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TECHNICAL NOTE

Microvia process guidelines

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1 SCOPE, PURPOSE, ACKNOWLEDGEMENT

This guideline document provides recommendations to PCB manufacturers for the processes associated to the manufacturing of microvia technology. This document can also be used as a guideline for conducting a process audit.

Besides the manufacturing processes, the reliability of microvia technology is also affected by their design, such as aspect ratio, drill diameter (aperture), the dielectric layer uniformity, the style of glass weave, the copper distribution and the distance to adjacent microvias and core vias, via density and pitch, among other things. Specific limitations to these design aspects are not within the scope of this document.

In addition, acceptance criteria are not in scope of this document, as they are specified in ECSS-Q-ST-70-60.

These guidelines intend to cover the global overview of the processes and discuss precautions. This cannot be done without going to a relatively high degree of technical detail. Nevertheless, these guidelines are no replacement for the expertise of chemistry suppliers and their process instructions, which typically go into an even greater level of detail.

These guidelines have been drafted with support from PCB experts PE Goutorbe from ADS and J-M Guiraud from TAS as well as the following experts from chemistry suppliers: R Massey, K Wurdinger, T Aillas from Atotech; S Sullivan, C Colangelo from DuPont (formerly Dow Electronic Materials); W Bowerman, R Bellemare from MacDermid Alpha. The guidelines have been reviewed by the PCB manufacturers of the PCB/SMT WG (see distribution list).

2 DOCUMENTS

No	Reference	Document Title
AD01	ECSS-Q-ST-70-12C	Space Product Assurance – Design of PCBs
AD02	ECSS-Q-ST-70-60C	Space Product Assurance – Qualification and procurement of PCBs

No	Reference	Document Title
RD01	IPC-2221B	Generic Standard on Printed Board Design
RD02	IPC-6012E	Qualification and Performance Specification for Rigid Printed Boards
RD03	IPC-6012ES	Space and Military Avionics Applications Addendum to IPC-6012D
RD04	https://www.ipc.org/ContentPage.aspx?pageid=IPC-Issues-Electronics-Industry-Warning-on-Printed-Board-Microvia-Reliability-for-High-Performance-Products	IPC Electronics Industry Warning on Printed Board Microvia Reliability for High Performance Products
RD05	AspS 1031	Airbus DS Alert on microvia reliability
RD06	TAS 20-006	Thales Alenia Space Warning Notice on microvia reliability

3 NOMENCLATURE

3.1 Abbreviations

AD	Applicable Document
AOI	Automated Optical Inspection
Cu	Copper
DPA	Destructive Physical Analysis
EBSD	Electron BackScatter Diffraction
EC	Electroless copper
ECSS	European Cooperation for Space Standardisation
ED	ElectroDeposited
e.g.	for instance
ESA	European Space Agency
HDI	High Density Interconnect
ICD	Interconnect Defect
i.e.	which is
IPC	Association connecting electronics industry (originally: Institute for Printed Circuits)
IST	Interconnect Stress Test
µvia	Microvia
max	Maximum
min	Minimum
PCB	Printed Circuit Board
PCB/SMT WG	Working group for PCB and assembly technology
PID	Process Identification Document
PTH	Plated Though-Hole
RD	Reference Document
SEM	Scanning Electron Microscopy
XRD	Xray Diffraction

3.2 Terms and definitions

Target pad	The internal copper foil that the microvia interconnects.
External pad	The external copper foil that the microvia interconnects. This is also named: “capture pad”. However, the term “capture pad” is often confused with “target pad”. Therefore the term “capture pad” is not used in this document. “Pad” and “land” are synonymous.
[qualification]	Indicates a recommendation for an in-depth verification for the (internal or third-party) qualification of the process.
[in-process verification]	Indicates a recommendation for verification of the process that is repeated periodically, for instance each work shift. This can also include a repeated verification that was performed for qualification.
[lot conformance test]	This is a verification done for each batch or each panel. This term is not used in the present document, as it is covered by AD02.
“should”	Indicates a recommendation. In addition, the formulations “to recommend” and “is preferred” are occasionally used.
“can”	Indicates a possibility.
“may”	Indicates a permission.
“shall”	Indicates a requirement and is not used in this document.

4 GENERAL PROCESS OVERVIEW

4.1 Process overview

The following paragraphs discuss recommendations of each of the main process steps of microvia manufacturing, which are the following:

- Laser drilling
- Pre-etching
- Desmear
- Electroless copper
- Flash plating
- Via fill plating

In addition, microetch is typically implemented within the process line after desmear, prior to EC and prior to via fill plating, as well as in the pre-etch process. Rinses are implemented in most process steps, as well as pre-dip and post dip baths.

This document considers that laser drilling and copper filling are the baseline for microvia manufacture (as opposed to mechanical drilling and resin filling). While this document states a preference for horizontal processing, many recommendations are targeting vertical processing because this is most widely used.

Recommendations in this document may be advantageous for the reliability of microvias, whereas there might be consequences or disadvantages for other aspects of PCB manufacturing processes. This document prioritizes the microvia reliability.

4.2 General recommendations

a. Microvia manufacturing should occur separately from mechanical via manufacturing. This allows for optimization of desmear, microetch and EC for the microvias, without consideration to the mechanical vias. The main disadvantage of doing so is thicker plated copper layers, which can be a problem for fine line etching. And another possible disadvantage is longer processing time.
b. Horizontal desmear/microetch/EC/galvanic line is preferred over a vertical line, as it allows more accurate process control. Horizontal equipment provides better solution exchange due to floodbars and ultrasonic bars. Vertical equipment needs special features like vibration and shocking. A disadvantage might be that horizontal processing offers less flexibility and requires high investment. In addition, conveyorised systems are available for both horizontal and vertical set-up and their use is recommended.
c. For vertical lines, racks are preferred over baskets.
d. [in-process verification] Spacers on baskets should ensure consistent positioning and subject to periodic verification. Mechanical wear on spacers should be prevented as it alters the positioning as well as it dampens the mechanical movement from vibrations.

e. Because small spacing can restrict chemistry flow, process performance should be verified in these conditions. The margin with respect to the implemented min spacing should be investigated.
f. A daily inspection of mechanical aspects of the line should be performed, including vibration systems, handling systems, nuts, bolts, rack, basket, spacers. This is in addition to the verifications of the chemistries and bath conditions.
g. The line, transport racks, baskets, tanks, pipes, overhead lighting, ceiling and surroundings should be clean. Periodic verification of cleanliness and a routine maintenance schedule should be in place.
h. Pre-dip and post-dip baths can contain (intentionally) small amounts of active process chemistry from previous or subsequent processes. These baths should be treated as critical as an active bath for its process control, monitoring of contamination and replenishment. These baths should be run as a dynamic process (i.e. with agitation).
i. Process guidelines from the laminate supplier should be taken into account. They may need to be adjusted to accommodate the specific set-up and technology.
j. An audit from the chemistry supplier should be performed for each part of the process line. This should be performed by a (senior) expert. It is recommended that the auditor is not the same person that recently performed the (initial) installation of the line or that conducts periodic maintenance. Critical as well as non-critical recommendations from the chemistry supplier should be implemented.

4.3 General verification

a. [qualification] The maximum overhang (also named undercut), glass fibre protrusion, aspect ratio, diameters on top and bottom should be covered by the qualification.
b. [qualification] The efficiency of chemistry flow in microvias should be verified for all processes taking into account the (highest) density of microvias, as well as the design features specified in 4.3a. A high density of microvias can consume a large part of active components of the chemistry locally in the bath. Verification can be performed by characterizing the deposit, cleanliness and general aspect. It is not possible to measure chemistry constituents inside the microvias.
c. [in-process verification] Adhesion between target pad, EC, flash copper and via fill copper should be verified periodically, for instance by pull test and/or by thermal stress and DPA.
d. [in-process verification] Adhesion between various copper layers depends on continuous crystal growth across the interfaces. This is named epitaxy. A qualitative assessment should be performed periodically, for instance by using SEM, FIB, EBSD, XRD, electropolishing and/or ion beam polishing.
e. [qualification] Verification of process performance should cover the min and max of process parameters including: temperature, dwell time, additives, contaminants, bath age, among others. This is usually done by the chemistry supplier for the initial set-up. The process parameters can be modified by the PCB manufacturer in conjunction with the chemistry supplier to tailor for the specific technology to be manufactured, in which case the changes should be verified.

f. [in-process verification] Verification should be performed across the panel to investigate if the centre and edges of the panel receive equal process efficiency. Also, dependency with circuit and hole pattern should be investigated. This should be done for initial qualification and it should be repeated periodically.
g. [qualification] Verification should be performed on multiple panels within a job load (in basket or rack).
h. [qualification] Verification should be performed from batch to batch.
i. [qualification] Verification should be performed to cover the qualified design features (such as diameter and aspect ratio). It is considered good practice to perform verification of more complex features than what is covered by the qualification.

5 SPECIFIC PROCESS RECOMMENDATIONS

5.1 Laser drilling

a. The opening of surface copper may be done by laser or by wet chemistry
b. Microvia holes should be drilled in the dielectric using lasers, not with mechanical means.
c. [in-process verification] The efficiency of laser ablation through resin and through glass determine the shape and dimensions of the microvia. This should be verified per batch, for instance using microsectioning, SEM and/or 3D microscope.
d. [in-process verification] In addition, an in-process top-down inspection of the microvia target pad should be performed periodically by SEM to verify that the organic residue and recast copper on the target pad is within nominal limits, which may be provided by chemistry/process suppliers or by experience from the PCB manufacturer.
e. [in-process verification] The laser drilling should result in a straight hole wall, to maximize the contact area to the target land and to avoid a ‘barrel’ shape. Alternatively, the hole wall can be slightly inclined (e.g. max 20°) which generates a slight conical shape of the microvia. This can be beneficial for chemistry flow (even though the inclined hole wall reduces the contact area to target land). Inefficient drilling typically leaves the second glass weave (when using 2 prepregs) partly uncut, which causes a very conical hole wall that reduces contact area to target pad or an irregular barrel shape that is not favorable for chemistry circulation during subsequent plating steps.
f. After laser drilling, there should be another laser process (defocussed UV clean step, named UV skiving, or alternatively a CO_2 cleaning step) for the cleaning of the target pad, similarly to desmear. In case of UV skiving, this can slightly ablate the copper. The power of the laser should be verified to be high enough to perform the cleaning, but low enough to avoid softening or otherwise altering the copper of the target land. Softening the target land during this process can result in the fixation of ash, carbonization, resin debris to the target land, which is the opposite effect of what the process intends to do.
g. Laser drilling should avoid copper overhang on the external pad because this is not easily removed by subsequent processing. Overhang limits the chemistry flow. An additional copper etch process may be implemented. This can remove a slight amount

(few microns) of overhang but not a significant amount. The main purpose of copper etch is cleaning of target pad as per chapter 5.2.

h. [qualification] The morphology of the copper foil of the target pad should not be altered by the laser drilling or cleaning in a way that reduces adhesion of EC. See 4.3d.
i. Laser drilling creates a lot of heat that can affect the copper morphology on the target pads. Therefore, laser drilling should follow a non-optimised (for speed) pattern that allows to cool before drilling the adjacent hole. The slight disadvantage of this is that it takes longer. This precaution may not be necessary in case the power of the laser has been verified not to cause heating or alteration of the copper.
j. [in-process verification] The penetration depth to the target pad of laser drilling and laser cleaning should be specified and subject to periodic verification. A slight penetration may be expected for UV laser, whereas no penetration is expected for CO2 laser. Penetration generates recast copper.
k. [in-process verification] Absence of breakout from target pad or penetration should be verified by visual inspection or Xray.
l. [in-process verification] Registration of drilled hole to target pad and to external pad should be verified by microsectioning and measurement of annular ring in x- and y-direction on all 4 corners of a panel.
m. The procedures should specify the allowable wait time after laser drilling until subsequent processing (pre-etch). Generally there is no criticality expected from this wait time, but it is good practice to specify it in procedures.

5.2 Pre-etch and pre-cleaning

a. Pre-etch process should be implemented prior to desmear.
b. Pre-etch should be performed using peroxide or persulfate and is best accomplished using a horizontal process line. It is implemented prior to desmear to remove recast copper and organic contaminates without being overaggressive to the copper of the target pad. This will reduce macro-roughness. See also 5.4b.
c. On horizontal pre-etch equipment, depending on their design, panels should be processed twice and turned over to compensate for differences from top to bottom and to ensure all microvias are equally processed. Care should be taken that the double pass does not cause a too high amount of etching.
d. High pressure water cleaning should be implemented.
e. Mechanical brushing (as done for through-going vias) should not be performed at this stage of microvia manufacturing.
f. After pre-etch, panels may be dried and a wait time may be implemented. The max wait time should be specified in procedures. A wait time, without drying should not be performed.
g. Cleaning (and swelling) in solvent should be implemented prior to chemical desmear, either as a pre-clean step or as the first active process within the desmear line. This should include ultrasonics in a horizontal set-up, or vibrations in a vertical set-up. The power of the ultrasonics or vibrations should be periodically verified.

5.3 Desmear

a. A desmear cleaning process should be implemented to clean target pad (and hole walls) after laser drilling. Desmear may be performed using plasma. Desmear should also be performed using wet chemistry (permanganate). A combination of both should typically be performed, in which case plasma should occur before wet chemistry because wet chemistry can help removing ash residues from plasma process.
b. On vertical chemical desmear equipment, panels may be processed twice to ensure all microvias are equally processed. On horizontal desmear equipment, panels should be processed twice and turned over to compensate for differences from top to bottom. Some equipment may be already compensate for this.
c. [qualification] The efficiency of plasma desmear should be specifically verified across a panel, and from panel to panel depending on its position inside the chamber. See 4.3.
d. [qualification] It should be verified that permanganate cannot dry inside microvias during the max drip time permitted to the process. Possibly, drip time should be minimized after consulting with chemistry supplier. Sodium permanganate is recommended since it has better solubility than potassium permanganate and is, therefore, more easily removed by the neutralizer.
e. [qualification] The desmear process is critical. The failure mode between EC and target pad is an important failure mode of microvias. The efficiency of the process should be verified across the panel, among panels of a job load (basket or rack) and among batches. See 4.3.
f. [in-process verification] Periodic, e.g. daily, weight loss measurement on test samples of applicable laminate types should be done to ensure process efficiency. To accurately measure the expected low amount of weight loss it is essential to implement a strict measurement protocol, including bake out, elimination of static charge, environmental control of relative humidity and temperature. The protocol can be obtained from the chemistry supplier. The weight loss values should be determined taking into consideration the materials, technology and equipment set-up.
g. The typical chemical desmear neutralizer is of the non-etching type. Alternatively, hydrogen peroxide and sulfuric acid neutralizer is available and has a side reaction that etches copper from the target pad. In this case, the etch rate and other process parameters should be verified in the same way as microetch. See 5.4.
h. A separate step for glass etch or glass frost may be implemented after desmear. This can be included in the neutralizer.
i. [qualification] The max wait time after desmear prior to subsequent processes (microetch and EC) should be verified by the qualification.

5.4 Microetch

a. Microetch is equally critical as desmear, as these processes determine the surface preparation of the target pad, among others. Microetch should be implemented as follows:
    - before desmear (named ‘pre-etch’ and covered by chapter 5.2)
    - after desmear within its process line
    - prior to EC within its process line
    - between plating processes (flash and via fill and pattern/panel plate).

b. A pre-wetting stage should be implemented prior to microetch. In case processes run wet to wet (without drying), this is already accounted for.

c. Persulfate may be used for microetch to remove film layers from the conditioning and activation processes (e.g. for PTH manufacturing) and to increase the surface topography by exposing the copper grain structure. This will increase micro-roughness. See also 5.2b. Sodium persulfate or potassium peroxymonosulfate (e.g. Caroat) is recommended for its stable etch rate.

d. Vertical microetch should be performed in a bath including vibrations, oscillations and a pump that ensures circulation and filtration of the bath with accurate flow control. This is to ensure efficient chemistry flow inside the blind microvia holes and uniformity across the bath. An air sparger (bubbles) on both sides of the panel can be used to further improve chemistry flow. In addition, ‘eductor’ systems are available that ensure circulation inside the microvias by ‘venturi’ effect. Also, a ‘hammer’ system is in use that provides a mechanical shock, similarly to vibrations.

e. [in-process verification] Vibrations should be measured on panels periodically to ensure efficient transfer of mechanical movement. The lack of mechanical clamping of racks and panels, or the spacers in baskets, can dampen vibrations. The measurement may be done in air, as measuring in liquid chemistry may be difficult.

f. [in-process verification] Etching efficiency inside microvias should be verified periodically across the panel and from panel to panel depending on its location in the bath. See 4.3. Longer process time at a lower etch rate typically provides better uniformity across the panel. Etching efficiency can be verified for instance by roughness measurement or penetration depth measurement using DPA and top-down SEM imaging. The copper roughness on target pad is the result of laser, pre-etch, desmear and microetch. Copper roughness on intermediate plated copper layers is the result of microetch only.

g. [in-process verification] Etch rate on the surface of a test sample should be verified prior to each working shift. The etch rate coupon should be used only once because the measured etch rate will change on a single aged coupon. Procedures should specify if the coupon needs to be pre-cleaned and what possible effect such surface preparation may have on the etch rate measurement.

h. [qualification] Plated copper etches at a different rate than copper foil (that is typically of type ED electrodeposited). The correlation between the etch rate of a test sample and the etch rate of copper plating (that is on the surface of the target pad) should be established.

i. [qualification] The surface condition (roughness, cleanliness) inside microvias should be established for the min and max etch rate on test samples. This should be done in consultation with the chemistry supplier. A certain min etch rate ensures proper cleaning, while max etch rate prevents the occurrence of wedge voids in corners due to the recessed target pad.

j. Bath components and copper build-up in the microetch bath should be monitored. For instance, sulfuric acid can change copper morphology without having much impact on etch rate.
k. There should be no wait time, and no drying after microetch prior to subsequent processes (EC or plating). The priority level in the automated process control software should ensure this. Extended rinsing should not be performed if this is to replace wait time (in dry environment). This is specified to prevent oxidization. However, slight oxidation is possible to be removed by catalyst pre-dips.

5.5 Rinse

a. Rinse processes should be implemented in almost all main process steps. And each process step should have its own dedicated rinse.
b. Cross contamination to other baths should be prevented by cascade rinse and/or counterflow rinse. Alternatively, a high rinse flow on a single bath may also be efficient.
c. [in-process verification] Efficiency of rinsing should be verified by investigating the dilution factor and cleanliness of the final rinse bath. Typical dilution factors are 2000 to 10000.
d. Critical vertical rinse processes should include vibrations, oscillations, pH-control, filtration and a pump that ensures circulation of the bath with accurate flow control. In addition, an air sparger (bubbles) on both sides of the panel may be used in rinse processes after microetch. In addition, some rinsing may be static and/or spray rinse.
e. [in-process verification] Vibration should be measured on panels periodically to ensure efficient transfer of mechanical movement, as per 5.4e. This verification can be done in air, but it might be difficult to do in liquid.
f. Rinse flow meters should be installed on each bath separately and allow for accurate flow monitoring.
g. Rinsing after catalyst prior to EC should be acidified to prevent oxidation. Rinsing after microetch should be acidified to prevent deposition of copper oxide. This should be implemented only if it is in-line with the recommendations from the chemistry supplier.
h. Periodically, e.g. once a week, the rinse baths should be emptied, cleaned and completely renewed. Cleaning should ensure the removal of any algae and other contamination.
i. [qualification] The effect of running rinses at max age should be verified.

5.6 Electroless Copper EC

a. Alternative metallization processes to EC can be in use, such as direct metallization.
b. It is preferred to run wet-in-wet processes from microetch to EC, as per 5.4k. In case this is not done, it is important to implement an initial wetting step in the EC process.
c. The EC process should be efficient to deposit EC on all of the hole wall of all microvias in one single pass of the process. A double pass is an alternative to patch up process inefficiencies, such as non-uniform deposition or poor adhesion. Double pass can be performed on old equipment and for manufacturing through-going vias. This is one of the reasons why microvias should not be processed at the same time with through-going vias that may need double passing, as per 4.1a.
d. There is a very strong relationship between conditioner, catalyst, accelerator/reducer and EC. A change in one step has impact on other process steps and should, therefore, be subject to verification.
e. The efficiency of rinsing after conditioner, catalyst and accelerator/reducer should be verified as per chapter 5.5. In addition, it should be verified that rinsing is not excessive. Long rinsing of conditioner can reduce the conditioner's efficiency. Long or incorrect pH rinsing of catalyst can cause particulates (or insoluble hydroxides) that could deposit on copper surface and reduce adhesion.
f. [qualification] Deposition rate inside microvias should be correlated with deposition rate obtained on the test sample. This is named throwing power. This verification can be achieved, for instance, by overplating with nickel (galvanic or electroless) to avoid smearing of copper (during microsectioning) and subsequent SEM analysis.
g. [in-process verification] The deposition rate should be verified using the test sample prior to each working shift. The sample laminate of the test sample should be used only once because the measured plating rate on an aged sample will change. The sample should be of the same laminate as the technology to be manufactured and copper cladding should be etched off.
h. [in-process verification] The EC adhesion to target land should be verified periodically, for instance by pull test or thermal stress and DPA. See 4.3c.
i. [in-process verification] The morphology of EC should be verified and compared to the target land and plated copper. Aligned grain boundaries and visible interfaces are an indication of poor joint integrity. The aspect should not be amorphous. See 4.3d. Top-down SEM inspection is preferred over cross-sectioning to avoid polishing artifacts and because it allows to inspect a larger surface area.
j. There should be no wait time, and no drying after EC prior to subsequent processes (flash plating).
k. It should be verified that the time to transfer to subsequent flash plating is minimized to prevent drying, oxidation or contamination of EC inside microvias.
l. [in-process verification] The procedures should specify the min and max EC deposit thickness inside the microvia holes. This should be verified periodically.
m. [qualification] The efficiency of EC deposition should be verified across the panel, among panels of a job load (basket or rack) and among batches. See 4.3. EC deposition should be determined on the hole wall and on the target land. The target land typically receives less EC thickness which is deemed beneficial for reliability. EC deposition can be determined for instance by cross-sectioning and SEM, possibly using overplating (for instance with Nickel), or by a back-light test.

n. The efficiency of EC deposition should be verified for the parameters specified in 4.3a+b.
o. Palladium (as a preparation to EC) deposits mainly on dielectric and to a much lesser degree on target pad. Rinsing should be implemented after Palladium process, in which case it is not expected that Palladium can affect the epitaxy/crystal growth of EC compared to the target land.

5.7 Copper plating (flash, via fill, pattern/panel)

a. [qualification] Plating uniformity should be verified across the panel, among panels of a job load (basket or rack) and among batches. See 4.3.
b. [qualification] Plating uniformity is affected by current density, and thus the pattern design of surface copper and microvia pitch. This interdependency should be specifically verified by determining min and max plating on patterns with low and high current density. See 4.3f.
c. Waiting time in galvanic bath after the nominal duration of plating should be avoided. Zero current can result in reversed or unexpected plating and cause deposition of contaminants on the freshly plated copper layer. Care should be taken that residual low current does not result in different copper crystallography. Maximum duration for residual low current should be specified and substantiated by characterization of the copper. Full current is recommended for microvia reliability but it has the disadvantage of plating thick copper (on surface).
d. There should be no wait time, and no drying after flash plating prior to subsequent processes (via fill plating). In case this is not done, there should be significant cleaning and microetching, e.g. about 1-2 micron. The thickness of flash plate should be sufficient to sustain such amount of copper removal. As an alternative, in case of pattern plating at the same time of microvia fill plating, care should be taken to ensure the acid cleaner (pre-dip) and microetch processes remove any residue from the imaging process. It is possible that flash plating is combined with via fill plating into a single process.