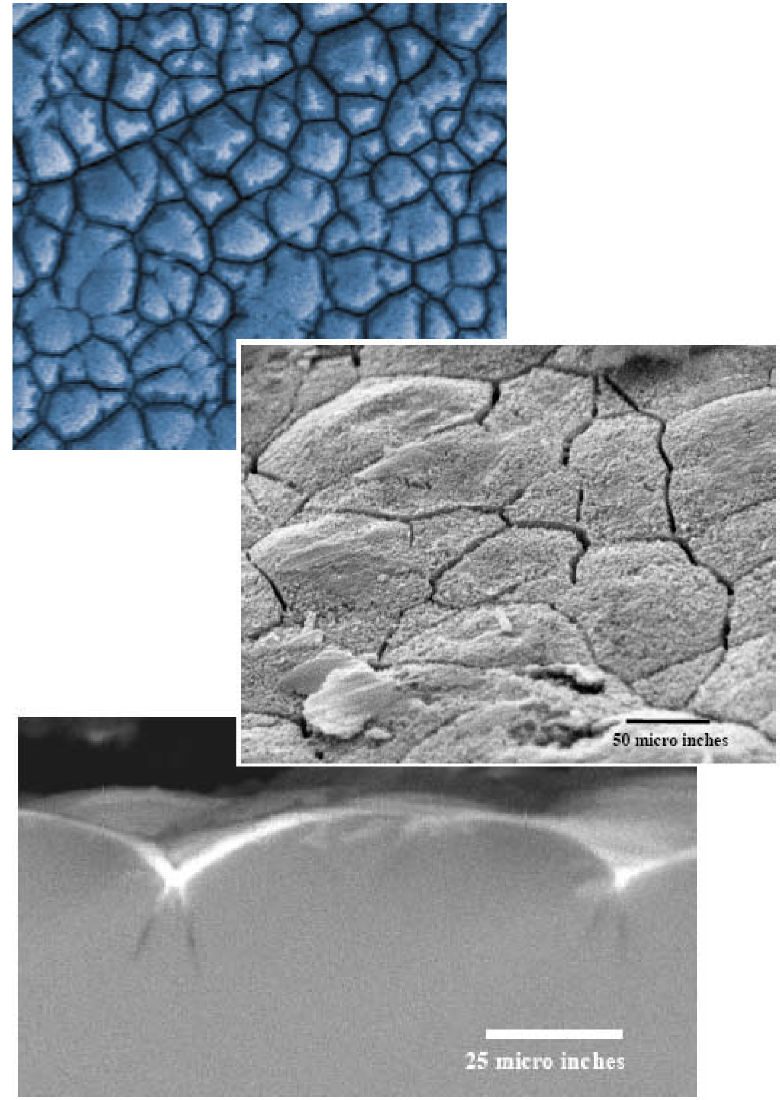
Plating Material (Board)

- Options
  - Electroless nickel/immersion gold (ENIG)
  - Immersion tin (ImSn)
  - Immersion silver (ImAg)
  - Organic solderability preservative (OSP)
  - Others (Pb-free HASL, palladium, etc.)
- Relatively low level of concern
  - Available and in use for more than 5 years
  - Issues similar to SnPb

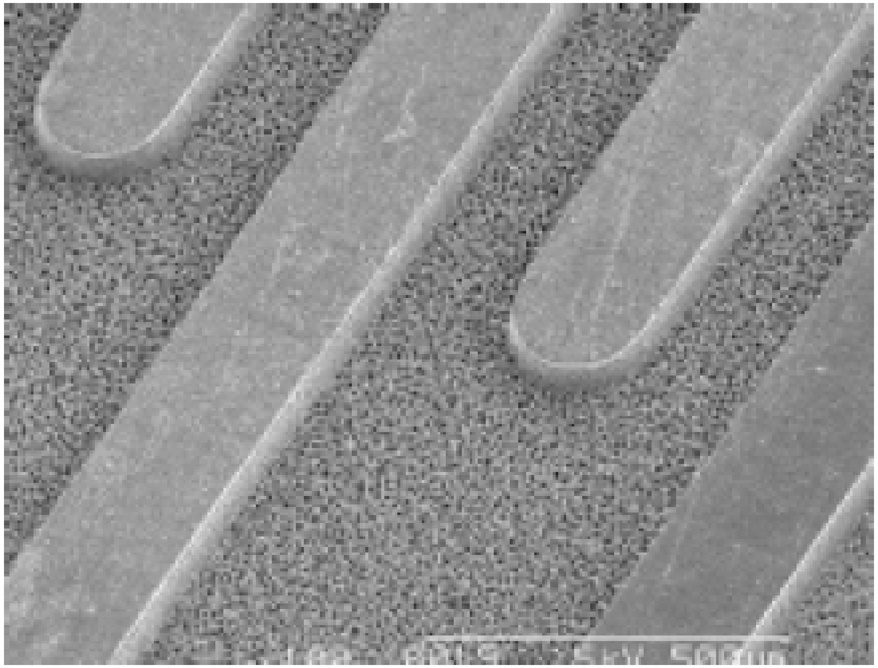
Quality Issues with Board Plating

- ENIG
  - Initially, replacement of choice
  - Black pad (still not explained to the satisfaction of most OEMs)
  - Bond pad adhesion (problem with corner balls on very large BGAs)



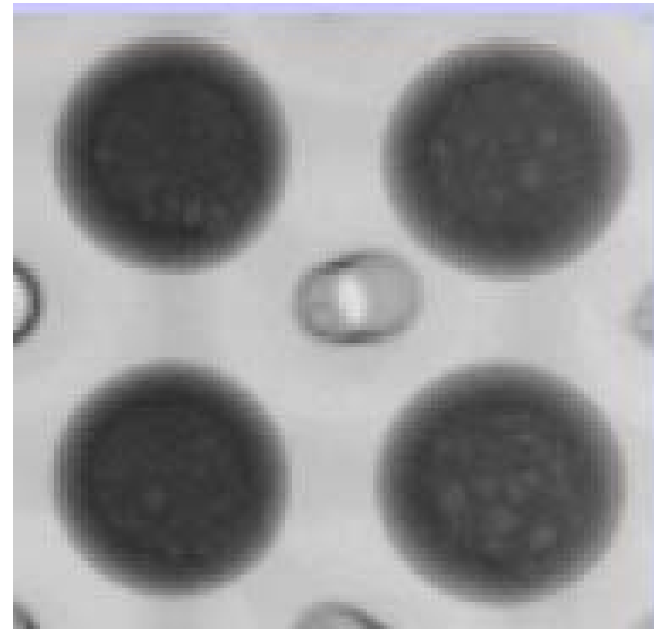
Board Plating (cont.)

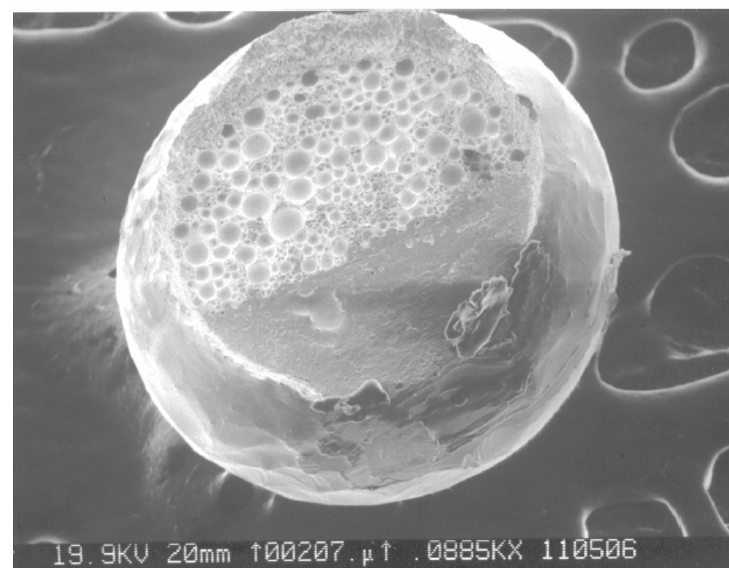
- ImAg
  - Aggressively marketed by plating suppliers
  - Long shelf life (>4 years)
  - Issues: Migration, voiding and tarnish



Champagne Voiding

- Definition
  - Creation of large number of small voids near or at solder/plating interface
- Root cause
  - Speculated to be due to poor control of organics
- Also seen in OSP and ENIG
  - Elevated occurrence with Pb-Free
  - Primarily associated with ImAg





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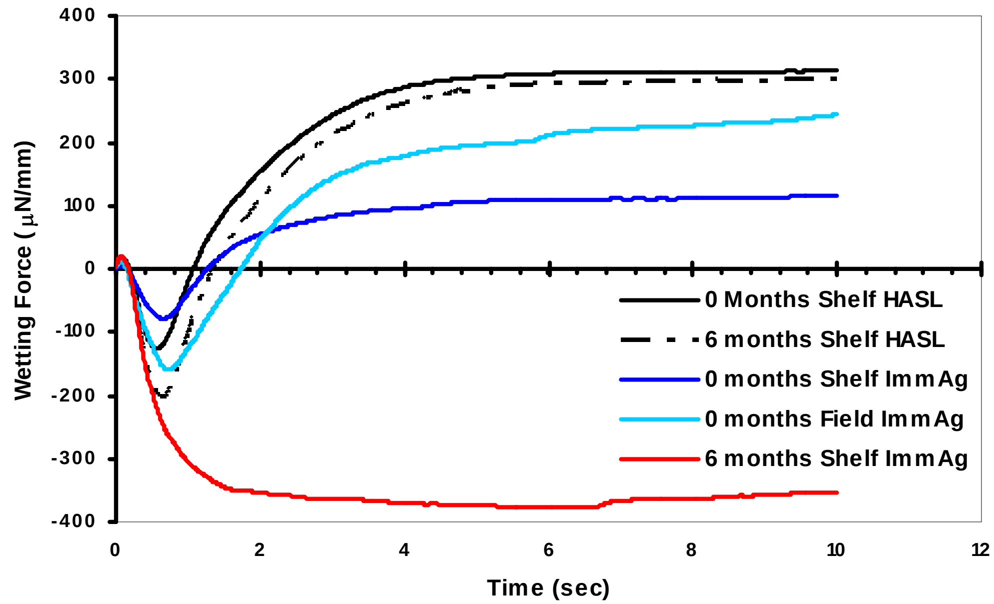
ImAg and Tarnish

- Solderability an issue
  - True for most HASL replacements
- Significant degradation when exposed to corrosive gases
  - Atypical shelf life test



- Loss of solderability after 1 day under mixed flowing gas (MFG) exposure, class II conditions
  - Equivalent to 6 months in light industrial environment

Plating Material (Board)

- ImSn
  - Limited shelf life (~1 micron thickness)
    - 1 year at room temperature
    - Equivalent to 4 hours at 155ºC
  - Whiskering probability extremely low (but observed)
  - Increasing in popularity
- OSP
  - High market share (30%), then issues
  - Limited shelf life (~3 to 6 months); claims of increased voiding in area array attachments
  - Difficult to visually assess plating quality
  - Surprising choice of some high technology companies with high reliability demands (telecom, storage)

Avoiding Issues due to Board Plating

- Continuous production (just-in-time)
  – OSP, ImSn
- Low volume, high complexity mix
  – Indeterminate storage times
  – ImAg, ENIG
- Corollaries
  – ImAg preferred for repetitive contact (e.g., keypads)
  – ENIG preferred for single connection (e.g., edge connectors)
- Require statistical process control (SPC) on all plating parameters (chemistry, temperature, etc.)
  – Use of x-ray and construction analysis for initial build

Printed Boards

- The primary “wearout” failure mechanisms in printed boards
  - Conductive anodic filament (CAF) formation
  - Electrochemical migration (ECM)
  - Barrel cracking in plated through holes (PTHs)
- Research on the influence of Pb-free on these mechanisms is surprisingly scarce
  - Approx. 10 -20 published papers
  - Est. 200 papers on lead-free solder durability

CAF and Pb-Free

- Minimal research performed to date
  - Potentially catastrophic results
- Turbini(SMTA, 2000)
  - Frequency of events increased by 3X to 400X
- Brewin(2004)
  - Time to failure reduced from >750h to 50h

Flux	SIR (Ω) 201°C reflow	SIR (Ω) 241°C reflow	#CAF at 201°C reflow	#CAF at 241°C reflow
Polyethylene glycol-600(PEG)	$<10^6$	$<10^6$	90	55
PEG/HCl	$<10^6$	High 10^8	None	None
PEG/HBr	$<10^6$	High 10^8	None	None
Polypropylene glycol 1200 (PPG)	$>10^{10}$	$>10^{10}$	None	455
PPG/HCl	$>10^{10}$	$>10^{10}$	None	379
PPG/HBr	$>10^{10}$	$>10^{10}$	1	423
Polyethylene propylene glycol 1800 (PEPG 18)	High 10^9	High 10^9	1	406
PEPG 18/HCl	High 10^5	High 10^9	10	135
PEPG 18/HBr	10^{10}	High 10^9	9	279
Polyethylene propylene glycol 2600 (PEPG 26)	High 10^5	High 10^8	None	91
PEPG 26/HCl	High 10^5	High 10^9	6	218
PEPG 26/HBr	10^{10}	High 10^9	None	51
Glycerine (GLY)	$>10^{10}$	High 10^9	None	56
GLY/HCl	$>10^{10}$	High 10^9	None	583
GLY/HBr	$>10^{10}$	High 10^9	3	104
Ocyl phenol ethoxylate (OPE)	Low 10^9	Low 10^9	None	83
OPE/HCl	Low 10^5	Low 10^9	14	62
OPE/HBr	$>10^{10}$	High 10^9	2	599
Linear Aliphatic Polyether (LAP)	Low 10^7	Not Tested	None	Not Tested
LAP/HCl	Low 10^7	Low 10^9	15	203
LAP/HBr	Low 10^7	Low 10^9	None	272

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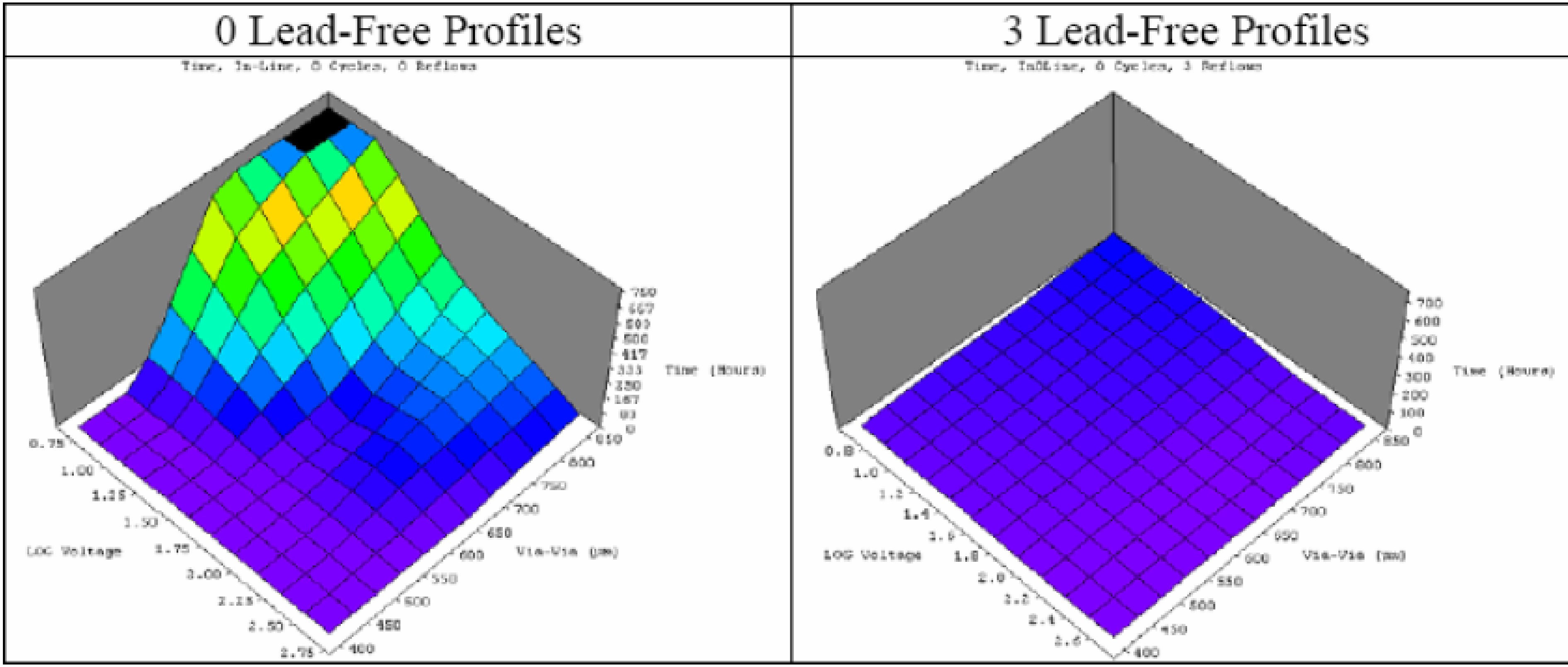
CAF and Pb-Free (cont.)



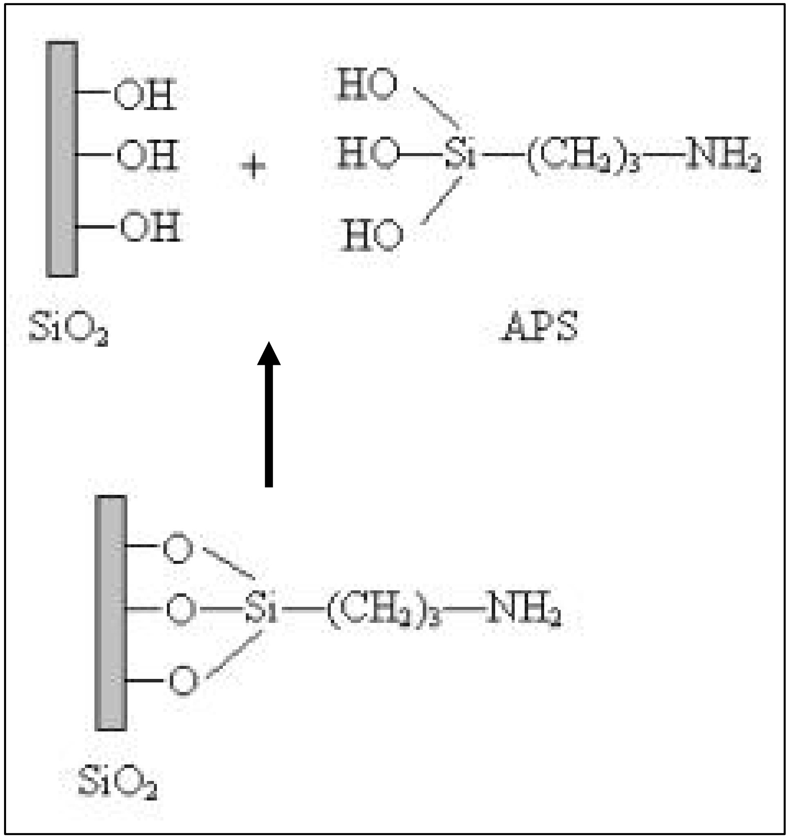
Brewin, et. al., “Susceptibility of Glass-Reinforced Epoxy Laminates to Conductive Anodic Filamentation”

Industry Response

- Major concern over specific products
  - Large size, fine pitch BGA on multilayer (>14) FR-4
  - High number of potential initiation sites
  - Manufacturing / design can create defects
  - Solutions?
- Reconsider vapor phase reflow
  - Minimize temperature distribution (max temp of 235C)
- CAF ‘Resistant’ Laminate
  - Use of binders in epoxy formulation
  - Specialized glass fiber and weave technology
  - Expensive
- Phenolic cured epoxy
  - Multiple vendors; lower price differential
  - Claim of improved CAF performance not completely validated
- Improvements in silane application

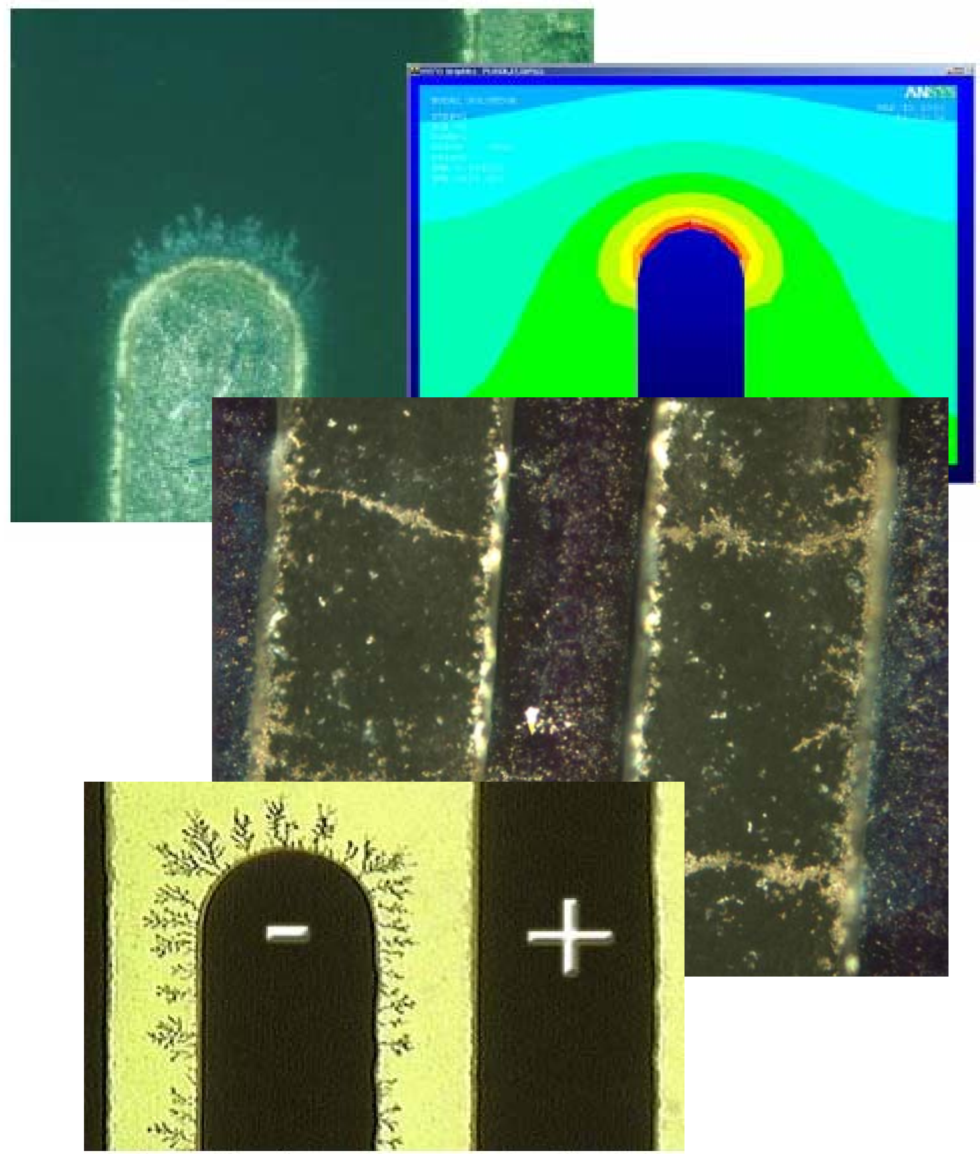
Path Formation Mechanism

- Classic CAF is along the fiber/epoxy interface
- Numerous studies have indicated that exposure to elevated temperature-humidity conditions weakens glass/polymer bonds based on silanes
- Hydrolysis reaction
  - $Si_2O + H_2O \leftrightarrow 2SiOH$
- Attempts at improving the bonding at this interface have resulted in improved CAF performance



Electrochemical Migration / Dendritic Growth

- What does Pb-Free mean to electrochemical migration (ECM)?
  - New plating materials
  - New interconnect materials
  - New flux chemistries
- Higher reflow temperatures / poor intrinsic solderability
  - Requires more aggressive flux formulations
  - Initial indication of elevated occurrence of qualification failures
- Action items
  - Do not necessarily rely on EMS provider
  - Qualify at lower temperatures (40^oC vs. 85^oC)



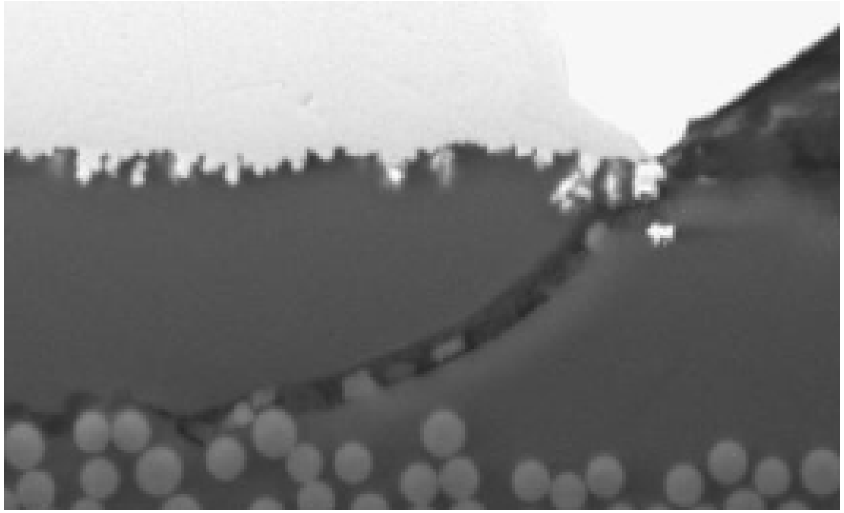
Dendrites formation around cathode

Impact of Pb-Free Reflow
Contaminant Diffusion in PCB

- Due to the high temperature reflow associated with lead-free assembly, contaminants (example chlorine) from interior of the PCB migrate faster to the surface, resulting in higher level of contaminants at the surface
  - Incoming boards before soldering Cl= 2.06 µg/inch^2
  - After reflow at 220°C Cl= 3.85 µg/inch^2
  - After wave soldering at 250°C Cl= 18.2 µg/inch^2
- Typical IPC inspection methods may not effectively capture this behavior (IPA/DI at 80C for 1 hour)
  - This puts more stringent requirement on incoming contamination levels, cleaning methods after assembly

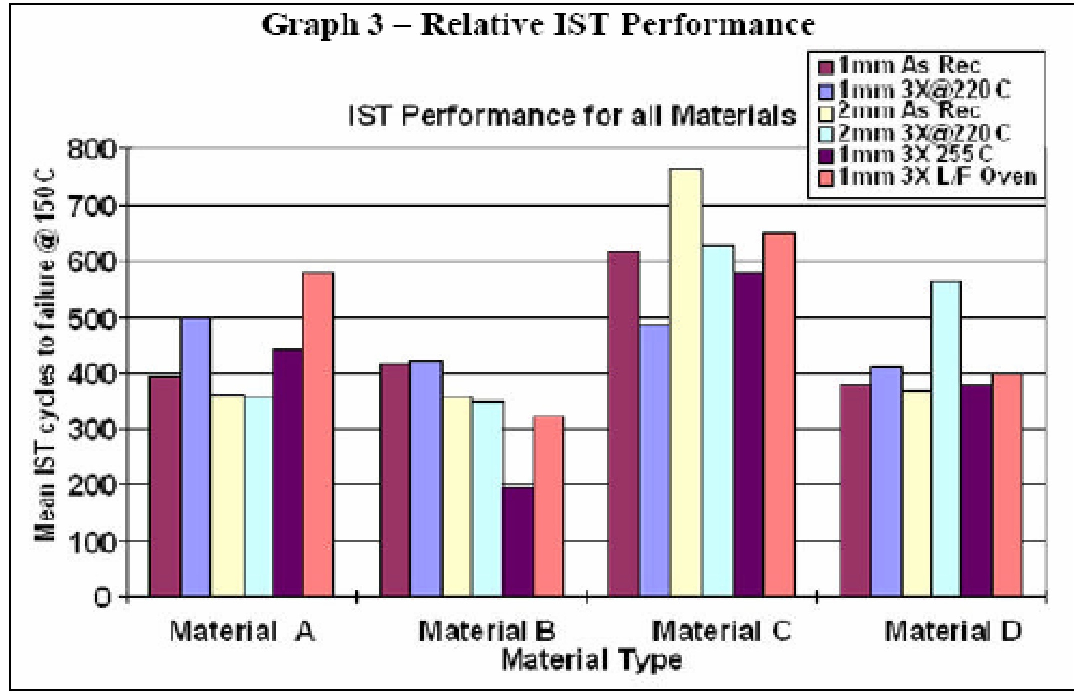
Printed Board Damage

- Low glass transition (Tg) boards may be susceptible to physical damage in higher temperature lead-free processes
  - Charring, delamination or cracking
  - Paper phenolic(i.e., CEM) especially susceptible
  - Greater susceptibility with increased moisture intake
- High Tg does not necessarily indicate an ability to survive lead-free temperatures
- Lead-free processes may also require a change in solder mask
- Inks, markings and adhesives also susceptible
- Higher temperature increase probability of PTH overstress
  - May affect PTH reliability as well



PTH/Via and Pb-Free

- Influence on PTH reliability
  - Primarily 3 publications (Reed, 2000; Smetana, 2002; Leys, 2003)
- Preliminary findings
  - Sufficient Tg and/or Z-axis CTE prevents degradation
  - May be a second order effect
- Industry response
  - Movement to Tg of 150 - 170C
  - Low out-of-plane CTE increasingly popular



Property/Condition	Material A	Material B	Material C	Material D
Resin System	High Tg Epoxy	High Tg Enhanced	High Tg Epoxy	Mid Tg Epoxy
Tg (DSC)	175°C	210° C	175°C.	155°C
Tg (TMA)	165°C	200° C	170°C.	150°C
Tg (DMA)	195°C	240°C	180°C	160°C
Degradation Temperature (TGA - 5% weight loss)	362°C	357°C	325°C	330°C
Z axis expansion* (50 to 260°C in %)	3.20%	3.50%	3.70%	3.80%

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Product Qualification

- Reliability issues will be strongly driven by manufacturing defects and product size
- Small products (portables)
  - 30 mil thickness, less than 4 x 4
  - Max reflow temperatures ~235C
  - Minimal stresses internal to the board
- Medium products (consumer, controls)
  - 60 mil thickness, less than 12 x 12
  - Max reflow temperatures ~245C
  - Moderate stresses internal to the board
- Large products (server, telecom)
  - >90 mil thickness, 12 x 18 and greater
  - Max reflow temperatures ~255C
  - Potentially severe stresses in the board (e.g., high aspect ratio vias)