Copper Migration in Flip-Chip Substrates Under Biased-HAST Conditions

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Introduction: Reliability Qualification Testing

- Stress-test-driven qualification for plastic packages per JEDEC JESD47 includes unbiased and *biased* humidity testing as part of the standard battery of reliability tests

Qualification Test	Test Method	Sample Size
Preconditioning	JESD22-A113 Per package MSL and reflow 260C rework required if reflow < 260C	Prior to HTS, TC, bHAST/THB, uHAST
High Temp Storage (HTS)	JESD22-A103 150C 1000 hours	25 x 3 wafer/assy lots
Temperature Humidity Bias (THB)	**JESD22-A101 85C/85%RH, Vmax; 1000 hours**	25 x 3 assy lots
Highly Accelerated Stress Test (bHAST)	**JESD22-A110 130C/85%RH , Vmax; 96 hours**	
	JESD22-A110 110C/85%RH, Vmax; 264 hours	
Unbiased HAST (uHAST)	**JESD22-A118 130C/85%RH 96 hours**	**25 x 3 assy lots**
Temperature Cycle (TC-B)	JESD22-A104 -55 to +125C 700 cycles	25 x 3 assy lots

Biased Humidity Tests

- Both humidity tests accelerate failure mechanisms related to the presence of moisture for non-hermetic packages
  - Biased: Galvanic and Electrochemical corrosion. *Requires bias boards.*
  - Unbiased: Galvanic and chemical corrosion. No bias boards.

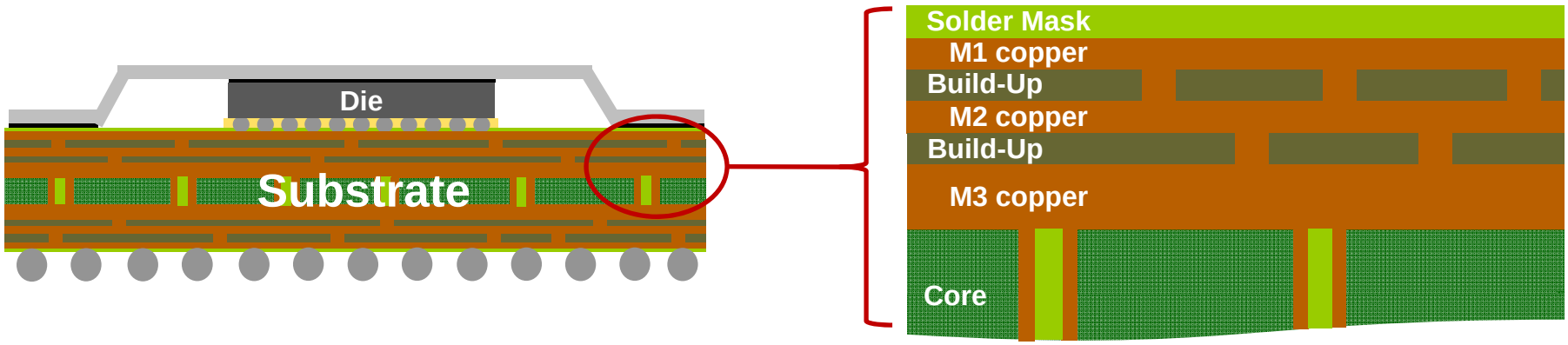
Introduction: Biased Humidity Testing

Test	Condition	Bias	Duration
THB	85C/85%RH	Vmax	1000 hours
bHAST	110C/85%RH	Vmax	264 hours
bHAST	130C/85%RH	Vmax	96 hours

- Benchmark test is THB (Temperature Humidity Bias)
- Accelerated biased-HAST (Highly Accelerated Stress Test) often implemented to reduce test time
  - Accelerated durations generally based on Al corrosion failure mechanisms
  - Durations may not be directly applicable to other materials
- JEDEC cautions accelerated bHAST testing may result in artificial failures
  - i.e. would not occur in standard THB testing nor of any consequence to device operation in the field
- Nevertheless, bHAST is widely adopted for all package types

Experimental: Flip-Chip Construction

- Flip-Chip Package Construction
  - Standard bumping
  - Standard underfill
  - Lid
  - BGA
  - 6-layer 2-2-2 build-up substrate
    - BT fiberglass reinforced resin core
    - Copper metallization
    - Standard build-up dielectric
    - Standard solder-mask



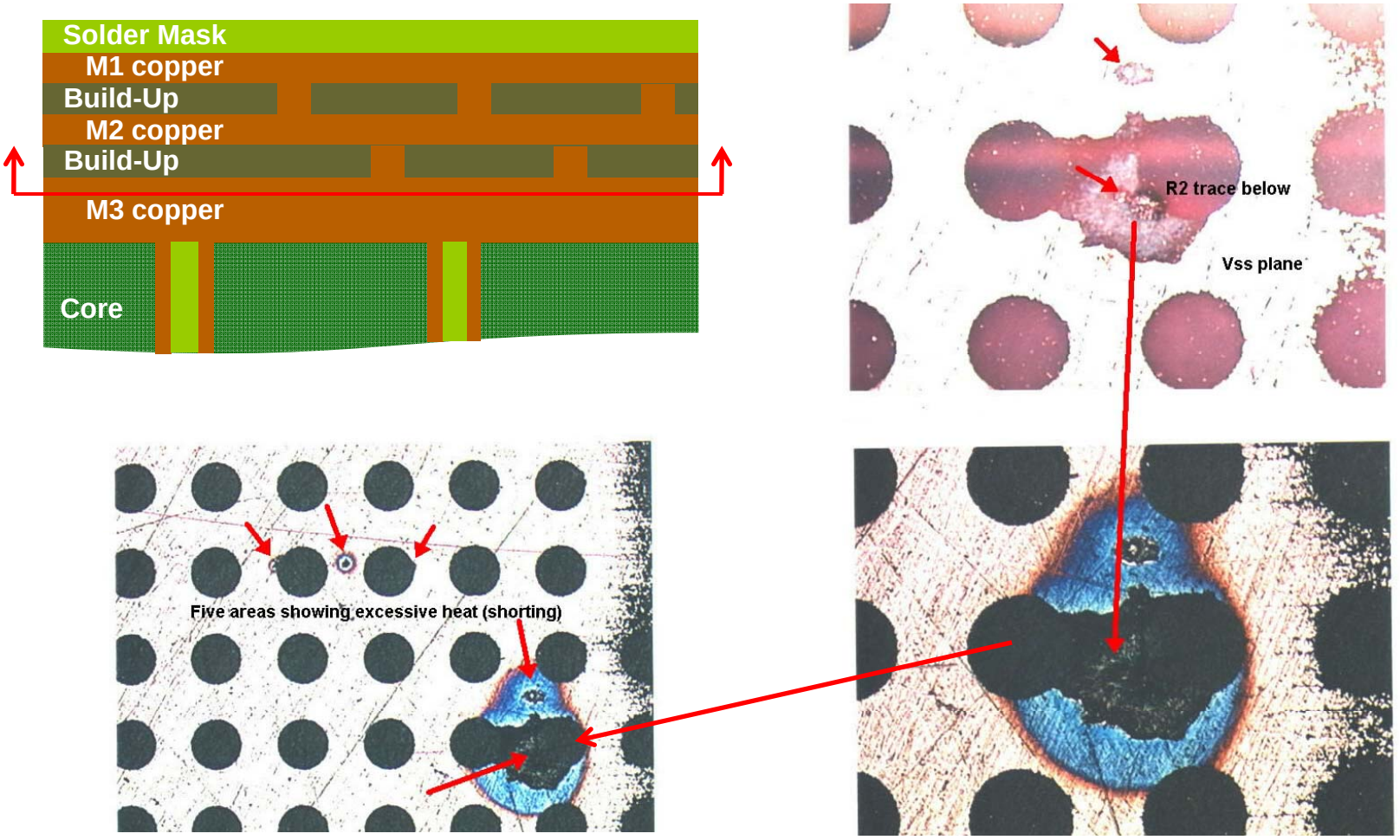
Experimental Test Matrix and Results

Test	MSL4/260C Preconditioning	Temperature	Humidity	Bias	Test Points (hours)	Electrical Failures
THB	Yes	85C	85%	Yes	1000	No
bHAST	Yes	110C	85%	Yes	264, 528	No, No
bHAST	Yes	120C	85%	Yes	160*, 264	No, No
bHAST	Yes	125C	85%	Yes	120*, 264	No, Yes
bHAST	Yes	130C	85%	Yes	96	Yes
HTOL	No	125C	<10%	Yes	1000	No

*125C/85%RH and 120C/85%RH are not officially sanctioned conditions per JEDEC. Durations were extrapolated from standard conditions of 96 hours at 130C/85%RH and 1000hours 85C/85%RH.

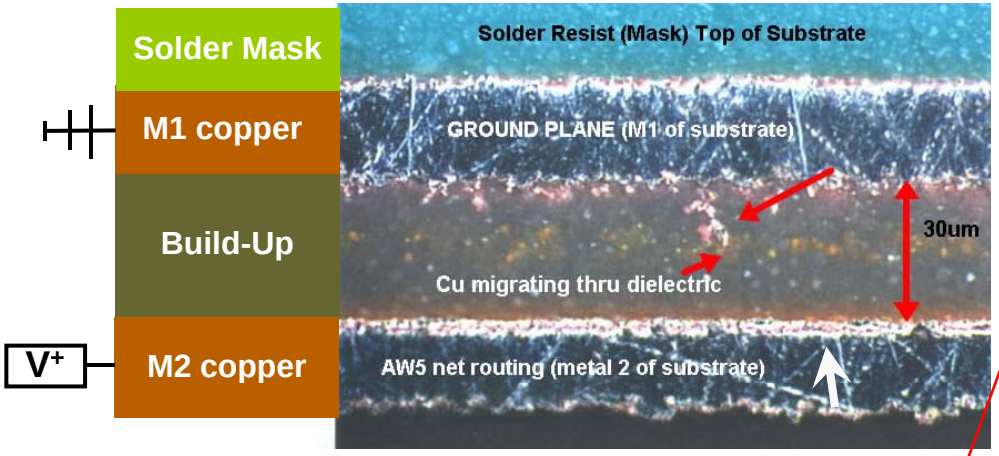
- 130C/85%RH and 125C/85%RH bHAST
  - Failures with signatures ranging from bake-recoverable device leakage to shorts
- 120C and 110C/85%RH bHAST
  - No failures
- 85C/85%RH THB
  - No failures
- 125C HTOL (High Temperature Operating Life) - bias and low humidity
  - No failures

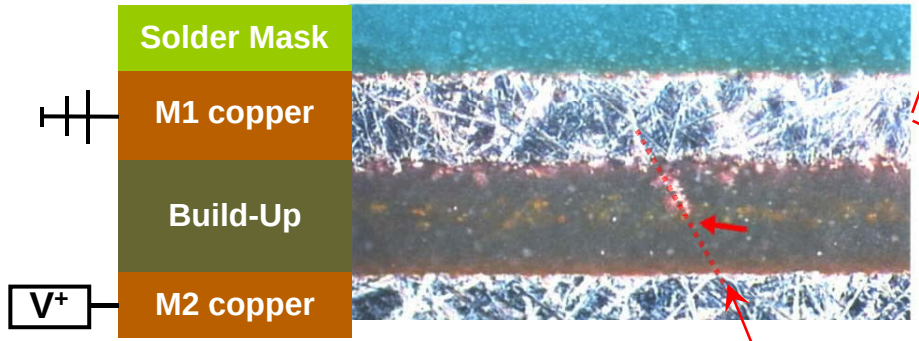
130C/85%RH, 96hrs bHAST Physical Analysis Failing Devices Horizontal Section

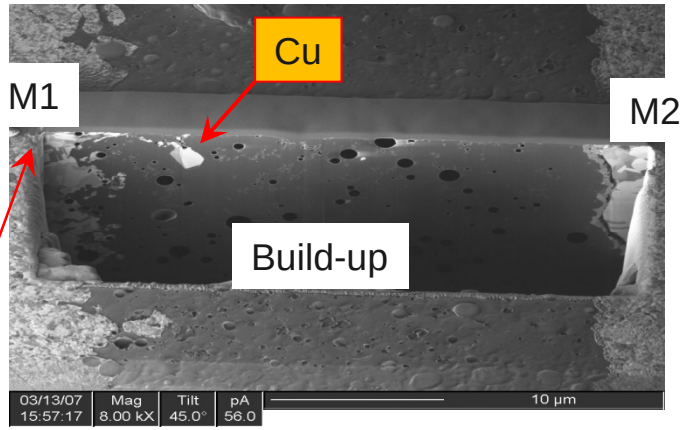


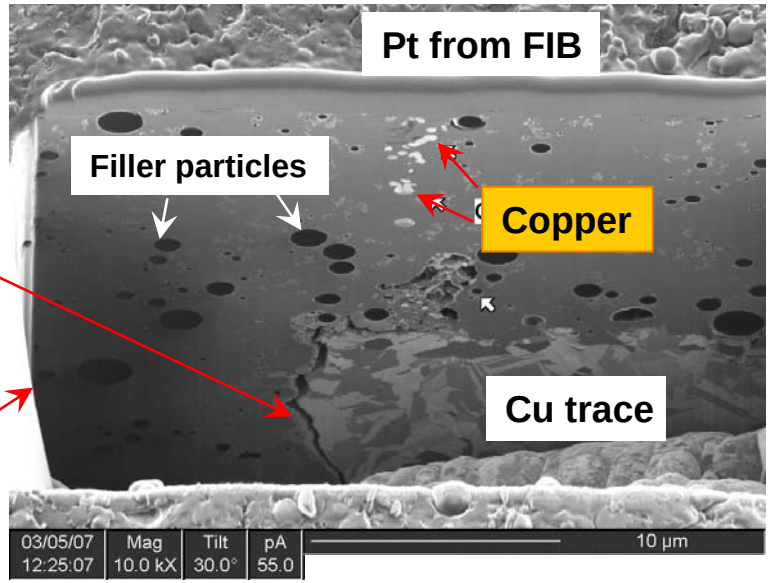
Localized EOS and Metal 3 shorted to Metal 2

130C/85%RH, 96hrs bHAST Physical Analysis
Failing Devices Cross Sections





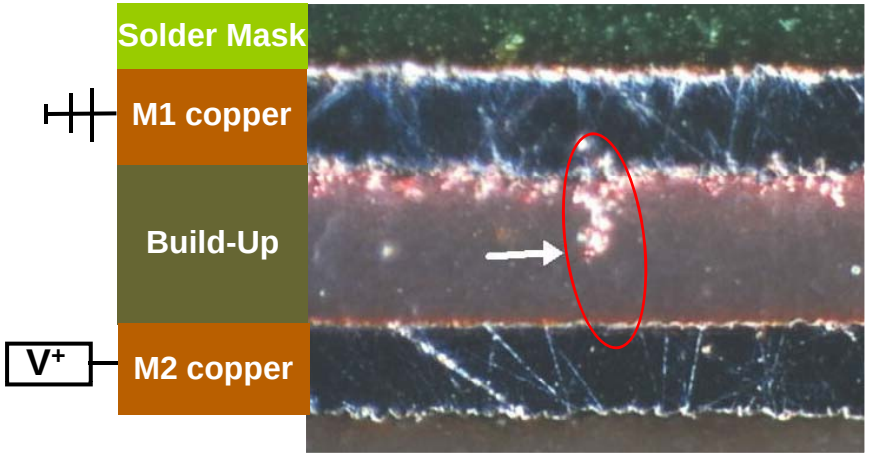




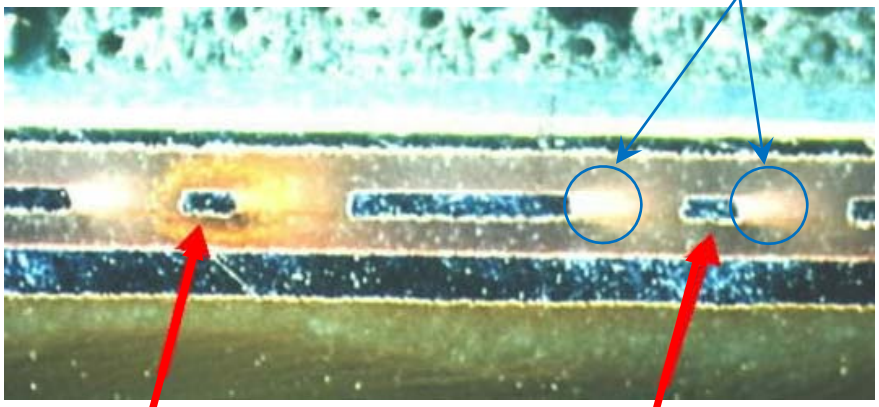
FIB Cut

Copper in build-up dielectric growing from M1 ground toward M2 biased trace

130C/85%RH, 96hr bHAST Physical Analysis Electrically Passing Devices Cross Sections

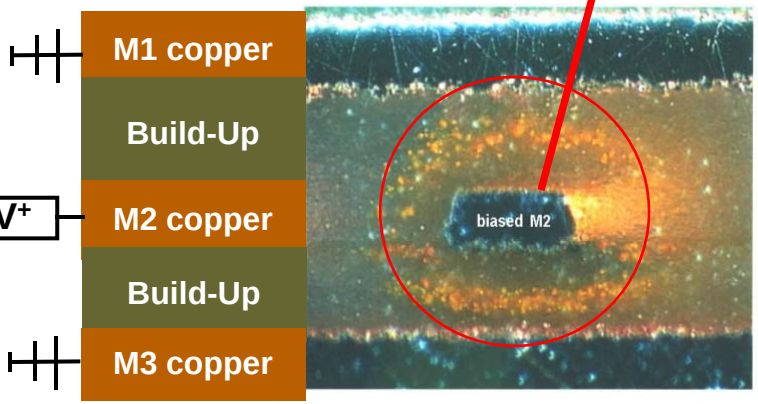


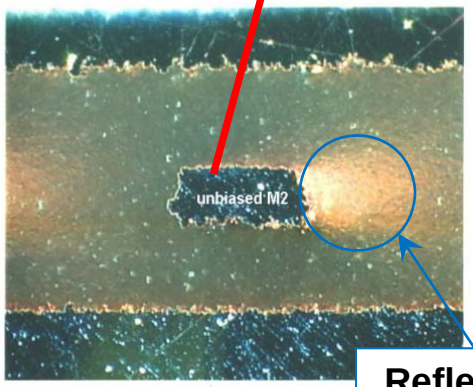
Reflections from Cu traces



Copper between biased traces

No Copper between unbiased traces



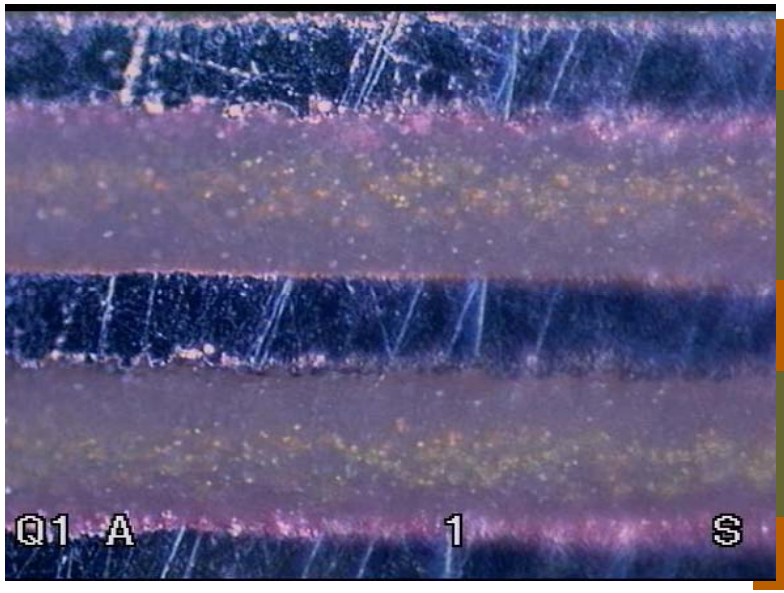


Reflection

Copper in build-up dielectric for electrically passing devices
No copper migration for unbiased traces

125C/85%RH bHAST Physical Analysis

120hr Electrical Pass



M1 copper

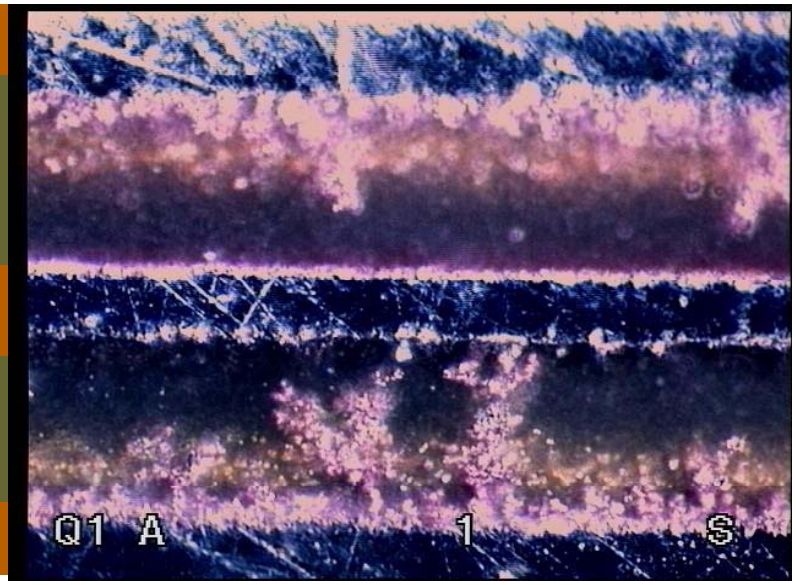
Build-Up

M2 copper

Build-Up

M3 copper

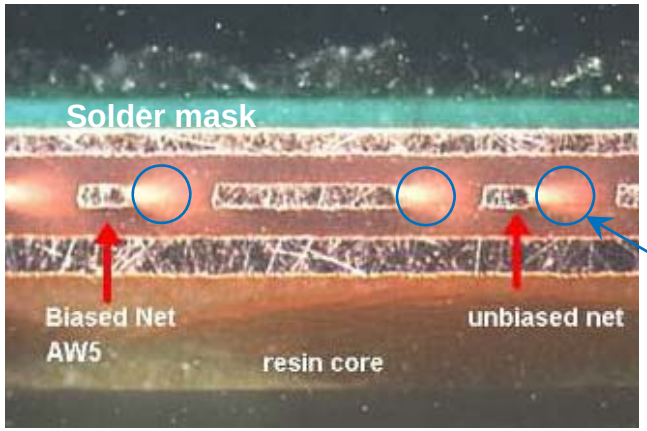
264hr Electrical Fail

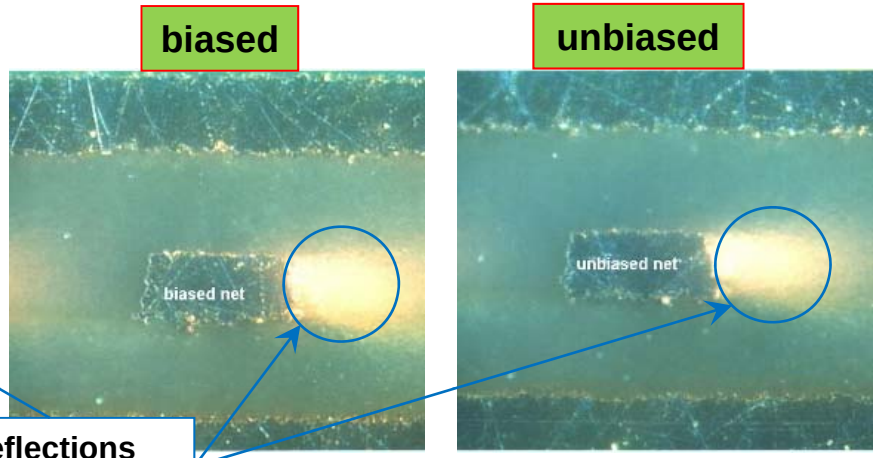


Copper in build-up dielectric growing from M1 and M3 toward M2 biased traces

110C/85%RH bHAST, 85C/85%RH THB, 125C HTOL Physical Analysis

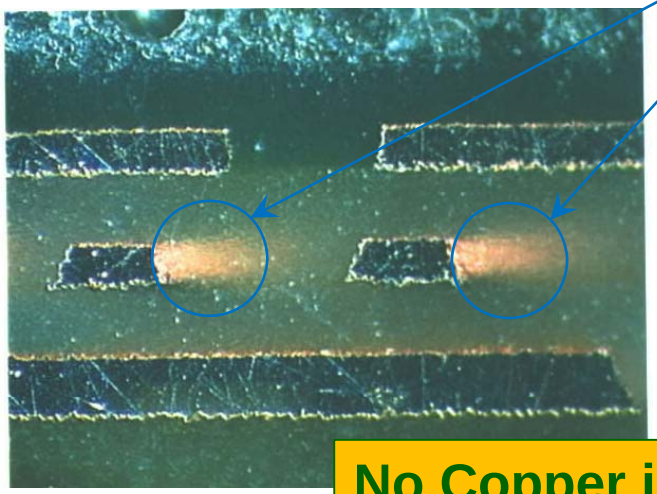
110C/85%RH, 264hr bHAST



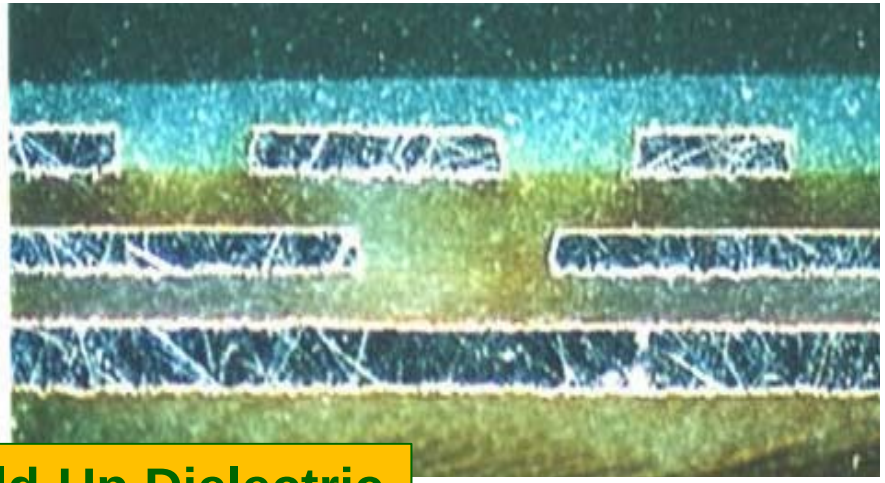


Reflections from Cu traces

85C/85%RH, 1000hr THB



125C, 1000hr HTOL



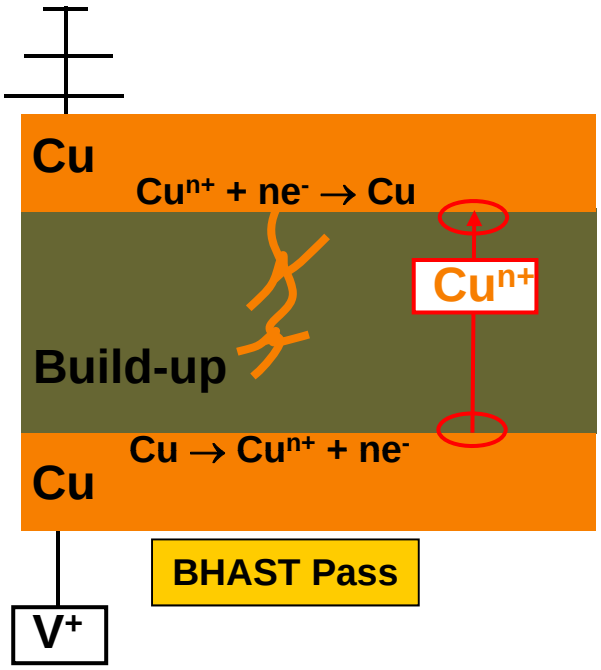
No Copper in Build-Up Dielectric

Summary of Results

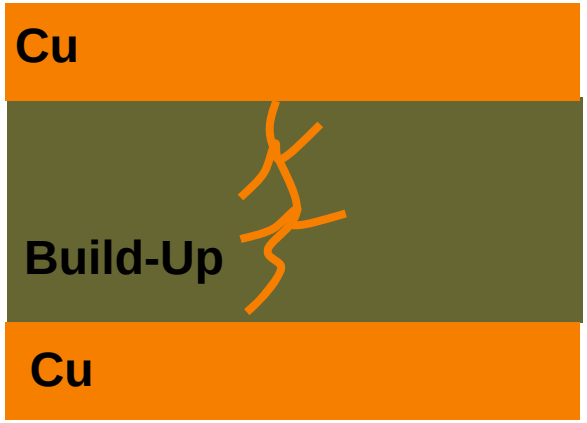
Test	MSL4/260C Preconditioning	Temperature	Humidity	Bias	Test Points (hours)	Electrical Failures	Copper Migration
THB	Yes	85C	85%	Yes	1000	No	No
bHAST	Yes	110C	85%	Yes	264, 528	No, No	No, No
bHAST	Yes	120C	85%	Yes	160, 264	No, No	No, No
bHAST	Yes	125C	85%	Yes	120, 264	No, Yes	Yes, Yes
bHAST	Yes	130C	85%	Yes	96	Yes	Yes
HTOL	No	125C	<10%	Yes	1000	No	No

- 130C/85%RH bHAST - failures and copper migration
- 125C/85%RH bHAST – failures in extended testing and copper migration
- 120C and 110C/85%RH bHAST
  - No failures
- 85C/85%RH THB
  - No failures
- 125C HTOL (High Temperature Operating Life) - bias and low humidity
  - No failures

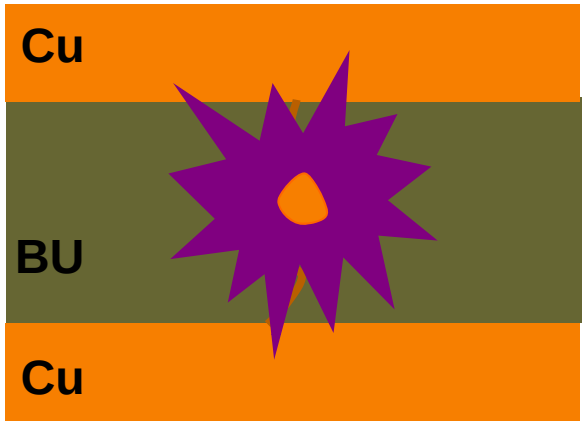
Proposed Model for Copper Migration and Failure



BHAST Pass



bHAST Bake-Recoverable Fail (moisture completes circuit)



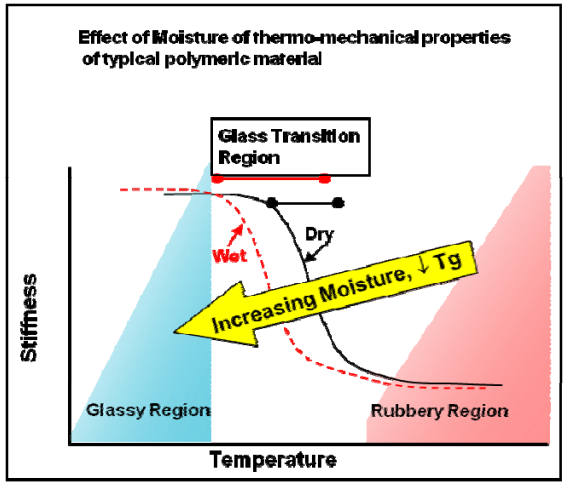
bHAST Hard Fail (localized EOS) Damaged dielectric Melted Cu

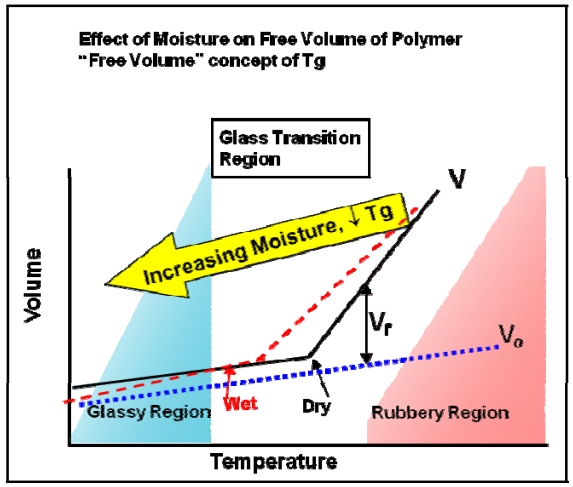
- Copper is liberated from the positive anode along with free electrons.
- Copper ions move under bias through the bulk build-up resin and deposit on the cathode at lower potential (ground in this case).
  - Different than classical CAF (Conductive Anodic Filament) where copper migrates along interfaces between resin and fiberglass reinforcement in the substrate core.

Open question is why does build-up material not behave as robust dielectric under 130C/85%RH bHAST conditions?

Proposed Model for Copper Migration and Failure Temperature Dependence of Copper Migration

- Build-up material is robust dielectric at 110C and 120C/85%RH bHAST but breaks down at 125C and 130C/85%RH bHAST
- Behavior correlates well with humidity induced reduction in the glass transition temperature (Tg) of polymers





- Above Tg, the free volume of the build-up dielectric is increased while its bond strength and stiffness is decreased
- Tg of build-up dielectric is ~150C in dry state measured by TMA
  - For temperatures $\geq$ 125C and high humidity, the Tg of the build-up dielectric is reduced to at or below the stress temperature
- The reduction in Tg to below stress temperature with moisture along with applied electric field provides a means for electrochemical migration of copper

Conclusions

- For Flip-Chip build-up substrates, there is a threshold effect in temperature and humidity below which copper migration does not occur under bias
  - Copper migration does not occur for temperatures of 120C or lower with humidity of 85%
  - Copper migration does not occur for temperatures of 125C and low humidity (e.g. HTOL)
  - Copper migration does not occur up to 130C/85%RH with no bias
- Model proposed based on reduced Tg of build-up dielectric with combination of high temperature and high humidity
  - Copper migration occurs with bias and moisture above Tg
  - No copper migration occurs below Tg
- Results consistent with the cautions in JEDEC standards
  - Accelerated bHAST testing may result in artificial failures that would not occur in standard THB testing and not representative of field operation
- Caution must be taken when applying bHAST stress conditions >120C for Flip-Chip build-up substrates

Acknowledgments

- Physical Analysis
  - Frank Baiocchi
  - John DeLucca
  - Ron Weachock