Microvia Fabrication: When to Drill, When to Blast!

Sportsphoto Ltd/Allstar/LucasFilm 1977.

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SUMMARY: As today's designs become increasingly dense, PCB fabricators' capabilities are tested—especially when drilling for microvias. By using DFM rules, fabricators can match the best method of manufacturing with the type of microvia being incorporated into a PCB design. Moreover, many fabricators will be surprised to find out which capabilities they may already have in-house, versus those that need to be outsourced.

Early into 2013, PCB shipments showed double-digit decreases. With this in mind, board houses have a choice: Either batten down the hatches and wait for the storm to settle, or innovate and enter into new markets to increase sales. One market that is often avoided by North American board houses is the microvia market, which includes through, buried, and blind microvias. This market is often regarded as a pay-to-play segment, where barriers to entry include the cost of engineering and perceived equipment needs. It is possible to dispel some of these myths by doing an in-depth analysis of the via formation process.

Best-practice methods for PCB via fabrication are as varied as the definition of the microvia. All things considered, the best practice is to consult the design rules when determining each via type's optimal drilling method.

While there is no set definition for microvia, the industry primarily considers these to be drilled holes with diameters of 0.012" or less.

Moreover, there are three primary subsets of this term in PCB designs:

- **Through via:** Traverses from top layer of PCB through to bottom layer
- **Blind via:** Starts at outer layer and ends at inner one
- **Buried via:** Begins and ends at inner layers only (not visible from exterior)

Because they use very similar mechanical drilling processes, through and buried vias are simpler to fabricate as they utilize mechanical drilling.

Mechanical Drilling

Mechanical drilling is the most prevalent method used for via formation; nevertheless, most fabricators are only confident to drill down to 8 mil diameter vias.

I created my own false glass floor when a customer requested a 3 mil through via in a multilayer flex board based on my supplier's feedback.

In questioning a supplier on an application in which we had to drill a 3 mil through via in a multilayer flex board, I was told that we need to have 220k-280k RPM spindles in order to drill such a small hole. Buying a new high-end drilling machine for a single project was completely out of the question. At that point, we could have rejected the order, but my Wildcat Crew at Saturn Flex doesn't do things that way. After a few cold ones, we figured that this guy didn't know his poo, and that as long as we held the chipload on his recommended parameters, we should theoretically be able to drill using our 125k RPM spindles. Since then we've successfully drilled and plated over half a million 3 mil through vias. Lesson: don't listen to people who don't have the same at stake as you do.

With that lesson learned, we further experimented to identify the limits of mechanical drilling and came up with the following design rules, along with a rationale for each. I'm sure that these can be tweaked from shop to shop based on experience, type of machines, and required process flows, but they should prove to be a good start.

Mechanical Drilling – Through Holes

Let's start with through-hole drilling, which will cover through vias as well as standard (not stacked) buried vias. As we try to achieve smaller and smaller diameters, materials selection and operating parameters become increasingly more important as the processing window is much smaller. (This topic could be an article all to itself, so we will just cover it from a 10,000-foot overview.)

First, we must consider drill bits and their operating parameters. Personally, I am not a fan of using a "one size fits all" strategy when it comes to feeds and speeds for different brands of drill bits. If your facility shops around between drill bit vendors based on price, then you should reconsider your strategy—at least for microvias. It's best to partner with a quality drill bit supplier who has proper technical support to help you dial in feeds and speeds based on their drill bit geometries and your material characteristics (material type, cure level, machine type, etc.).

Next, we should look at the type of entry and backup material being used on either side of the PCB production panel. Most shops use standard 7 mil aluminum entry and techboard backup because they are the cheapest and most readily available materials in the market. While cost-effective, these materials do have their drawbacks when it comes to microvia formation.

Aluminum entry provides for a hard surface for first contact of the drill bit, making the drilled via location prone to "drill walk." Drill walk is basically just what it sounds like—the tip of the drill bit slides along the surface before grabbing material and drilling through. The end result is that the true position of the hole can vary from hole to hole, potentially causing violations of IPC Class II and III standards for annular ring. In extreme cases, this can contrib-

Figure 1: Standard aluminum entry.

Figure 2: Bullseye entry.

ute to drill breakage, which requires scrapping the product since it is too difficult to manually remove a broken microvia bit from a hole and redrill. We've used a product from Insulectro/LCOA, called Bullseye, to remedy this condition. Essentially it is 3 mil aluminum coated on one side with what appears to be a modified soldermask, although I'm sure it's something much more complex to justify what they charge for this stuff. The mechanism by which this entry works is fairly simple. The coating on the surface is soft and almost tacky, so that once the drill bit makes contact, the drill tip is held to center and panel penetration is as vertical as possible. This results in the holes being much closer to true center.

Techboard backup is made up of wood fiber held together by adhesive. When drilled into, it breaks up into larger chunks of wood fiber that are then pulled up into the hole through the flutes of the drill bit. The adhesives used in the techboard make these chunks of material prone to impaction into the side wall of the hole, or plug the hole entirely. Often, even the most robust hole cleaning systems that incorporate high pressure water spray and ultrasonics cannot remove this debris, resulting in via failures. Thankfully, the industry offers a variety of solutions. Suppliers such as Dosco, Tapco, and Insulectro (among others) offer premium backup materials that use pressed virgin fiber with a melamine coating. Some products such as LCOA's Slickback and Dosco's PinkBoard incorporate a lubricant underneath the melamine coating to cool drill bits, further improving via quality. The melamine coating provides a hard surface against the exit point of the drill bit to minimize burring. Instead of breaking up into large chunks of material, the virgin pressed fiber almost explodes into a very fine powder that is easily evacuated by the drilling machine's vacuum system through the flutes of the drill bit. While significantly more expensive than standard techboard, they more than pay for themselves through the avoidance of scrapped, high-end product.

Blind Vias

Due to the complexity and myriad types (low-aspect ratio blinds, stacked blind/buried, sequentially-laminated blinds) blind vias pose a much more complicated build.

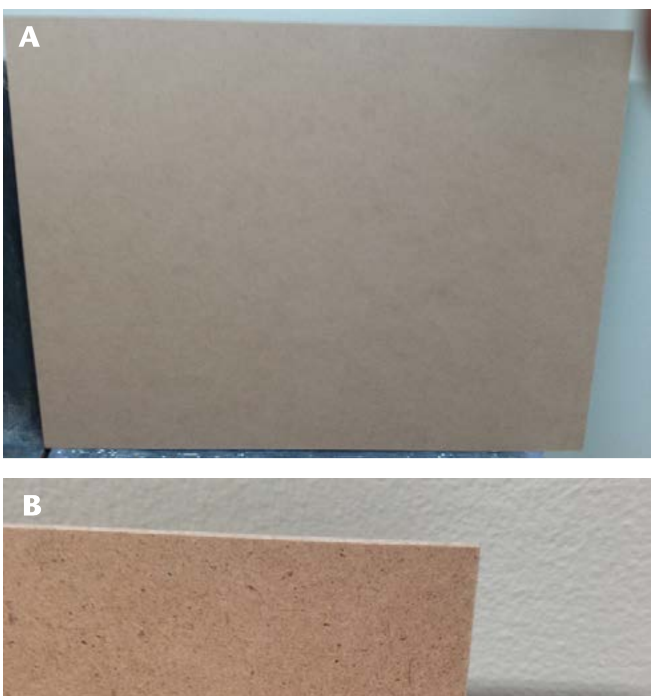

Figure 3, a and b: Standard techboard.

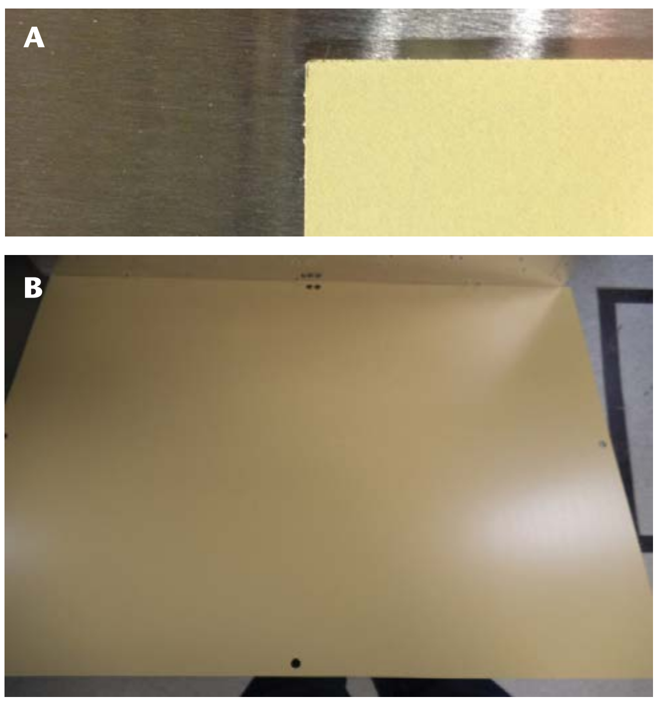

Figure 4, a and b: Spectrum gold board.

These include:

- Low aspect ratio blinds: Typically these are less than a 1:1 depth-to-diameter (aspect) ratio, most often found in HDI PCB designs and only traversing 1-2 layers. These are best formed using a controlled depth drilling (mechanical or laser) process.
- Stacked blind/buried vias: These also are typically less than a 1:1 aspect ratio for each individual hole, but are stacked on top of each other to achieve a higher aspect ratio blind via that traverses multiple layers.
- Sequentially laminated blind vias: These are typically greater than 1:1 aspect ratio and traverse multiple layers.

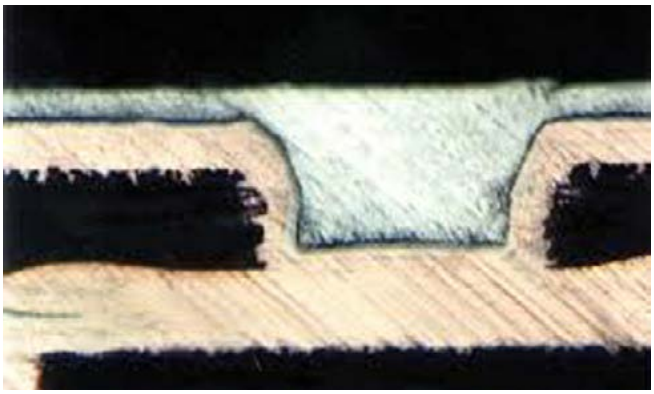

Figure 5: Low aspect ratio blinds.

Figure 6: Stacked vias.

When determining the best method for fabricating various vias, most fabricators simply delineate between laser drilling low aspect/stacked vias and mechanically drilling everything else. Unfortunately, utilizing a laser drill requires either a large (>$500k) up-front equipment investment, or outsourcing to a third party for this process, which adds lead time and cost. I would propose utilizing design rules to differentiate vias that are suited for mechanical vs. laser drilling. Let's explore each of these methods individually with respect to design rules, pros, and cons.

Mechanical Drilling – Blind Vias

Advances in drill bit manufacturing have resulted in numerous offerings from drill bit suppliers in terms of a variety of drilling geometries and diameters. Most suppliers offer drill bits down to 2-3 mils in diameters with tight length and diameter tolerances, which covers most, if not all, PCB designs with blind vias.

In order to utilize mechanical drilling for blind vias effectively, we must first determine the design rules for your shop. By design rule, I mean the maximum aspect ratio that your machines are able to hold. The primary machine characteristic is the Z-axis tolerance that the machine is able to hold. For purposes of this article, we are going to rely on published tolerances from the machine manufacturers, although it is best to run a capability study on your machines to identify the true Z-axis toler-

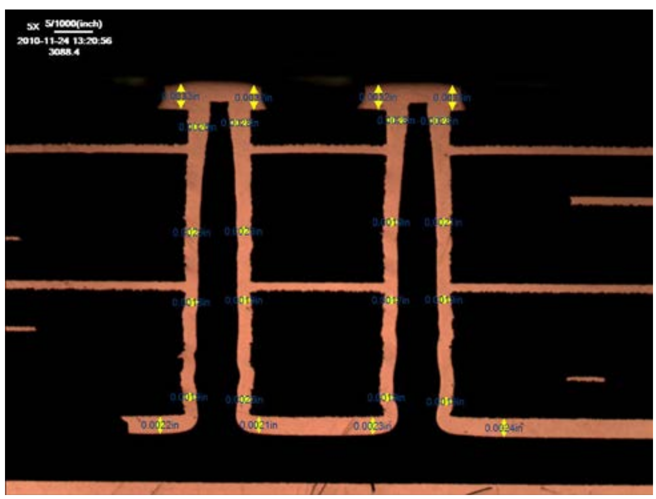

Figure 7: Sequentially laminated blinds.

ance your machine is capable of holding.

In general, most of the older machines such as the Excellon System 2000 and Century 2001 systems can hold a Z-axis tolerance of +/- 0.002". Newer machines such as the Schmoll and Mania equipment that we use utilize surface contact drilling systems and linear Z-axis scales that are capable of holding +/- 0.0005". Assuming your plating setup is ideal, as described in Built Board Tough (*The PCB Magazine,* January, 2013), you can expect to be able to plate to a 1:1 aspect ratio. To build in a buffer for drilling machines' Z-axis tolerance, I use an aspect ratio of 0.8:1 for vias down to 4 mils as my design rule. We sometimes push this to 0.9:1 for larger diameters and have had success in production volumes.

As we can see in Figures 8 and 9, mechanically drilled blind vias look much different than laser drilled blind vias due to this Z-axis depth tolerance.

Another drawback of mechanically drilling is that most mechanical drills do not have inner layer X-ray or vision systems. However, there are tricks to getting around this. Most shops do have X-rays to view through-hole to inner layer alignment to determine proper scale and shift of the drill file to optimize registration. If there are no through-holes in the PCB, you can still utilize coupons and through holes to determine proper position settings for the blind via drill program. Getting the secondary side blind vias to register to the primary side blinds (and through-holes if they are in the design) requires another trick.

I utilized a coupon that features a through-hole in the center that is drilled along with the primary side blind vias. Before we drill the secondary side blind vias, we drill four blinds around the through-hole and use a piece of artwork to verify registration, as described in the diagram below. You can then adjust the X/Y datum to optimize the blind via registration to the through-hole and primary blind vias. It's simple, but very effective and removes image registration issues in downstream processing.

In summary, I would argue that mechanical drilling is a far superior method for heart-of-the-range blind via designs. Not only is the cost per hole lower, but the hole quality is better due to a wider process window in dealing with a variety of stackups/materials.

Laser Drilling

Personally, my general rule of thumb is to use laser drilling only for blind vias, which is what it is conventionally used for. However, we received

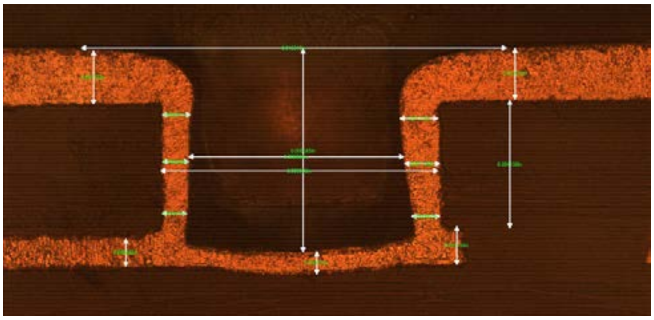

Figure 8: Mechanical blind — overshoot.

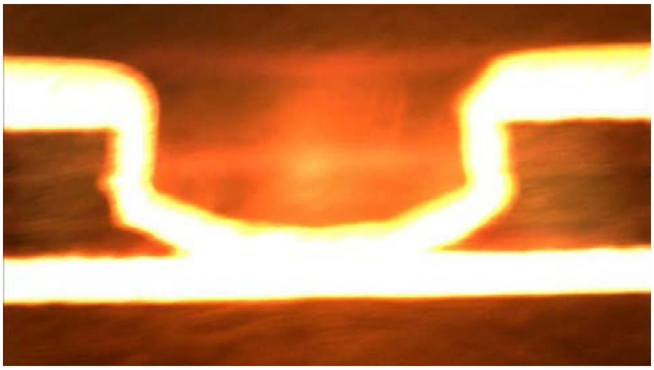

Figure 9: Mechanical blind — undershoot.

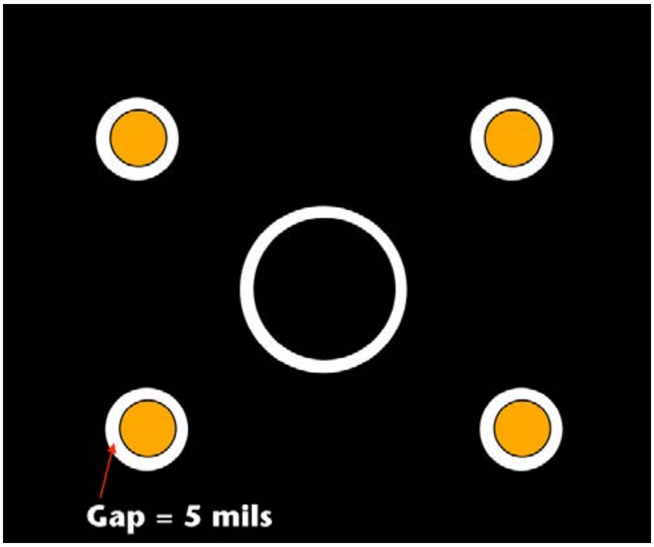

Figure 10: Blind via registration coupon.

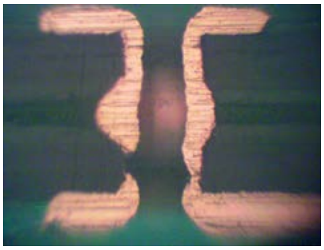

Figure 11: Laser through via, partially plated.

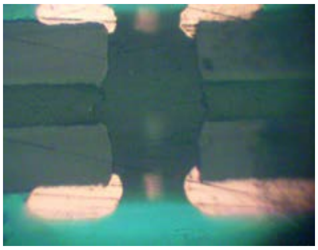

Figure 12: Laser through via, non-plated.

a project that required 3 mil through vias in a flex multilayer package (see "Mechanical Drilling" section) and based on the supplier's feedback, we did not think we could drill these mechanically. Our engineers figured that under tight operating controls we could achieve through vias successfully using a laser drill. Unfortunately, the results didn't match up to our dreams and we experienced a 100% fallout in that production run, lost about $30k in premiums, and never again uttered the words "laser through-hole."

As you can see from these rough sections, the laser ablated the different materials in this flex cap core construction differently. The middle adhesive portion was much more affected than the core portions, making the through hole after plating pretty much resemble my figure. Needless to say, this wasn't the best application for a laser drill, proving mechanical drilling to be the best option.

Now, back to blind vias. I'm a huge supporter of using mechanical drilling to create blinds, but only under the proper conditions that meet my design rules. My design rules for using a laser drill to create blind vias include:

1. Aspect ratio is 0.9:1 to 1:1
2. Blind via diameter is less than 3 mils

Aspect Ratio

Your design rule for aspect ratio should be adjusted based on the Z-axis tolerance of your mechanical drill. The laser can hold a much tighter aspect ratio because it is not prone to over drilling. The reason is that, at least in our Excellon Cobra Hybrid laser, it uses a YAG laser to ablate the surface copper, and a CO_2 laser to ablate the dielectric. CO_2 is very efficient at ablating through dielectric, but isn't able to ablate through the copper (at the wavelengths at which we are using it). As such, the via will terminate exactly at the target copper layer without risk of ablating through. The only thing you have to worry about is having enough power applied to ablate all the way through the dielectric to prevent under-drilling the via and not making contact to the target copper layer.

Blind Via Diameter

There's not much else I can say about why I choose not to mechanically drill less than 3 mil blinds other than I've been too much of a wimp to try it out. Also, in defense of my manlihood, most designs with blind vias less than 3 mils in diameter are also pushing the 1:1 aspect ratio, which would fall into my laser design rules.

That being said, getting into laser drilling forces you to hurdle significant barriers to entry. Not only is the machine relatively expensive at over $500k, it requires a significant amount of process engineering to design laser recipes to ablate through various combinations of dielectrics and via diameters. Fortunately, there are outside services such as Micron Laser in Washington that enable a fabricator to dip their toe in this technology without adding financial risk to their organization.

Conclusion

I hope that I've dispelled the industry myth that the microvia portion of the PCB market is a pay-to-play segment. Not only are mechanical drills more than capable of creating blind vias, they are used at most PCB fabricators' facilities. If your design rules require the use of a laser drill, laser drilling services are available to provide a buffer for you to grow your business before you commit capital and resources to bringing this technology in-house. **PCB**

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