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Electroless Copper Process Control using Back and Frontlight Evaluation

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PCB fabrication is a complex, multi-stage process, with many opportunities for yield loss. Whether using an electroless copper or a direct plate process, metallization of through holes and blind vias, prior to electroplating, is a complex operation. In order to maximize overall yield, it is necessary to operate all processes with appropriate controls. In addition to controlling the operating parameters of each process step it is equally important to perform confirmation testing after each process sub-section. This allows detection of unexpected process excursions, input material changes and provides confirmation of the individual process controls.

Evaluation of coverage provided by the plated through hole process (PTH process) is an important quality control check, which provides some assurance that the deposition process is functioning properly and allows any unexpected problems to be detected at a stage where re-work is possible.

The best way to eliminate plating defects caused by deficiencies in a PTH processes, is to evaluate the quality of electroless copper coverage by routinely performing backlight (BL) and frontlight (FL) testing. BL testing can detect incomplete electroless coverage, while FL testing can establish the location of coverage problems (epoxy or glass) and also determine electroless copper morphology and adhesion to the epoxy, glass and inner-layers (1, 2, 3).

While a BL test is an excellent way to detect changes in overall coverage of product coming out of the PTH process, the relatively small sampling size limits the ability of this technique to detect low level, random voiding, such as might be associated with poor drilling quality / debris or bubble voids.

SAMPLING FREQUENCY

While it would be best to evaluate coupons from every rack / basket processed, to confirm electroless copper plating quality, this may not be practical. Each customer needs to establish an appropriate sampling frequency to maintain their process at the desired quality, by balancing the required resource against the possible impact on yield of lower levels of sampling. One commonly used approach is to remove a coupon from a panel from every rack / basket that is processed, but only check the BL/FL on every 4th sample. If a defect is detected, it is then possible go back and evaluate the other saved coupons from the remaining racks / baskets.

In addition, if it is found that different locations within a rack or basket (for example, outer panels versus central panels) give different coverage performance, it may be appropriate to take samples from more than one location within each rack / basket.

COUPON DESIGN AND LOCATION CONSIDERATIONS

BL or FL tests are typically carried out on an un-mounted PCB coupon. Sections of this type typically contain between 5-10 holes of the same diameter, aligned along the same axis. The hole diameter chosen for evaluation may vary, depending on the type of product being manufactured. Our preference is to test hole sizes between 0.016” - 0.043’’ (0.4 mm -1.1mm). Holes smaller than 0.016” will be much more difficult to prepare and those larger than 0.043” are typically used for mechanical assembly rather than electrical connection. It is best to choose locations that have at least 0.25” (6.0 mm) clearance both above and below the holes, as the presence of other holes behind the set of holes under evaluation will make it impossible to provide the uniform back-illumination required for BL testing.

There are several ways in which a backlight coupon may be processed. Our preferred approach is to incorporate a backlight coupon into an unused area of all production designs, most commonly the outer edge. This allows a test coupon to be taken from any panel within a rack, without sacrificing any finished circuits. This also allows any effects associated with production lot specific variables, such as drilling or laminate materials, to be checked.

Two other approaches that may be used are:

- Use test coupons made from a single material, typically the most common laminate processed, containing a variety of hole sizes.
- Use coupons from scrap panels after the drilling operation

When using either of these two approaches, it is important to attach the coupons to the plating racks, so that they are exposed to the same fluid flow, agitation and vibration as the production panels. However, a drawback to both these approaches is that lot-specific factors, such as laminate type or drilling, will not be detected. Using coupons integrated into production panels is the only way to be sure that all the process conditions have been replicated.

COUPON PREPARATION

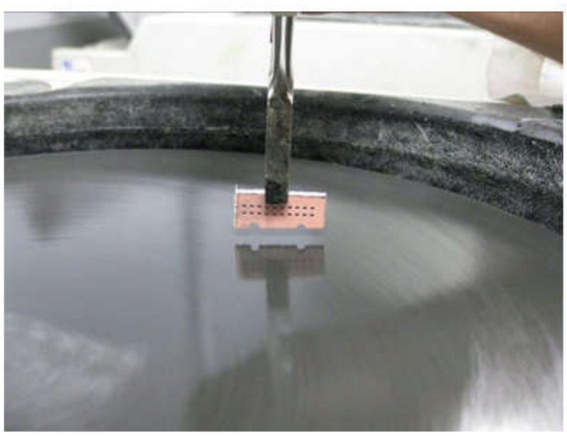
Once coupons have been processed through the PTH process, the holes to be evaluated can be extracted, using a router or a band saw. It is best to leave enough clearance around the holes to allow convenient handling during the subsequent preparation steps.

To carry out a BL or FL test, the coupon must be cut or ground to as close as possible to the central axis of the row of holes, while ensuring the holes are free of burrs or debris, and that the thickness of the coupon (from back surface to the middle of the hole) is sufficiently thin to allow light transmission through the sample for BL tests (~ 0.125" / 3.0 mm). In addition, the sample preparation process must not damage the surfaces to be evaluated.

Once the coupon is removed from the panel, it may be prepared by either using a diamond saw to cut into the holes, or by grinding the coupon down using a wet grinding wheel. Rough grind to the middle of the holes, using either 120 or 240 grit paper, and remove any debris around the holes with 400 or 600 grit paper. When grinding coupons, it is best to use a small pair of smooth faced pliers to hold the coupons, as shown in Figure 1.

First grind down to 1-2 mm from the back of the hole to be inspected, then flip the coupon over and grip the 1-2 mm area with the pliers, being careful keep the pliers away from the holes. After the sample has been prepared, rinse thoroughly with water and dry with compressed air.

Note: Care must be taken during sample preparation not to apply excessive air pressure during sample drying. For those materials that are harder to texture during desmear, the degree of mechanical bonding of electroless copper to the substrate is lower, and electroless copper may be removed, particularly at the interface between outer layer copper foil and dielectric material.



Back side rough grind

Front side rough grind

Figure 1: Sample Preparation

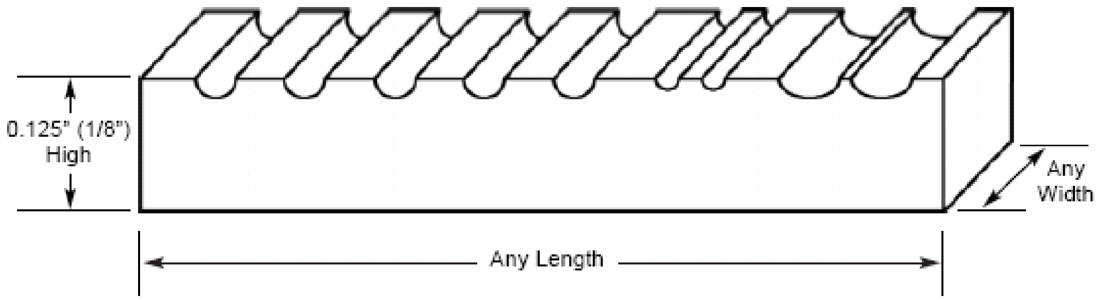


Figure 2: Sample Geometry

COUPON INSPECTION

A microscope capable of 50-200x magnification, with an additional light source (preferably adjustable) behind the coupon is required. Initial focusing should be made, with frontlight, on the bottom middle of the cut holes. After initial focusing, the frontlight should be turned off and the sample viewed by backlight. Transmitted light will be visible in those areas where there is incomplete electroless copper coverage.

Each hole should then be individually assessed. While many assessment scales can be used, we prefer to use a 0.5 - 5.0 numerical scale, with 5.0 representing complete coverage. We use a series of standard images (4) to try to ensure that ratings are applied consistently over time, by different operators. These images are intended to be used as a guide and frequently do not match the exact appearance of the actual backlight being evaluated.

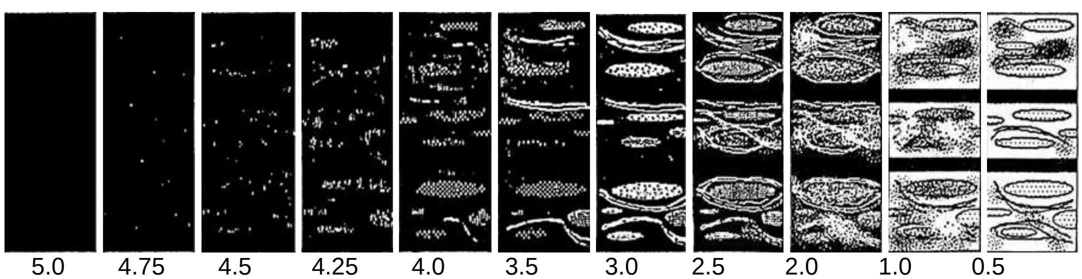


Figure 3: Example of Backlight Scale

The acceptance criteria for backlight will vary from customer to customer. Generally, a backlight rating of 4.25 or better indicates that the coverage and uniformity of the subsequent copper electroplating will meet requirements.

INTERPRETATION OF RESULTS

Once each hole is rated under backlight, examine the voided areas using frontlight to determine the location (on epoxy or glass), void type, deposit morphology and plating quality.

In order to make the assessments less subjective, we have established the following terminology to more accurately identify the different types of coverage defects and deposit morphology that may be seen on BL/FL coupons.

TOG – "Thin plating on glass"
These defects may occur if the electroless copper covers the glass, but is thin enough to allow some light to pass through. Obviously, this is more likely to occur if a thin deposition electroless copper process is being used.

Typical Causes for this defect include short dwell times in the electroless copper bath, improper control of electroless copper bath components, poor conditioning and/or catalyzation, excessive rinsing after the conditioner or catalyst, or excessively long dwell times in the micro etch after the conditioner step.

TOE – "Thin plating on epoxy"
This defect is similar to TOG, except that the defect location is on epoxy.

TOE can be caused by the same factors as TOG (above). There are also some high Tg or filled resins that are particularly hard to condition and catalyze, and thinning can occur on these as well.

ROP – "Ring of Pearls"
This defect may occur at the interfaces between dielectric material and copper layers, most commonly on the oxide or "B" stage side of the inner layer. In severe cases, it can also occur on the "C" stage side.
While the term ring of pearls is based on the discontinuous appearance of the ring of light often seen in these areas, there are times when the light ring may be continuous. When such voids are seen at the outer layer foil interfaces, they may be referred to as "rim voids".

The most common cause of this defect is poor drilling, leading to two different types of damage:

- Fractures between the "B" stage and inner layer.

  In this case, the subsequent desmear process may open up the fractures, making them more difficult to cover with electroless copper. The thinner the electroless copper deposit applied, the more likely that ROP will be seen.

- Create nail heading

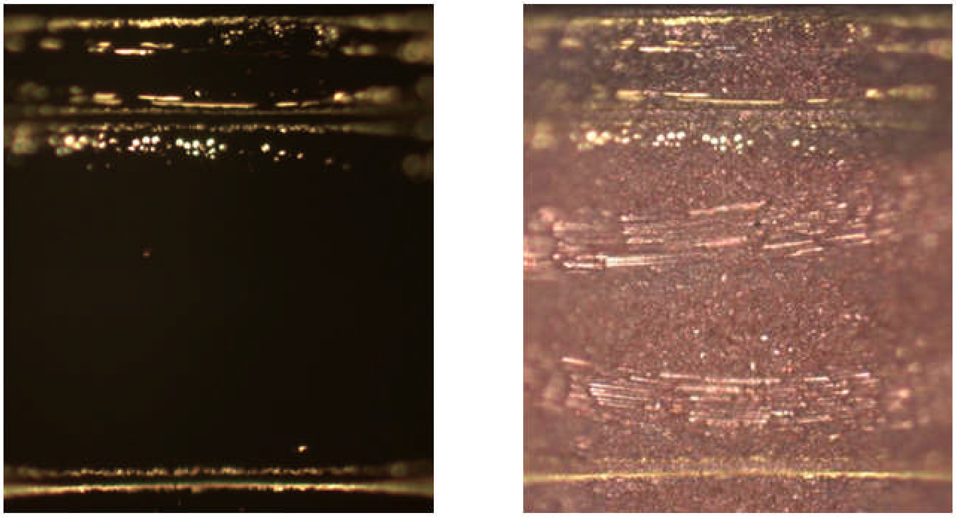
  In this case, the copper inner layers are deformed over the dielectric surfaces above and below the inner layer. Once panels are processed through the micro etch, (depending on the etch rate) this deformed copper (nail head) can be removed, exposing the dielectric areas. Since these areas are not exposed to the conditioning chemistry prior to the microetch, the degree of absorption of catalyst is reduced**,** increasing the likelihood of poor coverage. "ROP" is less likely when a neutralizer that etches some copper (i.e. sulfuric/peroxide based systems) is used prior to the conditioning step.

GTV – "Glass Tip Voids"
Glass tip voids are defined as those that occur on glass bundles that are perpendicular to the hole wall (shaped like an eye). This defect is simply due to lack of electroless copper coverage on the glass tips.

While the typical causes of this defect are poor conditioning and/or catalyzation, they can also be related to over-rinsing at any point between the conditioner and electroless copper steps. Long micro etch times, or an aggressive micro etch, can also strip the conditioner from epoxy and glass surfaces, leading to poor catalyzation and voiding. Since glass areas are harder to condition, an over-aggressive micro etch will create glass voids first.

TGV – "Transverse Glass Voids"
Transverse glass are those bundles oriented parallel to the hole wall. The dimensions of the glass bundles will vary, depending on the prepreg and/or core material used. Again, this defect is simply due to lack of electroless copper coverage on the glass surfaces.

Typical Causes are similar to those for GTV. In addition, voiding can occur on transverse bundle areas due to poor adhesion of the electroless copper to the glass. The copper deposit may then "pop off" the glass during or after deposition and create a void (see discussion of "pop-off" and wrinkles below for more details). This happens more often on thick than thin glass.



Backlight Frontlight

Figure 4: Backlight and Frontlight Images Showing ROP, GTV, TGV.

PO – "Pop Off"

When the electroless copper deposit fails to adhere to the glass and starts to crack, it may eventually "pop off", leading to a TGV. Since TGV can be caused by several different root causes, evaluation for "pop off" can provide additional information about the defect mode.

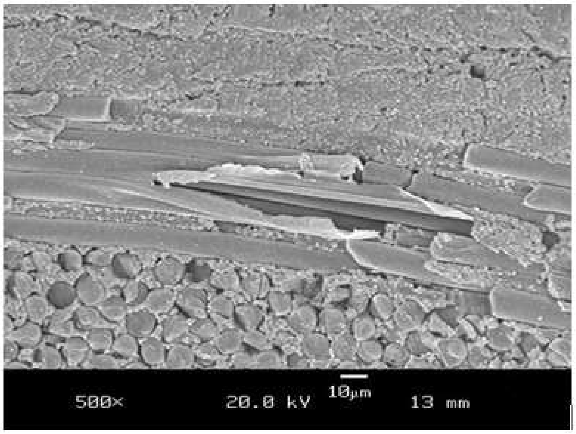


Figure 5: SEM of "Pop Off" (PO) on a transverse glass bundle

Typical Causes for "Pop Off" are over conditioning and catalyzation, however the electroless copper thickness and glass thickness can also play a role in causing this defect. The thicker the electroless copper, the more likely it is to "pop off" the glass, due to the stress within the copper deposit. In addition, thicker glass is more likely to show "pop off" compared to thinner glass, due to the increased surface area of the thicker glass. There can be occasions when, upon examination of the glass using frontlight, poor adhesion or buckling of the electroless copper can be seen, but the backlight is not affected. This weak bond between the electroless copper and glass is an indicator of the potential for TGV on other areas of the panel.

WR – "Wrinkles"

In some cases, rather than the electroless copper popping off the glass, the copper has a wrinkled appearance, although many times, no glass voiding can be seen in the coupon. Therefore the presence of wrinkling is worth noting because it is an indication of less than perfect glass adhesion and, if seen, it may be useful to check additional samples to see if any evidence of voiding is present.

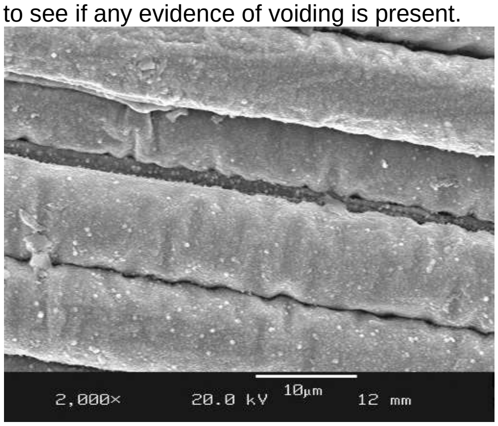
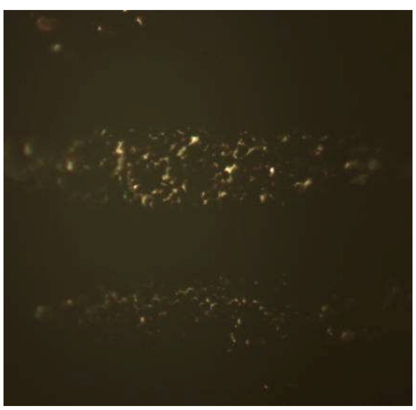


Figure 6: SEM of wrinkling on a transverse glass bundle

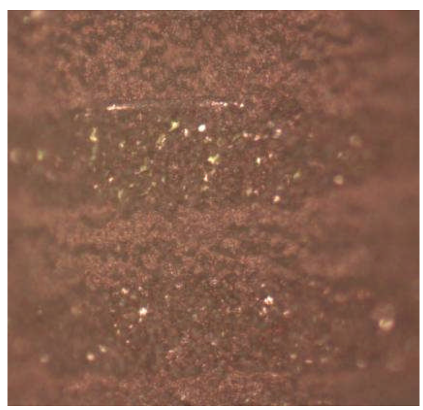
TAG –"Thinning around Glass"

This defect occurs predominantly around glass tips, and is frequently mistaken for GTV during back light examinations. Upon closer evaluation of the void areas using frontlight, you can clearly see the light is coming through from areas around or in between the glass, rather than the glass area itself.

This defect is more often seen on lower Tg than high Tg materials, due to their higher epoxy removal rates. The more aggressive the desmear process, the more likely TAG defects are to occur. Additionally, thinner electroless copper deposits are more susceptible to TAG.



Backlight



Frontlight

Figure 7: Backlight and Frontlight Images Showing TAG
The areas around the glass tips have incomplete electroless copper coverage.

PL – "Copper Peeling"
This defect occurs on epoxy areas and is similar to PO, except that it occurs on the epoxy portion of the hole.

Typical causes for "PL" are over conditioning and catalyzation. However some laminates are more prone to this defect, due to lack of texturing during the desmear process. While higher Tg materials are typically harder to texture than lower Tg materials, not all materials follow this pattern. Other factors that can impact texturing and PL are the type of epoxy used and whether fillers are used. Flex materials can also be very difficult to texture and are prone to PL and blisters (EB).

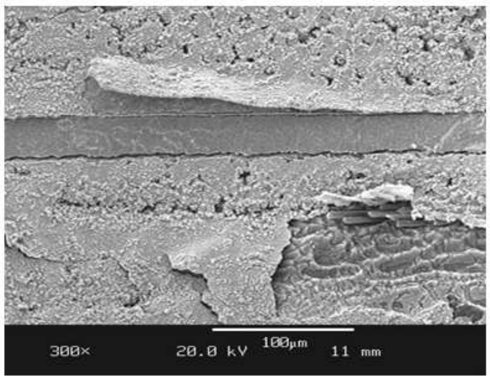


Figure 8: SEM of the electroless copper peeling (PL) from epoxy areas of a holewall

EB – "Electroless Blister"
This defect can occur on either copper inner layers, or the epoxy portions of the hole wall. In either case they have the appearance of a bubble of electroless copper on the surface of the hole. If present, this defect will typically show up in many locations within a panel.

The typical cause of this defect is poor adhesion of the electroless copper deposit to the hole (epoxy or copper inner layer). The main causes for EB are the same as PL.

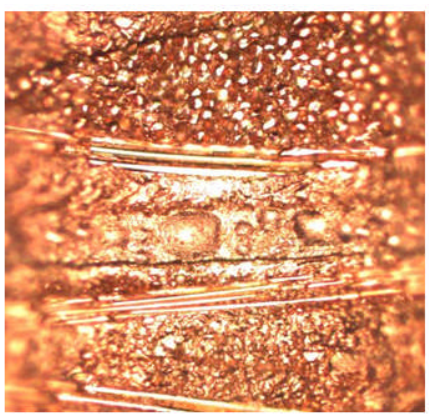


Figure 9: Frontlight of the electroless copper blistering off the copper inner layers in a hole

DATA RECORDING

The coverage of each individual hole in the coupon should be determined and recorded, based on the backlight scale used. Once all the holes have been rated, record both the average BL rating and also the lowest BL rating for any of the holes. Including the lowest BL reading will provide some indication of the consistency of the electroless copper coverage throughout the coupon being inspected.

Once each hole is rated for coverage using backlight, re-inspect the holes using frontlight to determine where the voids are occurring and the morphology of the copper deposit. To determine the copper deposit morphology, it is best to examine the transverse glass bundles due to their relatively smooth surface. This smooth surface will better reflect the true morphology of the copper deposit, than the surface of the roughened epoxy.

At times it may be helpful to go back and forth between front and backlight, to determine where the void is located. Examine the voids carefully, as many times light will pass through areas around the glass tips and not in them (TAG). It is also useful to estimate the percentage of glass voiding versus epoxy voiding throughout the coupon, to better determine the cause(s) of the voids. Table 1 shows an example of a backlight log sheet and the legends used to record void types.

Table 1: Sample Data Recording Format for Backlight / Frontlight Test Results

Laminate Material	**Sample ID**	**Hole #1**	**Hole #2**	**Hole #3**	**Hole #4**	**Hole #5**	**Average**	**Void Type**
FR-4	#1	4.8	4.7	4.9	4.9	4.9	**4.84** **(4.7)**	95% glass, TAG, PO,TGV

Note: Under void type, record the percentage of voids that are located on the glass areas

PO – Pop off
EB – Electroless blister
TAG – Thin plating around glass
TOG – Thin plating on glass
TOE – Thin plating on epoxy

WR – Wrinkling on glass
PL – Copper peeling off epoxy
TGV – Transverse glass void
GTV – Glass tip void
ROP – Ring of pearls

CONCLUSIONS

Failing to identify PTH process defects until circuits are completed is expensive, not only in material and processing costs, but also in costs to customer relationships when delivery times are not met.

Careful inspection of production BL coupons on a regular schedule can help identify potential quality issues in the PTH process and allow you to capture product at a stage where it can still be re-worked. Monitoring trends in overall BL coverage levels and in the locations at which coverage is declining over time can provide early warning of emerging process control or bath issues, such as contamination or excessive bath age.

In addition, performing a BL characterization on newly introduced laminate materials allows a determination of whether the PTH process chemistry is capable of providing the required performance, or if adjustments are required to the process.

Used properly, the BL test is an invaluable tool for both quality assurance and troubleshooting PTH process problems.

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