Void Detection in Large Solder Joints of Integrated Power Electronics

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What are power electronics

- Solid-state electronic devices which control and convert electric power
- Engine control units, AC/DC-, DC/DC-converter
What are **integrated** power electronics

- Advanced packages of power electronics to improve efficiency and reduce size and costs
- Based on MOSFET or IGBT technology

Classic 2D-wire-bond design

IPEMs – Integrated power electronic modules
Integrated power electronics – Applications

- Electric vehicles, hybrid vehicles, battery charger
- Uninterrupted power supplies, emergency generators
- Converters for photovoltaic and wind power stations
- Railway drives, lighting control devices
Structure of IPEMs

Die (e.g. IGBT)

Solder joint die - base material

Base material (e.g. ceramic substrate)

Solder joint base material - heat sink

Heat sink

source: Indium Corporation
Structure of IPEMs

Die (e.g. IGBT)

Solder joint die - ceramic substrate

Heat sink

Solder joint ceramic substrate - heat sink

Ceramic substrate

Void

$[\alpha_v] < 25\%$
# Types of voids

(source: Intel, 2005)

<table>
<thead>
<tr>
<th>Type of Voids</th>
<th>Description</th>
<th>Photos</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Macro Voids</strong></td>
<td>Voids generated by the evolution of volatile ingredients of the fluxes within the solder paste; typically 4 to 12 mils (100 to 300 μm) in diameter, these are usually found anywhere in the solder joint; IPC’s 25% max area spec requirement is targeted toward process voids; NOT unique to LF solder joints. Sometimes referred to as “Process” voids</td>
<td><img src="image1" alt="Macro Voids Photos" /> <img src="image2" alt="Macro Voids Photos" /></td>
</tr>
<tr>
<td><strong>Planar Micro Voids</strong></td>
<td>Voids smaller than 1 mil (25 μm) in diameter, generally found at the solder to land interfaces in one plane; though recent occurrence on Immersion Silver surface finish has been highlighted these voids are also seen on ENIG and OSP surface finishes; cause is believed to be due to anomalies in the surface finish application process but root cause has not been unequivocally determined. Also called “champagne” voids</td>
<td><img src="image3" alt="Planar Micro Voids Photos" /> <img src="image4" alt="Planar Micro Voids Photos" /></td>
</tr>
<tr>
<td><strong>Shrinkage Voids</strong></td>
<td>Though not technically voids, these are linear cracks, with rough, ‘dendritic’ edges emanating from the surface of the solder joints; caused by the solidification sequence of SAC solders and hence, unique to LF solder joints; also called sink holes and hot tears</td>
<td><img src="image5" alt="Shrinkage Voids Photos" /> <img src="image6" alt="Shrinkage Voids Photos" /></td>
</tr>
<tr>
<td><strong>Micro-Via Voids</strong></td>
<td>4 mil (100 μm) and more in diameter caused by microvias in lands; these voids are excluded from 25% by area IPC spec; NOT unique to LF solder joints</td>
<td><img src="image7" alt="Micro-Via Voids Photos" /> <img src="image8" alt="Micro-Via Voids Photos" /></td>
</tr>
<tr>
<td><strong>Pinhole Voids</strong></td>
<td>Micron sized voids located in the copper of PCB lands but also visible through the surface finish; Generated by excursions in the copper plating process at the board suppliers</td>
<td><img src="image9" alt="Pinhole Voids Photos" /> <img src="image10" alt="Pinhole Voids Photos" /></td>
</tr>
<tr>
<td><strong>Kirkendall Voids</strong></td>
<td>Sub-micron voids located between the IMC and the Copper Land; Growth occurs at High Temperatures; Caused by Difference in Inter-diffusion rate between Cu and Sn. Also Known as “Horsting” Voids</td>
<td><img src="image11" alt="Kirkendall Voids Photos" /> <img src="image12" alt="Kirkendall Voids Photos" /></td>
</tr>
</tbody>
</table>
Test Equipment Requirements

• Reconstruction of overlaying solder joints
• Separation of voids in different layers
• Determination of relevant parameters **for every layer:**
  – Biggest void, Sum of all voids
  – Local distribution of voids = thermal connection
  – Measurement accuracy: 0.1mm² - 0.3mm²
• Complete inspection within the production cycle
• Inspection in (partly-) mounted state, e.g. with heat sink
XRay Inspection Basics - Review

X-Ray Beam penetrates the pcb
- Dense material – high absorption
- Less signal on the detector

Geometry defines
- Magnification
- Parallax angle

Detector Entrance Window (DEW)
Focus Detector Distance (FDD)
Focus Object Distance (FOD)
Parallax Angle (\(\alpha\))
X-Ray Source
Camera
Def: Automated Optical Inspection

Main Principle

One or more images of the Area of interest

2D / 2.5D / 3D

Software analyzes images

simple or one-layer analysis
or multi-layer analysis with 3D image

14 February 2012
2D X-ray Technology: Basic Principle

PCB is always radiated orthogonally!
2D X-ray Technology: Pros and Cons

Pros
- Cost-effective system architecture
- High speed testing
- Simple programming

Cons
- Overlayed components and solder joints (e.g. at double-sided assembly) can't be inspected

Test of integrated power electronics
- Test of one solder layer (die - ceramic substrate) possible after first solder process, but:
- No separation of overlaid (second) solder joint possible!
2.5D X-ray Inspection: Basic Principle

Hidden solder joints are “separated” by off-axis view.
2D / 2.5D X-ray technology: Inspection of integrated Power Electronics

- Inhomogeneity by heat sink, ceramic substrate and die
- Voids can’t be assigned to a certain layer
2.5D X-ray Inspection: Pros and Cons

Pros

• Overlayed components (e.g. at double-sided assembly) possibly testable

Cons

• Very high programming effort
• Consistent library not usable
• High testing times

Test of integrated power electronics

• Test of one solder layer (die - ceramic substrate) possible after first solder process, but changes after the second solder process likely!
• Separation of overlaid solder layers impossible (random positions of voids)
3D X-ray Technology: Basic Principle

PCB is radiated from different angles. Image basis results from several 2D projections.
XRay Inspection - Basics

Multiple projections from several angles

+35°
0°
-35°
XRay Inspection - Basics

Simultaneous reconstruction of top and bottom side

Top Side

Bottom Side
XRay Inspection - Basics

Reconstruction of individual slices (i.e. PCB Sides)
XRay Inspection - Basics

Simultaneous reconstruction of top and bottom side
XRay Inspection - Basics

Reconstruction of individual slices (i.e. PCB Sides)
3D X-ray Technology: Opportunities

Algorithmic reconstruction of any layers.
Inspection of double-sided assembled PCBs.
3D X-ray Technology: Pros and Cons

Pros

- Safe inspection of overlaid components and solder joints
- Inspection of single layers for improved results
- Reconstruction enables a safe and convenient fault analyses
- Simple test program generation by consistent library

Cons

- Higher initial price
3D X-ray technology: IPEMs

• Inspecting the assembled IPEM – through heat-sink and housing
• Separating the area of interest in several vertical layers
• Analysis of voids – number, distribution, dimensions...
3D X-ray Technology with adapted Image Capturing and Reconstruction
Application example

- PCB size: 220mm x 90mm
- Assembling top side: 24 IGBTs, 24 diodes
- Solder joints top side: 48 / $\sum 37\text{cm}^2$
- Assembling bottom side: heat sink
- Solder joints bottom side: 3 / $\sum 108\text{cm}^2$
- Resolution: 11µm / Pixel

- Cycle time (double-sided inspection): 47s
Experiences and Limitations

**Experiences**
- Soldering process based on printed solder paste
- Heat sink made of AlSiC (Aluminium Silicon Carbide)
- High inspection quality and measurement accuracy possible

**Limitations / Challenges**
- Heat sink made of copper or stainless steel
- Soldering process effects very thin voids (reduced detectability)
- System modification (x-ray tube, intensifier) is needed
Summary

- Inspection of integrated power electronics = sophisticated test task
- X-ray inspection based on 2D / 2.5D principles not utilisable
- Full 3D inspection with adapted image capturing and reconstruction is necessary for test task