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PCB007 MAGAZINE

The Additive Breakthrough

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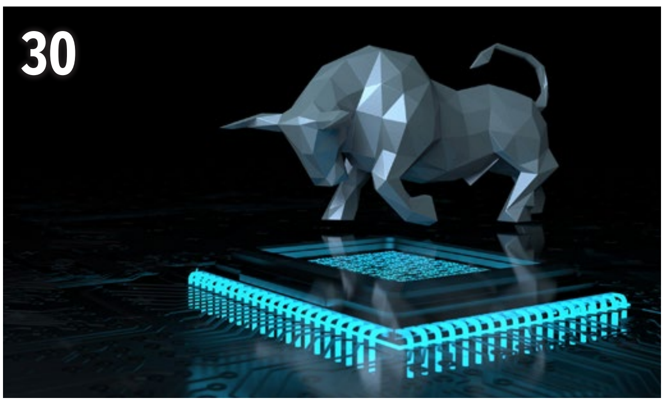
Do the Numbers Add(itive) Up?

How much is it going to cost to get into additive processing? Do the numbers really add up, or is it, as our parents used to say, a bunch of new math? What sort of ROI are we talking about? What equipment must you acquire in order to begin additive or semi-additive processing? Where's all the R&D?



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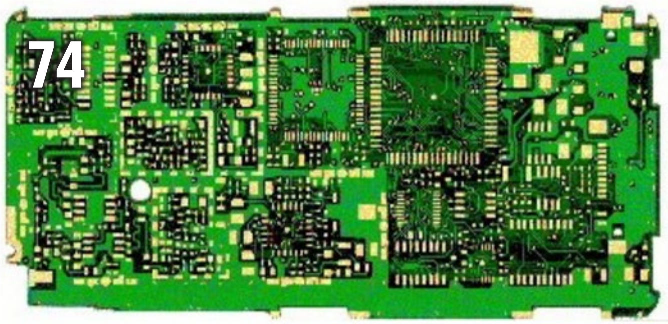

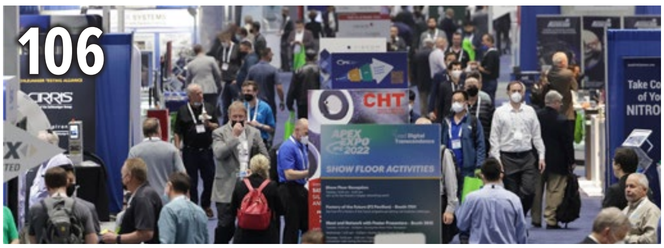

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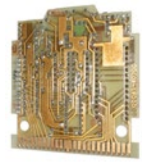

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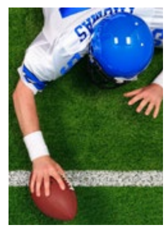

HIGHLIGHTS

Do the Numbers Add(itive) Up?

The Shaughnessy Report

by Andy Shaughnessy, I-CONNECT007

Remember when the new kid showed up in your fifth-grade class on the opening day of school? All your friends became 10-year-old Kojaks by snooping and interrogating witnesses. Where is this kid from? Which group is he going to hang out with at recess? Does he have a color TV? (That was an actual consideration when I was a kid. A color TV and a treehouse? You were my new best friend.)

Additive and its sibling, semi-additive (so named because it starts off with one subtractive etch step), are clearly the new cool kids in homeroom. They moved here late in the summer, just in time for the first day of school. There's still a moving van in their driveway, and there's plenty left to unpack. Everyone in the cafeteria is talking about them. They talk a good game, and they certainly have an intriguing back story. No one knows where they came from. I heard it was California. Or was it Texas?

Additive is an innovative idea, and a few companies have had great success with it. But the industry is still figuring out how it should be best utilized. It's not an add-on. It doesn't fit neatly into the existing system. And additive and semi-additive technologies such as Averatek's A-SAP™ (Averatek Semi Additive Process) may make certain steps of the existing fabrication process obsolete. That's a scary thing in an industry like ours which spooks easily.

During IPC APEX EXPO in San Diego, additive was on everyone's mind. On the show floor, additive was a hot topic, and I heard far more questions than answers. Is additive a disruptive technology? Will it displace tried-but-true subtractive etch technology, or is it merely another tool to have in our toolbox? What does a PCB designer have to do differently? Do EDA tools support it?

How much is it going to cost to get into additive processing? Do the numbers really add up, or is it, as my parents used to say, a bunch of new math? What sort of ROI are we talking about? What equipment am I going to have to acquire to begin additive or semi-additive processing? Where's all the R&D? Who's going to step forward and invest some real cash into additive and semi-additive and help establish a set of best practices for designers and manufacturers?

Most importantly, who are the experts in this field? Where can I go for answers? IPC offered a lifeline here, with probably a half-dozen conference presentations on additive and/or semi-additive processing. We should see more additive papers presented at conferences throughout 2022.

For this issue we asked a variety of contributors to share their stories about additive and semi-additive technology. Mike Vinson and Tara Dunn of Averatek weigh in with their thoughts on additive and their own A-SAP technology, including when it makes sense for OEMs to consider moving into the additive and semi-additive realm. Todd Brassard and Meredith LaBeau of Calumet explain why more competition would help speed along adoption of these processes, and why pure play additive technology could be the answer the microelectronics community has been waiting for, since additive allows manufacturers to scale down to form factors unattainable by subtractive etch. We also feature interviews with Alex Stepinski and Víctor Lázaro Gallego, as well as articles and columns by Mike Carano, Steve Williams, Happy Holden, Vern Solberg, Clyde Coombs, and Jordan Kologe and Leslie Kim.

I get the feeling that we're going to see additive and semi-additive processes really begin to mature over the next few years. Someone is going to step in and fund the R&D necessary for this to take root—maybe the Department of Defense? But it's coming, and we'll be following the additive conversation as it happens. **PCB007**

Andy Shaughnessy is managing editor of *Design007 Magazine* and co-managing editor for *PCB007 Magazine*. He has been covering PCB design for 20 years. He can be reached by clicking here.

Additive Reality:

Green Drops, White Drops or Both: Do Solder Mask and Legend Make a Good Team?

By Luca Gautero

Combining solder mask printing and legend printing seems like an obvious and attractive solution, sort of like bringing chocolate and vanilla together. Still, the gain relies on obtaining both functionalities without adding complexity. However, from the summary consideration in my December column on the equipment construction, two separate printhead arrays would best match the different requirements of legend and solder mask. In this column, the story continues.

One favorable advantage of a one-tool configuration is a single alignment step serving both coating processes. In the common configuration of printers, the alignment step bounds the table position to the substrate position. This means one substrate, one table. Even when the single tool has two printhead arrays, if a single table services the printing processes, parallelizing solder mask and legend coating remains unfeasible. Furthermore, the legend printing starts only after the solder mask coating is completed. Therefore, these two processes are strictly sequential on the same substrate.

The total average cycle time (TACT) is an important tool and process description. In a production floor with several tools, it is the highest TACT that defines the throughput of the complete production line. For this reason, the design of a line has a given target throughput for all incoming tools. This simplifies the optimization of the sequencing since all tools have a similar TACT.

To read this entire column, click here.

Summing Up the Facts in Additive and Semi-Additive Processes

Feature Interview by the I-Connect007 Editorial Team

Additive and semi-additive processes are getting a lot of attention lately, especially from OEMs who find that traditional subtractive etch manufacturing won't cut it for their cutting-edge applications. But what does a fabricator need to know to move into additive and semi-additive? When does it make sense for the OEM? We asked Averatek's Mike Vinson and Tara Dunn to add up the facts behind the hype for us.

Andy Shaughnessy: Where is additive and semi-additive right now? Is it something that's going to have to happen?

Mike Vinson: It depends on the application and semi-additive is shown to have the advantage of being able to replicate the subtractive processes in terms of fitness and conductivity. With fully additive, we don't often see those same conductivity numbers, but much of it's going to be application dependent. We're seeing a lot of interest in additive and semi-additive with standard circuit boards, as well as some 3D type circuitry that is beginning to get a lot of traction right now.

Shaughnessy: There's some debate going on. Will shops need to offer some form of additive to be competitive, or will it never displace the traditional subtractive process?

Tara Dunn: It certainly won't displace subtractive edge technology. As we all know, there's still a significant portion of the industry that's doing two-, four- and six-layer circuit boards with very large feature sizes. Additive processes are for the area of the market that is pushing the limits of what HDI technology can handle with subtractive etch, whether that be for line width, space, trying to break through that 75-micron barrier to go to 50 micron or below. Now we are reliant on multiple levels of stacked microvias and the ability to route in few layers will reduce that dependence. We all


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Tara Dunn

know there are a lot of reliability concerns with that in our market. Those type of applications, I think, are where the semi-additive processes are going to take over and offer some relief to the designers. Fabricators serving that portion of the market will have to strongly consider moving in that direction.

Barry Matties: What's the attitude toward additive or semi-additive?

Dunn: It depends on the market. Early adapters are embracing the technology and moving forward, and some of those are companies looking for a smaller package size. That's very important, and this enables them to do it. They're jumping in, taking the bull by the horns, and learning as they go. I think there's a whole group of other PCB designers and companies that are being cautiously optimistic. Let's see where the reliability data is. Let's prove it out with some testing. So, I see two different areas of adoption there.

Matties: With input costs rising, the case could be made that additive can lower your total. Are you seeing that as part of the impetus for people?

Dunn: I don't see the motivation being the cost savings, but it is a benefit. One customer we're working with has a design with 12 layers, three lamination cycles, and stacked microvias. Their drive was not for cost, but to simplify the design for lead-time purposes. It could be made on a shorter cycle time and be made more reliably. They wanted to shrink that form factor at the same time, so they could accomplish that by switching in some layers that had the semi-additive process. A combination of both technologies reduced their cost overall. But that wasn't what started the drive for the change in technology.

Mike can give a short tutorial on the difference between fully additive and semi-additive in terms of circuit board manufacturing.

Vinson: When we look at additive technologies, there are typically those that strictly add metal to the substrate or to the application and don't remove any of it. With subtractive, the more conventional ones are the ones where you start with a full metal coverage, then you subtract away the areas you don't want. Semi-additive allows us to add metal where we really want it in thick layers, subtract the metal that we don't want off the thin layers, and still leave the thick layers undisturbed. These processes are very attractive because, as Tara mentioned, they pretty much drop right into a conventional PCB facility. The additive process may require a bit more work and is going to limit how much metal you can build up without being able to remove anything around it, the shape of the trace that you'll get after that, or the pattern that you're putting down. So, while some applications are fully additive, most of the transition that you're going to see in the PCB industry will be toward semi-additive processes.

Matties: Fully additive opens a wide range of new material opportunities, doesn't it?

Vinson: Yes, it does. We're working with different types of dielectrics. We have a process we call ELCAT™, which allows us to build up additive traces in very, very fine features. Building them up into cavities that we put into the dielectric allows us to make those very fine.

We're also doing additive processes where we can put them on 3D structures. If somebody does a 3D printed dielectric or a molded dielectric, that has something other than a flat surface to be able to build up on that curve surface with fully additive process, also has a lot of advantages. Many of these applications don't really require very thick metals, so we can do that quite easily. The ones that do require thicker metals that can also be done, it's just not as common. The thicker metals typically will use semi-additive.

Dunn: So often now, when designers are starting to look at this technology, I'm being asked for design rules. Most PCB designers rely on their manufacturers' design rules. We've done that for decades, but I push back on that, trying not to set too many design rules too early in this development process because I think that challenges the creativity that you could have and limits some of the benefits beyond just the PCB layout.

We worked with one project that started out at eight layers—five signal layers and three power and ground layers. We redesigned that using the A-SAP™ technology and we actually didn't go very aggressively with it. I think we started at a 35-micron line and space and reduced it from eight layers to four—two signal layers and two power ground layers.

We did run into the impedance issues that you would expect when you shrink those line widths. So, we redesigned that to 50-micron line and 30-micron space, still using four layers. We then took it a step further and found that if you went from the four-layer and increased it to a six-layer, there were a lot of power considerations that could have an impact on the overall electronics. Taking that thought process away from just the PCB layout, I think we're going to find other benefits for electronics.

Matties: I would think that the cost of respins is going to come into play with inflation; people have to do it right the first time. What you're talking about is that, with modeling and predictive engineering, your odds of doing it right the first time substantially increases.

If readers are interested in getting into additive, is this something that they bring in and then develop the market, or do they wait for market demand? Is it the chicken and egg? Then, if there's a typical fabricator, what equipment and training would they have to invest in to become proficient at this?

Dunn: I think it's very much the chicken and the egg. PCB fabricators, collectively, are often hesitant to make capital investment until there's a proven market. Part of what I do is work with the OEMs and the PCB designers, helping to drive some of that interest in market demand information to the fabricators in the industry.

PCB fabricators, collectively, are often hesitant to make capital investment until there's a proven market.

Matties: And how's the response?

Dunn: It definitely is cautiously positive. Like I said, some people are jumping in with both feet. Others are waiting for reliability data. "Fabricator, here is my test vehicle. I need you to run these repeatedly and show us these reliability results." At the same time, we are developing technology that we're expecting to go to production in the next one to two years.

Matties: The timing is everything in that they must be in a product redesign cycle for it to make sense. For a fabricator, it's knowing that there's an organization like yours out there promoting and marketing it. Calumet has also made this point; this will accelerate and get stronger if we have more fabricators offering this technology, making it more proven or accepted.

Dunn: I think that's very true. And I think that OEMs are going to be hesitant to put all their eggs in the basket if there's only one fabricator that can produce using this technology, so the more fabricators producing, the more confidence there's going to be all the way around.

Matties: Now, assuming a fabricator already has LDI equipment, what other equipment or investment would they be looking at?

Vinson: For the fabricators, it's mainly the equipment to create the feature sizes that they need. Then maybe a few changes to things like, how clean they keep their areas to keep the size of the dust particles or the foreign particles down to match those feature sizes. But most of the investment is largely driven by the feature sizes needed, and things like optical inspection, tests, and probing. But the semi-additive process does allow for a huge reduction in feature size that will meet almost all the application needs today.

Matties: For a fabricator reading this, where is that tipping point, that time when they really must invest if they don't already have LDI and AOI? I'm assuming most of them have AOI these days, maybe not LDI.

Vinson: LDI will be almost an entry level requirement for these fabricators. The other things are going to be driven by feature size. They'll be needing to look at, say, sub-3-micron, 3-mil to 1-mil to sub-1-mil. They will all require different efforts and equipment to be able to get there. But a lot of their equipment they already have. A lot of the process steps that they have in hand will be able to translate forward into those areas. People think that rework is important for these fine features, but for the semi-additive process, it is not as important as it once was.

Matties: I was recently talking to a board fabricator who has direct imaging already in place. I asked them if they were going after the additive or SAP, and they said, "We're going to wait and see. We don't really have the resource." Well, if you already have direct imaging, my understanding is that AOI is probably the largest investment you would have to make, and everything else would be tank chemistry and methods. I'm not an expert like you, of course. But it seems to me that maybe there's a misunderstanding of what it really takes to get started with this.

Vinson: A lot of that misunderstanding is coming from some of the Asian competitors that are investing tens of millions of dollars into new fabrication facilities for these fine line features. Some of them are more modern, semi-additive processes like the ones Averatek is introducing in the marketplace. Those things aren't so onerous as they are for some of the other semi-additive processes that we're seeing from Asia.

Nolan Johnson: I'm imagining the team looking at this as a process to bring in-house, so how much investment do I need to make in my human resources to bring the appropriate expertise? What does my CAM team need to know? How do they get that expertise? How do I bring them up to speed so that they're experts with our first designs coming through?

Vinson: It doesn't take a great deal. It really depends on what kind of discipline you have in your facility. If the facility has been running the same products, year after year, a lot of the people are going to be ingrained into how those


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Mike Vinson

processes and products run. To change them over to a new one is going to be more difficult. But if it's a factory that's been constantly moving forward with their technology and reeducating their team on a regular basis, this should be just another step, or another note in what they're doing in terms of their overall pursuit of the market.

Johnson: Tara was talking earlier about not needing design rules, and that often is a way of communicating what one wants to do inside a new process. How does that fabricator get their CAM team up to speed?

Dunn: That's a good question, and it's something that everybody's working on as we go through this. A lot of that is just knowledge based—helping everybody involved with it from CAM through final inspection, becoming familiar with the process itself, and the capabilities of the process. Something else to keep in mind is the A-SAP process, or semi-additive process at Averatek, is not going to solve all the struggles for PCB fabricators. If you're struggling with, say, via-in-pad plated-over technology, having this new technology on its own won't fix that problem. You're still going to have to work through all the other fabrication processes, hurdles, and idiosyncrasies of building these complex designs.

That said, the additive process can simplify and, in certain cases, decrease the dependence on those types of technologies at the board fabrication level. That goes back to those design rules. What I continue to push for is more of a collaborative approach, at least until we get a strong base to start putting some rules in place.

Vinson: A lot of these design rules are going to be generated application by application, so where I start is with a good understanding of what the new boundary conditions are.

Matties: One of the things that was recently pointed out to me is that for fabricators offering additive, it opens the door to customers they aren't necessarily talking to, but wind up buying a traditional board in any case because there's interest in that technology. As we look at all the manufacturing resources that they need to bring into place, there's also marketing that they need to consider and how they're going to present their companies. What advice are you providing those companies to market?

Dunn: A nice marketing approach to this is that we're adding another tool in the toolbox for PCB designers. Not all designs are going to need additive processes. A lot of them will still be subtractive etch. So, for a fabricator to have a larger offering and expanded capabilities is a benefit to both the OEMs and to the PCB fabricators.

Matties: It sounds like this, obviously, is gaining traction. Is it where you expected it to be in terms of market acceptance at this point? Is it behind, ahead, or right on pace?

Dunn: I'm probably the over-optimistic person in our group. I wish the adoption had come a little bit faster. But I do think that having a year and a half where we haven't been able to meet face to face has slowed some things down, as well as just the acceleration and the PCB market in general; people are really busy. It's hard to look at new things. And it's hard to take that pause for a minute and consider new technology and new processes. But you're right that this is gaining traction, and we're seeing a lot of interest in the market and across all industries. It's not really narrowed into any specific industry. That makes sense because with electronics in general, we're trying to do more in less space.

Matties: Of course, seeing a shift in some of the supply chain attitudes is creating market opportunities as companies are looking for new suppliers, so it may be a perfect time to start talking about alternate methodologies for accomplishing their needs. What do you think the most important message is that we should be sharing with PCB fabricators regarding additive or semi-additive?

Dunn: The most important thing that I would like fabricators to understand is that there is a market demand for it, and that it is not as an intimidating of a process to bring into your facility as it might appear.

Vinson: In years gone by some of these changes from one point to another in the roadmap have been quite difficult and require quite a bit of investment. This looked like it would be from a lot of history that we've got, but it's really not so difficult to make that transition. If these PCB fabricators are seeing demand from customers or the ability to attract new customers with better business for them, then they should certainly consider what it takes to modify their manufacturing processes and bring these semi-additive processes online in their shops.

Matties: When you're talking to fabricators, what's the greatest resistance or the most asked question you get?

Vinson: We get questions such as, "We're going to put new processes in. Are they safe? Are they going to be environmentally friendly, or am I going to have to redo my entire facility to adapt to these things? And where am I going to have other pitfall areas?" As we talked about lithography earlier, they ran the gamut of questions, but they're pretty much the ones that we think they would be at. We're not really seeing anything too unusual or off the wall.

Matties: No real showstoppers?

Vinson: No, none that we can see. But there's a lot of hesitation and a lot of questioning at the beginning.

Matties: As you're saying, people won't wait and see the reliability, the performance overall, and market acceptance. It's just a process of giving it enough time and space to develop and prove itself.

Vinson: The market, though, is showing itself to be very robust and is pulling a lot of these shops toward the A-SAP process faster than they anticipated. We're seeing a lot of new interest from a lot of different areas simply because of that.

The market, though, is showing itself to be very robust and is pulling a lot of these shops toward the A-SAP process faster than they anticipated.

Matties: Is North America behind in the additive and semi-additive compared to Asia or other places?

Vinson: Yes. There's a lot more capacity in other places than there is here for these processes. From the point of view of technology or capability, we're not really behind, but we haven't really implemented it and have allowed a lot of it to develop overseas.

Matties: Who's driving the R&D? Is it coming out of Averatek or from OEMs? That's one of the big questions in the industry today is R&D generally. But for this specifically, who or what is driving it?

Dunn: It's from a couple of different places; much is driven from the larger military and defense primes looking ahead at their roadmaps for the next two to three years and wanting to make sure that there is a robust supply base to meet those needs. We're seeing a lot from the semiconductor side of the world as well, really pushing a lot of the boundaries of what we can do with even the A-SAP process.

Matties: You mentioned the military window is about three years; is that typical or are they, in some cases, looking beyond that?

Dunn: That's a very typical window. In some cases, we're working with people who currently design for high volume with A-SAP, they're looking to see the advantages of A-SAP, and the implementation for a lot of that will be three to four years. But I'm looking at roadmaps with OEMs now, that go out to 2028-29. It's definitely a long-range view with this technology.

Shaughnessy: As Calumet said, they're having fun with it, but it's not exactly profitable. Is it more fun than profit right now? Does that dovetail with what you all are seeing?

Dunn: I think that's a fair statement; it's definitely fun.

Matties: Obviously profit will have to be there for people to get excited, but it's a question of volume, not a question of technology.

Dunn: That's correct.

Matties: We certainly appreciate your insight on this topic. **PCB007**

Real Time with... IPC: Update From PCBAA

PCBAA Chairman Travis Kelly discusses with Nolan Johnson the latest updates on the new association's activities. The Printed Circuit Board Association of America is focused on advocating for manufacturing in America.

The Carbon Footprint of HDI: Direct Metallization vs. Electroless Copper

Article by Jordan Kologe and Leslie Kim
MACDERMID ALPHA ELECTRONICS SOLUTIONS

Introduction

As the electronics supply chain contends with the struggles of moving out of the pandemic and into a new normal, it is increasingly obvious that a new normal will be one with sustainability and resource conservation as the top priority. Over the past year, we have seen printed circuit board manufacturers encounter challenges associated with environmental regulations, water and power outages, and pressures from the supply chain to reduce environmental footprints.

From the perspective of a board fabricator, especially one that specializes in HDI, a highly resource-intensive step in the process of making a printed circuit board is the primary metallization step. All circuit boards that have multiple layers go through such a primary metallization, which is either electroless copper or direct metallization (DM). The main difference between a direct metallization process and the more traditional electroless copper plating process is that the former deposits a paint-like conductive coating through absorption onto the surface, while the latter deposits a copper coating from solution through chemical reduction. The DM coatings are most typically a carbon or graphite, and this kind of board manufacturing has been done reliably for nearly four decades.

Electroless copper processes have a larger carbon footprint than direct metallization for several reasons. Compared to direct metallization, electroless copper is more water and energy intensive, has a higher variety and amount of chemical ingredients, and has higher process variation. When looking at the comparison from the perspective of HDI, the impact of all of this becomes even more critical.

Eclipse Single Pass	Blackhole Double Pass	Electroless Copper
Cleaner	Cleaner	Cleaner
Cascade Rinse	Cascade Rinse	Cascade Rinse
Eclipse	Blackhole #1	Conditioner
Blow + Dry	Blow + Dry	Cascade Rinse
Post Etch	Conditoner	Micro-Etch
Cascade Rinse	Cascade Rinse	Cascade Rinse
Dry	Blackhole #2	Pre-Dip
	Blow + Dry	Palladium Catalyst
	Post Etch	Cascade Rinse
	Cascade Rinse	Accelerator / Reducer
	Dry	Cascade Rinse
		Electroless Copper
		Cascade Rinse
		Dry

Figure 1: Process steps for two commercial direct metallization processes compared to electroless copper.

HDI—Why Direct Metallization?

In conventional PCB multilayer, the primary metallization step is utilized once all innerlayers of the board have been laminated and drilled and the board is nearing completion. The microvia structure is the central feature of HDI that allows for the manufacture of high-density circuit boards today. The microvia essentially replaces the singular through-hole that connects multiple layers and allows individual layers to be routed to their neighbors directly and separately from other layers. To achieve this feat of engineering, however, every single build-up operation that the board goes through requires an additional run through a primary metallization step. It is for this reason that the electroless copper and direct metallization are under constant scrutiny from a reliability perspective. Yet, as we will discuss shortly, the sustainability question has not been widely examined. This is important since the volume of boards in the industry that use microvia designs is as high as it has ever been and will continue to grow to meet the needs of any electronic design that can economically benefit from increased circuit density.

With increasing volumes of PCBs being manufactured with HDI, there will be an even faster increase in the volume of boards passed through some form of primary metallization. For 2021, Prismark estimated that the total amount of board surface area considered to be microvia type designs (HDI PCB and package substrate) was in the range of 3 million square meters, while for all multilayer boards this was approximately 16 million square meters. Yet the amount of volume that passed through primary metallization lines in 2021 for these HDI designs was likely something closer to 15 million square meters if one assumes an average of five build-up steps per board design. This is because, while a 12-layer multilayer board would only need a single pass through an electroless copper line to create the plated through-hole that connects all layers at the end of construction a 12-layer, any layer HDI board would need to pass through the same electroless copper process five-plus times by the end of the construction.

This begs questions about sustainability and supply: Can we create an ever-increasing amount of printed circuit boards with HDI technologies such as mSAP while also meeting increasingly strict targets for carbon mitigation, while also meeting profitability expectations?

Comparing Electroless Copper and Direct Metallization From a Sustainability Viewpoint

So, where do electroless copper and direct metallization stand when compared side-by-side on sustainability? We will now break down

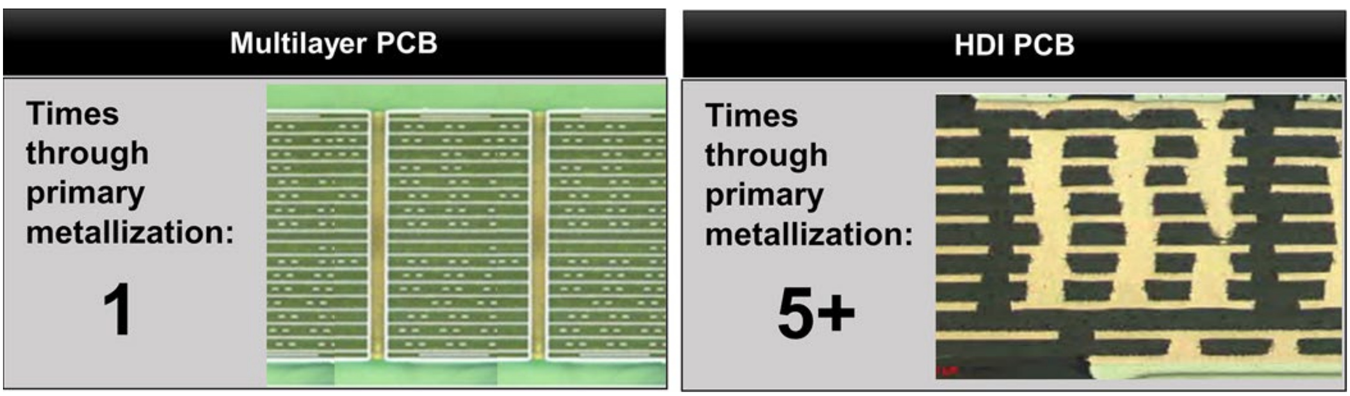


Figure 2: The resource-intensive primary metallization step is required for each additional build-up layer during HDI manufacturing.

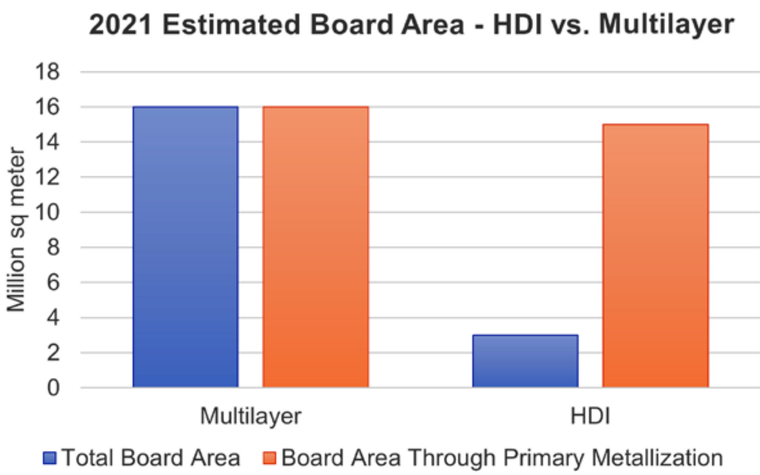


Figure 3: The surface area of HDI type boards going through primary metallization processes in 2021 may have been nearly equal to that of all multilayer boards.

these two processes on their merits from this perspective, provide some examples of where these would have met real world issues over the last year, and estimate the carbon footprint of the primary metallization process in PCB manufacturing. Direct metallization is a more sustainable primary metallization process than the traditional electroless copper primary metallization route because it uses significantly less water, power, and harsh chemicals.

Water Usage

Depending on the equipment and process selection, water usage varies when comparing the many ways of performing primary metallization. Horizontal processes use significantly less water than vertical processes because of the efficiency gained through how the boards move through the equipment. Direct metallization processes are almost exclusively horizontal. In vertical processing, large rinse tanks require more water in contact overall with the rack and boards, and the water that is in contact with the boards needs to be exchanged at a certain rate during each rinsing step to ensure that the process is sufficiently cleaning the boards in between each chemical processing step. Due to the number of chemical steps in a standard electroless copper line (more than seven), and the nature of the chemicals (heavy metals, chelators, catalysts), there are typically at least seven cascade rinse tanks in a single line. Even in large double pass DM lines, which are utilized for high volume production, there are just five chemical baths and only three cascade rinses. Comparing two high output lines of around 20,000 square meters per month, a double pass DM line would use approximately 25,000 liters per day while a vertical electroless copper line would use approximately 84,000 liters per day.

In August 2021, when water shortages were one of the issues seen in many areas around the globe, including the highly important island of Taiwan, the water consumption of these lines was more closely scrutinized than it had been in previous years. In Taiwan, there was a point where board manufacturers were examining the possibility of having to deliver tanker water to keep operations running at package substrate and high-end PCB fabrication sites. The price difference between the industrial tap water at the time was $0.43/ton while tanker water was $14.44 per ton. Figure 4 examines what the two lines would have consumed per day should the situation have progressed to the one described above.

	Industrial Tap	Tanker Water
Price / Ton ($USD)	$0.43	$14.44
Blackhole Water Usage Cost ($/day)	$10.75	$361.00
V. Electroless Copper Water Usage Cost ($/day)	$36.12	$1,212.96

Figure 4: Comparison of potential costs for DM vs. electroless copper during the Taiwan water crisis of 2021.

As far as estimation of CO_2 equivalents for water usage, we did not find them to be incredibly impactful due to the choice of inputs we utilized, as water production requires a comparatively low energy input in industrialized countries.

Power Usage

The power usage of direct metallization is consistently lower than electroless copper by a large factor regardless whether a horizontal or vertical equipment configuration. This is because the baths in an electroless copper process are greater in number and higher in temperature than in the direct metallization process. An electroless copper line has a:

- Cleaner (~50°C)
- Conditioner (~52°C)
- Micro-etch (~38°C)
- Palladium catalyst pre-dip (~25°C) and palladium catalyst bath (~33°C)
- Accelerator (~50°C)

The actual electroless copper bath (~45°C)

This is compared to the standard DM line, which has a:

- Cleaner/conditioner (~24°C)
- DM bath (~33°C)
- Post etch (~34°C)
- Blower and dryer

Due to this, power usage drops more than 50%, even for double-pass lines which just add an additional conditioner/carbon module. Comparing similar lines side-by-side as in the water example, an equivalent DM line will utilize around 62,000 KWH/month, while a vertical electroless copper line will be in the range of 147,000 KWH/month.

As with water outages, 2021 also saw several periods of time where power rationing was required at many board fabricators in Asia. Those who were running direct metallization were able to supply their customers for longer and with a lower overall usage than those running electroless copper. For estimation of the CO_2 equivalent, which is what is to follow, we converted the KWH using standard methods which can be arrived at on the U.S. EPA website.

Chemical Ingredients and a Model for Total CO_2 Equivalent

While it is too large a topic to break down in this article, the chemical ingredients that are used to make up the total component list in an electroless copper process are numerous and in general much more stressful on the environment from the raw materials stage than direct metallization. When building a model for CO_2 equivalent, we utilized actual consumption data at customers to create a baseline amount and then backtracked what each quantity of the component would generate in terms of kilograms of CO_2, using the most utilized method of manufacturing. Conversion

Electroless Copper		Direct Metallization	
Bath	Operating Temp	Bath	Operating Temp
Cleaner	50°C	Conditioner	24°C
Conditioner	52°C	Blackhole #1	33°C
Micro Etch	38°C	Conditioner	24°C
Pd Pre Dip	25°C	Blackhole #2	33°C
Pd Catalyst	33°C	Post Etch	34°C
Accelerator	50°C		
E'less Copper	45°C		

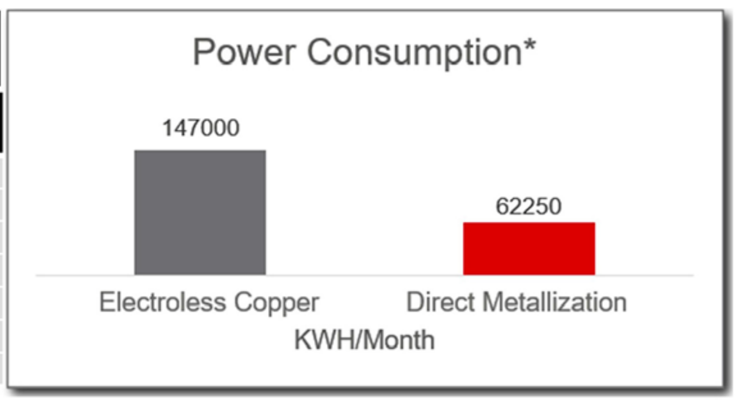


Figure 5: Power consumption of direct metallization is lower because there are fewer baths with lower bath temperatures.

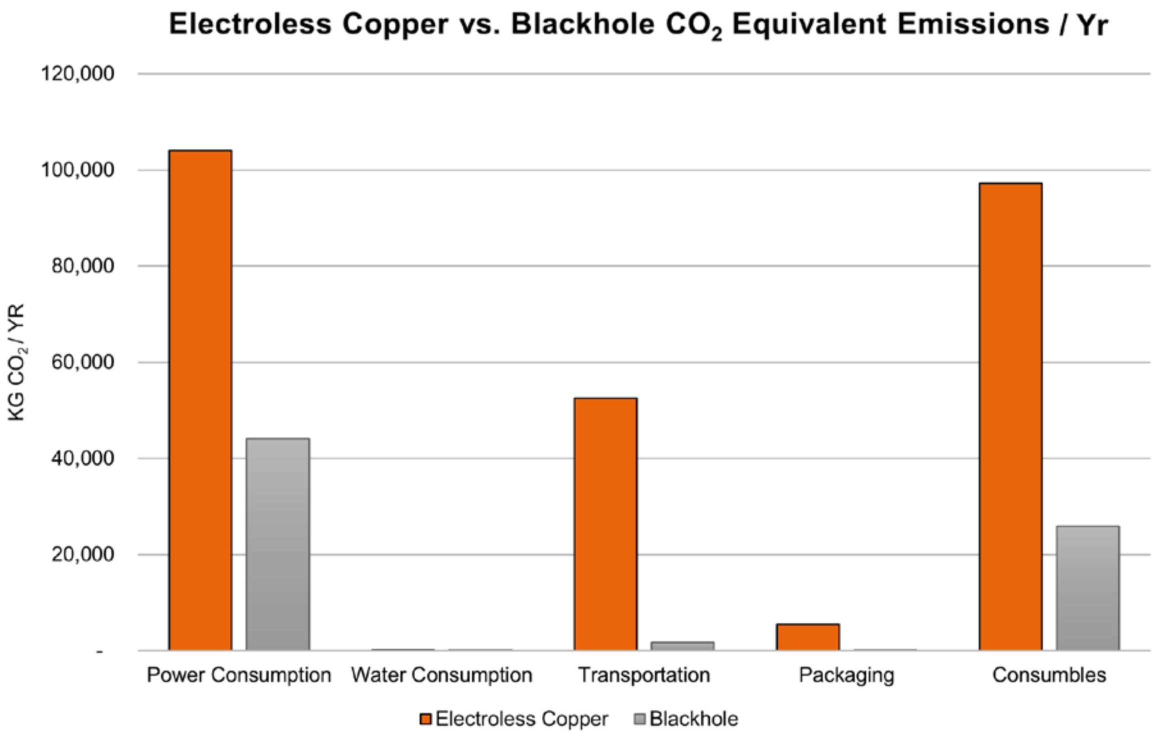


Figure 6: Yearly Kg carbon dioxide emissions for electroless copper vs. Blackhole direct metallization.

numbers were obtained from sources which utilized databases like Ecoinvent or publicly available government data. It is very important to note that the snapshot that we have created with this very early model is quite limited in scope, and only looks at the emissions from the act of running primary metallization at the fabricator and consuming the chemicals utilized.

In our model, the output of which is shown in Figure 6, provides an estimate for total yearly emissions of kilograms of CO_2 from equivalently sized DM and horizontal electroless copper lines that output 20,000 square meters per month. The categories evaluated are power consumption, water consumption, transportation, packaging, and chemical consumables. For transportation and packaging, due to the volume of chemicals required to operate an electroless copper line, we were able to calculate a significant difference in emissions for delivery of the chemical products to the fabricator. Packaging estimates were based on the

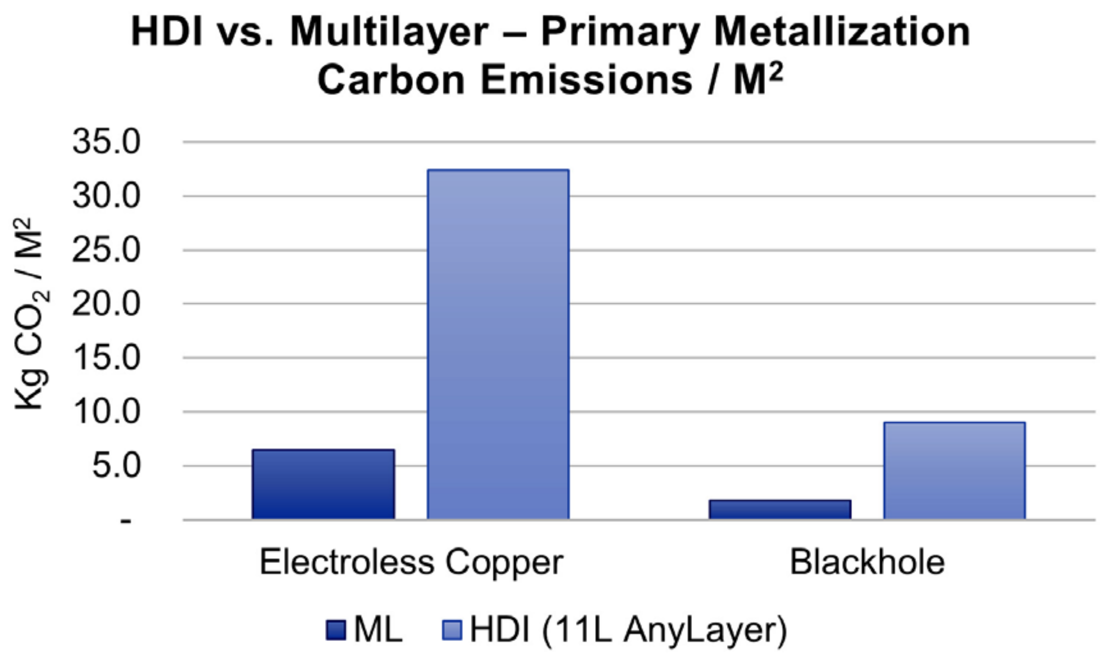


Figure 7: While HDI does increase carbon emissions, direct metallization minimizes this significantly.

total emissions produced by the production of five-gallon pails and 55-gallon drums. From this, we estimate that the horizontal electroless copper line with this size output is generating a minimum of around 260,000 kg equivalent CO_2 per year, while the direct metallization line is producing 72,000 kg equivalent CO_2 per year through just the five categories examined, within the scope as outlined.

This is even more important for manufacturers inside of or thinking of entering the HDI space. Using the calculations above, one can then come to a rough estimate for the difference in CO_2 output per board square meter that these two different primary metallizations have in multilayer vs HDI (Figure 7).

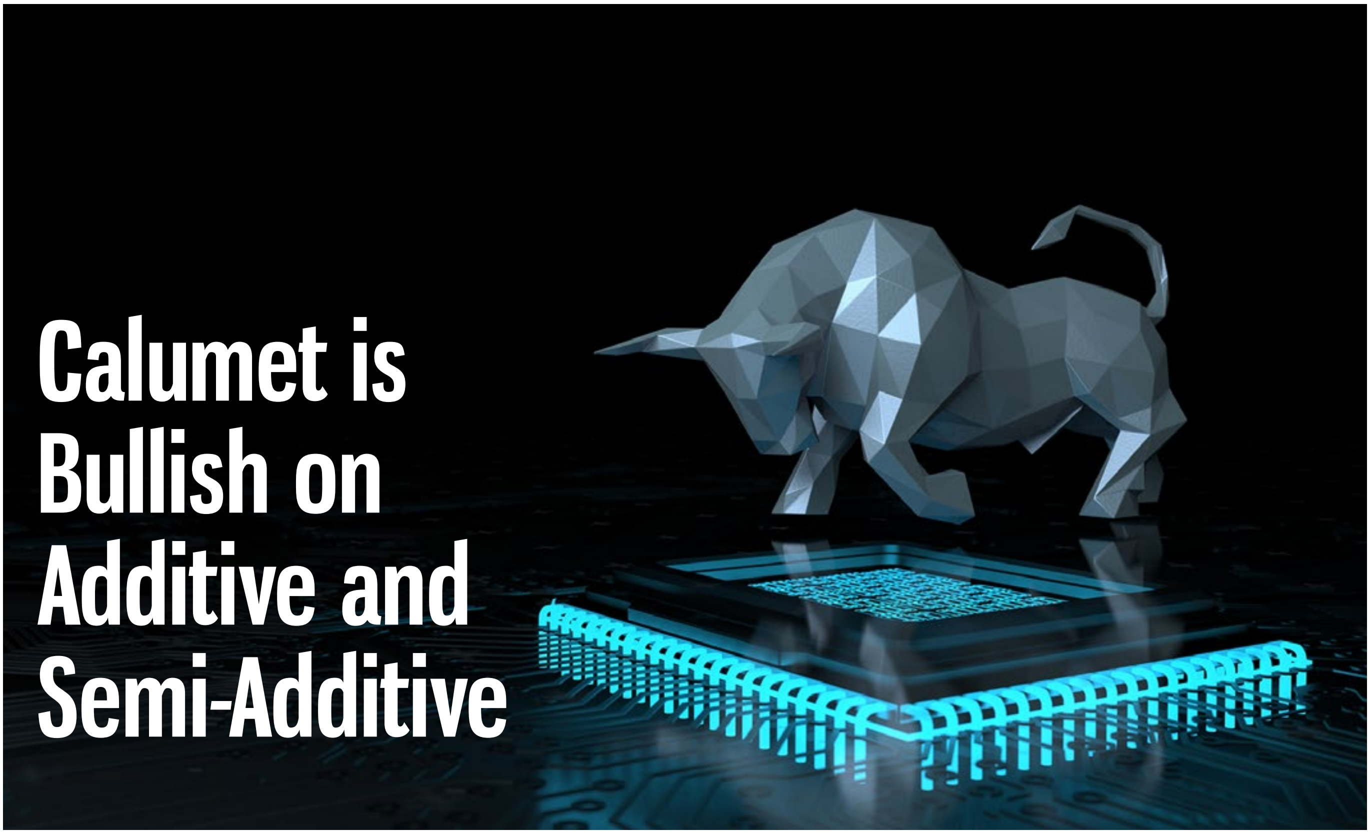
Conclusion

The main goal of this article is to open the discussion to the industry to examine the broader impacts of the primary metallization step in the manufacturing of printed circuit boards, and to add to the discussion on what frameworks are being used to quantify carbon output in our supply chain in general. Globally, there are more than 600 direct metallization lines already contributing to carbon reduction within the electronics supply chain. As a supplier, we are continuously working with the industry to generate data so that this technology can be a stand-in replacement to electroless copper far into the future. In a future that is fraught with increasing risk of environmental regulation, the electronics industry needs to be open to the possibility that electroless copper may someday no longer be an economically viable option. PCB007

Leslie Kim is director of primary metallization at MacDermid Alpha Electronics Solutions.

Jordan Kologe is technology marketing manager at MacDermid Alpha Electronics Solutions.

Calumet is Bullish on Additive and Semi-Additive



Feature Interview by the I-Connect007 Editorial Team

Calumet Electronics has been a domestic pioneer with additive and semi-additive electronics manufacturing processes. We recently asked Calumet's Todd Brassard and Meredith LaBeau to discuss the state of this technology, which traditional processes they might replace, and some of the challenges facing OEMs or PCB shops that are considering these options.

Barry Matties: We're seeing more additive and semi-additive. Let's start with what these technologies represent to Calumet.

Todd Brassard: I'm sure some of your readers will go a little crazy at our use of the word "additive." In my mind, pure "additive" manufacturing is 3D-printed or deposition-based processes while "semi-additive," in the context of circuit board substrates, involves a seed layer of copper (A-SAP™) or a very thin layer of copper foil (mSAP) with plated copper traces and features.

We understand the distinctions between terms additive and semi-additive; we do not use "additive" to necessarily describe a process, but rather as a proper noun to name the thing and contrast it against "subtractive" processes. For example, when working with Averatek's A-SAP™ technology, the seed layer is so thin that it is removed with a simple microetch. To me, the process is so close to being purely additive, I name it an additive process.

Matties: Is it going to be a mandatory offering for most fabricators in the coming years? Or is this something that will still be limited in scope?

Meredith LaBeau: What is driving the need for additive manufacturing—and I use this term "additive" as Todd just described—is design size and complexity. Next generation electronics will be much smaller. This is easy to see just following the mobile device industry. An elec-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tronic interconnect manufacturer in the U.S. can only go so small with traditional subtractive manufacturing processes.

Another piece of this push toward additive technology is environmental. There will be many more conversations about the environmental impact of manufacturing processes, and these considerations will factor more heavily into contract awards. With traditional subtractive processes you're removing copper, but with additive processes you're mostly adding copper. I believe there's going to be a shift in design to reduce waste streams regardless of technology, as part of the wider ESG movement.

Todd Brassard

Brassard: Yes, ESG: environmental and social governance.

Matties: Is that becoming more prevalent?

LaBeau: We are just starting to see environmental considerations seep into conversations and design considerations at our level.

Brassard: We are seeing more environmental considerations flowing down from the DoD. The DoD wants to see transition to greener solutions. Calumet is learning the ropes of federal funding and we believe environmental considerations must be included in any submitted proposal. We've been seeing these types of requirements added to RFPs in the last few years. Personally, I believe this is a good thing. We should be paying attention to what we are doing to the planet; this is just common sense.

LaBeau: The additive and semi-additive movements are not just about miniaturization, but also system performance and integrity. Additive and semi-additive technologies provide for better copper trace and feature formation which improves signal integrity and shortens transmission lines, allowing faster bit rates and higher frequencies. For example, radar and communications systems achieve higher performance when trace walls are square and smooth. Combine the potential for feature formation with advanced materials and chemical processes and a wide array of possibilities emerge. As an example, Calumet can plate copper on transparent substrates; just imagine the applications, for example, in the augmented reality space.

Brassard: Barry, you asked if the industry will be required to move to additive technologies. This really depends on whether the U.S. electronics manufacturing industry hopes to compete with Asia any time soon. Not with capacity—that ship has already sailed—but with capability and technology. If smaller electronics enables more powerful electronic systems, then Asia is clearly in the lead with their semi-additive and build-up technologies. Asia's manufacturing capability simply outclasses U.S. capability in every way that matters. Where most U.S. PCB manufacturers hit the wall at 75-micron traces, Asian manufacturers are routinely running at 18 and pushing down to 8-micron features. Your question resonates at two immensely different scales; first, the domestic industry, and second in consideration of the individual PCB shop.

Lawmakers are putting a tremendous amount of time, energy, and funding into increasing the U.S. capability to manufacture chips. Applause and well done, but this only solves part of the problem. Until we can produce not only the chips, but also the electronic interconnects to wire the chips into systems, the U.S. will remain woefully dependent on Asia for the advanced substrates, circuit boards, materials, chemistries, recipes, processes, and R&D necessary to be globally competitive. The U.S. government should be saying, "We must have the capability to wholly manufacture in America what we can imagine and design in America."

Matties: So then, does the government have a role to play?

Meredith LaBeau

Brassard: Yes, the U.S. government will very likely be required to bootstrap U.S. PCB and substrate manufacturers at a cost somewhere between $1-3 billion in funding to help close the gap with Asia. The real question is, when will the U.S. government and Department of Defense figure this out and start looking at the entire electronics ecosystem and not just the chips?

Matties: How about the individual board shops?

LaBeau: With respect to individual PCB manufacturers venturing into additive technologies, it really depends on the interests, financial position, workforce, and existing capabilities of each shop. It's important to understand that small-to-medium-sized PCB shops will never mass produce the interposers used with high-volume computing microelectronics, CPUs, or GPUs. This is a billion-dollar venture as IPC has explained. However, production of high-mix, low-to-medium volume organic substrates used with OEM ASIC chips packaged onto organic substrates is well within reach of those manufacturers who catch the substrate bug. Think microelectronics advanced packaging. OEMs are already scouring the countryside in search of domestically produced IC substrates.

Brassard: For those manufacturers who do not catch the substrate bug, which will be many if not most, nothing is necessarily lost. The demand for domestically produced PCBs, at least the more advanced technologies, is off the charts and is likely to stay this way for many years to come, with the most acute imbalances between supply and demand being the very complex PCBs for next-generation systems. Elegant technologies such as A-SAP allow traditional PCB manufacturers to push down to 18-microns with relative ease and Merck's Ormet allows PCB complexity to soar while significantly reducing manufacturing complexity. These non-traditional manufacturing technologies are game changers for PCB shops and the United States.

To give domestic PCB shops and the domestic electronics industry a fighting chance, the U.S. government needs to kickstart the industry by enacting favorable legislation. Then let economics take it from there—if the government wants to be able to attach the chips to something without sourcing or going outside the country. As the Printed Circuit Board Association of America teaches, "chips don't float" in thin air.

Matties: The PCBAA is driving some of this awareness in Washington now. Are you part of that and is that part of the impetus?

Brassard: Yes, we are a founding member of the PCBAA which is a new association laser-focused on rebuilding the PCB industry in America, our industry. The member companies of the PCBAA, which include a rapidly growing list of PCB manufacturers and PCB supply chain companies, are committed to raising awareness and driving a resurgence of PCB manufacturing in the United States.

LaBeau: The U.S. Partnership for Assured Electronics (USPAE) is also gaining traction and playing an important role in providing the DoD with an interface to industry experts and channeling program funding. USPAE leadership provides expert guidance, advice, and opportunities to meet other organizations and people from the industry and government who are working to solve the same problems. The DoD's Executive Agent for PCB and Electronic Interconnect Technology is also providing leadership at a critical time for the industry. After two challenging decades for the PCB industry, the uptick of activities of these and other organizations is a good sign.

The DoD's Executive Agent for PCB and Electronic Interconnect Technology is also providing leadership at a critical time for the industry.

Matties: Yes, I agree.

Brassard: IPC continues to be that driving force to bring everything together, build a resilient electronics ecosystem, and move the U.S. toward Factory of the Future. Their government relations team serves a vital and expanding role in providing expertise and guidance to the U.S. government, where lawmakers need to be informed and educated about the necessity of having a strong electronics manufacturing industry in the United States and how to get there.

Matties: Back in the IBM and RCA days, most of the R&D was coming out of the captive OEMs. When we went to job shops, what happened to the R&D?

LaBeau: I'll let you in on a little secret. Most early-career engineers do not want to work in a job shop, at least the ones who are graduating from universities these days. They have no desire to do build to print. That is just not innovative or interesting. Our simple idea of wanting to attract and retain the best people has, in large, part fueled our desire to increase our technical know-how, which eventually took us to adopting additive and other forward-thinking technologies. We also believe this is a great corporate strategy to find niche markets and develop a meaningful future.

Matties: You're talking about a cultural shift in the way that you're running your business to do this, though.

Brassard: Making meaningful cultural changes within an organization is challenging. For as much progress as our company has made in the past decade, we face cultural challenges every day as we identify where we need to go, the milestones we must accomplish to get there, and the behaviors we need to exhibit to be successful. We are still working toward achieving our cultural goals and look forward to the explosive growth that can come from the right culture in a high demand market.

LaBeau: Because semi-additive and additive technologies are relatively new fields in the United States, young engineers have an opportunity to get in on the ground floor, so to speak. This is an inroad for young engineers.

Matties: Well, I agree, because the more we're looking at the hiring and training issue—the gap that's in our industry—one of the things that we always bring up is we're competing against all these other industries for workforce that are more challenging, more appealing. Being a job shop, a print-to-order thing, is not that exciting. This creates big hiring challenges.


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the country and world. Innovation requires manufacturing to be close to allow rapid iteration, failures, and successes. With the puzzle pieces to innovation scattered across the country and world, Calumet has been working to bring together OEMs with big problems and supply chain with big solutions, where Calumet is the crucible to execute the iterations. I can say without a doubt that we would not be learning as much as we have without OEMs giving us tough problems to solve and our chemistry, materials, and equipment suppliers pouring on their expertise. We all want to do it in America. What we could use is a little help from the government so we can move faster. Also, all parties must find clear paths to generating new revenue from these new technologies.

Brassard: Calumet is still a job shop, just like every other PCB manufacturer. But will PCB manufacturers survive or thrive without a paradigm shift? As the pressure mounts to move manufacturing back to the U.S., OEMs are asking big questions about capability, capacity, lead-times, and how much it's going to cost them to build in the United States. OEMs will need PCB manufacturers that can provide expertise, solutions, and take the journey of innovation with them. We have been working for years to break the mold and become something more than a job shop, which is how we found ourselves venturing into additive manufacturing, a very exciting and unexplored manufacturing technology in the United States, and we want to bring our customers and suppliers along for the ride.

LaBeau: Yes, Todd uses this analogy about Calumet being a focusing lens for industry, where OEMs and electronics supply chain work closely through our company to develop novel solutions where everybody wins.

Brassard: We are working to emulate the idea of an industrial commons. If you travel back 30 years, you will see vertically integrated manufacturing that afforded rapid innovation. Over the past three decades, the U.S. industrial base has been fractured and distributed across

Matties: This must be a lot more fun for you guys as fabricators, to begin with, being in this path.

Brassard: Well, there is fun and there is profitable. The latter will prove to be most important.

LaBeau: We are first and foremost a high-volume board shop when compared to other domestic manufacturers, maybe fifth largest for volume in the country. This is our bread and butter and generates all the revenue that pays for the R&D. Funding R&D from operations is not attractive to most PCB shops, many of whom who are making money for the first time in 20 years in the current strong market. They do not need any distractions, as they have more demand for their conventional products than they know what to do with.

With respect to a new market of products enabled by semi-additive processes, we are seeing that U.S. designers lack experience designing at the smaller scales. Designers that are exploring additive manufacturing are doing so on their most complex designs, which makes sense, but it means the additive technology is being piled on top of an already messy build. It will take some time before board designers take full advantage of ground-up additive design.

Matties: What is the tipping point for a designer to say, "This is where I must look at this? Or this is where I could look at it?"

LaBeau: One example would be placing a component with particularly dense I/O or having to add layers to accommodate fan-out. A designer can rout many more 20-micron traces than 75-micron traces inside of a BGA. The ability to redesign PCBs to take advantage of additive manufacturing will depend on where a design is within the OEM's lifecycle, although component shortages may force redesigns. When it comes to new engineering or manufacturing technologies, for example, direct dispense solder mask, the PCB industry is pretty risk averse. To get PCB shops to accept new manufacturing methods, the product had better not come out looking much different. Conversely, taking a little risk may just lead to a PCB shop developing manufacturing capabilities that support next generation electronics.

Matties: It's better to be in the front than in the rear. The first fax machine didn't make all the money. It was the second one.

Brassard: Again, the fracturing of the manufacturing pipeline represents a significant barrier to innovation. One way we believe we can break down these barriers is with the multi-party NDA, allowing OEMs to have direct conversations with supply chain CTOs and high-level engineers with the goal of developing novel solutions. You want 2,500 or 5,000 I/Os on a substrate the size of your thumbnail? You will need the materials, chemistry, lithography, and equipment suppliers and distributors' CTOs in the room with the OEM. I'm thinking about this as a "micro industrial commons." If the team can make it work, all companies have something novel to sell to their customers.

Matties: In terms of demand or interest in additive, are you seeing a growth curve?

LaBeau: Yes. In fact, we have three designs running on our shop floor now that are using semi-additive technology. The customer is forced to adopt it because they could not find a working solution using subtractive manufacturing in the U.S. anywhere, and they need to do it for their end use applications.

Matties: From a manufacturing perspective, is it more challenging or demanding for your team to build an additive vs. a traditional, if you will?

LaBeau: The A-SAP process, for example, is not more challenging, but neither is it simpler. It really fits in line. The part that you can't overlook is it sometimes requires a few additional pieces of equipment. You may need to have some money to purchase equipment which has not been necessarily available in our industry. What we're seeing is we can get

down to, for the sake of conversation, about 20 microns. But with different photolithography equipment technologies you can get down to 8 microns. From there, the problem becomes cleanliness and handling; we're talking class 1,000 cleanrooms for much of the process and class 100 cleanrooms for imaging.

Matties: The real investment is in the imaging department in terms of new equipment.

LaBeau: Sure. Also, chemical and etching lines, and for substrates, laminators, and laser drills.

Brassard: This really depends on the additive process employed at a shop. We understand a variety of additive processes. For example, the A-SAP technology's feature size is not limited by their chemistry; the limitation arises from a shop's imaging capabilities, cleanliness, handling, and ability to work at small scales.

We need standard 80-90% yields to do this business and, as Happy Holden likes to remind us, our engineers must thoroughly understand the failure modes.

We are successfully imaging down to 18 microns using Orbotech LDI machines rated for 25 microns on epoxy/glass PCBs and ABF build-up substrates. Where imaging at 15 microns is a must for standard C4 bumps in microelectronics, we are pushing down to 8 microns over the next couple of months. What are the yields going to look like? We'll see. We need standard 80–90% yields to do this business and, as Happy Holden likes to remind us, our engineers must thoroughly understand the failure modes.

Shaughnessy: If somebody was running a traditional board shop, and they were about to start doing additive and semi-additive, what equipment might they have to invest in?

Brassard: Think chemical processes: tanks, transports, timers, and chemistry.

LaBeau: Yes. Also, depending on what kind of resolution a shop wants to achieve, the photolithography and AOI equipment. Todd is referencing getting the right chemistries for working with thin materials, internal stresses, and Z-axis expansion, which can be a little different than traditional subtractive PCB manufacturing. Also, if traces are getting smaller, then there's laser drilling and microvia plating.

Matties: What's the projected demand?

Brassard: Isn't that the question everyone's asking? That's the million-dollar question.

Matties: Right. Are we talking about an industry-wide transformation, or is it a few shops that will meet demand? Because if, as a fabricator, I invest in this technology, now I really need to invest in my marketing to sell my ability to produce this and convince somebody that they should be utilizing it.

Brassard: The domestic electronics industry will continue to feel the unrelenting pressure of miniaturization. If the U.S. can't catch up and keep up, our country will only continue to fall further behind. Asia is just going to keep getting better with cutting-edge manufacturing. Presently, they are manufacturing massive amounts of very advanced consumer technology (mobile devices, high-speed computing) every day, where the U.S. is just trying to get enough capability and capacity to meet the minimum needs of the DoD prime OEMs which are urgently working to find any capacity in the United States. The more advanced the electronic system, the increasing unlike-

liness you can produce it in America. OEMs must dumb down their electronic systems to manufacture in the United States; so much for supremacy of electronics systems. What's interesting is that we, Calumet, are not doing anything that cannot be replicated by another board shop. This is important. There's nothing proprietary about what we are doing.

Matties: But this work that you've done has created opportunity for your company in other ways, right?

Brassard: When you can field an F1 race car, people tend to believe you can make a great sedan. The business opportunity is scaling new technologies coming out of R&D to create new and better income streams for PCB shops. But Meredith is correct, market adoption will take some time. We need two or three PCB shops to take up additive manufacturing because OEMs need multiple suppliers; this would help speed up industry adoption, having sourcing options. OEMs want competition, choice, and redundancy. When OEMs and supply chain work together following a creative commons-like model, the entire industry moves forward as each partner brings what they have learned and developed to market for their U.S. customer base.

Matties: I think Lee Iacocca said, back to your point, "We sold more Dodge Neons because we built the Dodge Viper."

Brassard: That's right. We have seen this. We can have conversations with just about any OEM today. That wasn't true five years ago because we just blended into the background. Now, if an OEM has a problem manufacturing a mHDI PCB or IC substrate in the U.S., we will look at it. This is in defiance of the build-to-print model. However, we are pretty filled-up with projects. We are creating financial hurdles for OEMs to overcome before we will engage; you know, supply and demand. Unfortunately, this is not deterring some OEMs, which only shows their need to manufacture in the U.S. is becoming more urgent. I don't want to give the wrong impression, we very much still "build to print," but the aspect of our company that is breaking the model as an "innovative manufacturer" is very active.

Matties: With this pandemic, that obviously shifted the whole supply chain mentality.

Brassard: There's no doubt that the pandemic demonstrated the U.S. overreliance on offshore manufacturing and exactly how far U.S. manufacturers have fallen behind. I am reminded of a strategy-based video game I used to play. The winner, whether human or computer, typically had the largest industrial output during the game. The game taught me about battles of attrition. Whomever can produce the most product wins by wearing their opponents down, unless there is a decisive technology that makes industrial capacity less significant.

Matties: What is the most important message we should be communicating to the industry regarding additive and semi-additive?

LaBeau: I really think people need to be aware of what additive technology is, and that they understand how to get their shop to utilize it. Maybe they're not ready for it yet. What are the opportunities, and where can they begin to dabble with additive technology?

It seems that if we can prepare the material correctly, we can apply copper to anything. If a company can have foresight as to what the future can bring and start to think about their design for manufacturing, and engineering, and how they take the next step to utilize an additive technology, or even use thinner foils, that's a first step into mSAP. Just use some thinner foils, and start to baseline your Cpks, and how you can keep going further and further.

No one can flip that coin that easily unless their capital expenditure budgets allow for rapid expansion. We're still working at the numbers, but we believe it's somewhere in the realm of a couple million for a small shop that's already in business, just to add a couple of specialty materials, specialty imagers.

It comes down to needing low-stress chemistries, some different prepping chemistries, and different etching chemistries because of adhesion. I would also suggest that additive technology is not that far away from what you're already doing. It is not this complete change; well, it is, because we're adding instead of subtracting. But you're still using a lot of your same traditional pathways to bring the technology to bear.

Nolan Johnson: Can you foresee the additive process being as economical as subtractive in the future? Is it as economical already?

Brassard: Maybe it's not about additive being as economical as subtractive, but rather what new opportunities are opened to migrate a shop toward a more profitable business. Sure, there are cost tradeoffs between subtractive and additive manufacturing. There are the capital costs of upgrading a factory, consumption of specialized chemistries and direct materials; it really depends on how the additive technology is applied in product realization.

For instance, a designer may take an existing design that needs to drop from 75- to 55-micron traces to achieve the desired fanout for a high density I/O chip. Converting a couple of layers from subtractive to additive processes will allow this, but it's going to be a pure cost adder because nothing else about the design changed to take advantage of the economy of scale that additive can achieve.

On the other hand, taking full advantage of the small scales of copper traces and features that additive can achieve, designers can meaningfully reduce cost by reducing board size, eliminating layers, and running fewer lamination cycles. If a standard 18" x 24" panel originally fit six parts, the new smaller board may fit 80 parts. Dividing the panel cost by 80 rather than six results in per part cost savings.

This scenario adds cost for additive, but removes cost by reducing size, layers, and cycles, and the panel is cut up into a greater quantity of parts—like how components have been miniaturized to reset profit margins by getting more parts out of the same materials. The result is cost savings and a reduced form factor that may benefit the final system in which the final PCBA is placed.

Johnson: I have a similar question regarding operating costs for an additive line: Can you see that reaching parity with subtractive in the future at some point?

Brassard: As Meredith indicated earlier, we do not have a separate factory where we're doing additive manufacturing. Ninety percent of the processing that we do for an additive board is identical to what we do for a subtractive board. In some cases, we will realize the traces by etching and in other cases we'll grow the traces.

LaBeau: You're going to have some capitalization costs, but I don't think your operating costs will change that much by the time you get it into a production environment.

> There are challenges to overcome in learning additive manufacturing.

Brassard: There are challenges to overcome in learning additive manufacturing. Like anything new, it's about many iterations, and learning from each failure and success. Many iterations and working with amazing engineering teams at OEM and supply chain partners. Being a few years into the process, Calumet Electronics has gained the know-how. Next, it's scaling capacity to start meeting some of the needs of the domestic market. Calumet is exactly the type of small business that the DoD wants to be strong and thriving in the defense and commercial markets. The DoD would like to see many PCB shops with high technology manufacturing capabilities to provide redundancy, reduce risk, and reduce cost through competition. But I'll say it again: the U.S. government and DoD need to help "jump start" the U.S. electronics manufacturing industry, and not just the chips, but the entire ecosystem.

Matties: Some of the partnerships with the OEMs come in, and they fund a lot of this. Are you seeing that co-op?

LaBeau: Not at the level we would like to see just yet.

Brassard: Nothing gets the attention of OEMs like supply chain shortages or disruptions. As demand continues to increase for complex technologies to be produced in the U.S., the urgent need may drive more and better funding opportunities.

Matties: I've seen in the past where they have funded equipment.

LaBeau: Well, they can, but often a shop can only use the equipment on the OEM's work. This is not especially helpful in building a strong shop. Perhaps it's more effective at a larger scale.

Matties: Thank you both for your time. This has been great.

LaBeau: We are always happy to support knowledge growth in the industry; thank you for having us.

Brassard: Thank you. Always a pleasure. PCB007

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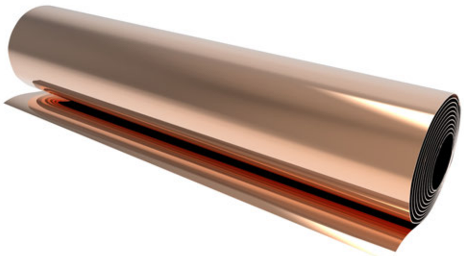

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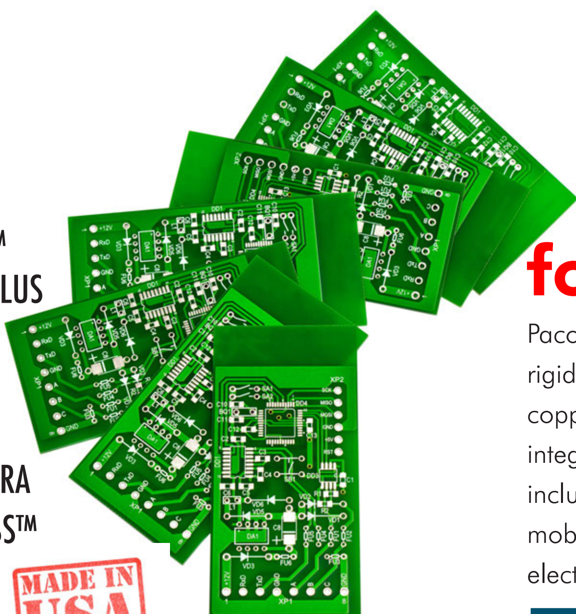

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Electronics Industry News and Market Highlights

IDC Expects Internet of Things Spending in Asia Pacific to Reach $437 Billion in 2025 ▸

Asia Pacific spending on Internet of Things (IoT) will expand by 9.6% in 2021, accelerating from 1.5% in 2020. The latest release of IDC's Worldwide Semiannual Internet of Things Spending Guide indicates a gradual growth of IoT market in the region across the forecasted years (2021-2025) and is expected to reach $437 billion by 2025 with a CAGR of 12.1%.

Qualcomm Collaborates with SB Technology, Cybertrust Japan to Proliferate Smart Cities, 5G IoT Solutions ▸

Cybertrust Japan Co., Ltd., SB Technology Corp., and Qualcomm Technologies, Inc., announced they intend to collaborate to support the deployment of smart solutions through the Qualcomm IoT Services Suite offering to help businesses and entities looking to adopt and integrate smart solutions initially in Japan, with intent to expand globally in the future.

The Future of Tech: 2022 Technology Predictions Revealed ▸

The IEEE Computer Society (IEEE CS) has unveiled its annual Technology Predictions, addressing the long-lasting influence of the pandemic on tech advancements, as well as introducing new fundamentals and anticipated trends shaping the industry for 2022 and beyond.

China's Share of Global Chip Sales Now Surpasses Taiwan's ▸

Global chip sales from Chinese companies are on the rise, largely due to increasing U.S.-China tensions and a whole-of-nation effort to advance China's chip sector, including government subsidies, procurement preferences, and other preferential policies.

Stanford Engineers, Physicists Study Quantum Characteristics of 'Combs' of Light ▸

Unlike the jumble of frequencies produced by the light that surrounds us in daily life, each frequency of light in a specialized light source known as a "soliton" frequency comb oscillates in unison, generating solitary pulses with consistent timing.

Survey: CEO Optimism Hits 10-year High ▸

In a recent survey, CEOs indicated they are the most optimistic they have been in 10 years about the prospects for a stronger economy in the coming year. More than three-quarters of CEOs, 77%, predict the global economy will improve, while only 15% expect worsening conditions.

Georgia Tech Wins Commerce Department Grant to Develop AI Manufacturing Economic Corridor ▸

The Georgia Institute of Technology was awarded a grant from the U.S. Department of Commerce's Economic Development Administration (EDA) as part of its $1 billion Build Back Better Regional Challenge. Georgia Tech is one of 60 entities to be awarded funding to assist communities nationwide in their efforts to accelerate the rebuilding of their economies in the wake of the pandemic.

Leadership 101—The Laws of Victory and Momentum

The Right Approach

by Steve Williams, THE RIGHT APPROACH CONSULTING

Introduction

Good leadership always makes a difference; unfortunately, so does bad leadership. This leadership truth continues as we will be talking about laws 15 and 16 of the 21 Irrefutable Laws of Leadership, devised by John C. Maxwell.

The Law of Victory

Great leaders are committed to victory and make things happen, period. To make this point I would like to borrow a lesson from Genghis Khan in my book Notorious: Business Lessons from History's Most Ruthless Leaders. Khan was a brilliant military strategist that built the largest land empire in history in the 12th century. No matter what you think of him, the man knew how to win.

Lesson seven in the book is "Lead from the Front." One of the most enduring mantras in leadership is "Never ask a follower to do something you are not willing to do yourself." That certainly applies here; people want to follow

a leader that is out front with his sword drawn and not back in the tent (or in our case, one that sits in their office all day). Lead by example is a common thread throughout the 21 Irrefutable Laws of Leadership for a reason; it works.

There are three parts to the Law of Victory that leaders need to embrace:

1. Unity of vision. No matter how talented individual team members may be, without unity of vision everyone is pursuing their own agenda. Look at any number of sports teams that woulda, coulda, shoulda based on the talent of their players but fizzled out with no clear direction.

2. Diversity of skills. Poor leaders build their teams with like-minded employees to themselves. Big mistake; groupthink is the enemy of success and stifles creativity. Diversity of knowledge, education, experience, personality, and strengths will always result in better decision making.

3. Raising team members to their potential. This is another common thread and one poor leaders ignore. Poor leaders feel threatened by others with more knowledge, experience, etc., while great leaders want people smarter than themselves. Getting the right people on the bus is not good enough; getting them in the right seat is just as important.

The Law of Momentum (The Big Mo)

Momentum can be a leader's best friend. Think of a train slamming into a 10-inch thick, steel-reinforced concrete wall starting 100 feet away from a dead stop. The wall will stop the train. Now take the same train and same wall, only the train has been barreling down the tracks for miles at 70 mph; the train will smash right through the wall. That is momentum.

There are seven key facts about momentum:

1. Momentum is the great exaggerator. When things are going well, momentum makes them even better. When things aren't going well, momentum makes them seem worse. This is because when you have momentum, you don't worry about small problems and larger ones seem to work themselves out. Without momentum, even small obstacles seem insurmountable.

2. Momentum makes leaders look better than they are. When you're winning, people are willing to overlook your shortcomings and forget about your past mistakes. The present and future are what matters.

3. Momentum helps followers perform better than they are. When you've got momentum, everyone is excited and motivated. As a result, the team plays better than expectations. The Law of Big Mo boosts everyone's success.

4. Momentum is more natural to steer than to start. An intrinsic part of the Law of Big Mo is that it's hard to get going, but once you're moving, you can control where it takes you.

5. Momentum is the most potent change agent. With enough momentum, any change is possible. People trust leaders with a proven track record and are willing to get on board with your vision once they see that you're taking them in a positive direction.

6. Momentum is the leader's responsibility. Creating momentum requires a firm goal, a good team, and motivation, all of which the leader must establish. It is your responsibility to initiate momentum and keep it going strong.

7. Momentum begins inside the leader. The Law of Big Mo starts with a vision that you must believe in. When you do, that belief becomes contagious.

"All leaders face the challenge of creating change in an organization. The key is momentum—what I call the Big Mo. Just as every sailor knows that you can't steer a ship that isn't moving forward, strong leaders understand that to change direction, you first have to create forward progress—and that takes the Law of the Big Mo."
—John C. Maxwell

Follow these guidelines and the Laws of Victory and Momentum and you will truly be surprised at the results. Focus on enhancing your leadership skills to lead by example and the results will be epic. PCB007

Steve Williams is president of The Right Approach Consulting. He is also an independent certified coach, trainer, and speaker with the John Maxwell team. To read past columns or contact Williams, click here.

Real Time with... IPC: Additive and Semi-Additive Manufacturing

Mike Vinson of Averatek discusses the latest in Averatek's LMI to pattern copper structures on 3D objects including Rogers' TMM® laminates and Radix™ Printable Dielectric, with Happy Holden.

Additive, Semi-Additive, and Subtractive Fabrication

Trouble in Your Tank

Feature Column by Michael Carano, RBP CHEMICAL TECHNOLOGY

Introduction

Is seems the operative word today is additive circuit board manufacturing, or for that matter, additive for everything. It is true that the use of additive manufacturing technology has found its way into different industries. While there may be several advantages to adopting additive technology in various industries, one should take a step back and truly assess where we are today in relation to conventional and advanced printed circuit board technology. It makes sense to understand the differences between fully additive, semi-additive, modified semi-additive (mSAP) and subtractive. In the end, there are several options available to the fabricator and OEM to achieve high density and ultra-density circuitry to support higher end technologies, including IC substrates.

Overview

In my opinion, there is much confusion with respect to additive fabrication for printed circuit boards. Well over 45 years ago, there was full build (or "fully additive") circuit technology. One could employ a special pre-catalyzed substrate and build up the circuity with an electroless copper process. However, the circuitry would still need to be formed via subtractive process.

Predating the full build electroless process was the CC4 technology. A microroughened substrate was coated with a metal catalyst, then plated to 25-plus microns over an approximately 24 hour period.

With respect to advanced packaging, where designs require ultra-fine line interposers and substrates, achieving HDI designs that require

fine-line interposers with sub 25-40 mm lines and spaces is severely challenged and perhaps near impossible to create copper features with these dimensions. A fully subtractive process is where foil copper, plated copper, and even panel-plated copper requires a significant amount of copper to be etched. Along with undercut concerns, as well as the etch factor, one can see the limitations of such a process. Let's review some of the options for fine-line and high-density applications.

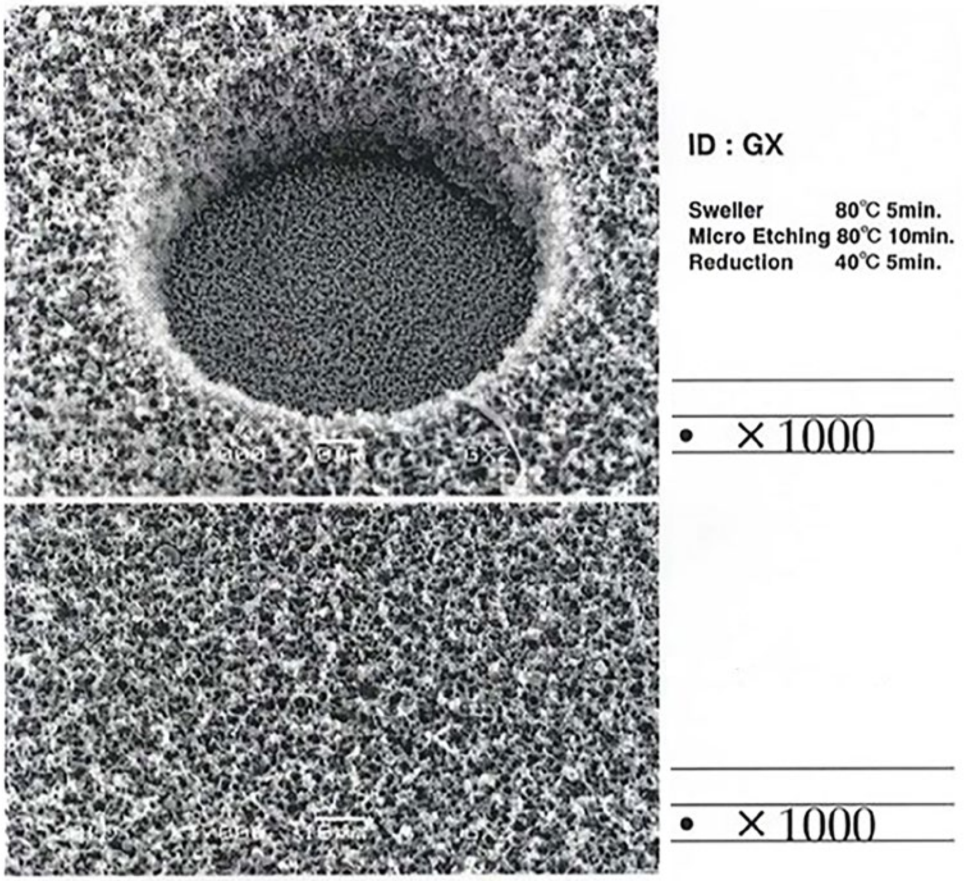

Figure 1: Via formation and film roughening prior to metalization. (Source: Ajinomoto)

Microvia technology appeared in the mid-1990s to allow fine-pitch area array semiconductor packages to be surface mounted. Now, microvia technology is used not only on the surface of the board, but also to interconnect to embedded devices—both formed and inserted—and allow "any layer via" board construction for multilayer applications. The IPC Roadmap identifies where the proficiency within different global locations impacts processing operations. There are not many technical issues between geographies, but they can be significant. Sometimes the technical variation deals with what is more prevalent in portable devices produced around the world. Since a fair number of products are produced for semiconductor carrier applications, the metrics on rigid interconnections reflect Japan/Asia/Europe capabilities.

Build-up Film (Ajinomoto)

The ABF process from Ajinomoto has taken hold in the high density and ultra-high density circuit designs. The process utilizes a dielectric film that then is metalized with a thin deposit of electroless copper. The ABF film is prepared prior to electroless copper by chemically roughening the surface (Figure 1). A brief overview of the process is detailed in Table 1.

Resin Coated Copper (RCC)

Of course, there are other options as well. The following process uses a material known as RCC or resin-coated copper (Table 2).

RCC has been on the market for over two decades. The dielectric resin is coated onto a copper foil and does not contain any glass. While the un-reinforced resin works well with laser via formation, the RCC does tend to "move" somewhat more than reinforced resins.

Table 1: The ABF process from Ajinomoto.

1. Apply dielectric film over layer over core.	
2. Form microvias with laser or photo-process.	
3. Electroless Cu (very thin; tightly controlled).	Add 2–3 µm Cu to dielectric surface and blind via
4. Apply resist, expose, develop (pattern plate resist pattern; resist does not conform to the via because via diameter is only 50–75µm, therefore resist can be cleanly developed. Via depth: 40–50 µm).	
5. Electroplate up to 20 µm Cu on surface, about 17µm in via.	Cu thickness on surface (plated area): 22–23 µm. Cu thickness in via: about 19–20 µm
6. Resist strip.	
7. Flash etch for differential etching.	Remaining Cu height about 19µm on surface. Cu in via: about 16–18 µm
8. Repeat steps from Step 1 for multilayer build-up.	

Table 2: Process using resin-coated copper.

1. High density innerlayer core	
2. Apply resin coated foil	Cu foil thickness 1/2 oz (17 µm). Cheaper and easier to handle than 1/4 oz Cu. Now 1/3 oz (11 µm) becoming popular because of availability, cost, and relative ease of handling
3. Reduce Cu thickness (etching)	Remaining Cu thickness 0.2–0.3 mil (5–7.5 µm)
4. E-less Cu	Add 0.5µm Cu; total thickness: 5.5–8 µm on surface, 0.5 µm in hole
5. Panel plate (Occasionally: no panel plate, in which case the process resembles the Japanese process)	Add 5–7.5 µm panel plated Cu.; total Cu thickness: about 13 µm on surface, about 7 µm in hole
6. Microetch	Remove 1–2 µm Remaining: about 11–12 µm on surface, about 5 µm in hole
7. Apply resist, expose, develop	
8. Electroplate	Add about 20 µm on surface, add about 15 µm in hole. Total Cu thickness: about 32 µm on surface, about 20 µm in hole
9. Apply tin metal etch resist.	
10. Strip	
11. Etch	Etch: Cu protected by metal etch resist. Surface Cu remains at 32 µm, in hole about 20 µm

Controlled Surface Etch

A less popular method (controlled surface etch or copper thinning) starts with one-half or one-ounce foil and thins the copper to a lower thickness via etching. As an example, one can reduce one-half ounce copper foil layer to one-quarter or one-eighth ounce through cupric chloride or alkaline etching. This seems easier than trying to work with super thin foils from a handling perspective. An advantage of copper

Table 3: Controlled surface etch process.

Step	Copper Thickness
1. High density innerlayer core (prepared by T & E, all subtractive processing, 40–50 µm L/S)	9 µm base Cu and 10 µm panel plated Cu (total about 18–20 µm)
2. Apply dielectric layer over core	
3. Form microvias with laser or photo-process	
4. Electroless Cu (very thin; tightly controlled)	Add 2–3 µm Cu to dielectric surface and blind via
5. Apply resist, expose, develop (pattern plate resist pattern; resist does not conform to the via because via diameter is only 50–75 µm, therefore resist can be cleanly developed. Via depth: 40–50 µm)	
6. Electroplate up to 20 µm Cu on surface, about 17 µm in via	Cu thickness on surface (plated area): 22–23 µm. Cu thickness in via: about 19–20 µm
7. Resist strip	
8. Flush etch for differential etching	Remaining Cu height: about 19 µm on surface. Cu in via: about 16–18 µm
9. Repeat steps from Step 2 for multilayer build-up	

thinning is that one has excellent adhesion of the copper to the C-stage laminate.

A version of the process is shown in Table 3.

Emerging Technologies

There are several new processes gaining interest for HDI and ultra HDI. These include SAP type processes using liquid metal inks and other types of seed layer for enabling of metalization of the substrates, with the ultimate goal of achieving sub 1 mil lines and spaces.

In a future column, I will present additional insight into these newer processes along with the advantages for the printed circuit designer. PCB007

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

Advanced Boards for Heterogeneous Integration

Happy's Tech Talk #5

by Happy Holden, I-CONNECT007

My Tech Talk #4 was about SAP technologies. I also introduced the IC strategies of heterogeneous integration. But even Karl Dietz's Tech Talk column wrote about advanced board technologies for IC interconnections many times from 2000 to 2010.[1,2]

Introduction

The expansion of IC functionality usually progresses with the shrinking of IC geometries, called "Moore's Law" after Gordon Moore who first coined the phrase. But now that geometries are below 5 nm, the costs and difficulties are creating a barrier to much further advances. So, the solution seems to be to mix IC die on the same substrate as a system-in-package (SiP) that is now called heterogeneous integration (HI).

Heterogeneous Integration

The constant reduction in semiconductor transistor geometries has created a situation that appears less costly to break up very large-complex dies into smaller dies and combine them with modular dies, now named chiplets, and tiny discretes on an organic substrate using these exceedingly small trace and spaces along with very tiny vias. Three architectures have become the most likely candidates to accomplish this task (Figure 1):

- Multiple IC die on a package substrate using a PCB, glass, or ceramic material
- Silicon or glass interposer between the die and package
- A small, embedded silicon bridge in the package substrate that connects the various die and discretes

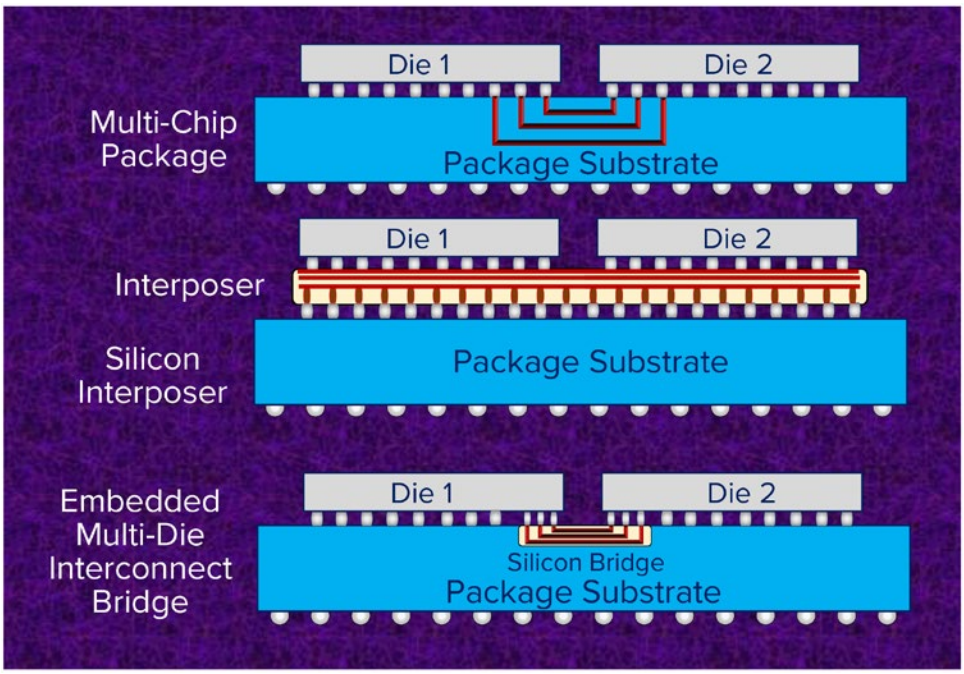

Figure 1: Vision of heterogenous integration packaging options favor these three architectures. (Source: ASM NEXX[3])

Multi-Chip Packages

The current conventional flip-chip is a ball grid array package (Figure 2). The structure is one or two layers of the additive Ajinomoto build-up film (ABF) on a traditional high performance HDI core (1 + 2+ 1). New ABF processes utilize a high-temperature RCC (usually polyimide) to permit higher temperature assembly processes[5] (Figure 3).

Silicon Interposer

The increasing complexity of HI will add more functionality to these substrates and result in interposer modules (Figure 4) that will contain IC chips of various materials/connections, embedded components, RF/antennas, optical waveguides, and even energy storage.

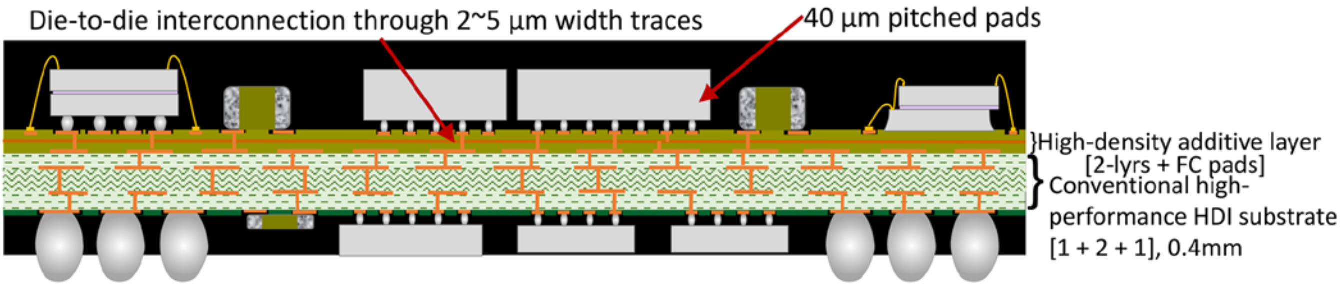

Figure 2: Current double-sided molded ball grid array using ABF and high performance HDI. (Source: Semiconductor Engineering[4])

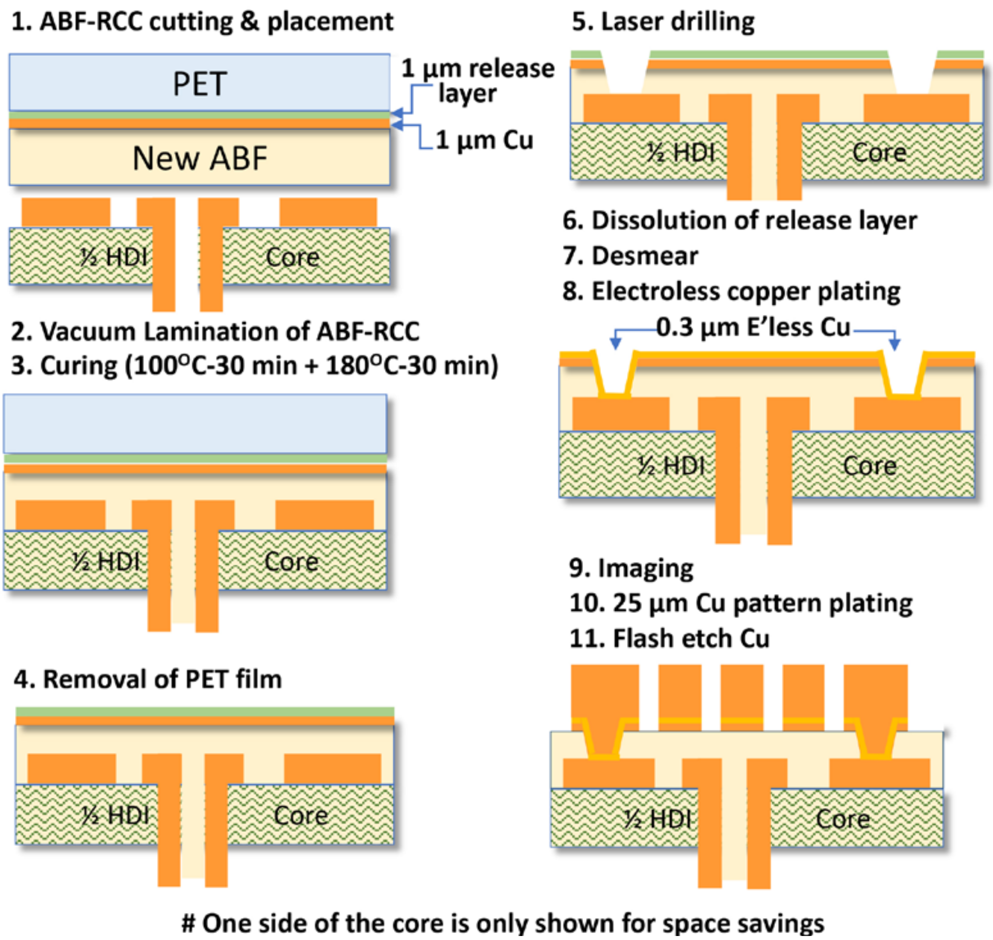

Figure 3: New manufacturing process using ABF plus RCC. (Source: ABF Technical Report[5])

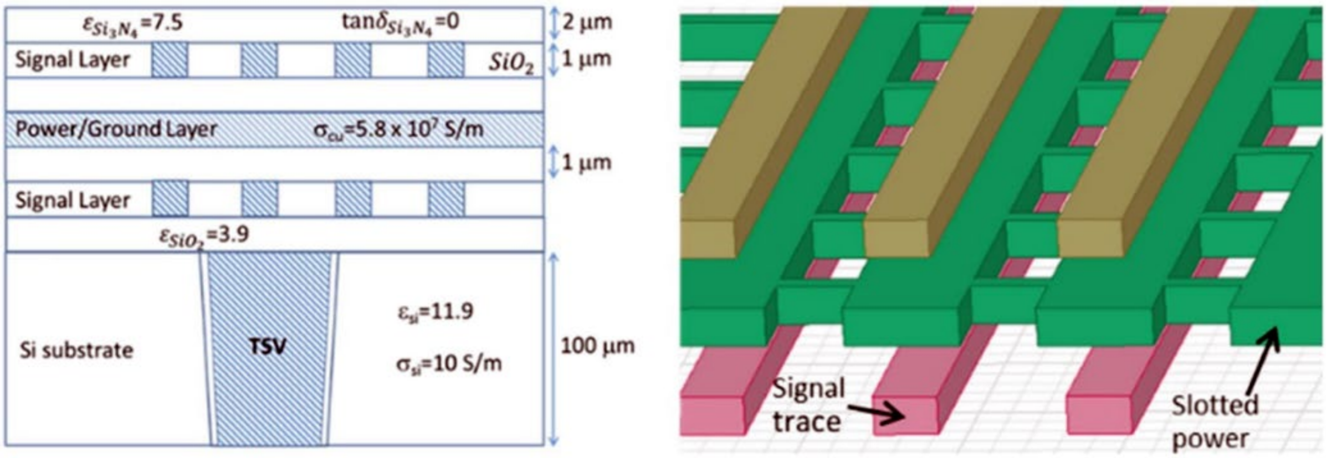

Figure 4: Silicon interposers have the advantage of CTE and density but with a higher cost for the TSVs. (Source: HIR Roadmap[6])

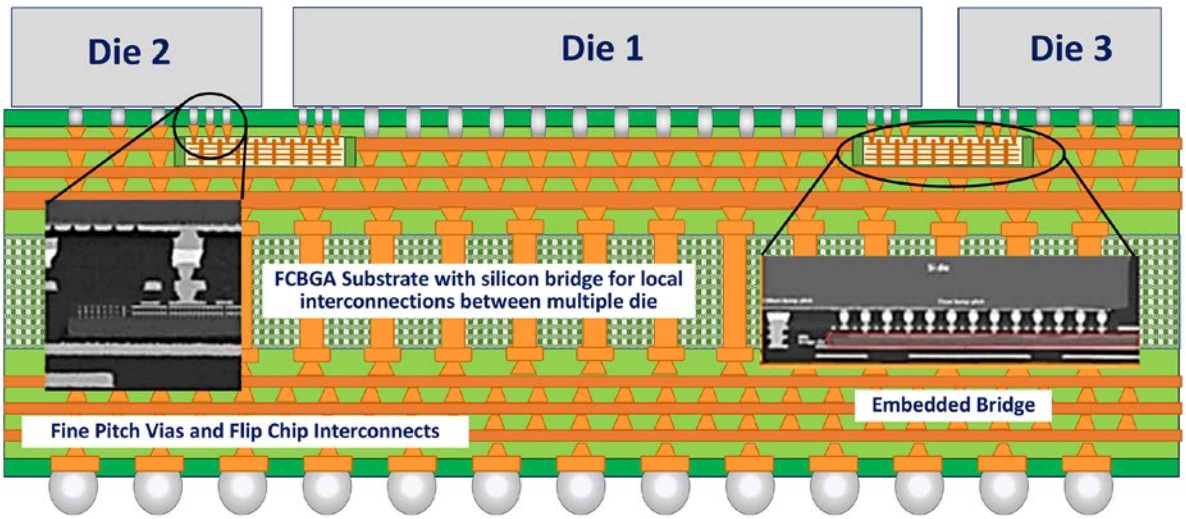

Figure 5: The silicon embedded multi-die interconnect bridge (EMIB) provides traditional multi-chip package substrate with the die-to-die density of expensive silicon interposers. (Source: HIR Roadmap, version 2020, p. 10, Intel[7])

Embedded Multi-Die Interconnect Bridge

A third architecture has emerged with Intel's proposal of using small silicon bridges (called EMIB) embedded in the substrate to provide the interconnect density of interposers while using the lower costs of package substrates (Figure 5).

Table 1 and Figure 6 compare the advantages and disadvantages of the three HI packages.

Table 2 and Figure 7 compare the materials frequency performance. Glass used in LCD displays is considered a main candidate to replace silicon.

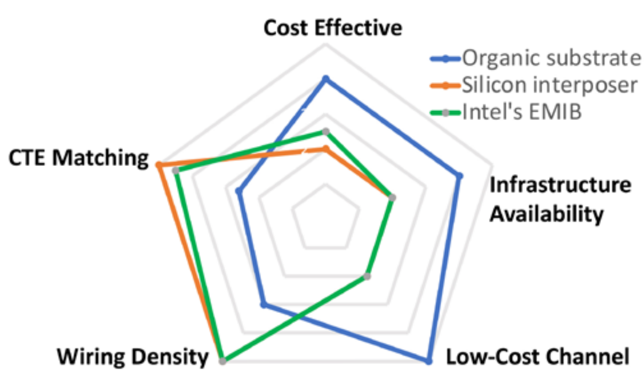

Figure 6: Five characteristics of the three HI packaging alternatives. (Source: HIR Roadmap[6])

MULTI-CHIP PACKAGE	• Poor density of die-package connections • Poor density of die-die interconnections
GLASS/SILICON INTERPOSER	• Good density of die-interposer connections • Good density of die-die interconnects • Higher cost of large interposer + thru-silicon vias
EMBEDDED MULTI-DIE INTERCONNECT BRIDGE	• Good density of die-bridge connections • Good density of die-die interconnections • Low cost of small silicon bridges

Table 1: The advantages and disadvantages of the three HI packages (Source: HIR Roadmap[6])

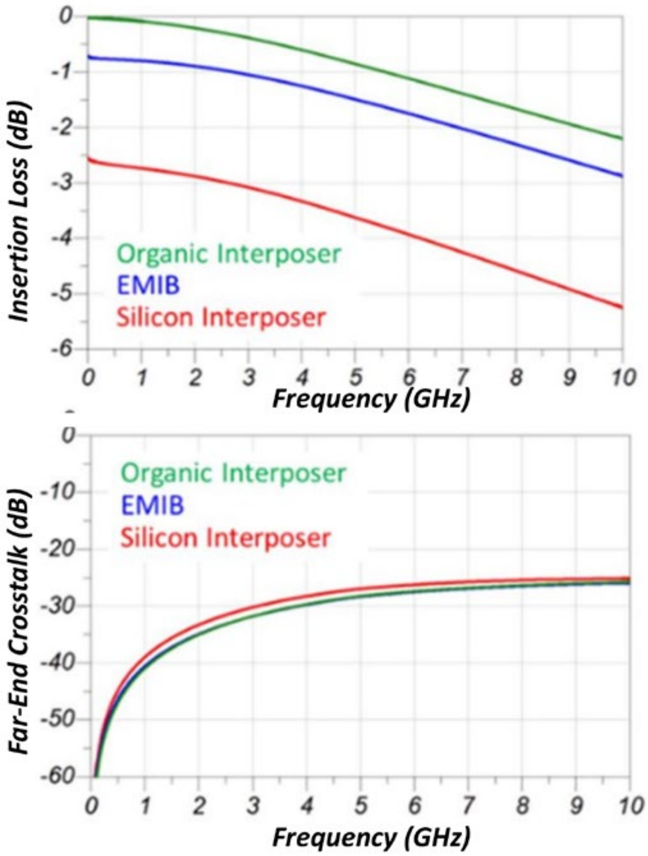

Figure 7: Frequency performance of the three packaging alternatives. (Source: HIR Roadmap[6])

Interposer Type	H (μm)	T (μm)	W (μm)	S (μm)	ε_r	Tan (δ)
Organic	10	10	7	7	4.6	0.02
EMIB	2	1	2	2	3.9	0.001
Silicon	1	1	1	1	3.9	0.001

Table 2: Geometries and characteristics of materials for alternative package substrates. (Source: HIR Roadmap[6])

Challenges for PCB Fabs to Implement IC Packaging

There are around six to eight organic IC substrate fabricators in the world—all in Asia (Japan, Taiwan, Korea, and Malaysia). Currently, none are owned by China but that should change soon. All of these will migrate to making the HI substrates in high volume. If North America or the EU plan to manufacture the new HI substrates, several challenges will need to be overcome:

- Material: ABF or similar films with their specialized vacuum lamination equipment and surface preparations for additive Cu will need to be mastered

- Costs: Labor intensive back-end processes will need to be minimalized or eliminated (this has caused other N.A. IC substrate fabs to close)
- Assembly: Currently, there are no high-volume OSAT semiconductor assemblers in N.A.; these will have to be established
- Customer support: Customer consulting, modeling, and engineering interfaces will need to be added
- Test: Testing HI substrates will be specialized and needed tooling will have to be established
- Co-design: It will have to be determined if the HI substrate fabricator will need to be capable of EDA design and modeling similar to today's IC packaging and OSAT vendors

The complete list of challenges can be seen in Table 3.

Conclusion

The search for packaging solutions for the emerging heterogeneous integration systems has just begun. Its foundations will be the FCBGA, silicon interposer, and 2.5D packaging solutions in use today, but with more emphasis on lower cost, higher performance, and geographic availability. Figure 8 shows the Intel concept of their EMIB and

Materials	• New materials (surfaces, RF materials) • Material interactions • Failure modes • Thermal mismatch
Cost	• New package platform (FO, embedding) • Complex systems
Assembly	• Technology diversity (sensors, antenna, ICs, passives • Pitch, soldered and non-soldered components
Customer Requirements	• Reliability and application specific requirements • Temperature/cooling • Performance • Pitch, dimensions, thickness
Test	• Application specific (incl. mixed signal, media, etc.) • Electrical, mechanical, and thermal aspects • Self-testing, incl. BIST
Co-design	• SiP requiring a system <-> package co-design • Different libraries in one project • Multiple domains with different scaling properties • Thermal, mechanical, and electrical analysis

Table 3: Challenges for implementation.

$M	2000	2019	2020	2021F	2021F/ 2020	2025F	2020-2025 CAAGR
Commodity	$10,342	$8,092	$7,911	$8,860	12.0%	$9,343	3.4%
Multilayer	$22,217	$23,877	$24,763	$28,279	14.2%	$31,683	5.1%
HDI	$2,074	$9,008	$9,874	$11,237	13.8%	$13,741	6.8%
Substrate	$3,505	$8,139	$10,188	$12,168	19.4%	$16,194	9.7%
Flex	$3,450	$12,195	$12,483	$13,831	10.8%	$15,364	4.2%
Total	$41,570	$61,311	$65,219	$74,375	14.0%	$86,325	5.8%

Table 4: PCB production forecast by technology (Source: IPC- NA Adv Pkg Ecosystem Gap Analysis report[8])

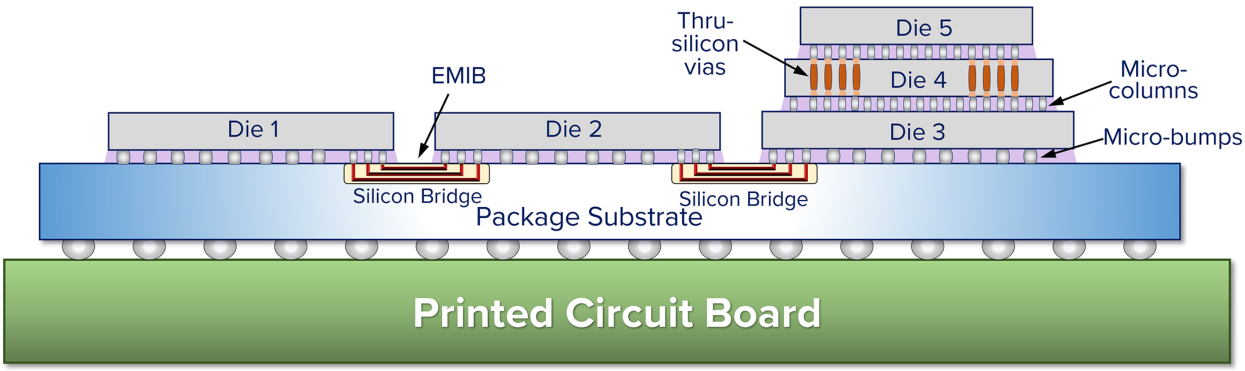

Figure 8: Intel's concept: EMIB and Foveros technologies combined to provide a high-density package for advanced computing and communications.

Foveros technologies to create the high-density solution required for next-generation products.

The best projections for the PCB fabrication industry for the next five years are that the highest growth will be for high-density boards of HDI (6.8%) and chip substrates (9.7%) as seen in Table 4 from the IPC Report, "North American Advanced Packaging Ecosystem Gap Assessment," available free from the IPC[8]. **PCB007**

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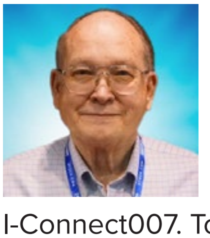


Happy Holden has worked in printed circuit technology since 1970 with Hewlett-Packard, NanYa/Westwood, Merix, Foxconn and Gentex. He is currently a contributing technical editor with I-Connect007. To read past columns or to contact Holden, click here.

The Novelty of the InduBond Press System

Feature Interview from IPC APEX EXPO
by Barry Matties, I-CONNECT007

The technology isn't new, but as Víctor Lázaro Gallego, technical director at Chemplate Materials, describes to Barry Matties, it's the application of a heat technology that is making waves for its efficiency.

Barry Matties: You are the creator of the InduBond Press System. Tell me about that.

Victor Lazaro: The unique thing on this press is not the press itself, but a unique way to create the heat that is needed for the lamination process. We don't heat like the traditional system does, which is basically indirectly, through hot oil, heaters, or steam. We heat the separator plates directly using electromagnetism induction.

Matties: We've been following this technology and we're well aware of it, first hearing of it from Alex Stepinski. And, we've done an interview with Sunny Patel at Candor, who has his installed now, correct?

Lazaro: Yes, correct.

Matties: What really caught my attention is the efficiency at which this unit operates. The heat-up time is instant, essentially. You also have the ability to cool your panels in the same press, because you don't have to worry about the heat-up time, which allows for a higher quality product. Overall, the cost to run this is quite low.

Lazaro: Yes, it is very low. Actually, I'm glad you mentioned the efficiency because this technology is heating just the mass that needs to be laminated, which is just the panels and the plates above and below on the press tack. The big efficiency came from the fact that we are not heating up the giant masses that are the

platens in the standard presses, and the platens mechanically are connected to the frame itself.

In this scenario, we have, let's say, 10 tons of steel that are being indirectly heated up to then transfer this energy to the panels. Our efficiency ratio is equal to the times less of a mass that you are heating up, so our package is being heated up directly by the induction, but we are not heating up the big masses of the platens; not the press, not the room itself. We had calculations done and we are in the range of 70 to 80% savings in energy.

Matties: Is this a strategy to bring in a unit like this, make an investment, but ultimately lower their cost of lamination?

Lazaro: Yes, it is.

Matties: What ROI should they expect on this unit? Let's talk averages.

Lazaro: It depends, of course, on the throughput and the kind of panels, but the ROI is between four to five years.

Matties: What sort of investment does somebody have to look at compared to a traditional press system?

Lazaro: Depending on the options and the size, this machine is in the range of $250,000 or $300,000. A similar system that occupies even more footprint, and needs the boiler for heating the oil, is in the range of $400,000.

Matties: So, they save on the money up front, of course. They don't need a cooling press now also, correct?

Lazaro: Correct, because of the installation power. A company needs to have the line big enough to supply the power to the machine. Now this machine has one-third of the installed power.

Matties: What sort of amperage circuit would they need on this?

Lazaro: In the range of 50 amps, compared to a 150-amp circuit in the conventional process.

Matties: Right. So, it draws considerably less. Now in terms of product quality, what's the performance expectation? Are they going to get a higher quality product out of this press?

Lazaro: Yes. Everything rests on the fact that we are not heating up the platen that then needs to transfer the energy from top and bottom to this press stack that is in the middle of the two platens. Here in this system, every single separator plate on the press stack heats up individually at the same time. Now we don't have a thermal lack or temperature delays. What you expect from this technology is a very similar thermal profile on every single panel along the height of the press stack, so that gives you far more quality and repeatability.

Matties: How many installations do you currently have in the circuit board industry?

Lazaro: We introduced this technology first in 2019, and since then we have placed 14 machines.

Matties: What is a buyer's primary concern with this system?

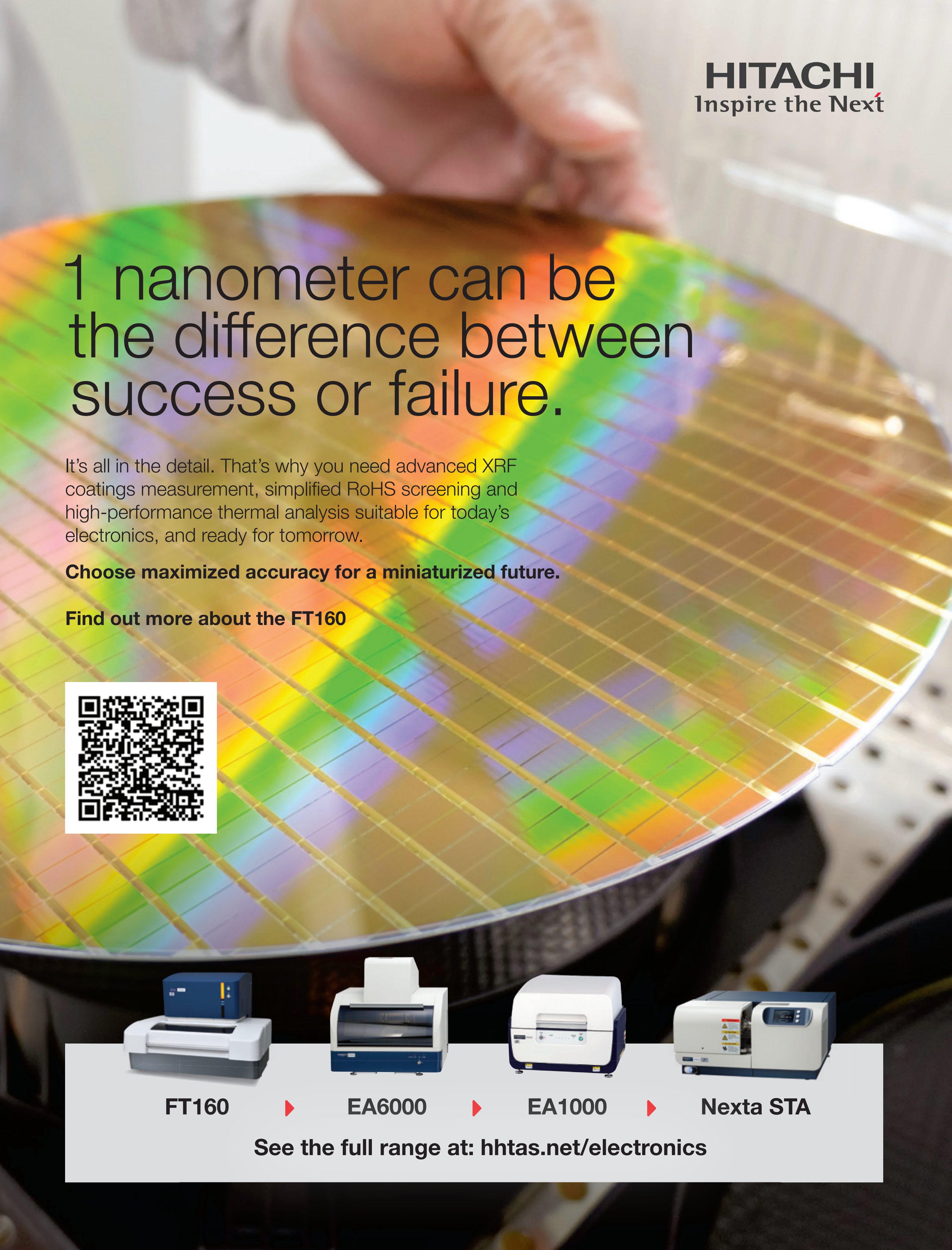
Lazaro: It's just the novelty, number one, because the benefits are so nice that it creates some skepticism at the beginning. But once the customer sees the potential and we show them the facts by maybe testing, like a recent customer in California, where we ran a face-to-face comparison, they prove it to themselves. They ran 20 traditional panels on their press, and then they came to another company on the East Coast to run the same panel, same construction. They made a face-to-face comparison, apples to apples, and came back with their report. We did nothing other than run the test, and the results are fantastic.

Matties: Victor, thank you so much, and thanks for bringing this technology into our industry. It's not new technology in terms of the induction side of it, it's just the application and you've brought it to our industry specifically.

Lazaro: Correct. The principle, the physics of the system, is probably 300 years old, since electricity was discovered, basically, but it's just the application, which is not trivial as it looks like.

Matties: Great. Thank you very much.

Lazaro: You're very welcome. **PCB007**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Inspire the Next
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MilAero007 Highlights

Real Time with... IPC APEX EXPO 2022: Blackfox Mixes It Up with Training Opportunities ▸

Andy Shaughnessy speaks with Jamie Noland, master IPC trainer and marketing manager for Blackfox, about current and upcoming training opportunities and what you can expect from them at the show. Blackfox has expanded its offerings to reach a wider audience, including some very basic classes for beginners.

Lockheed Martin Achieves First Ultra-Secure, IIoT-based Smart Factory With IPC-CFX, Aegis' FactoryLogix ▸

Aegis Software announces that Lockheed Martin's Lufkin facility has connected key SMT machines of all types using the IPC-CFX standard, providing IIoT data for Aegis' FactoryLogix MES platform in a single standard language, contextualizing accurate, timely, detailed data into smart manufacturing values, all in a highly secure environment.

Calumet Electronics Earns IPC-1791 QML Recertification ▸

Calumet Electronics further positions itself as an industry leader in printed circuit board and IC substrate engineering for the defense industry with its recent IPC-1791 Qualified Manufacturers Listing (QML) recertification.

ANGELS Nanosatellite Celebrates Second Anniversary in Orbit ▸

On December 18, 2019, Arianespace launched a Soyuz rocket from the Guiana Space Center, Europe's Spaceport in French Guiana (South America).

Nano Dimension Establishes First AME NanoLab Facility to Advance Multi-Layer Printed Electronics ▸

Nano Dimension Ltd. announced a collaboration with TTM Technologies, Inc. to open its first AME NanoLab at TTM's Advanced Manufacturing Center in Stafford Springs, Conn.

Tikehau Ace Capital Enters Exclusive Negotiations for the Acquisition of the Group ELVIA PCB ▸

Tikehau Ace Capital has entered exclusive negotiations to acquire 100% capital of ELVIA PCB, a specialized manufacturer of electronic printed circuits boards for demanding markets, such as aerospace and defense, automotive, industrial, medical, railway and telecom.

BAE Systems Awarded $154M to Deliver Engineering, Technical Integration Services to U.S. Navy ▸

BAE Systems has been awarded a five-year indefinite delivery, indefinite quantity contract worth up to $154 million to continue supporting the U.S. Navy's Naval Air Warfare Center Webster Outlying Field.

Ventec's USA Facility Receives AS9100-D & ISO 9001:2015 Quality Certification ▸

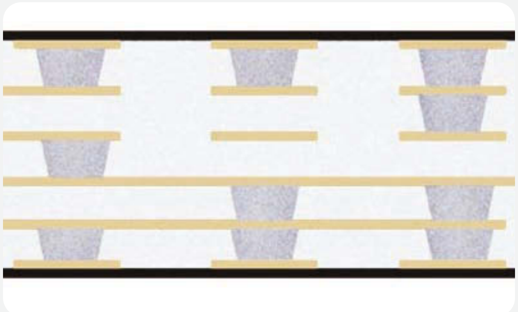
Ventec International Group is pleased to announce that its U.S. facility in Fullerton (CA), is now certified according to AS9100 Revision D and ISO 9001:2015, the quality-management standard for the aviation, space, and defense industries.

Metallizing Paste

High reliability high layer count semiconductor package board application

Applications

Inter-layer connections



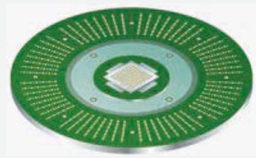
High layer count high-speed data transmission boards

Consumer electronics

e.g. : High-speed data transmission substrates for smartphones

Automated test equipment (ATE) boards

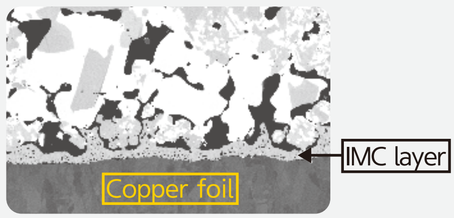
e.g. : Probe cards



Features

What is "Metallizing paste"?

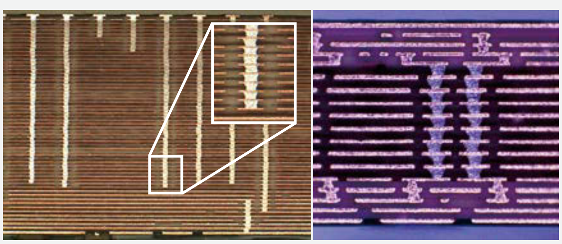
High and low melting point metal particles formulated, transient liquid phase sintering paste.
High and low melting point metal particles formulate intermetallic compound(IMC) layers.
IMC layers achieve high reliability connection on copper foil.



- IMC layer formation with copper foil
  Stable circuit connection reliability with various base materials
- High heat resistance and high thermal conductivity
- No through-hole plating required, enabling fine pitch routing

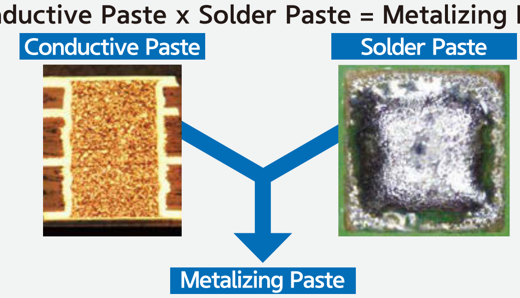
Product line-up & properties

Product			MP8300	MPA500	MPA510	MPA550 (NEW)
Filler	Conductive particles		Silver, Copper, Solder	Silver, Copper alloy, Solder		Silver coated copper, Solder
	Average particle size	µm	4 - 6		2 - 4	4 - 6
Binder	Resin		Epoxy			



Actual products of FICT LIMITED
Cross section image of F-ALCS® PCB

Conductive Paste x Solder Paste = Metalizing Paste



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Ralph.Jacobo@all4-pcb.us - 818.531.2687

PCB Adoption of Innovations

Feature Article by Happy Holden
I-CONNECT007

For North America, there is a growing need for more ultra-high-density HDI capability. Some of the reasons for the slower adoption of SAP/HDI fabrication may rest with two obstacles: Subtractive processes have difficulty as they approach 50-micron traces and spaces (0.002"), and it is not clear what the total system acquisition costs will be for ultra-HDI.

Introduction

As PCB geometry begins to require 50-micron traces/spaces, subtractive processes start to have yield and imaging problems. Semi-additive processes (SAP) are the chemical processes that are used for these applications. My column in the January issue of *PCB007 Magazine* outlines the various SAP processes used by our industry. The other factor is the uncertainty in how much ultra-HDI is going to cost. This forms a real obstacle for implementation of SAP. One reason may be the absence of density metrics. Performance measures are needed for the difficulty to assemble surface-mounted components with fine-pitch; the amount of density required on the printed circuit to mount all these fine-pitch devices in the area provided.

In my opinion, the primary goal for PCB development process engineers is to implement new customers' new products and/or new processes as part of expanding the business. As Figure 1 shows, implementing new technology is an "S-shaped curve." Lastly, it supports a strategic plan that the owners or the CEO have in terms of what is the long-term goal that you can constantly be working on. Risk reduction is one of those tasks.

Risk Reduction

Although the rewards for ultra-HDI or an SAP process are very concrete, the PCB designer may be more focused on the risks. In the development process, the risks to the customer need to be articulated and adequate solutions developed that allow the rewards (higher density) to tip the scales in favor of its adoption (Figure 2).

This was true for me in popularizing HDI in the late 1980s. Hewlett-Packard had developed laser drilling because of a need for low-inductance blind vias on its Finstrate COB in 1982. Publications about the technology in the HP Journal and at the IPC Technology Forum interested some OEMs like Siemens and IBM, but many OEMs had a "wait and see" attitude. It was not until HP proposed an alternative design to a new device called the "cellular

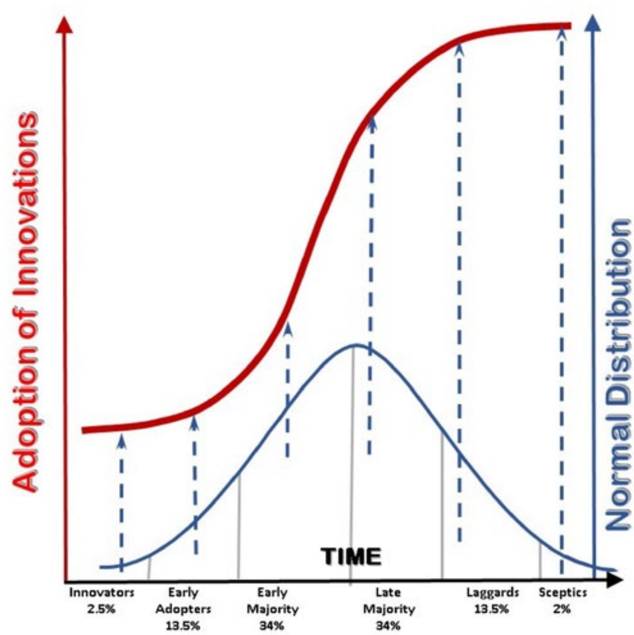

Figure 1: Adoption and innovation of new products and processes provides the opportunity for growth and rapid profit creation; PCBs contribute to this end. (Source: *24 Essential Skills for Engineers*[1])

Figure 2: The rewards do not balance the risks unless the risks are removed.

phone" in 1993, that Japan jumped on HDI for mobile phone boards.

The risk reduction process as seen in Figure 3 is an important aspect in the roll-out of innovative technologies.

Re-design Report

At HP, a mobile phone customer came to us for advice on their new phone board, as we had over 20 years' experience miniaturizing the hand-held calculator. Their board was unique; it was seven layers with unbalanced construction and three sub-component plated-through-hole boards laminated by an autoclave. I wrote a design report where our first proposal was to use controlled-depth blind vias by drilling and annealing to reduce the warpage. But the second proposal was to employ our new laser-

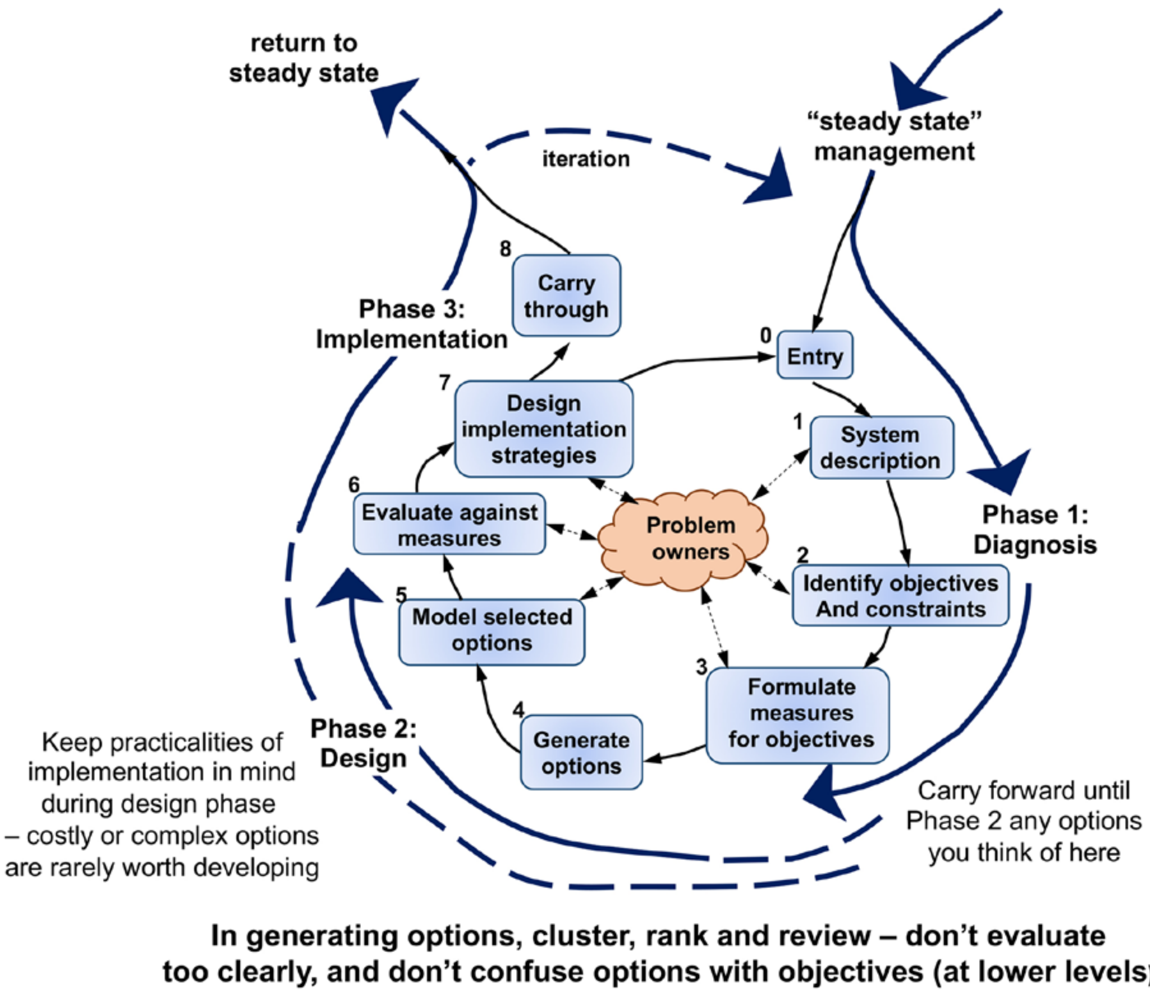

Figure 3: A general model of system intervention strategy. (Source: *24 Essential Skills for Engineers*)

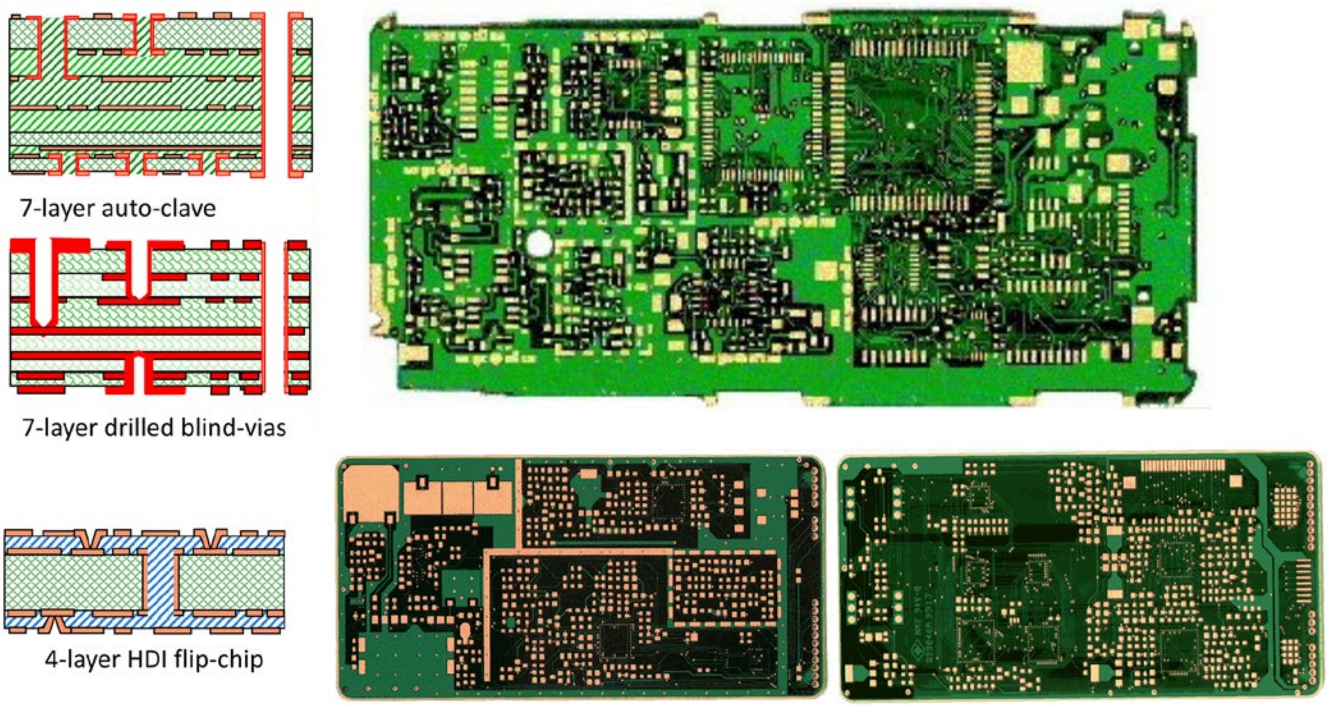

Figure 4: The three different constructions and two size options for the new cellular phone in 1993.

drilled blind vias, finer lines, and stud-bumped flip-chip for the IC. All this could be done in four-layers and at one-quarter the size.

These three alternatives are shown in Figure 4. The four-layer option was too radical for them, but the blind-via option turned out to work very well and was adopted. Later, the Japanese followed the miniaturized-HDI option.

We built samples of the two options, with two versions of the HDI option: one in rigid FR-4, the other in polyimide flex. The remarkable feedback was, “Can we keep these for testing? Our R&D says the HDI boards are not possible to build.”

IPC-2315 HDI Design Guideline

The design report on the HDI alternative proved to be so successful that an IPC subcommittee was formed to create a new document, the IPC-2315 HDI Design Guideline. This was first published in 2000 and the committee was comprised of interested OEMs, PCB fabricators, and interested suppliers. The guideline is still available today, with updates and the cooperation of the JPCA.

Density Modeling

If the goal in using ultra-HDI is to take advantage of its density reduction capabilities, then the use of density models in the design report or new design guideline is appropriate. These models can help calculate the density improvement and size or layer reduction with using finer traces and spaces from ultra-HDI design rules. If the board has already been designed, then the CAD system can report on the “Manhattan distances” of the traces on each layer. Measuring the total routed area on each layer will give you the centimeter per square centimeter metric to calculate what the size would be for ultra-HDI routings. If the boards have not been designed yet, then there are seven wiring models that I have used and studied[2] and the one I favor is the statistical wiring model by Coors, Anderson, and Seward of the Colorado School of Mines (Figure 5).

Where Do You Start?

Between 2000 to 2010, I recommended to OEMs and fabricators that they should not jump into using HDI until some preliminary

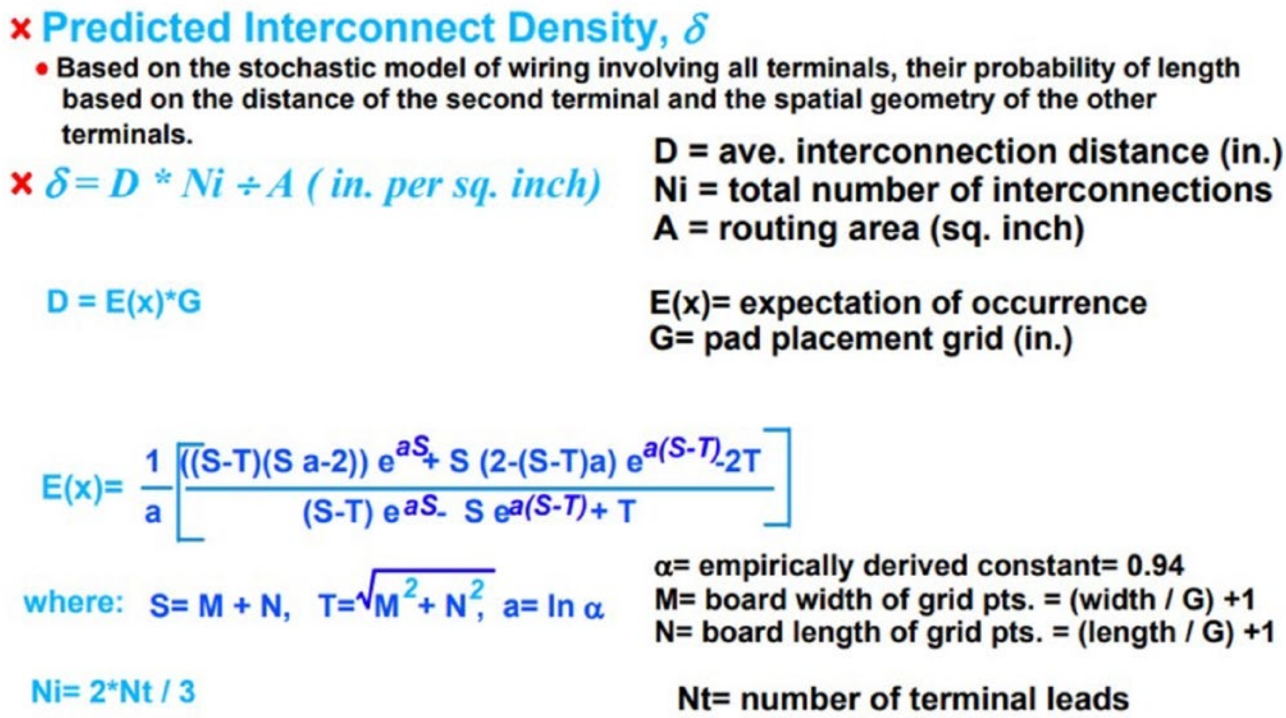

Figure 5: CSM's density modeling algorithm[2].

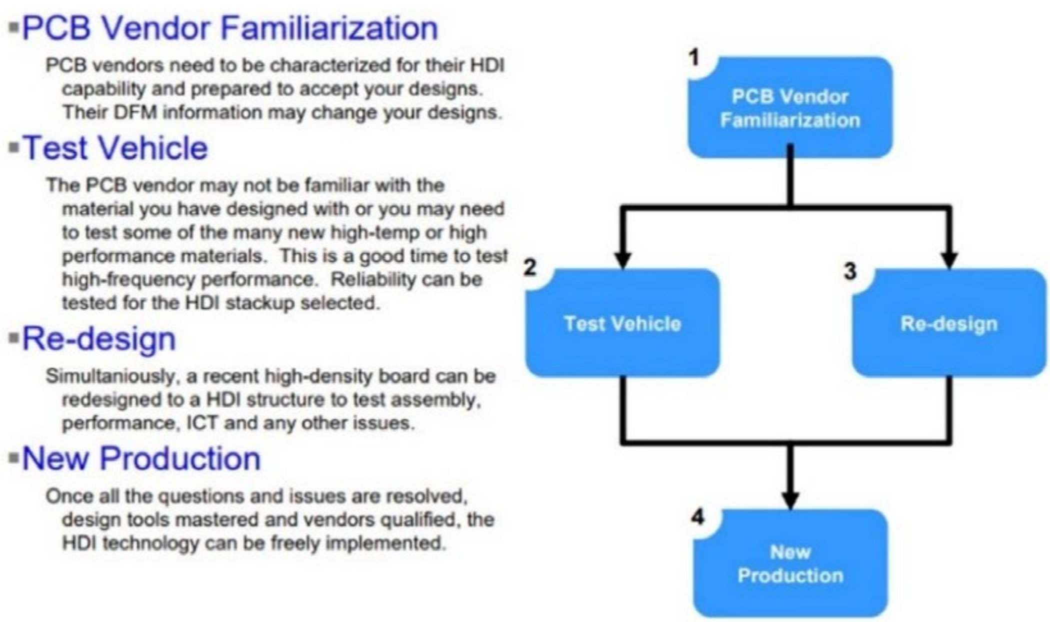

Figure 6: Four steps on how to get started when risks are visible.

steps were undertaken. These four steps were (Figure 6):

1. Educate yourself on this new SAP technology and familiarize yourself with your fabricator's capability.
2. Create a test vehicle that permits reliability testing and can answer new questions about design rules and materials.
3. Redesign one of your most recent HDI or multilayer designs using the new ultra-HDI design rules you have been testing.

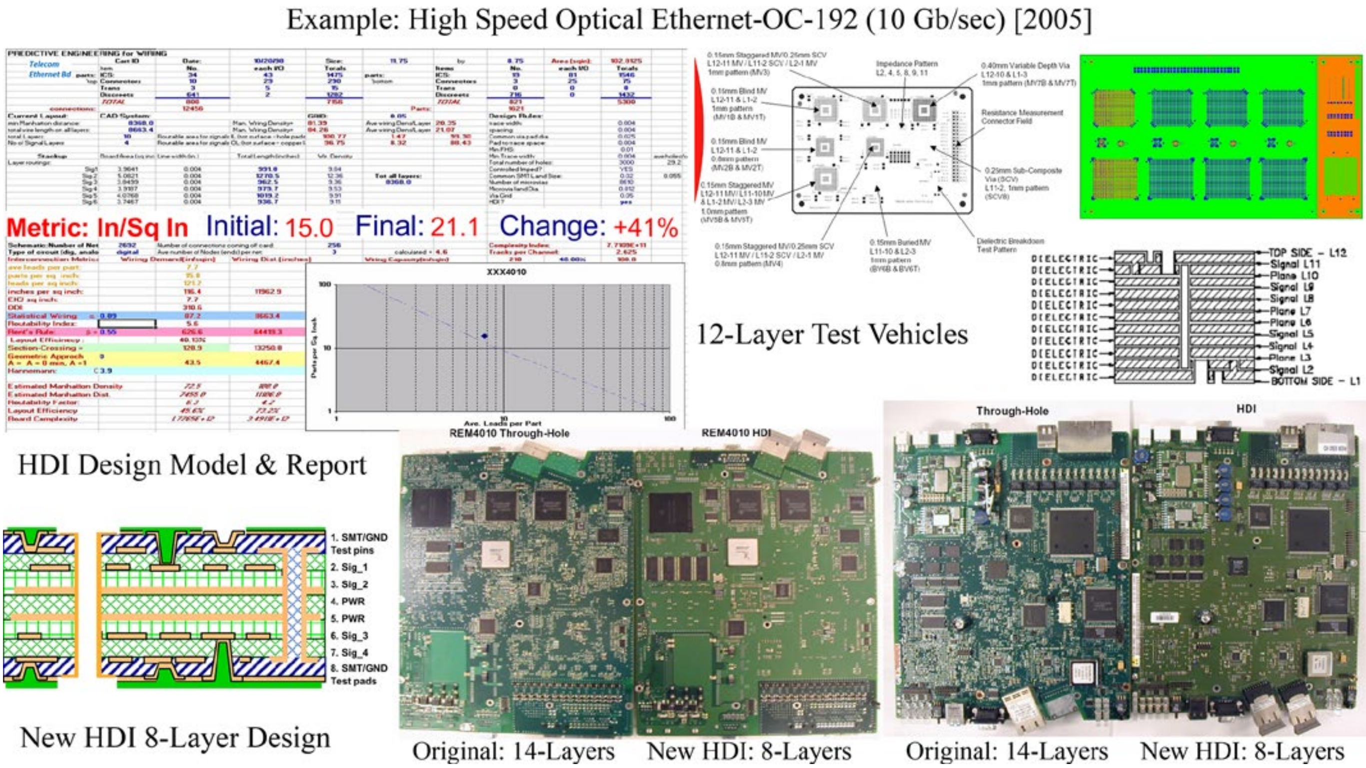

Figure 7.

Do not move any of the part placement so that any samples can be assembled for further testing.

4. Once you have accomplished these three steps, then codify the design process and look for opportunities for new products or designs.

Figure 7 shows one such OEM's report on using this four-step process and design report to get into using HDI in their products. **PCB007**

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2. "Chapter 3: Design of Advanced Printed Circuits (HDI)," *The HDI Handbook* by Happy Holden, a free eBook download available here.

Alex Stepinski: Taking Control of Input Costs

Feature Interview by Barry Matties and Nolan Johnson
I-CONNECT007

Barry Matties and Nolan Johnson talk with Alex Stepinski about strategies to lower costs in brownfield facilities. Alex has extensive experience designing and optimizing manufacturing processes and is currently helping companies implement straightforward step-by-step solutions to move into smarter manufacturing across different industries.

Barry Matties: Alex, brownfield factories are stuck with space limitations and automation is a challenge. What could be a different way of thinking about a brownfield site and why it makes sense?

Alex Stepinski: First, I want to address a fundamental bias. Many people associate me with the greenfield sites that I've architected over the past years, and which became an Industry 4.0 example in the United States. It's not because that was the only way to do it, but because that was the business case. The business plan at the time was to build new facilities for OEMs that didn't have any PCB fab capabilities.

Brownfields do not follow the same plan to implement Industry 4.0. The investments to do so can be done over a longer period based on available monies and can be done to address the biggest opportunities first. I think there's a little bit of a roadmap that any brownfield can follow.

The first step is serializing your products, and there are many options to do this. The best ones, in my experience, are laser based, using lasers from some of the sensor suppliers in the market, and many of the suppliers can integrate this for you into a piece of equipment so you don't have to increase your footprint. It's probably one of the only things that you might need to add. It doesn't increase your footprint.

Once you serialize your products individually, then everything turns into a sensor-and-software problem, and this doesn't add to the footprint in most cases. Industry 4.0 is about correlating data and making decisions based on interpolations of data, doing regressions, and things like this. It's not advanced artificial intelligence. Advanced AI in business is

Alex Stepinski

when you do image recognition, natural language processing; this is the forefront right now, as well as very advanced algorithms that are dealing with B2C sales, marketing analytics, self-driving, and so forth. This is where AI is focused because it is the biggest return. You can buy equipment that even has some of these features. You don't have to touch the concept of AI.

But on the PCB and EMS side, it's more "AI light," or "more-than-Excel algorithms." Something we called just a normal algorithm 20 years ago is now called AI. It's a sexy term. Robots aren't taking over the world any time soon. The fundamental things to do in a brownfield to tease out value from a planning perspective is just a step-by-step approach, one process at a time.

It's probably a one- or two-person engineering job. You give them subject matter expertise, availability, make sure they know how to do some basic coding, understand sensor options, and then they go process by process. What are some of the interpolations you can do? Well, just getting a time stamp. All you need is a photo sensor to know something went through the machine, and then you can also code at some point when it went through, when it came out. You could do this in one step or multiple steps.

The sensor kit for most processes is generally $5,000 to $10,000 per tool to get time and basic settings, and then you save their recorded data, which is just the serial number that you scanned, the times it went through the machine; you save it into a database. If you can pull the error codes by time out of your machine and put that in a data table, then you can correlate the two together and you can know something happened: "I heard an alarm while this panel was being processed." Making an API to your other systems adds further interpolations that can then lead to predictive recipes/decisions.

The first step is understanding what is and is not important and being able to make some basic interpolation. Take AOI, for instance. This is a measurement site in PCB fab. The AOI machine has a lot of information built into it. It has all the false calls that it saw, and it says how long it took to start and finish the job.

You can also code information in there on the real defects and then take all of this, put it in the database, and correlate it to your serial numbers. When you test it later, you can correlate these serial numbers together and understand the root cause of escapes; a lot of escapes happen because of poor AOI setup, operator errors, things like this, and it gives you an opportunity to improve your procedures in these areas to reduce scrap.

This is an interesting area of focus to get a good return because in a layer, shorts and opens are typically the defects that we scrap boards for. You can reduce the frequency. Additionally, you have your use of regression in place of direct measurements. In PCB fab, for example, there are a lot of legacy specifications to cross-section everything. And when you have no controls in the process, cross-section is the only option.

But if you add some very simple controls, you can avoid cross-sectioning just about everything. What are the simple controls? We get ideas from other industries. For instance, gravimetric measurement, or weight. Rather than chop up every panel to check the plating thickness, there are three things that you can do. Every circuit board shop has them. You need a scale, a CMI, and a CMM.

This is a great way to address legacy equipment that doesn't have a lot of controls. You can use some simple things in your factory to take measurements and not need a major upgrade where you only have one machine and it must be replaced, or you don't have space to put a second machine next to it. That's a big opportunity.

With a lot of the equipment, you can also get upgrades to get some better data collection to put into your database, and all this can be done with cloud computing. You just buy space as you need it and gradually scale up. The challenge with many brownfield sites is they have fully capitalized equipment kits, much of which is not suited for Industry 4.0. You can just add on some features, so it is suited because you don't want to spend money on a brand-new machine for just a few added features.

Now, if something is extremely old, you haven't maintained it, and everything is broken, then replace it. But if the equipment's being maintained and you only need a few things, then just do the upgrades. That's the approach for a brownfield. You start generating enough payback to do some new investments.

Then you start to get the culture of adding sensors and collecting data. This is where we need to be in this industry. If you're a process engineer and you can't code, then it's probably not for you. You need to take some classes, and if you're not liking it, it's not suited for you, and you need to hire somebody who can do it.

One of the challenges is this "missing generation" in our industry. There are a lot of graybeard folks who don't code, and a lot of young folks who do, but they don't have subject matter expertise. And there are few people in the middle, so this is the thing that needs to be overcome.

You need a team of subject matter experts, and you need the young folks so it's a little more effort than if you had good demographics. In other places, it's the more experienced engineers who have both skills, so you must create this bridge.

You need a team of subject matter experts, and you need the young folks so it's a little more effort than if you had good demographics.

Nolan Johnson: It sounds like the goal is to go through a relatively simple implementation process in an existing factory to get the data needed to be more predictive, and use that to become even more efficient in the processes and reduce waste, thereby improving input and operational costs and giving you more control over what your input costs will look like. Is that correct?

Stepinski: That is absolutely correct. That's the way forward in my opinion, because otherwise you're leaving a lot of money on the table.

You can't outsource these things economically, and here's why. A printed circuit board shop is not an engineered factory. A brownfield is not an engineered factory; it's an evolved factory. It's more like an animal. Over decades you added equipment, the varying vintages and suppliers, with different chemicals and procedures from one shop to another—all this evolved by trial and error mostly over time.

A little bit of engineering, but mostly trial and error because they didn't have PLM systems, or the tools do this in a different way.

Because of this, every factory is quite unique. If you call somebody and say, "Help me fix my factory," you will get a standard solution which will be a lot more expensive than using your own small team to tweak this situation.

Johnson: The idea of the integration team you were speaking about makes a lot of sense.

Stepinski: I think that's the right approach. I've seen how it's done in different industries. I've gone to MIT to study Industry 4.0, and this is how people do it. It's the most cost-effective way. In our industry, everybody is very supplier-dependent, but the supplier is biased to get you to spend money on upgrading your equipment, and then you don't really have Industry 4.0 because you blew your money on one or two pieces of equipment.

What's better for the whole ecosystem is for board shops to have a process engineering team that does these processes step by step. Then you generate enough funding to do some significant investments that have a good NPV through the cash flows that emerge from these improvements. This is better for everybody. It's better for the suppliers and the board shops, and you have a more robust industry. To me, this is the best approach.

In PCB shops, there aren't really any processing engineers; they're manufacturing engineers in just about all PCB shops. They troubleshoot problems with parts, deal with downtime situations, and occasionally bring in a piece of equipment. Process engineering is implementing Industry 4.0, going ahead and making systems, collecting data, doing predictive studies, and doing this without the supplier as much as possible.

If you're very reliant on the supplier, the supplier is running your factory in their interests, not in yours. You must always have a balance. Working with suppliers is great if you can stand on the same footing as they are. A dialogue, a dialectic, is the best opportunity to create value. But when the supplier is much more knowledgeable than you are about all these things, it turns into a zero-sum agreement, the supplier wins, and you get something, but you left a lot of value on the table.

That's my assessment. It's about doing your own R&D. You just need a two-person engineering team; you get them set up with some subject matter experts in the factory and go process by process. In a few years you're fully Industry 4.0.

Johnson: So, you have process by process and start collecting the data to put into the database. The first phase is collection. From there, you can start to track escapes, go back to find out what was going on in the processing of that particular part number that ended up being an escape, being a fault. I get that. But as you start moving, then what?

Stepinski: Then you can make very inexpensive changes to your procedures to address this, and you're going to use some money emerging out of the factory system improvements for yourself to do further investments.

Johnson: Right. As we're looking at phase one, how does that help in a practical sense to control your input costs or your process costs?

Stepinski: You must pareto your wastes. Where do you have the most waste? There are many

***Worldwide patents pending*

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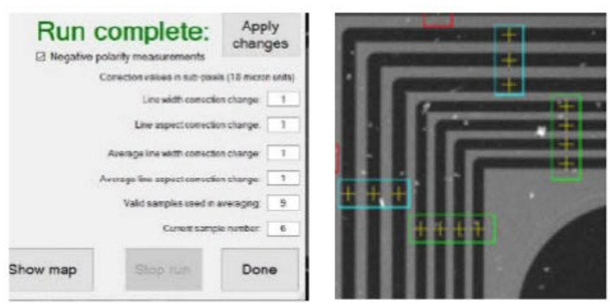

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different types—overproduction, inventory, just scrap, cycle time, not meeting commitments. You need to assess what you feel is most impactful to your business, and that's what you target for your first project.

Industry 4.0 is based on engineered sensors which, when combined with data science, allow the emergence of foresight to improve efficiencies. You put sensors on your equipment and make simple control boxes—this is very easy stuff at the end of the day. Engineers coming out of school know how to do this, but they get thrown into a PCB shop with a bunch of dinosaurs, and slowly they turn into dinosaurs themselves. Don't let the Jurassic ecosystem absorb them. Get them to focus on what they know best.

They shouldn't be led by pre-existing biases about how things are done. Use their education and give them information they need to do a better job of it. This is one of the challenges when you have senior people who don't know this stuff. It creates a challenging dynamic to manage younger engineers who do know. You don't want a situation where the young people are leading everything because they're missing a lot of experience too.

They shouldn't be led by pre-existing biases about how things are done. Use their education and give them information they need to do a better job of it.

It requires that the more seasoned folks take some online courses, something very common in different industries. They don't become the coders, but they learn enough to manage these folks.

Johnson: I'm starting to imagine that a one- or two-engineer team is comprised of an elder manufacturing expert and a younger process expert.

Stepinski: It could be, or you have two process people for redundancy who just poll the experts, just because one of the great risks in this data engineering data science is people get enough knowledge in a competitor, customer, or supplier, which then hires them. A big issue with the "AI space," which is data engineering, data science, and analytics, is it's very under serviced. There is a constant need for a hundred thousand people to fill these roles. So, you must keep them happy, and be very careful. There are many cases of companies losing their whole departments because they found a better opportunity.

Keeping your folks educated is not hard to do using online courses through Coursera, IBM, Google, and more. Everybody needs to spend a few hours a week learning (think old world apprenticeship). If you've been in the business for 30 years, you don't have to learn how to code if you've never done it. But you can learn enough to say, "Hey, new hire, this is what we're thinking from a scope perspective of how we want to approach this," and lead them in the right direction. Then, they can take care of the details for you. That's the most cost-effective way to approach this, and everybody benefits.

At the end of the day, you free up more capital for investment, eventually new equipment, but at the beginning, it needs to be a homegrown program.

Matties: We often hear that hiring is a great challenge to begin with, and labor costs for operators generally have gone up. When people think of lowering costs, they think of automation. But in a brownfield site, they'll often say automation doesn't fit in their factory. How does your strategy help lower labor cost?

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Stepinski: The first one to two years will be a little challenging. You can reduce your capital purchases and invest a little bit of this, or you could finance some of your capital equipment if you're not doing it now, so you don't have a spike in cost for the short term.

This is a proven approach in many other industries. But what's missing is the general education of how to do this. While there are many resources online, people need to take the time. I've heard from many companies that implemented AI or Industry 4.0 that it's important the stakeholders in the organization commit themselves to spending a couple hours a week reading, listening, or watching something to learn how the rest of the world does it.

Matties: Regarding direct labor cost, I'm understanding that if a metric is revenue output per employee, then productivity will go up because of yields, throughput, and so on. What is the right measure for someone today to say we want to reduce our labor cost by whatever the X happens to be for them, without necessarily getting rid of people? Because like I said, they don't see where they can bring in an automated line especially in a brownfield site.

Stepinski: I think this is an old idea where you say, "I'm going to automate the factory, so I don't need any labor in a brownfield. Alex built a brand-new automated factory; boy, we wish we had that because we wouldn't need so much labor." That's not the way to look at it.

There are challenges as boards get more complex and there is a tendency for human error the higher the complexity gets in PCB manufacturing. No matter who you have, they will make errors. Some make less than others, but as you add steps to build the boards, it gets more complex. You're fighting this all the time.

It's getting more difficult to find direct labor. In the near term, you say, "Hey, I really need to upgrade all the equipment in my shop. I can't afford to do it, so the first step is to make things as efficient as possible to free up capital so I can go and do it in a systematic way over the next few years."

You need to have a strategy, which should be to refresh the equipment kit so that you are not so dependent on your experienced operators, more dependent on your systems and processes, and you develop a body of knowledge on how to manage that process. Once things are documented, you can tolerate higher rates of turnover in these situations. You're not going to have trouble finding direct labor to work in your sloppy place because it won't be sloppy after all this is done.

I've been hearing the same excuses for many years, now that I was doing these past projects, and anyone who started this when I built my first factory at Whelan, they'd be finishing up right now, and be very happy. And they wouldn't have spent very much money at all. Upskilling the workforce is the key, the ones who can provide the most value right away, making sure all the stakeholders are knowledgeable on how to do this, and not trying to hire a supplier or hire a company to do it all for you. That's very expensive.

Matties: The takeaway is to become a process-oriented company that relies on systems rather than people.

Stepinski: Yes. Most PCB shops have an ERP system, but you need to go a step further. You need to get an MES system. The cost is typically $500–$2000 per user for an annual license. It will do all your correlations for you. You don't need to do too much, just add sensors and put in measurement plans. There's not much to it.

But how many PCB shops in America have MES systems? It's not something they do. The more advanced facilities overseas already have this. You take it a step further and you get a product lifecycle management (PLM) system to manage your NPI process for you, so you can group products into families and have a predetermined engineering process for how you do things, so you're not just doing trial and error all the time on new products.

There are a lot of complexities and no one person knows all the constraints in the factory at any one time, unless it truly is a mom-and-pop shop.

You can have more predictive results that you'd be able to extrapolate, "I'm taking this order. It's got these conditions." You have an MES system, a PLM system, it automatically tells you it's not going to make it by the date you committed. It's going to be four days late, for example, or it's going to be four days early. But you must use a system like this to know this. There are a lot of complexities and no one person knows all the constraints in the factory at any one time, unless it truly is a mom-and-pop shop.

That's the approach, but we are really late to the game. These tools have been on the market for years now. Other very complex industries have adopted it, but PCB is just behind in this area for whatever reason.

Johnson: How do you make that leap from capturing the data with the sensors, looking at your error situation, and then moving into a more predictive system? You started making the point that by using your systems, over time you could start to predict things like the expected weight of a new part number as it goes through the process. How do you get from data collection to using that to predict and then check against those predictions?

Stepinski: The CAM software systems on the market have the tools built into them to tease out the key input variables that you need to correlate to the data. You take this information and build your correlations, your regressions—whether they're linear or nonlinear, it's immaterial—and then you have equations based on simple correlations that you can use to predict your recipes. It's very straightforward.

Johnson: Alex, phase one is setting up sensors and collecting the data. And if phase two, for example, is starting to be able to do predictive work using that data, is there a phase three?

Stepinski: Phase three is now you've made your efficiencies such that you can do more. Now, what does "more" mean? Once you learn how to do your own process engineering instead of outsourcing it to the suppliers, which is what I would say is being done right now and it's encouraged even by ISO to do things like that, use your suppliers for everything.

I think you need to have native capabilities to do this kind of work, and then you can take on bigger Industry 4.0 projects. Do that by partnering with suppliers now that you're on a stronger footing with them so you're not doing zero-sum discussion so there's value creation happening. You can also just take on bigger R&D projects, add a couple people to your team, and do bigger things yourself.

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

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

All the developments that I did in our first factory at Whelan were internal. The wastewater technology, unique processes, and everything, that was just time—measuring things, breaking things out, analyzing them and having the time to do that. Process engineering should be independent of the manufacturing group. In the U.S. PCB shops, it's not the case. It's part of the manufacturing group. It's not an independent group that just does process engineering and development.

They're just working on parts all the time. There aren't enough people to get things done. This is really the challenge. You must staff it. You do that either with adding people or killing people with hours if it's a family business, I guess.

Matties: Right. Well, part of it is capital. People say that there's not a lot of profit left in circuits, and so it's that chicken and egg thing. You have to commit to your future to invest the dollars today.

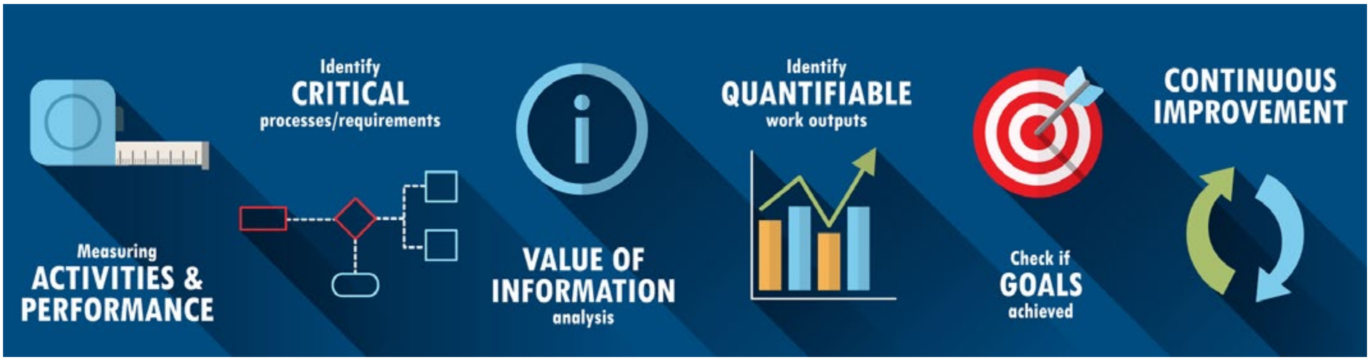
Stepinski: Barry, I think if you can improve your yields and reduce your cycle time, you can charge more for your product. First, people will tolerate that to some extent because you're adding value. Second, you reduce your costs internally for wastes. It's knowing up front the best way to approach it. You must analyze your existing organization and see where the weaknesses are. Ideally you do it by getting rid of the weaknesses, adding the talent, and paying for it that way. This is one way to approach it if you truly have not one penny to spend.

Matties: You must make your choices. I think the word you used earlier was culture. What you're describing is, back from the 1980s, TQM or total quality management. The goal is to reduce waste, and we have evolved tools to help us do that in ways that we didn't have then. When we start looking at that, it's about eliminating waste in every step of your process.

Right now, we're talking about manufacturing processes, but when you look at total input cost, this attitude should be carried out through all your systems, sales process, and accounting processes, because you're talking about a culture of continuous improvement, as we've been talking about or defining.

Stepinski: I think we need to rest on the agile lean stuff that's been done. Particularly, there are a lot of agile tools in the market that are very inexpensive that you can get out of the cloud and start setting up your different process steps. You can do business processes with many different tools. ERP, for example, is for finance people. Manufacturing needs an MES system. Engineering needs a PLM system. This is what's needed to make the whole package work. The finance people make the decisions when the margins are so low because it's what it comes to at the end.

Matties: But as you're talking about education, I also think there's a level of training or education of process improvement, generally logistics and systems education, that needs to happen on a general level.



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Stepinski: The neat thing is there are so many online resources for this, you can do it in your spare time. You can take systems engineering courses four hours a week for six months, and then you are pretty well versed in how to design complex systems. Many schools offer this, it's inexpensive, and you can take all the coding overview courses. The key is being able to scope out a project. You don't even need to do it yourself. You need one or two people hands-on in the factory to scope it out. But at the end of the day, you're not necessarily the ones coding it. You just need to communicate to a freelancer. Try freelance.com or remote.com and hire somebody for a couple weeks for a project. They might even be on the other side of the world and could be extremely inexpensive.

The neat thing is there are so many online resources for this, you can do it in your spare time.

Matties: A great way to invest dollars into your company is to invest in people who will learn these skills like systems training and what you're describing.

Stepinski: Exactly. Anybody can do it, but if you don't have any coding background, it's going to be a bigger learning curve and you must understand that. My approach would be if I had an existing factory, I would force the experienced people to learn X, Y, and Z, but not too much because they're holding everything together at this point. I would bring on one or two people who have an easier time learning all this information, then you just develop your project scope documents and outsource it for cheap money. It might cost a couple hundred dollars to outsource some of these things. That's it.

Matties: For a manager, they don't have to learn all the steps. They just have to learn what's possible and practical for their application so that they can communicate based on understanding what's possible.

Stepinski: There are different levels of magnitude. Right now, people think, "If you want to have Industry 4.0, you've got to buy a whole new factory." And then some think you just need to buy a few machines. But if you spend a few hours a week reading something, you're going to find that it costs hundreds to low thousands of dollars to get the programming done, and you're just going to buy a few sensors for hundreds and low thousands of dollars. You just need to have one or two people who can implement it. That's all.

Matties: Was there any one thing, Alex, thinking back to as early as Whelen or perhaps before or currently, in terms of a book or something that really changed your thinking that someone could go read or any other sources that you would recommend?

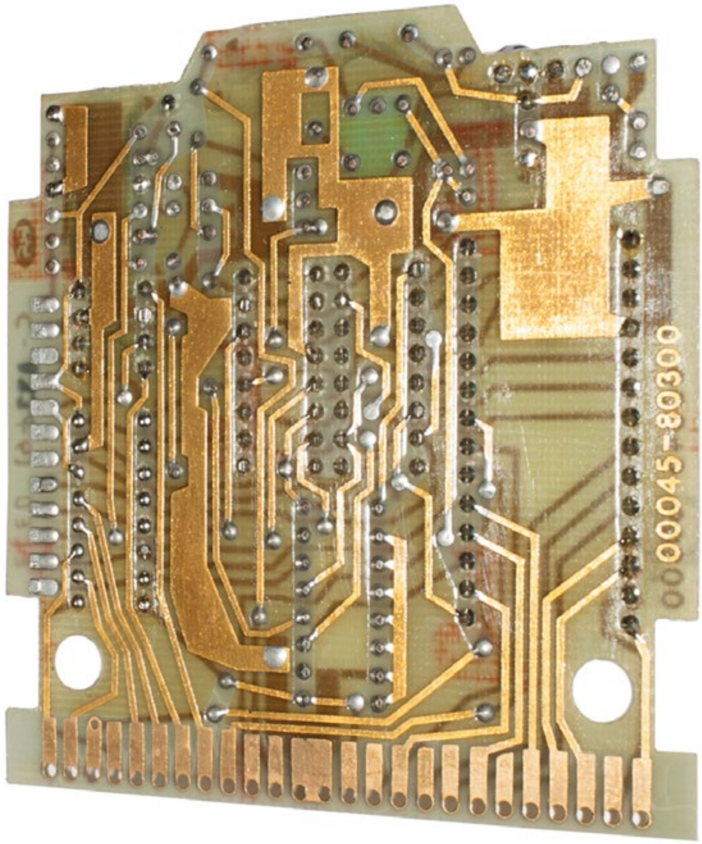
Stepinski: I would recommend *System Architecture: Strategy and Product Development for Complex Systems,* by Bruce Cameron, Daniel Selva, and Edward F. Crawley. Another good one is *Industry 4.0 for SMEs: Challenges, Opportunities, and Requirements*, by Dominik T. Matt, Vladimir Modrak and Helmut Zsifkovits.

Matties: Okay, great. Thank you.

Johnson: This has been very insightful learning how an existing facility can move toward Industry 4.0 while gaining additional control over input costs, all without a lot of expense! PCB007

This interview originally appeared in the February 2022 issue of *SMT007 Magazine.*

The Origin of HP's Printed Circuit Solder Process



Wikimedia Commons: Mister rf

Article by Clyde Coombs

A story went around Hewlett-Packard in 1961 that when Dave Packard looked inside a newly designed transistorized electronic instrument, he was surprised, even shocked, to see—instead of wires—a motherboard and a row of printed circuit boards. Given a very bad corporate experience with single-sided boards a couple years earlier, printed circuits had a very bad reputation for quality and reliability, not only at HP, but in electronics generally. However, Dave (as he preferred to be called) realized that the size of the transistor, and the number used in the instrument, required this "new" interconnection technology, and that was alarming. So, he asked if there was anybody in the company who actually knew about printed circuits. That was how I first met Dave Packard.

When the "transistor revolution" started in the 1950s, HP was one of the earliest non-consumer companies to design products using this new technology. By 1960, all new HP products were being designed this way. One of the early "transistorized" products was a line of electronic "counters" that would become HP's best-selling product for several years. This was the instrument that Packard was inspecting, and the future of the company was suddenly linked to these boards, like it or not.

Packard had a right to be concerned. The production problems of using printed circuits in HP products had not been thought out. HP engineers knew how to design these instruments, but there was literally no thought given to how to assemble them. We couldn't do the same things in the same way, only smaller. It was clear that we had to do some different things, and some things differently. But which was what?

While the extended argument at HP over the construction and fabrication of the board itself played out, there was an equally important and controversial issue of how to solder the assembled boards. At the time, the electronics industry had a long history of using rosin fluxes to avoid destructive conductive paths created

from post soldering residual material. It was feared that these conductive paths could easily develop, especially in humid environments, from acid flux residues. However, we could not see rosin fluxes used in our kind of mass production.

HP had actually started using acid fluxes with the introduction of eyelets, but that general process had also introduced reliability questions that had not been fully answered. The biggest issue with the use of non-rosin fluxes (usually acid based) was that they required a water wash. This brought up more concerns about moisture and acid flux residue being trapped under components and amplified the issues concerning potential immediate failure due to the conductive paths, and long-term reliability problems. In addition, there was a concern about the component reliability issues due to corrosion.

The biggest issue with the use of non-rosin fluxes (usually acid based) was that they required a water wash.

In HP's case, all this was further complicated by Dave Packard's decision to use gold as the etch resist. This happened when he inspected the first double-sided plated-through board and realized that the gold-plated circuitry on the top side would be exposed. He turned it over in his hands, looked at the glint of the light in the holes, and said, "It looks quality, and when you buy HP you should not only get quality but it should look quality."

The only reason he was looking at a gold-plated board in the first place was because I had not yet developed a solder plating process, and just used gold as a stop gap in order to demonstrate the value of plated-through-hole technology as compared to eyelets. In addition, I had not yet developed a nickel-plating process. As a result, the gold was plated directly over the copper. One of the unintended consequences of this decision was the basically hidden total cost of the gold used. A small number multiplied by a big number can still be a very big number, and, at one time, HP bought one million dollars of gold on the Canadian spot market. In addition, due to the solubility of gold into solder, the solder pots became literal gold mines, and we had "prospectors," before we figured out how to secure them and have the solder sent to a gold reclamation company.

We also had to deal with another more basic issue due to gold on plated boards. The problem was that a relatively small amount of gold in the solder can raise the melting temperature significantly. In addition, gold in the solder can lead to creating more than one intermetallic and contribute to brittleness in the joint. In general, this is not a big issue in a large solder pot, but the solder in a small hole with heavy gold plating can have a much higher percentage of gold. No other company took on this combination of problems in soldering.

To me this was the equivalent of a war on two fronts:

1. Developing a plated-through-hole fabrication process.
2. Developing a process to solder to gold plated boards.

I was doing it alone.

For the soldering issue, the first thing was to find out whether anybody knew how to solder to gold-plated circuit boards. I sent the same letter to three solder companies asking for information on the issue. The first response was just a copy of their catalog; so much for that. The second response was a letter from the chief technologist of the company who wrote, "If anybody is stupid [he really used the word] enough to want to solder to gold they should get out of the business." He then added, "In any case they should learn the fundamentals of soldering documented in the enclosed 'Handbook.'" This turned out to be a 12-page pamphlet purporting to be "all you need to know about soldering." I have never been so angry, before or since. I thought it was a legitimate question and deserved an answer. For example, "We don't recommend soldering to gold," would have worked. I threw the letter and "Handbook" into a wastebasket, then retrieved the letter, tore it up, and threw it back into the wastebasket. I considered taking the wastebasket out to the parking lot and setting fire to it. I did not write to either company to thank them for their help.

The third letter was sent to Alpha Metals. The head of marketing got the letter and, as he told me later, decided something was happening at HP, and they needed to find out about it. He made an appointment, flew to San Francisco, collected the local representative, and came to see me. I explained my problem and, instead of laughing or insulting me, he suggested we look at a new solder that their chief technologist, Howard Manko, had developed and patented. (Howard later contributed five chapters on solders and soldering to the first edition of the Printed Circuits Handbook.) This alloy was also advertised to be less prone to developing dross and made (so they told me) a more consistent joint. In addition, the solder pot did not have to be cleaned and the solder replaced as often as the present alloys. He also suggested we consider a new flux developed by the Battelle Memorial Institute based on uric acid, which was very aggressive and would clear inorganic contaminants from almost any metal being soldered and ensure the solder would only deal with joining metals. This one-two punch sounded almost too good to be true. Instead of the Lone Ranger coming to the rescue, I was now concerned that I was dealing with Professor Harold Hill of "The Music Man," selling me a boys' band. However, it was the only game in town at the time. As a result, I got a purchase order for both and started to try to understand if this was leading me into the assembly process of the future or another HP printed circuit reliability disaster (and unemployment).

The biggest plus, from my point of view, was that there were no HP product designers or production engineers telling me I was making a mistake that imperiled the entire company and offering advice I had to follow up. In this case, however, there might have been a point.

With the strong acid flux, we had no choice but to use a water wash, and a rigorous drying process.

With the strong acid flux, we had no choice but to use a water wash, and a rigorous drying process. The first thing we tried was a Hobart Kitchen-Aid dishwashing machine. We just treated the soldered boards like dirty dinner dishes, and, after the drying cycle, blew the remaining moisture off with an air hose that made very strong dry air blasts. They also made a very high-pitched noise that attracted Bill Hewlett's attention. He felt the operators should not be subjected to that level of white noise, even with ear protection. We had measured the level, but he was adamant.

This resulted in a series of steps to protect the operators and eventually led to the design of an in-line soldering, washing, and drying machine that was quieter than the ambient environment. However, the washing machines did seem to do the job, and, in the interim, we had several. As part of all this, however, I also had to learn a lot about reliability testing. We did not want to be sending time-bombs to the customer.

Given the time it was taking to develop the plated-through process, we had time to debug the soldering process. Fortunately, the Alpha solder and flux actually did the job as advertised. Looking back, I think other solders and fluxes could probably have been successful as well. Given the approaching start of production for the new instruments, however, my priority was to get a process in place, which worked. It took some experimenting to fit it all into our process, but our ability to use a water wash was the key. It also took some time to do the accelerated life testing, but we could see no reliability problem. In addition, we learned how much gold was needed to be an effective etching resist and reduced the gold in the solder joint. The result was a basic process used by HP for decades, until surface-mount technology changed everything. The process was eventually mechanized and automated, but the solder and flux remained the same.

Another unintended consequence concerned the gold plating of the board's connector fingers, without a nickel underplate. This required special mating connectors. All this changed when subsequent process engineers revisited the process. A nickel underplate, with a small gold flash, was substituted for thick gold, and HP stopped buying gold in Canada. Standard connectors could be used, and with all of this, they kept the quality look Dave Packard wanted. **PCB007**

Clyde Coombs is the editor of the *Printed Circuits Handbook,* which was first published in 1967. The seventh edition, published in 2016, was co-edited by Happy Holden, who, like Clyde, retired from HP after many decades.

Real Time with... IPC: New Materials and Additive Manufacturing

Trevor Polidore of Rogers Corporation discusses with I-Connect007 guest editor Tara Dunn the introduction of their new materials for 3D printing. They also look at the trends in materials for additive manufacturing.

Supplier Highlights

Insulectro Presents Power Chats at IPC APEX EXPO 2022

Insulectro presented 13.5-minute power chats in cooperation with DuPont, Isola, InduBond® and EMD Electronics during this year's IPC APEX EXPO at the San Diego Convention Center in January.

Real Time with... IPC APEX EXPO: Burkle Has a Sharper Image

Kurt Palmer, president of Burkle North America, speaks with Editor Nolan Johnson about the latest advancements in imaging and the equipment that Burkle planned to demonstrate at IPC APEX EXPO this year.

Real Time with... IPC APEX EXPO: Taiyo Focuses on Collaboration

Don Monn, Midwest regional sales director at Taiyo America, reviews the progressive adoption of inkjet solder mask technology and comments on how Taiyo's collaborative relationships with suppliers and customers have enabled logistics to be successfully managed through difficult times.

Atotech Presents Four Technical Papers at IPC APEX EXPO

Atotech, a specialty chemicals technology company and leader in advanced electroplating solutions, presented four technical papers at IPC APEX EXPO this year. For Atotech's work on analyzing and improving the crystal structures in plated microvias, our technical paper has been selected as Honorable Mention for the 2022 IPC APEX EXPO Technical Conference.

DuPont Interconnect Solutions Introduces Pyralux HP Laminate Adhesive System at IPC APEX EXPO 2022

DuPont Interconnect Solutions (ICS), a business within the Electronics & Industrial segment, introduced the Pyralux HP laminate adhesive system at IPC APEX EXPO.

Rogers' Shareholders Approve Acquisition by DuPont

Rogers Corporation announced that at a special shareholder meeting, its shareholders voted to approve the previously announced acquisition of Rogers by DuPont de Nemours, Inc.

Gardien Group Now offers Insulation Testing and Micro-Short Detection

We now offer insulation testing and micro-short detection on our flying probe lines running the Gardien FPX software.

Agfa Announces Price Increase for PCB Phototooling Products

Agfa announces a worldwide price increase on all IdeaLINE phototooling films and chemistry used for the production of printed circuit boards and metal structuring applications.

Isola Supports High-Speed Digital Circuits at IPC APEX EXPO 2022

Isola Group, a leading global manufacturer of copper-clad laminates and dielectric prepregs for printed circuit boards, was on hand at IPC APEX EXPO 2022 with examples of its high-performance circuit materials for high-speed digital circuits, including Tachyon 100G and I-Tera MT40 materials.

A Lesson on Automated Optical Shaping

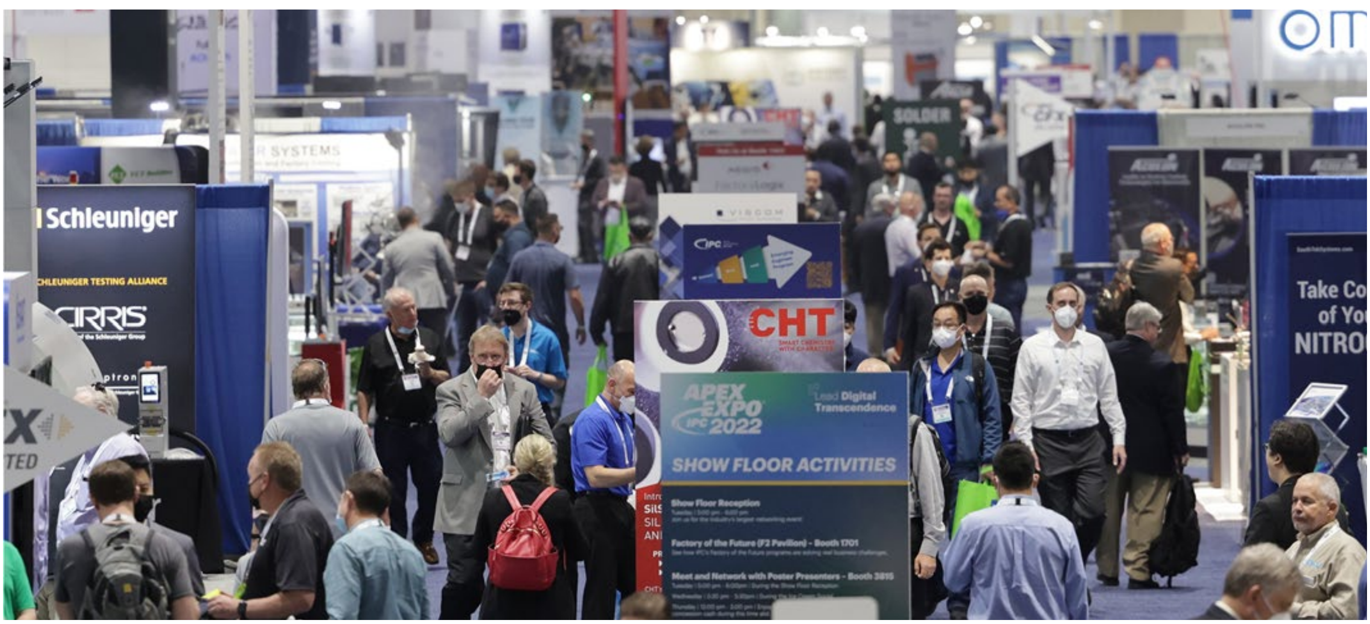
Designers Notebook

by Vern Solberg

IPC APEX-EXPO show and conference was safely back in full swing after skipping 2021. Because my primary interest is printed circuit board and assembly processing, I ventured onto the show floor to review the evolution of some of the systems on exhibit that may contribute to process efficiency and end-product quality. A key benefit of attending a show like this one is that the board and assembly manufacturers can view and compare similar product offerings in one place.

One topic I was most interested in reviewing was the progress made on automated post-etch inspection of circuit board panels used for multilayer circuit boards. High-volume production environments rely on automated inspection to identify defects in the circuit pattern before the lamination process. Several automated inspection system manufacturers on the show floor demonstrated their products' attributes and unique features. Automated optical inspection (AOI) systems use data accessed directly from the circuit board's CAD file and rapidly checked the circuit image on each panel.

The circuit board is the platform that supports and interconnects all component elements that enable the electronic assembly to function. To accommodate the current generations of electronics, the high I/O and very fine-pitch semiconductors simultaneously minimize circuit board size, forcing designers to increase circuit layers and implement finer conductor lines and spaces for interconnect. Fabrication imperfections that occur during imaging and etching stages in the fabrication process, if not identified, may impact the circuit board's functional integrity.



Companies have found that human inspection of the individual circuit layers consumes a significant amount of time, and even with magnification, may not identify all defects on the panel surfaces. When fabricating complex, multi-layer circuit boards, automating image verification on all circuit layers before lamination has proven indispensable. These AOI systems are programmed to identify circuit path irregularities: opens, shorts, or anomalies within the circuit paths that are outside the user-defined tolerance limits.

Companies have found that human inspection of the individual circuit layers consumes a significant amount of time...

I had the pleasure of interviewing Chad Smith, the AOI expert representing Orbotech West. The 35-year-old company is well known for a broad range of products—including automated inspection, direct imaging for defining the PCB circuit pattern, and photoimageable solder mask coatings to precision ink jet printing. The system I found most interesting was identified as an automated optical shaping (AOS) system. This AOS system is unique because it not only locates and identifies the defects in the etched circuit pattern, it has the ability to automatically correct the defects.

As it was explained to me, the key to this process is the company's image acquisition technology where it captures precise images of the defect area, analyzes and compares the defect shape to CAM data used to initially develop the circuit pattern image, and defines where excess copper requires ablation as well as pinpoint the location of interrupted portions of copper conductors that need to be reformed.

Eliminating excess copper, for example, shorts, protrusions, copper splashes, and excessively-sized features, is accomplished using built-in laser ablation technology. The laser reshaping process eliminates the unwanted excess copper, reforming the circuit features to the original profile defined in the CAM file. An example of a copper bridge defect and the result of laser circuit reshaping is compared in Figure 1.

Regarding copper removal, the laser process can provide reshaping down to 25 µm for both copper conductor features and the spacing separating features. As far as copper ablation speed, the manufacturer estimates that the sys-

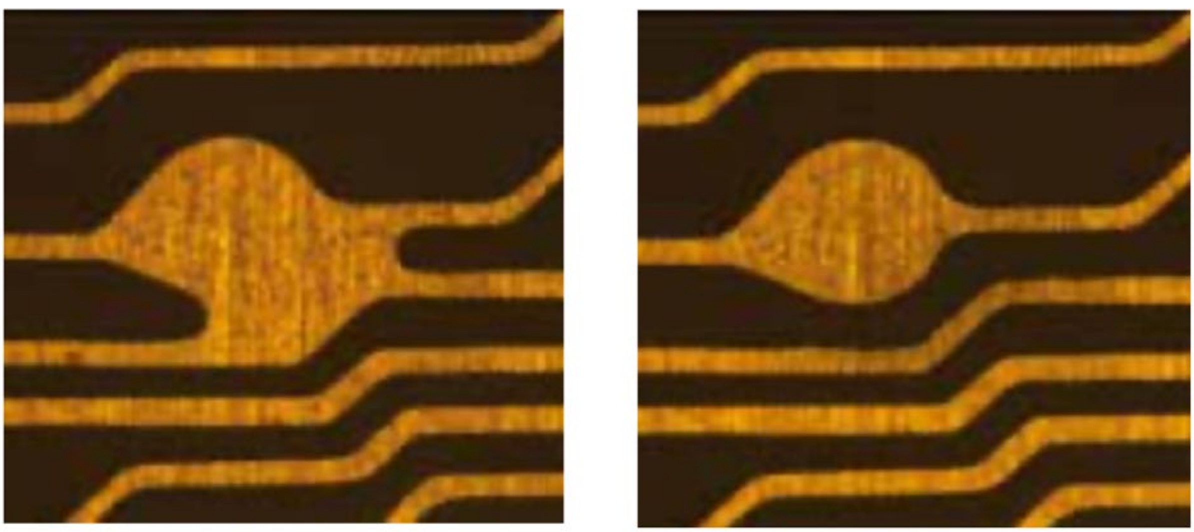


Figure 1: 3D laser ablation enables precise reshaping and elimination of excessive solder.

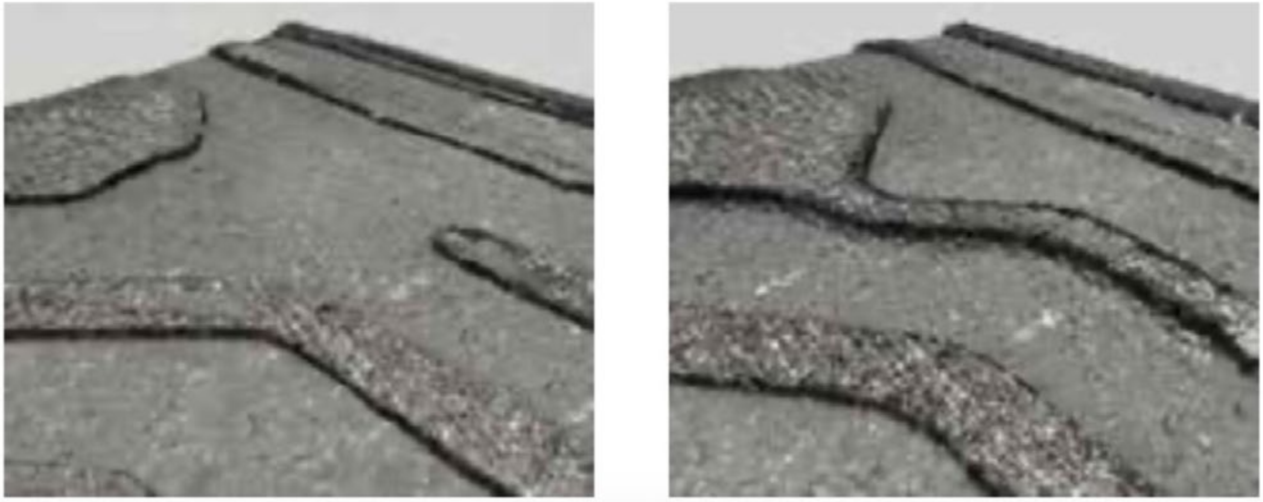


Figure 2: Comparing conductor pattern images before and after 3D copper reshaping.

tem can identify and eliminate up to 80 bridge or short defects per hour.

Rebuilding missing conductors is another form of reshaping. This condition would have commonly forced the fabricator to scrap that portion of the multilayer board set. The capability to add copper to the laminate's surface, however, rescues the panel layer from elimination. To prepare for the additive 3D shaping process the surface area where metallization is to be added is textured. Following preparation, a narrow pattern of molten copper is deposited onto the surface, physically bridging the gap between features, as shown in Figure 2.

The AOS system is designed to accommodate a panel size as large as 24" x 30" (610 mm x 762 mm) and the company states that a single operator can control up to four AOS systems simultaneously, correcting defects, and managing the reshaping process without manual intervention. Additionally, remote image verification capability is offered that will enable the operator to monitor all copper defects and confirm the shaping process completion from a remote computer.

In addition to correcting opens in the circuit path, defect repair may include filling nicks and pinholes in the conductor path and rebuilding shapes impacted by localized over-etching. While conductor width and spacing can be as narrow as 30 µm, large pattern deposition of half-ounce copper is also possible, although limited to an area of 550 µm square. The process time required to restore copper conductors or correct other defects on the FR-4 laminate material's surface is in the range of 30 locations per hour, depending on the conductor's length, width, and specified copper thickness (half- or one-ounce).

Orbotech states that "this system is the world's first one-stop solution that both removes excess copper and precisely restores patterns where copper is missing." The process is said to enable top quality repair of the most advanced PCB designs, including any-layer HDI and complex multilayer circuits. A key objective of the manufacturer in developing this capability was to furnish the circuit board supplier the tools to ensure uncompromised end product quality and minimize delays in fabrication while virtually eliminating waste. **PCB007**

Vern Solberg is an independent technical consultant, specializing in SMT and microelectronics design and manufacturing technology, and an I-Connect007 columnist. To read past columns or contact Solberg, click here.

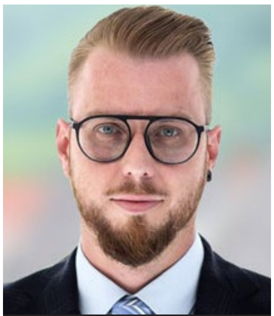
TOP TEN

EDITOR'S PICKS

CES 2022: Half Virtual, Still Valuable, and Here's Why

Another CES has wrapped up, and while not fully back to its glittery self, the show still managed to create quite a buzz in the electronics world. Attendance was about half of its typical 150,000 as hundreds of companies still touted their wares and I'm excited to share with you what I discovered.

Catching Up With RBP Chemical and Schlötter


Matthias Hampel


Ernie Litynski

It's always great to see two very good companies form a mutually beneficial alliance. I was lucky enough to watch this particular strategic partnership come to fruition this year between RBP Chemical and Schlötter. I sat down with Matthias Hampel, global executive representative-PCB and electronics at Schlötter, and Ernest Litynski, president of RBP Chemical Technology, to get the inside story.

Best Technical Papers at IPC APEX EXPO 2022 Selected

The best technical conference papers of IPC APEX EXPO 2022 have been selected. Voted on by members of the IPC APEX EXPO 2022 Technical Program Committee (TPC), the paper authors were recognized during show opening remarks on Tuesday, January 25.

Eltek Names Ron Freund as Chief Financial Officer

Eltek Ltd., a global manufacturer and supplier of technologically advanced solutions in the field of printed circuit boards, announced that its Board of Directors has named Ron Freund as its Chief Financial Officer, effective January 1, 2022.


Ron Freund

IPC: Supply Chain Challenges Continue to Hamper Electronics Production

IPC's January 2022 Economic Outlook report finds that supply chain challenges remain acute and have improved little from the previous month. Shortages continue to hamper production levels and lead times remain long.

U.S. Market Première of Ventec Aerolam Base Material Solutions for Aerospace & Defense Electronics

At IPC APEX EXPO 2022 in San Diego, Ventec International Group Co., Ltd. (6672 TT) premiered 'aerolam' in the US market. A base-material solutions set, aerolam is specifically curated for the diverse and unique requirements of aerospace and defense applications.

Happy Holden's Five Must-Reads of 2021

Over the past year, I-Connect007 has published more than 4,000 news items, nearly 300 articles, and 350 columns from the leading expert voices in the industry. We also have interviewed dozens of fabricators, assemblers, and designers on the most relevant and pressing topics in the ever-evolving PCB industry.

Additive Reality: Green Drops, White Drops or Both: Do Solder Mask and Legend Make a Good Team?

The combination of solder mask printing and legend printing seems an obvious and attractive solution, like bringing chocolate and vanilla together. Still, the gain would rely on obtaining both functionalities without adding complexity. In this column the story continues.

Day 1: It's Show Time!

IPC APEX EXPO officially opens today, and as Crosby, Still and Nash once sang, "It's been a long time coming." The last live IPC APEX EXPO was held two years ago and was—for many of us—the last trade show we would attend before the pandemic hit.

Technology and Development Prospects for the European Marketplace

Nolan Johnson speaks with Tarja Rapala-Virtanen, technical director of the EIPC, who breaks down the current state of the European market and which technologies and market segments are seeing growth.

For the latest news and information, visit **PCB007.com**

Career Opportunities

MacDermid Alpha
ELECTRONICS SOLUTIONS

R&D Scientist III, Orange, CT

Job Description: The scientist will be a leader in technology for plating chemistry development, electrolytes, and additives. The position is hands-on, where the ideal candidate will enjoy creating and testing new aqueous plating processes and materials to meet the most demanding semiconductor applications related to Wafer-Level Packaging and Damascene. The qualified candidate will work as part of the R&D team while interacting with scientists, product management, and application engineers to commercialize new products for the advanced electronic solution business.

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Prototype Engineer, Sawanee, GA

Job Description: The purpose of this position is to provide direct technical and customer support for the Electronic Polymers (EP) product line of the Semiconductor Solutions Group for existing products as well as new and developmental products. The position is responsible for leading the team with customer builds and proof of concept designs directly engaging with customers. The position will lead a variety of technical, customer support, quality, marketing, process, and production related projects.

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KYZEN
Where Science and Care Converge.

Regional Manager
Midwest Region

General Summary: Manages sales of the company's products and services, Electronics and Industrial, within the States of IL, IN & MI. Reports directly to Americas Manager. Collaborates with the Americas Manager to ensure consistent, profitable growth in sales revenues through positive planning, deployment and management of sales reps. Identifies objectives, strategies and action plans to improve short- and long-term sales and earnings for all product lines.

DETAILS OF FUNCTION:
- Develops and maintains strategic partner relationships
- Manages and develops sales reps:
  - Reviews progress of sales performance
  - Provides quarterly results assessments of sales reps' performance
  - Works with sales reps to identify and contact decision-makers
  - Setting growth targets for sales reps
  - Educates sales reps by conducting programs/seminars in the needed areas of knowledge
- Collects customer feedback and market research (products and competitors)
- Coordinates with other company departments to provide superior customer service

QUALIFICATIONS:
- 5-7+ years of related experience in the manufacturing sector or equivalent combination of formal education and experience
- Excellent oral and written communication skills
- Business-to-business sales experience a plus
- Good working knowledge of Microsoft Office Suite and common smart phone apps
- Valid driver's license
- 75-80% regional travel required

To apply, please submit a COVER LETTER and RESUME to: Fernando Rueda, Americas Manager

fernando_rueda@kyzen.com

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Career Opportunities

Career Opportunities

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Career Opportunities

Printed Circuits, a fast-growing printed circuit board fabricator, offers:

- Excellent opportunities for advancement and growth
- Dynamic manufacturing environment
- Excellent health, dental and other benefits
- Annual profit-sharing plan
- Signing bonus
- Additional incentives at the leadership level
- Clean facility with state-of-the-art manufacturing equipment
- Highly collaborative corporate and manufacturing culture that values employee contributions

Laminator Technician

Nature of Duties/Responsibilities

- Layup cover lay
- Layup rigid flex
- Layup multilayer/CU core boards
- Oxide treat/cobra treatment of all layers/CU cores
- Shear flex layer edges
- Rout of machine panel edges and buff
- Remove oxide/cobra treatment (strip panels)
- Serialize panels
- Pre-tac Kapton windows on flex layers (bikini process)
- Layup Kapton bonds
- Prep materials: B-stage, Kapton, release sheet
- Breakdown: flex layers, and caps
- Power scrub: boards, layers, and caps
- Laminate insulators, stiffeners, and heatsinks
- Plasma cleans and dry flex layers B-stage (Dry)
- Booking layers and materials, ready for lamination process
- Other duties as deemed necessary by supervisor

Education/Experience

- High school diploma or GED
- Must be a team player
- Must demonstrate the ability to read and write English and complete simple mathematical equations
- Must be able to follow strict policy and OSHA guidelines
- Must be able to lift 50 lbs
- Must have attention to detail

Wet Process/Plating Technician

Position is 3rd shift (11:00PM to 7:30AM, Sunday through Friday)

Purpose

To carry out departmental activities which result in producing quality product that conforms to customer requirements. To operate and maintain a safe working environment.

Nature of Duties/Responsibilities

- Load and unload electroplating equipment
- Fasten circuit boards to racks and cathode bars
- Immerse work pieces in series of cleaning, plating and rinsing tanks, following timed cycles manually or using hoists
- Carry work pieces between departments through electroplating processes
- Set temperature and maintains proper liquid levels in the plating tanks
- Remove work pieces from racks, and examine work pieces for plating defects, such as nodules, thin plating or burned plating
- Place work pieces on racks to be moved to next operation
- Check completed boards
- Drain solutions from and clean and refill tanks; fill anode baskets as needed
- Remove buildup of plating metal from racks using chemical bath

Education and Experience

- High school diploma or GED required
- Good organizational skills and the ability to follow instructions
- Ability to maintain a regular and reliable attendance record
- Must be able to work independently and learn quickly
- Organized, self-motivated, and action-oriented, with the ability to adapt quickly to new challenges/opportunities
- Prior plating experience a plus

Production Scheduler

Main Responsibilities

- Development and deployment of a level-loaded production plan
- Establish manufacturing plan which results in "best possible" use of resources to maximize asset utilization
- Analyze production capacity of manufacturing processes, equipment and human resource requirements needed to produce required products
- Plan operation manufacturing sequences in weekly time segments utilizing production labor standards
- Maintain, align, and communicate regularly with internal suppliers/customers and customer service on key order metrics as per their requirements
- Frequently compare current and anticipated orders with available inventory and creates replenishment plan
- Maintain master distribution schedule for the assigned facility, revise as needed and alert appropriate staff of schedule changes or delays
- Participate in periodic forecasting meetings
- Lead or participate in planning and status meetings with production, shipping, purchasing, customer service and/or other related departments
- Follow all good manufacturing practices (GMPs)
- Answer company communications, fax, copy and file paperwork

Education and Experience

- High school diploma or GED
- Experience in manufacturing preferred/3 years in scheduling
- Resourceful and good problem-solving skills
- Ability to make high pressure decisions
- Excellent written and verbal communication skills
- Strong computer skills including ERP, Excel, Word, MS Office
- Detailed and meticulous with good organizational skills
- Must be articulate, tactful and professional at all times
- Self-motivated

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Career Opportunities

Manncorp™

SMT Operator
Hatboro, PA

Manncorp, a leader in the electronics assembly industry, is looking for a **surface-mount technology (SMT) operator** to join their growing team in Hatboro, PA!

The **SMT operator** will be part of a collaborative team and operate the latest Manncorp equipment in our brand-new demonstration center.

Duties and Responsibilities:
- Set up and operate automated SMT assembly equipment
- Prepare component kits for manufacturing
- Perform visual inspection of SMT assembly
- Participate in directing the expansion and further development of our SMT capabilities
- Some mechanical assembly of lighting fixtures
- Assist Manncorp sales with customer demos

Requirements and Qualifications:
- Prior experience with SMT equipment or equivalent technical degree preferred; will consider recent graduates or those new to the industry
- Windows computer knowledge required
- Strong mechanical and electrical troubleshooting skills
- Experience programming machinery or demonstrated willingness to learn
- Positive self-starter attitude with a good work ethic
- Ability to work with minimal supervision
- Ability to lift up to 50 lbs. repetitively

We Offer:
- Competitive pay
- Medical and dental insurance
- Retirement fund matching
- Continued training as the industry develops

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Manncorp™

SMT Field Technician
Hatboro, 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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Career Opportunities

Career Opportunities

Career Opportunities

OMRON
SPI AOI AXI

Account Manager
(SPI | AOI | AXI)

Omron Automation Americas is actively seeking an energetic and focused Account Manager to help support our Automated Inspection Solutions product business (SPI, AOI and AXI).

This position is based within any major city covering the Western-US region (including Dallas, Austin, Phoenix and Northern/Southern California). The goal is to work independently and alongside our strong rep. partners in the territory to further expand our business in industries and market segments where we have high potential for continued success and growth.

This is a rare opportunity to join the dynamic team of professionals at Omron and work for a true, industry leader.

To learn more about this exciting role, please contact us directly via:

shawn.arbid@omron.com

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Prototron Circuits

Sales Representatives

Prototron Circuits, a market-leading, quick-turn PCB shop, is looking for sales representatives for all territories.

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- Solid reputation for on-time delivery (99% on-time)
- Excellent quality
- Production quality quick-turn services in as little as 24 hours
- AS9100
- MIL-PRF- 31032
- ITAR
- Global sourcing
- Engineering consultation
- Completely customer focused team

Interested? Let's have a talk.
Call Dan Beaulieu at
207-649-0879
or email to
danbbeaulieu@aol.com

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Career Opportunities

SIEMENS

Siemens EDA
Sr. Applications Engineer

Support consultative sales efforts at world's leading semiconductor and electronic equipment manufacturers. You will be responsible for securing EM Analysis & Simulation technical wins with the industry-leading HyperLynx Analysis product family as part of the Xpedition Enterprise design flow.

Will deliver technical presentations, conduct product demonstrations and benchmarks, and participate in the development of account sales strategies leading to market share gains.

- PCB design competency required
- BEE, MSEE preferred
- Prior experience with Signal Integrity, Power Integrity, EM & SPICE circuit analysis tools
- Experience with HyperLynx, Ansys, Keysight and/or Sigrity
- A minimum of 5 years' hands-on experience with EM Analysis & Simulation, printed circuit board design, engineering technology or similar field
- Moderate domestic travel required
- Possess passion to learn and perform at the cutting edge of technology
- Desire to broaden exposure to the business aspects of the technical design world
- Possess a demonstrated ability to build strong rapport and credibility with customer organizations while maintaining an internal network of contacts
- Enjoy contributing to the success of a phenomenal team

***Qualified applicants will not require employer-sponsored work authorization now or in the future for employment in the United States. Qualified Applicants must be legally authorized for employment in the United States.*

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ARLON
ELECTRONIC MATERIALS

Arlon EMD, located in Rancho Cucamonga, California, is currently interviewing candidates for open positions in:

- **Engineering**
- **Quality**
- **Various Manufacturing**

All interested candidates should contact Arlon's HR department at 909-987-9533 or email resumes to careers.ranch@arlonemd.com.

Arlon is a major manufacturer of specialty high-performance laminate and prepreg materials for use in a wide variety of printed circuit board applications. Arlon specializes in thermoset resin technology, including polyimide, high Tg multifunctional epoxy, and low loss thermoset laminate and prepreg systems. These resin systems are available on a variety of substrates, including woven glass and non-woven aramid. Typical applications for these materials include advanced commercial and military electronics such as avionics, semiconductor testing, heat sink bonding, High Density Interconnect (HDI) and microvia PCBs (i.e. in mobile communication products).

Our facility employs state of the art production equipment engineered to provide cost-effective and flexible manufacturing capacity allowing us to respond quickly to customer requirements while meeting the most stringent quality and tolerance demands. Our manufacturing site is ISO 9001: 2015 registered, and through rigorous quality control practices and commitment to continual improvement, we are dedicated to meeting and exceeding our customers' requirements.

For additional information please visit our website at www.arlonemd.com

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Premier Training & Certification

IPC Instructor

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

Independent contractor, possible full-time employment

Job Description

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

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

Qualifications

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

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

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

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

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U.S. CIRCUIT

Plating Supervisor

Escondido, California-based PCB fabricator U.S. Circuit is now hiring for the position of plating supervisor. Candidate must have a minimum of five years' experience working in a wet process environment. Must have good communication skills, bilingual is a plus. Must have working knowledge of a plating lab and hands-on experience running an electrolytic plating line. Responsibilities include, but are not limited to, scheduling work, enforcing safety rules, scheduling/maintaining equipment and maintenance of records.

Competitive benefits package.
Pay will be commensurate
with experience.

Mail to:
mfariba@uscircuit.com

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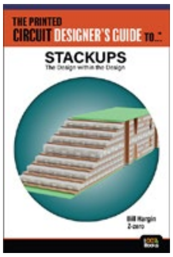
I-007e EDUCATIONAL RESOURCE CENTER

Latest I-007eBooks



The Printed Circuit Designer's Guide to... Stackups: The Design within the Design

by Bill Hargin, Z-zero

Finally, a book about stackups! From material selection and understanding laminate datasheets, to impedance planning, glass weave skew and rigid-flex materials, topic expert Bill Hargin has written a unique book on PCB stackups. **Get yours now!**

The Printed Circuit Designer's Guide to... High Performance Materials

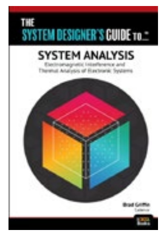
by Michael Gay, Isola

This book provides the reader with a clearer picture of what to know when selecting which material is most desirable for their upcoming products and a solid base for making material selection decisions. **Get your copy now!**

The Systems Designer's Guide to ... System Analysis

by Brad Griffin, Cadence

In this book, the author, Brad Griffin of Cadence, focuses on EM and thermal analysis in the context of data center electronics systems. Be sure to also **download the companion guide** for end-to-end solutions to today's design challenges.

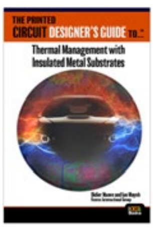


I-007eBooks The Printed Circuit Designer's Guide to...

Thermal Management: A Fabricator's Perspective

by Anaya Vardya, American Standard Circuits

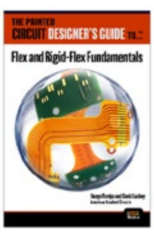
Beat the heat in your designs through thermal management design processes. This book serves as a desk reference on the most current techniques and methods from a PCB fabricator's perspective.



Thermal Management with Insulated Metal Substrates

by Didier Mauve and Ian Mayoh, Ventec International Group

Considering thermal issues in the earliest stages of the design process is critical. This book highlights the need to dissipate heat from electronic devices.



Flex and Rigid-Flex Fundamentals

by Anaya Vardya and David Lackey, American Standard Circuits

Flexible circuits are rapidly becoming a preferred interconnection technology for electronic products. By their intrinsic nature, FPCBs require a good deal more understanding and planning than their rigid PCB counterparts to be assured of first-pass success.

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