Improving Yield and Profitability with Laser Drilled Blind Microvias

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Abstract
Laser drilling has clearly captured the technology lead in the formation of HDI microvias with a 78% ownership,[1] currently dominating over photo defined, plasma etched and mechanically drilled methods. Processing speeds are now cutting the costs for laser drilled blind microvias to a level where more and more OEM's are considering microvias as an alternative to further fine line technology with its inherent yield issues. This paper will review the critical elements of microvia processing technology in an overview and focus on the elements that improve yield in laser drilling. Further, some simple suggestions will be offered to help control and improve yields of laser drilled blind microvias.

Introduction

There is excellent data available on the overall process yield (as opposed to yield data on sequential steps) of microvia technology on IPC sponsored work [IPC D-36 Subcommittee titled "Printed Board Process Capability, Quality, and Relative Reliability (PCQR[2]) Benchmark Test Standard"] on the web site of Conductor Analysis Technologies, Inc., (CAT) at www.cat-test.info. However, none of this data points to the source of microvia failures, which typically results from one or a combination of the following.

1. Design – appropriate metallic surfaces to eliminate breakout at the bounce pad.
2. Alignment - material movement in lamination or incorrect scaling.
3. Laser drilling – correct energy, beam alignment, "bounce pad" alignment and design.
4. Cleaning – proper removal of debris and materials left at the bottom of the blind microvia.
5. Plating – good throwing electrolytic copper after proper metallization of via walls.

Designing Blind Microvias

Blind microvia design rules generally are forced to comply with the registration efficiencies and plating capabilities of an individual circuit board fabricator. As a general rule a 1:1 aspect ratio is recommended where the opening of the microvia is equal to or greater than the depth of the dielectric plus copper clad material. Most fabricators of circuit boards already work with the knowledge of what design features they can achieve from years of drilling mechanical holes and therefore know what is needed at the design or CAM for managing material and filmwork movement, limiting breakout and what size bounce pads are necessary.

When using a laser drilling system that is not capable of removing copper, such as the most common laser used in the circuit board industry today, the carbon dioxide or CO_2 laser drilling systems, the circuit board design must include a data output to locate and chemically etch openings in the outer layer of clad copper. The alignment of these etched reliefs or "etched windows" as they are often called is critical for high yield. Alignment fiducials are typically added into the four corners of the panel and etched along with the windows. The laser system can then optically align and scale the image for accurate delivery of the laser beam into the center of each etched window.

Figures 1 and 2 above depict the areas of concern that need to be defined in order to maximize the yield of laser drilled blind microvias at both the design and CAM entry before the panel and boards are fabricated. A variable depth interconnect can be used to interconnect inner layers or all three outer layers. A "donut" must be designed and etched on the internal layer that lines up with the outer etched window and bounce pad.

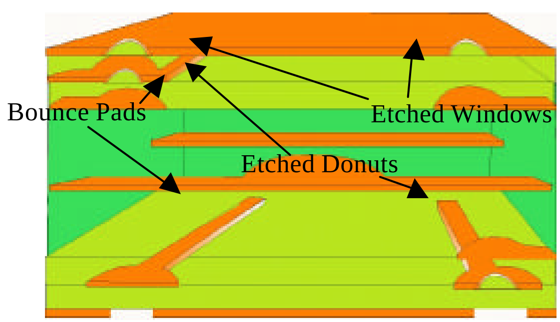

Figure 1 - Pre-Laser Drilled Lay-up

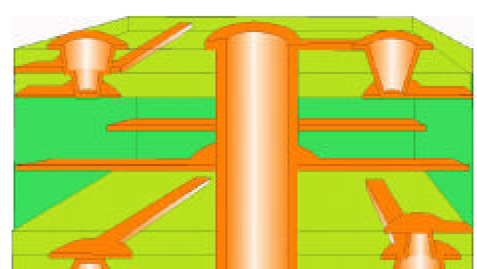
Figure 2 - Variable Depth Plated Microvias

There are some proven conditions that will help move toward single digit dppm. These start at the design level. Higher yields were found in tests done by CAT where 100µm (4 mil) vias with 250µm (10 mil) lands were used.[2]

Alignment of Material or Etched Feature

There are methods for "skiving down" into the dielectric material to find buried fiducials using an Ultraviolet (UV) Nd:YAG or Nd:YLF laser system to accurately remove the copper clad surface and carefully locate the image on the second or third layer. This method is only useful when used to locate to one level in the panel; that is when multiple layers are miss-aligned, finding their location will not solve this Z-axis alignment issue. The only solution is to make sure the layers are properly scaled at the CAM design station so that they align for both laser drilling and mechanical drilling, allowing appropriate annular rings on each layer.

Tests done by CAT have defined that a 75µm (3 mil) annular ring is sufficient in most microvia design cases to keep breakout to a minimum.[2] Enlarging the annular ring on a microvia pad (surface, intermediate or bounce) to 100 µm (4 mil) can further insure even higher yields.

Another effective method for improving alignment issues is to use an X-Ray to locate and drill tooling holes for achieving more accurate filmwork alignment when "windows" are etched in the outer clad copper for creating a conformal mask that is typically used with the Infrared (IR) or CO_2 laser system.

The authors suggest and encourage the suppliers of the newly introduced Direct Imaging Lasers (DIL) to further improve alignment for etching windows by incorporating an X-Ray for assisting the image alignment before etching on solid copper clad panels.

While very little data is available for targeting the failure mechanisms in blind microvia fabrication, much work has been done at the alignment step to distinguish this step as a major contributor to poor yields.[2] Cross-sectioning is one sure method for defining the failure mechanism which can readily show miss-alignment. However, that is normally done after the panel has been plated so that a conductivity test like bed-of-nails testing can help locate a failure site.

The photomicrograph in Figure 3 above shows a laser drilled blind microvia after plating that fully missed the bounce pad. This could be a design flaw, significant material movement, or most likely a misplaced etched window.

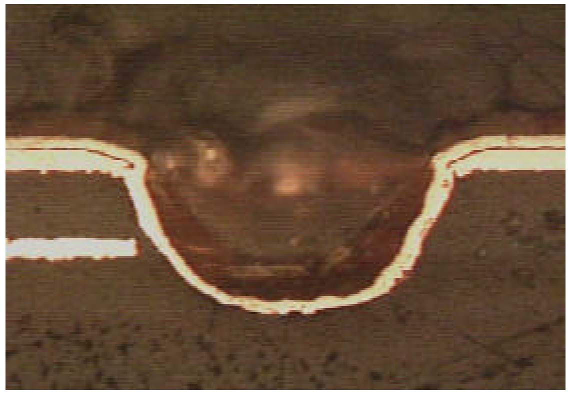

Figure 3 - Miss-Alignment Cross-Section After Plating

Laser Drilling a Blind Microvia

There are only a couple of areas for potential defects in the laser drilling process that can cause poor yields. Some assumed laser drilling defects are not always due to a blunder of the laser system but in many cases can be the results of a poor design or poor tooling at the CAM workstation. The Figure 4 shows some of these conditions.

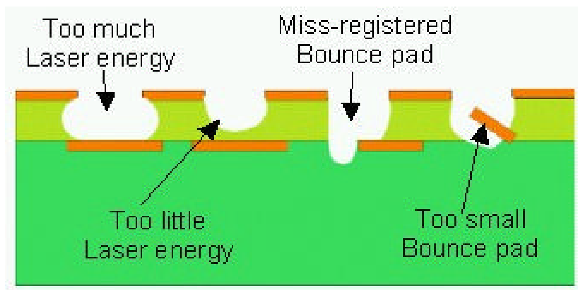

Figure 4 - Defects From Poor Laser Drilling, Poor Material Handling Or Design

Material movement, which typically is an outcome in the lamination of the innerlayers under heat and pressure, is typically taken into account at the CAM workstation at the order entry. A good CAD/CAM operator should be able to calculate and predict the movement of the material and adjust the placement of the etched windows over the buried pins or pads on subsequent layers.

Ideally there is enough pad surface with annular ring so that the laser drilling through the etched window can have some latitude and still completely hit the bounce pad. (See Figure 5.)

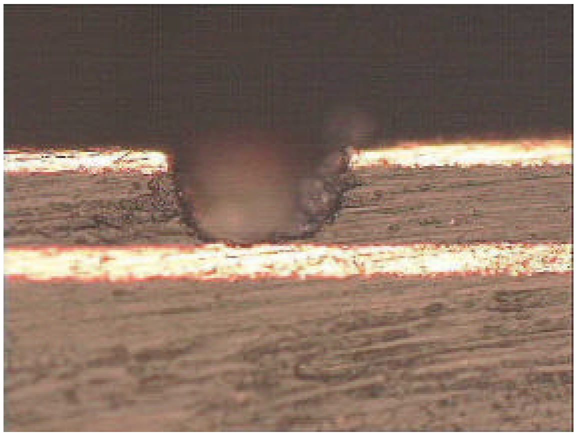

Figure 5 - Cleanly Drilled With Taper Via Wall

There has been some suggestion that the foot at the bottom of the typical CO_2 laser drilled blind via leaves too much material and must be removed with cleaning. The fact is that the more gentle the angle flowing into the pad the less stressful the transition from the dielectric to the pad. A right angle at the surface of the blind via or at the bottom will collect most of the stress point and that is where failure occurs. Unfortunately there is not a tremendous amount of data to support this supposition, but logic and some tests done in the recent past using the IST via testing test vehicle lean this way.[4] More work must be done to better define the actual mechanism for failure.

The photo-microsection in Figure 6 shows something that is not common but is clearly a defect that can be avoided. The pad at the base of the etched window is the same diameter or just slightly smaller. Every laser system generates heat when removing dielectric material and therefore can challenge the adhesion of the pad, especially when it is not anchored concentrically. In the case below, the pad is only anchored on one side and has been raised during the laser drilling. In the case for these test coupons there are no traces that connect to the bounce pad so it is readily moved, especially since it is smaller than the entry of the laser beam.

Two major type of lasers are used in the fabrication of blind microvias and are best known as CO_2 and "YAG". The "YAG", Ultra-Violet or UV laser systems are typically the Neodymium-doped, Yttrium-Aluminum-Garnet (Nd:YAG) or the Neodymium-doped, Yttrium-Lithium-Fluorine (Nd:YLF). These UV lasers can actually laser drill the copper on the surface and produce windows. While this does eliminate the need for etched windows and donuts, the extended time necessary to laser drill the copper adds significant costs to the process. In addition there still remains the need to align the bounce pad at the third level just as it is necessary for mechanical drilling. For these reasons the CO_2 laser drilling systems enjoy the majority-installed base of laser systems used for producing microvias.[1]

Figure 6- Bounce Pad Smaller Than Etched Window

One of the typical after-products of laser drilling materials like FR4 that demand high energy, when using a CO_2 laser system, is carbonization on the inside surfaces of the via. This condition is further compromised as the typical laser beam is pulsed multiple times. With multiple rapid pulses the laser beam does pass through the debris as it is evacuated or removed and therefore can create HAZ and carbon build up both on the bounce pad and along the sides of the via wall. One laser system has been reported that is able to drill certain dielectric material like non-woven aramid with a single pulse omitting the circumstances where the laser beam reacts with the exiting debris.[3] In fact it is reported that the single pulse laser drilling can be formed down to the third level leaving extremely clean bounce pads and via side walls.

Cleaning the Blind Microvia

Laser drilled blind microvias are normally cleaned because of several issues that are normal after laser drilling. A symptom that is typical from the use of a CO_2 laser drilling system is a condition called HAZ. This acronym stands for "heat affected zone" and is a normal by-product from a CO_2 since it uses the mechanism called photo-thermal or heat that vaporized the dielectric material.[1] Along with the vaporization can come the more difficult to remove carbonized material and debris. The sure-fire way to clean any blind microvia that is heavily affected by HAZ is to use Plasma cleaning. However, one must be careful not to over use the Plasma, as it is typically a unidirectional process and can create a more "barreled" microvia, which is significantly more difficult to plate, as shown in Figure 7.

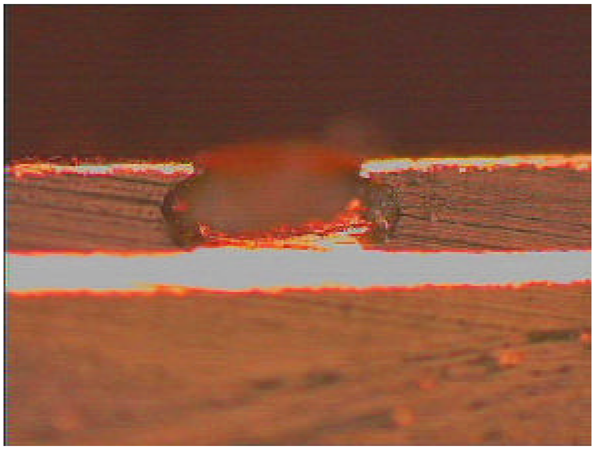

Figure 7 - Barreled Blind Microvia - Over Energy From Laser Drilling And Heavy Plasma Etch.

The UV lasers use a different mechanism than the CO_2 to remove dielectric material called photo-chemical. This method of material removal is not exactly the same as what happens in exposing photo resist with a UV light source, but is it very similar. The chemical bonds are broken in the polymer and with very little effort the material is evacuated. The conditions for this to happen include a larger number of pulses from a high laser beam influence or energy per unit area.

It has been stated that "pulse repetition rate influences how fast a job can be done and therefore the cost." [5] This is generally a very true statement but the bottom line goes back to how fast the via is 'cleanly laser drilled'. There is another CO_2 laser technology that reports clean via processing with single pulse laser drilling, even down to the third level, which clearly defies the above statement.[3] The best formula for cost-effectively and cleanly removing dielectric material might better be stated as the highest amount of energy in Joules or power (stated in Watts or Joules/second) that can be tolerated in the via without damaging either the copper on the surface or at the bounce pad. This formula also creates the widest process window and greatly improves yield.

Plating Blind Microvias

The first objective is to metallize the via wall of a blind microvia which has not been an overly difficult challenge. Two basic methods are used, assuming that the bounce pad has been properly cleaned and activated. These two methods include the old and standard method of electroless where the non-metallic surface is catalyzed so that copper can cover the surface in preparation for electroplating. The other method is called direct plate where a conductive surface is created that allows electroplating to slowly build up until it can be fully electroplated to a desired thickness. (See Figure 8.)

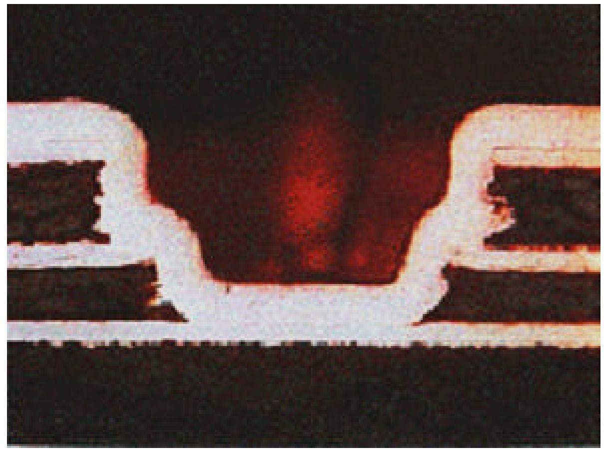

Figure 8 - Variable Depth Evenly Plated

There have been significant improvements in plating blind microvias with improved chemistries, pulse and other frequency altering methods for current distribution in plating power supplies. Most of the traditional chemistry suppliers can assist with help in reconfiguring tanks and power supplies to help without adding significant extra cost.

Published reports state that periodic pulse reverse, and a non-DC plating technique can actually plate consistent thickness of copper in three different areas including microvias, through holes and surfaces (high to low current density) on a HDI panel.[6] Sometimes called sequential plating, an electrically mediated process selects the appropriate waveform parameters for a particular feature size desired. This method can even plate blind microvias closed that are therefore filled and planarized. (See Figure 9.)

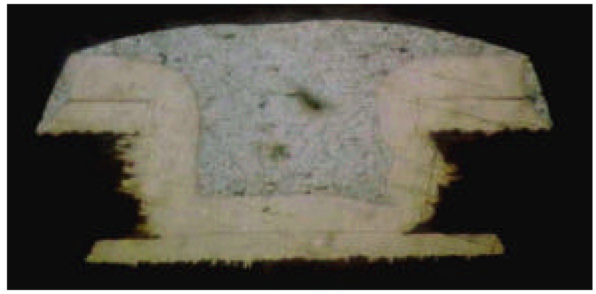

Figure 9 - Electroplated Solder Filled Blind Microvia in Non-Woven Aramid

Understanding the Costs of Yields

Most circuit board fabricators are very aware of the costs of poor yield. The idea of having to start extra panels to reach a certain final shipping yield to fill an order is a practice done by more circuit board fabricators. There is a crossover point where the number of panels started reduces the profits on that job to such an extent that it would have been better to not accept the order.

The idea is to figure how to cut rejects down so that all of the costs associated with a sale result in a high margin or profit.

Most fabricators know where they can find a high yield on etching and therefore know their limitations when it comes to line and space output. This is of course a part of the HDI format and one should be able to move toward 75 µm (0.003") lines and spaces in order to become active in this emerging market. At the same time it is important to know the process parameters for producing blind and buried microvias.

Most circuit board fabricators that have captured control of material movement and have respectable plating practices, can quite readily move to produce blind microvias. There is no published yield data known to these authors on the mechanisms for rejects specific to laser drilled blind microvias, just overall process yield data as mentioned in the opening paragraph of this paper. However, the authors can strongly suggest that if there were published data it would show that in most cases the principal reason for poor yields is due to miss-alignment to the bounce pad. Second the authors believe data would show that when laser drilling high energy demand materials like FR4 with a CO_2 laser system, cleaning will result in either rejects or high resistance interconnections.

The solution to improving yields is to find the widest process window from the design steps, through the etching, laser drilling, cleaning and plating steps.

Conclusion

Yield is always an issue and especially critical in these times of tight budgets, stagnant sales, when pressure to reduce selling prices proliferates and margins fall.

With all of the things that can go wrong in the process of fabricating laser drilled blind microvias, what becomes most evident is that one needs to find the "widest process window" with the most tolerant design and yet still meet the finished circuit board performance specification.

In addition, **Single Digit "Defects in Parts Per Million" (dppm)** is what most fabricators would like to see which is basically 99.991% yields or better. With careful and prudent process choices, this can be achieved in the production volumes of laser drilled blind microvias. The first step and consideration is to find the widest process window that fits within the existing facilities and operation. Once high yields are accomplished, then the fabricator can begin tightening and closing down on the design features of laser drilled blind microvias.

There is a gentle balance for fabricating profitable HDI or Microvia circuit boards. Since the profits are so greatly influenced by yield it is very important to understand and evaluate the yield causing problems. In addition, there is no single answer to solving yield problems and improving conditions for sustaining a high consistent yield. However, by following the five points listed below a fabricator can move significantly in a positive direction for creating high profits and gain high yield when fabricating laser drilled blind microvias

1. Design - try to use bounce pads or donuts with 75 µm (0.003") to 100µm (0.004") annular rings.
2. Alignment: using the design guides above will help extend the process tolerance, but finding an individual fabrication specific process for capturing the tightest alignment will be a major step in allowing the annular rings to decrease. Understanding material movement will also be an important step in improving this critical ingredient.
3. Laser Drilling - find a process that has the largest or most open process window. One that leaves the least amount of debris, HAZ and carbonized surfaces. Watch out for the costs at this step, as the number of microvias can rapidly grow to a projected number of 100,000 to 250,000 on a panel. The extended time to laser drill panels clearly then becomes the most expensive component of the entire process.
4. Cleaning - finding the laser drilling process and system that leaves the cleanest surface can greatly enhance the plateability and improve yield.
5. Plating - technical help from many of the vendors is readily available and can improve yield and eliminate failure at this process step.

Following the advice above will "Yield Enhanced Profits" in the production of laser drilled microvias.

References

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