Filling Micro-Vias
Theoretical and Practical Aspects

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Abstract:

Via filling becomes a necessity when chip carriers and other components shall be directly mounted onto the vias and when via dimensions are as small as the Cu layer to be deposited. During the process of blind and through microvia filling one observes a throwing power change with the deposition time and depending on the via dimensions, respectively. A change of the current density profile can be beneficial to meet via filling requirements in production. The filling capability depends on many chemical and physical parameters. In the paper presented the influence of the major variables, ranging from organic and inorganic additives to pulse parameters are being explained. Examples from horizontal and vertical production lines are shown and optimum via geometry considerations will be discussed.

Introduction

With increasing number of interconnects new technologies in PCB and package manufacturing, like the sequential built up (SBU), are being developed. At the same time structures and distances on the panels are being sized down to degree that a filling of the so-called microvias becomes a necessity.
Thereby efficient fan-out by mounting components and packages directly on the vias is assured. Vias with dimensions in the range of the Cu thickness to be deposited can only be plated with sufficient process security, if filled without inclusions. Certain IC package applications have this requirement for blind and through vias.

Some theoretical considerations

When looking at the plating process for microvias (MVs), one can conceive the most characteristic and most application relevant feature of these small structures.
What has been a constant and measurable entity in printed circuit board plating so far, becomes – when treating microvias – a variable and therefore a great unknown.

The throwing power, which describes the ratio of current density in the through hole to the applied current density, was so far defined merely by the latter and the (initial) dimensions of the via.

Compared to the initial dimensions, diameter and board thickness/depth of the blind via do not change considerably in the course of plating normal (non-micro) vias. The throwing power therefore remains constant throughout the deposition time and is easily determined by a decent microsection.

With microvias however the relative dimensional change during plating is considerable, with the throwing power (TP) not remaining constant and being a function of time.

A blind microvia (BMV) of todays mass production with diameter of 100 µm and a dielectricum of 70 µm (including Cu clad) is required to show a minimum Cu thickness of 15 µm in the hole. Even with a minimum TP of 100 % assumed the remaining dimensions after Cu deposition will be 70 µm / 70 µm (see Figure 1).

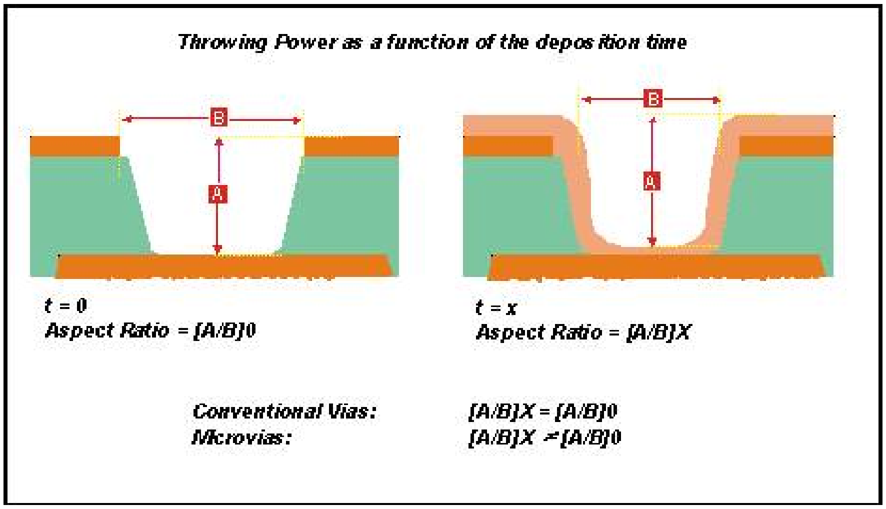


Figure 1: *Change of BMV Aspect Ratio during Cu deposition*

The aspect ratio of the descibed via shifts from 1:0.7 at time t_S (start) to 1:1 at time t_E (end). There is no question that with constant applied current density the TP will decrease from t_S to t_E. The TP measured after Cu deposition can therefore only be a mean acroos the entire process.

Two important conclusions can be drawn from the depicted example in figure 1. The displayed microvias can only be completely filled without inclusions, if current densities and processes with a minimum TP much greater than 100 % are selected. Furthermore a process of maximum efficiency for filling of microvias (with respect to product quality and productivity) involves the adaptation of the plating parameters (current density and pulse parameters) to the plating needs defined by the dimensions at a given time t.

Therefore the throwing power is a function of plating time and given dimensions at time t, respectively. The parameter “Aspect Ratio” as a reference does not define the dimensions with satisfactory precision. For a ratio of 1:1 and a given current density applied a BMV of 50 µm diameter will exhibit a lower TP than one of 100 µm diameter. In fact both dimensions, diameter and depth or thickness, independently determine the value of TP. And both parameters substancially vary with time t.

Thus:

$$TP = f(t) \qquad \text{(I)}$$
$$TP = f(CD, diameter\phi, depth\delta)$$

The local CD^{loc} and the minimum current density $CD^{\min}$ in the via are defined as follows:

$$CD^{loc} = CD \cdot TP^{loc}$$
$$CD^{\min} = CD \cdot TP^{\min}$$

The minimum Cu thickness deposited in time t is obtained by solving equation (II):

$$d^{\min} \approx \int_{t=0}^{t} CD^{\min} dt$$
$$\text{(II)}$$
$$d^{\min} \approx \int_{t=0}^{t} CD \cdot TP^{\min} dt$$

Refering to equation (I) Tp^{min} is an unknown function of time. Equation (II) can therefore not be integrated without further boundary value conditions defined.

Besides the requirement to fill the vias without inclusions, the final surface Cu thickness has to remain below a certain limit to meet fine line etching necessities.

The function of CD·TP integrated with respect to plating time needs to be optimised to stay below a maximum allowable Cu thickness. At the beginning of the deposition (at t_0) the function CD·TP with CD – as depicted in figure 2 - is relatively well known. It can be determined by microsection evaluations after short plating times.

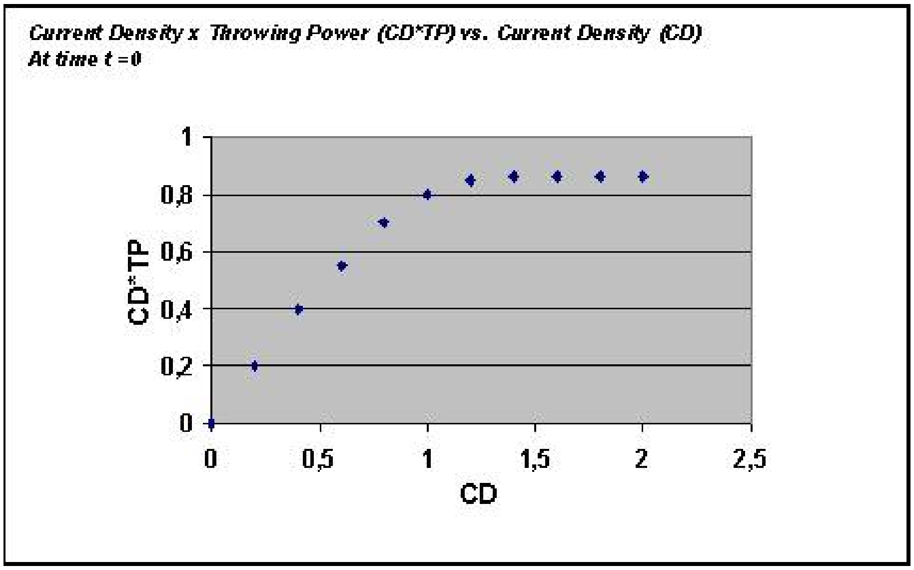


Figure 2: *A possible function of CD·TP with CD at time t_0 (for given microvia dimensions*)

Since the throwing power changes in the course of plating, the displayed function from Figure 2 is only valid for time t=0. With plating time and depending on the initial current density a different function for CD·TP with CD will result. The entire plating cycle is characterized by infinitesimal changes of CD·TP with CD; it can be defined by a three dimensional plot of CD·TP with CD and t.

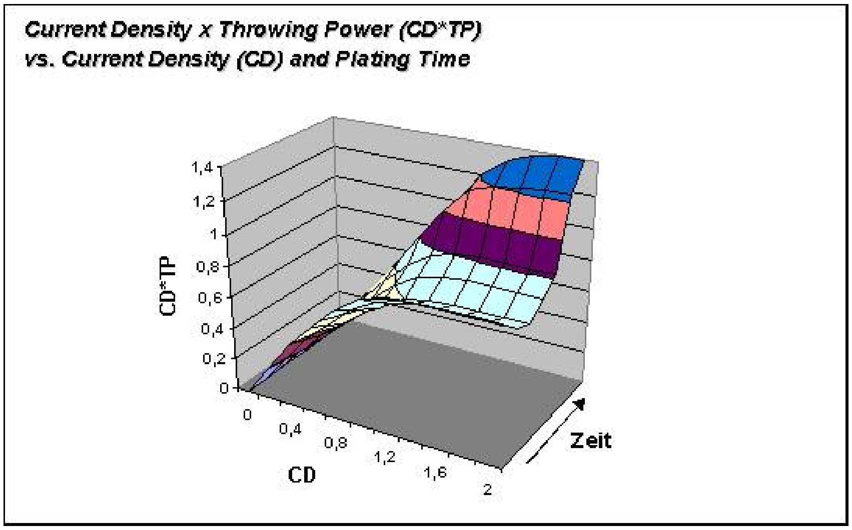


Figure 3: *Exemplary Representation of CD·TP with CD and t for microvia filling*

The deposition with respect to the 3D function shown is characterized by a single line. It defines the current density – time function chosen. For a given microvia it may follow the program depicted in Figure 4.

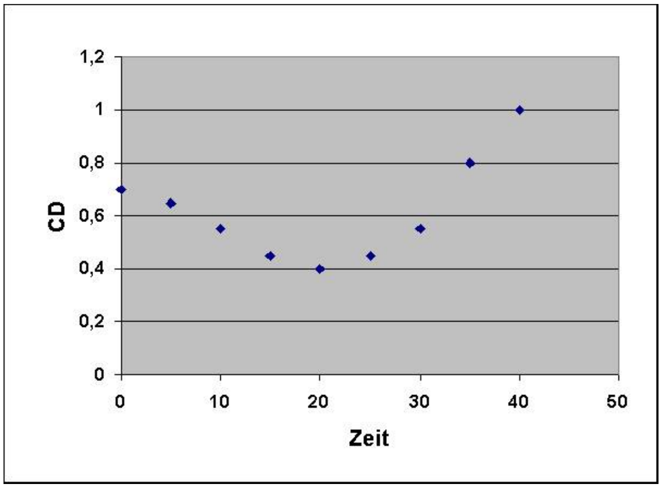


Figure 4: *An optimized function of CD with t for microvia filling*

Any other current-time sequence will result in a CD·TP-CD-time characteristic differing from Figure 3. The initial microvia dimensions will have an impact on the shape of the 3D function as well.

The Application

The n-dimensional equation described above can not be solved exactly and therefore only suitable approximation models can be used for via filling applications.
With respect to the microvia dimensions given, i.e. a laser drilled blind via of 90 µm width and 75 µm dielectricum, and knowing the function of CD·TP with CD for t=0, one will select the most suitable initial CD.

After the deposition of 10 µm and a TP of 130 % on the capture pad the resulting BMV will have an aspect ratio of app. 1:1 with 70 µm width and 70µm depth. To successfully fill this via without inclusions a lower current denity with increased throw is required. After 10 µm further deposition the BMV opening is at 50 µm with a depth of around 25 µm. Now a higher current density can be applied, since the dimple left needs to be levelled only.

The desribed process is explained schematically in Figure 5. The entire filling process is divided into several parts with a corresponding current density and an average throwing power.

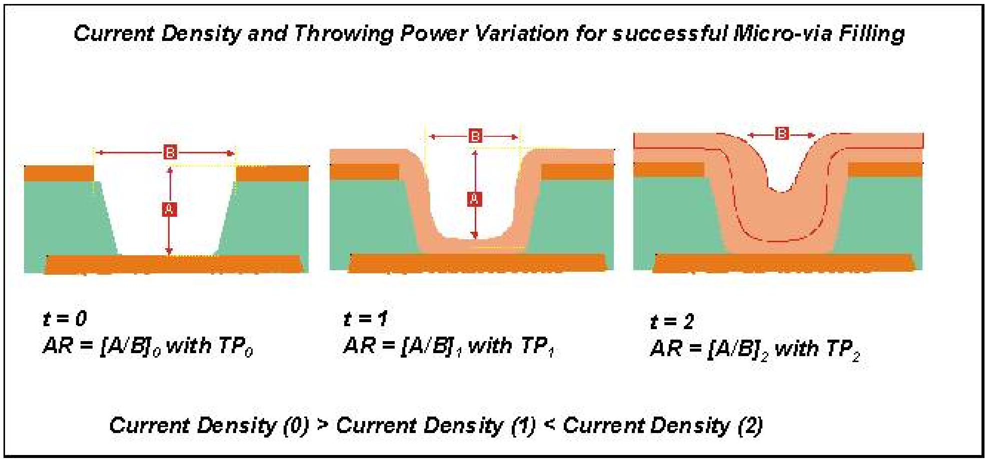
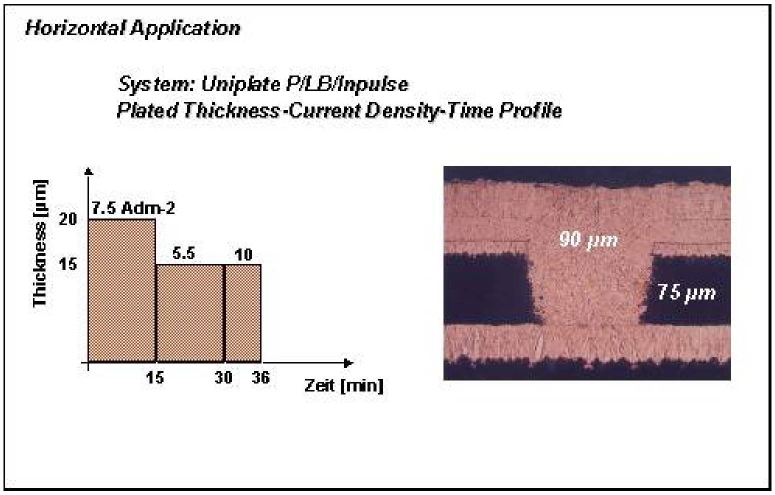


Figure 5: *Representation of a Via Filling Process, which itself is divided into three parts of differing current density*

Horizontal Application

In Figure 6 a microsection of a filled BMV of 90/75 µm initial dimensions is displayed. The average CD applied was 6 Adm^{-2}. The process was carried out in a horizontal Cu plater with insoluble anodes and reverse pulse plating applied. The current density for via filling was varied according to the reasoning explained above; the first plating interval of 20 µm took place at 7.5 Adm^{-2}, then 15 µm were deposited at 5.5 Adm^{-2} and finally the process completed with another 15 µm at 10 Adm^{-2}.



Horizontal Application

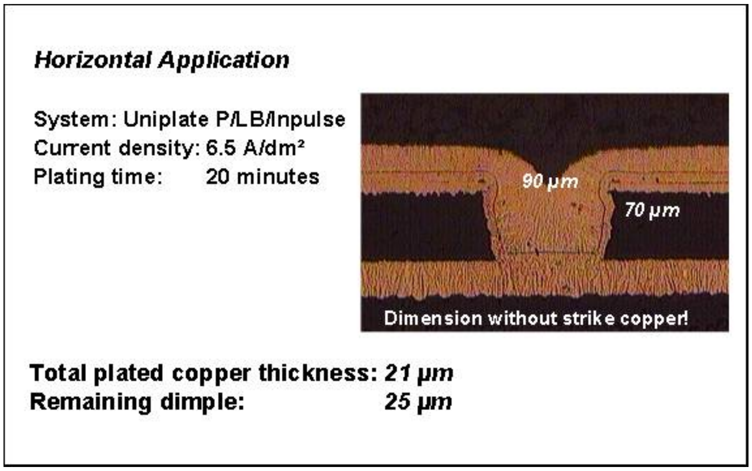
System: Uniplate P/LB/Inpulse
Plated Thickness-Current Density-Time Profile

Figure 6: *Microsection of a Filled Blind Microvia with corresponding thickness-CD-Time Profile*

The resulting surface Cu thickness of 50 µm is not suitable for fine line applications and has to be reduced by differential etching. The necessary full panel process can impose further difficulties for structuring the PCB or package surface.

Further tests have been carried out to optimise via filling with lower surface copper thickness. This has been made possible by modifications to the Uniplate system, equipment and chemistry. Figure 7 shows a micro-via diameter 85 µm and depth 70 µm processed in one pass through a Uniplate module. Parameters were 6.5 A/dm² average current density and plating time 20 minutes with a resulting surface copper thickness of 22 µm.

As can be seen the micro-via is not fully filled, the remaining dimple is approx. 25 µm. It can however be expected that if 30 µm is plated on the surface then the micro-via will be filled.



Horizontal Application

System: Uniplate P/LB/Inpulse
Current density: 6.5 A/dm²
Plating time: 20 minutes

Total plated copper thickness: ***21 µm***
Remaining dimple: ***25 µm***

Figure 7: *Microsection of a Filled Blind Microvia in optimised Uniplate system*

To achieve complete filling with a copper surface thickness of 20 µm the via dimensions have to be reduced to diameter 60 µm and depth 60 µm as shown in figure 8.

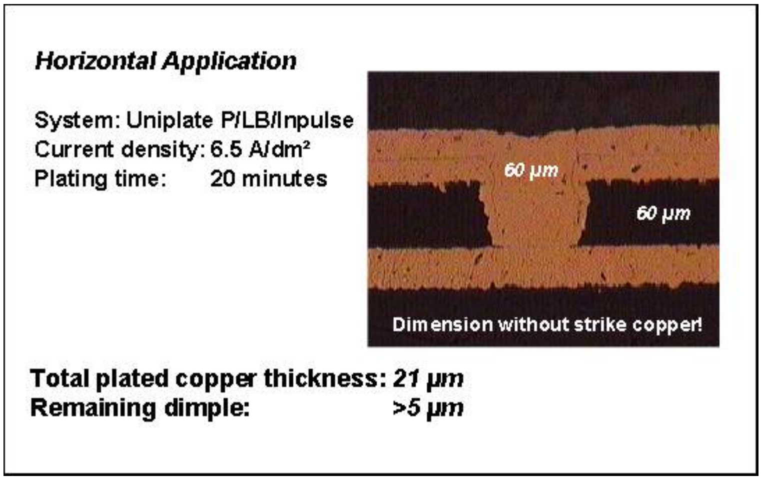


Figure 8: *Microsection of a Filled Blind Microvia showing nearly no remaining dimple.*

Vertical Application

Blind vias, which are currently being filled in production, possess a depth of approximately 40 µm at a diameter of around 100 µm. Thereby a deposition of 25 µm in pattern technology should not be exceeded. The most important chemical parameter for a systems adaptation to a via filling application are:

- The Cu Ion concentration
- The organic additives
- The Chloride ion concentration
- The temperature
- The bath agitation

Figure 9 compares two microsections of a 90/40 µm BMV, which was plated at 2 Adm^{-2} for 60 minutes. The influence of the Cu concentration for the filling behaviour of the electrolyte is demonstrated. A higher metal content considerably improves the filling result.

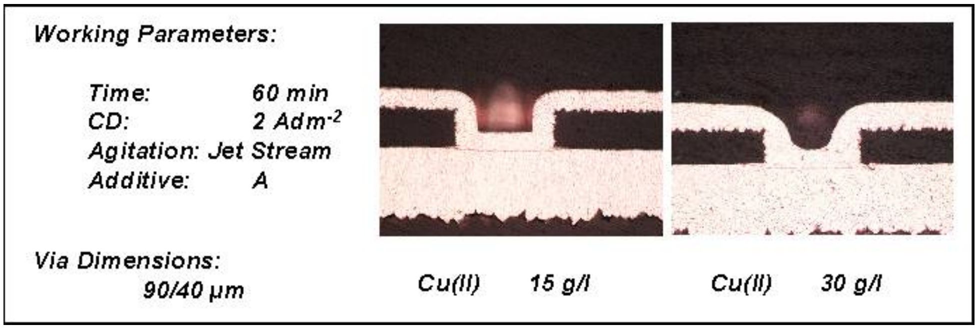
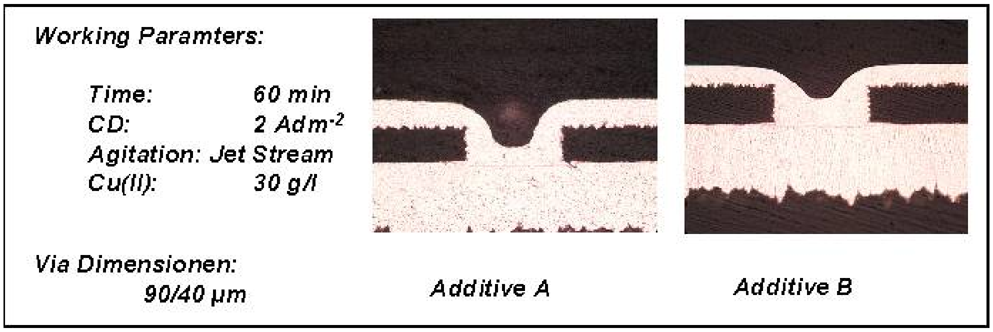


Figure 9: *Dependence of Filling Result with Cu Concentration*

The selection of the organic additives – nature and concentration – is undoubtedly most important for the bath performance with respect to via filling. In particular various leveller components are indispensable for the success of the operation. A comparison of two different levellers used for via filling is depicted in Figure 10.



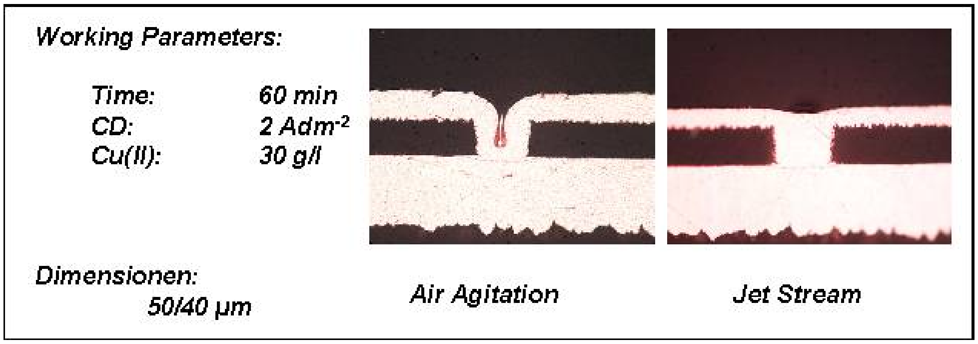
Working Paramters:

Time: 60 min
CD: 2 Adm^{-2}
Agitation: Jet Stream
Cu(II): 30 g/l

Via Dimensionen:
90/40 µm

Figure 10: *Dependence of via filling performance on leveller additive species*

Bath velocity relative to the printed circuit board can be influenced by various means. Air agitation, flight bar movement, pump rate and flooding direction can change the distribution of the Cu plated. This is true for conventional deposition processes as much as for the filling application. The usage of i.e. jet streams can lead to a significant improvement of the throwing power, as can be seen in Figure 11.



Working Parameters:

Time: 60 min
CD: 2 Adm^{-2}
Cu(II): 30 g/l

Dimensionen:
50/40 µm

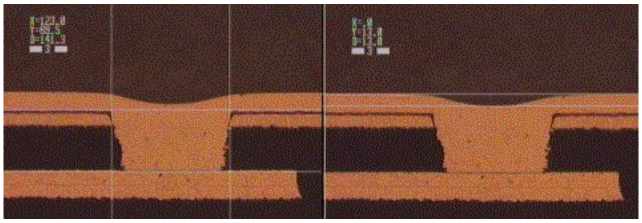
Figure 11: *Dependence of via filling performance on bath agitation*

Figure 12 shows a filled micro-via from a production printed circuit board with dimensions diameter 125 µm and depth 70 µm. The copper plating electrolyte is based on a modified leveller system which shows advantages in via filling particularly with depths greater than 40 µm. In this case a maximum dimple of 15 µm was seen.

Vertical Application Latest Results with a new leveller system

Working Parameters:

Time: 80 min
CD: 1.5 A/dm^2
Leveller: new Type



BMV Dimensions:
125/70 µm

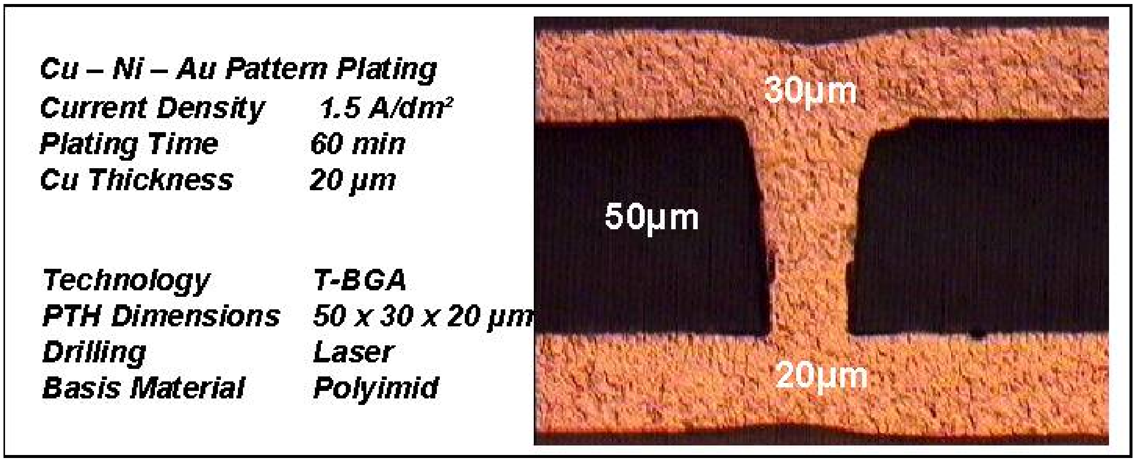
Remaining Dimple: ***max. 15 µm***

Figure 12: *Via filling with modified leveller system.*

Filling of Through Vias

When the dimensions of through holes are in the range of the Cu to be plated, then, in order to ensure sufficient process security, the filling of these vias becomes inevitable. On one hand improper filling can lead to entrapped process chemistry, on the other hand complete hole plugging of micro through holes in cores for SBU applications can become an increasingly difficult task.

The example shown in figure 13 was taken from a ball grid array substrate and displays a filled through microvia. The polyimide foil of 50 µm thickness had been laser drilled with a through hole of 20-30 µm diameter resulting.



Cu – Ni – Au Pattern Plating	
Current Density	***1.5 A/dm²***
Plating Time	***60 min***
Cu Thickness	***20 µm***
Technology	***T-BGA***
PTH Dimensions	***50 x 30 x 20 µm***
Drilling	***Laser***
Basis Material	***Polyimid***

Figure 13: *Filled Through Microvia in a BGA Substrate*

Summary

The dimensions of through and blind microvias have reached a limit where, due to various reasons, the filling of these cavities becomes a necessity. Especially in Japan the technique of via filling has already made it into production. This has been witnessed recently on the JPCA show in Tokyo, where high end package and PCB producers have presented production results and plating systems suppliers have explained their solutions for via filling.

The filling of vias in production is restricted to the vertical application at present. However there are extensive development activities at Asian and European manufacturers to use horizontal systems for this technology as well. In the near future we will also see horizontally filled vias without inclusions and with low resulting surface Cu thickness.