cause issues in the solderability or reliability of the coating.

The key target for the development of immersion gold electrolytes is always to create a solution with the lowest possible corrosive attack avoiding (e.g., the creation of surface corrosion, which might cause defects in soldering and bonding applications).

Several teams have studied the gold immersion reaction and the influencing factors on ENIG corrosion. The target of this article is to show how the ENIG layer can be rated during development, which types of corrosion can be really critical for the final application, and how misinterpretation of light microscope or SEM data can lead to false judgment.

This study shows where the focus in gold electrolyte development, as well as PCB judgment, has to be put to allow a reliable evaluation of a forecast for the production performance.

Introduction: Why 'No Obvious' Nickel Corrosion Does Not Necessarily Mean 'No Problem'

The ENIG finish is still covering a major portion of the sales volume in the surface finish market, offering a reliable finish to allow soldering as well as Al wire bonding. Due to the long experience in the market, it has been proven to be a robust process leading to reliable solder connections. Nevertheless, due to the nature of the process where an immersion plating electrolyte is used in the second step, it implements the dissolution of nickel during the gold deposition, which may impact the performance of the finish in case the dissolution reaction is uncontrolled. The nickel dissolution reaction is usually named as "nickel corrosion" or a greater extent "nickel hyper corrosion," which is sometimes referred to as "black pad." This becomes particularly true when the corrosive attack of the gold electrolyte dissolves the nickel layer homogeneously on the upper surface of the nickel deposit,

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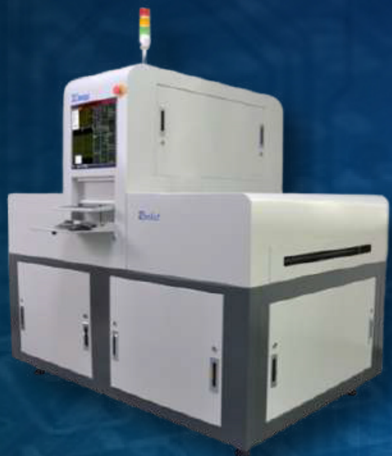

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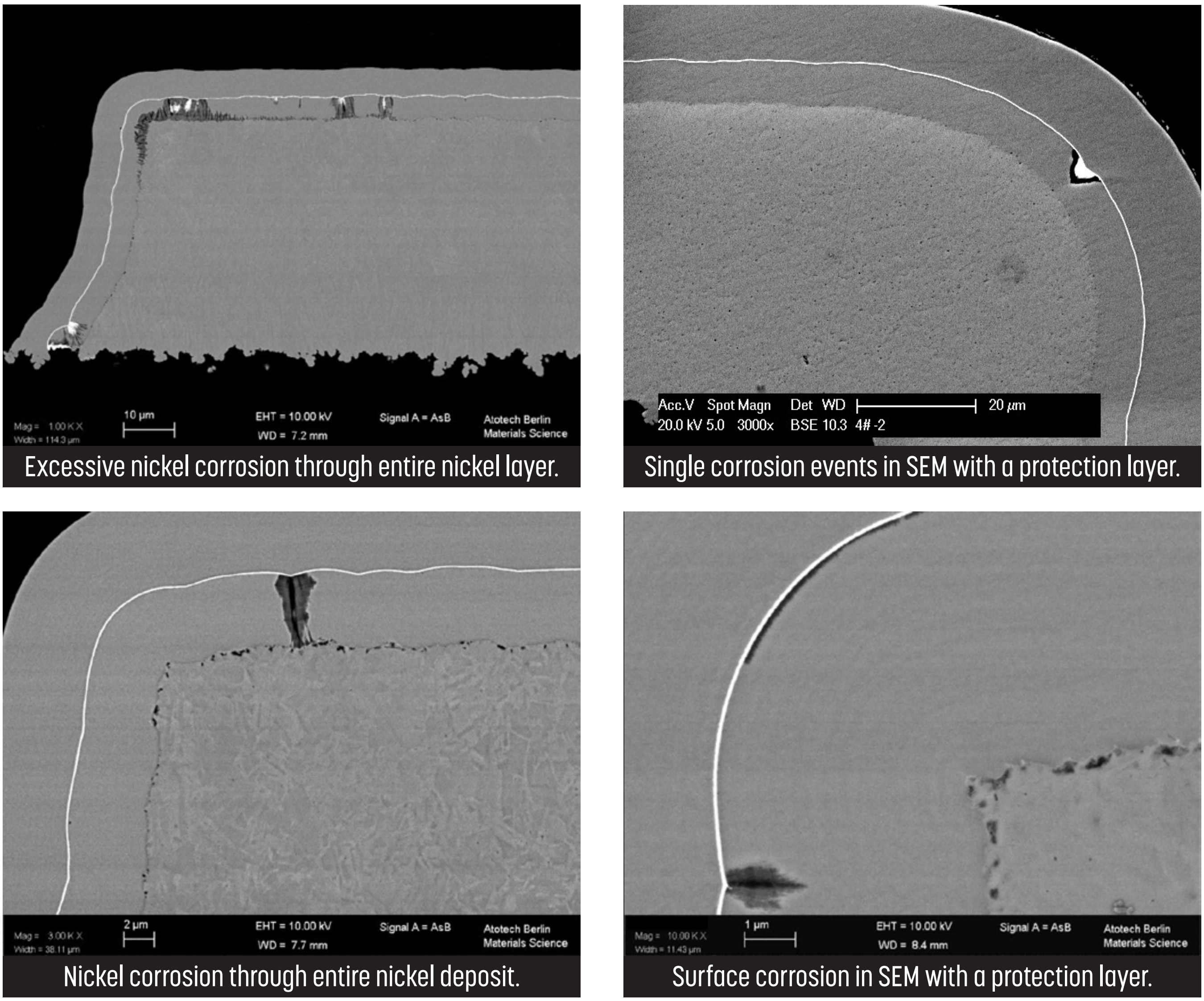
which leads to a dark appearance if the gold layer is stripped off.

As it has been observed, in some cases the IMC formation can be disturbed in such areas of hyper corrosion, which may lead to poor solder joints, and the observation of nickel corrosion has always been a parameter to control the quality of the final ENIG finish. Basically, depending on the nickel and gold electrolytes being used, the shape and intensity of the corrosion events may vary strongly. In general, it can be distinguished between single small corrosion events in bite or spike shape, which do not necessarily impact the IMC formation due to their marginal area portion, as shown in Figure 1 on the top right. When comparing the different types of corrosion, the obvious target for the chemical process development appears to create a process with a minimum attack of the nickel layer during the gold plating step.

Corrosion Evaluation in Product Development

One of the main challenges during the development of the electrolyte, besides the identification of the best electrolyte formulation is to implement objective and statistical evaluation criteria to characterize the performance of the deposit and identify positive and negative trends in the development process.

In the Atotech process development, a broad catalog of criteria has been implemented, which



Excessive nickel corrosion through entire nickel layer.

Single corrosion events in SEM with a protection layer.

Nickel corrosion through entire nickel deposit.

Surface corrosion in SEM with a protection layer.

Figure 1: Exemplary pictures of different types of ENIG corrosion.

has to be fulfilled to get a process to the market. These criteria include target requirements for the bath properties, process handling, as well as the performance of the final finish.

The final finish parameters—such as appearance, etch resistance, thickness distribution, soldering and bonding performance, and IMC formation—are evaluated and judged according to internal pass/fail criteria and international standards such as IPC. Additionally, in the development of an ENIG process, the judgment of the corrosive attack of the nickel layer becomes one of the most important criteria to rate a sample as passed or failed. The challenging task when implementing corrosion criteria is to find the best compromise between time effort, statistical relevance, and objective rating.

What is so critical? In general, there are different options to evaluate an ENIG layer for corrosion: either the judgment is done in cross-section, or the evaluation is done on top view after stripping the gold. Table 1 gives an overview of the general benefits or drawbacks of one or the other method.

Comparing the two approaches, the analysis of the cross-section can give a better overall picture of the amount and depths of the corrosion at the same time. Therefore, the cross-section analysis has been chosen as the preferred tool for internal bath judgment and development. To implement an evaluation system, which is independent of the single operator/evaluation person and allows the creation of comparable results, a rating table has been established internally to rate the amount and depth of the corrosion event at the same time.

In this rating table, the corrosion is judged in terms of amount and depth. During the numerous evaluations, it turned out that corrosion events are more likely in plated through-holes (PTHs) rather than on pads. The focus of the evaluation is put on rating corrosion in PTHs only. To allow a statistically relevant statement, it is recommended to do the investigation on a minimum of two different areas at the PCB with a minimum of three PTHs per area. Another decision point is whether the investigation should be done by a light microscope or SEM. Again, there are a number of benefits and disadvantages connected to the one or the other method (Table 2).

	Top-View Analysis	Cross-Section Analysis
Preparation	Low effort	High effort
Information about corrosion area	Yes	Yes
Information about corrosion depth	No	Yes
Information about the corrosion type/shape	Limited information	Yes
Possible to do by a light microscope	Limited resolution	Yes
Possible to do by SEM	Yes	Protection layer recommended

Table 1: Benefits and drawbacks of different evaluation methods for ENIG corrosion.

	Light Microscope	SEM
Effort for investigation	Low	High
Size of the investigated area	Can be large due to the fast method	Single images only (recommended 10), time-consuming
Investigation time	Fast	Slow
Resolution	Low	High
Detection of small events	Requires high experience due to lower contrasts	Easy

Table 2: Benefits and drawbacks of evaluating cross sections by light microscope or SEM.

When comparing the two tools, it seems clear that compromises become necessary. The investigation by a light microscope allows a comparably easy and fast examination of large areas with a tool that is available almost everywhere. In contrast, the efforts to prepare SEM images of the cross-sections are higher. The tool is more expensive, the sample preparation (as well as the examination itself), consumes more time; on the other hand, the resolution is higher. Imaging with SEM allows us to detect smaller corrosion events, which might not be detectable with a light microscope evaluation.

For both methods, there is the limitation that only a very small detail of the whole panel can be examined. To create a representative result that reflects the performance of the whole panel, the selection of investigation areas of the full panel is important. These areas should be selected from different locations on the panel, and the number of pads, or through-holes, which are investigated should be enough to allow a representative picture of the panel.

In the current version of the IPC-4552A, a description for the evaluation of ENIG corrosion is contained, which leaves room for interpretation at the current stage. The target of the ongoing revision of the specification is to more clearly define the required number and locations to be investigated and the rating to judge panels as acceptable or rejectable. The investigation is supposed to be done by a light microscope with a magnification of 1000x.

For the plating process development and improvement, it was found that a more systematic comprehensive method is necessary to allow the judgment of gradations between "pass" and "fail"—hence a minimum of two locations of a panel where at least four PTHs are investigated is selected. As the PTHs are more critical than the pads in regard to the plating process conditions, such as agitation and solution flow, the focus in the corrosion evaluation is put on the study of the through-holes. Results show that the risk for excessive nickel corrosion is higher in PTHs and, in particular, at the through-hole entrance where the solution flow is highest.

To allow the most objective way of rating, which excludes the impact of the operator, a table has been implemented in the process development, where the corrosion is rated in regard to the depth in the nickel layer and the number of events.

Different classes of corrosion depths are defined, which are specified as 0–20%, 21–40%, 41–100%, > 100%, and surface corrosion (Table 3). Using this method allows a quantitative judgment of corrosion, which enables the engineer to compare different process conditions with statistical tools and relevance.

Notice that 0–20% of corrosion includes all corrosion events, which penetrate the nickel layer thickness up to 20%. Such corrosion events are usually rated as less critical because the attack on the nickel is low, and the impact on soldering and IMC formation is negligible. Further, 21–40% includes all those corrosion marks, which penetrate the nickel by 21–40% of the thickness. Such kind of corrosion is also expected to be less critical as long as the number of events is not too high because there is still enough volume left of the nickel layer thickness. More critical are those corrosion events, where the penetration depths are between 41 and 100%, as this indicates that the corrosion event might penetrate the nickel down to the copper layer (such as in Figure 1 at the bottom left image) so that the barrier function of the nickel layer is affected and cop-

		Number of Identified Corrosion Events					
Sample ID	Pad/PTH ID	0–20%	21–40%	41–100%	100%	>100%	Surface corrosion
1	1	3	5	1	0	0	0
1	2	2	3	4	0	0	0
...	...						

Table 3: Exemplary table to rate corrosion in process development.

per may migrate to the surface or to the solder joint.

Corrosion events penetrating the nickel layer more than 100% are so severe that, in such cases, the copper underneath is also attacked and dissolved, bearing an even higher risk to lead to solder joint failures. Such events are very rare and usually a clear indication that the ENIG process is not run in the specified range.

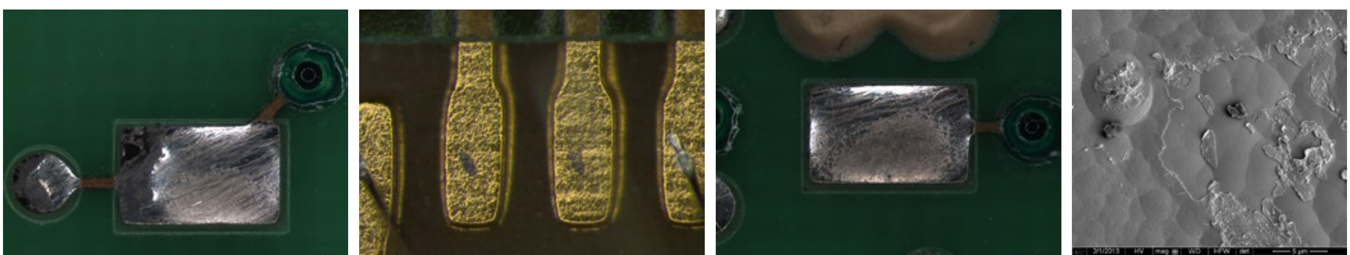
Finally, a type of corrosion is rated, which we call "surface corrosion." It typically consists of a sponge-like nickel structure and does not penetrate the nickel in depth. Due to the sponge-like structure of the nickel, the increased light absorption leads to a darker appearance after the gold stripping, which leads to the common term of "black pad." Black pad corrosion is usually spread over larger areas up to several µm in diameter at the top surface bearing the highest risk to lead to soldering or bonding failures. This is due to the fact that a large area is affected, and in this area, the formation of the IMC during the soldering is inhibited. Or, in regard to bonding applications, the adhesion between nickel and gold is weakened, and a predetermined breaking point is created, where the gold layer lifts off the nickel [1].

Limitations: When a Light Microscope is Not Enough

In the internal product development process, the rating, as described previously, was implemented to allow a reliable, representative, and statistically relevant judgment of the ENIG corrosion. Usually, a combination of light microscope and SEM is applied, where the light microscope is used for screening evaluations and the SEM to confirm the performance of single settings with a higher resolution. Applying this method allows the creation of a far more comprehensive and conclusive data set than compared to the evaluation based on the IPC-4552A. The major difference on one hand is the finer gradation of the rating and the higher resolution of the SEM image. In the history of the process development, however, it still required adjustments, and it became clear that there are limitations in the detection of critical samples.

If the main target for an immersion gold electrolyte is to show no corrosion in the cross-section, it may happen that critical surface corrosion is simply overseen; through the means of light microscopic evaluation, it is not possible to detect if the penetration depth to the nickel layer is low. This may even be true for SEM investigations if the contrast is low, and now the protection layer applied to prevent the gold layer from delaminating. In such cases, it is possible that a finish that is rated as "corrosion-free" may show critical soldering and bonding defects. Some exemplary images of what the failures may look like are collected in Figure 2.

The bond lift-offs show that the gold layer is peeled off in the respective areas, even though from the top surface no clear indication for excessive corrosion can be observed. Comparing the two soldered pads, the defect pads show a clear indication for solder dewetting with the nickel underneath appearing dark in some of the dewetted areas. For a better understanding of the failure, high-resolution SEM cross-sec-

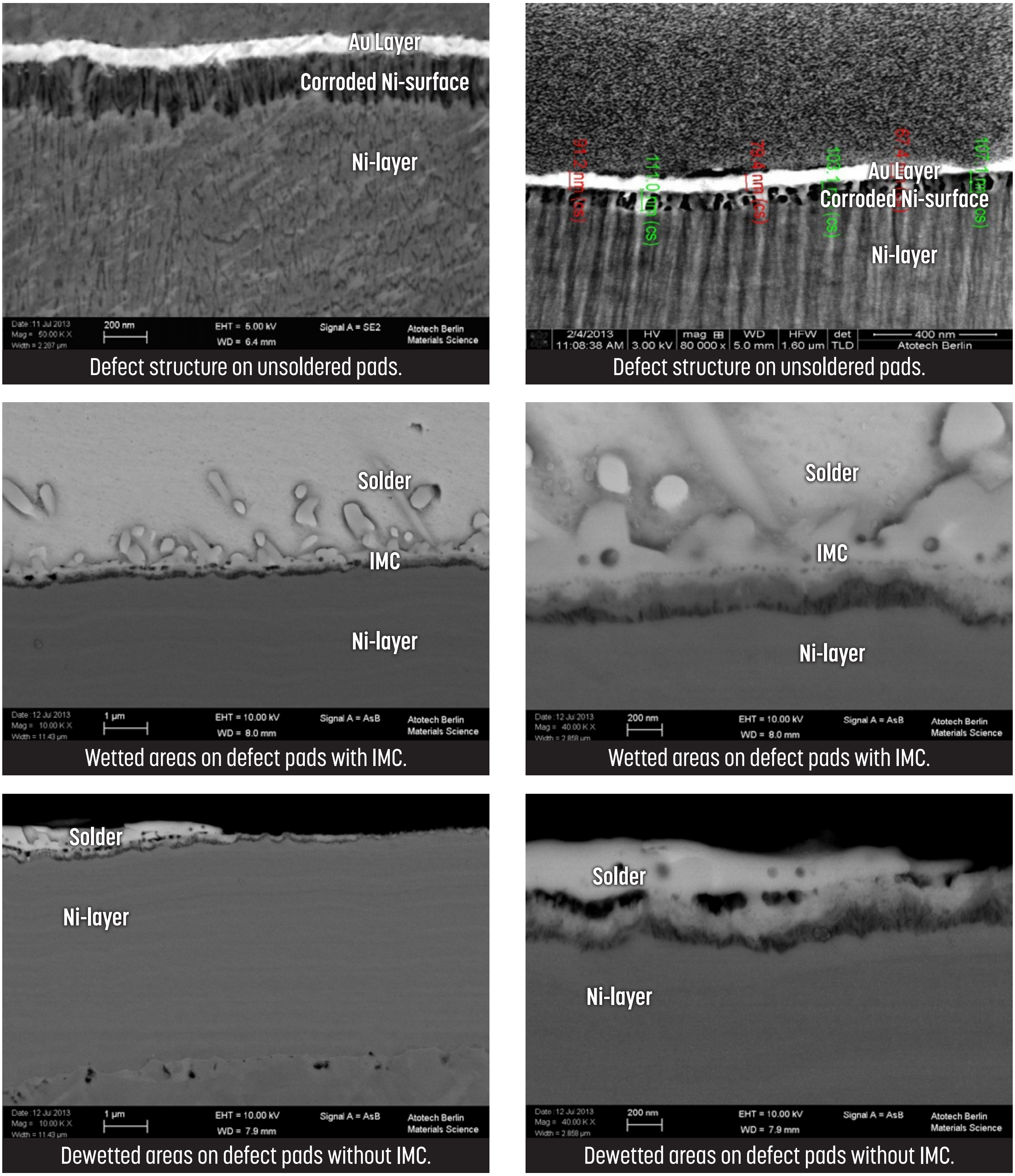


Pad showing dewetting after soldering. | Pads with gold peel off after wire bonding | Full wetted defect-free pad | Detailed SEM image of the ENIG surface after bond lift-off

Figure 2: Exemplary pictures of failure modes of ENIG finishes in soldering and bonding.

tions were prepared, and the pictures are summarized in Figure 3.

What becomes obvious when comparing the failure images in Figure 3 is that it seems to be in particular if the corrosion is spread over wide areas of the nickel/gold interphase, not necessarily penetrating deep to the nickel. Rather than that, the corrosion is concentrated to the upper surface, having an overall depth of often not more than 100 nm. Such defects



Defect structure on unsoldered pads.
Defect structure on unsoldered pads.
Wetted areas on defect pads with IMC.
Wetted areas on defect pads with IMC.
Dewetted areas on defect pads without IMC.
Dewetted areas on defect pads without IMC.

Figure 3: Exemplary SEM images of defect pads in a cross-section.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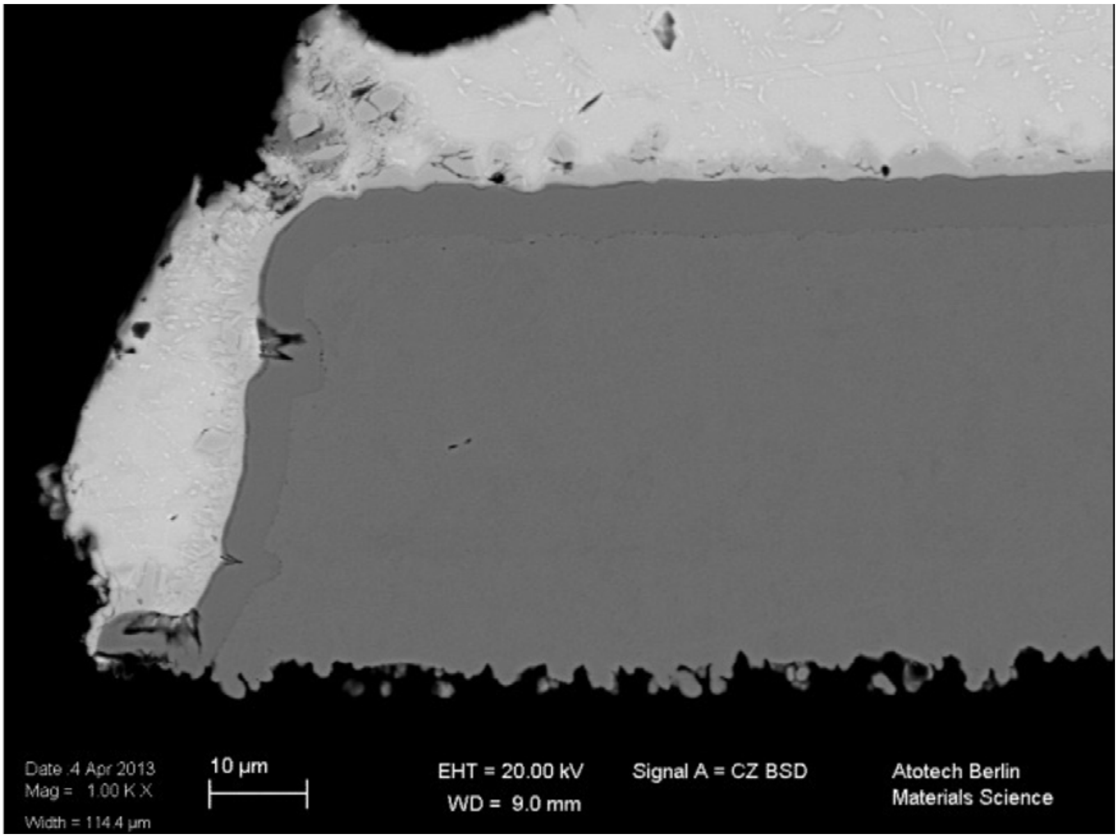

Figure 4: IMC formation at a single corrosion location on a soldered pad.

will be difficult to detect in a simple light microscope picture and require a high-resolution SEM for reliable detection. Also, the application of a protective layer applied on top of the gold layer can help to provide better contrast and reduce the risk of misinterpretation of artifacts created during the cross-section preparation. This type of surface corrosion, as shown in Figure 3, finally bears a high risk for soldering as well as for bonding applications.

Due to the shape of the corrosion, not deep but distributed over large areas, this may inhibit the formation of the IMC, and by that, lead to solder dewetting after the reflow step. For the bonding application, the "sponge"-like nickel surface acts as a kind of predetermined breaking point where the gold lacks the adhesion to the nickel and easily peels off. Compared to a pad with single and deep corrosion events, it appears that the single corrosion locations are far less critical (Figure 4).

Even though the corrosion events almost penetrate the full nickel layer, the IMC forms densely and thoroughly, and the pad is fully wetted with solder. This serves as an indication that the appearance of single corrosion events is judged to be less critical for the solder joint reliability or the bonding adhesion than the appearance of large area surface corrosion. Therefore, to create a realistic judgment of the potential risk of the corrosion for the solder or bonding joint, it is highly recommended to select a representative and well-distributed investigation spot and confirm the light microscope evaluation by complementary high-resolution SEM study.

Summary and Conclusion

ENIG corrosion is one of the most discussed topics for ENIG finishes in the PCB industry and is continuously being negotiated to define clear criteria for the acceptance of the final finish. One of the key targets in electrolyte development is to reduce the corrosive attack as much as possible. The method for the evaluation of corrosion, which is presented in this article, allows a statistical judgment and comparison of different final finishes. In particular, for product development, this is important to identify trends and distinguish between small effects.

Comparing the corrosion rating with assembly data from solder and bonding performance, it appears that the surface corrosion is rated as the most critical type of corrosion in regards to the solder and bonding reliability—rather than the single corrosion events that were found to be non-critical, as the IMC can easily bridge and cover the defect and allows for a defect-free and complete solder wetting. For the reliable judgment of the expected performance of an ENIG finish, it is recommended to not only screen the finish with a light microscope or low-resolution SEM but also focus on surface defects, which might be overlooked in the first view. In the final application, these can be the most critical ones. **PCB007**

Editor's Note: This article was originally titled "ENIG: Corrosion and Learning From Failures—Why 'No Obvious' Nickel Corrosion Does Not Necessarily Mean 'No Problem.'"

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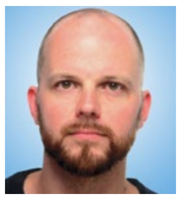
Britta Schafsteller, global product manager for selective finishing, Atotech in Berlin, Germany.

Gustavo Ramos, global product director for selective finishing, Atotech in Berlin, Germany.

Mario Rosin, application manager selective finishing high end, Atotech in Berlin, Germany.

Sebastian Weissbrod, development engineer in the R&D department for selective finishing, Atotech in Berlin, Germany.



Timo Schlosser, technical engineer for selective finishing high end at Atotech in Berlin, Germany.

New Insights Into Lithium-Ion Battery Failure Mechanism

Researchers have identified one of the reasons why state-of-the-art nickel-rich battery materials become fatigued after prolonged use. Lithium-ion batteries used by EVs are likely to dominate the EV market for the foreseeable future, and nickel-rich lithium transition-metal oxides are the state-of-the-art choice for the positive electrode, or cathode, in these batteries.

Currently, most EV batteries contain significant amounts of cobalt. However, cobalt can cause severe environmental damage, so researchers have been looking to replace it with nickel. Nickel-rich materials degrade much faster and require additional study to be commercially viable for applications, such as EVs.

"To fully function, battery materials need to expand and shrink as the lithium ions move in and out," said Dr. Chao, first author of the article. "However, after prolonged use, we found that the atoms at the surface of the material had rearranged to form new structures that are no longer able to store energy."

What's worse is that these areas of reconstructed surface apparently act as stakes that pin the rest of the material in place and prevent it from the contraction, which is required to reach the fully charged state. With this knowledge, the researchers are now seeking effective countermeasures, such as protective coatings and functional electrolyte additives, to mitigate this degradation process and extend the lifetime of such batteries.

(Source: University of Cambridge)

Supplier Highlights

RBP Releases Circutek CC-720 PTH Acid Cleaner Conditioner ▸

Circutek CC-720™ is an acidic cleaner/conditioner for use in the electroless copper metallization process in the PCB industry. It is formulated to remove fingerprints, light soil, and other contaminants from copper foil.

Frontline Launches InShop Data Analysis Software ▸

Frontline, a software PCB solutions subsidiary of Orbotech, launched InShop®, a new Industry 4.0 software solution for PCB manufacturers. InShop will provide PCB manufacturers with a fast and insightful analysis of data from across the production floor to monitor operations and detect anomalies in near real-time.

Limata's Innovative LUVIR Technology Speeds up PCB Solder Mask Production ▸

Limata, a provider of laser direct imaging systems for PCB manufacturing and adjacent markets, announced the availability of its proprietary and field-proven LUVIR Technology® on all X-series model types. This unique LDI technology significantly increases the speed of solder mask direct imaging at a lower total cost of ownership (TCO).

Nova Drilling and Fabrication Expands Capabilities With Excellon Laser Systems ▸

Nova Drilling and Fabrication Services based in Milpitas, California, expands laser capabilities with the addition of two COBRA-II Hybrid UV and CO2 laser systems from Excellon.

Atotech Expands Its Software Capabilities ▸

Atotech, a global provider of specialty surface-finishing solutions, announced it signed a definitive agreement to acquire Visutech Plating, along with certain assets from its partner company, koenig-pa GmbH.

MacDermid Alpha Releases Systek ETS 1200 Pattern Plating Metallization for Embedded Trace Substrates ▸

MacDermid Alpha Electronics Solutions, a global leader in specialty materials for electronics, announced the release of Systek ETS 1200, the latest addition to the Systek family of IC substrate manufacturing solutions.

Hitachi Chemical Launches Mass Production of 5G-Compatible Printed Wiring Board Material ▸

Hitachi Chemical Co. Ltd. launched mass production of "MCL-HS200," an advanced functional laminate material for printed wiring boards, with low transmission loss and low warpage properties required for semiconductor packaging substrates used in such fields as fifth-generation mobile communications systems (5G), advanced driver-assistance systems (ADAS)*1, and artificial intelligence in March.

Rogers Introduces RO4450T Glass-Reinforced Thermoset Multi-Thickness Bondply ▸

Wireless circuit designers can now enjoy a true breakthrough with Rogers Corporation's RO4450T™ bondply. This product offers designers a spread glass-reinforced bonding material in seven thickness options ranging between 0.0025" (0.064mm) and 0.006" (0.152mm), greatly improving flexibility for high multilayer board count designs.

Seacole Specialty Chemical Installs Rooftop Solar Array ▸

Seacole Specialty Chemical activated its new 200 megawatt-hour rooftop solar array at its corporate offices in Plymouth, Minnesota.

Immersion Plating Reaction in Electronics Manufacturing

The Plating Forum

by George Milad, UYEMURA INTERNATIONAL CORPORATION

Plating or metal deposition is a key component in the manufacturing of electronic packages (circuit boards and integrated circuits). Plating occurs when a metal ion in solution (electrolyte) is reduced to the metal. The reduction takes place when electrons are supplied to the ion:

$$M^{++} + 2e^- \rightarrow M^0$$

The source of electrons differs with the type of plating as follows:

- Electrolytic plating: Electrons supplied by an external power supply (rectifier)
- Electroless plating: Electrons are supplied by a reducing chemical agent that is present in the electrolyte
- Immersion plating: Electrons are supplied by the oxidation of the (metal) substrate

This column will be dedicated to the immersion reaction.

Immersion reactions occur between metals according to their location in the electromotive (EMF) series. The EMF series is a listing of the elements according to their half potentials or tendency to lose electrons (get oxidized), or their tendency to gain an electron (get reduced), measured in voltage. Elements that lose electrons (reducers) have negative voltage values, and elements that gain electrons (oxidizers) have positive E^o voltage values.

Table 1 shows the half potentials E^o measured in volts of common elements, and metals are ranked with respect to their inherent reactivity. The metals located at the top of the series are considered the noblest with the highest level of positive electrochemical potential.

Metal-Metal Ion Equilibrium	Electrode Potential (E^o v) vs. Hydrogen
$Au - Au^{+2}$	+ 1.498 v
$Pd - Pd^{+2}$	+ 0.987 v
$Ag - Ag^{+}$	+ 0.799 v
$Cu - Cu^{+2}$	+ 0.337 v
$H_2 - H^{+}$	0.000 v
$Sn - Sn^{+2}$	- 0.136 v
$Ni - Ni^{+2}$	- 0.250 v
$Fe - Fe^{+2}$	- 0.440 v
$Zn - Zn^{+2}$	- 0.763 v
$Al - Al^{+3}$	- 1.662 v

Table 1: A partial listing of metals according to their "electromotive series" ranking.

The electromotive force that drives an immersion reaction is determined by the difference in E^o (half potential) between the reduced and oxidized elements. The reduced element is the element receiving electrons and is derived as follows:

$$E_{cell} = E_{Red} - E_{oxd}$$

If the cell potential is positive, the reaction is spontaneous. A negative voltage indicates that no reaction will take place.

In printed circuit fabrication, immersion plating plays a key role in the following processes:

- Immersion gold in electroless nickel/immersion gold (ENIG)
- Corrosion in ENIG
- Immersion gold in electroless nickel/electroless palladium/immersion gold (ENEPIG)
- Palladium catalyst on copper
- Immersion silver
- Immersion tin

Immersion Gold in ENIG

The deposition of gold on the electroless nickel substrate is an immersion reaction. The presence of nickel metal in an electrolyte containing gold ions creates a spontaneous deposition reaction. The EMF of the cell comes up to + 1.75 v, and the difference between the half potentials of gold +1.5 v (reduced species) and nickel –0.25 v (oxidized species) can be expressed as follows.

ENIG reaction:

$$E_{cell} = E_{Au} - E_{Ni}$$
$$E_{cell} = +1.5\ v - (-0.25\ v)$$
$$E_{cell} = +1.75\ v$$

Corrosion in ENIG

Corrosion may occur when the electrons released by the oxidation of nickel reduces the hydrogen ion present in solution releasing hydrogen gas. The EMF of the cell is + 0.25 v and is the difference between the half potentials of hydrogen (0.00 v) and nickel (–0.25 v).

Electroless nickel/hydrogen ion corrosion reaction:

$$E_{cell} = {}_{EH} - E_{Ni}$$
$$E_{cell} = 0.00\ v - (-0.25v)$$
$$E_{cell} = +0.25\ v$$

The EMF driving force for this reaction is only 14% of the EMF for the gold deposition reaction and would only occur if the availability of the gold ion is interfered with. An example would be localized areas (crevices) where gold is depleted.

Nickel corrosion can be mitigated by:

- Eliminating crevices in the nickel
- Reducing the acidity of the electrolyte (reduced hydrogen ion availability)
- Reducing the half potential of nickel by increasing its phosphorous content

Immersion Gold in ENEPIG

Electroless palladium/immersion gold reaction:

$$E_{cell} = E_{Au} - E_{Pd}$$
$$E_{cell} = +1.5\ v - (+0.98v)$$
$$E_{cell} = +0.52\ v$$

In this galvanic cell, the gold is the reduced species, and the palladium is the oxidized species. Comparing the EMF of this cell to the EMF of the nickel/gold cell, it is clear that this reaction is less driven and would proceed slower than the deposition of gold on nickel. This creates a problem if the underlying nickel is accessible to the gold electrolyte. In this case, the gold would exchange with the nickel layer under the palladium and nickel corrosion would occur. For mitigation of nickel corrosion, refer to my previous column titled "Can 'Nickel Corrosion' Occur In ENEPIG?"

Palladium Catalyst on Copper

For an immersion palladium on copper reaction:

$$E_{cell} = E_{Pd} - E_{Cu}$$
$$E_{cell} = +0.98\ v - (+0.16v)$$
$$E_{cell} = +0.72\ v$$

Immersion palladium on copper is an integral part of electroless nickel (EN) deposition. For EN to initiate on the copper substrate, the copper surface must be catalyzed. The catalyst is immersion palladium. In this galvanic cell, the palladium is the reduced species, and the copper is the oxidized species. Palladium sits below gold and above copper in the EMF series. Immersion palladium on copper is a spontaneous reaction driven by + 0.72 v. A palladium deposit is specific to the copper substrate and will not deposit on laminate or solder mask.

The uniformity of the palladium catalyst layer is critical. The uniformity depends on the pre-treatment of the copper surface, which must be free of oxidation or any contaminants. An uneven palladium distribution would lead to uneven EN initiation, generating crevices in the EN deposit, which are potential sites for nickel corrosion.

Immersion silver on copper:

$$E_{cell} = E_{Ag} - E_{Cu}$$
$$E_{cell} = +0.8\ v - (+0.34v)$$
$$E_{cell} = +0.46\ v$$

The driving force for this reaction is + 0.46 v and would proceed spontaneously. Although the reaction is straight forward, the design of the electrolyte for immersion silver is a differentiating point from one supplier to the other and may include anti-tarnish components.

Immersion tin on copper:

$$E_{cell} = E_{Sn} - E_{Cu}$$
$$E_{cell} = -0.14\ v - (+0.34\ v)$$
$$E_{cell} = -0.48\ v$$

Replacement reaction between Cu and Sn^{2+} cannot occur in a standard electrolyte because the EMF voltage is negative (- 0.48 v). The half potential of Cu is + 0.337 v, which is much higher than that of Sn is – 0.136 v.

For tin to immerse on copper, the half potential for copper must be reduced below the half potential of tin. The addition of a copper ion complexing agent, such as thiourea, will decreases the half potential of copper to – 0.620 v. (E^0 for $Cu[SC(NH_2)_2]_4 = -0.620\ v$).

In the presence of thiourea, the EMF for the immersion reaction is positive and would proceed spontaneously:

$$E_{cell} = E_{Sn} - E_{Cu[SC(NH_2)_2]_4}$$
$$E_{cell} = -0.14\ v - (-0.62\ v)$$
$$E_{cell} = +0.48\ v$$

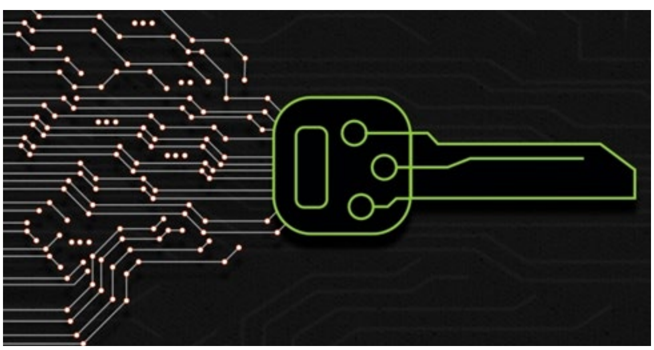
A good understanding of the principles of immersion plating goes a long way in eliminating costly defects that may occur during fabrication. It is a powerful tool in analyzing failure, as well as the subsequent assignable cause, and recommending corrective action. **PCB007**

George Milad is the national accounts manager for technology at Uyemura. To read past columns or contact Milad, click here.

Helping Companies Prioritize Cybersecurity Investments

Cyberattacks have continued to grow in recent years because we never learn how they happen. Many organizations don't know which types of attacks lead to the largest financial losses, nor how to best deploy scarce security resources. A new platform from MIT's Computer Science and Artificial Intelligence Laboratory (CSAIL) is quantifying companies' security risk without requiring them to disclose sensitive.

The team received internal data from seven large companies that averaged 50,000 employees and annual revenues of $24 billion. By securely aggregating incidents that took place at the companies, researchers analyzed which



specific steps were not taken. Among other findings, they determined that the three following security vulnerabilities had the largest total losses, each in excess of $1 million.

1. Failures in Preventing Malware Attacks

Malware attacks, like the one last month that reportedly Garmin to pay a $10 million ransom, are still a method. Companies continue to struggle to prevent such attacks, relying on regularly backing up their data and reminding their employees not to click on suspicious emails.

2. Communication Over Unauthorized Ports

Every firm in their study said they had implemented the security measure of blocking access to unauthorized ports, yet attacks gaining access to these ports accounted for a large number of high-cost losses.

3. Failures in Log Management for Security Incidents

Every day, companies amass detailed "logs." Companies could be using machine learning and AI more efficiently to help understand what's happening, including—crucially—during, or even before, a security attack.

(Source: MIT News)

I-Connect007
GOOD FOR THE INDUSTRY

2020 IPC High-Reliability Virtual Forum Review

Edited by Happy Holden
I-CONNECT007

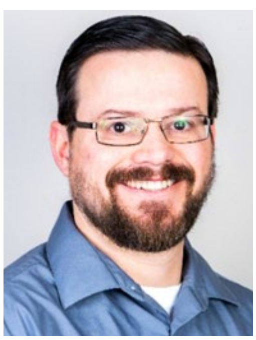
Introduction

The IPC High-Reliability Forum planned for May 2020 in Hanover, Maryland, was rescheduled as a virtual conference in July because of the COVID-19 pandemic. This is the third annual event, and, like the past two, it continues to grow with more than 150 in attendance. The forum focuses on electronics for critical military, aerospace, automotive, and medical applications required to function without interruption for an extended lifetime where downtime is not acceptable.

This event covered a broad range of topics related to reliability and an opportunity to share expert knowledge and experience in determining and understanding the causes of failure and selecting the best design rules, materials, processes, and test methods to maximize product reliability. The other objectives of the forum were to discuss the industry's best efforts to date to mitigate weak-interface microvias through recently adopted design parameters, test protocols, and product sorting, and to solicit attendee support for the various sub-teams of the IPC Weak Microvias Task Group.

Day 1

John Perry



To begin, IPC's John Perry, director of printed board standards and technology, greeted everyone and opened the virtual conference. He also introduced Dennis Fritz as the opening speaker.

Dennis Fritz

Fritz is a technical consultant with Fritz Consulting, chairman of the IPC V-TSL-MVIA Weak Microvia Interface Committee, and an I-Connect007 columnist. The theme of his presentation was "An Introduction From the Microvia Task Group." In this context, microvia holes constituted the focus of this forum.

In his introduction, Fritz made it clear that there was no intention to scare designers and users away from microvias; they remained a reliable PCB interconnect construction when properly formed and screened by IPC methods. But there was a valuable opportunity to discuss a potential reliability issue primarily associated with multiple levels of stacked microvias. He stressed that staggered or even single-level microvias still needed to be manufactured carefully and tested to IPC standards.

Additionally, Fritz included a review of the background and history of the problem, as described in the IPC-WP-023 white paper, and an introduction of the panel members and their interest in this problem. A big fishbone diagram illustrated the complexity of the subject, defined the project categories, and nominated the working teams.

The obvious long-term objective was to provide design, material selection, and processing guidance to enable the industry to achieve reliable higher density structures. Fritz implored delegates to support the work of the IPC V-TSL-MVIA Weak Interface Microvia Failures Technology Solutions Subcommittee, contribute relevant data with the assurance that sources would not be disclosed, and join one of the working teams investigating this perplexing and currently expensive PCB industry problem.

Next, Fritz showed many real examples of microvia failure since microvia challenges and reliability issues have become a great concern to the PCB manufacturing industry. He provided updates on the work of members of the IPC V-TSL-MVIA Weak Interface Microvia Failures Technology Solutions Subcommittee and opportunities to learn about the latest developments in methods to reveal and explain the presence of latent defects, identify causes and cures, and consistently and confidently supply reliable products.

The IPC-V-TSL-MVIA Subcommittee is working with IMEC in Europe on its European Space Agency (ESA) microvia reliability study. IPC is using its test vehicle to test stacked microvias on a typical high-Tg laminate, and D-coupons are being fabricated for IPC.

James W. Fuller, Jr.

The next speaker was James W. Fuller, Jr., VP of engineering and technology development at Sanmina Corporation. He discussed the use of a smartly designed test vehicle, coupled with a unique IST test protocol, that provided the company with the tools to improve microvia robustness quickly and definitively.

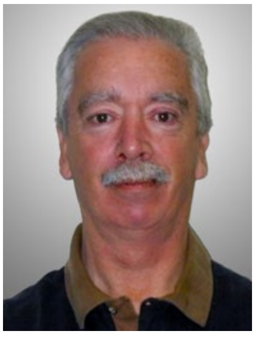
One key challenge included, "How can the technical team evaluate lot-to-lot differences using current test protocols?" Next, the project was to identify and implement an effective combination of a coupon and test that allows for a significant differentiation of product processes by making the coupons more sensitive and make the test more aggressive and test to failure.

Their IST system was utilized to create a new, more aggressive test coupon at new temperature extremes. The new coupon had 4-, 5-, and 6-mil microvias with these via constructions:

1. L1-14 through via and L2-13 buried via
2. L1-2-3 and L14-13-12 stacked via offset from buried L2-13
3. L1-2 and L14-13 blind via stacked on buried L2-13
4. L1-2-3 and L14-13-12 stacked via on buried L3-12
5. The experimental results for stacked microvias resulted in Table 1.

The results of Sanmina's work provides a platform that allows for actionable data from site-to-site, simple evaluations of electroless process control and selections, the evaluation of material choices, and the differentiation of laser equipment, noting the influence of desmear and glass etch, as well as comparisons of design considerations.

Bill Birch



Bill Birch, president of PWB Interconnect Solutions Inc., and **Hardeep Heer,** VP of engineering and CTO of Firan Technology Group (FTG Corporation), were the next speakers. Their presentation, "Reliability of Microvias: Troubleshooting MV Failures," addressed their findings from recent WMI DOEs. They discussed various contributing factors causing microvias to fail and what has been done to make microvias more reliable. Their findings for Type 1 10-layer microvias board are presented in Tables 2 and 3. All the testing was

Four Coupons Per Cell		Process A "On"			Process A "Off"		
		N+1 mil	N mil	N-1 mil	N+1 mil	N mil	N-1 mil
Process B "On"	N+1 mil	132			126		
	N mil		22			48	
	N-1 mil			4			9
Process B "Off"	N+1 mil	254			3		
	N mil		80			0	
	N-1 mil			19			0

Table 1: Experimental results, stacked microvias, IST cycles to failure.

done after 6X pre-conditioning at 245°C before thermal cycling for 250 cycles at 190°C for microvias. The resulting failure mode was confirmed as the interfacial separation between the electroless copper and the target pad copper foil.

DOE #1

DOE #1 focused on specific process variables associated with:

- Post laser ablation micro-etch pre-treatment (single pass-double pass)
- Hold times between laser ablation and loading into the electroless line (level 1: zero hold time; level 2: two-hour hold time)
- Electroless copper thickness (0.8–1.0 microns)
- The influence of coupon position within the test panel
- 36 coupons were related for reliability testing.

Using a series of case-history examples, illustrated by a combination of optical microscopy and X-ray with scanning electron microscopy and energy-dispersive for failure analysis, showed all failure was electroless lifting.

Panel #	1	3	5	7	9	11	13	15	17
IST Cycles	Unstable	14	10	24	9	7	3	8	13
	2	18	Unstable	27	11	3	3	10	15

Panel #	2	4	6	8	10	12	14	16	18
IST Cycles	10	Unstable	2	11	Unstable	Unstable	2	9	23
	14	Unstable	11	Unstable	6	4	Unstable	3	23

Table 2: Test results for panels and the number of cycles completed before 10% resistance change; all failure was electroless lifting.

Unstable Failures by Location		Unstable Failures by Cu Deposit		Unstable Failures by Hold Time		Unstable Failures by Micro-Etch	
U/L	1/10	0.8	7/16	Zero	3/16	1X	4/16
MID	5/17	1.0	9/16	2 Hr.	5/16	2X	4/16
LR	2/7						

Up to 5 Cycles to Failure by Location		Up to 5 Cycles to Failure by Cu Deposit		Up to 5 Cycles to Failure by Hold Time		Up to 5 Cycles to Failure by Micro-Etch	
U/L	4/10	0.8	7/16	Zero	8/16	1X	9/16
MID	8/17	1.0	9/16	2 Hr.	8/16	2X	7/16
LR	4/7						

Table 3: Coupons with unstable results and those failing below 5 IST cycles. All failure was electroless lifting.

Micro-Section A				Micro-Section B				Micro-Section C			
Conventional No Flash				Conventional With Flash				Vertical Plating With Flash			
Coupon	Cycles	% Change	Results	Coupon	Cycles	% Change	Results	Coupon	Cycles	% Change	Results
P1-1	250	3.4	Passed	P3-1	250	0.9	Passed	P5-1	10	10	Failed
P1-2	173	10	Failed	P3-2	250	1.1	Passed	P5-2	Unstable	10	Failed
P1-3	250	0.8		P3-3	250	1.9	Passed	P5-3	250	1.1	Passed
P1-4	250	0.3		P3-4	250	1.2	Passed	P5-4	3	10	Failed
P1-5	250	0.7		P3-5	250	1	Passed	P5-5	49	10	Failed
P2-1	125	10	Failed	P4-1	250	1.8	Passed	P6-1	2	10	Failed
P2-2	250	7.7		P4-2	250	1.5	Passed	P6-2	6	10	Failed
P2-3	250	1.8		P4-3	250	1	Passed	P6-3	46	10	Failed
P2-4	250	1.5		P4-4	250	1	Passed	P6-4	2	10	Failed
P2-5	250	2.1		P4-5	250	1.9	Passed	P6-5	62	10	Failed
125 cycles to failure				Passed 250 cycles				Unstable (pre-cycle failures)			

Table 4: DOE #2 IST test results.

DOE #2

DOE #2 involved the impact of the electrolytic process to improve reliability (Table 4):

- Conventional copper deep tank line with mechanical agitation with/without a copper flash plating

DOE #3

DOE #3 was a referee test to repeat DOE #2 with 21 panels (Table 5):

- Conventional copper deep tank line with mech agitation with/without a copper flash plating
- HDI copper filling using only the conventional line

DOE #4

DOE #4 was a comparison to the production electroless line with 21 panels (Table 6):

- 16 panels use production electroless line
- Five panels use the new electroless line
- The current production electroless line all survived the 250 cycles to 190°C
- The IST testing discovered the 10 failures of the new electroless plating line

Coupon	IST Cycles	Micro-Section
36-1	14	
36-2	123	
36-3	24	A
37-1	81	
37-2	16	B
37-3	Unstable	
38-1	17	C
38-2	90	
38-3	No Test	
39-1	124	
39-2	10	D
39-3	No Test	
40-1	132	
40-2	Unstable	E
40-3	No Test	
41-1	9	
41-2	24	F
41-3	No Test	
42-1	20	G
42-2	Unstable	
42-3	No Test	

13 coupons failed before a maximum of 124 cycles.

Table 5: DOE #3 IST test results; low performance consistent with DOE #1.

Electroless Copper Line	Coupon	IST Cycles	HDI % Change	Micro-Section	Coupon	IST Cycles	HDI % Change	Micro-Section
Prod	36-1A	250	0.2		36-1B	250	1	
Prod	36-2A	250	0.3		36-2B	250	1.0	
Prod	36-3A	250	0.11		36-3B	250	0.3	
New Line	37-1A	8	10	A	37-1B	3	10	
Prod	37-2A	250	1.1	B	37-2B	250	0.9	
Prod	37-3A	250	1.3		37-3B	250	1.0	
Prod	38-1A	250	0.1		38-1B	250	0.4	
New Line	38-2A	4	10	C	38-2B	1	10	
Prod	38-3A	250	0.1		38-3B	250	0.3	
Prod	39-1A	250	0.1		39-1B	250	0.3	
Prod	39-2A	250	0.1		39-2B	250	0.7	
Prod	39-3A	250	0.2		39-3B	250	0.1	
Prod	40-1A	250	0.5		40-1B	250	0.3	
Prod	40-2A	250	0.4		40-2B	250	0.5	
New Line	40-3A	19	10		40-3B	1	10	D
Prod	41-1A	250	0.4	E	41-1B	250	0.4	
New Line	41-2A	4	10	F	41-2B	Unstable	10	
Prod	41-3A	250	0.5		41-3B	250	0.5	
New Line	42-1A	69	10	G	42-1B	15	10	
Prod	42-2A	250	1.1		42-2B	250	0.6	
Prod	42-3A	250	0.9		42-3B	250	0.4	

The current production electroless line all survived the 250 cycles to 190°C. The IST testing discovered the 10 failures of the new electroless plating line.

Table 6: DOE #4 IST test results (low).

Conclusions from the DOE tests indicate that electroless copper deposits are responsible for the majority of weak microvia interface failures and that the newly released IPC-6012E does not require extended testing or micro-sections, creating a risk of positive results.

Gerry Partida

Gerry Partida, field application engineering manager at Summit Interconnect, presented on "Current Concerns Over Microvia Failures." He reviewed concerns regarding the reliability testing of microvias, provided an overview of HDI processes, and presented the use of current test methods. In particular, he emphasized the superiority of testing with IPC-D-coupon and IPC-TM-650 test methods 2.6.7.2 and 2.6.27. Gerry also presented data that showed that traditional thermal testing using IPC-2.6.7.2 will pass coupons that fail reflow. IPC-TM-650-2.6.27B found 17% of the coupons that passed the thermal cycling test failed the SMT reflow test in the first few reflow cycles.

Failure analysis indicated that the failures occurred near the center of the coupons. Test runs were repeated using lower blind via aspect ratios and larger laser drill diameters, and all coupons passed the reflow tests 100%. It is critical that tests be performed on microvias using production materials, design rules, stackups, and pre-/post-clean processes using the IPC-TM-650-2.6.27B test method before products are shipped to customers.

Dr. Maarten Cauwe

Maarten Cauwe, Ph.D., team leader of advanced packaging at IMEC-CMST, explained "Microvia Technology Assessment for Space Applications." Dr. Cauwe is a member of the IPC Special Committee on the weak microvia interface problem and a frequent contributor to his work with the ESA at IPC APEX EXPO and SMTAI.

The work presented is part of the ongoing ESA project on high-density PCB assemblies, led by IMEC and with the aid of ACB and Thales Alenia Space Belgium. The goal of the project is to design, evaluate, and qualify HDI PCBs that can provide a platform for assembly and the routing of small-pitch area array devices (AAD) for space projects. Two categories of HDI technology are considered: two levels of staggered microvias (basic HDI) and up to three levels of stacked microvias (complex HDI).

Within the project, various test methods for evaluation microvias are assessed. Interconnection stress testing (IST) and reflow simulation combined with traditional thermal cycling is currently the method of choice in ESA's ECSS-Q-ST-70-60C standard for qualification and procurement of PCBs. Alternatives as convection reflow assembly simulation (IPC-TM-650 2.6.27B) and current-induced thermal cycling (CITC, IPC-TM-650 2.6.26A) are explored in this study.

Dr. Cauwe began by updating the results of Phase I testing in the ESA program. The results indicated that for the three build-up layers, the semi-stacked inside (L1-L2/l3 stacked) was superior (no failures) compared to the semi-stacked outside (L1/L2-L3) construction for both the 0.8-mm pitch D-coupons and for the 0.5-mm D-coupons using polyimide materials. The modified high-Td epoxy SI materials passed at both pitches, but he noted that the single-prepreg used was 25 microns thinner. This was verified in failure analysis that the high Td SI materials strain was 9960 ppm at 190°C compared to the polyimide's 11340 ppm at 210°C. Theoretically, it is 22% lower than the polyimide due to CTE-Z and thickness, verified by modeling. Also, IMEC used finite element analysis to help determine the effects of microvia interfacial stress.

Jerry Magera

What was the source of the weak microvia interface? According to Jerry Magera, senior staff principal engineer at Motorola Solutions, it all began with the microvia target pad in his presentation on "The Complete Path to Least Resistance." He focused on the often maligned electroless copper process and proclaims that the IPC-6012E performance specifications for metallization for PCBs of "sufficient for subsequent plating" is too vague, sets low expectations for deposit quality, and is the reason optical microscope views of well-formed electrolytically copper filled microvias fracture during solder reflow thermal excursions.

Continuous resistance measurements during component reflow assembly revealed thermally induced microvia failures that were subsequently located by cross-section analysis at and in the vicinity of that electroless copper deposit. The fascinating elegance of electroless copper is not appreciated, relegated today as a transient step in the copper metallization process, with function reduced to a conductive liner within the laser-ablated microvia cavity that bridges the target pad to the adjacent copper layer to support electrolytic copper fill plating. However, it must form a metallurgical bond between the target pad and electrolytic copper plating to survive reflow assembly. Four-wire resistance measurements of microvia daisy-chains confirmed substantial chain to chain variation attributed to the electroless copper deposit in the microvia.

The results of four-wire resistance measurements completed on simple L1L2 and L3L4 microvia daisy-chains at ambient temperature are presented for samples prepared with production-ready processes by PWB manufacturers. The measurements objectively revealed the actual variation in the quality of the electroless copper deposit lining the microvias that was missed by weight-gain and backlight assessments. Published electroless copper deposit thickness ranged from 0.3–3.0 µm for immersion times of 4–30 minutes, depending on the process implemented.

Structural variations exist in microvia field-failure interfaces on products that had passed existing IPC and OEM validation tests and micro-section inspections but had retroactively failed IPC 2.6.27A testing and been investigated using micro-sections produced by focused-ion-beam (FIB) trench-machining techniques. These revealed defects that had been missed by conventional optical microscopy. Three modes of interface failure had been observed: between electroless copper and target pad, between electrolytic copper fill and electroless copper, and within the electroless copper. There was often a mix of all three failure modes.

Scanning electron microscope (SEM) examination of the surfaces of target pads after laser drilling and electroless copper showed some interesting variations in grain structure, which Magera explained in terms of the different rates of growth of (100) and (111) planes in the face-centered cubic crystal structure of copper. The evidence suggested that substrate morphology,

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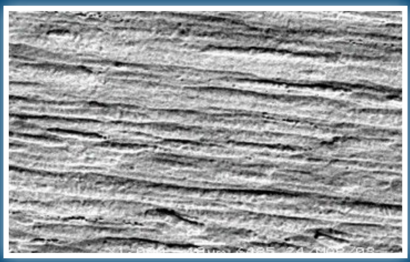
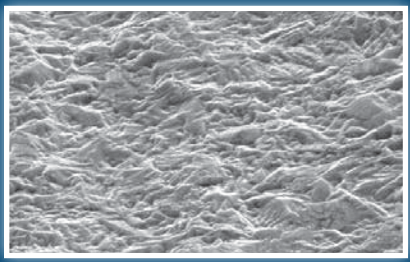
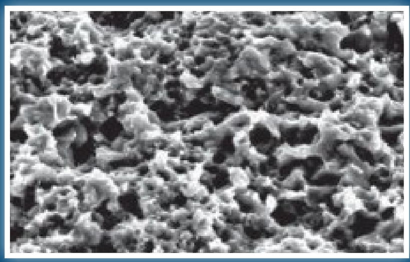


MECHANICAL SCRUB



TRADITIONAL MICROETCH



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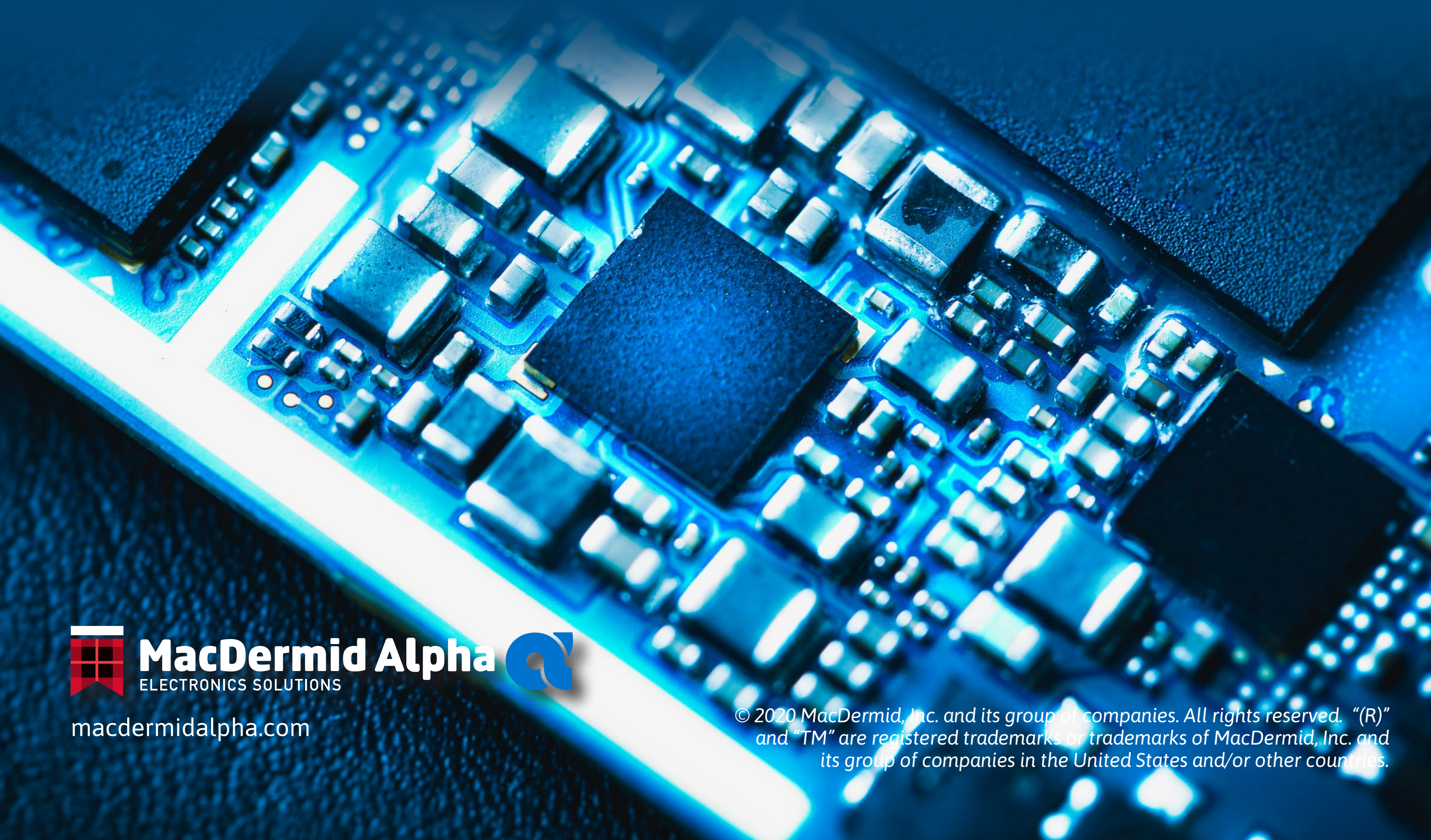

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chemistry, and process control all affected the copper deposit structure.

Magera recommended further FIB, SEM, and X-ray diffraction studies of microvia target pads (as laser-drilled, before catalyst predip and after electroless copper, correlated against process control data to identify critical control variables) to determine the conditions required to produce consistent interface structures and identify the appropriate copper crystal lattice structure for best practice. And it was proposed that IPC-6012E 3.2.6.1 be updated to better define the requirements for electroless copper.

Day 1 Q&A

John Perry then read questions sent in by attendees, followed by an open session for the speaker panel, with questions like, "What is needed to achieve and ensure reliable microvia structures?" The ensuing discussion was lively and interesting. Many topics were discussed, and the panel went 30 minutes longer than scheduled.

Day 2

Chris Mahanna

Day 2 opened with a presentation by Chris Mahanna—president, owner, and technical manager at Robisan Laboratory Inc.—titled, "We Experienced a Microvia Failure; Now, What Do We Do?"

Chris opened with the statement, "With all the publicity around weak microvia interfaces and the horrible functional failures caused by them, it is easy to become overwhelmed by their notoriety and the complexity of the problem. Effective action needs to be taken to understand and mitigate risk, but where does one start?"

His presentation provided a framework for the failure analysis, variables to the related risk, corrective actions, and quality assurance to limit and quantify the risk. The three starting steps are:

1. Verify: Confirm that you have a weak interface microvia failure and not a simpler failure. Isolate the failure to specific microvias.

2. Assess: Keep it simple by concentrating on three variables: (1) the density of your microvias; (2) the Tg of your laminate; (3) and the susceptibility of your circuits to a marginal increase in propagation delays through the interconnects.

3. Take action: Take steps to dramatically reduce future risks by changing the design. Consider your fabricator's capabilities and/or install screening immediately.

Lance Auer

Lance Auer, an Engineering Fellow at Conductor Analysis Technologies, discussed "Performance-Based Microvia Reliability Testing: What You Need to Know." Auer discussed the implementation of a performance-based reliability test methodology:

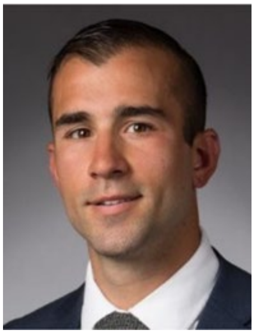
- Test sample (coupon) must match production board, holes and lands, staggers, spacing, fill, signal/plane layers, and solder mask
- Convection reflow assembly simulation per IPC TM-650 2.6.27B
- Air-to-air thermal shock per IPC TM-650 2.6.7.2C

Both test methods are examined in detail with respect to the requirements of the test system:

- Control and performance
- Data acquisition
- Documentation and reporting

Auer summarized the recommendations for performance-based acceptance testing, which was agreed at the IPC APEX EXPO 2020 committee meetings must represent the boards being manufactured and the time/surface temperature of reflow. He demonstrated the thermal profiles for reflow simulation and thermal shock testing and showed examples of change-in-resistance measurements corresponding to microvia failures. Again, Auer reinforced the IPC microvia warning that traditional inspection techniques utilizing thermally stressed micro-sections and light microscope alone are no longer an effective quality assurance tool for detecting microvia-to-target plating failures.

Kevin Kusiak



Speaking with many years' experience of reliability testing and failure analysis, Kevin Kusiak, electronics engineering senior staff at Lockheed Martin Space Systems, gave a comprehensive presentation on "Microvia Reliability Testing Utilizing D-Coupons to Understand Best Design Practices." This session detailed a project Kusiak is leading to design and test coupons, which will give LMS insight to best practice design variables of PCBs utilizing microvias.

The test vehicle will be:

- Multiple via structures of varying microvia diameters across 54 different D-coupons
- 37 coupons for plated hole evaluation through micro-sectioning and SEM-FIB analysis
- Four peel strength coupons with embedded microvias
- 5-, 6-, and 7-mil diameter; 0-, 5-, 10-, 15-, and 20-mil pitch (center to center)
- Fabricated by two different vendors recording bath parameters during the processing of panels

He also explained the IPC-TM-650 2.6.27 reflow cycle, 12x reflows at 260°C using OM testing followed by IPC-TM-650 2.6.7.2 100 thermal shock from -55–205°C and failure criteria, and the via failure mode that will be observed as an open or measurable resistance change at or near the peak temperature.

Marc Carter

Marc Carter, president and owner of Aeromarc LLC, as well as an I-Connect007 columnist, addressed "Stacked Microvia/ Weak Interface Reliability Study Project." For over a year, a committed group of companies and individuals has been developing a reliability modeling study. This study combines empirical confirmation structures and testing protocols with advanced reliability simulation in a three-phase, three-year iterative study (simulate, test, refine, and repeat). The goal is to provide an urgently needed enabler of greater miniaturization in the form of increased complexity "stacked microvias" currently limited by an incomplete understanding of the forces and mechanisms (click here for background information).

While several company-specific studies have generated excellent proprietary data, these do little to benefit the wider industry. In part, this project aims to begin to raise the capability level and understanding of those in the electronics manufacturing supply chain for high-reliability, critical applications not privy to the proprietary studies.

The mutually agreed test vehicle is characterized by:

- 12-layer high-Td laminate with three build-up layers of various stacked and staggered microvias over buried TH vias fabricated by shop A vs. shop B
- Microvia formation methods of mechanically drilled vs. laser-ablated (UV/CO_2/UV)
- Alternative metallization of direct metallization vs. electroless copper
- 17 different D structured coupons
- Reflow simulation of eutectic (230°C vs. lead-free 260°C)
- Analysis by test lab A vs. test lab B

Figure 1: (Top) 2017 Reliability Forum.

Figure 2: (Right) 2018 Reliability Forum.

Michigan Tech University, with the help and software from ANSYS (Sherlock), will do the statistics and attempt to correlate results with simulation. The completion time is estimated at nine months, and the report/results will be made public once finished.

Final Q&A

The wealth of knowledge and experience generously shared by the presenters provided an excellent background for a panel discussion on weak-interface stacked microvia reliability, moderated by John Perry. Although the attendees did not have the opportunity to network and catch up on old times, the last Q&A roundtable session was robust. The success of this virtual conference was confirmed by the scheduled 30-minute session lasting over 90 minutes with abundant conversations on these topics and additional questions. The only thing missing from this virtual event was face-to-face networking from previous IPC Reliability Forums (Figures 1 and 2).

I can't speak for everyone who attended, but I believe it was an extremely rewarding experience for all 150+ participants. IPC also provided the entire two-day transcript for all attendees. **PCB007**

Happy Holden has worked in printed circuit technology since 1970 with Hewlett-Packard, NanYa/Westwood, Merix, Foxconn, and Gentex. He is currently a technical editor with I-Connect007.

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

Denny Fritz Unpacks Weak Interface and Stacked Microvia Reliability

Edited by Happy Holden
I-CONNECT007

On the first day of the IPC High-Reliability Forum, Denny Fritz gave a presentation on weak microvia interface and stacked microvia reliability.

Denny Fritz was a 20-year direct employee of MacDermid Inc. and is a retired engineer after 12 years as a senior engineer at SAIC, supporting the Naval Surface Warfare Center in Crane, Indiana. He was elected to the IPC Hall of Fame in 2012 and is now the head of the Hall of Fame Council of Fellows. Denny has also been involved with the weak microvia team for a couple of years and has participated in many technology roadmaps, better component activities, and standards for board fabrication—particularly Pb-free Electronics Risk Management (PERM). Currently, he is president of Fritz Consulting, as well as an I-Connect007 columnist who writes "Defense Speak Interpreted" on military and defense industry topics and applications.

Here, I have assembled the highlights of Denny's presentation, including the transcript, which has been slightly edited for clarity.


Denny Fritz

Today's Purpose Tomorrow

We certainly do not want to scare away any new designers. Microvias remain a reliable interconnection construction as long as you do things according to IPC test methods and observe practices that will come out in the presentations. However, we do want to alert you to a reliability issue that has been around for a couple of years publicly and maybe as many as 10 years. From some of the stories we've heard, many people thought that they were the only ones who had this problem until they compared notes with other companies that fabricate and use microvias. We are trying to find the root causes of the phenomenon, and we would certainly like any data that you can contribute. If you are not willing to contribute data, please support the working effort of our IPC teams. Where we stand today is to mitigate this microvia problem through design parameters, etc. The Weak Microvia Team is not here to specify product acceptance test methods but to work on the problem itself, so you'll get plenty of information in the presentations on the test methods.

Our objective is to give you a background on the problem, understand the causes, and help guide the efforts of individual companies and consortiums to find answers. This will give you an idea of the teams that are under the Weak Microvia Group, especially because this is on a test program that IPC is participating with IMEC and ESA.

Certainly, the overview explains how to prevent escapes from the fabrication process by understanding the capacity and yield impacts

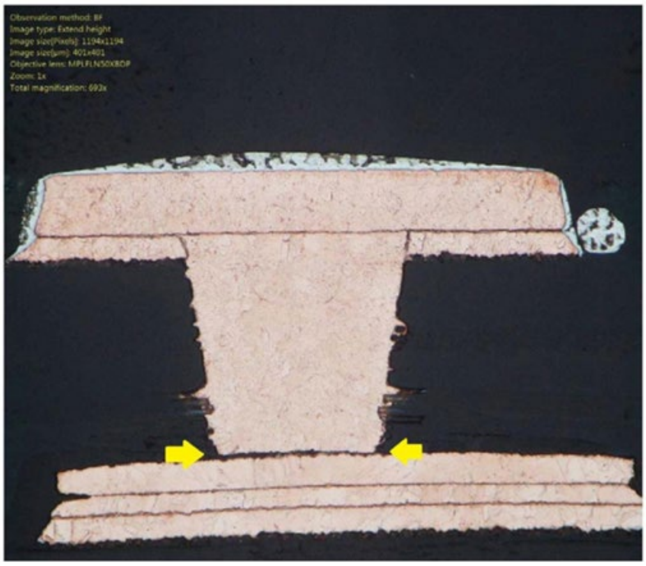


Figure 1: Older microvia failure due to contamination on the landing pad.

of sorting. Currently, we encourage people to avoid higher stacks, so you will see a Motorola presentation on that company's requirements for its own product. The IMEC testing on the test methods will be referred to as TM-650 2.6.26 and 2.6.27A; they involve multiple reflow cycles simulating assembly with continuous resistance monitoring.

Microvia Failures

When I first heard of this problem, I thought, "This is just a common problem out there of microvia failures." Figure 1 is a roughly 10-year-old slide, showing a one-stack microvia that obviously did not include a well-cleaned landing pad in the separation between the microvia fill; the internal layer is obvious on this cross-section. This is not the simple problem that we encounter today.

In Figure 2, a cross-section from Motorola Solutions shows an unpolished cross-section of a three-stack microvia on the left. On the right, with reflow and careful micro-edge, it is possible. You can see a line there, but this is a functional resistance that shows up in the testing. And you might pass this just with optical cross-section. It is an almost invisible problem because it's subtle—and that really bugs us. Figure 3 shows the methodology of using instrumentation to find these problems.

Figure 3 shows the instrumentation involved in finding these weak microvias. The two graphics on the left show thermal cycles. Against that, the resistance of the microvia sections is included in the daisy chain. On the third thermal cycle, the resistance went up infinitely, and the microvia opened. However, you can also see in all the cases the resistance comes back down after the end of the thermal cycle. In Motorola's case, with this data, when they stagger their microvias on the right, the thermal cycles did not change the resistance of the microvia daisy chain, and those are shown as good microvias.

With information from Raytheon (Figure 4), further analysis shows that there was no single

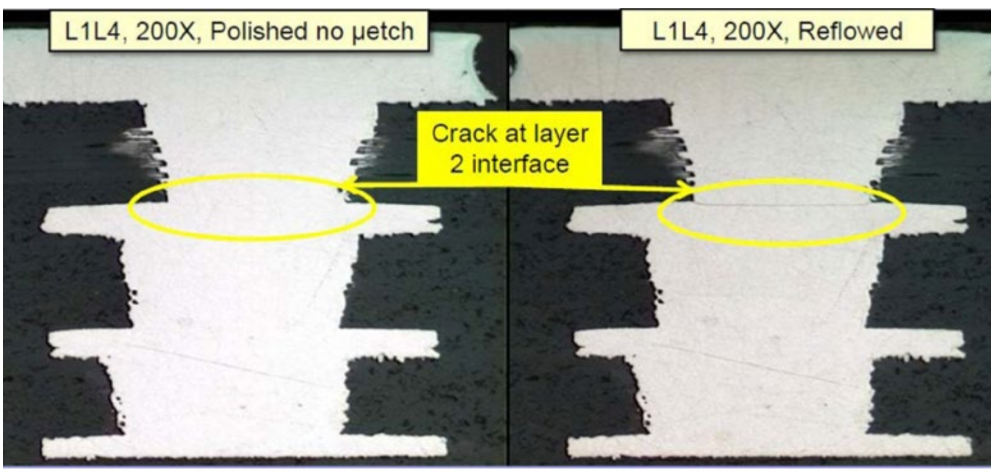


Figure 2: Two microvia stacked constructions with the typical microsection on the left, where the problem is invisible, compared with after reflowing, where it is almost invisible. (Source: Motorola Solutions)

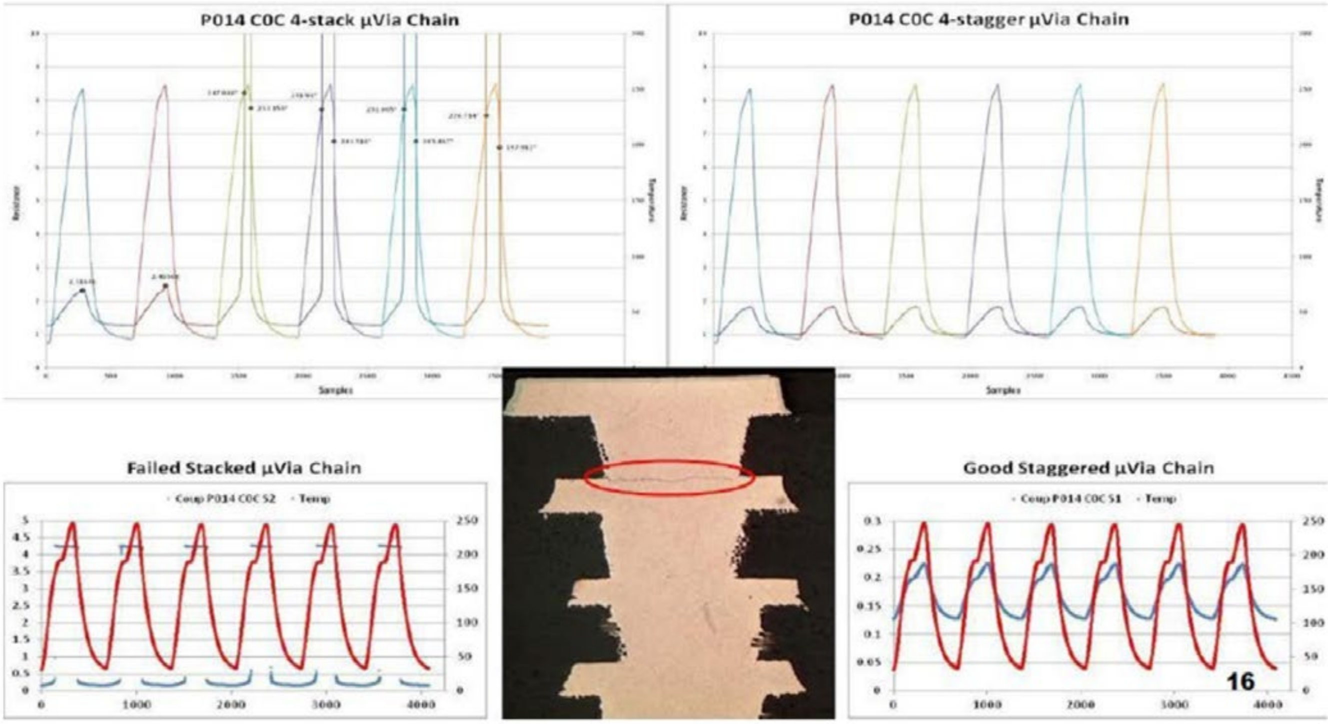
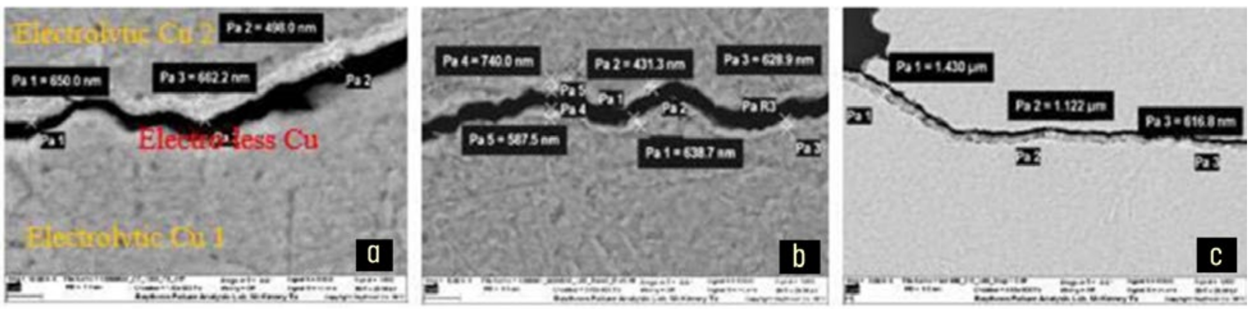
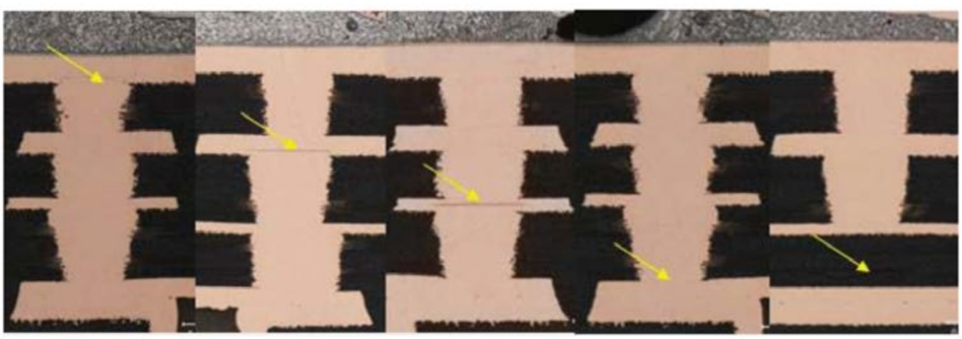


Figure 3: Two sets of three-level microvias, left-stacked, thermal cycled to reflow temps, opened, and then closed when cooled. Right-staggered and no-open/resealed connections. (Source: Motorola Solutions)



Microvia fractures propagated below (a), within (b), and above (c) electroless Cu region and oxidized, which is indicative of a mechanical intergranular fracture.



Microvia "partial" fractures found throughout stacked electroless Cu interfaces, as well as within the laminate resin, which indicates CTE-z stresses essentially the same at all levels.

Figure 4: Mechanical intergranular fractures of stacked microvias. (Source: Raytheon)

interface that was guilty all the time. The one on the left shows the interface between the electrode copper, and the landing pad within the electroless copper deposit is in the center; on the right is between the electroless copper and the fill. It does not necessarily occur on one stack. Although, you will see that there is currently more stress found in the deepest microvia.

The product characteristics are intermittent. They open more at hot temperature versus cold temperatures, and this self-healing effect is a real problem in intermittency. The failures occurred after the finished product was stored for weeks or months; it passed test at the time of fabrication and initial assembly but dropped out after storage. A failure after field deployment is the costliest of all failures. This is an unpredictable reliability issue that needs to be resolved.

Table 1 shows the structure of the IPC Weak Microvia Failure Committee Sub-Teams, including simulation and modeling. The two groups (1b and 1d) are in yellow, as we are melding the characterization and test methods team with the construction design elements

Weak Microvias Subcommittee Structure Adopted Early 2019
1A. Simulation and Modeling
1B. Characterization and Test Methods
1C. Laminate Materials
1D. Construction Design Elements
2A. Chemical Processes and Metallurgy
2B. Hole Formation
3. Data Collection (Reactivate After IPC Testing)

Table 1: IPC Weak Microvia Failure Committee Sub-Teams.

team. There is a laminate sub-team, a chemical processes and metallurgy team, and the whole formation team, which were highly active. A year ago, after formation and trying to collect field data (which was not forthcoming), this committee was inactive. It will reactivate after IPC test data from the test program that we outline is disseminated.

You might ask, "What can cause weak microvias?" Figure 5 shows a fishbone diagram

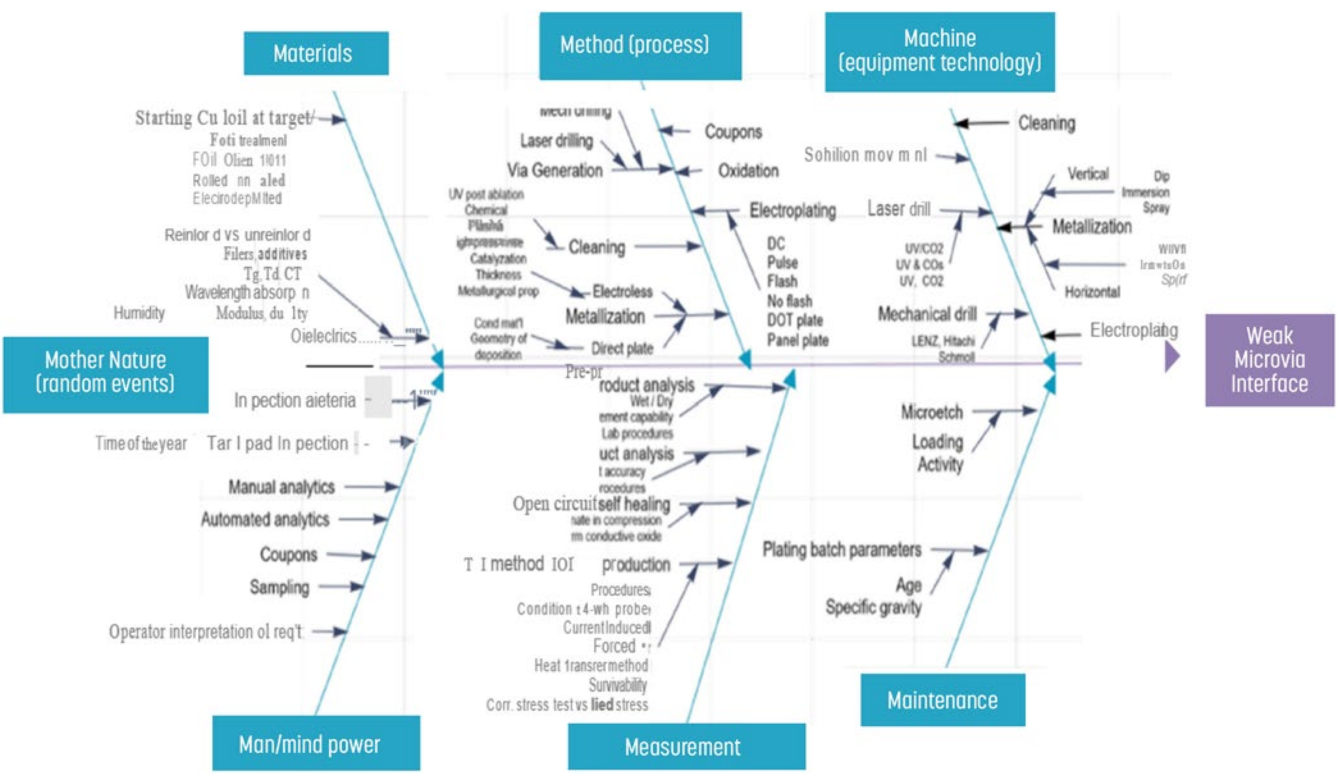


Figure 5: Various factors in the understanding of weak interfacial bonds for microvias.

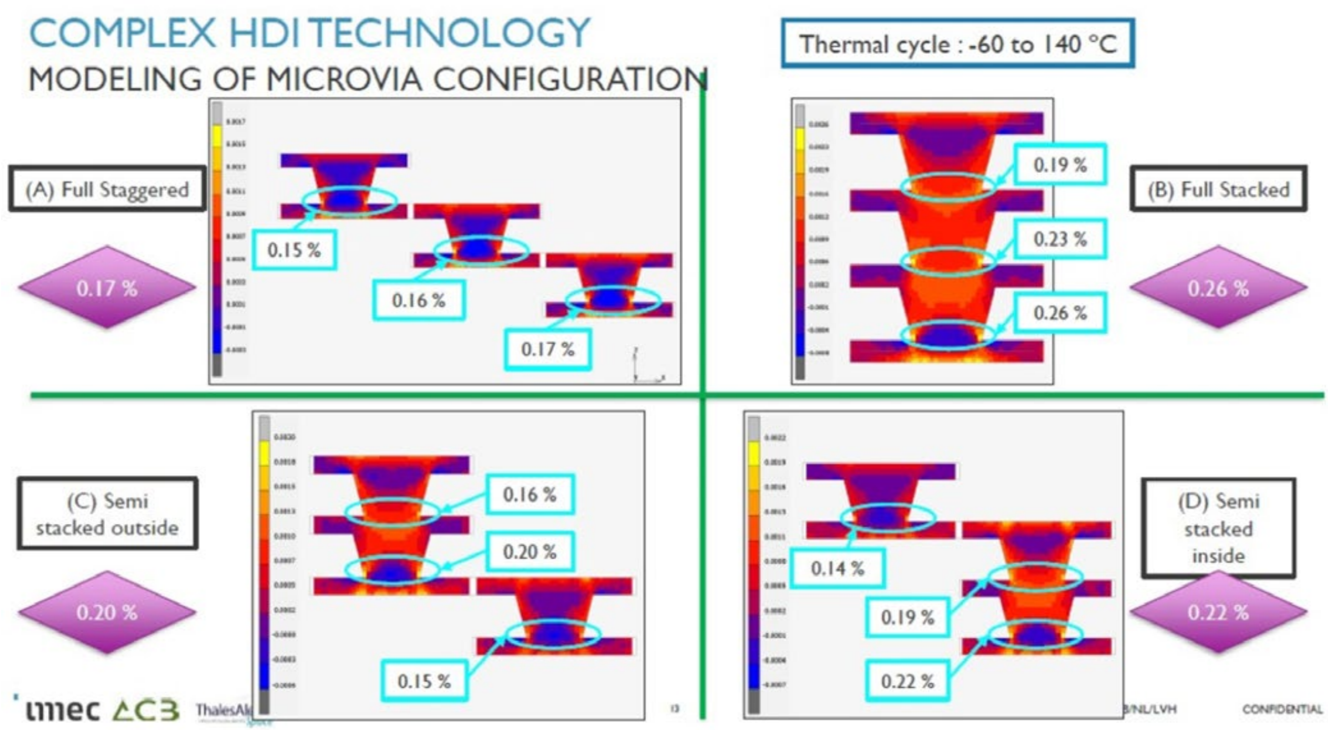


Figure 6: IMEC and ESA test simulations with actual builds and thermal stresses.

assembled by the team after just two months together. You can see that materials, methods, machines, maintenance, measurement techniques, and human inputs can all contribute to some aspect of the weak microvia team. It is a very thorny problem. To sort all of these out would be an immense undertaking for some kind of test design. These presentations review the efforts to determine the germane causes of weak microvia interfaces.

Figure 6 is from IMEC and ESA, which shows stress simulations from internal evaluations. On the upper left, you see staircase microvias. On the upper right, you see a three-stack of microvias, as well as semi-stacked "two over one" or "one over two" microvias.

You see that the most stressful situation is in the stack microvia. Unfortunately for us, that is the configuration that takes up the least space on the board; it's the most desirable from an interconnection density standpoint but the most likely to fail. Figure 7 shows IMEC graphics between a three-stack staircase and staggered microvias. They found that the staggered microvias have slightly less stress than the staircase microvias, at least in our simulation. You will see that most of these designs occur in some of the presentations of future work.

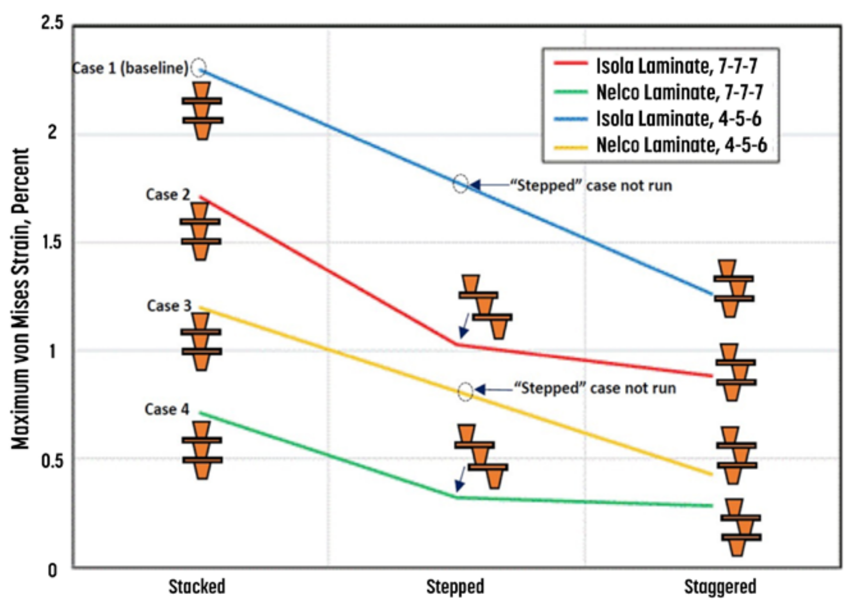


Figure 7: The effect of varying microvia configurations shows stacked as the most strained and staggered as the least strained. (Source: Raytheon)

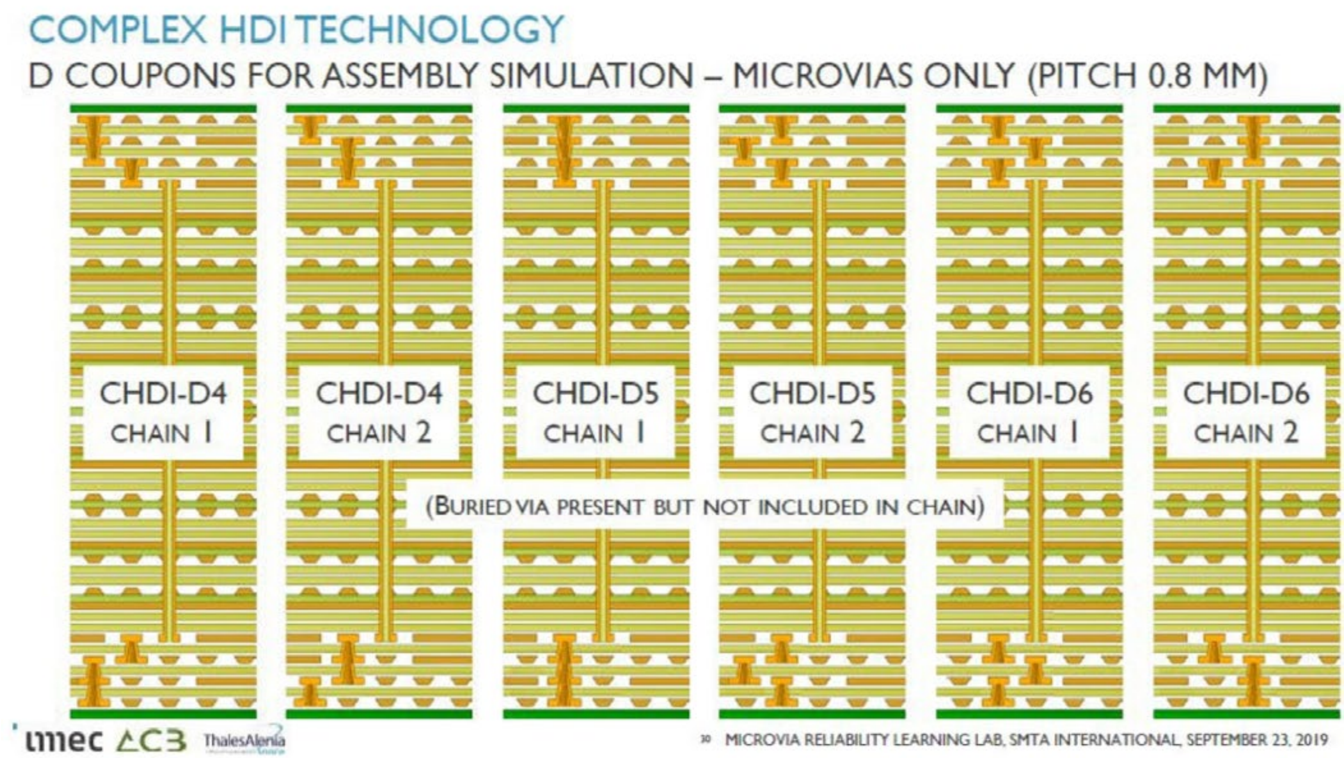
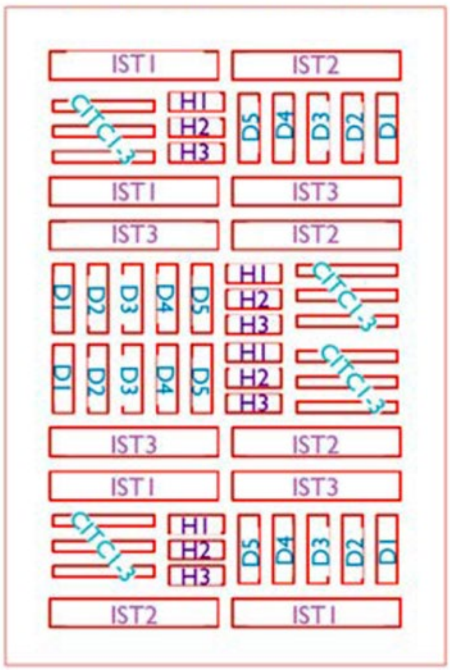


Figure 8: The modified ESA microvia test panel for the IPC reliability testing using the Hitachi high-Tg laminate. (Source: IMEC)

The test board that IPC has selected is from the ESA program (Figure 8). The chessboard—with a purchase order issued by IPC to participate with IMEC and its board fabricator, a CBF in Europe—uses this design of daisy chains. There are six different chains, and Figure 9 shows where they are placed on a panel.

Figure 9 is the panel that IPC is contracted to have fabricated at the EU fabricator, duplicating ESA.

These will be constructed in Hitachi 679F laminate, which is an epoxy qualified at CB and most similar to the North American constructions of microvia. It will use four different test coupons, depending on the instrumentation for the analysis of the D-coupon to the HATS to two other coupons. The CITC coupon, which is the old IBM-developed method, was carried forward by i-3 and possibly TM and the IST coupon.



	Hitachi 679FJ				
D coupon	D1	D2	D3	D4	D5
Per panel	4	4	4	4	4
Three panels	12	12	12	12	12
Six panels	24	24	24	24	24
Total	60 - 120				
HATS[2]	H1		H2		H3
Per panel	4		4		4
Three panels	12		12		12
Six panels	24		24		24
Total	36 - 72				
CITC					
Per panel	4		4		4
Three panels	12		12		12
Six panels	24		24		24
Total	36 - 72				
IST coupon	IST1		IST2		IST3
Per panel	4		4		4
Three panels	12		12		12
Six panels	24		24		24
Total	36 - 72				

Figure 9: Layout and number of the four coupons on the IPC test panel. (Source: IMEC)

Year	%Yield
2014	83.8%
2015	86.9%
2016	87.5%
2017	94.4%
Total	90.1%

Construction	%Yield
1 Layer HDI	98.5%
2 Layer HDI	95.7%
3 Layer HDI	85.0%
4 Layer HDI	62.3%

Table 2: Composite test results from years of testing microvias by reflow coupons containing a staggered chain and a stacked chain for each HDI construction type. (Source: Motorola Solutions)

Table 2 shows Motorola's results. When Motorola put in its sorting protocol, it showed yields from 2014–2017. These went up significantly with the protocol, and they learned that there was a breakdown after three-stack or a force that showed in their results anyway. Since the time this was initially presented, Motorola has had no failures.

Motorola has gone from preferred to unacceptable, and the preferred is staggered microvias and then two-stacks and with caution on a two-stack or three-stack construction. They require a management sign-off if you need three-stack microvias.

In summary, stacked microvias and even some others can fracture at a metallurgical interface, particularly during reflow and thermal cycling simulations. The failure level is not predictable with what we are doing today and how we understand the process. The test methods, like visual cross-section, are not effective in detecting the failures. The technique duplicates reflow assembly and potential problems.

T-type testing is the most widely used equipment today. You can minimize failures with design, and our team hopes to release a white paper design guide within a year. Is there more than one cause of this? If our industry was not in containment right now, we would have discovered the answer already.

Please understand that our team has been operating for over two years, working to identify the root causes. We are not particularly working on product acceptance. Try to help IPC. We certainly want higher reliability and high-density structures with four stacks or more. Join our working teams and contribute. PCB007

Gerry Partida Emphasizes Current Concerns Over Microvia Failures

Edited by Happy Holden
I-CONNECT007

Gerry Partida

At the virtual IPC High-Reliability Forum, Gerry Partida, field application engineering manager at Summit Interconnect, covered concerns regarding the reliability testing of microvias in his presentation titled "Current Concerns Over Microvia Failures." He also provided an overview of HDI processes and discussed current test methods. Here, I share Gerry's presentation transcript, which has been slightly edited for clarity.

Current Concerns Over Microvia Failures

I'm going to share the knowledge that our team has accumulated over 20 years of making microvias, as well as information on what can be done to test your microvias for acceptance as it applies to today's IPC standards. Have you ever had to hold your finger down on a component to make it work, and when you let up, it stopped working (Figure 1)? It might be the reason why you are here today.

Figure 2 shows a quote from an IPC news release warning about microvia reliability.

The industry has experienced failures of microvias after the boards have been completed and shipped to the customer, either at assembly or during thermal testing of a finished product. Customers have experienced failures that occurred even later. There is a way to check your microvia and ensure that you have a good microvia that will meet the assembly reflow process, as well as when doing thermal shock.

Why do we test and then look? We don't see a lot of commercial companies; we see a lot of high reliability. The military-aerospace sector is more interested in this than U.S. commercial companies, and there is a reason for that. When they build a lot of these space products, they can only put the component down one time. It cannot be reused. If it's a custom ASIC chip with 1,400 I/Os on a BGA, or an ASIC

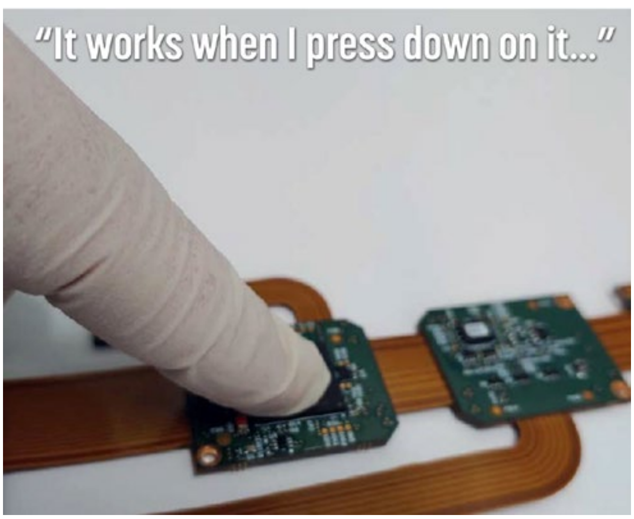


Figure 1: A finger pressing down on a component to make it work.

> "There have been many examples of post-fabrication microvia failures over the last several years. Typically, these failures occur during reflow; however, they are often undetectable (latent) at room temperature. The further along the assembly process that the failures manifest themselves, the more expensive they become. If they remain undetected until after the product is placed into service, they become a much greater cost risk and, more importantly, may pose a safety risk."

Figure 2: IPC microvia reliability warning press release.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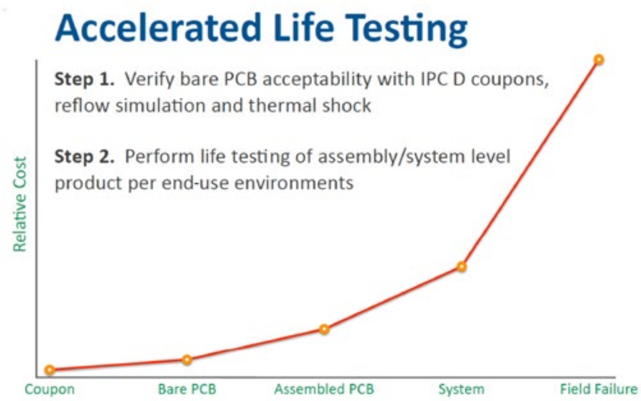


Figure 3: Why are we testing for reliability?

where that one component can cost $100,000, then you don't want to build a board and put a couple (or five or six) $100,000 components on a space board only to find out that the vehicle instructions are not reliable.

It is better to just test this coupon using a little bit of real estate. Put the same geometries, drill sizes, land sizes, and vias—whether they are stacked or staggered—in designs, build a coupon with planes and signals, and find out before you commit the components to the assembly. Now, you can test whether that structure can sustain the reflow you expect to do to the part.

You need to test that coupon for acceptance before you commit the parts. Many people have not tested with reflow temperatures, measuring resistance at reflow to find out what is going to happen. With OM testing and IPC TM650 2.6.27, you can measure the resistance at reflow and find out whether these boards will go through assembly safely. And you do not want to assemble the serial number that coupon came from. As seen in Figure 3, the cost of any failure goes up with time.

All of my testing is IPC 2.6.27 for real-world validation for today's demanding PCB design. I'm going to review the current evaluation methods that are required by a PCB fabricator and talk about the different temperature methods. Why did some methods not provide us a true assessment in some cases? And how does OM testing provide a real-world evaluation of your finished product by testing the coupons?

In our current evaluation methods, we take A-B coupons and thermal stress them, depending on the temperature. If it's tin-lead to 230°C or 260°C, then we evaluate the cross-sections and look at what we have after we micro-etched a polished coupon.

Our shops are required to do monthly performance testing. I will talk about that, as well as what happened to a board at electrical test, and why it does not really tell us whether we have weak microvias. I'll also show some real-world builds in which the D-coupon testing catches a non-conforming via when the resistance caught it, as well as it being non-conforming to IPC-6012 for internal evaluation.

Why did the older methods seem to fail us? When we do a micro-section on A or propagated B coupons, we begin by baking. We solder float them and then grind them. In the as-polished condition, we look for separations. If we do not identify the separation of a microvia evaluated at 200x, and if we do not notice anything, we will take a Q-tip with micro-etch and rub the coupon that has just been polished (Figure 4).

We see this result in Figure 5, especially the different layers of copper plate in the starting foil. There's a plated layer and layer two. In this example, the flash plated microvia plated shut. Then, we do the final calculating, but all the evidence is now gone, so it's kind of a moot point. We polish and look; if we don't

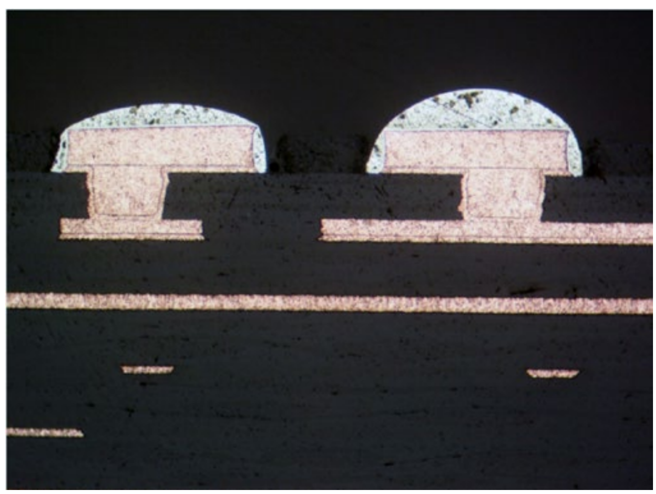


Figure 4: Micro-etched cross-sections hide small separations found in the polished condition.

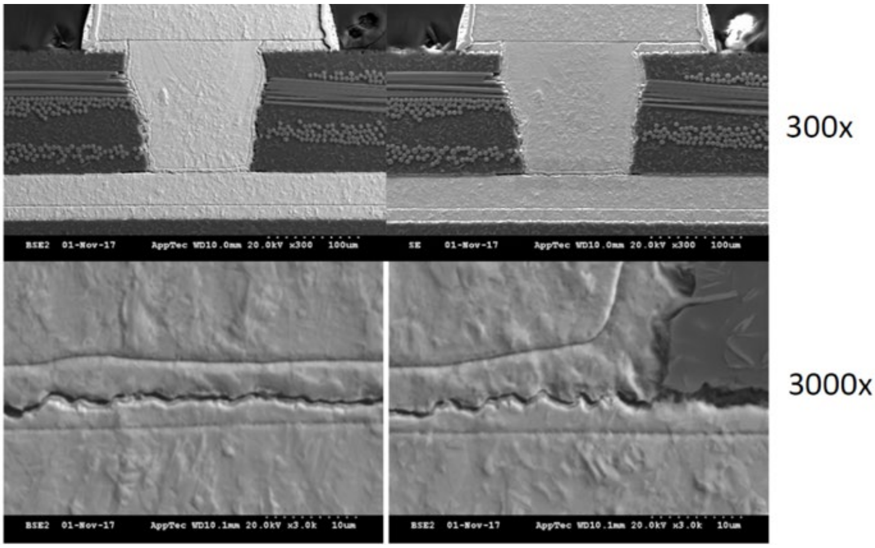


Figure 5: IPC-6012 requires examination from 200x up to 500x.

see anything at 200x, we micro-etch, which is where we can no longer see any separation.

But if we go to a higher magnification, we see what it looks like after micro-etching. The top picture of Figure 5 is at 300x. IPC requires that we start at 200x for a microvia, and if there is something that's questionable, go up to 500x. If we can't identify anything, it's deemed acceptable. But if we take those same pictures and go to 3,000x, we can see that separation is taking place. Our standards for what's required from a fabricator may not identify this separation, which leads to problems. They pass all of the cross-section evaluations and get shipped, but nobody did a thermal test of the D-coupon to show that there were weak microvias in the build. Instead, it will be found in assembly when your fingers are pushing down on the component.

Figure 6 is an example of the as-polished condition. On the left, you can see the three stack microvia, and there is no separation. Right after this point, when somebody evaluates it, they are going to take a micro-etch and look. The center picture shows a 2X tin-lead reflow, which is about 230°C, and it's a lot less stressful on the specimen. You can't really see a separation, but there might be a separation between the top and the middle of microvia on the target path. On the far-right column, you can see a separation occurring at the target pad on layer 2 to the microvia between one and two.

At that point, it should be deemed an unacceptable condition and non-conforming. It is so thin and slight that it could be missed. Once they ship, you are not going to see this demarcation.

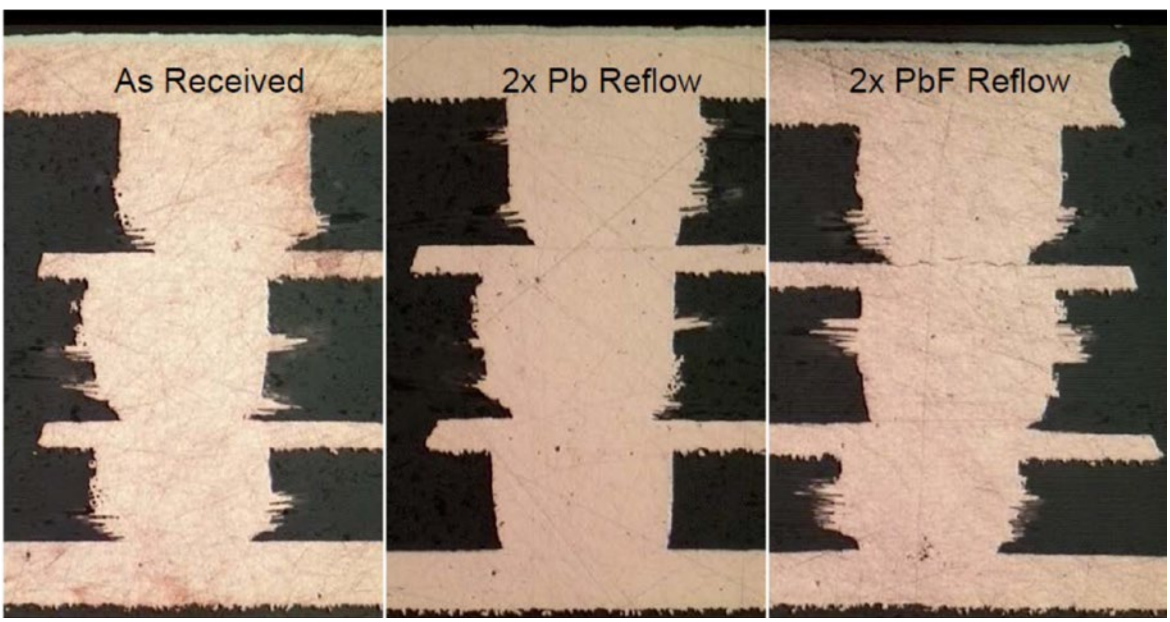


Figure 6: How older methods fail us.

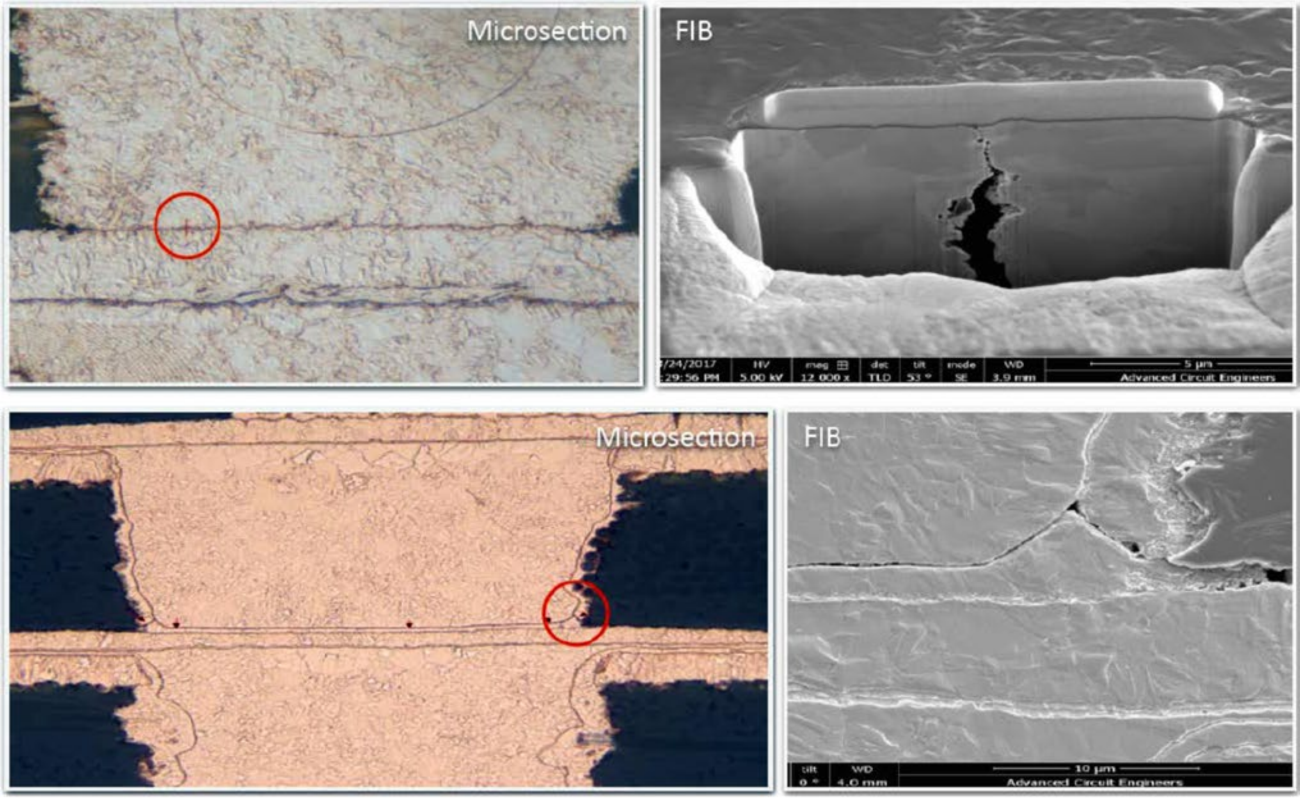


Figure 7: The older methods fail at detecting weak microvia defects.

If we were to take a specimen after micro-etch and everything was fine (Figure 7), we would focus on ion-beam milling and look inside it. You can find a crack; in some cases, there are failures. You find these cracks in the board, and now everybody's in a panic about whether these boards are going to work. I have seen many customers who have had 1,400–1,600 I/O BGAs using four-stacked microvias. I told them we were not going to build the boards. They said, "You build all our hardest boards." But I knew that this board was not going to get through their assembly.

Six months later, I was in their quality lab with two Ph.D.s. They were looking at a board, and I said, "Let me guess. When you put your finger down, they work." Their response was, "How would you know?" I was not going to build that board because they have this type of failure in them due to the four-stack migrations. They are only detectable by using very expensive, very sophisticated focused ion beam milling.

Another requirement these board fabricators have is monthly quality conformance testing for Class 3 suppliers. All we have to submit is the most complex board we built in that month to testing. The test checks rework simulation, bond strength, peel strength, dielectric with standing voltage, and moisture installation. But there's no way to test whether the board shop can actually produce microvias reliably.

When we've finished building a PCB, we test the electrical circuit boards at ambient room temperature. But a weak microvia still has enough connection and will not fail an electrical test, especially when the electrical test threshold is typically at a 10 ohms resistance value and anything under 10 ohms in a net is considered a connection. Therefore, the weak microvia is not going to be detected.

A funny story about testing at ambient room temperatures over the last five or six years is we've been working with reliability reflow testing of the coupons since the very beginning. In that time, some customers would not do the coupon testing and, therefore, had assembly problems. Typically, there were three- or four-stacked microvias involved. We shipped the boards. They called us and explained how they wanted to retest the boards after putting

Figure 8: Electrical testing at ambient temperatures will not find weak microvia interfaces.

them through a reflow oven six times. Now, they want us to retest on our testers to see if we have an open that occurs.

Again, this is at ambient room temperature. We were never going to find any weak microvias, even though they passed it through a reflow of six times. A customer might say, "I want to retest these boards, I will pay you for it." But when I look at the designs, I typically find that it was a three- or four-stacked microvia, which we highly recommend not doing (Figure 8).

In most cases, if you have a defective microvia only at reflow, then only resistance is open. In this example, you can see the six peaks. This is the resistance at each reflow cycle. The red line is a 5% threshold that we cannot exceed; if we do, it is a bad panel, and it is going to get rejected. Typically, you do not hear board shops saying this, but if we have a bad serial number, I do not want you to build with it. Rather, I want to throw it away. I do not want you to have failures. I will reject it. I will be happy that you are not getting bad products.

As you can see in Figure 9, the little line that goes over the 5% red line threshold is a defect. The resistance at reflow at the peak of reflow temperature went over the 5% threshold, but only as it cooled down. You will notice that the resistance went away, and it is now connected, or self-healed, at ambient room temperature. This gives that false hope that everything is fine. But you can detect these, in many cases, only at reflow with actual reflow temperature.

Traditional thermal testing with thermal shocks uses the chamber in which it normally cycles from a very cold temperature (-60°C) to 160°C. Originally, it was thought that you didn't have to check if the resistance changed after every reflow. The thinking was you just had to exercise through the six reflows. Then, you put them on the tester, and a whole measurement of resistance was only done in the thermal shock temp chamber (Figure 10).

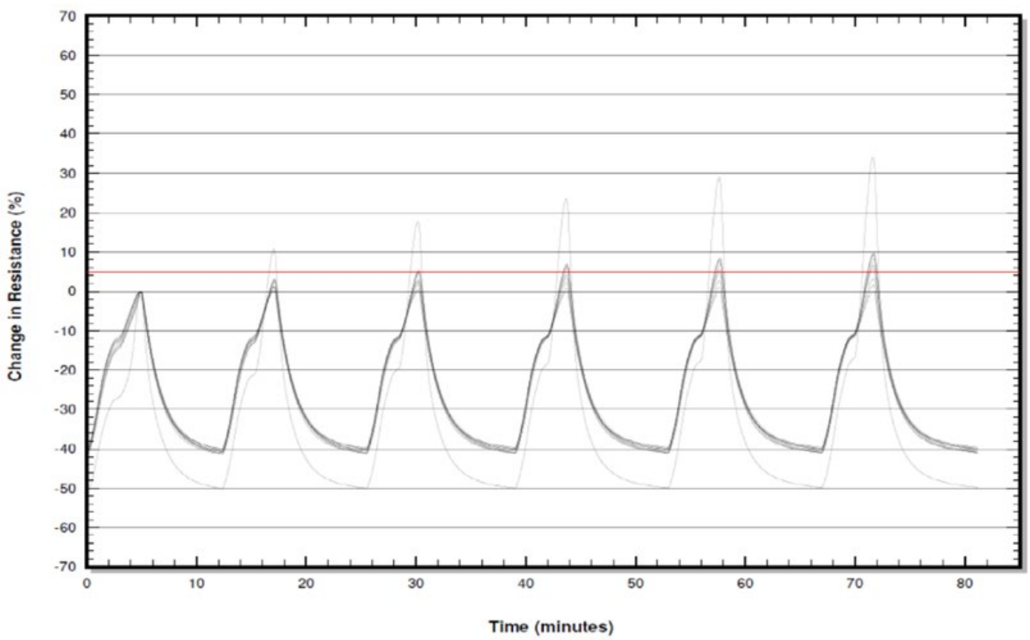


Figure 9: OM testing with four-wire resistance from ambient to reflow temperatures.

Coupon Number	Nominal Resistance at Room Temperature (ohms)		Reference Resistance at 175C (ohms)		Cycles to 5% Change		Change after 100 Cycles (%)	
	Net 1	Net 2	Net 1	Net 2	Net 1	Net 2	Net 1	Net 2
1	1.138	0.717	1.693	1.070	>100	>100	0.3	0.1
2	1.150	0.739	1.738	1.118	>100	>100	0.5	0.7
3	1.163	0.606	1.750	0.913	>100	>100	0.5	0.1
4	1.089	0.657	1.661	0.993	>100	>100	1.5	0.6
5	1.034	0.695	1.568	1.046	>100	>100	4.0	0.6
6	1.045	0.700	1.578	1.048	>100	>100	1.3	0.4
7	1.089	0.622	1.629	0.930	>100	>100	0.5	0.1
8	1.143	0.659	1.736	0.992	>100	>100	1.6	0.4
9	1.019	1.145	1.517	1.698	>100	>100	0.3	0.3
10	1.170	1.207	1.741	1.792	>100	>100	0.1	0.2
11	1.105	1.167	1.645	1.741	>100	>100	0.1	0.3
12	1.122	1.067	1.670	1.585	>100	>100	0.1	0.2
13	1.060	1.154	1.573	1.713	>100	>100	0.3	0.5
14	1.125	1.212	1.683	1.807	>100	>100	0.2	0.1
15	0.135	1.256	0.204	1.876	>100	>100	0.4	0.2
16	1.121	1.100	1.687	1.650	>100	>100	0.4	0.1
17	0.203	0.336	0.311	0.513	>100	>100	-0.2	-0.1
18	0.218	0.281	0.333	0.428	>100	>100	-0.2	-0.3
19	0.208	0.264	0.317	0.402	>100	>100	0.1	0.4
20	0.201	0.300	0.311	0.460	>100	>100	0.1	0.3
21	0.196	0.326	0.300	0.497	>100	>100	-0.2	-0.1
22	0.203	0.280	0.310	0.424	>100	>100	-0.1	0.0
23	0.210	0.304	0.321	0.463	>100	>100	-0.0	0.2
24	0.183	0.273	0.280	0.414	>100	>100	0.1	0.1

Figure 10: Examples of how thermal shock alone will pass coupons that fail at reflow.

Figure 11 is a report. If you just looked at the thermal shock on some coupons, and look toward the right, you will see yellow lines. The first two pairs of columns are how many cycles it went past 100 cycles. The requirement was 100 cycles. But when you did an OM test with reflow measuring, the resistance at reflow was followed immediately by thermal shock. The reason these are marked in yellow is that every one of the yellow-marked tests failed during reflow in that the resistance went over the 5% threshold.

If you just use the thermal shock, and if that is the only test you did, you would have declared all the parts as good. They passed ther-

Coupon Number	Nominal Resistance at Room Temperature (ohms)		Reference Resistance at 230C (ohms)		Cycles to 5% Change		Change after 6 Cycles (%)	
	Net 1	Net 2	Net 1	Net 2	Net 1	Net 2	Net 1	Net 2
1	1.117	0.708	1.905	1.210	>6	>6	0.2	-0.3
2	1.135	0.734	1.979	1.279	>6	>6	0.4	-0.2
3	1.147	0.591	1.990	1.039	>6	>6	1.7	0.3
4	1.063	0.649	1.885	1.136	>6	>6	2.6	0.0
5	1.017	0.689	1.782	1.197	2	>6	Open	0.2
6	1.030	0.693	1.790	1.189	3	>6	Open	0.3
7	1.072	0.615	1.845	1.055	>6	>6	1.1	0.0
8	1.119	0.652	1.969	1.124	5	>6	Open	0.5
9	1.006	1.126	1.700	1.903	>6	>6	0.5	0.5
10	1.157	1.192	1.955	2.011	>6	>6	0.5	0.5
11	1.092	1.150	1.855	1.967	>6	>6	0.2	0.6
12	1.108	1.052	1.880	1.780	>6	>6	0.2	0.2
13	1.044	1.135	1.766	1.950	>6	2	0.3	Open
14	1.106	1.192	1.903	2.038	>6	>6	0.6	0.2
15	0.133	1.237	0.230	2.120	>6	>6	0.4	0.3
16	1.102	1.086	1.915	1.872	>6	>6	0.4	0.0
17	0.202	0.334	0.355	0.585	>6	>6	-0.1	-0.3
18	0.217	0.280	0.377	0.485	>6	>6	-0.2	-0.2
19	0.208	0.263	0.357	0.456	>6	>6	0.2	0.3
20	0.201	0.298	0.354	0.524	>6	>6	0.2	0.5
21	0.195	0.325	0.341	0.563	>6	>6	-0.3	-0.2
22	0.203	0.278	0.352	0.483	>6	>6	0.1	-0.3
23	0.210	0.301	0.363	0.524	>6	>6	0.3	0.6
24	0.183	0.272	0.315	0.464	>6	>6	0.2	0.2

Figure 11: Same load from previous figure except these are reflow statistics.

mal shock. But if you did reflow—which is this slide, plus the thermal shock—you would say, “No, I don’t want to assemble those four serial numbers because they actually went open at reflow, even after thermal shock. They are still connected, and maintaining their connection those boards that have failed could lead to problems out in the field later.”

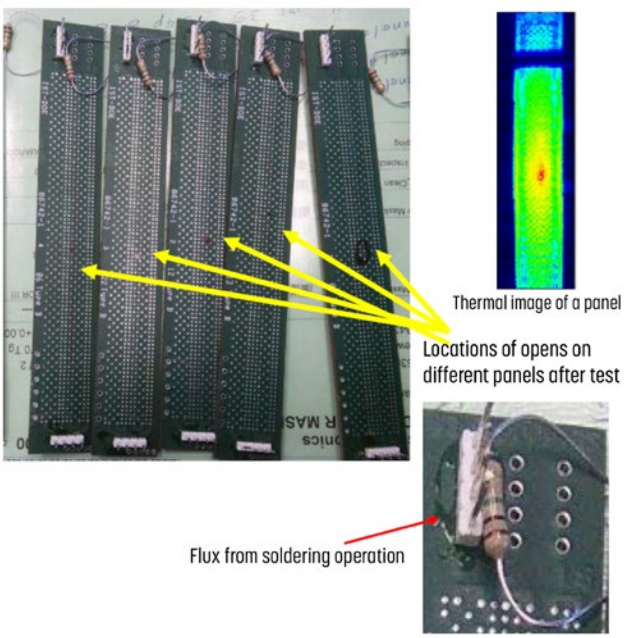
There is also the ability to evaluate using IST coupons and current to induce heat in the specimen to evaluate whether the structure is strong. It’s a great system to compare changing one process to the other, and I highly agree with that. It’s a good comparison system to say these are stronger than those, but it doesn’t take the coupon to reflow temperatures across the board, like we do with an actual board in assembly.

On the bottom right in Figure 12, what you see is the thermal image of a coupon, and a current is flowing through the daisy chain. The hottest point in the coupon is in the dead center, which is going to have the most stress. The connector is soldered on there. It is not as if it had reflowed the coupon and was going to reflow to have the problem with the connector. The actual coupon itself did not reflow across the whole coupon, just like your board is going to get reflow across the entire board. Then, there’s the example with the arrows.

You can see the little black dots where the arrows are pointing, where every failed microvia was on five different coupons. They are all in the center, where the heat’s the strongest. By the way, these all come from different panels and positions on those panels. I do not have the ability to make the weakest microvias in the middle of a coupon specifically over again when they are all the same geometries. It is a good comparison test to validate your process. But it does not take your coupon, which should have the same structures as your board and takes the reflow temperature just like your portal experience.

IPC-TM-650 2.6.27A comes to the rescue. What we are using is a D-coupon, which is approved by IPC. The coupon can be built by anybody by going to Conductor Analysis Technology and building your own D-coupon that meets the IPC requirements. When you generate your coupon, you have generated it just like your board. You need to know the diameter of your microvia or mechanical or buried vias and use the same land size.

You specify whether there is a plane layer on layer two or if it is a signal layer. You build the coupon exactly like your board so that it tests a structure just like your board. It is critical that you have the distance between the drill laser and the mechanical drill at the same distance,



- In some test methods, coupons are not thermally cycled at actual reflow temperature. The connector is soldered to the coupon and, therefore, cannot be reflowed.
- Coupon is a heating coil with five amps of current through a microvia daisychain. The temperature is theoretical, not measured. The greatest heat is at the center of the coupon as seen in the thermal image shown.
- OM coupons use the actual recorded temperature readings.

Figure 12: In IST testing the greatest heat is in the center of the coupon.

land size to land size; pad to pad size is meaningless. Instead, the edge of the laser drill to the edge of the mechanical drill, as they get closer to each other, start to fail at a higher percentage; the farther they go away, the safer they become. Again, you can use production house technology and generate your own coupons, and I highly recommend that the OEM checks the coupons that are generated by the board fabricator to make sure everything is correct. Again, the D-coupon matches the structure of your PCB. You are going to evaluate your structures in your process and the coupon that matches your product. If the coupon passes, your boards will be good in assembly.

The coupons go into a chamber. The OM tests are currently a 24 position test. You have coupon positions and can define different strategies of interconnects. In some cases, you may need two or three different coupons to do all of the different drill spans you have designed into your board. Each coupon can only have two different nets. If you have propagated vias of various configurations, you may need multiple coupons on the panel that goes into the chamber and is tested.

A real-life test is shown in Figures 13 and 14. It is kind of embarrassing, but this really hap-

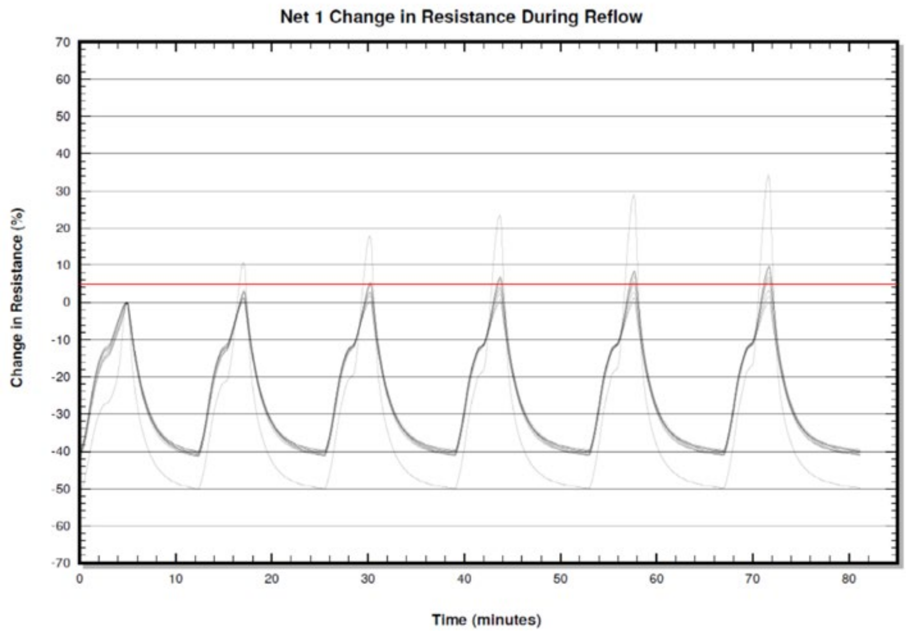


Figure 13: Example of test results.

Reflow Statistics

Coupon Number	Nominal Resistance at Room Temperature (ohms)		Reference Resistance at 230C (ohms)		Cycles to 5% Change		Change after 6 Cycles (%)	
	Net 1	Net 2	Net 1	Net 2	Net 1	Net 2	Net 1	Net 2
1	0.695	0.683	1.201	1.148	4	>6	8.2	0.1
2	0.674	0.671	1.146	1.127	5	>6	6.7	-0.1
3	0.725	0.731	1.235	1.222	6	>6	5.8	1.3
4	0.691	0.669	1.169	1.098	3	>6	9.8	0.2
5	0.715	0.737	1.205	1.204	4	>6	9.2	0.1
6	0.694	0.687	1.179	1.121	3	>6	9.6	0.2
7	0.674	0.698	1.123	1.160	>6	>6	1.6	0.0
8	0.710	0.714	1.180	1.184	>6	>6	-0.1	-0.0
9	0.692	0.700	1.167	1.166	>6	>6	3.2	0.0
10	0.659	0.647	1.351	1.093	2	>6	34.2	2.9

Notes:
1. Resistances greater than 15 ohms are "open".
2. Reference resistances greater than 3 times their initial room temperature resistance are "open".
3. Reference resistances are based on cycle 1 at high temperature.
4. Cells highlighted in red indicate failures.

Figure 14: OM test reflow statistics.

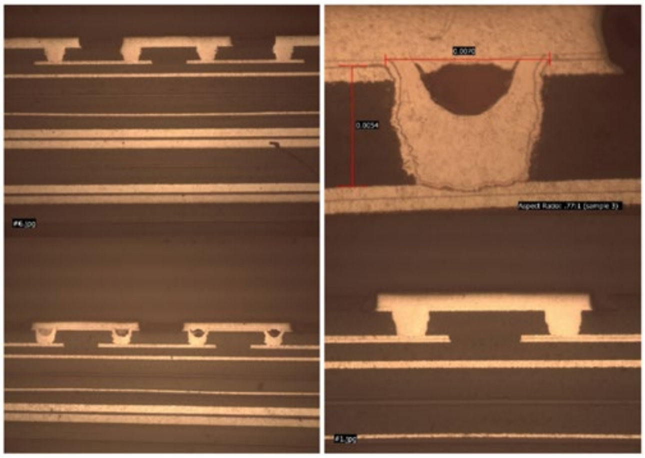


Figure 15: Example of WMI failure caught by OM testing.

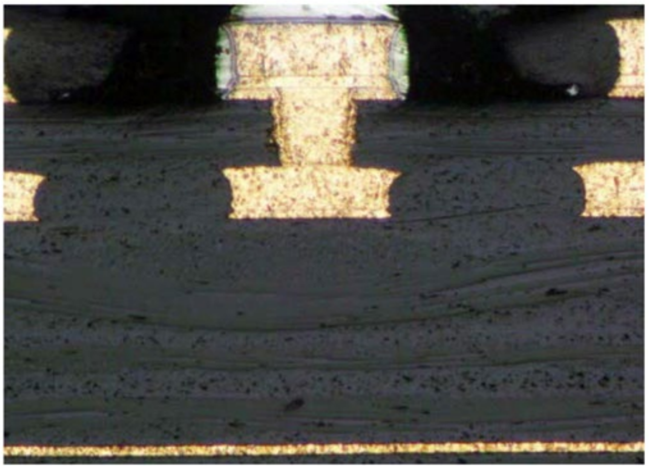


Figure 16: A microvia at 0.005″ with an aspect ratio of 1:1 and a dielectric target of 0.0045″.

pened. We built these boards, and every one of the reds failed reflow testing. Three of them passed.

Therefore, as seen in Figure 15, we had a void in the microvia at the cap plating. The one on the bottom right passed. When you build them right, they pass; but if you have problems, they will fail.

This is a real case study (Figure 16). I had a new CAM planner that planned for a 5-mil microvia; because of the price at five, it is a five-mil laser via, and the aspect ratio was high. I highly recommend 0.75:1.0.

Figure 17 shows the test cycle at 245°C. The black line is the actual temperature on the coupon. Here is what happened during the routine first reflow. It looked like it was okay, but then we started having failures at the second reflow, and it happened more and more as we got down to the sixth reflow cycle (Figure 18).

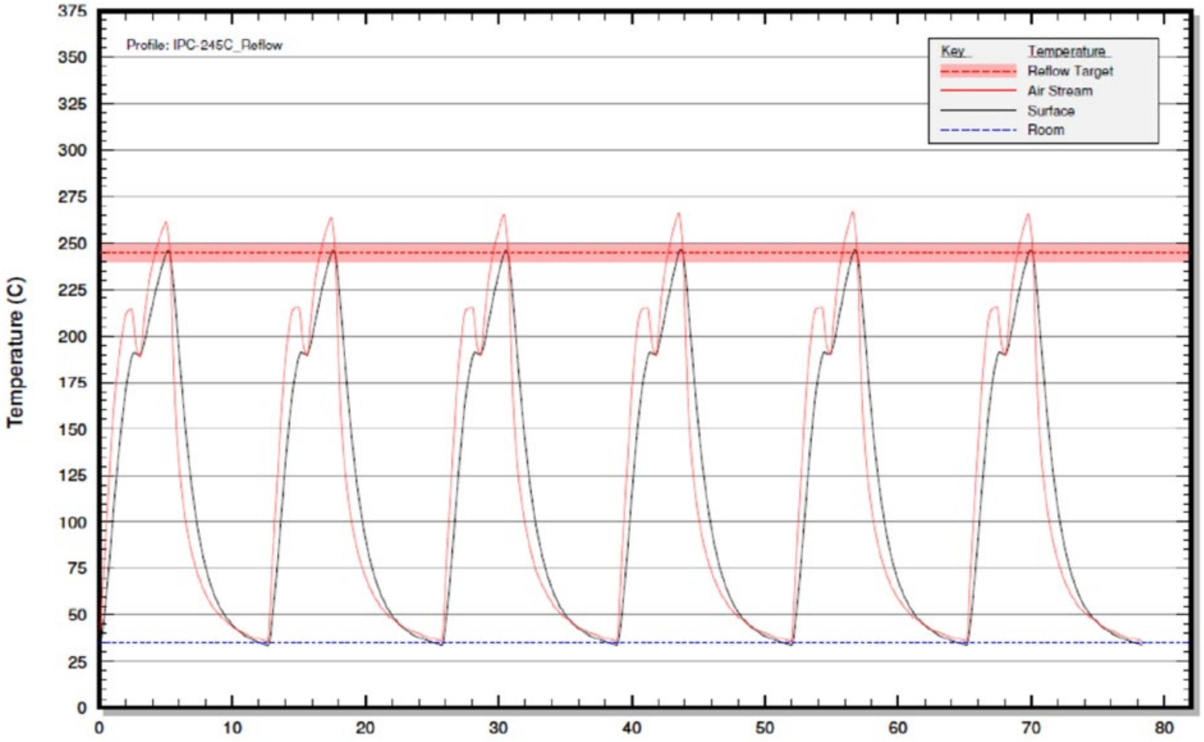


Figure 17: OM thermal cycling on the actual D-Coupons.

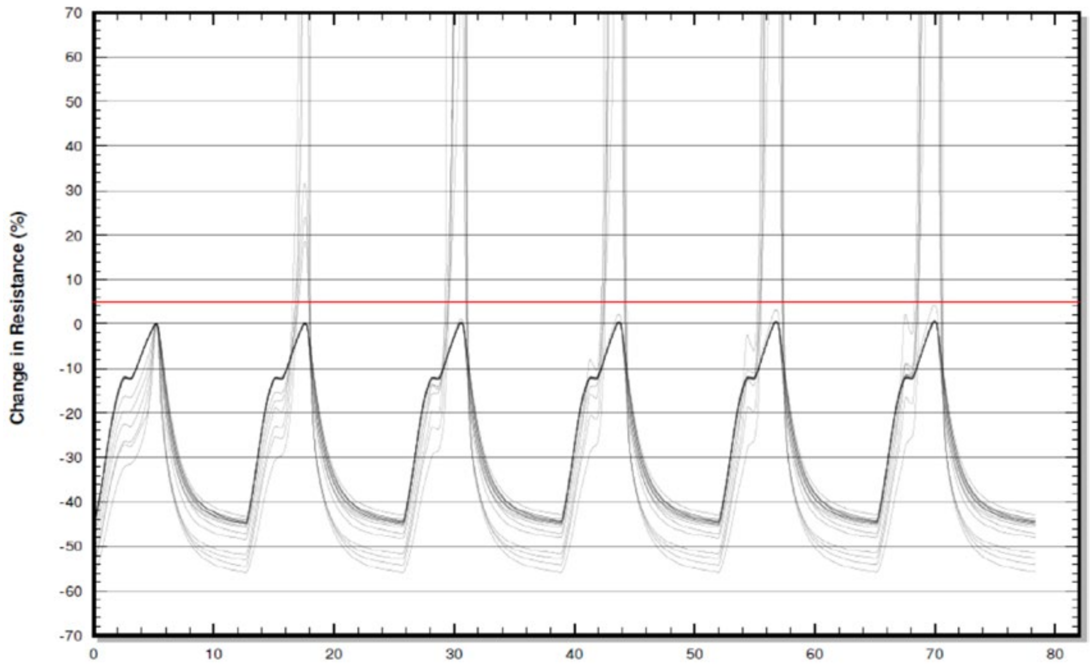


Figure 18: Resistance during the reflow of Net1 (notice that all coupons pass the first cycle).

Coupon Number	Nominal Resistance at Room Temperature (ohms)		Reference Resistance at 245C (ohms)		Cycles to 5% Change		Change after 6 Cycles (%)	
	Net 1	Net 2	Net 1	Net 2	Net 1	Net 2	Net 1	Net 2
1	0.435	0.514	0.995	0.913	2	>6	Open	0.3
2	0.477	0.551	0.868	Open	>6	1	0.5	Open
3	0.473	0.493	0.891	0.879	2	2	Open	Open
4	0.452	0.525	0.817	0.946	>6	4	0.9	11.6
5	0.486	0.584	Open	1.047	1	>6	Open	0.3
6	0.471	0.558	0.842	1.018	>6	2	0.6	53.2
7	0.478	0.488	0.922	0.855	2	>6	Open	0.4
8	0.465	0.526	0.818	0.932	>6	2	0.4	Open
9	0.503	0.540	1.071	0.962	2	5	Open	Open
10	0.577	0.602	1.045	1.095	>6	>6	0.3	3.9
11	0.466	0.531	0.826	0.936	>6	>6	4.4	0.5
12	0.452	0.520	0.810	0.943	>6	2	0.7	Open
13	0.480	0.530	0.860	Open	>6	1	0.8	Open
14	0.475	0.623	0.857	Open	>6	1	0.8	Open
15	0.433	0.472	0.937	0.837	2	>6	Open	0.4
16	0.437	0.492	0.783	0.893	>6	2	0.6	Open
17	0.479	0.535	Open	Open	1	1	Open	Open
18	0.419	0.460	0.749	0.820	>6	3	0.5	Open
19	0.470	0.594	0.964	1.062	2	>6	Open	0.8
20	0.510	0.560	0.920	Open	>6	1	0.6	Open

Figure 19: Failure by net.

Here is a coupon structure (Figure 19). The customer had two coupons per panel. He used a laser beam on only layer-one to layer-two on one coupon. Then, he had a buried two-to-seven by itself, and he wanted to do seven-to-eight microvias on the second coupon's second nets. Here are the results on the next page. These all failed because of microvia failure. We had to push the aspect ratio of the microvia. Therefore, I looked at it and found out we failed. We talked to the CAM department and told them to make the following changes.

We made the dielectric one mil thicker and corrected the laser via back to six mils, as seen

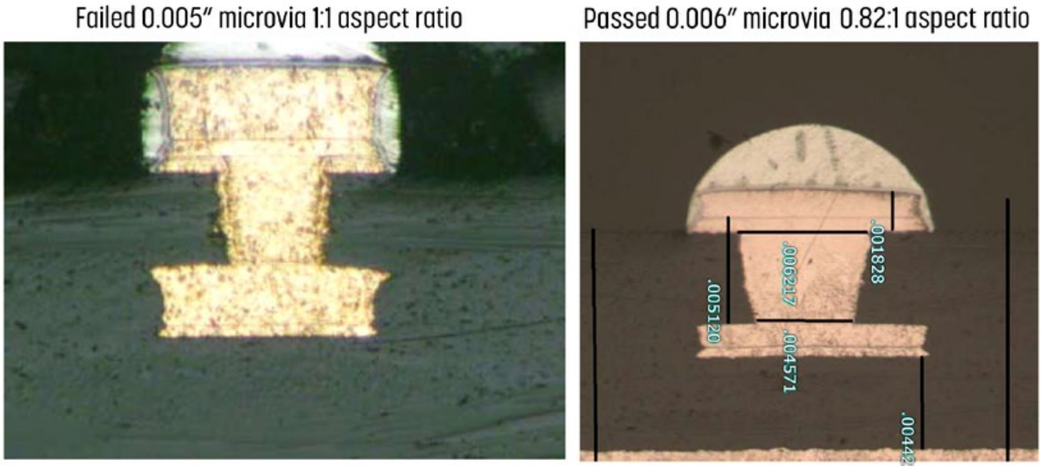


Figure 20: Remake with correct via and dielectric.

Coupon Number	Nominal Resistance at Room Temperature (ohms)		Reference Resistance at 245C (ohms)		Cycles to 5% Change		Change after 6 Cycles (%)	
	Net 1	Net 2	Net 1	Net 2	Net 1	Net 2	Net 1	Net 2
1	0.572	0.500	1.040	0.903	>6	>6	-0.1	-0.0
2	0.591	0.629	1.115	1.173	>6	>6	0.8	0.5
3	0.489	0.541	0.905	0.999	>6	>6	0.1	0.2
4	0.478	0.551	0.910	1.032	>6	>6	0.8	0.3
5	0.467	0.487	0.868	0.901	>6	>6	0.1	0.1
6	0.475	0.521	0.907	0.981	>6	>6	0.7	0.4
7	0.503	0.477	0.938	0.886	>6	>6	0.1	0.1
8	0.480	0.575	0.921	1.088	>6	>6	0.6	0.3
9	0.487	0.444	0.914	0.826	>6	>6	-0.1	0.0
10	0.485	0.556	0.931	1.052	>6	>6	0.7	0.3
11	0.531	0.522	0.993	0.974	>6	>6	-0.0	-0.0
12	0.557	0.600	1.063	1.129	>6	>6	0.7	0.5
13	0.530	0.516	0.977	0.948	>6	>6	0.1	0.1
14	0.515	0.570	0.973	1.062	>6	>6	0.8	0.5
15	0.552	0.526	1.022	0.974	>6	>6	0.0	0.1
16	0.544	0.606	1.031	1.139	>6	>6	0.9	0.6
17	0.494	0.554	0.921	1.030	>6	>6	0.0	0.2
18	0.553	0.604	1.061	1.146	>6	>6	0.8	0.5

Figure 21: 100% pass with the correct via and aspect ratio.

in Figure 20. Nothing goes over the 5% threshold, and Figure 21 shows a 100% pass. The difference is in dielectric, and laser via diameter was half of one of my hair's thickness, and that is even the manufacturing process window shop.

It is extremely critical that the geometries are conducive for the reliable passing of OM testing, and your boards will pass through assembly, just as well.

Summary

In summary, the OM test validation will prove that your design and material selections and structural constructions meet today's challenging PCB requirements. It is validated by actual reflow conditions to your design geometry and detects failures at reflow that heal at room temperature. These test records are the actual temperature on the coupon and resistance values. It validates propagated via structures that match the PCB design and are consistent with IPC-6000 requirements.

This data collection allows for better design practices. As you find designs that are not conducive for passing, you may want to change your design and increase the diameter of the microvia to eliminate certain structures and make your designs more reliable and profitable. **PCB007**

Editor Picks from PCB007

1 Got a Question? Just Ask Joe! ▶


Joe Fjelstad

A few months ago, we launched our "Just Ask" series with Happy Holden. Many readers took us up on it, sending all manner of questions for Happy to answer. Now, Joe Fjelstad—inventor, technologist, author, and Flex007 columnist—is getting in on the action. Here's your chance to pick Joe's brain. What's the one question about this industry that you've always wanted to ask Joe?

2 Trouble in Your Tank: CAF Formation—Correction of Misrepresentation of Origins and Causes ▶


Mike Carano

In Mike Carano's words, "In my April 2020 column in *PCB007 Magazine,* I incorrectly misrepresented the origins and causes of conductive anode filament (CAF) formation. This follow-up column will provide more insight and depth of knowledge on the CAF failure mode."

3 Aurora Circuits on Ultra-Heavy Copper PCBs ▶


Thad Bartosz

It's always fun to talk with a company that can do something different—in this case, ultra-heavy copper PCBs, meaning over 20-ounce copper. Wanting to know more, Dan Beaulieu talked to Aurora Circuits' Director of Business Development Thad Bartosz.

4 Punching Out! Due Diligence: Quality Inspection for Business Sales ▶


Tom Kastner

Although the due diligence process can be exhausting, Tom Kastner explains how it is important that buyers and sellers keep their eyes on the prize of closing, stay positive, and don't allow emotion to run the deal.

5 The PCB Norsemen: Leadership Styles for Success ▶


Didrik Bech

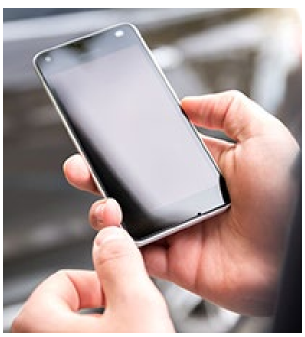
Leadership is the foundation of a successful business. Elmatica CEO Didrik Bech looks deeper into the various styles of leadership and shares his experiences and opinions.

6 It's Only Common Sense: Enough Already! ▶


Dan Beaulieu

"This is the time to have the strength to not only endure but also to find ways to thrive in these unprecedented times." Dan Beaulieu shares three things we can all be doing to make these abnormal times as normal and productive as we can with the situation at hand.

7 Sunstone Circuits Launches New Text Message Notification Feature ▶



Sunstone Circuits—a PCB solutions provider for prototypes, medium-volume, and production quantities—announced new optional order status text alerts (Sunstone order status) communication platform.

8 Catching up With VirBELA's Glenn Sanford ▶


Glenn Sanford

Have you been disappointed by trade shows and conferences being canceled or postponed? Have you wondered how some of these events are going virtual? Dan Beaulieu speaks with Glenn Sanford, chief strategy officer of VirBELA, about the company's platform and its impact on events.

9 Murray Percival Takes a Bite Out of Board Costs: Partners With Board Shark ▶

The Murray Percival Company, a supplier to the Midwest's electronics industry, announced a new partnership with Board Shark, a PCB solution provider.

10 W. Edwards Deming's Lost Chapters Recovered ▶


W. Edwards Demming

Happy Holden was cleaning up a bookcase recently and came across a tired, dog-eared set of papers that was Dr. Deming's initial draft of his book "On The Management of Statistical Techniques for Quality and Productivity," which he received when he came to HP to lecture about quality and productivity on March 11, 1981.

Career Opportunities

Fetching New Team Members

Find industry-experienced candidates at I-Connect007.

For just $750, your 200-word, full-column ad will appear in the “career opportunities” section of all three of our monthly magazines, reaching circuit board designers, fabricators, assemblers, OEMs, and suppliers.

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No contract required. We even include your logo in the ad, which is great branding!

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Barb Hockaday at barb@iconnect007.com or +1 916.365.1727 (-8 GMT PST)

I-Connect007
GOOD FOR THE INDUSTRY

smt007 pcb007 pcb design007

Career Opportunities

US Sales Manager

THE ROLE:

- To promote, sell and secure orders from existing and prospective customers in North America (USA, mainly, and Canada)
- To provide administrative help to our CFT Inc office in Glenside, PA
- To demonstrate our products to existing and potential customers and to assist them in selecting the copper treatments best suited for their needs
- To provide technical assistance to customers in case of claims, technical assistance, new product development
- To promote our products to OEMs
- To attend fairs (IPC, DesignCon,...), technical conferences (IPC 4562A,...) and customer presentations

THE PROFILE:

- Master's degree in engineering, with experience in technical sales
- At least 5 years of relevant experience in similar position
- PCB sales experience an advantage
- Very good knowledge of all product/services and international market regulations
- Knowledge of financial indicators
- Ability to work under pressure in order to meet deadlines
- Good organizational, planning, analytic, negotiation, presentation and people-management skills

We offer a permanent contract based on full-time presence as well as good salary conditions in an international environment. Curriculum vitae in English and French with application letter should be addressed to:

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jobs@circuitfoil.com

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Chemical Process Engineer
Fredericksburg, VA

Scope:

Responsible for implementation and maintenance of chemical processes used to manufacture printed circuit boards.

Responsibilities:

- Research availability of chemical processes
- Write plan for process implementation
- Implement process and perform failure mode analysis to establish correct operating conditions
- Write all necessary procedures and instructions for process operation, maintenance and safety
- Monitor process operation on a daily basis to ensure consistency
- Perform failure and root cause analysis when product/process problems occur
- Perform chemical analyses on processes when required

Knowledge and Skills:

- Ability to read, write and communicate in English necessary to perform the job
- Knowledge and application of statistical techniques for process control
- Knowledge and application of failure mode effect analysis techniques as applied to process improvement and process development
- Ability to lift 25 pounds
- Will be exposed to hazardous waste while performing daily job duties
- Will undergo chemical handling training prior to start and will actively participate in ongoing hazardous waste and chemical handling training

Education and Experience:

- Bachelor of Science degree in chemical engineering or equivalent
- Must have general knowledge of methods used to train people in the operation and theory of the processes they operate

Salary negotiable and dependent on experience.
Full benefits package.

lisabradley@ftgcorp.com

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Career Opportunities

MacDermid Alpha ELECTRONICS SOLUTIONS

We're Hiring!

Connecticut Locations

Senior Research Chemist:
Waterbury, CT, USA

Research, develop, and formulate new surface treatment products for the printed circuit board, molded interconnect, IC substrate, and LED manufacturing industries. Identify, develop, and execute strategic research project activities as delegated to them by the senior research projects manager. Observe, analyze, and interpret the results from these activities and make recommendations for the direction and preferred route forward for research projects.

Quality Engineer:
West Haven, CT, USA

Support the West Haven facility in ensuring that the quality management system is properly utilized and maintained while working to fulfill customer-specific requirements and fostering continuous improvement.

For a complete listing of career opportunities or to apply for one of the positions listed above, please visit us here.

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MacDermid Alpha ELECTRONICS SOLUTIONS

We're Hiring!

Illinois / New Jersey

Technical Service Rep:
Chicago, IL, USA

The technical service rep will be responsible for day-to-day engineering support for fabricators using our chemical products. The successful candidate will help our customer base take full advantage of the benefits that are available through the proper application of our chemistries.

Applications Engineer:
South Plainfield, NJ, USA

As a key member of the Flexible, Formable, and Printed Electronics (FFPE) Team, the applications engineer will be responsible for developing applications know-how for product evaluation, material testing and characterization, and prototyping. In addition, this applications engineer will provide applications and technical support to global customers for the FFPE Segment.

For a complete listing of career opportunities or to apply for one of the positions listed above, please visit us here.

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Career Opportunities

MivaTek Global

MivaTek Global: We Are Growing!

MivaTek Global is adding sales, technical support and application engineers.

Join a team that brings new imaging technologies to circuit fabrication and microelectronics. Applicants should have direct experience in direct imaging applications, complex machine repair and/or customer support for the printed circuit board or microelectronic markets.

Positions typically require regional and/or air travel. Full time and/or contractor positions are available.

Contact HR@MivaTek.Global for additional information.

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BÜRKLE NORTH AMERICA, INC.

Service Engineer

Schmoll Laser Drilling and Direct Imaging

Burkle North America seeks a full-time service engineer in the Northeastern U.S. This position will provide expert-level service on multiple laser drilling and direct imaging product lines. Install, commission, and maintain Schmoll products at multiple customer sites across the Northeast. The candidate will perform modifications and retrofits as needed. Maintain complete and detailed knowledge of Schmoll products and applications and handle a wide variety of problems, issues, and inquiries to provide the highest level of customer satisfaction. Assist customers with the potential optimization of their machine functions and work with clients on application improvements.

Qualifications

Required: Bachelor's degree from a technical college/university in an associated field. Three years directly related experience, or equivalent combination of education and experience. Must possess a valid driver's license and have a clean driving record.

Preferred: Experience in control systems and electronic troubleshooting, as well as in general electrical and mechanical service tasks. Experience and knowledge in the PCB manufacturing process, with a focus on laser drilling and/or direct imaging.

Send resume to hr@burkleamerica.com.

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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.

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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

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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.

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Career Opportunities

Manncorp™

SMT Field Technician
Huntingdon Valley, PA

Manncorp, a leader in the electronics assembly industry, is looking for an additional SMT Field Technician to join our existing East Coast team and install and support our wide array of SMT equipment.

Duties and Responsibilities:
- Manage on-site equipment installation and customer training
- Provide post-installation service and support, including troubleshooting and diagnosing technical problems by phone, email, or on-site visit
- Assist with demonstrations of equipment to potential customers
- Build and maintain positive relationships with customers
- Participate in the ongoing development and improvement of both our machines and the customer experience we offer

Requirements and Qualifications:
- Prior experience with SMT equipment, or equivalent technical degree
- Proven strong mechanical and electrical troubleshooting skills
- Proficiency in reading and verifying electrical, pneumatic, and mechanical schematics/drawings
- Travel and overnight stays
- Ability to arrange and schedule service trips

We Offer:
- Health and dental insurance
- Retirement fund matching
- Continuing training as the industry develops

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U.S.C. 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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Career Opportunities

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This position is responsible for IPC and skill-based instruction and certification at the training center as well as training events as assigned by company's sales/operations VP. This position may be part-time, full-time, and/or an independent contractor, depending upon the demand and the individual's situation. Must have the ability to work with little or no supervision and make appropriate and professional decisions. Candidate must have the ability to collaborate with the client managers to continually enhance the training program. Position is responsible for validating the program value and its overall success. Candidate will be trained/certified and recognized by IPC as a Master Instructor. Position requires the input and management of the training records. Will require some travel to client's facilities and other training centers.

For more information, click below.

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For information, please contact:
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barb@iconnect007.com
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Professionals Seeking Employment

DB MANAGEMENT GROUP
Strategic Business Growth Consultants

D.B. Management Group L.L.C. is currently working with many professionals who are seeking new positions. If any of these qualified professionals sounds like someone you would like to learn more about, contact **Dan Beaulieu** at **207-649-0879** or **danbbeaulieu@aol.com.** If you are a qualified professional looking for a new opportunity, contact Dan as well. Fees are 10% of candidates' first year's annual compensation. There is no fee for candidates.

Click here to learn more ▸

President, Company Leader, Business Builder
This professional has done it all. Built new businesses and turned around hurting businesses and made them successful. A proven record of success. This candidate is a game-changer for any company. He is seeking a full-time leadership position in a PCB or PCBA company.

General Manager PCB and PCBA
Senior manager with experience in operations and sales. He has overseen a number of successful operations in Canada. Very strong candidate and has experience in all aspects of PCB operations. He is looking for a new full-time position in Canada.

Regional Sales Manager/Business Development
Strong relationship management skills. Sales experience focused on defense-aerospace, medical, high-tech PCB sales. Specializes in technical sales. Also has experience in quality, engineering, and manufacturing of PCBs. He is looking for a fulltime position in the Southeastern U.S.

Field Application Engineer (FAE)
Has worked as a respected FAE in the U.S. for global companies. Specializes in working alongside sales teams. Large experience base within the interconnect industry. He is looking for a full-time position.

Business Development Manager
Understands all aspects of interconnect technical sales from PCB design and fabrication to assembly and all technologies from HDI microvias to flex and rigid-flex. Has also sold high-tech laminates and equipment. Proven record of sales success. He is looking for a full-time position.

CEO/President
Specializes in running multi-million dollar companies offering engineering, design, and manufacturing services. Proven leader. Supply chain manager. Expert at developing and implementing company strategy. Looking to lead a company into the future. He is looking for a full-time position.

PCB General Manager
Forty years of experience serving in all capacities, from GM to engineering manager to quality manager. Worked with both domestic and global companies. Available for turn-around or special engineering projects. He is looking for long-term project work.

Process Engineering Specialist
Strong history of new product introduction (NPI) manufacturing engineering experience: PCB/PCBA. Held numerous senior engineering management positions. Leads the industry in DFM/DFA and DFX (test) disciplines. He is looking for either a full-time position or project work.

VP Sales Global Printed Circuits
Worked with a very large, global company for a number of years. Built and managed international sales teams. Created sales strategies and communicated them to the team. One of the best sales leaders in our industry. He is looking for a full-time position.

Plant Manager
This professional has years of experience running PCBA companies. Led his companies with creative and innovative leaderships skills. Is a collaborative, hands-on leader. He is looking for a full-time position.

National Sales Manager
Seasoned professional has spent the past 20 years building and growing American sales teams for both global and domestic companies. Specializes in building and managing rep networks. He is looking for a full-time position.

Global Engineering Manager/Quality Manager
Has experience working with large, global PCB companies managing both engineering and quality staff. Very experienced in chemical controls. She is interested in working on a project-by-project basis.

CAM Operators and Front-end Engineers
These candidates want to work remotely from their home offices and are willing to do full-time or part-time projects.

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