Production of Flexible Circuits in Reel to Reel Horizontal Production Systems

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Abstract
Reel to reel production of flexible circuits where the substrate consists of a continuous roll is a technique commonly used in mass production. This method is an obvious solution for efficient handling of the very flexible and sensitive materials used.
This paper presents the latest innovations for production of flexible circuits in a continuous horizontal production system incorporating desmear and electroless copper metallisation followed by electrolytic copper reinforcement with reverse pulse plating.
The special requirements of flexible material handling in particular in combination with thin copper foil are discussed together with the options available for metallisation and electrolytic copper plating equipment. This demand for thin copper foil is becoming more common for flexible applications to enable tighter line and space specifications. The copper plating system uses a special clamp on one side of the substrate with large contact area which ensure good electrical contact with the thin material also at high applied current densities and under reverse pulse plating.
The advantages of horizontal plating systems for this application are shown, in particular the use of insoluble anodes for copper plating to maintain surface plated copper uniformity and quality. In the system shown the use of segmented insoluble anodes is critical to ensure the best possible surface distribution at the high current densities used. The importance of uniform electrolyte agitation is discussed and methods to achieve this with varying substrate thickness are shown. The metallisation and also electrolytic copper plating utilises frequency controlled pumps and also a special active level control system to maintain optimum working conditions irrespective of the material being processed and the pump flooding set up.
This combination of features in the equipment allows the use of high production current densities even with thin flexible base materials with thin conductive layers.
Results are shown from production systems being used to produce material with various material types and thicknesses. One example has laser drilled glass reinforced substrate with through vias which are metallised and subsequently through hole copper plated in a complete reel to reel production system.

Introduction
Horizontal systems for electrolytic copper plating are in full production for thin core and flexible base materials for conformal copper plating and also for blind micro via filling applications. Such horizontal equipment is ideally suited for this type of production due to the handling capability for thin core and especially substrates with thin copper foil. The systems show significant advantages over traditional vertical processing systems as has been described in [1]. For the metallisation of the substrate before electrolytic copper plating horizontal processes have become the system of choice, in particular the combination of horizontal electroless copper metallisation with wet to wet transport into horizontal electrolytic copper plating has become the standard for HDI applications. Wet to wet transfer can eliminate yield loss due to handling and also gives an optimal processing for through vias and especially blind micro vias. For flexible and also flex-rigid circuits the metallisation process must be modified to meet the specific base material characteristics critical aspects are discussed in [2].

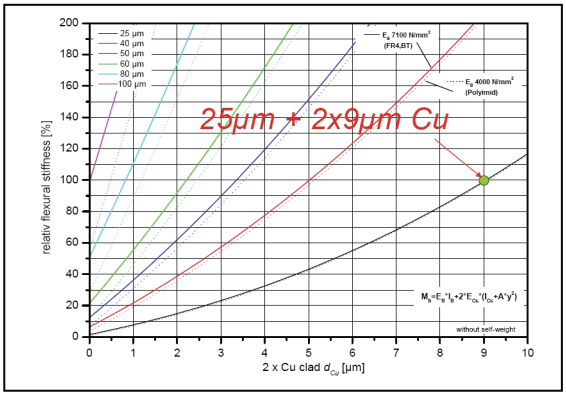

Figure 1- Relative Rigidity of Base Materials

The flexibility of the base material is the critical aspect in any production system; figure 1 shows the variation in relative bending of substrate foils in relation to the copper foil thickness and also the base material thickness. The thinner the material and the copper foil the more flexible it becomes and the more difficult to transport safely through a production line. In addition to this the copper foil thickness has implications on the surface plated copper distribution due to the reduced specific resistance of the thin copper foil used in HDI applications. Material clamped only on one side as is typically the case will have a poor surface distribution at relatively high plating current densities, such high current densities are required to gain the necessary productivity from the equipment. Reduction of current density will give improved results but at the cost of production volume. Figure 1 shows as a reference point the flexibility of a base material 25µm thick with copper foil 9µm however future requirements for fine line circuit applications require copper foil at approx. 3µm; this has in the region of only 20% of the rigidity of the material with 9µm copper foil. An alternative to single sheet processing is the use of reel to reel plating systems which offer handling advantages due to the continuous material.

Horizontal Reel top Reel Copper Plating

Uniplate pretreatment and Inpulse copper pulse plating modules have been modified to allow reel to reel production by addition of dedicated handling devices and optimization of the existing features of the equipment. The metallisation process uses a stand alone desmear and electroless copper module which processes the material as a continuous roll which is then transferred for electrolytic copper plating. Both metallization and copper plating use dedicated handling equipment consisting of an uncoiler at the start of the line as shown in figure 2 and postreatment with dryer and coiler as shown in figure 3.

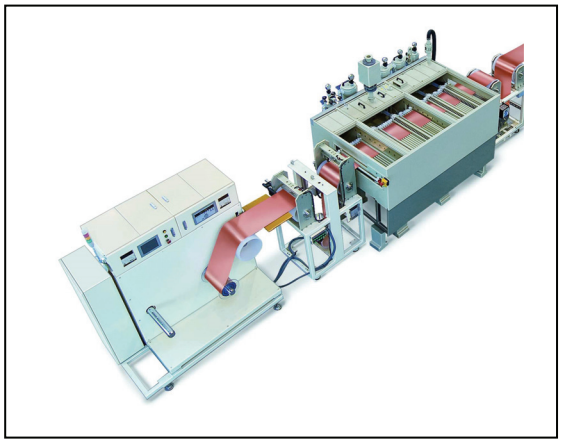

Figure 2 – Uncoiler and Pretreatment Module

The photograph shows the equipment configuration together with the pretreatment before the copper plating module. The pretreatment consists of acid cleaner followed by a triple rinse; the acid cleaner process is based on sulphuric acid together with special low foam cleaner and has been optimized to handle the thin continuous material with electroless copper in the through holes. In the processing line special handling devices are incorporated to prevent any misalignment of the material and to ensure accurate transport and synchronization with the clamp drive as well as to enable continuous production by acting as a buffer between production lots.

In both the metallization processes and also the electrolytic plating process full automatic analysis and control systems are used. These systems can analyze critical processes and control the dosing system to ensure working uniform working levels. Experience has shown that more uniform working levels may allow reduction in process set point with no danger of leaving the required process range. Lower working range set point means that process consumptions may be reduced which has a positive impact on process running cost. After copper plating the processed material is rinsed, treated in an anti tarnish process followed again by rinsing and then dried. The dryer must ensure no moisture is present on the surface before the coiler accepts the plated material from the production line. Photograph 3 shows the coiler and also the anti tarnish module followed by triple rinse and dryer after acid copper plating.

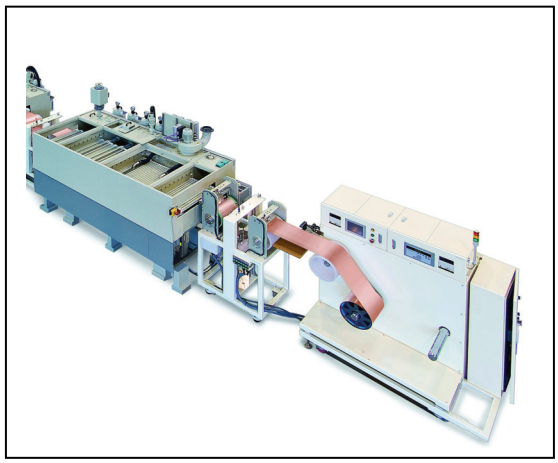

Figure 3 – Post treatment with Dryer and Coiler

The acid copper plating module is equipped with a special clamping system designed for flexible base materials which are immersed in the working electrolyte this acts to cool the contact area and is one factor enabling high current density operation. Together with the clamp drive system the clamps ensure accurate transport of the material synchronized with the handling devices and also good electrical contact to the copper foil. Accurate material transport is critical for flexible materials as any "crimping" during plating would be fixed into the substrate after copper deposition and would cause difficulties in subsequent processes. Due to the accurate and large surface area of the clamping system a relatively high current density can be used in the production of reel to reel materials whilst maintaining acceptable plated copper surface distribution. Photograph 4 shows the clamping system in the partly disassembled plating module which also shows the position of the plated material and the upper and lower anodes. Also shown is a close up of one anode assembly consisting of four anode segments.

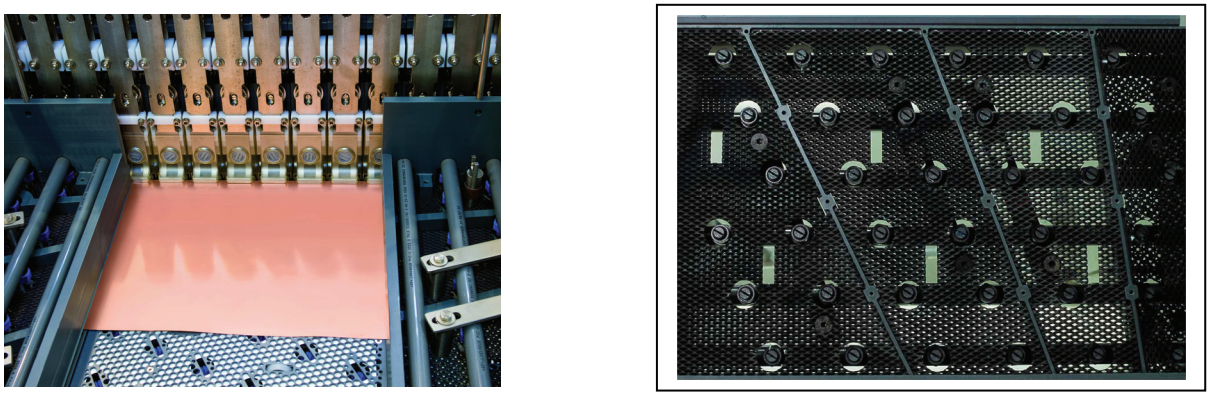

Figure 4- Clamp System and Segmented Insoluble Anodes

The anodes in the plating module are segmented and insoluble consisting of a titanium mesh coated to ensure uniform copper deposition. The use of insoluble anodes means that the plating window is constant and time consuming anode maintenance is not necessary and no dummy plating is required which saves processing time, copper metal is replenished using the patented iron redox replenishment system which has been described in [3]. The use of anodes with 4 segments enables optimum copper plated surface distribution even with thin copper foil and at high current densities. Each of the anodes is connected to a separate pulse plating rectifier with separate control system which means that the copper deposit can be controlled over the whole plating window. The plating electrolyte and all active solutions are maintained by fully automatic dosing systems to ensure constant working conditions. The dosing is made based on actual ampere hours plated or the area of material processed in the equipment. A correction factor is applied to each anode segment depending on the type of material being plated, the copper foil thickness and also the applied current density to ensure uniform deposited copper. The electrolyte flow in the copper plating module is adjusted with frequency controlled circulation pumps; the flow of electrolyte to the top side of the plated substrate and to the bottom side may be set independently. This capability was found to be important in controlling the transport of thin material in the line. Different flow settings were used for different substrate thicknesses for example a material 150µm thick with copper foil 3µm used different settings to those for a 60µm thick substrate. All materials required a different setting for top and bottom pumps, for best results with 150µm the setting for the top was double that for the

bottom circulation pumps. The working level of the electrolyte in the plating module is controlled by the circulation pumps and also by the rate of flow of electrolyte back into the module sump. This return flow is governed by pneumatic valves in the piping which are adjusted according to the type of material being processed. Ultra thin materials require reduced flooding from the circulation pumps but the working level in the plating chamber must be maintained to enable copper deposition.
Use of this system allows rapid and accurate adjustment of the circulation and flooding within the plating chamber without any equipment down time. The equipment may be set up for ultrathin material or for thicker more rigid material with no loss in production time. All modules in the plating line with active process steps and also rinse steps use an air knife system to prevent excessive drag out and resulting loss of electrolyte or rinse water. A schematic of the air knife system in a triple rinse is shown in figure 5.

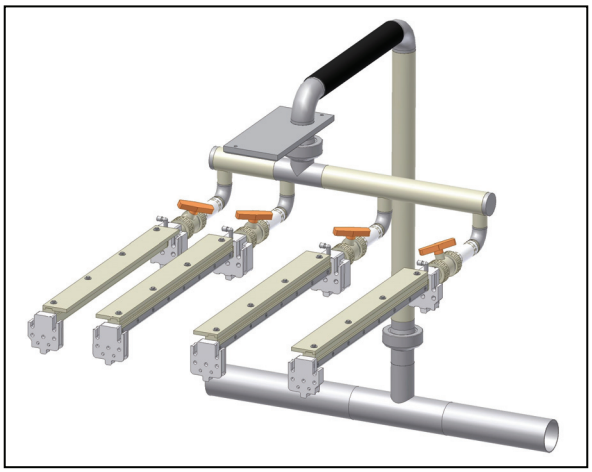

Figure 5 – Adjustable Air Knife System as Applied to Triple Rinse Module

The air knife system minimizes drag out loss and thereby reduces waste water loading and also enables reduced surface contact to the substrate being plated. The system is adjustable depending on the type and thickness of substrate being processed.

Copper Plating Results
The reel to reel plating system as described is capable to handle substrates between 150µm thick down to 20µm thick in both cases with 3µm thick copper foil. Through hole pulse plating at forward current densities of up to 10A/dm² have shown excellent throwing power in material 150µm thick and with hole diameter 100µm. The average current density is a maximum of 10A/dm² depending on the width of the material being processed. Conveyor speed is variable but with a target copper thickness of 17µm on the surface a speed of 0.7 m/min has been used, at this speed accurate transport of the material was seen with no web misalignment. The plated copper surface distribution with 150µm base material and 3µm copper foil as shown in figure 2 is within ± 10% absolute variation within the critical area for the application based on a continuous material with active width 300mm. The microsection result in figure 6 shows the plated copper after metallization and structuring of the surface plated deposit.

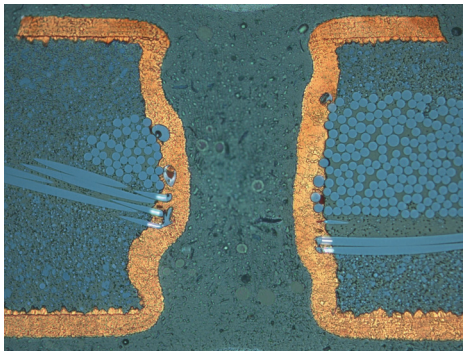

Figure 6 – Microsection of Metalized Glass Reinforced Flexible Material

As an extension to the capability of the copper plating system qualification of through hole filling of flex material has been completed, through hole filling in horizontal plating systems has been discussed more fully in [4]. This process uses modified

plating electrolyte and special pulse plating parameters to give a though hole completely filled by electrolytic copper. In figure 7 a microsection is shown of a filled through hole with diameter 100µm in a material 125µm thick. The surface copper plated was less than 15µm to achieve the result shown with a dimple remaining of less than 10µm.

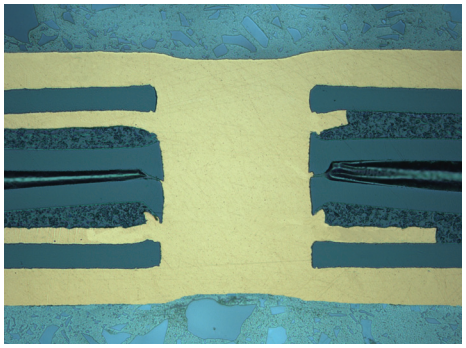

Figure 7 – Copper Through Hole Filled Flex Material

Summary

Horizontal processing systems allow easier handling of continuous roll material and allow higher applied current densities in comparison to conventional plating equipment which gives an equivalent increase in productivity. The large area clamp system which is under electrolyte working level gives a reliable contact even onto thin copper foil which meets required surface distribution specification. The equipment for continuous roll handling has been effectively incorporated into the Uniplate transport system to ensure reliable transport under production conditions. Use of automatic analytical control, systems gives the added advantage of more uniform working conditions and also the possibility to reduce running cost.

References

[1] S. Kenny, *Blind Micro Via and Through Hole Filling for Thin Core and Flexible Base Materials*. Circuitree Live, 2006.
[2] T. Magaya, *Pre-treatment and PTH Solutions for Flex-rigid PCB´s*. Circuitree Live, 2006.
[3] S. Kenny, K. Matejat, *HDI Production Using Pulse Plating with insoluble Anodes*. EIPC, 2000.
[4] S. Kenny, B. Roelfs, *Copper Electroplating Process for Next Generation Core Through Via Filling.* Pan Pac, 2009.

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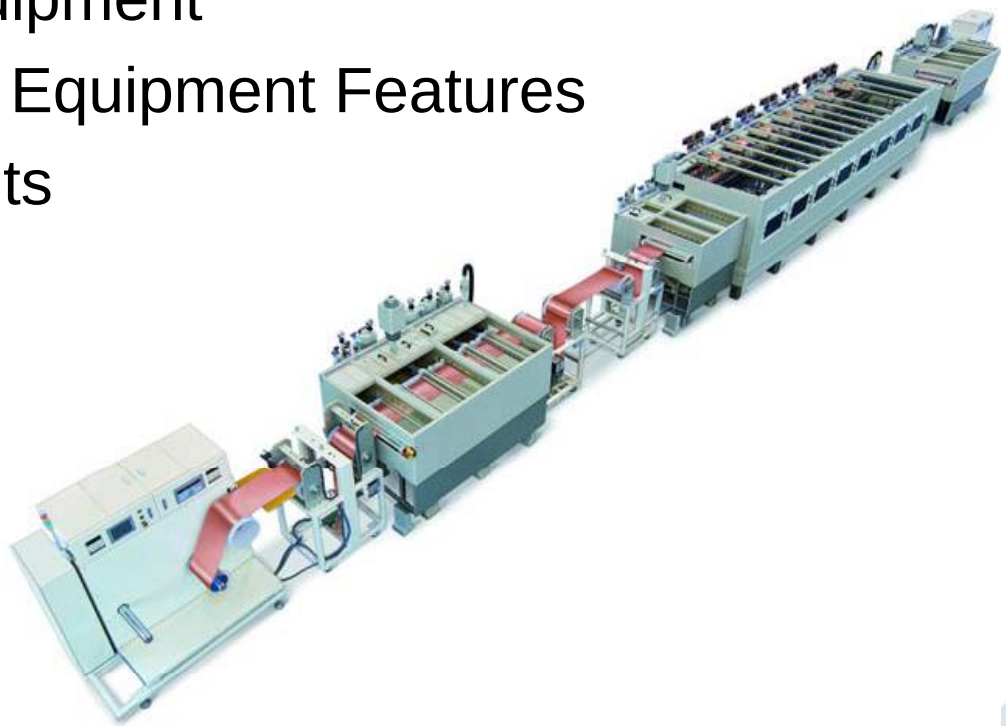
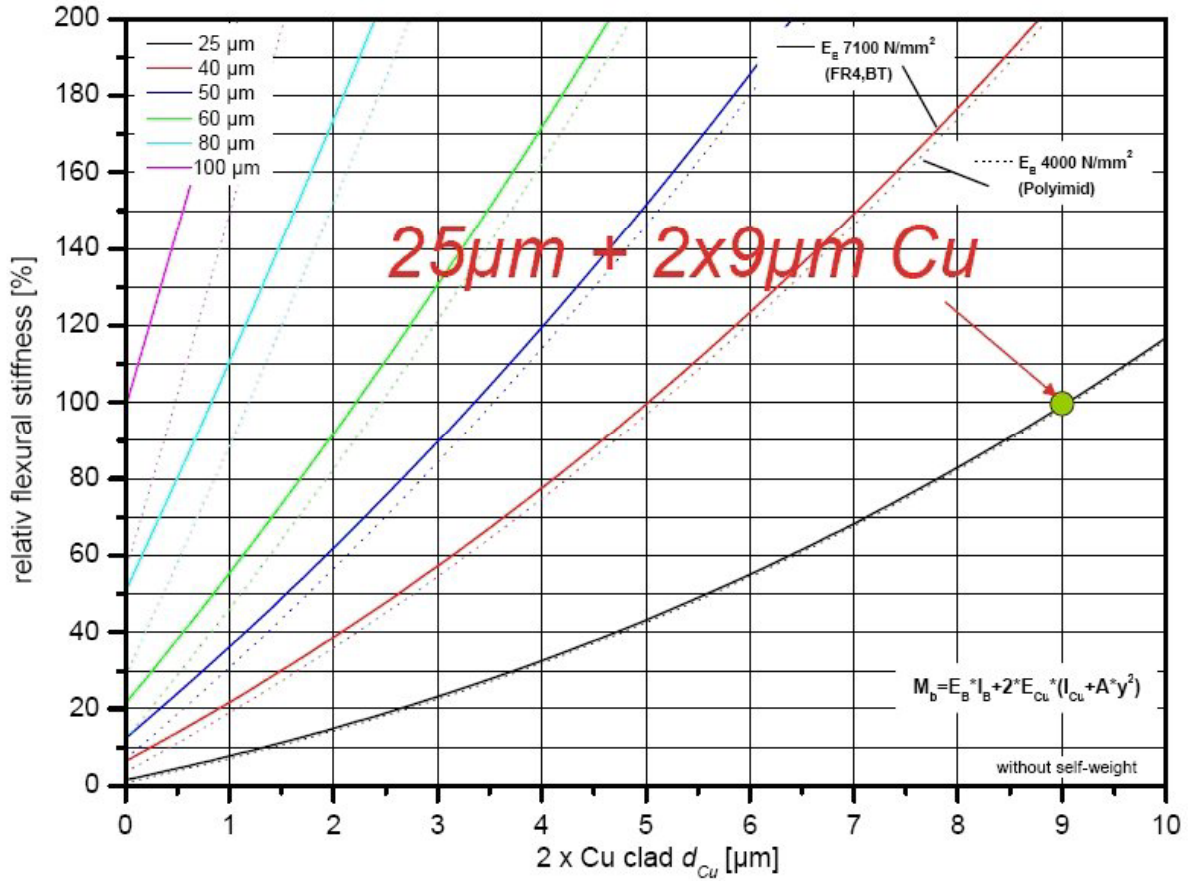


Introduction

- The Inpulse 2 system is ideally suited for conformal plating and also for blind micro via filling of thin core and flex base material
- The flexibility of the base material is the critical aspect in any production system
- Thinner material and copper foil becomes more flexible and more difficult to transport safely through a production line
- Current base material with 25 µm thickness and 2 × 9 µm copper clad are 4 times more rigid then future needed copper foil at 2 × ~3 µm
- As an alternative to single sheet processing the use of reel to reel plating systems offer handling advantages due to the continuous material

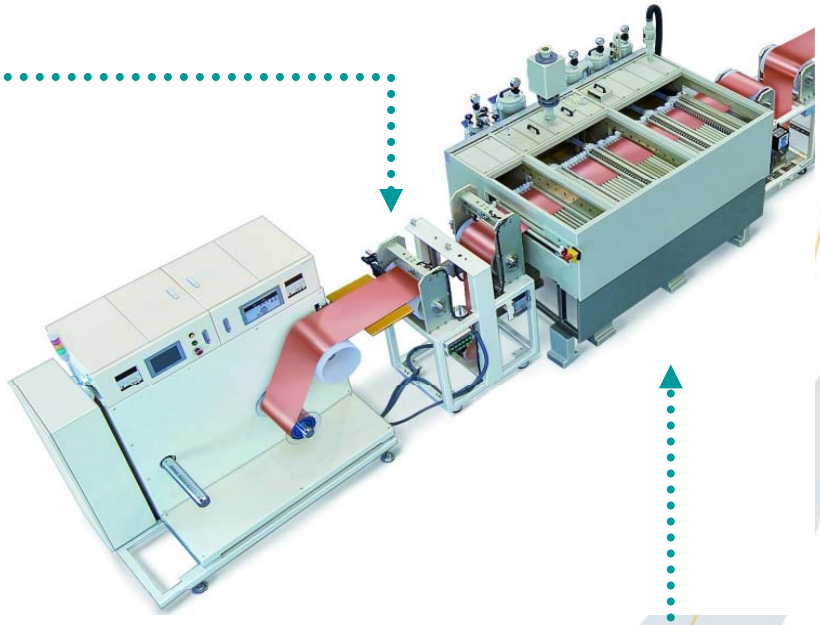
Base Material Relative Rigidity



Handling Equipment

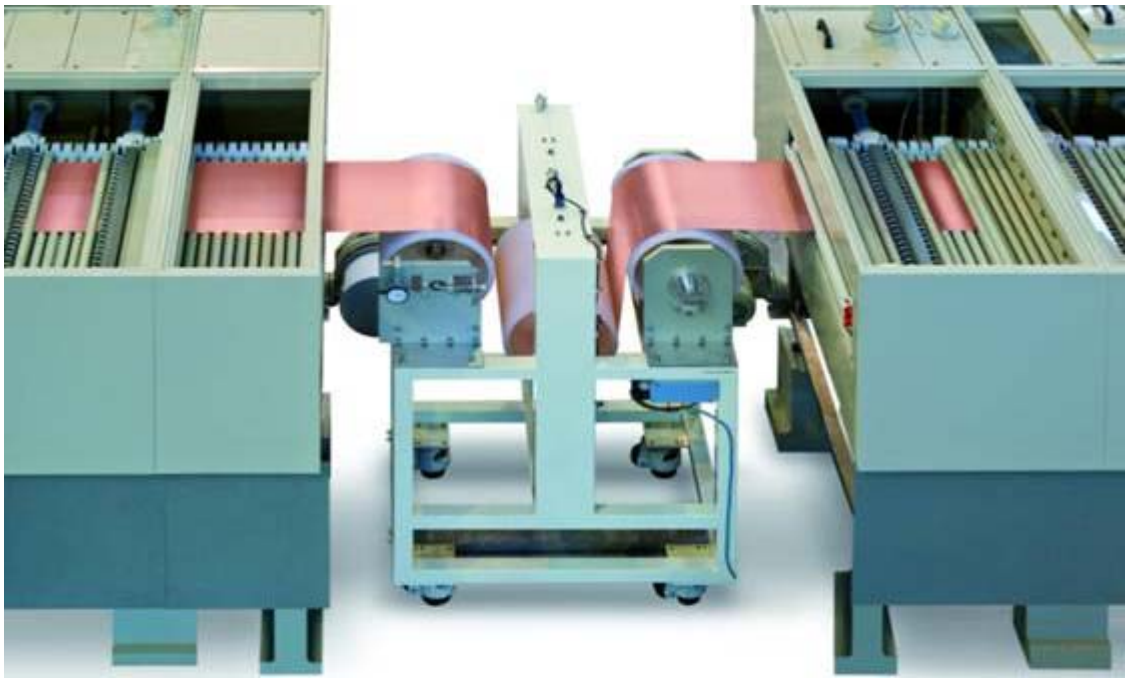
- Modification of InPulse 2 copper pulse plating module:
  - Addition of dedicated handling devices
  - Optimization of the existing features

- An uncoiler at the start of the line picks up the material
- The optimized pre-treatment consists of a sulphuric acid based acid cleaner together with special low foam cleaner followed by a triple rinse



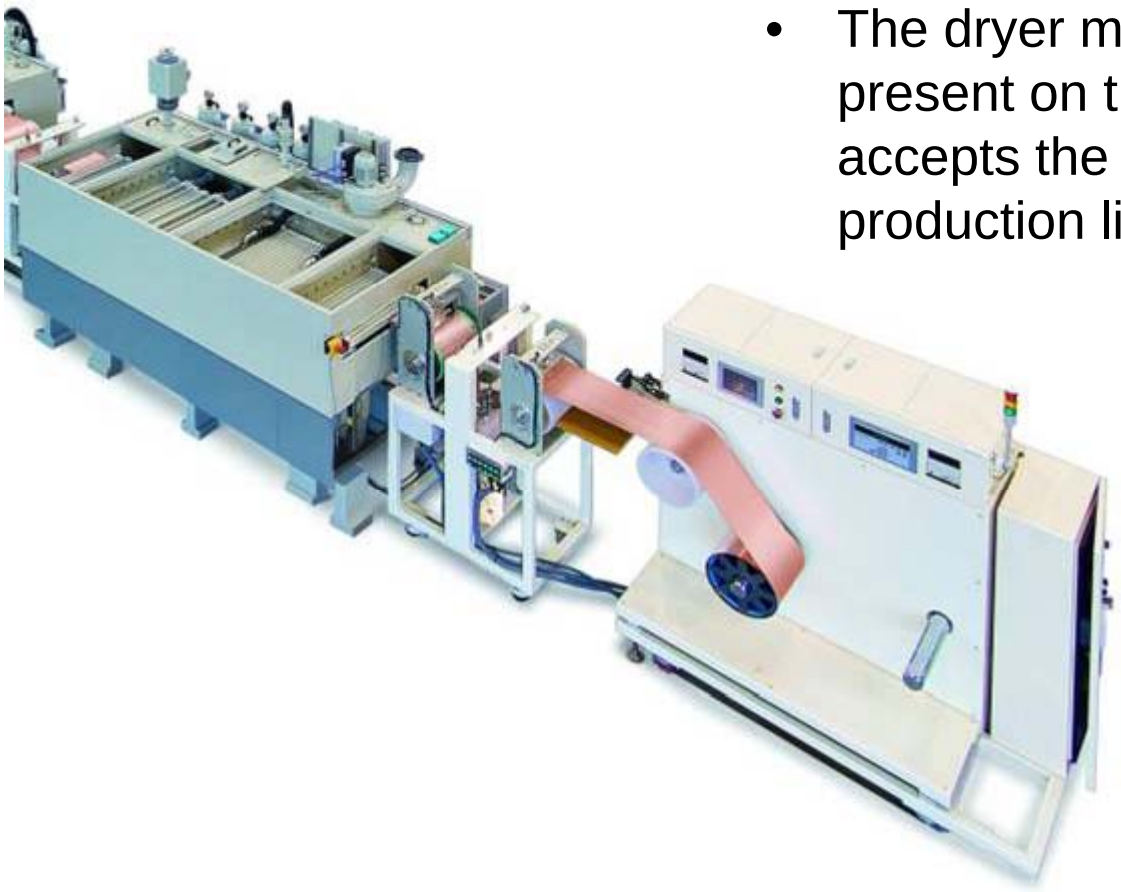
Handling Equipment

- Special handling devices are incorporated to prevent
  - Misalignment of the material
  - Accurate transport and synchronization with the clamp drive



R-t-R Plating Equipment Features

- After copper plating the material is rinsed, treated in an anti tarnish process followed again by rinsing and then dried.



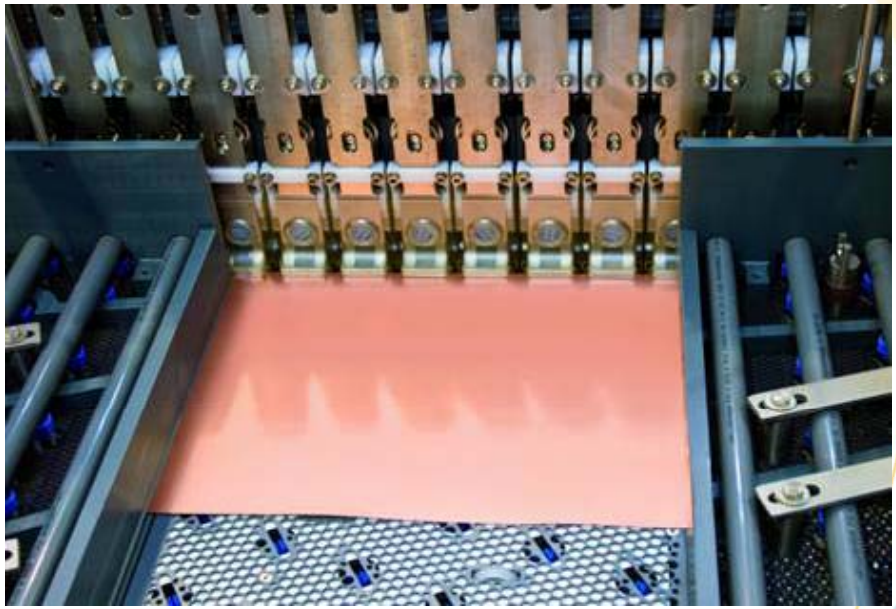
- The dryer must ensure no moisture is present on the surface before the coiler accepts the plated material from the production line.

Flex Clamp System

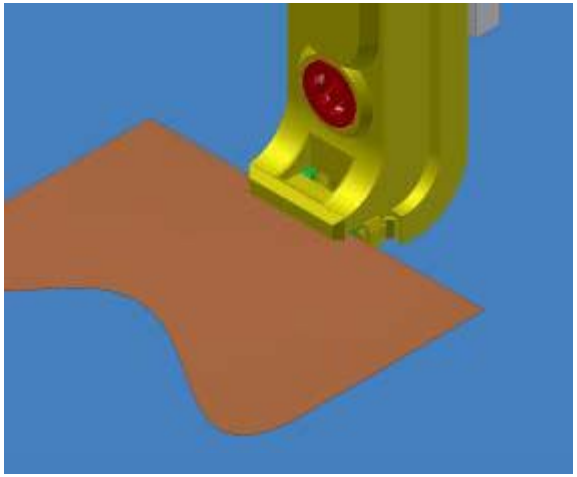
- The clamping area is immersed in the working electrolyte to cool the contact area
- Accurate and large surface area of the clamping system -> good electrical contact
- New designed clamp drive system for accurate transport of the material synchronized with the handling devices

➢ Enables high current density operation up to 10A/dm² RPP

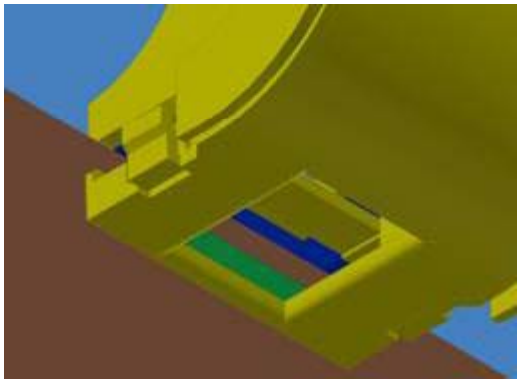
➢ Maintains acceptable plated copper surface distribution

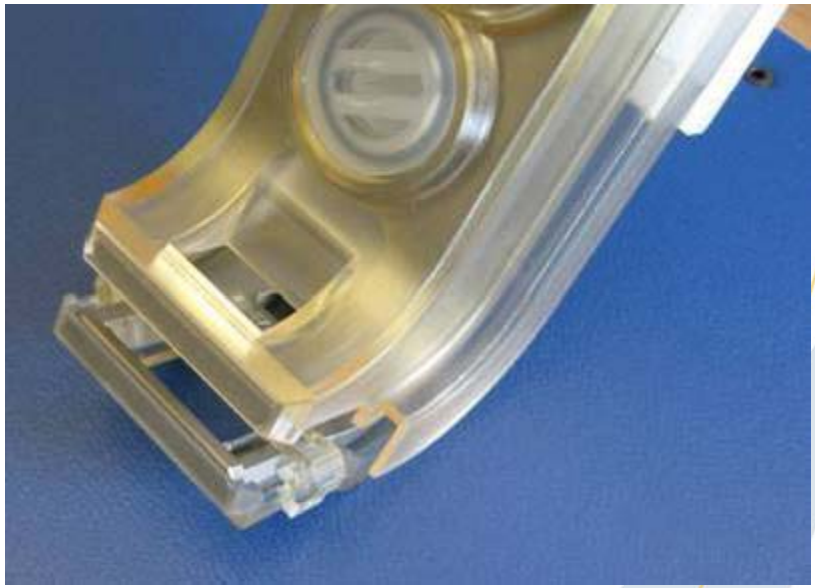


Detail Clamping System



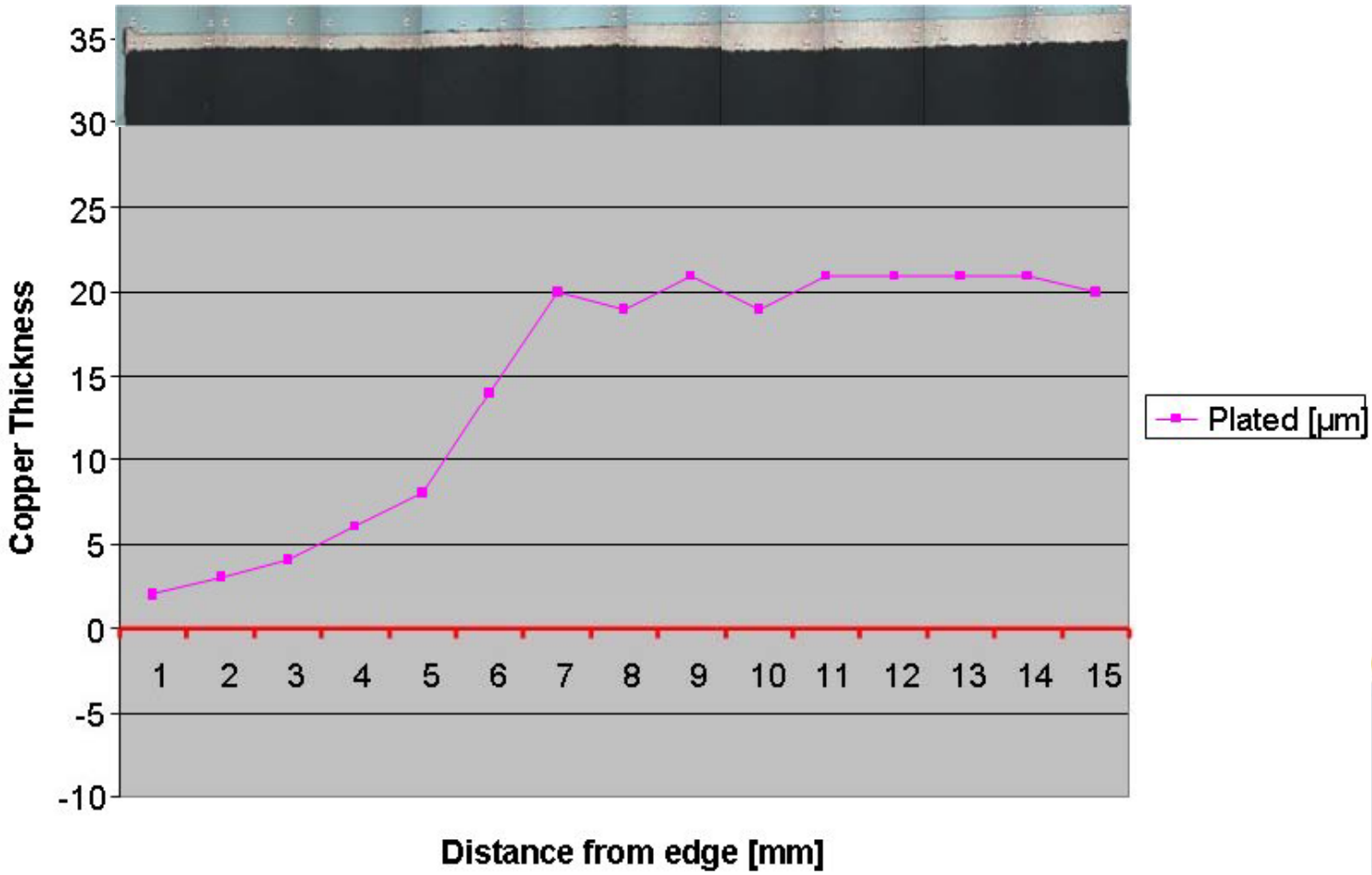
Standard clamp for InPulse2 system





More uniform surface distribution on „clamping “ side

Surface Distribution Clamp Side



Inert Anodes

Inert Anodes:

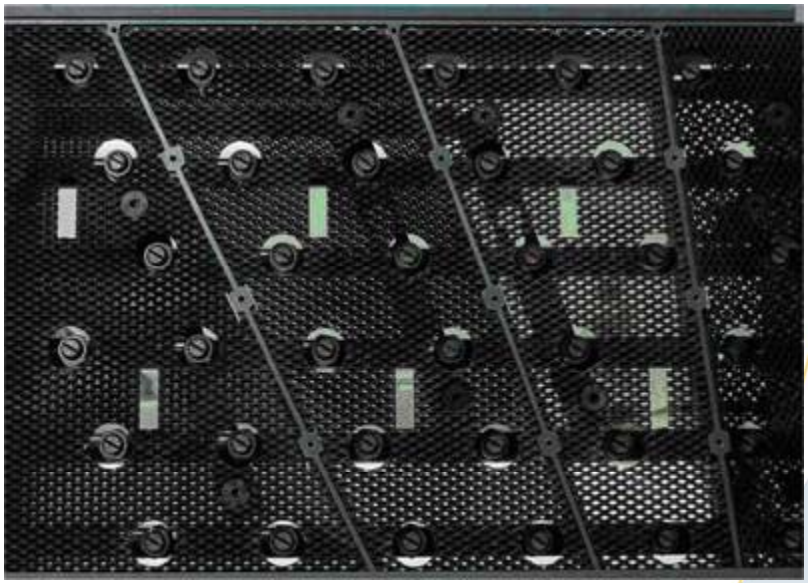
- Titanium mesh coated
- Replenishment of copper metal by patented iron redox replenishment system
- constant plating window

➢ no time consuming anode maintenance

➢ no dummy plating

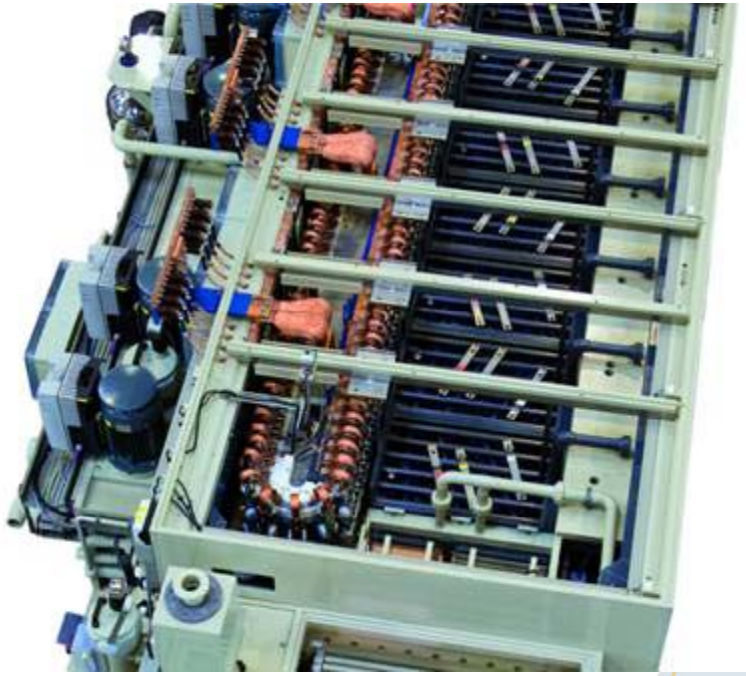
Inert Anode Unit

- 4 segments
- Each anode segment connected to separate pulse plating rectifier with separate control system
- Copper deposit can be controlled over the whole plating window.
- Optimum copper plated surface distribution



R-t-R Equipment Features

- Frequency controlled circulation pumps adjust the electrolyte flow
- Flow to the top and bottom side may be set independently
- ➢ Different flow settings for different substrate thicknesses are used



Air Knife System

- Modules with active process steps or rinse steps use an air knife system
- ➢ Prevention of excessive drag out and resulting loss of electrolyte or rinse water
- ➢ Enables reduced surface contact to the substrate being plated
- ➢ Adjustable system depending on the type and thickness of substrate being processed

Air knife system in a triple rinse

Equipment Control Features

- Plating electrolyte and all active solutions are maintained by fully automatic systems
- Control based on actual ampere hours plated or the area of material processed
- Correction factor to each anode segment depending on
  - Type of material being plated,
  - Copper foil thickness
  - Required A/dm^2 to ensure uniform deposited copper
- Critical components also controlled by automatic analysis

Benefits Of Automatic Control Systems

- Tighter control of bath parameters
- Uniform processing conditions
- More constant quality
- Record of production conditions
- Reduced consumption and consequently costs

Automatic Control For Pretreatment

- Controlling
  - Reducer
  - Electroless Copper
- 30% Reduction in consumption and costs based on comparable production

Automatic Control For Electrolytic Cu

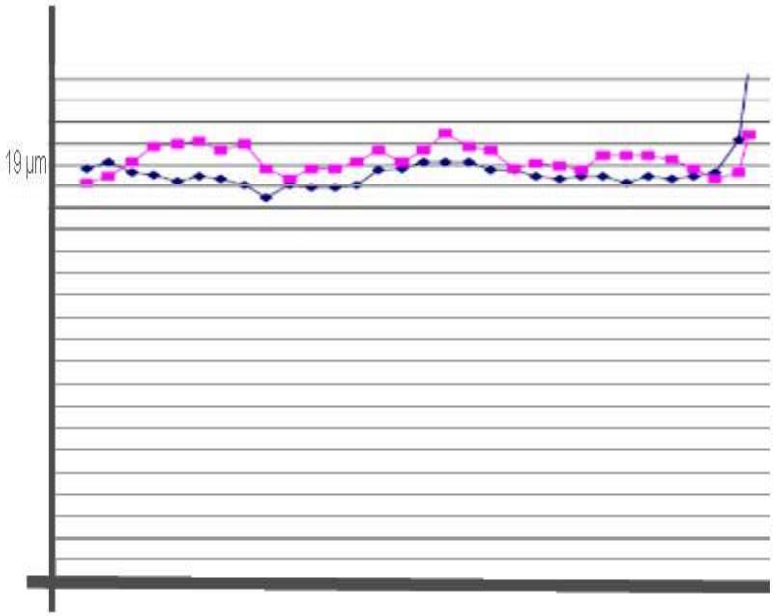
- One unit for up to 3 production modules plus electrolyte reference sample
- Concentration range
- Cu^{2+}:38 - 75 g/l (±5%)
- Fe^{3+}:3 – 10 g/l (± 5%)
  1 – 3 g/l (± 10%)

Plating Parameters

- Substrates: 150µm thick down to 20µm thick with 3µm thick copper foil.
- Maximum current density at 10A/dm² depending on width of the material
- Variable conveyor speed
  - at target copper thickness of 17µm on the surface a speed of 0.7 m/min is used to ensure no web misalignment

Production Surface Distribution

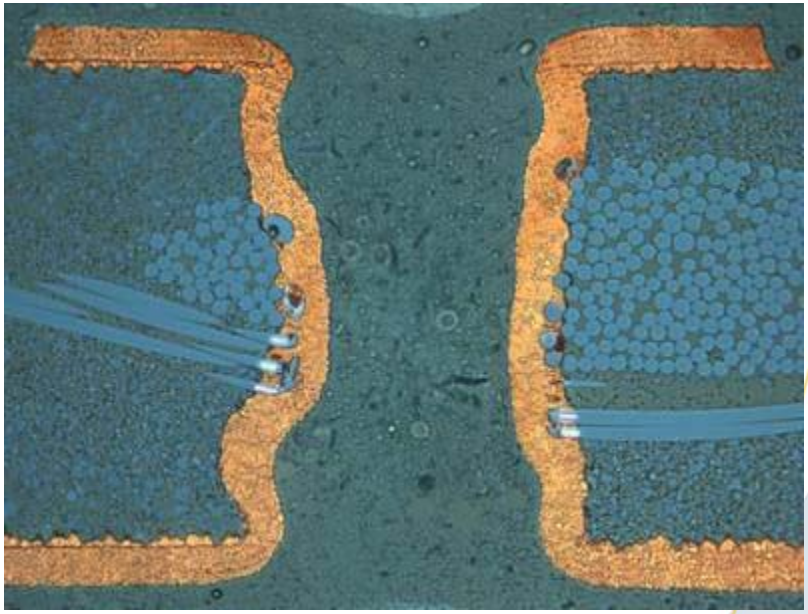
- Result in production is within ± 10% absolute variation within the critical area for the application
  (150µm base material + 3µm copper foil)



Plated copper surface distribution

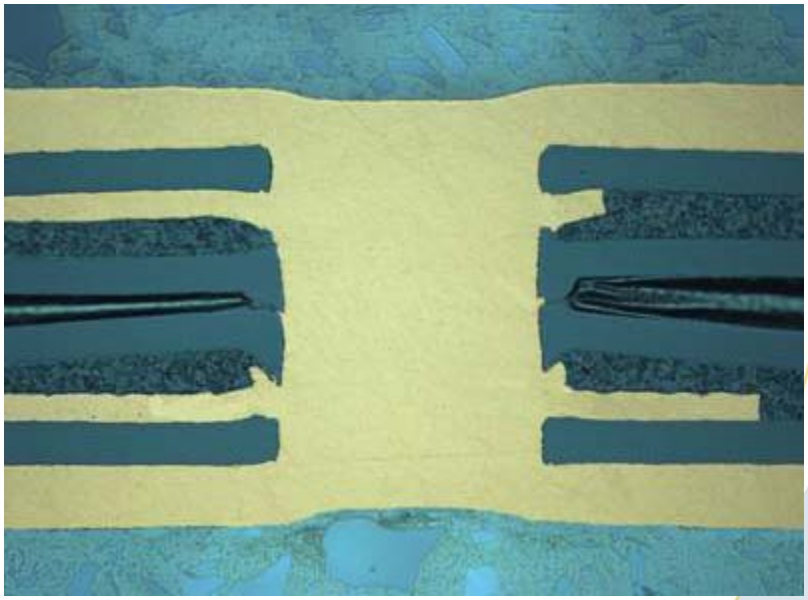
Conformal Plated Through Hole

- Foil thickness 150µm thick with hole diameter 100mm
- Plated copper 18mm to 20µm on surface



Filled Through Hole

- Flex material 125µm thick with hole diameter 100µm
- Plated copper surface approx 15µm
- Remaining dimple approx 10µm



Uniplate 2 RTR Summary

- Specially developed equipment for continuous roll handling to ensure reliable transport
- Easy handling of continuous roll material fór metallization and electrolytic copper plating
- High applied current densities possible up to 10A/dm²
- Large area clamp system under electrolyte working level assures required surface distribution specification

Thank you for your attention.
Any questions?

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