BLIND MICROVIA TECHNOLOGY BY LASER

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ABSTRACT

The most costly process in the fabrication of today's multilayer printed circuit board (PCB) is the process of making z-axis interconnections or vias. This is driven at the fabrication level by two factors, the size of the vias including microvias ($\leq$ 0.150mm diameter) being demanded and the growing number of vias that are on a panel. There area several methods for producing blind microvias, including laser microvia drilling, photo-microvia formation, plasma etched microvia and mechanical microvia drilling. The two that are now clearly leading as emerging technologies are photovia formation and laser drilling. Laser technology has been around for nearly 30 years, but has only recently found "production" acceptance in the circuit board marketplace as a method for producing blind vias, especially within Surface Mount Pads. Many decisions must take place when planning for the installation of a laser process, starting with a decision to do subtractive, additive or semi-additive processing.

Key Words: Laser, BGAs, QFPs, Microvia, Via-in-Pad

"Of all the interconnection methodologies, the manner in which holes (or vias) are produced has the most effect on the relationship of the interconnecting structure and how it is produced." [1]

INTRODUCTION

When review the options for laser drilling, a fabrication facility first needs to decide if subtractive or additive plating methods are to be used. Subtractive processing is most commonly used in today's circuit board industry, where the panel is fabricated using copper clad material and the copper clad is chemically etched away, yielding the traces that comprise the circuits inside and outside multi-layer circuit boards. Of course the typical subtractive processes are more complex than just etching copper with the use of plated etch resists that are typically metallic, such as solder or tin. Additive processing is actually simpler in overview, but more difficult with material treatment a key factor. When a circuit board is produced by additive processing, the dielectric is not clad with copper as in the subtractive process and must be conditioned to accept copper that is typically plated onto the surface. The copper can be selectively attached to the dielectric surface and configured in the form of the circuit pattern alleviating the need to etch the outer circuit patterns. A modified method, which is called semi-additive, actually produces the copper clad as a plated coating over the entire outer surfaces of the circuit panel and then is processed in the same fashion as the subtractive processes described above.

The following statement from a major electronic equipment manufacturer in the communications field has been quoted from a paper delivered at IPC Expo '98[2]:

> *It has been shown that the size of the via capture pad is the major contributor to board complexity in dense circuit designs. All of the microvia technologies directly address this problem by the use of much smaller capture pads, or by the total elimination of capture*

pads when the microvias are placed directly in the component solder pads. Vias in solder pads have no effect on solder joint reliability.

Extensive work with many board suppliers worldwide has shown that there is no correlation between the method that a supplier uses to form microvias and the price an equipment manufacturer is charged for an HDI board. It seems that, although lasers form vias sequentially while the other methods form them simultaneously, the supposed cost advantage of the mass via methods at higher via densities is offset by process difficulties, lower yields, and other factors. It is also apparent that both laser via and photovia methods are less costly than the multilayer mechanically drilled technology against which they really compete. It may be that the cost of putting in microvias is inconsequential in the pricing of the product.

Experience and computer simulations show that the improvement in circuit performance gained from the use of high performance materials in the HDI layer is minimal for many applications. Some structures such as 50 ohm striplines cannot be manufactured with HDI dielectrics given existing design rules. The added thickness of a standard FR-4 laminate is needed. Other nonstandard structures are possible, such as lower impedance lines, which might prove useful. For applications where high performance materials are found to be necessary, the laser method for fabricating vias would have an advantage over photolithography at this time. Most of the materials that would be termed "high performance" are easily ablated with a laser, but they are not photoimageable.

Subtractive, Additive or Semi-additive

The advantage of both the additive and semi-additive methods is that microvias can be formed or drilled into the dielectric material prior to plating the surface. Additive processing can eliminate the etching process or with semi-additive processing it can allow the deposition of extremely thin copper on the outer layers for very fine line etching. Both laser drilling and photovia can produce blind microvias in the raw dielectric material for either additive or semi-additive processing. Photovia exclusively demands one of the additive or semi-additive processing plans at the moment. Reliable plating processes have been reported, with adequate circuit adhesion using the additive and semi-additive techniques, however in most cases they are not at the same adhesion strengths as the more common clad materials.

Laser Drilling Decisions

Once a decision has been made on subtractive vs. additive or semi-additive processing, the laser process can be more clearly defined. When producing laser drilled microvias in a dielectric material for additive or semi-additive processing, the laser beam diameter must be the same or smaller than the intended diameter of the microvia. This can be done by one of two methods. One method is to make sure the lenses used with the laser beam produce the appropriate size beam diameter or smaller. A smaller beam diameter can be used as in the case of the Ultraviolet or UV (Nd:YAG) lasers so that trepanning can occur. Trepanning is the method whereby a small diameter beam is moved in a circular manner as if you were using a reciprocating saw and cutting a hole in a plywood sheet. Infrared or IR (CO_2) lasers typically have larger beam diameters than UV lasers and need a mask to control the beam diameter generally before it strikes the dielectric material. In addition, lasers can be de-focused to change the diameter of the useful beam emitted onto the panel to enlarge from the minimum or nominal diameter size. In every case the amount of laser energy that is absorbed by the dielectric material controls the quality and size of the microvia limiting a large variation in microvia diameters without changing laser system characteristics.

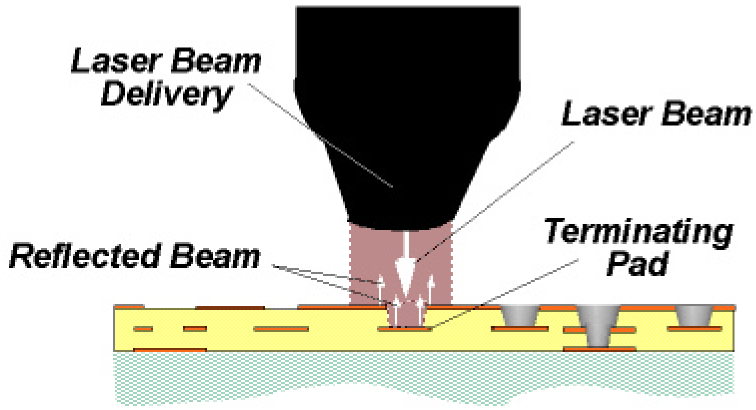

Figure 1. IR Laser - Reflected Beam

The most simplified method for laser drilling is to use a conformal mask. Conformal masks are readily produced by etching windows in the outer layer of a multilayer circuit panel after it has been laminated and before mechanical drilling. The etched windows allow the laser beam to absorb the dielectric material and rapidly change it to a vapor. The IR lasers that are finding extensive use with conformal masks can be set to reflect naturally off the copper surface and also the pad that is buried below the dielectric material.

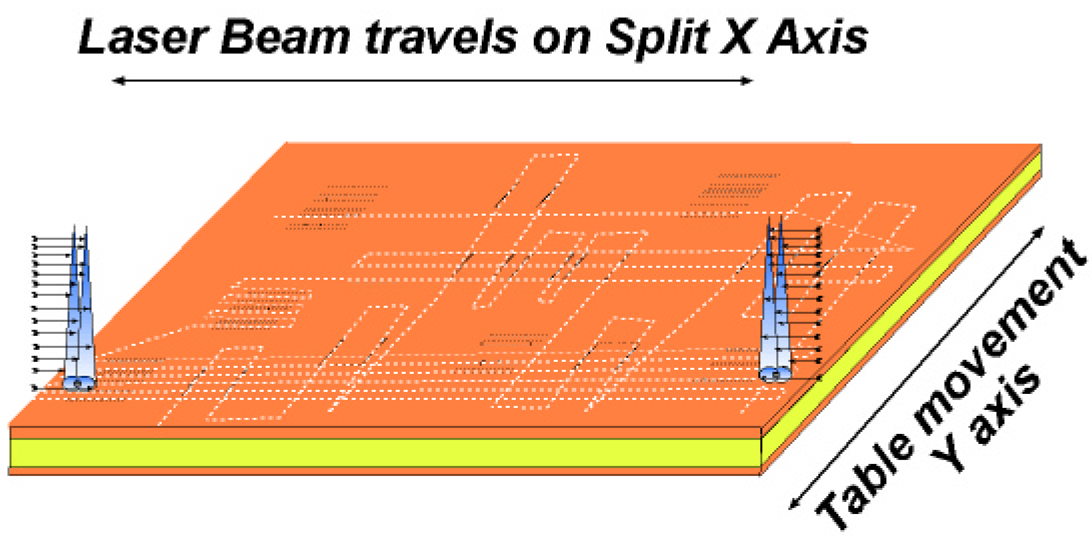

Figure 2. Conformal Mask

By using the oversize IR beam and the etched window in the conformal or copper mask the laser beam can penetrate deep into the dielectric material and reflect off the base copper material at the bottom of the blind microvia. The results are a quality blind via-in-pad that not only helps hold the pad down during the soldering process in the assembly, it is most advantageous to the circuit board designer that is chartered with interconnecting electronic components predominately using surface mounts pads.

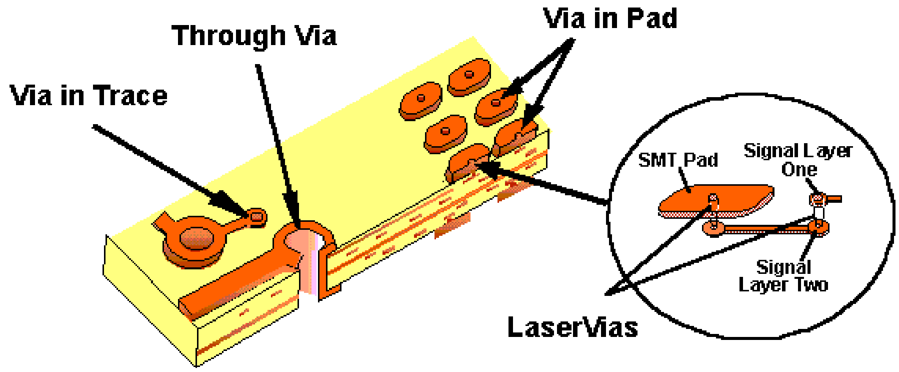

Figure 3. "Single Depth" Microvias

A new laser system has been designed that will actually produce multiple depth vias with a single pulse.[3] The ability to drill down multiple depths with a single pulse provides a very cost-effective method for producing "stacked vias".

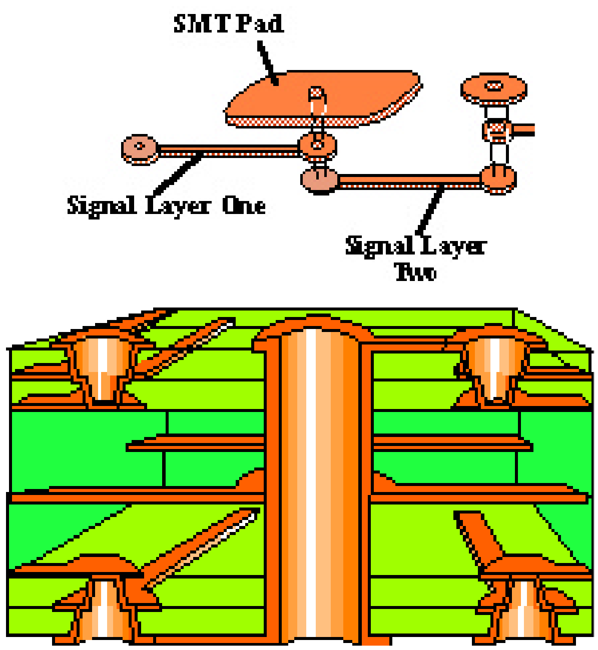

Figure 4. "Multiple Depth" Microvias

More On Laser Technology

The most confusing reality about laser technology is the fact that the denser the material, the more energy is needed to vaporize it. Within the circuit board process, copper is the most dense material followed by the glass in FR4. The organic polymer that is normally Epoxy is not dense and therefore takes very little energy.

The challenge when using a very high-energy source like a laser to remove different materials is to control the energy, so as to not damage the materials that react violently to the high energy. There are several ways to control this energy. First is to use a short wave laser that can pulse at a very high rate. With this technique a very "hot" laser beam (measured in either joules or watts) can be pulsed in rapid fashion to remove most dense materials. The absorption of the beam is also a major consideration that must be noted. It should also be noted that with the use of this high-energy beam, the beam diameter is limited. Otherwise too much energy will be emitted onto the material and create a large managed area. So the beam diameter is limited in size for removing dense materials like copper and FR4. This forces these high-energy lasers to use a technique called trepanning for removal of material in an area greater than the beam diameter. Trepanning has been discussed in the Introduction of this paper.

The high-energy beam lasers that are finding use for removing copper and FR4 are from the UV segment of the light wavelength chart. It might not be clear yet, but the high energy, short wave length that allows these lasers to vaporize dense materials also is the reason why they are quite slow in processing circuit board panels with the ever-increasing microvia demand.

UV Lasers:

There are two types of UV lasers being introduced. They are the Neodymium-doped, Yttrium-Aluminum-Garnet (Nd:YAG) and the Neodymium-doped, Yttrium-Lithium-Fluorine (Nd:YLF). The Nd:YAG with its frequency shifted state (266 & 355nm) is a continuously pumped, repetitively q-switched laser system and the Nd:YLF is a diode pumped, q-switched laser system. Both metals and organic materials (dielectric materials) are readily absorbed by the frequency of the beam that exits these two UV laser systems. Much effort has been given in an attempt to move the absorption toward the dielectric material away from the metal absorption characteristics, however the UV's still are absorbed by the metals at a higher rate than the organic materials. This serves the UV laser systems well in the removal of copper foils from the surfaces of circuit board panels, but creates very tight process controls for dielectric removal. The typical high energy focused beam with a short wave length from the UV lasers must enter the dielectric window of a conformal mask either after it has been chemically etched or vaporized by the UV laser in a near exact position in order to remove the dielectric material. Furthermore the typical small beam diameter that is delivered needs to trepan the opening in order to remove the dielectric material for today's typical fabrication plating process. This of course adds significant time to the laser processing of large panel areas, resulting is significant high per blind microvia costs.

Infrared Lasers

On the other side of the wavelength spectrum are the long wavelength lasers or IR lasers. While these lasers are not able to remove copper with the longer wavelength they emit, they are used in metal cutting where a single material is involved because they are cheaper to operate. These lasers naturally penetrate deeper and therefore are usually not pulsed at the same rate as the UV laser.

The IR lasers are naturally reflected by metals especially copper and therefore can use a larger beam size over a conformal mask and emit enough energy to penetrate deep into the dielectric material. While the IR lasers are not able to remove copper and are also slow in removing FR4, they need to spend less time over a given organic material than the UV which needs to be pulsed a great number of times. In addition the UV laser has to trepan to remove a typical area of organic material for today's circuit board plating techniques. With the IR laser beam it is possible when using a proprietary beam delivery system, to pulse the laser beam over a copper etched window (conformal mask) a single time. In fact it has been demonstrated that multiple vias can be effectively single pulsed using an over sized defocused beam. [3]

There are also two types of Infrared laser systems being introduced that are both Carbon Dioxide. [Reports of another kind of CO_2 laser for drilling circuit boards in Japan have been noted, but little information on this laser in known.] The CO_2 laser is situated to drill organic polymers with its long wavelength and natural tendency to be reflected off of metal, especially copper. The two types of CO_2 laser systems are the Sealed RF Excited CO_2 and the TEA CO_2. The other system listed above have found little acceptance into the market primarily due to the fact that they do not effectively drill a broad range of dielectric materials, they are expensive to run, hard to control or they are not situated to drill large panel areas.

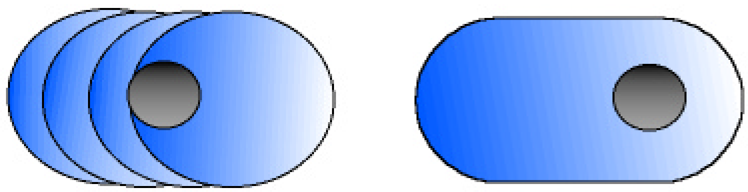

Figure 5. Over Sized Defocused Beam

In reality, as the beam rapidly moves across the etched window over the conformal mask, the beam is actually elongated as depicted in the right drawing in the above figure 5. The elongated effective beam area can clearly be demonstrated by laser drilling dielectric material without the conformal mask. The elongation is governed by the speed of the beam movement and the pulse duration, however the energy needed to enter the etched window for complete dielectric material removal is a combination of beam speed and beam pulse duration.

THE LASER MICROVIA CHALLENGE

Many fabricators are working on different microvia technologies with the focus on making interconnections between the outer layers and one layer down. If one is to truly understand the design advantages of microvias, it quickly become obvious that interconnections will need to be made to level three and eventually to levels four and five. Build up technologies offer this kind of interconnection where the panel is built in layers by placing one microvia interconnect technology over another one. In fact it has been reported and shown that even the photovia practitioners use a laser to interconnect periodically.

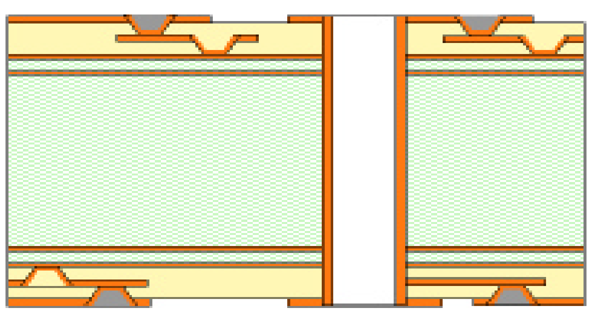

Figure 6. Buildup Technology "Staggered Vias"

The figure 6 on the previous page shows a typical build up technology that can be done by photovia, plasma or laser techniques. It will be clear that processing costs will provide the path to the microvia technology of choice in the near future. Even though a technology issue like the staggered via can be solved, it does not mean it will be the most cost effective method for fabricating the circuit board. In the case of staggered vias versus stacked vias, the staggered vias take several extra process steps and in some cases can double the cost of fabricating the circuit board.

Fabrication

Today Z-axis interconnections are finding the most activity, as drilling has become the highest single process step in the fabrication process. The demand for reducing the diameter of the drilled holes, called microvias, along with the ever-increasing number of Z-axis interconnections are the two main driving forces behind the cost increases for drilling.

This demand for microvias has further complicated the increase in z-axis costs. Especially when the focus is on the demand for blind microvias, which are the most effective or cheapest interconnection methodologies from the CAD designer's point of view. Designers use a costing chart to prioritize the various methods for interconnecting circuits. The method of choice or the one that allows the most density is generally the cheapest from the CAD designer's point of view. However, this interconnection choice has not always been the cheapest at the Fabrication stage of building circuit boards. Today it is clear the blind microvia is the Z-axis interconnect method that needs to be fabricated. As the designs move to demand multiple depth interconnections, which can be done by the build up method shown in Figure 2, or the stacked method shown in Figure 3. With the stacked method, the vias can be laser drilled in the same fashion as the mechanical drilling is done, and save the costs of producing a nearly complete second panel, which is demanded of the buildup technologies.

The great effort to increase the output of laser drilling equipment has finally made laser drilling a viable alternative to mechanically drilled blind vias and now can be considered a true production process. This is not the case, however with all laser drilling processes. The key to introducing a true production process happens only when all of the physics are understood and taken into consideration. It is important to match the circuit design with the material and laser process.

It is further important to know what the true <u>average</u> output of the laser system really is and the <u>peak</u> output. This can only be determined when a test circuit is drilled with the various laser systems.

"WHEN ALL IS SAID AND DONE"

The real issue is to match a microvia technology to the fabricators current and projected technology plan. The quickest and easiest plan is to continue to use the subtractive method for producing multilayer circuit boards and just insert the laser drilling step as a sequential process before traditional mechanical drilling. While this will involve an additional "etch window" step after lamination, it is clearly the smoothest and quickest method to introduce a microvia technology.

The next question after discovering how easy it is to produce laser drilled panels, is to look at the cost on a per via bases and it will lead to: "How many panels can be produced with a given laser system?" Or when it really comes down to determining the value of a laser system it is how many vias per second and how much do they cost, so that these costs can be passed on to the customer. To weed through all the capabilities and understand the true outputs of the various laser systems is a difficult task as published outputs are generally not given from an agreed "common ground" specification. Many capabilities are published using peak drilling speeds and do not represent the true output, which should be the average laser drilled via output for a panel. In addition, for measuring true production capabilities, load, alignment and unload should be part of the average laser drilled via output equation. Laser drilled via output is always circuit design dependent, so it is even more important to set a standard for testing the output of laser systems. This issue is not dissimilar from the confusion that has plagued circuit board mechanical drilling room engineers for years.

Cycle Time- "How many panels per hour?"

What should really be studied is the "cycle time" for loading, aligning, laser drilling and unloading a circuit board panel to understand the output from any given laser drilling system. At the moment, the leading laser technologies are the RF Excited CO_2 using non-woven reinforcement.

CONCLUSION

Microvias are clearly the most aggressive technology to enter into the circuit board industry since electroless copper was introduced. The microvia processing decision is a difficult one at best. Without considering the other competing microvia technologies, one must really understand which laser technology is right for the current and future emerging microvia market. Clearly the UV laser systems offer the most flexibility with the ability to drill copper, FR4 dielectric materials along with the newer microvia materials like Aramid, unsupported epoxy or polyimide materials and photo-dielectrics. However, the processing speeds (vias/second or panels per hour) are not generally acceptable for production. On the other hand, the CO_2 systems with material processing limitations clearly enjoy production capability today and should continue to gain output capability as new developments are introduced.

REFERENCES

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BIOGRAPHY

Larry W. Burgess has over thirty years experience in the interconnect packaging disciplines. He holds a Bachelor's Degree in chemistry and has held Management and Engineering Management positions at fortune 100 electronic companies. He is President and Chief Technical Officer at MicroPak Laboratories, Inc., where he has licensed technology to Sandia National Laboratories. MicroPak has recently formed a joint venture with Pluritec Italia. Currently Mr. Burgess has just opened the first in a series of Laser Drilling Centers in North America to support the upcoming demand for laser drilled blind microvias.