Will Modern Additive Manufacturing Revolutionize PCB Manufacturing?

Feature Interview by the I-Connect007 Editorial Team

In this interview, Alex Stepinski of Smart Factory Design delves into the evolving landscape of additive manufacturing technology in PCB fabrication. He highlights the historical shifts in additive and subtractive processes and emphasizes the recent focus on fine patterning and 3D printing. He discusses the challenges faced in achieving fully additive processes, citing past experiences and the need for extensive process control. The conversation also explores the drivers and barriers to adoption, with Alex underscoring the importance of OEM involvement and targeted marketing efforts.

Marcy LaRont: Alex, as high-density PCB requirements move to sub-25 micron features, traditional subtractive PCB processes simply cannot get us there. Let's talk about additive manufacturing technology as it relates to PCB manufacturing: What are its advantages, disadvantages, and costs? Where is the technology headed?

Alex Stepinski: Additive processes have been part of PCB fabrication since the beginning. Industry has basically just vacillated the ratio of subtractive to additive over time.

It changes based on production and process strategies. As always, there is the consideration of how to get where you need to be technologically, with reliability, and with the equipment you already have. Historically, companies have approached their manufacturing differently. Some companies were all panel plating. Some companies were all pattern plating, and some were a mix of the two. Today, you have a synthesis of both.

Recent discussions around additive have focused on very fine patterning, which forces

Alex Stepinski

a higher ratio of additive plating than historically has been commonly experienced in the market. The other aspect is 3D printing, an additive method that's been growing in recent years. We started talking about solder mask 20 years ago. Finally, some companies are leading the way in advanced 3D printing of solder mask.

Now, we are also starting to see additive in materials in conductive and dielectric layers. There are a host of different additive processing methods being applied today. There is still a lot of due diligence that needs to be done. In 2013, I helped build the first additive factory globally. It was 100% inkjet for resists and solder mask. No one has done a fully additive facility since that time. It worked very well for low-tech products. The challenge was that the process window was very small and required a lot of customization. Unfortunately, that inkjet supplier went out of business years later because nobody else could hold the process window that tightly without an inline process like ours.

To really have a fully additive process, and not just 3D printing, you need a lot of process control that we don't generally have in the market.

Barry Matties: It seems like you are describing a process engineer, someone who pays close attention to monitoring and controlling processes. Do you see a lack of process engineers?

What I am talking about with the additive factory example is a case study from 10 years ago. A lot of process development was needed to identify the process control specifications. Once that was done, we were able to hold the specifications without significant supervision. Unfortunately, a lot of what we learned back then relative to additive is lost knowledge. From what I've seen in the market, people are relearning many of those lessons now. Adoption is still in its infancy, but I am happy to see it finally picking up.

In addition to inkjet solder mask, there are electrochemical methods for 3D printing. One is a light-based system known as laser-induced forward thrust (LIFT). This was from a company in Israel that was printing with a laser. They would coat material on a carrier and hit it from the backside with a laser, which determines the resolution and volume of the drop. The smaller the spot size in the laser, the higher the resolution. Lasers are fast. This same gentleman invented a copper additive process for the company he worked for at the time. He was interested in the board fab side of things but the barriers to entry were too high. So much material science still needs to be developed.

So, there is the material aspect, the specification aspect, and the communication plan to educate customers that the product will look a little different than the product manufactured through the traditional subtractive processes. But potentially, there are so many gains. The pluses far outweigh the minuses.

Matties: Inkjet technology is where this is going.

The actual board buildup is more complicated, but yes.

***Matties:** Alex, who's driving this? Will it be a customer, the OEM that comes in and tells the fabricator they want additive? Or will it be the technology itself that drives it?*

You need a large corporate player or a consortium of players driving it who are really committed to making it work for it to become more pervasive within PCB manufacturing. There needs to be a concerted effort and broader interest in it happening.

I can say that every major OEM I have worked with in the past two years has adopted solder mask 3D printing technology. They do it for various reasons, whether it's thickness control, the ability to have a very dynamic service condition to put extra mask in some places and make things really flat, or just willingness to take the risk to avoid the traditional process. With conventional coating processes, the flatness is a reflection of the underlying topography of the surface, so you're just conforming. With 3D printing, you can fill and compensate as well. You can put extra mask in certain places, and the same can be true with dielectric materials. You can build dielectrics this way. There is probably the most industry support right now for inkjet solder masks as an additive process.

***Matties:** From the supplier side, who advocates for this technology the most?*

So far, the push is primarily from the equipment manufacturers. The ink manufacturers have to adopt it because it's starting to get traction. They've been holding back on it because they sell less ink.

The PCB shops look and see 100 qualifications they have to do, which doesn't excite them. What excites them is the simplicity of the mask process. In some PCB shops, if they didn't have to do the qualifications, they'd be thrilled to adopt it. But the qualifications are a challenge. For others, the very traditional mindset of the industry is a barrier. We like to hang on to the same specs for 30 years.

***Matties:** Regarding the qualifications, since the customer has to approve new materials, the fabricator needs to show some substantial gain to undertake that endeavor. The board winds up with solder mask either way.*

Absolutely, and the fabricator is the wrong person to push this change. PCB shops are job shops. They build the spec, they don't define them. It is the people who define the specs who need to see what the trade space is, who can then see what they gain by going in this direction. Lithography is crisp and clean. There is more variation in inkjet, but does it really matter? With 3D printing, you have excellent registration and a better profile for assembly. It is a different animal.

When I talk to OEMs, I tell them, "You can change the thickness. You can have better dielectric and control of electrical properties, potentially some mechanical benefits depending on how they're set up for assembly, and things like that. If OEMs understood, the technology would be adopted much more quickly.

LaRont: What about the pretreatment of material for the 3D printing process?

That is an interesting area as well. Recently, we have seen more chemical suppliers with chemistry that pretreats the material surface before you put down the ink.

But what is most interesting is the prospect of using the inkjet as a coater, replacing the whole coating process with 3D printing technology as an initial step, while continuing to use direct imaging lithography. The 3D printer will coat nicely and do a better job at managing thickness. It can replace one of the dirtiest processes we have with a sustainable technology. If you use it as a coater, the qualification challenges go away.

Matties: Another huge benefit on the fabricator side is they are getting rid of many process steps.

The fabricators want it. It's the qualification approvals that are stopping it. This is the first logical step. If I were to make a marketing plan for this, I would first try to sell our 3D printing coater as a replacement for the existing coater, which doesn't need half the controls as the one that makes a pattern. That way, you can get the solder masks mass qualified. You can formulate the mask for blanket coating. The next step is pattern printing. You do it in two steps. Don't try to eat the elephant in one bite.

Matties: I like that. Coat, image, and mask is the order of priority. Other than solder mask technology, are there other additive processes that you see developing?

3D printing is a big topic, but there is also additive plating, which is talked about a lot. In that, they are trying to use very thin seed layers, or even trying to sputter-direct. They start with bare laminate, or they etch off the copper and build it back up, making their own seed layers. Creating substrates through this process is the source of some of the largest yield challenges. There are a whole host of different, leading-edge processes that are available for substrate build-up.

Right now, I believe the truly leading edge is more on the dry side, outgassing the surface, kissing it with the plasma treatment, then putting down metals—copper or copper and titanium. It's a very controlled process. It's always cheaper to do wet process, and you still can with defense and aerospace. But with the high price and low risk tolerance of military products, the dry process is a better choice. People are exploring this trade space. There is a lot of push to develop both wet and dry, but as of today, I'd say the dry side is very slightly ahead. There's a lot developed in both directions.

Matties: What makes building up substrates so challenging?

Just think about it compared to a regular circuit board. Historically, with conventional circuit board manufacturing, we just metallized bare dielectrics in the holes; whether it's a through-hole or microvia, it's a hole. The holes are an order of magnitude larger than the feature sizes. Typically, on the leading-edge substrates, you will have to use full SAP and similar processes. As a result, people are learning about the fluid dynamics of dealing with the whole surface of a circuit board. You end up with defects here and there. Whether the

defects are outgassing of the dielectric—which can redeposit in places and show "puddling"—or some kind of mechanical damage at a microscopic level, it's all visible. When we were just plating holes, we simply looked to see whether the light was coming through, or if the bottom of the microvia was okay. Now, we must look at a huge surface area, and that surface area is a whole different animal.

Controlling the outgassing is important. You have to clean out the surface. There's so much solvent that can come out that you need different methods for cleaning. One supplier who is sputtering uses a nitrogen blanket with laminar flow, which sweeps the solvent away. Another supplier uses a vacuum to extract it, but a vacuum can redeposit solvent on the surface. We even have outgassing problems with some materials just doing epoxy via fill in holes, never mind fully exposed surfaces.

For a problem like outgassing, you now take that and magnify it times 10 because you're looking at the whole surface of the panel. Then you magnify it another 10 times because of the density of the features on the substrates. Then you probably need to add yet another factor of 10 for other issues. So, you have a few orders of magnitude higher complexity. Yield issues typically have to do with this topic.

LaRont: Do you see significant adoption by U.S. PCB fabricators over the next decade?

We will see more of it. From a sustainability standpoint, it is the way the world should want us to go. The OEM PCB fab shops have been much keener at adopting this and they push their suppliers. Whenever an OEM gets involved, it's a good thing, whether it's putting up their own captive shop, or working with the supplier to develop specifications. The OEM is going to drive the adoption rate.

I would say the ideal situation is to take a company/supplier that is currently considered a leader for inkjet printing equipment and combine that with an ink supplier, and then combine that with some solid OEM marketing, and make that a new company. That is the type of organization that will be the most capital-efficient at driving technology adoption in the market. The current ecosystem is very slow because you don't have this unified push across all the channels and it's debatable right now as to which way it will go. The technology is developing. The issue is partnering to maximize efficiency. I think the suppliers have the resources in place to do a good job. It is just that the partnership is missing.

LaRont: Who is talking to the OEMs about this?

That's a good question.

Matties: Inkjet suppliers on the equipment side have a vested interest in getting the OEMs to spec or qualify the material, especially the solder mask, but I like your approach. Start with coating.

Walk before you run. I believe the ink suppliers are also talking to the OEMs. I just wonder if it's not a little disjointed because there's not enough fabricator involvement. You need to give the OEM a full analysis of every single benefit, throughout the whole process, and then work with them directly on implementation.

LaRont: Alex, what about standards for these new technologies and processes? Do you see a significant role for IPC or another group in pushing this technology forward through standards?

IPC is a bit like a governing entity. I don't believe they are the right group to be pushing it, but they should help facilitate it. The standards come out through input from all the stakeholders. We are still very early in the development stages. Standards usually arrive when the products are more mature.

Matties: That's true. We just conducted an interview about in-mold electronics (IME). Standards are already being developed, but the auto industry is pushing for it.

If OEMs don't push it, it doesn't happen.

LaRont: Thank you, Alex, for helping us understand this better.

You're welcome. **PCB007**