ICDs (InterConnect Defects)

What are they?

Where do they come from?

How can we make them go away?

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Definition of ICD

- ICDs are any defect that occurs adjacent to the innerlayer copper post.
- Some common types are smeared resin, hole debris, and post separation.
- ICDs are broken up into 3 categories:
  - Type I – Between inner layer copper and electroless copper
  - Type II – Between electroless copper and electrolytic copper
  - Type III – Elsewhere in copper
- We will only refer to Type I.
Example of ICD types

Type 1 or 2

Type 3
Categorizing Type 1 ICDs

- **Debris type**
  - (Debris interfering with interconnect bond)
    - Drill debris
    - Smear
    - Dielectric filler powder

- **Separation type**
  - (Separation of interconnect bond)
    - Copper cleanliness
    - Drill work hardening
    - Rinsing residue
    - Poor electroless copper quality

- This approach helps communicate root cause
Why do we care?

- **Type 1 Debris type ICDs are not closely related to finished product defects**
  - Fail IPC and Military specifications – Product generally can’t be shipped
  - Have been tested at multiple companies without exhibiting significant impact on through hole reliability

- **Type 1 Separation type ICDs are closely related to the formation of open circuits in assembled PCB’s.**
  - Valid reliability concern
  - Specification failure
ICD debugging comments

- In general, not enough work is done to determine what type of ICD is occurring
- Dominant response to ICD is to increase desmear level
  - Works on smear and debris
    - But is not necessarily the root cause
  - Can make Separation type ICDs worse
- Desmear process changes by PCB fabricators are common, but very hesitant to change electroless copper parameters
Debris Type  
Where do they come from?

- **Direct Cause**
  - Debris generated during the hole drilling process coats (or sticks to) the drilled hole wall
  - Debris is not entirely removed during post drill cleaning – Primary cleaning is called desmear process (or smear/debris removal processing)
  - Debris interferes with formation of “flawless” interconnect interface

- Debris type ICDs are visible as built, and do not require thermal stress to occur.
Primary Debris Type ICD causes

- **Drilling**
  - Hot drill bits do not drill cleanly and create more debris, that tends to be adherent to the copper and hole walls.
  - Worn drill bits tend to heat up easier and have the same appearance as Hot drill bits.
  - Sub-optimal drill parameters or drill bit design.

- **Desmearing**
  - Many low Dk, low Df materials are more chemically resistant than standard epoxy (FR-4) type materials.
    - More aggressive desmearing is required
      - Plasma etching processing is effective on these materials.
      - Enhanced chemical desmear processing may be needed.
      - Enhanced process control tools may be required.
Contamination Type Debris

- This type has gotten the most attention in Asia
- Main cause
  - Powdery debris after drilling
Examples of Debris Type

- Note lack of wicking and glass protrusion
  - Bad plasma or poor chemical desmear
The primary characteristic of this failure type, is that a copper to copper bond is pulled apart during thermal exposure

- Normally visible only after thermal stress or reflow

Two modes

- Low strength – Copper plating bond is too weak to handle normal stress levels during thermal exposure
- High stress – Design and material related. Additional stress is concentrated on specific interconnect locations
Primary Separation Type ICD causes

- **Low bond strength**
  - Poor plating adhesion to the hole wall
  - Lack of good bonding surface in hole wall
  - Lack of clean oxide free copper surface in the hole wall
  - Electroless copper properties are poor

- **High Stress during thermal exposure**
  - High CTE material
  - Design resin content
  - Very thick copper plating
  - Nickel plating
  - Larger hole size
  - Board thickness
  - Interconnect pad configuration
Examples of Separation Type ICDs
Examples of Separation Type ICDs
Continued

Post Separation Type

D-Void Type
Getting Rid of ICDs

- ICD formation is strongly related to two key factors
  - PCB fabricator processes
  - Raw material type

- Capable and consistent processes in drilling is best approach
  - Avoids creation of ICDs

- If ICDs are found follow this path
  - Review samples and findings from problem orders
  - Identify the type of ICD
  - Follow troubleshooting method for this type of ICD
Drilling generates the debris that causes most of this type of ICD.

Get drill parameters under control
- Good vacuum levels at drilling
- Correct chip load
- Correct cutting speed
- Bits in good shape, not worn or damaged

Beware of combinations of high cutting speed and low chip loads
- This combination creates high heat levels and more debris

Significant copper nailheading is commonly found with Debris based ICDs
- Reducing nailheading helps reduce debris ICDs

Assess drilling quality using SEM of half holes
Debris ICD Type Troubleshooting
Desmear

- Desmear removes the debris generated by drilling – Good desmear is critical for consistent results
- If using Plasma Etching, Get weight loss under control – Efficient etching
  - Temperature control is the main issue
    - Etch rate rises with time if panels are cool at the start
    - Hot panels may have overetch and plating adhesion issues
  - Dry boards before plasma etching – water vapor from dielectric reduces plasma etch effectiveness
  - Measure etch rate on coupon with drilled holes, not surface coupons
    - Weight loss of 30mg/DM2 in holes, or 45-50mg/DM2 for surface coupons is a good target
- PCB Fab’s with good Plasma Etching process have very little ICD issues, when plasma etching is used – Best Practices
  - Dry and preheat panels, load panels “warm-hot”
  - Control weight loss amount and even distribution of weight loss over full load
- SEM’s of half holes is the best tool to characterize Plasma Etching process effectiveness, along with weight loss control.
Chemical desmear has two functions
- Effective at washing out debris
- Removes resin – Removal rate is very dependent on dielectric resin type

Chemical desmear issues
- Sweller type
  - Some materials not compatible with all sweller types – particularly NMP type
- Weight loss
  - Similar to plasma etching, characterize and keep this process under control
- Chemistry control
  - High MnO2 levels can cause debris to form
- Agitation, rinsing, ultrasonics
  - Very important on chemical desmear lines
  - Permanganate bathes are very viscous so agitation is critical
  - Good performing PCB fabricators have very good agitation
Creating a strong connection between the innerlayer copper and the electroless copper layer is the best way to avoid ICDs.

The following is a partial list of factors affecting interconnect strength:

- Good metallurgical copper bond
  - Clean copper, no chemical residues
  - Oxide free copper surface
  - Good grain structure on copper foil

- Strong electroless copper
  - Appropriate thickness
  - Controlled deposition rate (not too fast)
  - Good grain structure

- Good hole wall adhesion

- Copper foil thickness
  - Thicker is better

- No localized drill damage
Separation Type ICD Debugging
Strength of bond

- Determine copper etch weight loss
  - Best over 30u” (0.75 um) removed in holes

- Use good water quality on electroless copper line rinsing
  - Over desmear can also lead to rinsing issues

- Improve hole wall adhesion
  - Good desmear, with adequate texture
  - Don’t over desmear or use too high temperature desmear
Separation Type ICD
Stress Causes

- **High z-axis expansion**
  - High resin content
  - Low TMA Tg
  - High expansion material

- **Poor copper hole wall adhesion**
  - Puts strain on interconnects, instead of distributing through out hole wall

- **Design factors**
  - Tight grid hole patterns
  - Large hole size
  - Pads only on layers 2 or N-1
  - Board thickness
  - Localized resin content (regions requiring high resin fill)

- **Solder shrinkage in holes**
  - Pulls copper away from hole wall

- **Uncontrolled or over-temperature exposure**
  - Poorly controlled solder fountain rework (example)

- **Constraining surface finishes**
  - ENIG, Electrolytic Nickel/Gold
Separation Type ICD Debugging
Stress Reduction

- Process to achieve good hole wall adhesion
  - Allow options for single ply and heavier glass styles
- Reduce resin content in the stack-up
- Do not use nickel plating
- Avoid design factors
  - As noted on previous slide
General Commentary

- ICDs are rare in the US and Europe
  - Long history of Military and High Reliability electronics has resulted in good processing practices

- ICDs are PCB process related
  - Strong processes with good process control do not see significant problems

- Some material types are more likely to have ICDs
  - Materials with inorganic fillers, and more chemically resistant resin systems
  - Require tighter processing windows, or extra desmear steps, to achieve excellent results
  - Plasma etching is more common on these types
ICDs are a significant PCB industry issue, primarily in Asia.
High performance material systems are more likely to have ICDs
Many fabricators have consistently good results, no ICDs
  - Use best practices at drilling and desmear
ICD type identification, good engineering, and good controls have been effective at eliminating ICDs
Isola and other companies continue to perform Research into the causes of ICDs
  - Working to make the system more robust