Challenges for Achieving Automotive Grade 1/0 Reliability in FCBGA and fcCSP Packages

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Memory Product Development
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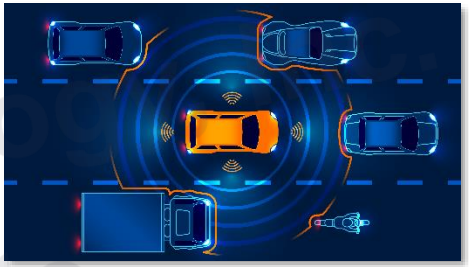
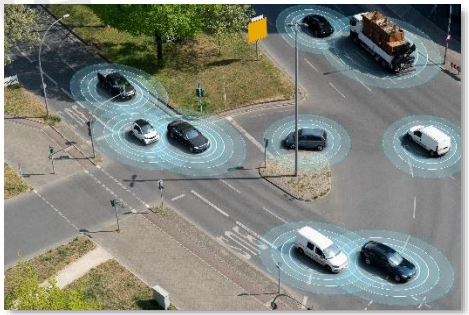
Automotive Lifetime Requirements

- Standard requirements
  - 15-year reliability, 10k hours operation time, 300k miles
  - Zero defects
  - High temperature environments
- Electric vehicles – charging and pre-conditioning
- Self-driving – over 100k hours operation time





AEC Q-100 Requirements

AEC Q-100 Grade	Operating Temperature Range	Temperature Cycling Requirement	High Temperature Storage Requirement
0	-40 to 150°C	TCH: -55 to 150°C 2000 cycles	175°C: 1000 hours 150°C: 2000 hours
1	-40 to 125°C	TCH: -55 to 150°C 1000 cycles	175°C: 500 hours 150°C: 1000 hours
2	-40 to 105°C	TCB: -55 to 125°C 1000 cycles	150°C: 1000 hours 125°C: 1000 hours
3	-40 to 85°C	TCB: -55 to 125°C 1000 cycles	150°C: 1000 hours 125°C: 1000 hours

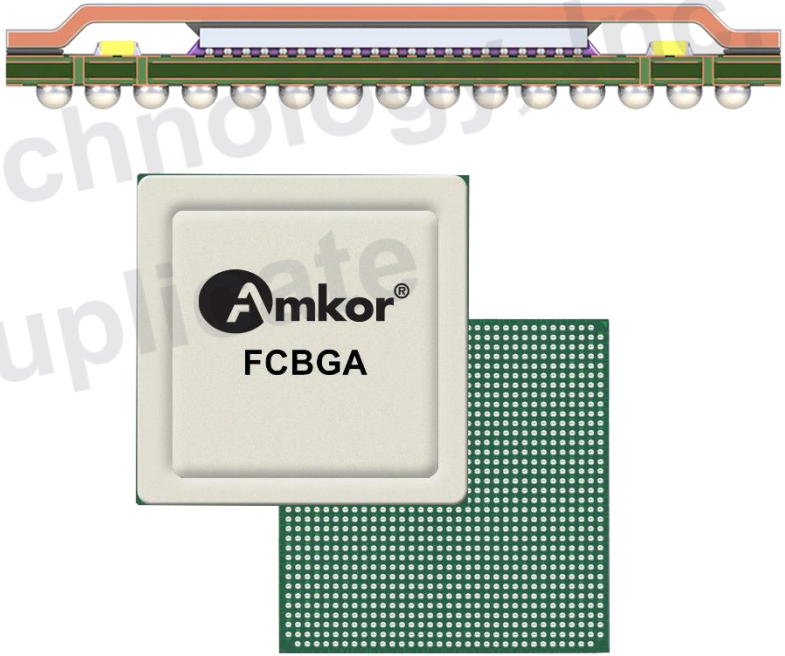
- Additional evaluation up to 2x standard requirements is common
- 4000 hours HTS ~6 months/evaluation!
- Methods needed to screen and evaluate materials before reliability

Source: AEC-Q100, Rev. H

FCBGA

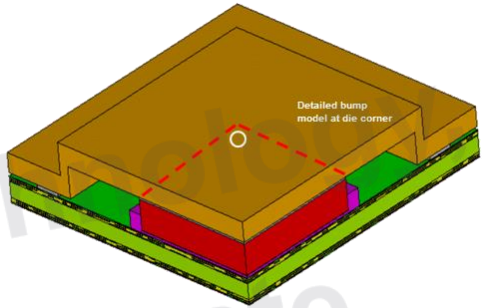
FCBGA Automotive Challenges

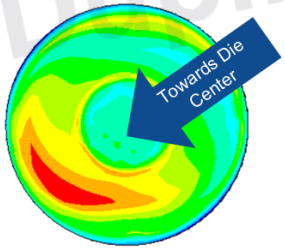
- Larger packages for greater integration
  - Sensors
  - ADAS
  - Infotainment
  - V2X
- TC challenges
  - Substrate crack
  - Bump crack
  - UF crack
- HTS challenges
  - Underfill oxidation → UF surface cracking
  - IMC growth → solder voiding



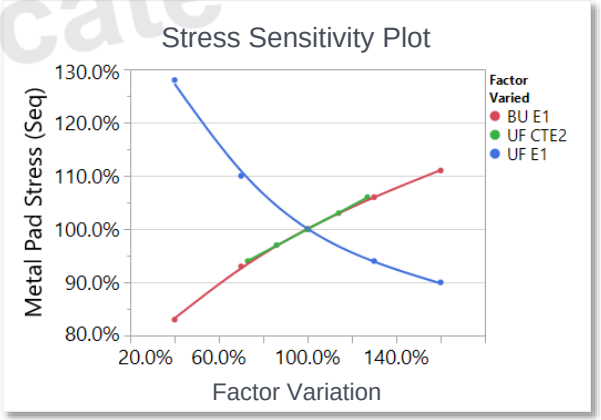
Material Property Simulation

- Multiple failure modes simulated
- Critical materials and properties identified
- Aged properties needed
  - Buildup
  - Underfill
  - Solder resist





Metal Pad

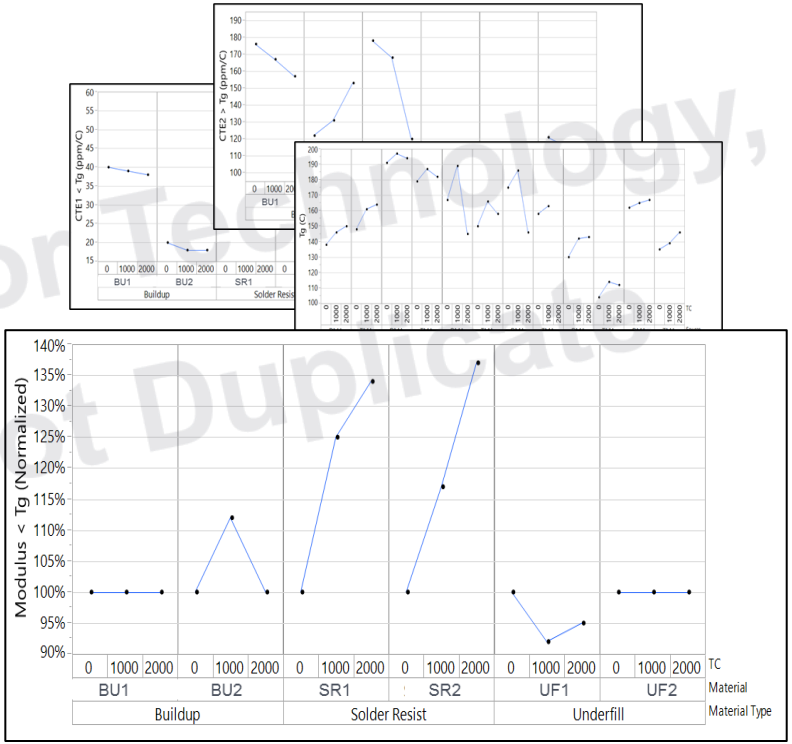


FCBGA Material Aging

- Aged properties collected after TCH: -55 to 150°C
- Materials evaluated
  - Buildup
  - Solder resist
  - Underfill
- Properties measured
  - CTE
  - Modulus
  - Tg

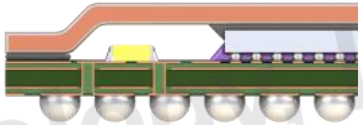
FCBGA Material Aging

- Buildup
  - Modulus – no change
  - CTE1 – decreases
  - CTE2 – increases
  - Tg – increases
- Solder resist
  - **Modulus – large increase**
  - CTE1 – decreases
  - CTE2 – decreases
  - Tg – decreases
- Underfill
  - Modulus – no change
  - CTE – no change
  - Tg – no change



FCBGA Test Vehicle

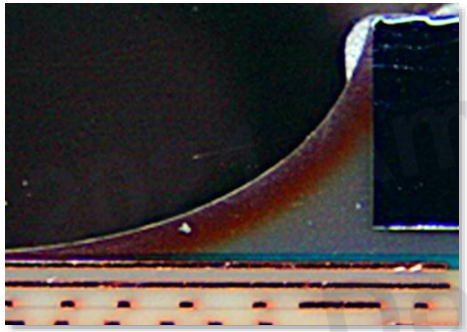
- **Successful G1 BOM selected**
  - Passed AEC Grade 1 criteria
- Passed G0 engineering qual
  - 150°C HTS
- Materials evaluated
  - Core
  - Solder resist
  - Underfill
- Ongoing UF development
  - 175°C HTS

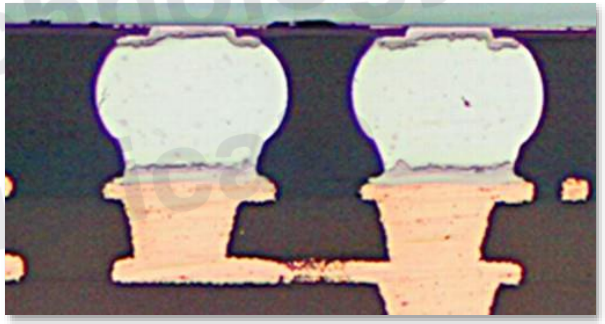


35 mm FCBGA Test Vehicle	
Body Size	35 mm x 35 mm
BGA Pitch	1 mm
Die Size	15 mm x 15 mm
Bump Pitch	150 µm
Substrate	3-2-3 0.4 mm core

HTS 150°C – 2000 Hours (G0)

- Oxidation but no UF cracking
- Solder voiding not observed

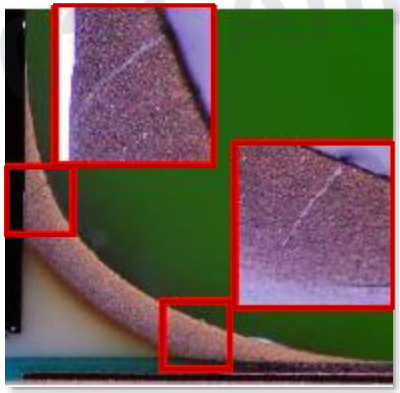




- Grade 0 150°C does not present the same challenges as 175°C for the same grade

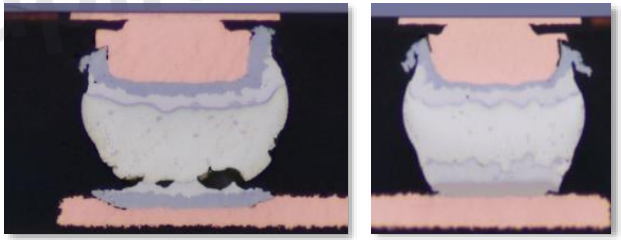
HTS 175°C – 1000 Hours (G0)

- Underfill surface oxidizes and cracks
- Crack can lead to delamination at die edge and into substrate



- IMC growth and solder voiding in substrate pad
- ENEPIG substrate finish eliminates voiding at 175°C

Bump cross section: 1000 hrs @175°C



SOP ENEPIG

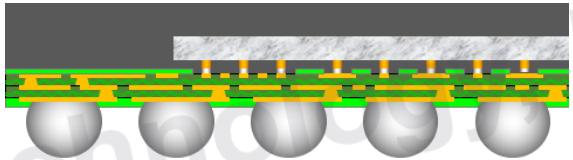
Thermal Cycling

- Failure modes
  - Substrate crack near die corner
  - Corner bump crack
  - Underfill fillet crack
- Low CTE core materials to reduce substrate cracking
- Simulations show that underfill modulus and CTE need to be balanced to prevent both bump and fillet cracking
- One underfill material passed both grade 1 and 0 TCH

fcCSP

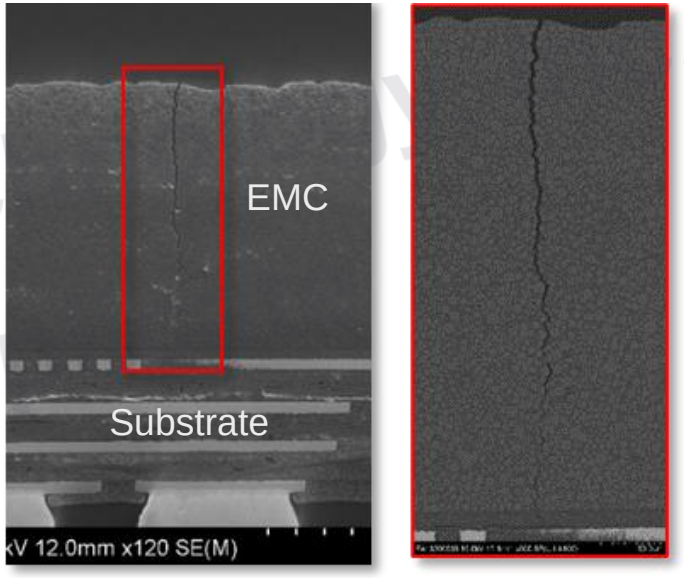
fcCSP Automotive Challenges

- Material degradation
  - HTS and TC
  - EMC embrittlement
- Long HTS time
  - 2xG0



Material Degradation

- EMC
  - Oxidation
  - Embrittlement
  - Cracking
- Material properties change during HTS
- Die and EMC thickness are key parameters for determining cracking

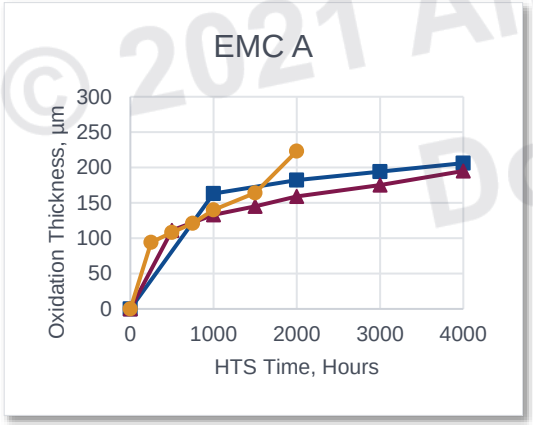


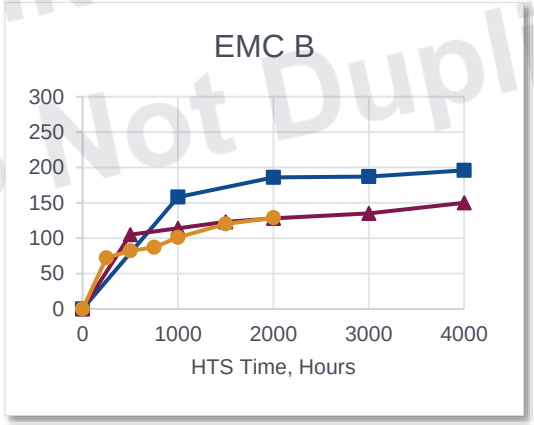
EMC Material Evaluation

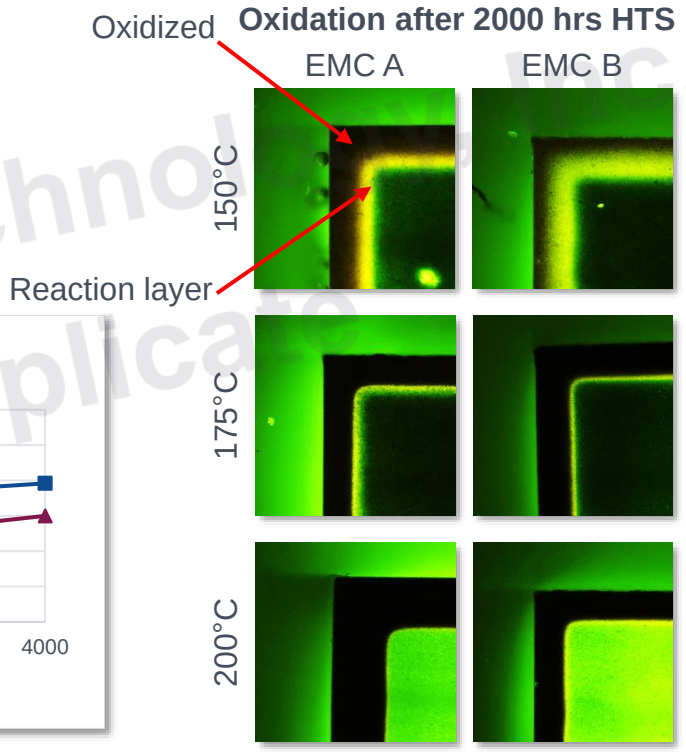
- Aged properties needed to screen new materials
- EMC samples characterized after HTS at 150°C, 175°C and 200°C
  - Modulus
  - CTE
  - Shrinkage
  - Flexural strength
  - Oxidation thickness

EMC Oxidation in HTS

- Oxidized and “reaction” layers visible after HTS
- Some EMCs showed lower oxidation thickness at higher temperatures

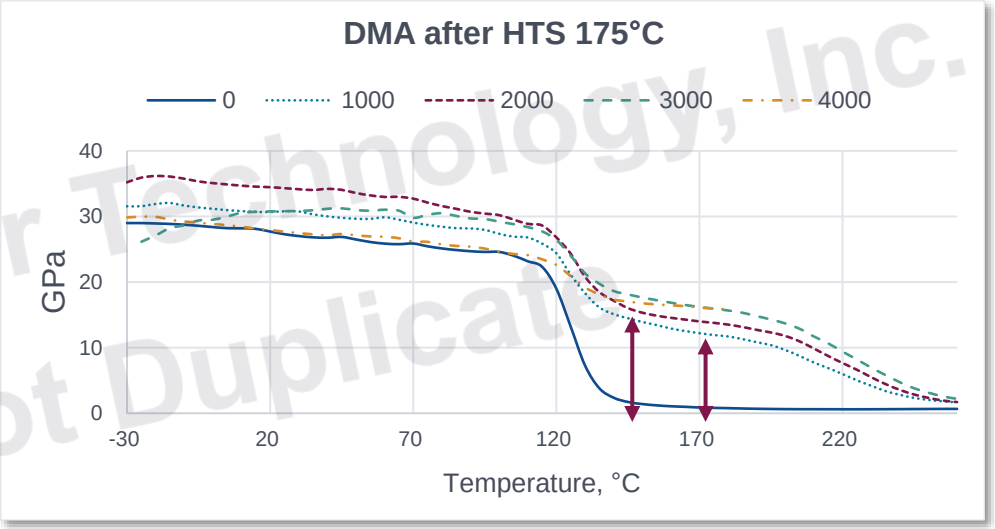






EMC Modulus in HTS

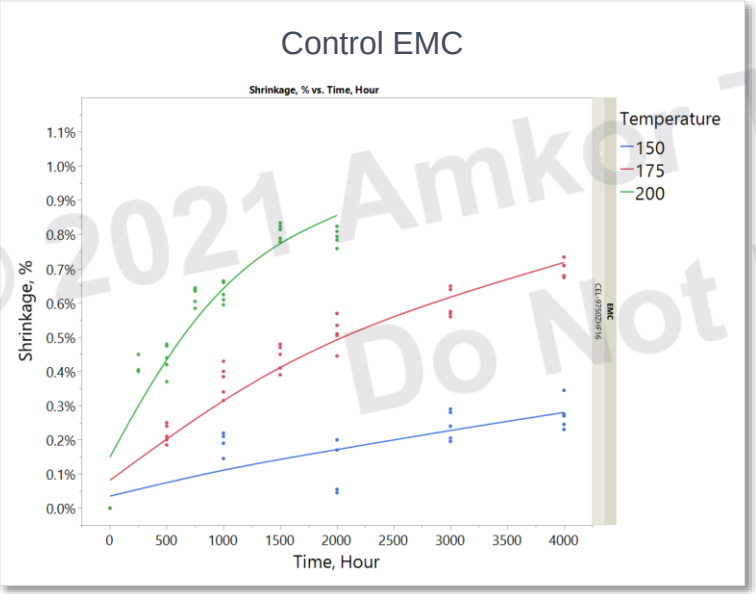
- Glass transition over a large temperature range
- Large gap above Tg between modulus of aged EMC and non-aged
- Property mismatch between aged and non-aged EMC layers introduces mechanical stress during HTS



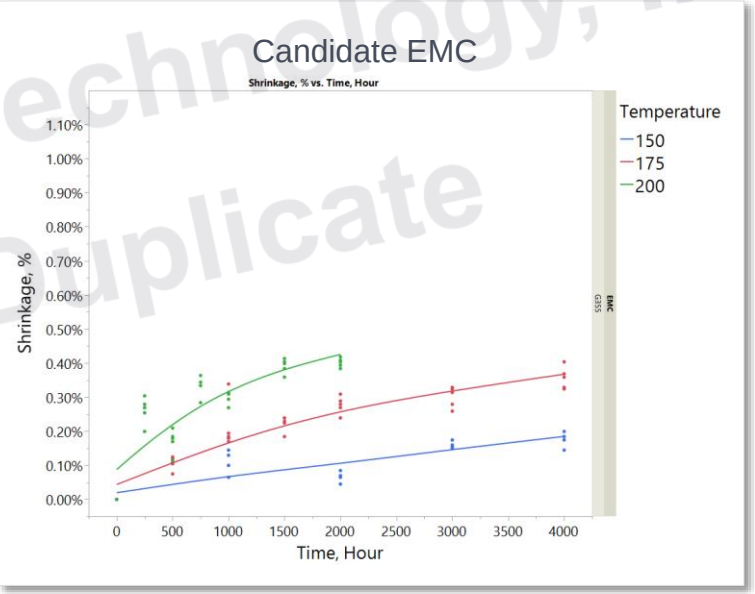
EMC Shrinkage in HTS

- Materials with low HTS shrinkage expected to reduce cracking

Control EMC

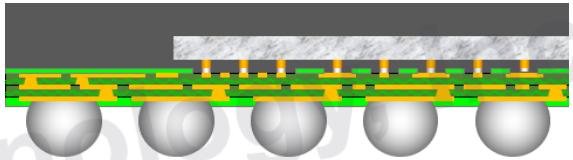


Candidate EMC



fcCSP Solutions

- Three candidate EMCs passed 2xG0 HTS and TC with no cracking
- Multiple EMC candidates selected based on aged property evaluations
  - High Tg
  - Low shrinkage
  - Oxidation behavior
- Additional DOE evaluating substrate thickness and materials ongoing



12 mm fcCSP Test Vehicle	
Body Size	12 mm x 12 mm
BGA Pitch	0.35 mm
Die Size	7 mm x 7 mm
Bump Pitch	45/80 µm
Substrate	4L ETS

Conclusion

- FCBGA
  - G1 package qual completed
  - Underfill cracking at 175°C is remaining challenge for G0
- fcCSP
  - Package qualifications completed to 2xG0 requirements
- Grade 0 conditions
  - 150°C HTS requirement not equivalent to 175°C HTS
  - New failure modes appear at 175°C within the same AEC-Q100 grade
- Simulation and material characterization reduces DOE and development time

Thank You

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