New Challenges for Higher Aspect Ratio: Filling Through holes and Blind Micro Vias with Copper by Reverse Pulse Plating

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Abstract

This paper presents systematic investigations on complete Through Hole filling for cores by a Cu electroplating process as an alternative to the common paste plugging process. This electro plating process consists of two steps, a first process to merge both centers of the through hole walls (X- plating) followed by filling up the resulting Blind Micro Vias. Processes and manufacturing technology are described as well as current limitations and requirements. Complete filling of through holes is achieved by Reversed Pulse Plating, RPP. This Through Hole filling technology is targeting both at HDI production and also at the packaging level.

Through Hole filling by RPP offers a viable alternative to the standard paste plugging for core processing in substrate manufacturing. Current core manufacturing requires a paste plugging process for through holes so that subsequent build up layers can be produced by sequential lamination, the flat core surface is essential for stacked via and also via in pad technology.

This paste plugging process requires additional process steps, each of which has its own limitations and contributes to the overall cost. Filling the core through vias by electroplating can eliminate the plugging process and significantly reduces the number of overall process steps which will also reduce costs. Moreover, it offers certain advantages such as potentially higher reliability in accelerated aging tests and an improved thermal management as the thermal conductivity of a completely copper filled through via is significantly higher than a paste plugged through via.

Today's challenges in the so called Through Hole Filling process are represented by through holes with a high aspect ratio. Voids after X-Plating occur easily for smaller through hole diameter and higher board thickness. In addition, depending on designs, different pitches on one board increase the difficulty to achieve an acceptable plating uniformity. This paper presents systemic variations of some key parameters and concentrates on the performances of the second plating step, the blind micro vias filling. Main focus is laid on recess distribution. Parameters as reverse pulse parameters, inorganic concentrations (Cu, Fe, and sulfuric acid), organic concentrations, electrolyte flow and temperature have been systematically varied and their influence on the filling performance are described.

Introduction

Through Hole filling by RPP offers a viable alternative to the standard paste plugging for core processing in substrate manufacturing. Current core manufacturing requires a paste plugging after Cu galvanization for through holes so that subsequent build up layers can be produced by sequential lamination, the flat core surface is essential for stacked via and also via in pad technology.

Instead of plating only a conformal Cu barrel into the through via it is now possible to completely fill it with Cu and thus eliminate the need for the plugging process reducing significantly the number of overall process steps and costs. Moreover, it offers certain advantages such as potentially higher reliability in accelerated aging tests and an improved thermal management as the thermal conductivity of a completely copper filled through via is significantly higher than a paste plugged through via.

Today's challenges in the so called Through Hole Filling process are represented by through holes with a high aspect ratio. Voids after X-Plating occur easily for smaller through hole diameter and higher board thickness. In addition, depending on designs, different pitches on one board increase the difficulty to achieve an acceptable plating uniformity. To understand the limitations of the process we are aiming at an identification of the key parameters. As there are two steps in the through via filling process we divided our experimental work accordingly. The 1st section will give an overview over the process itself (fig 1), the 2nd section will concentrate on the formation of the X (merging through via walls) and the 3rd section will deal with electrochemical filling of the resulting blind vias. Most of the tests have been conducted in a single board cell (volume 400 l) i.e. each plating cell is handling exactly one 18"X 24" sample board. Different test panels have been used and are described within the experiment itself.

All panels have been electroplated in the so called panel plating mode i.e. there were no dry film patterns on the board during plating. This panel plate technology is being used in standard production processes by applying the resist and the conductor pattern in a subsequent step.

General description of through via filling

Table 1 describes the process flow of the electrochemical through via filling technology

Table 1: Process steps characterizing the EC Cu Through Via Fill technology

Electrochemical Cu Through Via filling	
1.	Drilling
2.	Seed Layer Deposition (E'less Cu 0.2 -0.5 µm)
3.	Galvanic reinforcement (2-5 µm Cu)
4.	Galvanic Cu Filling -X-Plating (5-10 µm) -Via filling (10-15 µm)
5.	Dry Film Application and subsequent Structuring

The EC plating process is described in fig 1 showing the two main plating processes of step 4.

Fig. 1: Plating steps to a complete fill of a Through via with Cu, starting from a conformal plated layer . 2nd plating step is the formation of the X, resulting in 2 blind vias on both sides which are then completely filled

As an alternative electrochemical route one could consider a slow, conformal growth of copper on the side walls to a complete fill. That process has several disadvantages such as being slow (less productivity) and a higher risk for voids (see fig 2.)

Fig. 2: Conformal Cu growth to a complete fill may end up in producing a long ribbon like void

Moreover, this conformal technique would require too much Cu on the surface (approximately ½ hole diameter) whereas the above mentioned X-formation offers the possibility to significantly reduce the Cu overburden. That is achieved by applying a combination of reverse pulse plating and etching in one electrolyte. The electrolyte contains not only Cu but also Fe^{2+} and Fe^{3+}. Cu is deposited as usual on the cathode (panel) whereas the Fe2+ ions are used to carry the current at the dimensionally stable anodes (DSA) and prevent oxidation of organic additives. The oxidation product Fe^{3+} is being used to dissolve the consumed copper chemically in a second compartment filled with pure Cu balls/clippings and reduced again to Fe^{2+}. But the Fe^{3+} cannot only be used to replenish Cu but also to lower the amount of the Cu deposition on the panel surface.

$$Cu^{2+} + 2e^- \rightarrow Cu \qquad E = 0{,}340 \text{ mV vs. SHE} \qquad \text{(I)}$$
$$2\,Fe^{3+} + 2e^- \rightarrow 2\,Fe^{2+} \qquad E = 0{,}771 \text{ mV} \qquad \text{(II)}$$

Reaction (II) is electrochemically favored against (I) and thus the amount of Fe^{3+} reduces and determines the amount of deposited Cu. A control unit between plating and dissolving tank regulates the exchange between both compartments and can control the amount of Fe^{3+} within ±0.1 g/l which is a prerequisite for a good process control as can be seen later on in this report. The exchange of electrolyte is much stronger on the surface than in a via so that this effect is mainly observed on a surface and not in vias especially not in a blind vias.
With this technology we were able to reduce the amount of Cu overburden for a 100 µm thick core from 50 µm down to now 13 µm (see fig 4).

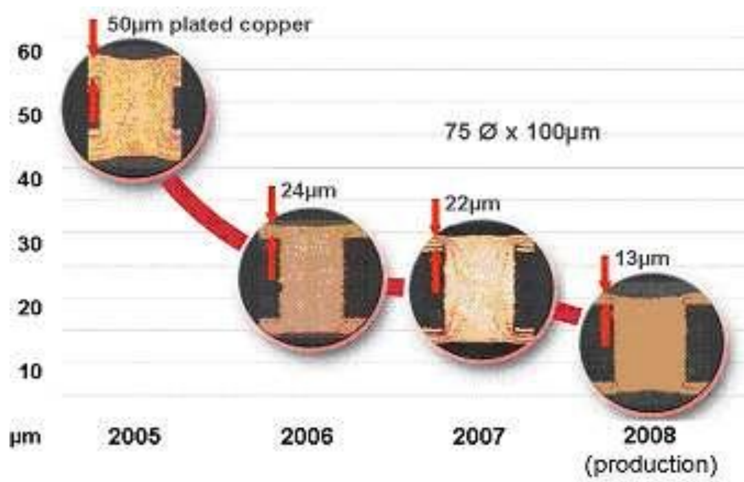

Fig 4: Development of through Via filling technology: reduction of Cu overburden for a 100µm thick core

This reduction was a prerequisite for a production scenario since the Cu thickness determines in the end the achievable lines and spaces in the circuitization process of approx. 2 x Cu overburden: i.e. 13 µm → 26 µm l/s.
Nevertheless, the main core thickness for IC substrates is thicker than 100 µm. Most of today's products show cores of 400 µm thickness or more. These cores are extremely difficult to fill without void formation and require a long plating time. So it was the aim of this work to expand the technology to such cores by determining main parameters and improve each step of the process.

Experimental
We are using several reverse pulse plating parameters in the following chapters and would like to explain notation
Example: 5/40 80/2 →
5= Forward or cathodic current density (ASD)
40 =Reverse or anodic Current density (ASD) -
80 = Cathodic plating time(ms)
2 = Cathodic plating time (ms) .
So 5/40 80/2 is an 80 ms cathodic pulse with 5 ASD followed by a 2ms anodic pulse of 40 ASD

X- Plating

As there are a huge number of parameters we started a first series of experiment in a small lab tool to determine which of the following parameters might have a significant influence. We used a small 20 L test cell, 400 µm thick core panels with 100 µm hole through holes and varied in several small DOE's of 3 parameters. We found that the parameters in italic showed a significant influence determined by statistical software tools and set up further experiments in a production tool on 400 µm panels with through hole of 100µm diameter.

- *Current density and pulse parameters*
- *Fe^{3+} concentration*
- *Temperature*
- *Cu concentration*
- *Cl –concentration*
- *Electrolyte agitation*
- Fe^{2+} concentration
- Sulfuric acid concentration
- Brightener (accelerator) and Leveller (inhibitor) concentration (commercially available Inpulse electrolytes)

The nature and type of additive has a big influence on the plating performance but in this specific case chosen ratio of brightener and leveller does not have a significant influence. We also investigated the influence of the **panel design** on the X- formation as it turns out that isolated and clustered through holes (small pitch, many neighboring through holes) may show different results as depicted in Fig 5.

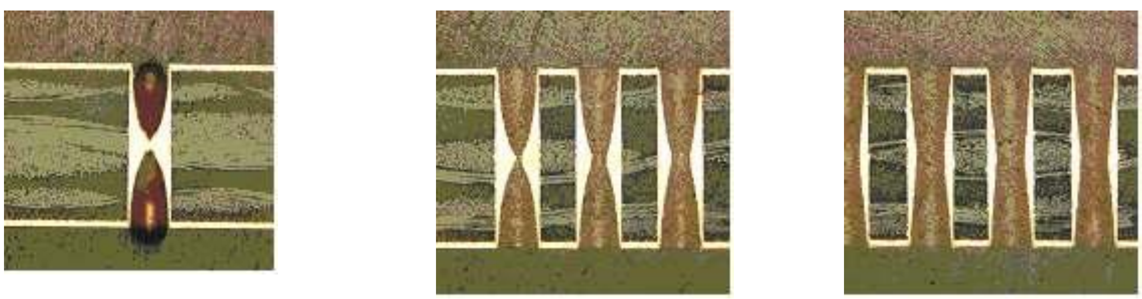

Fig. 5: Difference between isolated and clustered through holes. Left: isolated, right clustered TH with 200µm pitch, middle through holes a the edge of such a cluster

Parameters for this experiment at 40°C were

- Cu : 25 g/L
- H2SO4 : 200 g/L
- Fe2+: 15.0 g/L
- Fe3+: 0.5 - 1.0 g/L
- Cl^- : 100 mg/L
- RPP: 1.5/40 – 80/4

Commercially available additives were used according to data sheet. The differently located through holes required different plating times to form the bridge in the middle. So the minimum time to form the X is always determined by the clustered through holes.

Electrolyte flow

The difference between these clustered and isolated TH's could be minimized by increasing the electrolyte flow onto the panel. The flow direction was 90°C (rectangular) to the surface. Doubling the flow rate resulted in a homogenous X–formation with little difference. The effect of Fe3+ is even stronger as can be seen from Fig. 6. Here, we varied the Fe3+ concentration only from 0.5 g/l up to 1.0 g/l . The other electrolytic parameters were: Cu : 50 g/l sulfuric acid. The result is that with a higher ferric concentration a much slower X- formation is observed. Both experiments have been conducted under identical parameters. The consequence of this result is that the control of ferric ions is extremely important for handling the process. Therefore, we installed the control unit between the plating and the dissolving tank so that the ferric ion concentration can be controlled within ± 0.1 g/l.

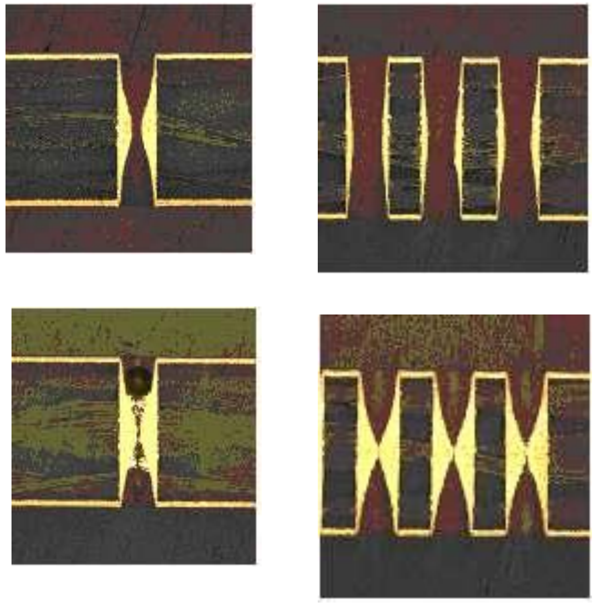

Fig 6: Effect of ferric ions on the X- formation: Top: 1.0 g/l and bottom 0.5 g/l ferric . Left isolated and right clustered through vias

The effect of Cu concentration on the X- formation is different to the usual Blind Via filling: In contrast to the latter process a lower Cu concentration turned out to be beneficial. The influence is significant both for the X- formation and for the distribution of the X between the isolated and clustered TH. An additional test run with 18 and 32 g/l Cu on very thick panels (3.2 mm with 0.3 mm hole diameter) confirmed the result. With these panels it is not possible yet to achieve through via filling but we did not aim at a complete X- formation since differences between experiments can better be evaluated before the X- is finally formed. We stopped plating after a certain time period (55 min) and measured the thickness in the middle of the hole compared to the surface. With the 18 g/l we increased the Cu thickness in the middle of the hole by a factor of 1.9.

The same effect had the increase of temperature from 20 to 40°C.

Summarizing our findings for the optimization of X- formation results in following proposals:

Use strong reverse pulse. A 5/50 80/4 for 15 min leads to closure of the X- formation on 400 µm cores with 100 µm diameter

Use lower Cu concentrations of 25 g/l for regular distribution

Use higher Cl^- concentration 90 instead of 60 mg/l

Use a strong electrolyte flow to minimize differences between clustered and isolated TH

Use low ferric concentrations (0.5 g/l)

Above mentioned parameters were used to plate a 400 µm/100 µm core as depicted in fig 7. Additional parameters were 240 g/l sulfuric acid and 5 g/l Fe^{2+} added as ferrous sulfate

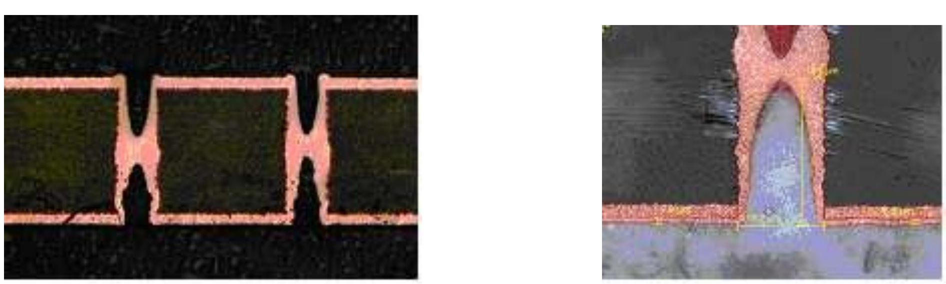

Fig 7: 400 µm thick core with 100 µm TH plated within 15 min. Right detail showing 9 µm plated Cu on the surface while > 50 µm Cu plated in the middle of the via

Blind Via Filling

Most of the following experiments have been performed with boards having three different BMV's with a depth of 40 µm and width of 75, 100, and 125 µm. These sample boards have been chosen because of their well defined and reproducible via structures. Information gathered on these boards was then applied on through vias to achieve the best possible result. All tests have been conducted with an Inpulse electrolyte system (Cu/Fe) with the same commercially available additive system.

Following parameters have been investigated:

- Reverse and Forward Pulse time and current
- Temperature
- Electrolyte Flow
- Fe3+ concentration

The Cu concentration has not been investigated in this series due to the fact that its effect is already well known: A high Cu concentration is beneficial for via filling.

Reverse and Forward Current: The 5/40 80/2 parameter set has been chosen as a start point. Fig. 8 shows the influence of the reverse time on the remaining dimple for the 3 different blind vias. The electrolyte was set up with 50 g/l Cu, 150 g/l Sulfuric Acid, 63 mg/l HCl with Inpulse brightener (accelerator) and leveller (inhibitor) and plated at 45°C

Increasing the reverse time has a significant effect on the filling performance as it changes from a deposit with a recess of a few µm into one with a convex dome on top of the via. As expected, the smaller vias are easier to fill as the larger ones. Shortening the cathodic pulse while keeping the anodic pulse constant leads to a similar result. This effect is in line with the explanation that via filling is mainly achieved by a changing ratio of accelerating and inhibiting additives in a via and surface. As described elsewhere [3] the Cu accelerating agents are depleted during a reverse cycle mainly on the surface but not in a via. There, a net accumulation and thus acceleration is observed. Net accumulation of accelerator in a via compared to the surface can be achieved either by a intensifying the depletion rate from the surface (stronger anodic pulse) or by increasing the frequency of the anodic pulse.

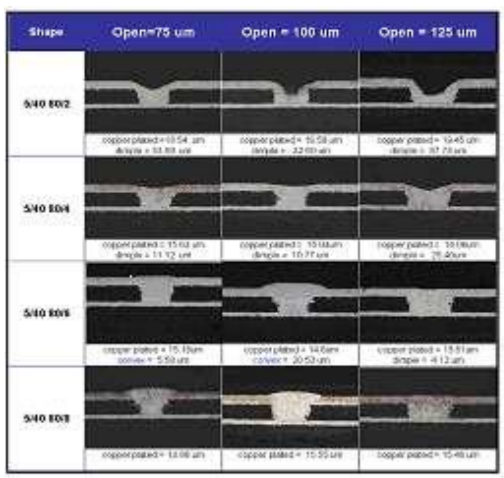

Fig. 8: Influence of the reverse (anodic) time (last no in left column in ms) on via filling. Filling performance significantly improves with reverse time

The effect of the forward and reverse current density on the dimple is shown in fig. 9 for the same electrolyte. Best results are achieved with lower forward current densities as it is expected. From via filling experiments in pure DC mode it is well known that lower current density usually leads to a better filling performance. This effect is also seen under reverse pulse conditions.

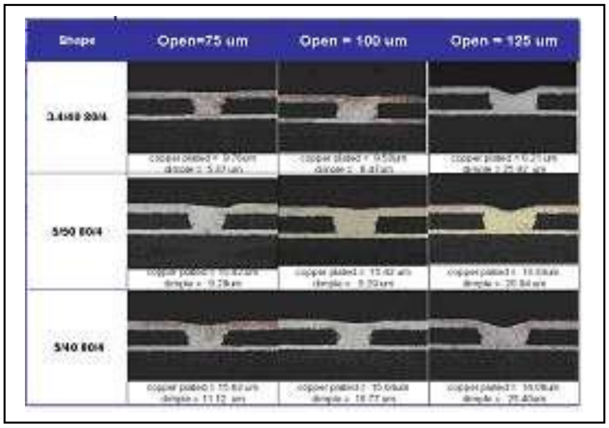

Fig. 9: Influence of the forward and reverse CD (1st and 2nd no left column in ASD) on via filling. Filling performance significantly improves with lower forward CD

Electrolyte Agitation

The influence of electrolyte agitation on the filling performance has been investigated by using frequency controlled pumps which feed the spray bars. The electrolyte is pumped through nozzles directly onto the board (90° angle). We used the same electrolyte set up as before. The frequency is then changed during the plating procedure, as it turned out that this procedure gave the best performance. At first, a thin protecting Cu layer with moderate pulse parameters is deposited and then followed by the modification of the electrolyte agitation. The higher the pump frequency the higher the agitation rate. At the end of the cycle again a moderate pulse layer is plated to achieve a smooth surface.
In general, one can observe with lower agitation rates a better via filling performance (fig 10). With increasing pump frequency significant dimples are observed so that the best results are achieved with low agitation rates.

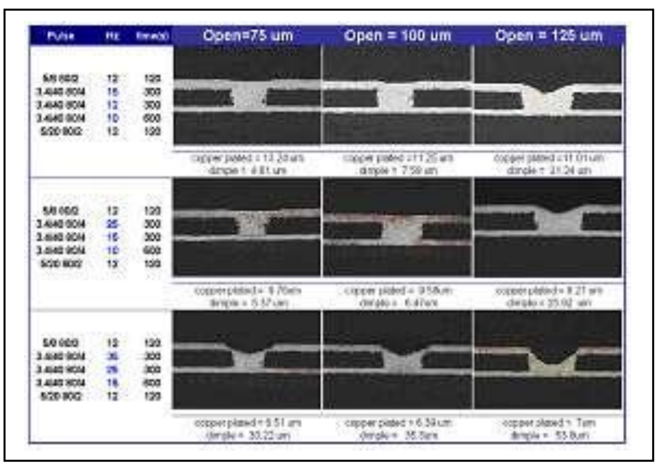

Fig.10: Influence of agitation on filling performance. Higher pump frequencies in blue relate to higher electrolyte agitation. Low agitation (top) improves filling performance

Temperature Effects

Since the dimple performance is depending on the adsorption/desorption ratio between accelerator and inhibitor one would expect a certain influence of the temperature. Therefore, we varied the temperature over a range from 25-50°C under the same electrolyte setup as before and used the best pump frequency program (top experiment in Fig. 10). As it turns out there is an optimum temperature of about 35°C but the influence of this parameter is not as strong as both aforementioned ones (pulse and agitation).

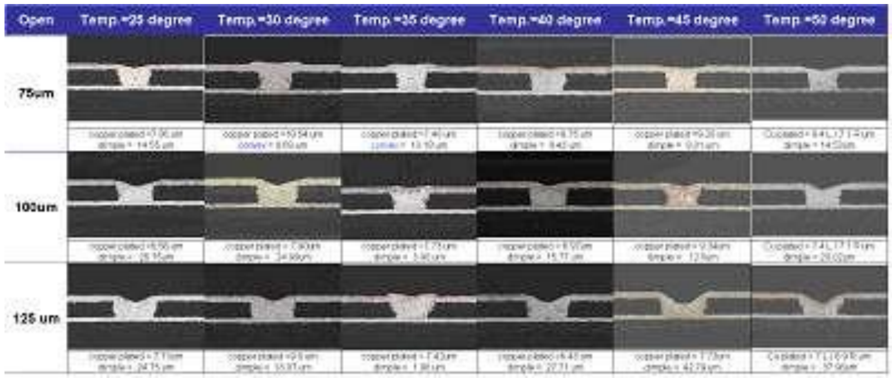

Fig. 11: Influence of temperature on Via filling

The panel surface is also affected. The surface becomes rough below 35 °C and very smooth above 40 °C, so that depending on requirements a compromise has to be found between good via filling and surface appearance.
Fe^{3+} Influence: It can be expected from equation (I) and (II) that the overall yield for the copper deposition is strongly affected by Fe^{3+}. Fig. 12 depicts this very strong dependency. This current yield is measured by weight difference against the theoretically possible Cu mass of 100%. A lower current yield than 100% usually needs to be counterbalanced by additional plating time. This is not necessarily the case for the via filling application since the amount of plated Cu on the surface is not equivalent to the amount in a via. The relevant parameter is the dimple not the amount of plated Cu on the surface. Hence, the amount of plated Cu can vary with the Fe^{3+} concentration to achieve the best performance. The experiments shown in the graph 13 were conducted with aforementioned electrolyte, pulse and pump parameters at 45 °C.

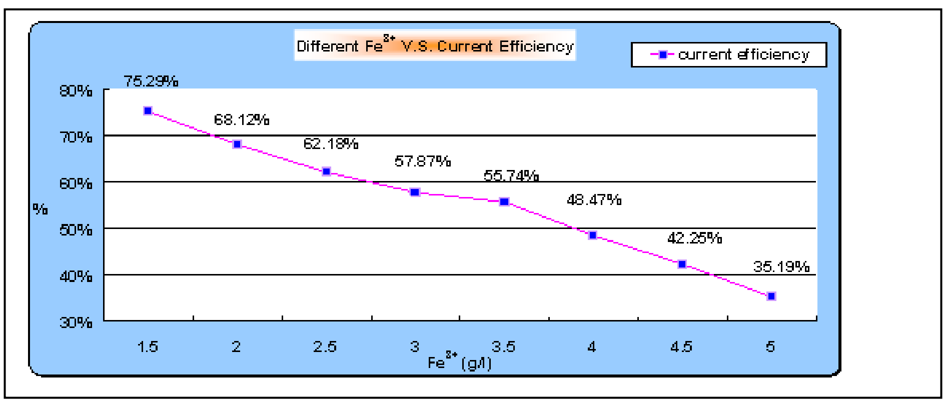

Fig. 12: Yield (Cu) as a function of Fe^{3+} concentration

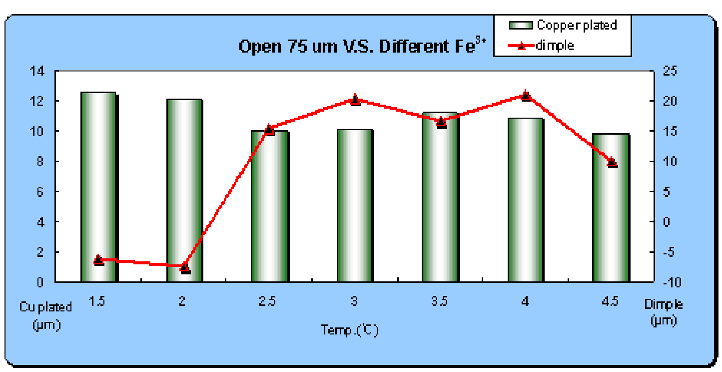

Fig. 13: Plated Cu thickness (columns) and Dimple (red line) as a function of Fe^{3+} concentration for 75 μm x 40 μm BMV's.

As it turns out dimples are lowest for lower ferric concentrations. Contrary to this is again the surface appearance of the boards. The surface becomes smoother with increasing ferric concentrations. Again a compromise between dimple performance and surface appearance has to be found.
Summarizing the optimization experiments to fill blind vias leads to following results

- Apply CD of about 3- 4 ASD cathodic and apply stronger reverse parameters to decrease the dimple (on cost of surface roughness): Best compromise 3.4 / 40 80 / 4. Via filling is achieved within 24 min.
- Decrease electrolyte agitation for a smaller dimple.
- Apply low Fe3+ concentrations, depending on required surface roughness
- Work at 35- 40 °C to achieve best dimple

Summary and out look

Aim of the above presented optimization experiments was to identify the best possible parameter sets and combine it for Through Vias thicker than 100 µm , especially for 400 µm thick cores. For some parameters a compromise between dimple and surface roughness had to be chosen.
This test series showed that for a successful fill of thicker core as 400 µm a split into different electrolyte types is necessary with very different parameter sets.

Table 2: Process parameters for both TH Fill steps

Parameter	**X- formation**	**Via fill**
Pulse Parameter	Strong reverse	Strong reverse
Overall current density	3-4 ASD	3-4 ASD
Temperature	40°C	35-40°C
Cu^{2+}	Low 20-30 g/l	High > 40 g/l
Fe^{3+}	Very low 0.5g/l	> 1.5 g/l
Electrolyte agitation	Strong	Low
Time	Approx 15 min	40-60 min

At this moment we can successfully plate and fill through vias for core with thickness of 300 µm or less within less than an hour and without occurrence of voids. Some examples are given in Fig. 14

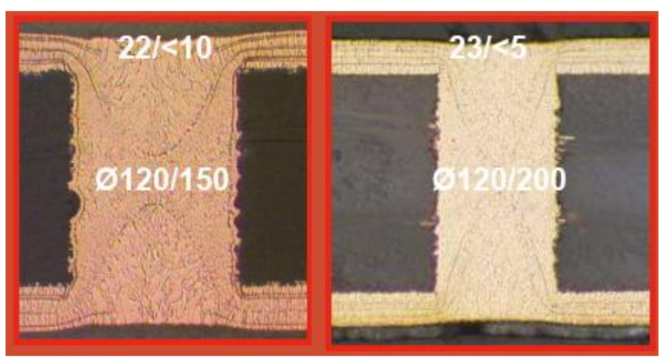

Fig 14: Filled vias : 150 and 200 µm cores which have been plated with 22 resp. 23 µm Cu to achieve less than 10 resp. 5 µm dimple

On the other hand 400 µm cores show still some voids. These voids are usually small (10 µm or less) (Fig. 15)

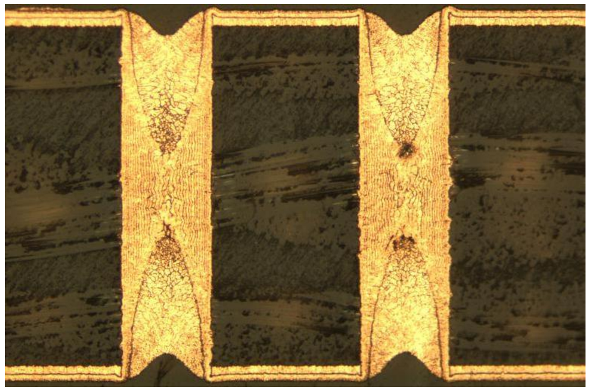

Fig 15: Completely filled TH showing small voids

Investigations on the effect of these voids are under way and further planned. Especially reliability measurements will be performed which should show whether the voids will lead to cracks or stay inside the via as they seem to be perfectly encapsulated. Whether this technology can be expanded over 400 µm cores is still unclear. There is a great potential for completely filled Cu vias as thermal vias since the thermal conductivity of Cu is several magnitudes higher as every paste. But the greatest hurdle for this application is the use of very thick panels (> 1mm) which require huge amounts of Cu and thus long process times.

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3. Stephen Kenny, Bernd Roelfs," High Aspect Ratio Package Core Production with Electrolytic Deposited Copper", IMAPS 2010 - Research Triangle, 43rd International Symposium on Microelectronics October 31 - November 4, 2010

New challenges for higher aspect ratio: Filling Through holes and Blind Micro Vias with Copper by Reverse Pulse Plating

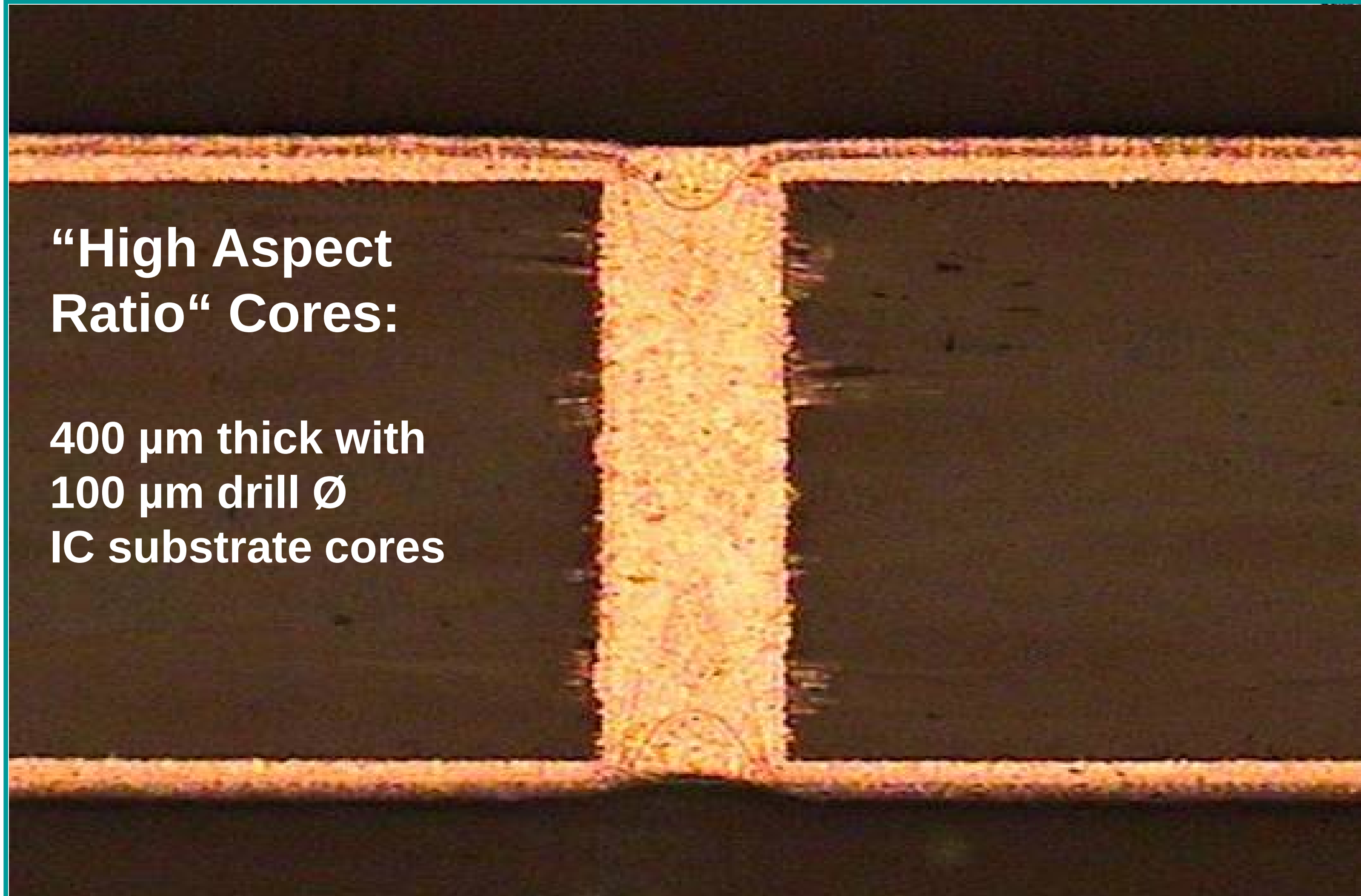
Nina Dambrowsky, Christof Erben, Stephen Kenny and Bernd Roelfs

Presented by Mike Palazzola

ATOTECH

Outline/Agenda

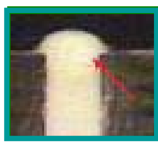
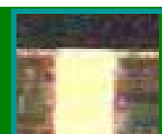
- Introduction to TH Fill
- Aim
- Experiments
- Conclusions

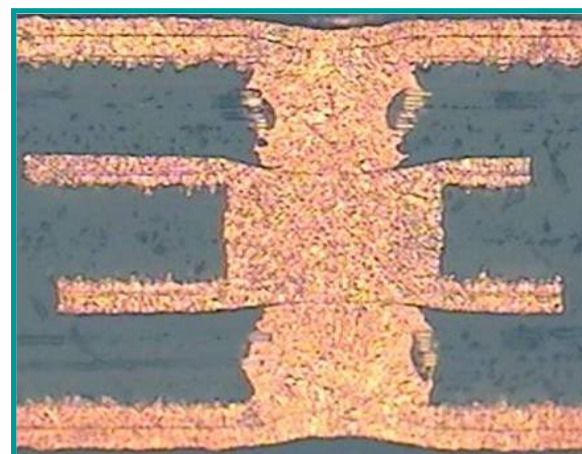


“High Aspect Ratio“ Cores:

400 µm thick with
100 µm drill Ø
IC substrate cores

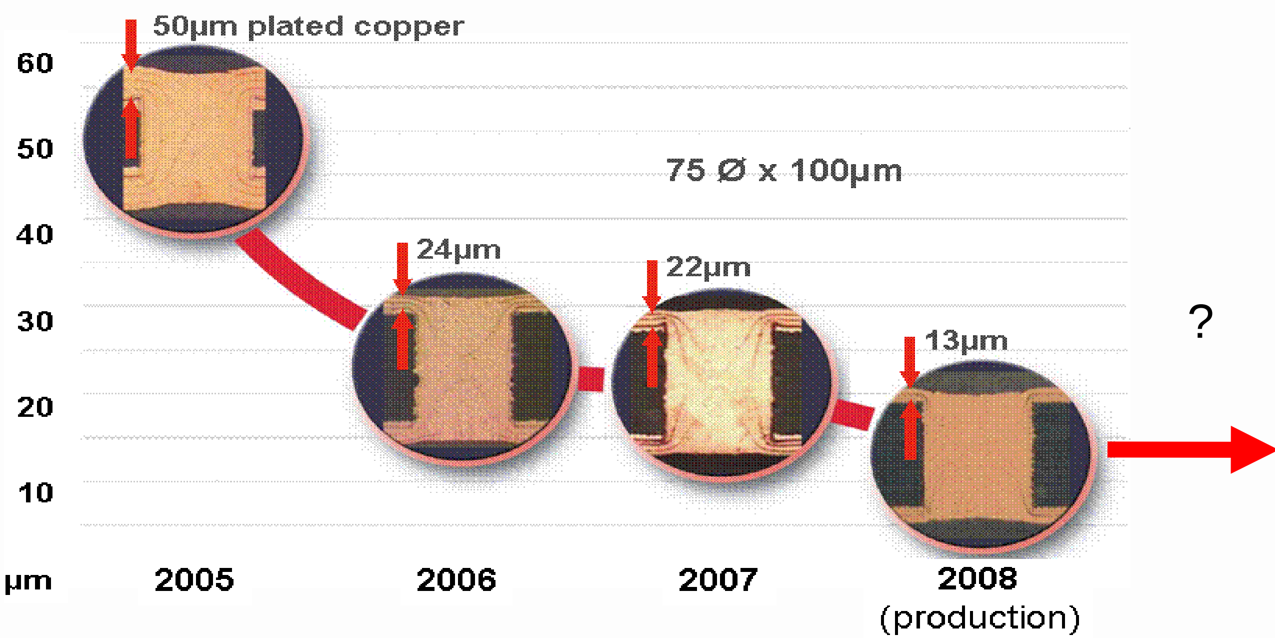
Plugging Processes in Comparison

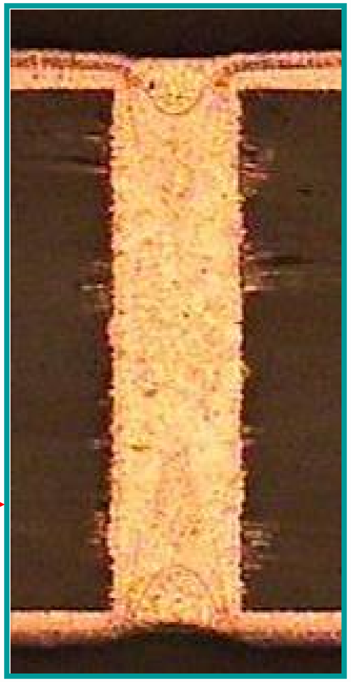
	Paste Process		Electrolytic Process
1	Through hole drilling	1	Through hole drilling
2	Cu seed layer (ativation)	2	Cu seed layer (activation)
3	E‘lytic Cu plate 18- 25 µm	3	E‘lytic TH fill 12 – 20 µm Cu
4	Resin plug	4	Dry film
5	 Cure		
7	Brush/Grind 		
8	2nd Resin metallization		
9	2nd Panel plate 18-25 µm		
10	Dry film		



Through Hole Filling

- Evolution of Electrolytic – TH Filling
- Surface reduction

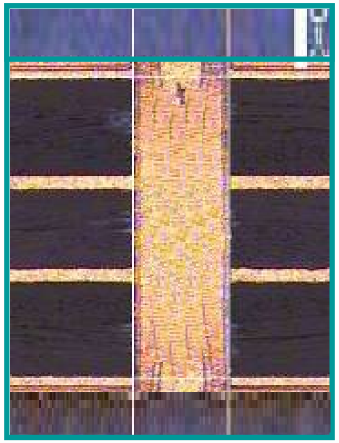




100 Ø x 400µm

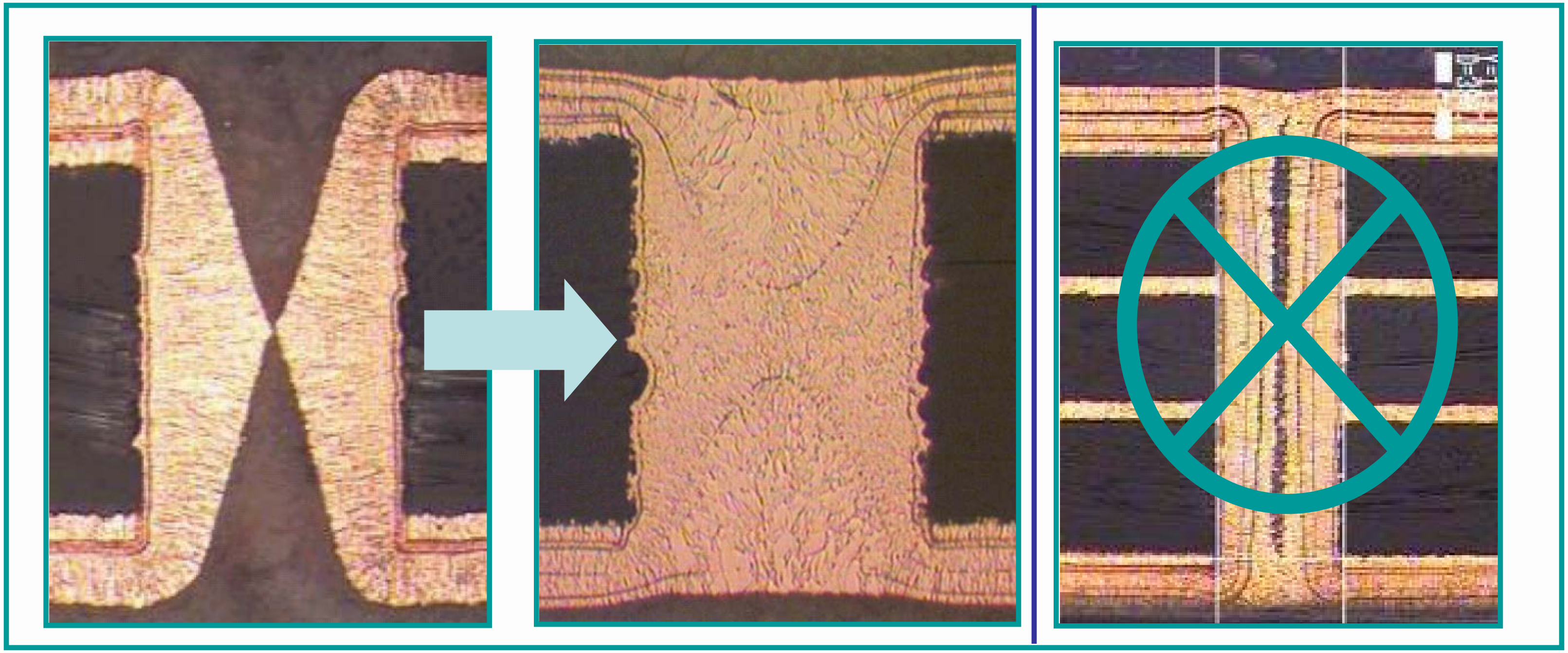
Aim – Fill 400 µm Cores

- **with minimum Cu on surface (< 25µm)**
  - For fine line application
- **without voids**
  - For higher reliability
- **within a plating time of 100 min**
  - For realistic production through put



Mechanism – Through Hole Filling

- 2 ways: Bridge vs. conformal



Aim – Fill 400 µm Cores

Separate process development for Bridge - and subsequent BMV filling
→ Two different developments for two different mechanisms:

1. **Bridge Plating**:
   – **Reshaping bridge for easier fill**
2. **BMV Filling:**
   – **Faster Via fill with new electrolyte**

Mechanism – TH Filling

- **Bridge-formation: Multiparameter field**

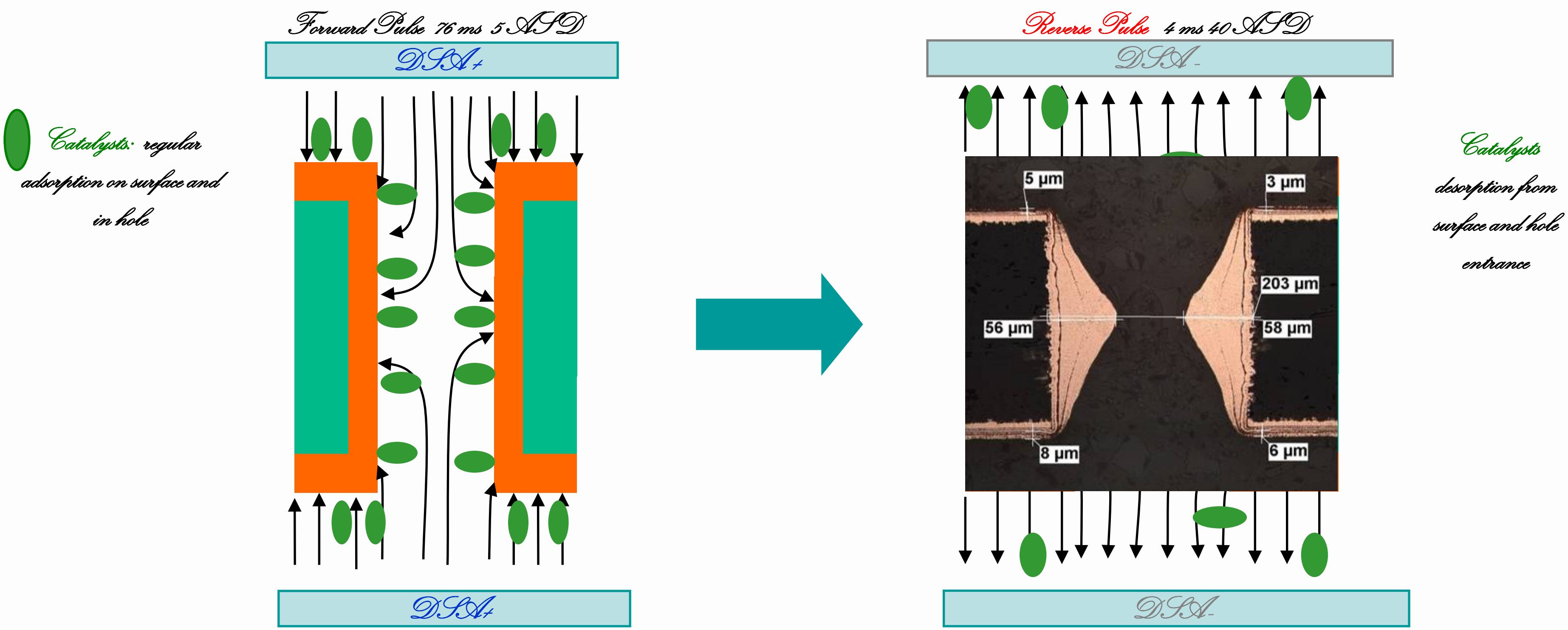
(Organic additives kept constant)

- – **Pulse Reverse Parameter**
- – **Panel design**
- – **Fe^{3+} Concentration**
- – **Agitation**
- – **Temperature / Cu^{2+}**

Influence

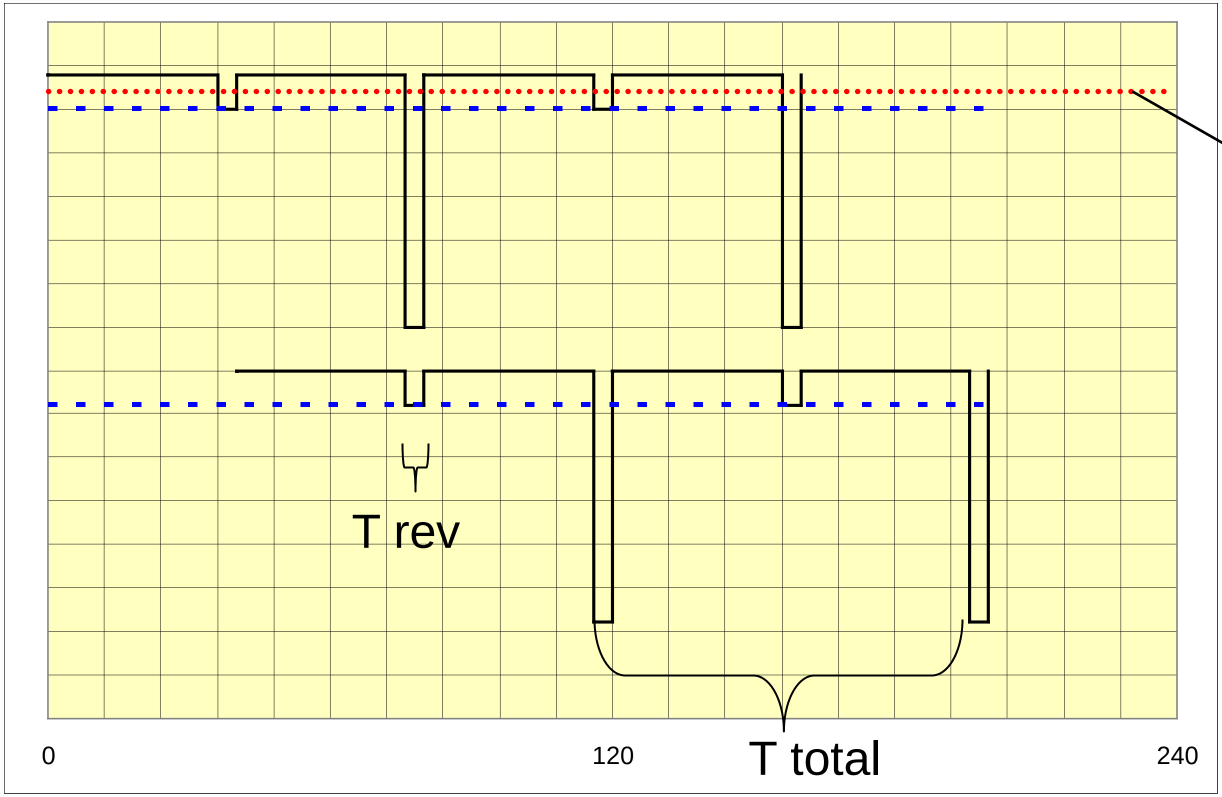
Mechanism – TH Filling

- **Bridge formation: Reverse Pulse**



Reverse Pulse Plating

- Current density vs. time



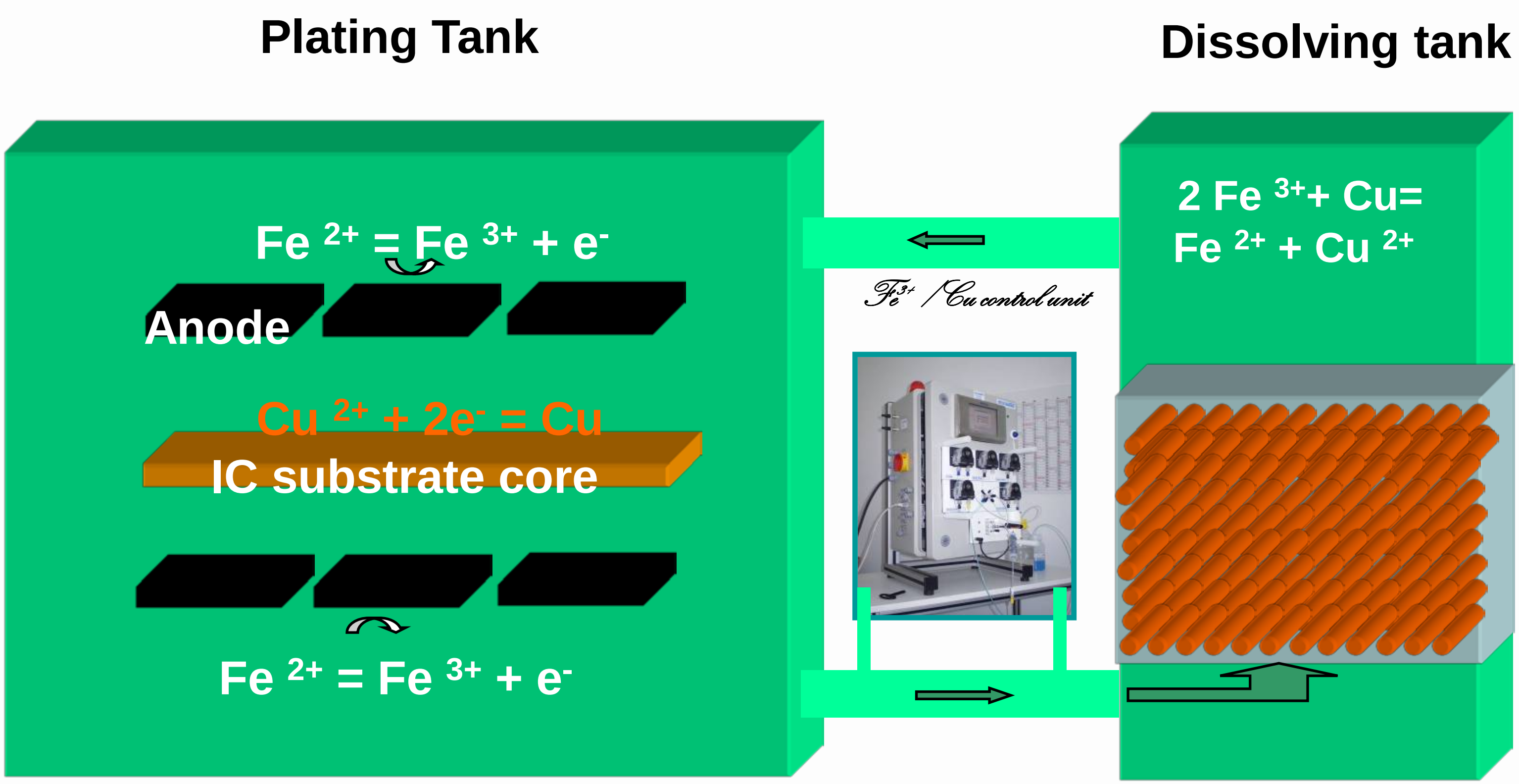
I ave/ I an   T total /T rev

5/40   40/4   180˚

Front side and rear side of panel see shift of reverse pulses by 180˚

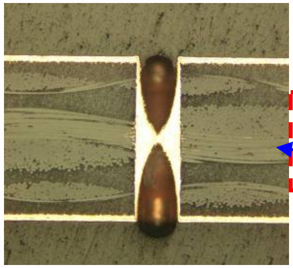
Mechanism – TH Filling

- **Surface reduction: Fe^{3+} Etch**



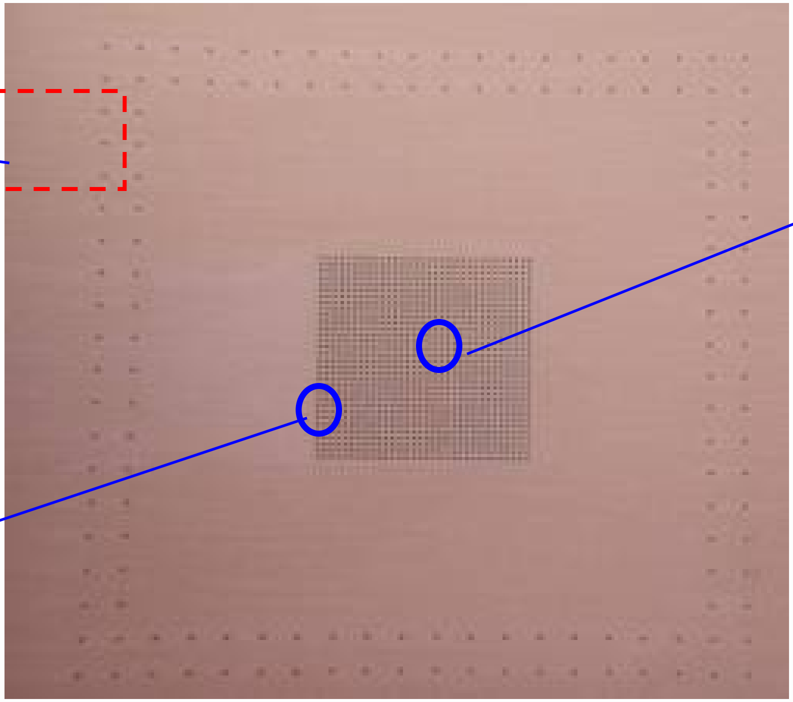
Panel Design Influence

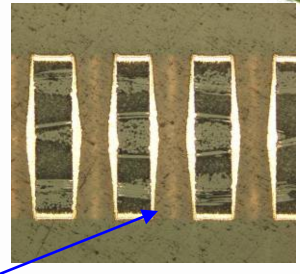
Test panels (100/400)



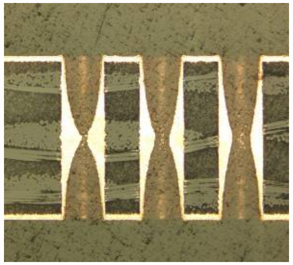
Isolated area

Pitch > 1,000um





Dense area Pitch 200um (middle of grid)



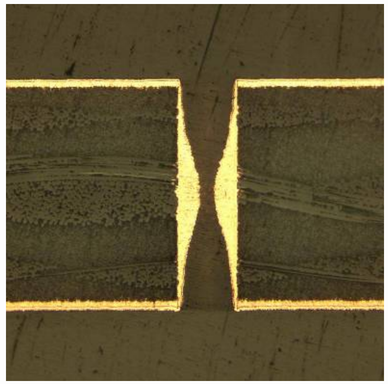
Dense area Pitch 200um (close to edge)

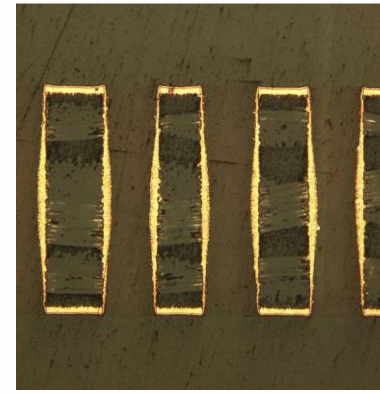
Panel Design & Fe^{3+} Influence

Pitch : >1000um (outside grid) | *Pitch : 200um (edge of grid)* | *Pitch : 200um (middle of grid)*

1.5/40/80/4/

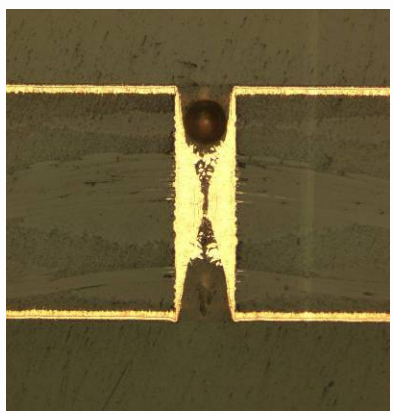
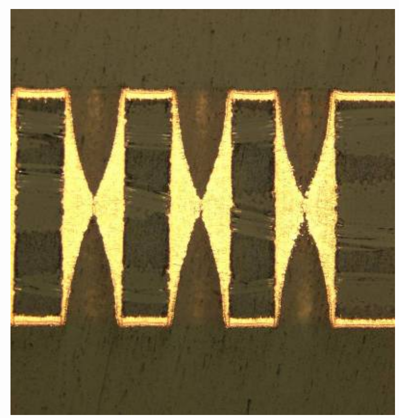
Fe3+ 1.0g/l





1.5/40/80/4/

Fe3+ 0.5g/l


- **Low Ferric ion concentration minimizes differences between different pitch areas**

Bridge-Plating Summary

- Strong reverse pulse. 5/50 80/4 for 15 min leads to closure of the X on 400 µm cores with 100 µm diameter

↓

Faster X- formation

- Fe^{3+} low (0.5 g/l) →
- Strong electrolyte flow →
- Low Cu concentrations 25 g/l → higher uniformity
- Low overall CD →
- Use higher Cl- concentration 90 instead of 60 mg/l →

↓

Better Uniformity between different pitches

Mechanism – BMV Filling

- **Multiparameter field**

(Organic additives kept constant)

  - **Pulse Reverse Parameter**
  - **Panel design**
  - **Fe^{3+} Concentration**
  - **Agitation**
  - **Temperature / Cu^{2+}**

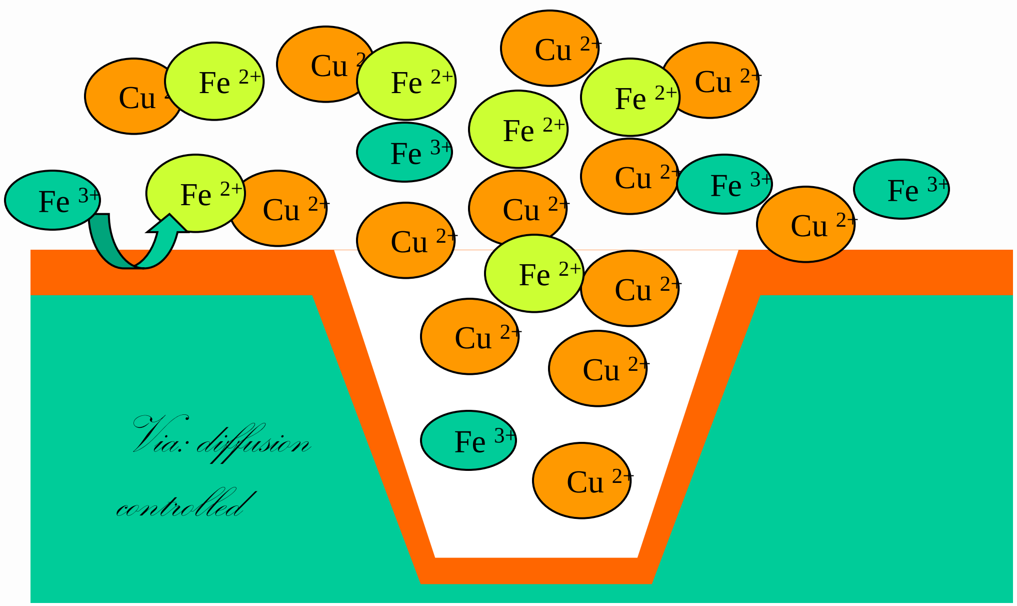
Influence

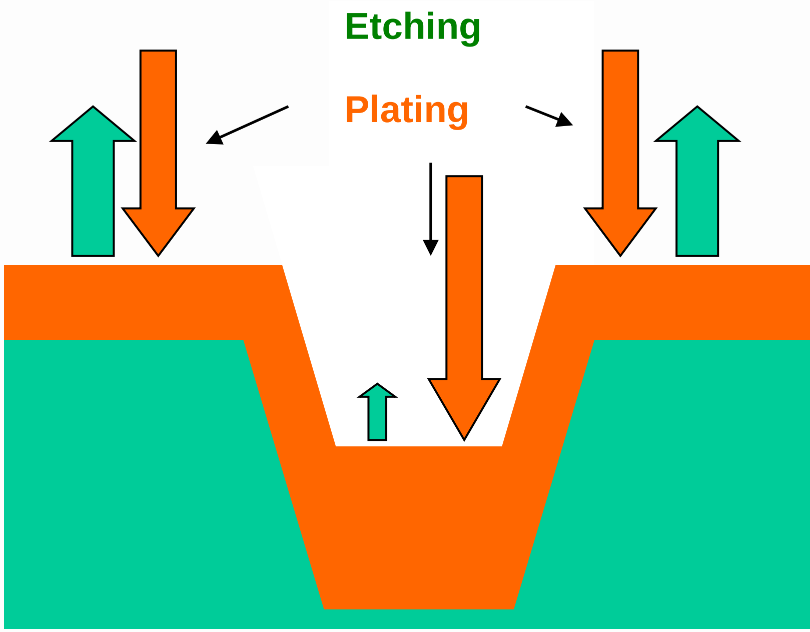
Mechanism – BMV Filling

- **Surface Reduction: Fe^{3+} Etch**

Surface: Convection controlled

Via filling assisted by inhibitors



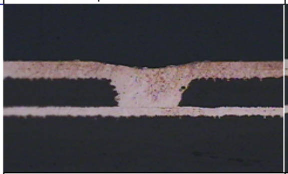
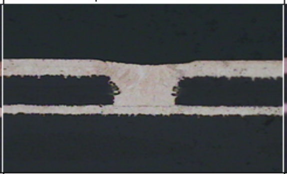
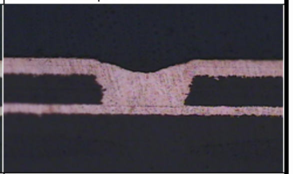
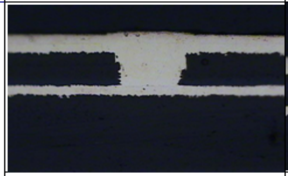
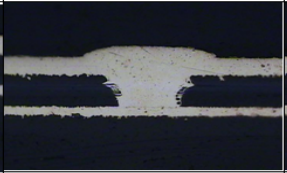
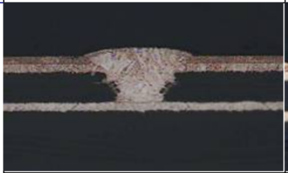
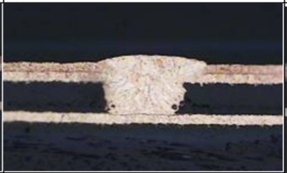
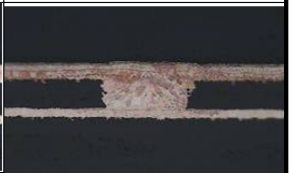


Reverse Time Influence

→While reverse time is increasing, the dimple is decreasing → dome

→at the same time copper thickness on the surface is decreasing

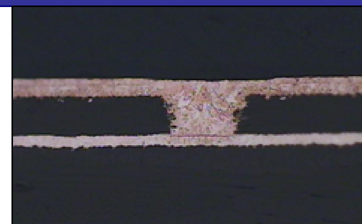
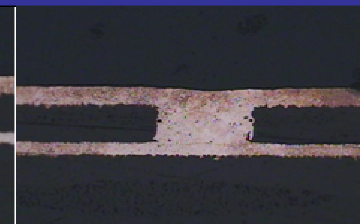
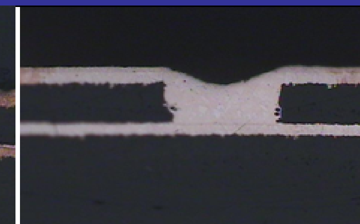
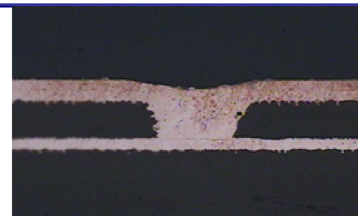
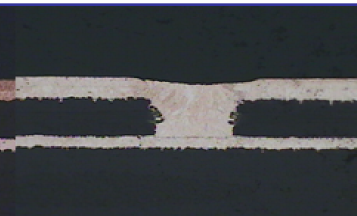
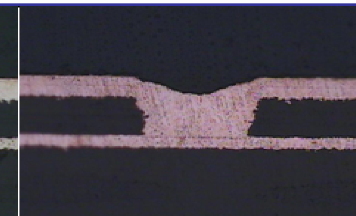
Cu content :	50g/L
Fe^{3+}:	3g/L
Temperature:	45° C

Shape	Open=75 um	Open = 100 um	Open = 125 um
5/40 80/2	 copper plated =18.54 um dimple = 33.89 um	 copper plated = 16.58 um dimple = 32.60 um	 copper plated = 19.45 um dimple = 37.73 um
5/40 80/4	 copper plated = 15.63 um dimple = 11.12 um	 copper plated = 15.04um dimple = 10.77 um	 copper plated = 14.06um dimple = 25.40um
5/40 80/6	 copper plated = 15.18um convex = 5.58 um	 copper plated = 14.6um convex = 20.53 um	 copper plated = 13.61um dimple = 4.12 um
5/40 80/8	 copper plated = 13.86 um	 copper plated = 15.55 um	 copper plated = 15.46 um

Higher reverse time decreases both Cu thickness and dimple

Current density Influence

→**Dimple gets smaller with lower overall current density**

Shape	Open=75 um	Open = 100 um	Open = 125 um
3.4/40 80/4	 copper plated = 9.76um dimple = 5.37 um	 copper plated = 9.58um dimple = 6.47um	 copper plated = 8.21 um dimple = 25.92 um
5/40 40/4	 copper plated = 15.63 um dimple = 11.12 um	 copper plated = 15.04um dimple = 10.77 um	 copper plated = 14.06um dimple = 25.40um

The smaller the average current density the smaller the dimple

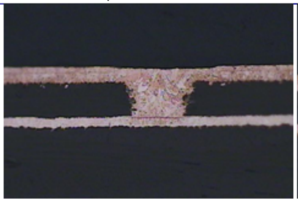
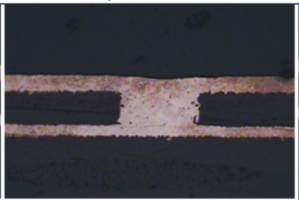
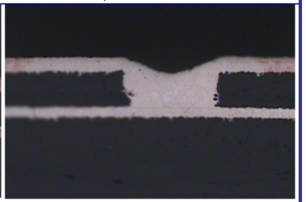
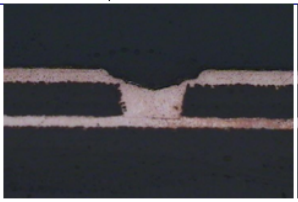
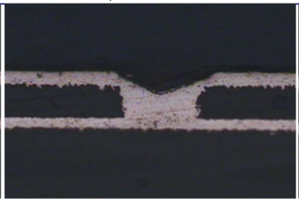
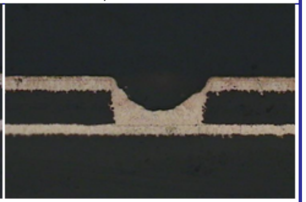
Electrolyte agitation

→ **Frequency controlled pumps spray 90° angle on to panel**

→**First step constant, as a protection layer**

→**Filling steps different pump frequencies, show improvement of dimple with lower pump frequency i.e. electrolyte agitation**

→**Higher pump frequency reduces copper on cost of dimple**

Pulse	Hz	time(s)	Open=75 um	Open = 100 um	Open = 125 um
5/8 80/2 3.4/40 80/4 3.4/40 80/4 3.4/40 80/4 5/20 80/2	12 15 12 10 12	120 300 300 600 120			
			copper plated = 13.24 um dimple = 4.61 um	copper plated =11.25 um dimple = 7.59 um	copper plated =11.01 um dimple = 31.24 um
5/8 80/2 3.4/40 80/4 3.4/40 80/4 3.4/40 80/4 5/20 80/2	12 25 15 10 12	120 300 300 600 120			
			copper plated = 9.76um dimple = 5.37 um	copper plated = 9.58um dimple = 6.47um	copper plated = 8.21 um dimple = 25.92 um
5/8 80/2 3.4/40 80/4 3.4/40 80/4 3.4/40 80/4 5/20 80/2	12 35 25 15 12	120 300 300 600 120			
			copper plated = 6.51 um dimple = 30.22 um	copper plated = 6.39 um dimple = 35.8um	copper plated = 7um dimple = 53.8um

Electrolyte agitation with strong influence on Cu thickness/dimple

Iron (III) Influence

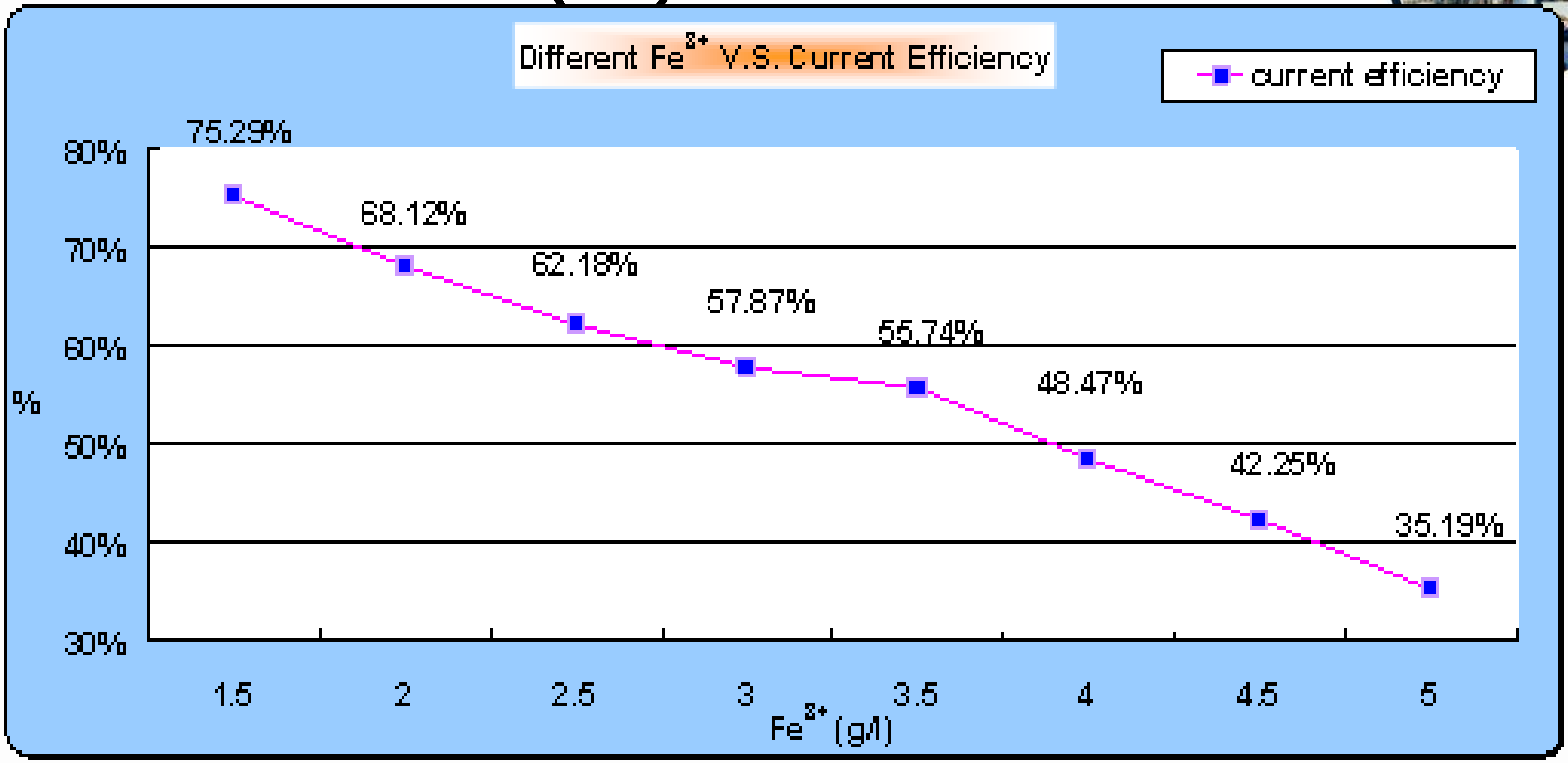
step	shape	pump	time (s)
1	5/8 80/2	12	120
2	3.4/40 80/4	25	300
3	3.4/40 80/4	15	300
4	3.4/40 80/4	10	600
5	5/20 80/2	12	120

Fe3+ (~g/l)	Cu2+ (~g/l)	T(°C)	Leveller (ml/l)	Brightener (ml/l)
1.50	51.83	44.7	14.61	9.82
2.00	50.45	43.9	14.61	9.82
2.51	50.48	44.4	15.97	11.45
2.99	49.90	42.5	15.26	10.29
3.45	52.79	43.3	15.26	10.29
3.95	52.56	45.1	15.70	12.07
4.38	51.58	44.3	15.70	12.07
4.79	49.10	45.1	15.70	12.07

→Surface roughness is decreasing with Iron (III) →Above 4g/L surface defects

Item	Fe^{3+}=1.5g/l	Fe^{3+}=2.0g/l	Fe^{3+}=2.5g/l	Fe^{3+}=3.0g/l
Surface				
	Fe^{3+}=3.5g/l	Fe^{3+}=4.0g/l	Fe^{3+}=4.5g/l	Fe^{3+}=5.0g/l
				

Iron (III) Influence



→Lowest roughness above 1.5g/L

→Best dimple between 2.5 – 3g/L → Working condition for BMV filling at 2.5g/L

→Best current efficiency at 1.5g/L

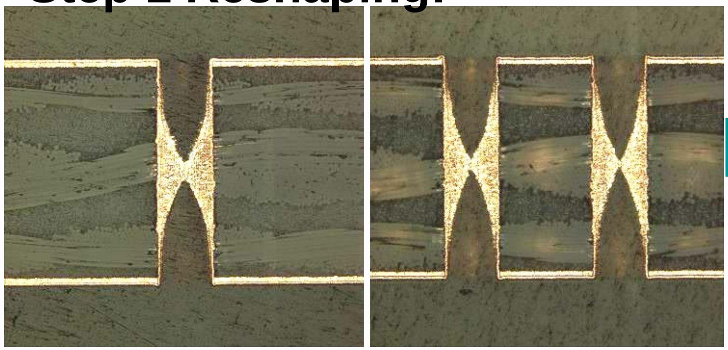
BMV-Plating Summary

- The stronger the reverse current the better the filling on cost of surface roughness→ compromise
- CD of 3 - 4 ASD is the best compromise between via filling and poductivity
- High Fe^{3+} concentration reduces the Cu overburden (>3 g/l)
- Strong electrolyte flow will increase the dimple
- High Cu concentrations 60 g/l decreases the dimple

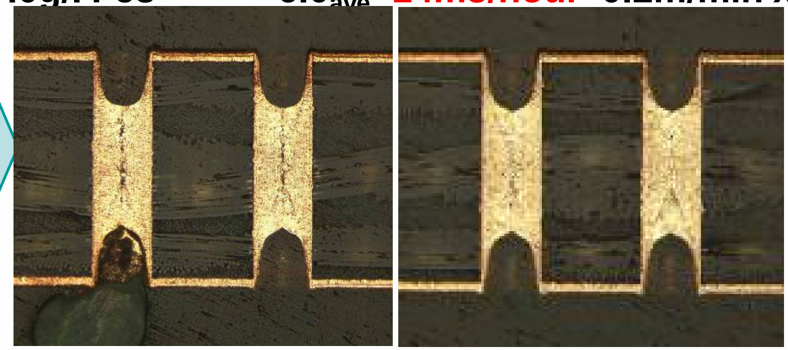
BMV-filling after bridging

Step 1 Reshaping!

7.0g/l Fe3+ 6.0_{ave} 14m3/hour 0.2m/min x2



Panel : after X



After reshape

Step 2: Fill up

Step 2: Fill up :

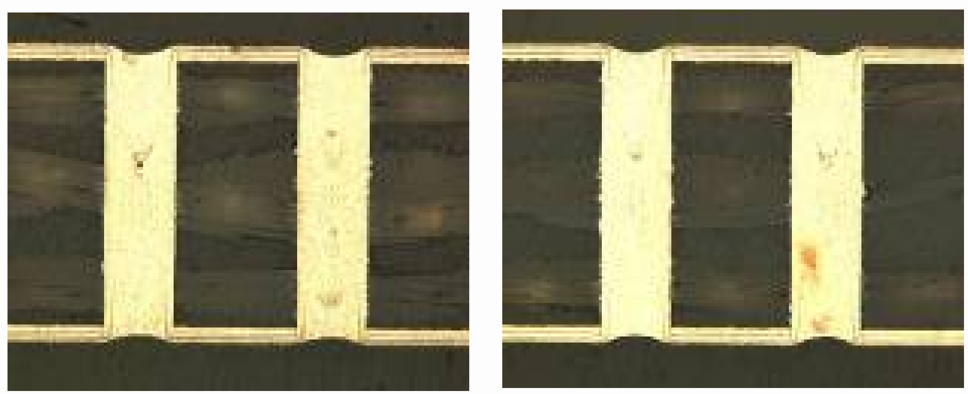
1st 3.5/10/80/4/THF

2nd 3.5/20/80/4/THF

7.5m3/hour

0.2m/min

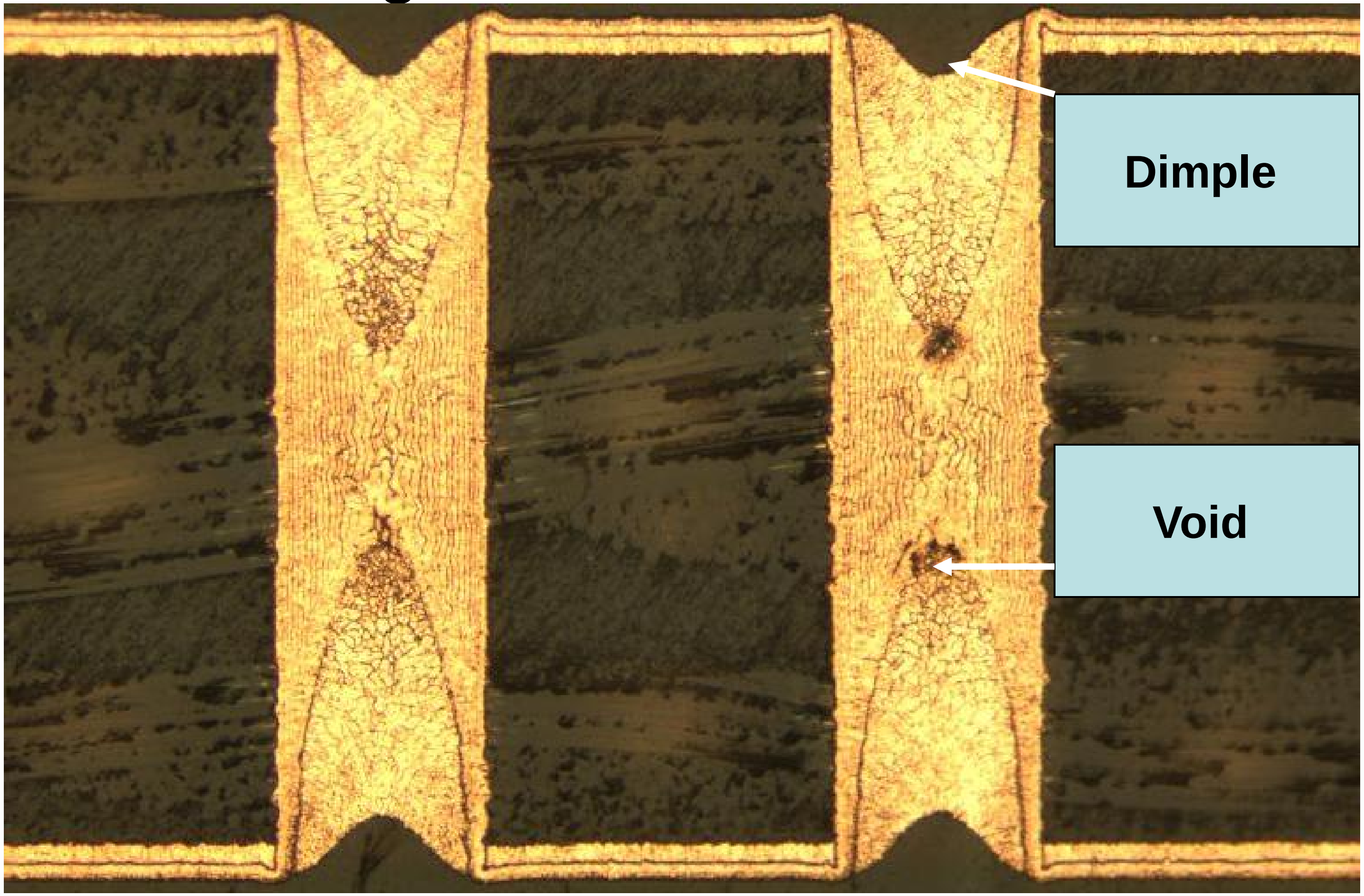
7.0g/l Fe3+



After Fill up

Problem: Micro voids after Fill up

Strong etchant and ultra sonic



Summary

- Through Filling is possible in this dimension, but needs to be divided in two process sequences
- Mostly developed, some voids

Outlook

- Improvement of current system

- Extending technology beyond IC substrate cores