An innovative "ChemicalVia" process for the production of high density interconnect printed circuit boards

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Abstract
The ChemicalVia process, patented by CERN, provides a new method of making microvias in high-density multilayer printed circuit boards of different types, such as sequential build-up (SBU), high density interconnected (HDI), or laminated multi-chip modules (MCM-L). The process uses chemical etching instead of laser, plasma or other etching techniques and can be implemented in a chain production line. This results in an overall reduced operation and maintenance cost and a much shorter hole production time as compared with other microvia processes.

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Introduction

With advances in the electronics industry and the need for high density circuit boards (PCB-HDI), microvia technology provides the solution for increased track density, a decrease in the size of electronic components, and/or a reduction of layer count with a better price-to-integration relationship. In particular, to gain more landing pads for small footprint components, the use of microvias is a necessity. As a result, microvia technology is already widespread and well developed in the electronics industry.

There are three different categories of microvias (Figure 1). Blind vias are plated holes located on the outer layer which make an interconnection to the next inner layer. Buried vias, normally formed before board lamination, are plated holes within the core of the circuit which do not connect to the board surface. Through-hole vias connect the top and bottom layers and pass through the entire thickness of the circuit board (Lau and Chang, 2000).

This paper discusses the possibility of making blind and buried vias by means of a chemical process patented by CERN (European Organization for Nuclear Research) called the ChemicalVia process (De Oliveira, 2002). This technology was first implemented for the production of gas electron multipliers (GEMs) which are devices used to amplify ionization of electrons in particle detection systems. GEMs are made of copper-coated polyimide perforated with a huge quantity (10^7) of holes of 50-100 μm diameter. After it was successfully implemented for GEM production, the ChemicalVia process was applied to making microvias as well.

The ChemicalVia process, which includes two innovative steps that are new to the electronics industry, is described in detail in the technological section. Results from one investigation to classify the etching behaviour of different polyimide materials is presented in the test section along with a discussion of the etching behaviour and adhesion of glue. Sample boards, used to qualify the ChemicalVia process according to industry standards, were created and some initial tests were carried out. Finally, the advantages and disadvantages of the ChemicalVia process are discussed and compared to other processes using techniques such as laser ablation, plasma etching, mechanical drilling and photo imaging.

Technological process

As the name suggests, the ChemicalVia process produces microvia holes in HDI-PCBs by chemical means. Most of the process is similar to that used in normal PCB production except for two innovative steps that allow for the interconnection between layers: the etching of the polyimide and the etching of the glue. As usual, a visual inspection or automated optical inspection (AOI) is required after each step to ensure that all dimensions are correct and to check for defects like missing holes or pin holes. The process sequence is as follows.

1. Patterning of the copper layer using normal photolithographic processes (lamination of photoresist, exposure, development, copper etching and resist striping).
2. Lamination of solid glue or application of liquid glue onto the first layer of the circuit.
3. Lamination in a press machine of a copper-coated polyimide foil onto the first patterned layer using liquid or solid glue (Figure 2(a)).
4. Patterning the upper copper layer with holes (using normal photolithographic processes) to permit the etching of polyimide.
5. Etching the polyimide (Figure 2(b)).
6. Etching of the glue (Figure 2(c)).
7. Metallizing the microvia holes (Figure 2(d)).
8. Patterning the circuit on the upper copper layer.

Polyimide etching

The equipment used to etch the polyimide consists of a sequence of three different and independent baths whose properties are shown in Table I.

Working with ethylene diamine requires extra attention for security and operator protection. The use of a respiratory mask and gloves is mandatory and handling of the circuit must be kept to a minimum. An automated production line

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Figure 1
The three different types of microvias

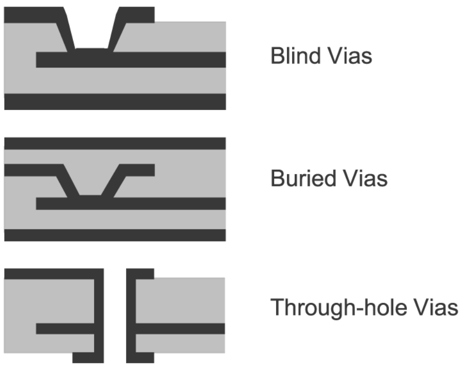
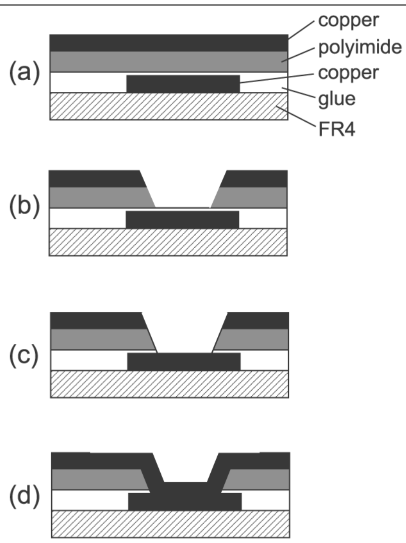


Figure 2
The four basic steps for making microvia holes by the ChemicalVia process



system is currently being designed for the etching of polyimide materials which minimizes the contact between the operator and the etching chemicals. Figure 3 shows a schematic diagram of such a system. Electronic controllers will be used to operate the pumps and valves at the desired time to pass the circuit through the entire etching cycle without any manual manipulation. Pipes, pumps and containers should be made of stainless steel and/or polypropylene materials.

There are two important parameters to control that influence polyimide etching and thus the final shape of the microvia hole: the temperature of the bath and its concentration of potassium hydroxide (KOH). With an increase in temperature, the shape of the microvia changes from conical to cylindrical form as shown in Figure 4. A similar effect can be observed by increasing the KOH concentration in the ethylene diamine bath which changes the isotropy of the etching process; a pure ethylene diamine bath is anisotropic and a pure KOH bath is isotropic.

The etching anisotropy and the etching rate of the polyimide also depend strongly on the type of polyimide material chosen, as presented in detail in the test section given below. For polyimide films most commonly used in CERN's PCB workshop, the etching rate is about 6 μm/min, thus the time required to create microvias of 100 μm diameter in a typical 50 μm thick foil is between 10 and 15 min.

Another important parameter to control during the polyimide etching step is the aspect ratio which is defined as the ratio of the polyimide thickness to the via hole diameter (Castaldi *et al.*, 1999). For a metallization process which uses a stagnant (or immersion) bath, the best electrical interconnection was achieved with an aspect ratio of 0.5 (Figure 5(a)). In a metallization bath that uses a spray process, it is possible to achieve good results with an aspect ratio of 1.0 or more (Figure 5(b)).

One advantage of the ChemicalVia process is that it is a mass via generation process; all the microvia holes of the outer layers of a circuit are created at the same time. Some electronic circuits involve huge number of microvias, such as GEM detectors, which can have as many as 10^7 holes on each piece. Using a special rack that holds 20 GEMs at one time, shown in Figure 6, it is possible to etch 2×10^8 holes in just 15 min.

A typical bath of 60 l can support 2×10^8 holes 100 times more, before the bath starts to degrade.

Glue etching

The glue etching system, shown in Figure 7, is a system that pumps the sulphuric acid (H_2SO_4) etching solution through 18 nozzles, nine on each side of the system, with the piece centered between the nozzles. The pressure is approximately 2.5 bar and the flow is 20 l/min. The etching time through 12 μm of solid epoxy glue is less then 15 s.

Care must be taken when working with high concentration of H_2SO_4. The system makes use of PTFE and stainless steel materials, and includes some security electronics which control electro-pneumatic valves and the system pump. It uses a closed circuit for H_2SO_4 and an open circuit for water, in which both fluids cannot flow at the same time.

To simplify the glue etching procedure and to minimize the etching time, it is necessary to do two things: control the glue thickness in the application step and promote a brown oxidation of the copper at the bottom. The glue should be applied in a way such that it has the same thickness as the copper lines of the circuit layer to which the microvia connections are to be made (Figure 8(a)). This will minimize the time of glue etching and also minimize the problems of under etching which can lead to layer delamination (Figure 8(b)).

The brown oxidation of the copper is made before the application of the glue and consequently before the lamination of the polyimide; it permits a visual control of the glue etching process. During etching, H_2SO_4 de-oxidizes the copper when it comes into contact with it. In this way, a color change in the hole can be observed that verifies whether all the glue below the surface of copper is gone. This permits a better control of the etching time and helps to avoid under etching.

The etching characteristics of four different types of glue materials were investigated: solid epoxy glue, liquid epoxy glue, glue from prepreg, and polyimide glue. Liquid glue is

Table I
Bath properties used to etch polyimide in the ChemicalVia process

Bath	Chemical contents	Temperature (°C)	Bath purpose
1	Ethylene diamine+KOH	60	Etches the polyimide
2	NGL 1740	45	Stops the etching and cleans
3	De-mineralized water	Room temperature	Rinses the board

Figure 3
Schematic view of an automated polyimide etching system

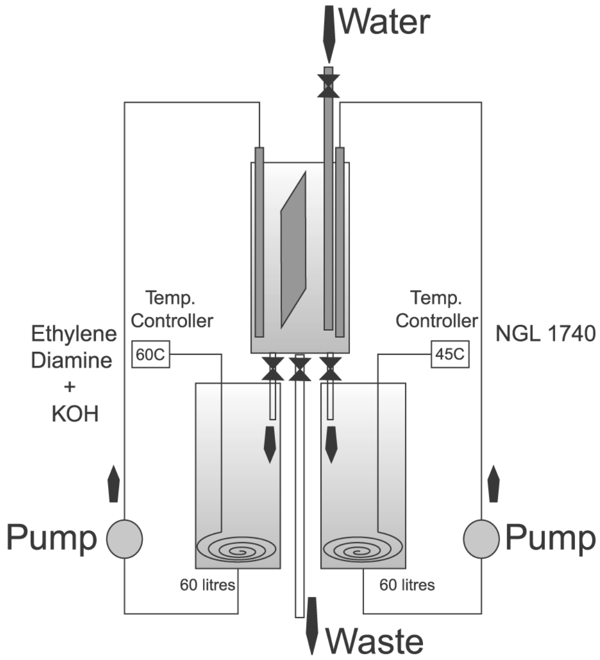


Figure 4
Influence of temperature and KOH concentration on the etching behaviour of polyimide

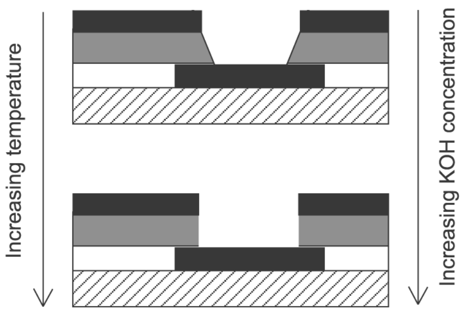
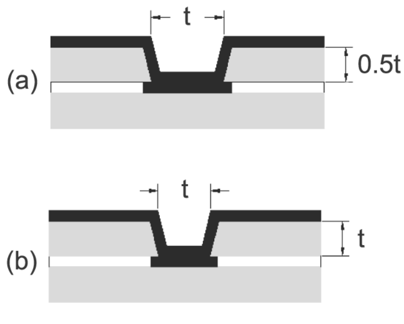


Figure 5
Preferred aspect ratio for a static metallization bath system (a) and with a spray system that uses nozzles (b)



more difficult to apply uniformly but is easier to etch than solid epoxy glue. Both epoxy glues dissolve quite rapidly in H_2SO_4. At the moment, two other types of glue application processes are being developed, one that would use glue from prepreg and the other that would use

Figure 6
Etching tool capable of holding 20 boards (300 × 450 mm) at one time

polyimide glue. The glue from prepreg would simplify the glue application process and the polyimide glue would permit us to combine both the polyimide and glue etching in the same step. This study is ongoing.

Material tests

This section discusses the types of polyimide and epoxy glue materials used in the production of microvia holes by the ChemicalVia process and presents the results of their etching behaviour.

The polyimide materials are sheets of polyimide coated on one or both sides by a copper foil. Flexible circuits are

Figure 7
Glue etching system

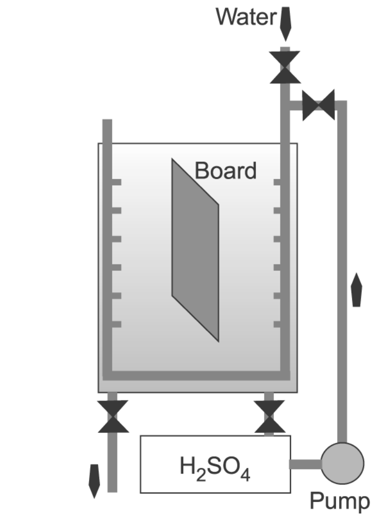
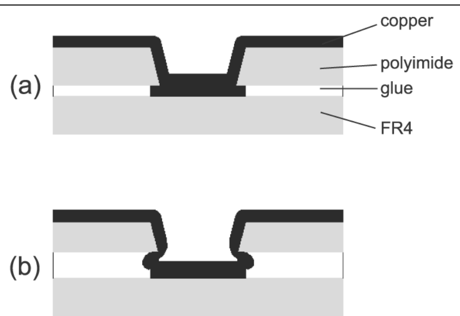


Figure 8
Influence of glue thickness on the etching. (a) The desired thickness; (b) excess of glue



normally built up of multiple layers of such copper-coated polyimide foils while rigid circuits normally use polyimide foils and FR4 board as a substrate.

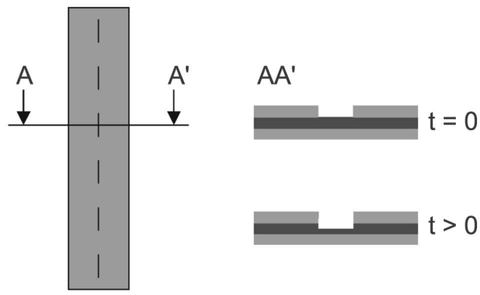
Several test samples of four different polyimide materials were prepared in order to characterize their etching behaviours. The four samples, described in Table II are polyimide foils coated with copper on both sides and with a series of small rectangular windows in the copper layer of one side. A schematic view of such a test sample is shown in Figure 9. Samples were etched for different time intervals in the ethylene diamine and KOH mixture (Table I), in baths of new or degraded etching solution. They were then cut and imaged at cross section in order to measure the remaining polyimide thickness as a function of the etching time and also to observe the etching profile.

Figure 10 shows a plot of the remaining polyimide thickness at the cross section as a function of the etching time for the four different materials.

Table II
Characteristics of different polyimide materials used to characterize etching behaviour

Polyimide material	Upper copper layer thickness (μm)	Polyimide thickness (μm)	Lower copper layer thickness (μm)
Polyimide 1	5	50	5
Polyimide 2	5	25	5
Polyimide 3	5	25	0
Polyimide 4	2.5	25	2.5

Figure 9
Schematic view of test sample used to characterize the polyimide etching



Polyimides 1 and 3 exhibit the same etching rate of about 6 μm/min, which is about twice as fast as polyimides 2 and 4. In general, polyimides 1 and 3 yield a better hole shape than polyimides 2 and 4. Figure 11 shows the shape of the microvia hole created in polyimide 1. The conical shape, due to the anisotropy of the etching, is better suited for metallization because the copper that will be deposited inside the hole will be thicker than the copper deposited in cylindrical shape hole. The final thickness of the deposited copper also depends on the aspect ratio of the microvia hole and on the type of bath.

Figure 12 shows the shape of the hole created in polyimide 2. The figure shows that under etching of the polyimide can result in poor metallization and a bad microvia connection. Polyimide 4 yielded a similarly bad hole profile due to under etching.

Considering the results from both the study of etching rates and the microvia hole shape, we can say that polyimide materials 1 and 3 are better for producing good microvia connections than materials 2 and 4.

Sample test board

Tests are currently underway to qualify the ChemicalVia process according to industry standards such as those from IPC, JEDEC, IEC, etc. Two-layer test boards, using an FR4 substrate glued together with a copper-coated polyimide foil, in which microvias form the interconnection between layers, will be produced using the ChemicalVia process. The materials used to create the test board are in accordance with IPC standards. Figure 13 shows an example of such a test board.

These test boards will use 80 and 50 μm microvia holes with aspect ratios of 0.625 and 1.250 produced by the ChemicalVia process. These test boards will be used to perform several types of tests: visual, dimensional, electrical, mechanical, environmental and chemical. The patterns used are daisy chain (blind via chains), via registration, surface insulation resistance, serpentine lines and dielectric breakdown.

Preliminary results from the test boards are promising as illustrated by a microscopic image of an 80 μm microvia hole shown in Figure 14. It shows the hole as viewed from above and at the cross section. Figure 15 shows a microvia poorly metallized by a stagnant bath due to its higher aspect ratio.

Advantages of the ChemicalVia process

Some advantages of the ChemicalVia process are listed below.

1 The process is compatible with standard assembly lines for printed circuits.
   - Simple implementation in standard PCB lines.
   - Every manufacturer will be able to produce HDI circuits.

Figure 10
Etching behaviour of four different polyimide materials as a function of etching time

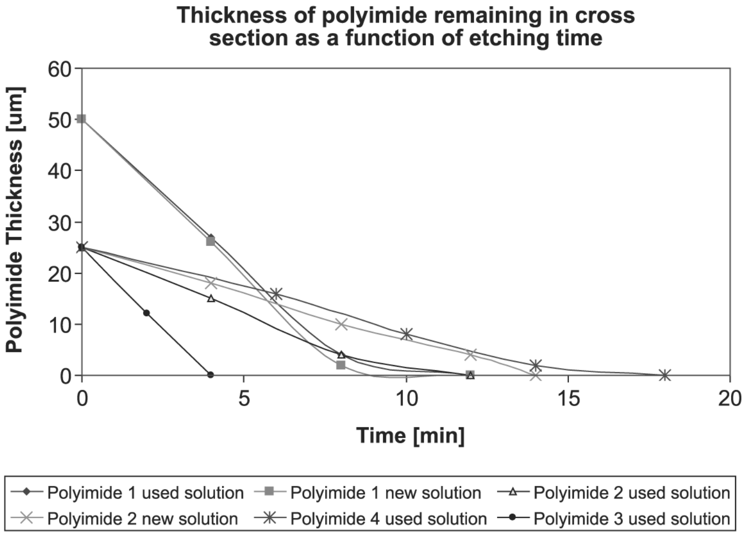


Figure 11
Cross section of plyimide 1 material showing desired shape of microvia hole

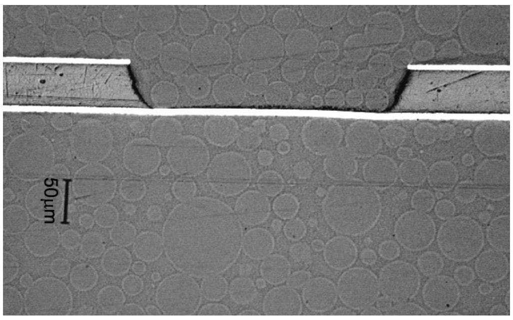
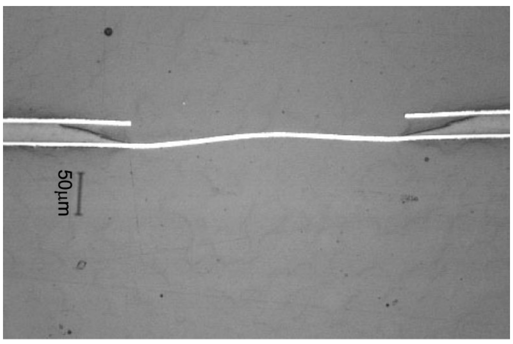


Figure 12
Cross section of polyimide 2 material showing under etching



2 Small initial investment in the standard PCB production lines.
3 Allows smaller companies to enter this market.
4 Low manufacturing cost.
5 Low maintenance cost.
6 Possibility to have a continuous assembly line.
7 Can form vias of any shape and dimension.
8 Global process – all the microvias in the same layer can be made in parallel at the same time.

For the ChemicalVia process, the more complex the circuit is, the more efficient the process will be. As an example, ten circuits with 200,000 via holes will take about 10-15 min using the ChemicalVia process as opposed to about 2 h with a hybrid laser system (250 holes/s). In the case of producing a single GEM, ChemicalVia process takes the same 10-15 min while the hybrid laser system would take 11 h. In the plasma etching process, the time to etch the same vias of the GEM is between 30 and 60 min but, has the disadvantage that the plasma process is isotropic and thus produces a poorer hole shape.

The disadvantages of the ChemicalVia process are as follows.

1 There are limitations on the types of base materials that can be used.
2 There is no possibility of forming a connection to the (n+2) layer directly from layer n.

However, the last listed disadvantage can be accommodated by first connecting layer n with the (n+1) layer, and then connecting the (n+1) layer with the (n+2) layer using a staggered via approach.

Comparison to other microvias technologies

As described in the previous sections, the Chemical Via process is a wet process that uses a chemistry other than heated KOH. It can be used to produce anisotropic etching and it is a mass via generation process. It is a process that is more economical for small and mid-size board production, than the photo-via or photo-imageable processes, and for circuits with higher microvia density the process is more time efficient. Thus for very high volume production of boards with a high density of via holes, the ChemicalVia process is very attractive. Furthermore, it is possible with the ChemicalVia process to make via holes with a minimum diameter of 40 μm on a polyimide material of 50 μm thickness, which is comparable with other microvia technologies. Table III summarizes a comparison of the ChemicalVia process with existing processes (Marcanti and Dougherty, 2001).

Figure 13
Sample test board used to qualify the ChemicalVia process

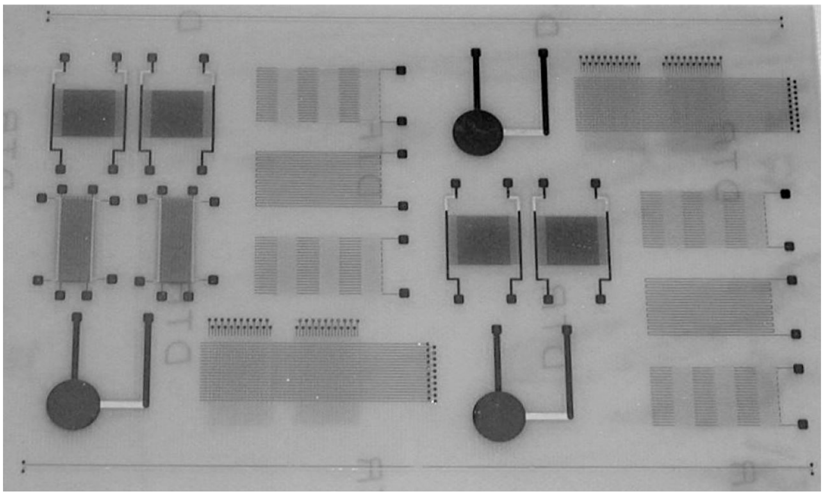


Figure 14
Top view (a) and cross section (b) of a good microvia hole with 80 μm diameter

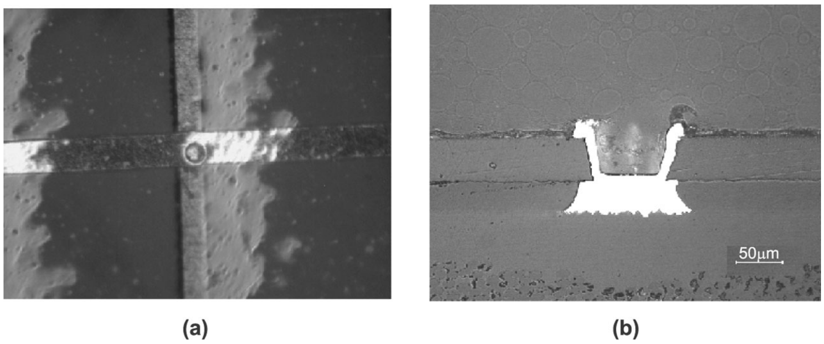


Figure 15
Cross section of a poor microvia hole

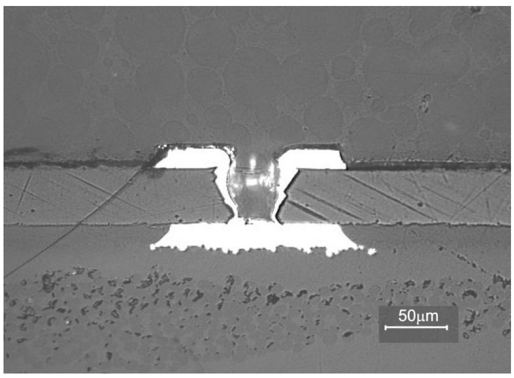


Table III
Comparison of ChemicalVia process with other technologies

	ChemicalVia	Laser	KOH	Plasma	Photoimage	Mechanical
Etching	Anisotropic	Anisotropic	Isotropic	Isotropic	Anisotropic	Anisotropic
Type	Mass via	Hole by hole	Mass via	Mass via	Mass via	Hole by hole
High volume production	Good	Less good	Good	Good	Good	Less good
Etching time	9-18 min	250 holes/s hybrid laser	–	30-60 min	–	–
Minimum via diameter	40 μm	30 μm	–	100 μm	–	–
Blind via production	Good	Good	Good	Good	Good	Difficult

Conclusion

The ChemicalVia process is a reliable solution for producing mass quantity microvias in high density circuit boards. The ChemicalVia process offers a significant advantage over plasma etching, in that it is anisotropic, which yields a better microvia hole profile and thus a better metallized connection between layers. As it is a mass via generation process, it offers a dramatic saving of time compared to laser etching in the case of circuits with high microvia density. Furthermore, it is less expensive and can be implemented in a standard PCB production line just by adding the different baths needed for etching of the polyimide and glue.

References

Castaldi, S., Fritz, D. and Schaeffer, R. (1999), "Limits of copper plating in high aspect ratio microvias", *Circuit World*, Vol. 25 No. 2, pp. 35-40.

De Oliveira, R. (2002), *Multi Chip Module Laminated - MCML*, Patent App. No. FR02/04305.

Lau, J.H. and Chang, C. (2000), "An overview of microvias technology", *Circuit World*, Vol. 26 No. 2, pp. 22-32.

Marcanti, L. and Dougherty, J.P. (2001), "Embedded passives: promising improved performance", *Circuits Assembly*, pp. 28-39.