

# Optimizing BGA to PCB Interconnections using Multi-depth Laser Drilled Blind Vias-in-Pad

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## ABSTRACT

Ball Grid Array (BGA) component packages challenge the circuit board design with signal routing and layout, creating in some cases extra board layers and added vias all resulting in increased costs for the Printed Circuit Board (PCB). As component densities increase and microBGA ( $\mu$ BGA) and other fine pitch components become more common, Microvia-in-Pad technology will ease the transition to these fine pitch components. This paper will present and profile a cost-effective solution to interconnecting BGAs on PCB's using laser drilled blind vias connecting the outer three or more layers of a multilayer circuit board. Following a discussion on the design advantages, a comprehensive outline of the PCB Fabrication process will explore a new procedure for the rapid production of Via-in Pad multi-depth blind via laser drilling.

Key Words: Laser, BGA, Via-in-Pad, Microvia

## INTRODUCTION

Ball Grid Array (BGA) packages are a natural spin-off from Pin Grid Array packages. As early as 1988 a few BGA packaging developers were attempting to evolve Pin Grid Arrays into surface mountable packages. Real BGA packages began showing up in 1990 and by 1993 a few major companies like Motorola, IBM and Compaq placed the BGA on the mainstream roadmap.<sup>1</sup> Currently BGAs are a class of packages and now are the package of choice for high pincount (>240) applications.

The pincount is forcing finer pitch and is expected to reach 1700 pin requirements in the year 2001 with a body size of 50 mm.<sup>2</sup> The signal I/O escape wiring and their interconnect to the other high I/O packages will require very dense Printed Circuit Boards (PCBs). Circuit Board Designers all have to provide solutions for interconnecting these high I/O components and while they can add layers, it becomes quickly apparent that "Via Starvation" is the biggest stumbling block to successful circuit design. Other solutions can be finer etched lines and spaces, which come at tremendous costs. Smaller mechanically drilled holes also become cost restrictive as holes are reduced to less than 0.010" (0.254 mm).

"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."<sup>2</sup>

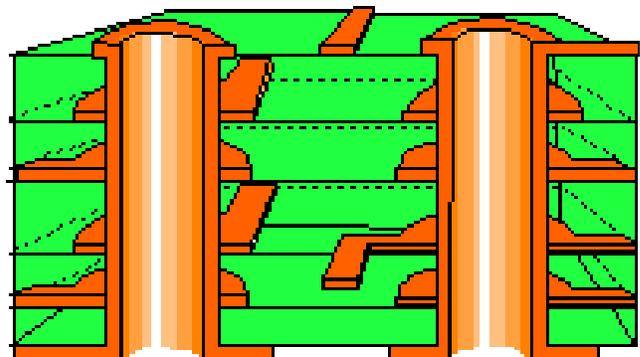


Figure 1 - Via Starvation

## FURTHER STUDY OF THE 'INTERCONNECT CHALLENGE'

While small through-vias (> 0.010") can certainly impact the design challenge, both blind and buried vias can most readily ease the interconnection conflicts for most Computer Aided Design (CAD) Auto-Routers.

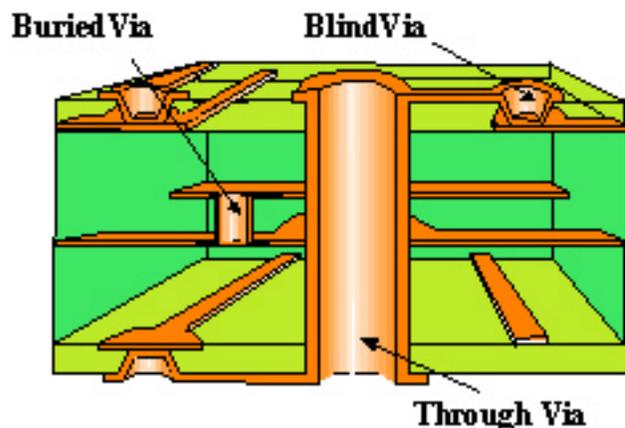


Figure 2 - Via Definitions

The circuit board packages that exhibit the small vias as blind or buried vias are all part of the High Density Interconnect (HDI) next generation packaging that will be the key enabling technology for the exploding markets in hand held electronics (computers, telephones and other electronic instruments).

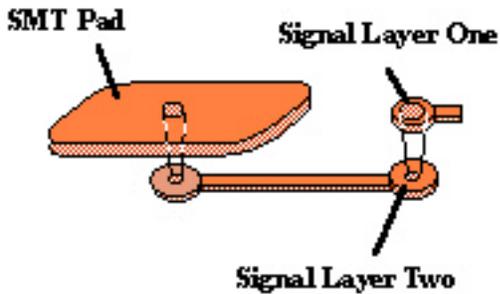


Figure 3 - Via in Pad - Two Layer

It has been shown that the size of the via capture pad is the major contributor to board complexity in dense circuit designs." <sup>3</sup> Via-in-Pad technology is another great enabling technology that along with microvias has removed the major contributor to circuit board density, "via capture pad" size from the surface of the circuit board now down into the board. In other words, Via-in-Pad pretty well eliminated the surface capture pad problem, however it still exists on inner layers especially when mechanically drilled vias are produced.

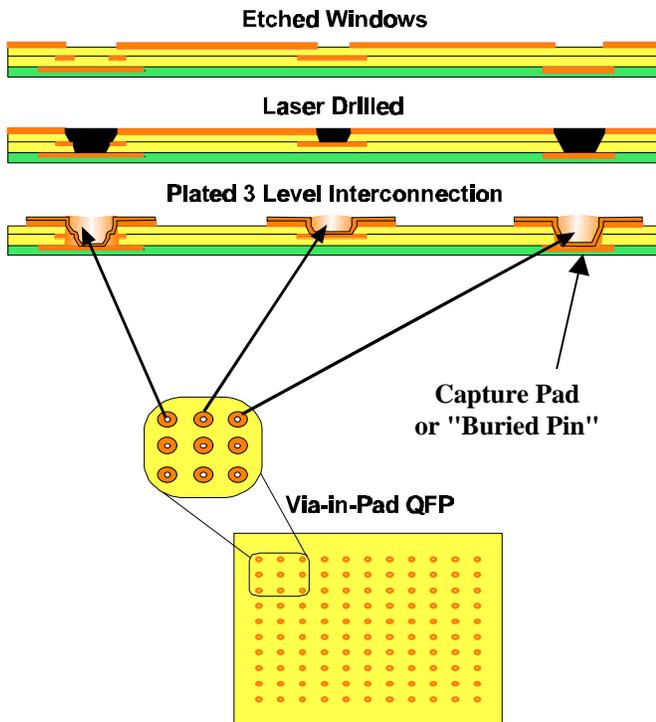


Figure 4 - BGA "Buried Pin"

The capture pad or buried pins can be the gating factor that will allow a dense circuit design to interconnect to other high density components. These pads can be reduced using either laser drilling as the Z-axis interconnecting methodology. The pad size can be reduced as the laser does not need the enlarged diameter in order eliminate damage from the rotating drill bit in mechanically drilled vias.

The design is further enhanced by the ability to make interconnections down three levels or more. This effect is especially important with BGA Designs when all the mounting can be done on a "Pads Only" surface and the circuit interconnections can be completed on the two adjacent buried layers, 2 and 3.

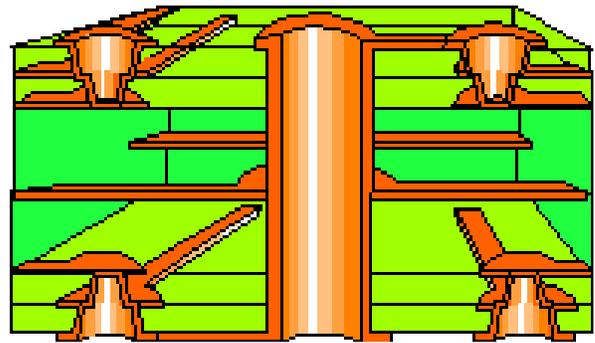


Figure 5 - Multi-Depth "Stacked" Blind Via

In recent tests, laser drilled vias have proven to more economical to produce even over mass via methods like photovia, because of the process difficulties, lower yields and other factors.<sup>3</sup> Laser drilled blind vias are especially valuable where high performance materials are found to be necessary as most of the "organic" materials are within the process parameters of lasers.

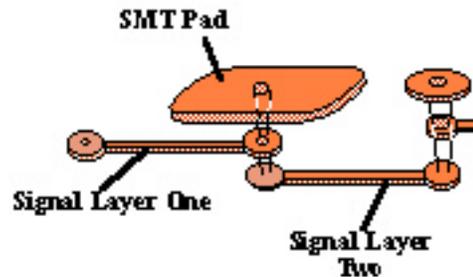
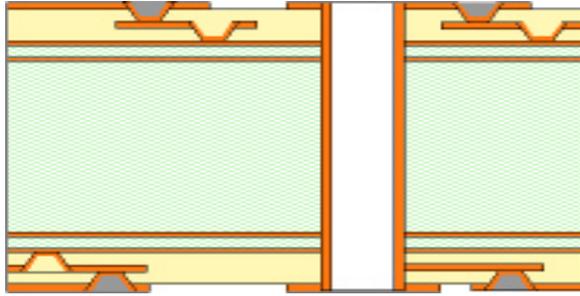


Figure 6 - Stacked Blind Vias - 3 Layer

What is not well understood is the value of using "stacked vias" as seen in Figures 5 and 6 above as opposed to "staggered vias" in buildup technologies, such as photovia and plasma via formation methods.



**Figure 7 - "Staggered" Blind and Buried Vias**

While the same basic densities can be achieved with either "Stacked or Staggered" via formation, there is significant costs for the staggered via formation method. When blind vias are formed they have to be metallized and therefore the process involves making nearly two circuit boards. This is quite costly and can be eliminated by using the stacked via process with the laser capability of drilling to multi-depths in the same fashion as you would with a mechanical drill.

**LASER DRILLED BLIND VIAS IN PRODUCTION**

A new laser system has been designed that will actually produce multiple depth vias with a single pulse.<sup>4</sup> The ability to drill down multiple depths with a single pulse provides a very cost-effective method for producing "stacked vias". In addition, as the densities increase the speed of laser drilled blind vias also increases for two basic reasons:

1. There is a demand for smaller diameter blind vias as the density increases. The smaller diameter blind via is filled with a smaller volume of dielectric, which takes less energy and therefore a shorter pulse duration.
2. As the pitch increases, more blind vias occupy a square unit of area and can be therefore drilled faster as the laser beam does not have to travel as far between pulses.

Since all laser systems accumulate their process efficiency through shortening the time to drill a via, the travel time between vias is most important.

The newly built system used for drilling multi-depth blind vias that has been built in Italy, is also capable of drilling multiple vias with a single pulse. The limitation for multiple laser drilled blind vias is based on pitch and the volume of dielectric needed to be removed by the laser beam. In a test using 0.003" (0.076 mm) Epoxy Thermount® dielectric, with 0.006" (0.15 mm) diameter blind via, on a 0.016" (0.4 mm) pitch; 58,000 blind vias were drilled in one minute. This equates to 974 blind vias per second. In this test, as many as three vias were drilled under a single pulsed beam from a RF excited 240 watt CO<sub>2</sub> laser system. With the pulse duration necessary to laser drill these blind vias and the capability of pulsing at great

than 1,000 times per second it is conceivable that double the via/second output may be possible in the future.

**MICROVIA DENSITY DEMAND**

Assembly and packaging requirements are challenged by the packaged pin count of components. The following charts depict some of the recent and future demand:<sup>5</sup>

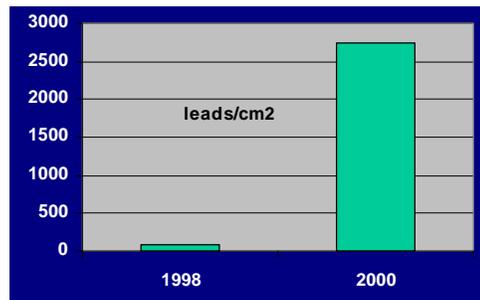
Commodity	40-208
Hand-held	100-256
Cost/performance	256-600
High performance	1089
Automotive	40-208

**Figure 8 - Packaged Pin Count Today**

Commodity	40-277
Hand-held	117-352
Cost/performance	300-352
High performance	1493-1824
Automotive	40-277

**Figure 9 - Packaged Pin Count 2000**

This projected growth is impressive, however the projected demand on I/O's when measured by leads per centimeter squared show how dramatic the growth in interconnects is projected to grow.<sup>6</sup>

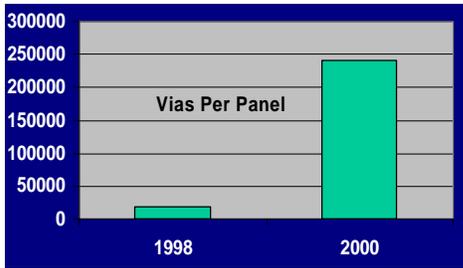


- 1998: 77 leads/cm<sup>2</sup>  
(495 leads/sq.in. )
- 2000: 2753 leads/cm<sup>2</sup>  
(17,760 leads/sq.in. )

**Figure 10 - Projected Growth in Leads/cm<sup>2</sup>**

The above chart is a clear roadmap for the circuit designer and the assembly people.

This second chart can easily be understood by the PCB Fabricator as all in-plant process work is done in panel units:



- 1998: 20,000 vias per Panel
- 2000: 240,000 vias per Panel

**Figure 11 - Projected Growth in Vias/Panel**

The effect of this phenomenal interconnect growth on the PCB fabricator is forcing all those interested in high density fabrication to look carefully at a microvia strategy. What is most critical is finding a process that will fit into the existing process minimal expansion and capital equipment expenditures. One of the critical factors for each fabricator to review is the effect on cycle time.<sup>2</sup> While on the surface photo via technology appears to have the least effect on the capital equipment expenditures, since most of the processes are done in the current inner layer and outer layer imaging process. What is not always first observed is that since the panels is handled at least once as is the outer layer image; as growth continues, the imaging processes will have to grow to accommodate this growth. This can turn out to be a significant expense as imaging areas continue to move to cleaner and cleaner environments.

Additional limitations with photosensitive dielectrics also have given rise to some quality issues as the technology matures. Depending on the process, additive or semi-additive plating is needed to metallize the photo-sensitive polymer. When buildup technologies are necessary (Figure 7) additional costs are incurred that can make multi-depth interconnections expensive. Nevertheless, photo via technology can be the least expensive microvia process when large quantities of microvias are produced on a single depth interconnection scheme.

The other major microvia technology, laser drilled vias, can be added as if it were an additional mechanical drill. The fastest laser drilling reported to date on large panel circuit boards is done with a RF excited 240 watt CO<sub>2</sub> laser system.

### LASER DRILLING PROCESS

All of the microvia technologies have an impact on the typical circuit board process at one place or another. Using a RF excited 240 watt CO<sub>2</sub> laser system is not exception, however the effect can be minimal. The material used for cost-effective blind via processing typically does not contain glass fibers. UV lasers and TEA CO<sub>2</sub> lasers have successfully processed FR4 material, however it is clearly

quite slow and does not produce a useable "cycle time" for volume circuit production.

With cycle time as a requirement and knowing the tremendous growth projected in microvias per panel (Figure 11), one must understand and think in panels per hour. If one is to try to envision the future, but use the past (how absurd, but real), a good number to use might be 20 panels per hour for a process equipment like a mechanical drill or a laser system. In both cases it finally results in hits per unit.

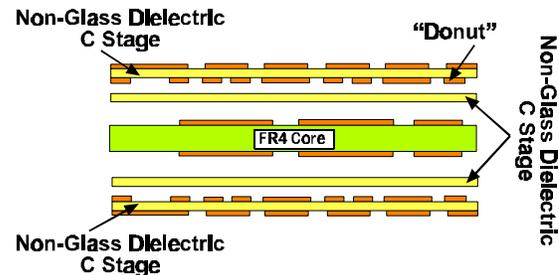
The need to supply the demand might be charted for 3 minutes (180 seconds) panel production as a cycle time as follows:

	1998	2000
Vias per Panel	20,000	240,000
Vias per second	112	1,333

**Figure 12 - Laser Equipment Efficiency**

When you understand the pitch growth as one of the givens with panel sizes remaining consistent, one might begin to feel comfort that these numbers can be reached with lasers just being introduced and the new developments that continue.

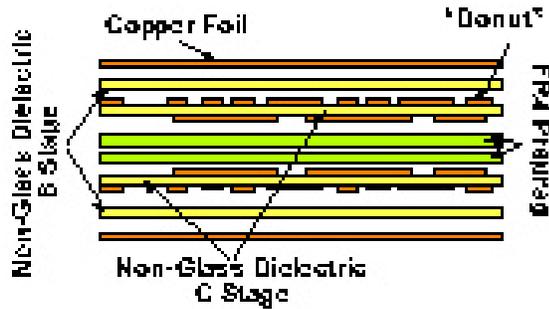
With only slight modifications to the typical multilayer fabrication process a laser drilled multi-depth blind via board can be effectively produced.



**Figure 13 - Core Cap Lamination**

All of the process steps are common and used daily for producing a Core Cap Laminated, multi-depth blind via circuit board. What is unique is the material lay-up as it is set for lamination.

The outer layer is basically processed as if it were an innerlayer. The slight difference is that the circuit is etched on the underside, but the windows used for the conformal mask by the laser are all that is etched on the topside. The alignment problems that plague any innerlayer process are also common for this stage. It is also recommended that double treat copper be used for this process as their appears to be a reaction when laser drilling on the third layer. This reaction is not seen when only single depth laser drilling is done with the RF excited 240 watt CO<sub>2</sub> laser system.



**Figure 14 - Foil Lamination**

The foil lamination technique is much less effective for providing registration between layer one and two. The most difficulty comes when attempting to find the buried "donuts" on layer two. This is why the preferred method is the core cape method for making three level blind interconnections.

### CONCLUSION

The challenge with dense circuit components such as BGA and other very dense electronic components can be answered with a planned and well thought out microvia technology implementation plan.

Once such plan using an RF excited 240 watt CO<sub>2</sub> laser system appears to be positioned to meet the challenge for panels of blind via interconnections from today's 20,000 per panel to the projected future of 240,000 per panel.

The key to understanding and defining an effective process is to realize what the "cycle times" will be for each step in the process. Laser drilling today's panels at just over 100 vias per second should keep the cycle times for a production laser system within a reasonable output of panels/day to make it feasible to adopt laser drilled blind via technology as one of leading candidate for the primary microvia technology. This will be especially evident when circuit boards demand microvia interconnections down to the third layer. Once circuits demand interconnects to greater than two levels, laser drilling will come into it's own as the interconnection of choice for microvia technology.

Today any multilayer fabricator can evaluate laser drilling as a method for fabricating microvias, by either using an existing test vehicle or creating or converting an existing circuit board for testing laser drilled blind via.

The next two years will see a tremendous growth in microvia technology with many options for Printed Circuit Board Designers, Fabricators and in Assembly. We can certainly be sure of one thing, all circuits for the future will be considerably more dense than what we see today.

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### BIOGRAPHIES

Larry 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 and Pluritec Italia. Currently Mr. Burgess has opened the first in a series of Laser Drilling Centers in North America to support the upcoming demand for laser drilled blind microvias.

Fabrizio Pauri holds an advanced engineering degree (Laurea in Ingegneria Meccanica) from Politecnico di Milano. Since 1995 he has been employed at Pluritec Italia in the Research and Development Department as a Project Manager of laser microvia drilling machines. Currently he is developing processes and new techniques for laser drilling existing and new circuit board dielectric materials.