Douglas O. Pauls

Principal Materials & Process Eng
Rockwell Collins
dopauls@rockwellcollins.com

Biography:
Doug Pauls is the Rockwell Collins expert-on-call for conformal coatings. He presently serves as the chairman of the IPC Cleaning and Coating General Committee and has been involved in cleaning and coating processes for more than 25 years. Pauls has been a part of MIL-I-46058 and IPC-CC-830 as well as the development and revision of the IPC handbook on conformal coating, IPC-HDBK-830.

Title:
Consideration for Selection and Implementation of Low VOC Conformal Coating into High Reliability Electronics Manufacturing Operation

Executive Summary
The purpose of this presentation is to provide considerations for selection of conformal coatings into electronics assembly operations. The types of testing required for selection and use of coating will be presented. Challenges and difficulties of implementation will be discussed. The overall impact of conversion from coating types will be presented.

Evaluating Conformal Coatings For Use In A High Reliability Manufacturing Operation

Douglas Pauls
Principal Materials and Process Engineer
Advanced Operations Engineering
Rockwell Collins
Cedar Rapids, Iowa

Overview

- Role of Conformal Coating
- Selection of a Conformal Coating (very high level)
- Materials Characterization Tests
- Operational Testing – Standard Test Assemblies
- Operational / Functional Testing
- Question / Answer Session

Role of Conformal Coating

- What Conformal Coating Is:
  - The process which only a mother could love and which gets blamed for most failures
  - ***Conformal coating is defined as a thin, transparent, polymeric coating that is applied to the surfaces of PWAs to provide protection from the end-use environment***
  - Much like varnish protects fine woodwork
- Three Primary Functions
  - Prevent solid particulate matter from contacting energized circuits
  - Prevent **liquid** water from contacting energized circuits
  - Provide some protection against destructive vapors in the end use environment (moisture, pollutant gasses, salt)
- Secondary Functions
  - Tin Whisker mitigation, fungus and flammability mitigation tools
- NOT
  - A Band-Aid to cure a poor design
  - A magical material with no engineering tradeoffs
  - A material that keeps out moisture indefinitely

What To Know Before Choosing a Coating

- What your end use environment will be
- What will the temperature extremes be and durations
- Know what other contaminants may go on the coating
- Know what the design life and anticipated life of the product are
- What are the consequences of failure
- How rugged will the enclosure be, or how open is the enclosure to the end use environment
- Know the frequencies in use on the product and how sensitive the circuit is to variations in dielectric constant and dissipation factor
- Consider the health and well being of the coating operators
  - Take a good strong whiff of the material you are asking operators to apply
- What kinds of tests will be used for product acceptance/burn in?
- ***EVERY*** conformal coating has an Achilles Heel

Conformal Coating Types

- There are two predominant coating specifications in the US:
  - MIL-I-46058 (military) and IPC-CC-830 (commercial)
  - Almost identical specifications
- They define 5 chemical families / groups based on the dominant resin present
  - Type AR – acrylics
  - Type UR – urethanes
  - Type SR – silicones
  - Type ER – epoxies
  - Type XY – polyparaxylylene (Parylene™)
- The military specification has not changed since 1995 (inactive for new designs)
  - So more modern materials, or hybrid coatings have trouble being classified under this system. But, we are stuck with it for the time being.

Comparison of Coating Types

Parameter	Solvent Acrylic	Water Acrylic	Urethanes	Silicones	Parylene
VOC Emission		S			S
Reworkability	S				
Smell					n/a
Cost	S				
Working Life		S			n/a
Thermal Resistance					S
Chemical Resistance				S	S
Abrasion Resistance					S
Humidity Resistance					
Salt Environment					S
Liquid Water				S	S
Manufacture Friendly					
Flammability				S	S
Fluorescence	S				

S = Area where coating is superior

From Plasma Ruggedized Systems

Rating Scale: 1 (Highest) to 4

	Acrylic (AR)	Polyurethane (UR)	Epoxy (ER)	Silicone (SR)	Parylene (XY)		
					C	D	N
Humidity Resistance	1	1	2	1	2	2	1
Humidity Resistance (Extended Periods)	2	1	3	2	2	2	1
Abrasion Resistance	3	2	1	4	1	1	1
Mechanical Strength	3	1	1	2	1	1	1
Temperature Resistance	2	3	3	1	2	2	1
Acid Resistance	2	1	1	2	1	1	1
Alkali Resistance	3	1	1	2	1	1	1
Organic Solvent Resistance	4	1	1	2	1	1	1
Dielectric Constant (1MHz@23°C)	2.2-3.2	4.2-5.2	3.3-4.0	2.6-2	-	-	-
Outgassing	3	2	3	4	1	1	1
Electrical Impedance	2	4	3	2	-	-	-
Optical Clarity	4	3	1	2	2	2	2
Bio Compatibility	-	-	-	-	-	-	-
Thermal Stability	1-2	2	2	1-2	1	1	1
Electrical Insulation	1-2	1-2	1-2	2	2	2	1
Reworkability	1	3	3	2	4	4	4
VOC's	1-3	2-3	2-3	1-2	1	1	1
RoHS	1	1	1	1	1	1	1
Thermal Conductivity	2-3	2-3	2-3	2-3	3	3	3
Adhesion	2-3	1-2	1-2	1-3	2	2	2

Source: www.Plasmarugged.com

Honeywell Matrix

Higher is better

	AR1	AR2	AR2	UR1	UR2	UR3	UR4	UR5	UR6	UR7	Factor
Tg	6	6	6	6			5	1	5	5	5
CTE	5	2	2	4			6	7	5	1	5
Dielectric Strength	9	9	9	5	5	7	10	3	5		1
Insulation Resistance	10	10	10	8	10	10	10	10	10	9	1
Abrasion Resistance	7	7	4	8	10	8	6	9	7	7	1
Cost											10
Modulus											8
Modulus*CTE											10
SR JP-8 (Fuel)	1	1	10	10	5	10	3	10	10	9	2
SR Mobil Jet Oil II (Lub Oil)	1	1	9	10	6	10	5	10	10	10	2
SR Brayco Micronic 756 (Lub Oil)	2	2	10	10	5	10	3	10	10	10	2
SR Isopropyl Alcohol	1	1	3	10	6	10	2	9	10	10	2
SR DowFrost (Deicing Fluid)	6	10	9	10	10	10	7	10	10	9	2
SR Castrol Braycote 889 (Coolant Fluid)	10	5	10	10	8	10	7	10	10	10	2
SR Skydrol 500 B-4 (Hydraulic Fluid)		1		10	3	10					2
Hydrolytic Stability	10	9	10	2	8	5	1	8	5	9	10
Hazardous Assessment											10
Reworkability	10	10	10	6	9	6	9	4	2		7
Pot Life	10	10	10	7	3	6	10	1	6	10	5
Material Component											5
Curing Cycle Time	8	8	7	4	5	7	1	5	5	10	6
AERO Current Usage	10	10	3	4	6	10	2	1	4	3	10
Summary	759	802	695	547	734	719	478	539	557	509	

Source: IPC/STMA Cleaning Conference 2010 Proceedings – Hector Valledares, Honeywell Aerospace

Start With Vendor Data Sheets – But:

- But, but my data sheet says …
- ASTM methods for material characterization not production use
  - Usually are for thin flat films on thin flat substrates, not the 3D aspects on actual product
  - Think – material characterization, not proof that it works
- Testing done by manufacturer who knows every trick in the book
  - Should be treated as an absolute best case, not a typical case
    - Can YOU cook as well as Emeril Lagasse?
  - Properties listed are also for new/fresh material, and few data sheets have any indication of how the material varies with age.
  - Many of the material properties shown are for room temperature and may vary significantly with temperature
- Material properties in the finished form can vary greatly depending on how you apply, dry, and cure the coating. It also depends on the surface topography.

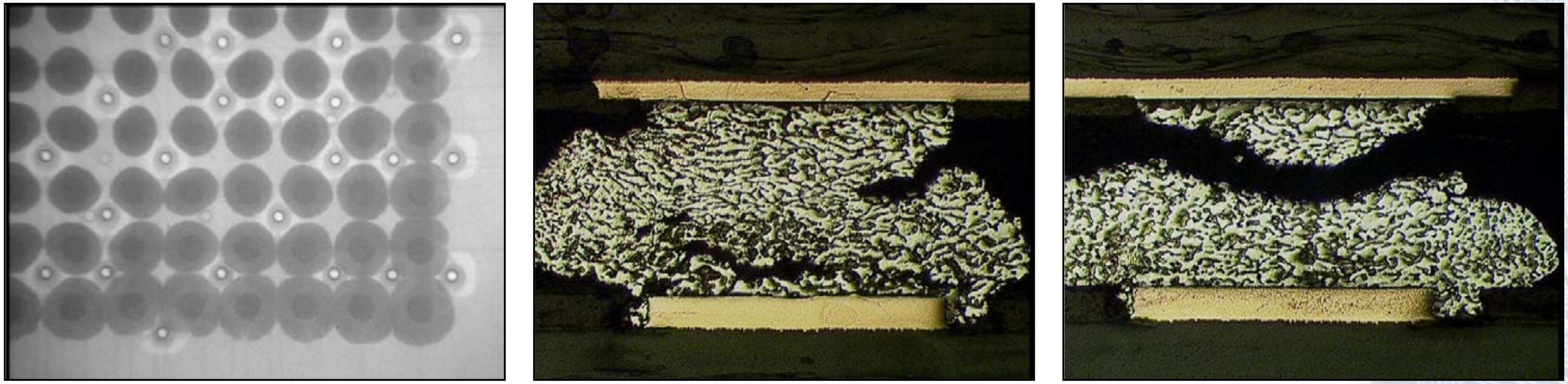
A Common Question

- What is the best coating to pass salt fog testing?
- ***The ability to pass salt fog testing (or similar harsh chemical environmental tests) is much more dependent on coating technique and quality than it is on the characteristics of the coating itself.***
- Almost all the coatings can both pass and fail humidity. A superior coating job with an inferior material has a better chance than an inferior coating job with a superior material.
  - Parylene example
- What you want is a continuous layer of coating, no pinholes or openings in the coating.
  - The more holes in the coating (design issue) the greater the chance of penetration
  - Connectors are the biggest problem, uncoated components second
  - Thicker coatings (3-4 mils vs. 1-2 mils) may help improve coverage
  - Spray application is far better in this respect than brush coating – more uniform coating, better edge coverage

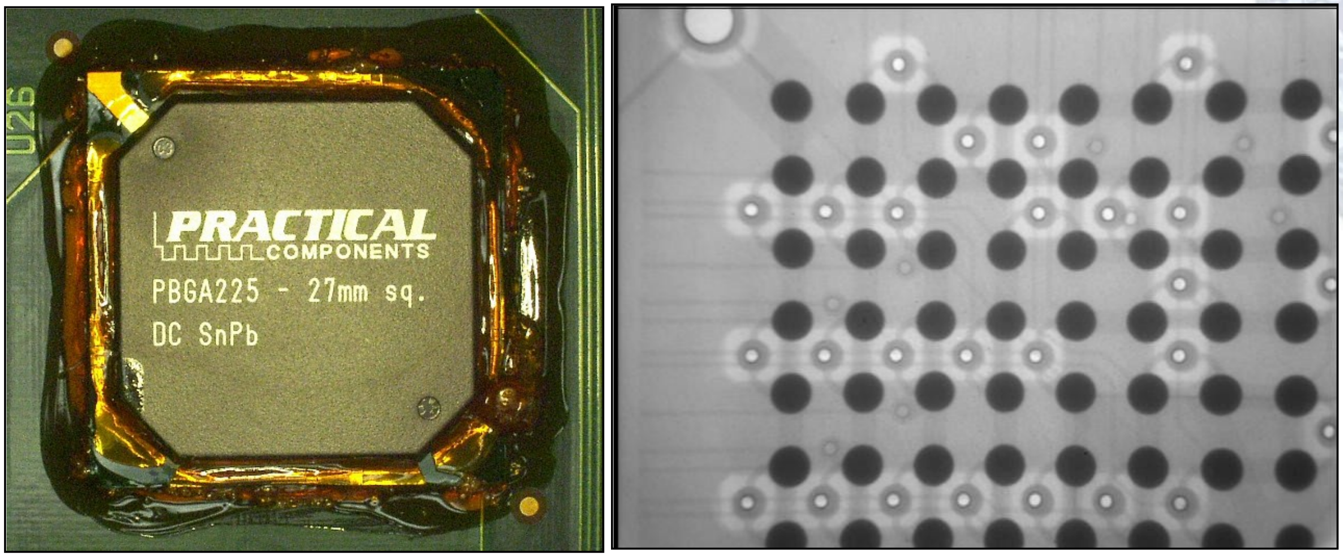
Coefficients of Thermal Expansion of Coatings

- Acrylics
  - 55 ppm/°C to 400 ppm/°C (depends on above or below Tg)
- Urethanes
  - 82 ppm/°C (2 part), 200-500 ppm/°C (1 part)
- Silicones
  - 300 – 450 ppm/°C
- Epoxies
  - 15-50 ppm/°C
- Parylene
  - 35 ppm/°C
- Solder: ~21 ppm/°C
- These figures are not all produced with the same method, so they are for illustration purposes only
- CTE values vary dramatically above and below Tg, and XY vs. Z
- CTE values vary depending on 1 part, 2 part, 100% solids, and method of curing (e.g. UV cure)

Conformal Coating as An Underfill – Bad Idea



Solvent Acrylic – After 2000 cycles



Water Based Acrylic After 2000 cycles – Diff Tg and Modulus

Tin Whiskers and Conformal Coating

- The Global Lead Free manufacturing changes means:
  - Lead free finishes on parts
  - Most common / cheapest is tin plated parts
  - Pure tin parts can spontaneously grow "tin whiskers"
  - Conformal Coat is one method of tin whisker risk mitigation
- For more information on Tin Whiskers, see IPC-WP-009 Summary of Tin Whisker Research References
- Many Class 3 use conformal coating to mitigate the risk from tin whiskers
  - Coating absorbs some of the stress of the whisker as it punches out, and makes it very difficult to punch back in the other side
  - If the whisker breaks off, it becomes metallic FOD. Coating helps prevent shorts.
  - No conformal coating eliminates the risk of tin whiskers

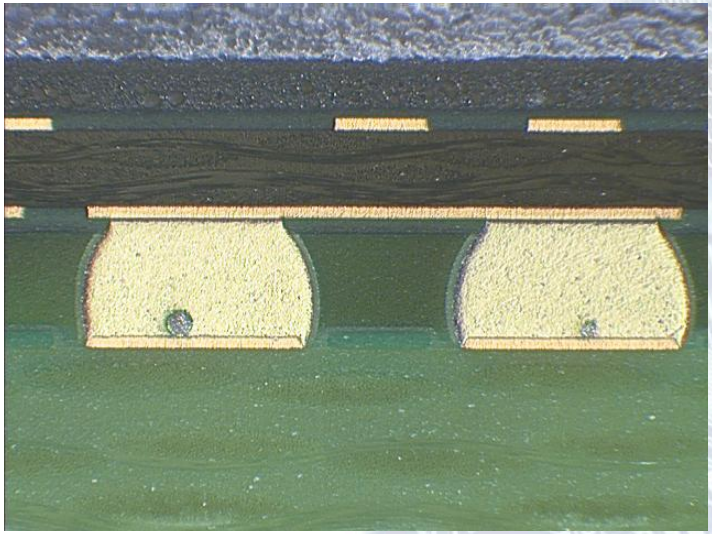
Tin Whisker Models

- CALCE Model
  - Acrylics (AR) =0.1
  - Acrylic (H20) = 0.05
  - Urethane (UR) = 0.01
  - Silicone (SR) = 0.1
  - Parylene (XY) = 0.05
  - No Coating = 1

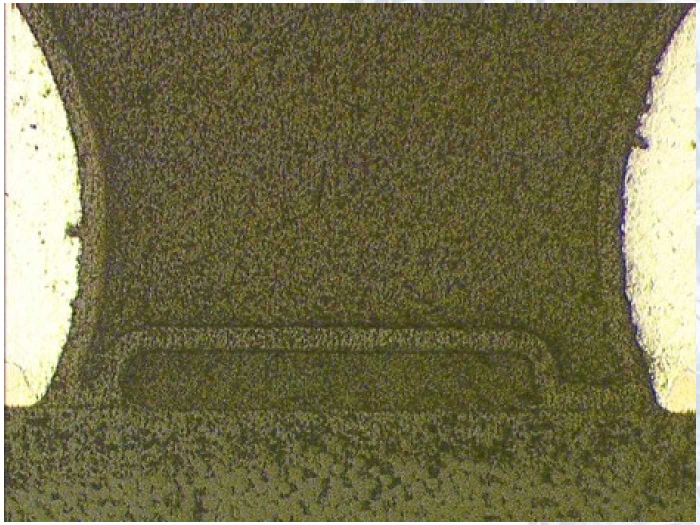
Leading Edge Tin Whisker Investigative Efforts

IPC-JSTD-001E Subcommittee Task Team:

Conformal Coating Material & Application
"State of the Industry" Assessment



The goal of the project is to document the current "State of the Industry" of conformal coating application on printed wiring assemblies.
The project will look at the major conformal coating types (i.e. AR, ER, UR, SR, XY) and method of application (i.e. spray, dip, brush).



The project will not evaluate individual companies or specific conformal coating products – plan is to do a "blind" documentation effort.

Metallographic cross sectioning will be utilized for measurement of thickness and coverage.

Contact: Dave Hillman,
ddhillma@rockwellcollins.com

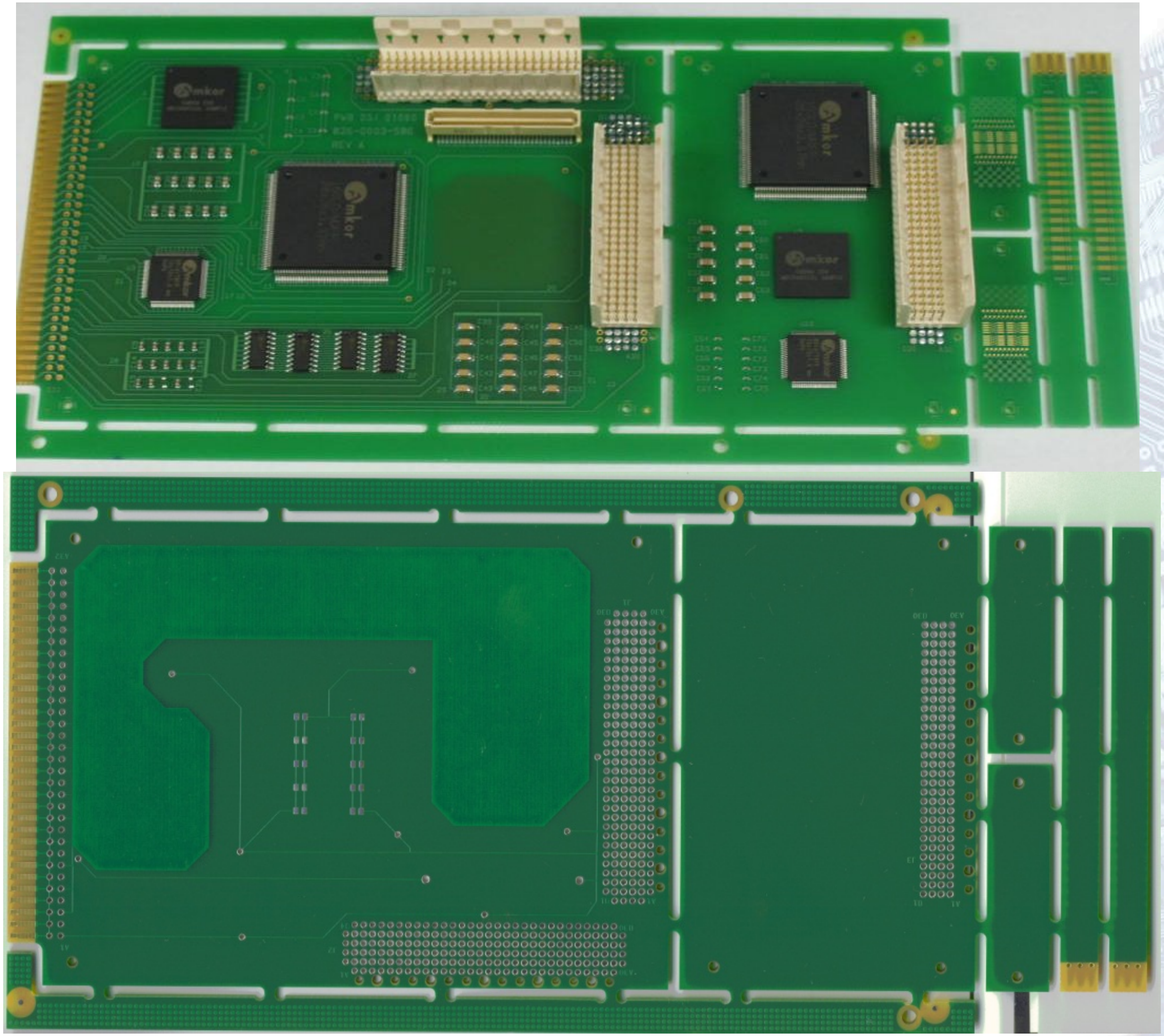
Other Important Considerations

- What are the Volatile Organic Carbon (VOC) or air emission laws are predominant where the coating will be applied?
- What is the regulatory outlook in the next 1-3 years?
- What are the OSHA considerations in your area for worker production?
- If you are a global company, what are the regulations where the unit is being serviced and repaired?
  - REACH, RoHS

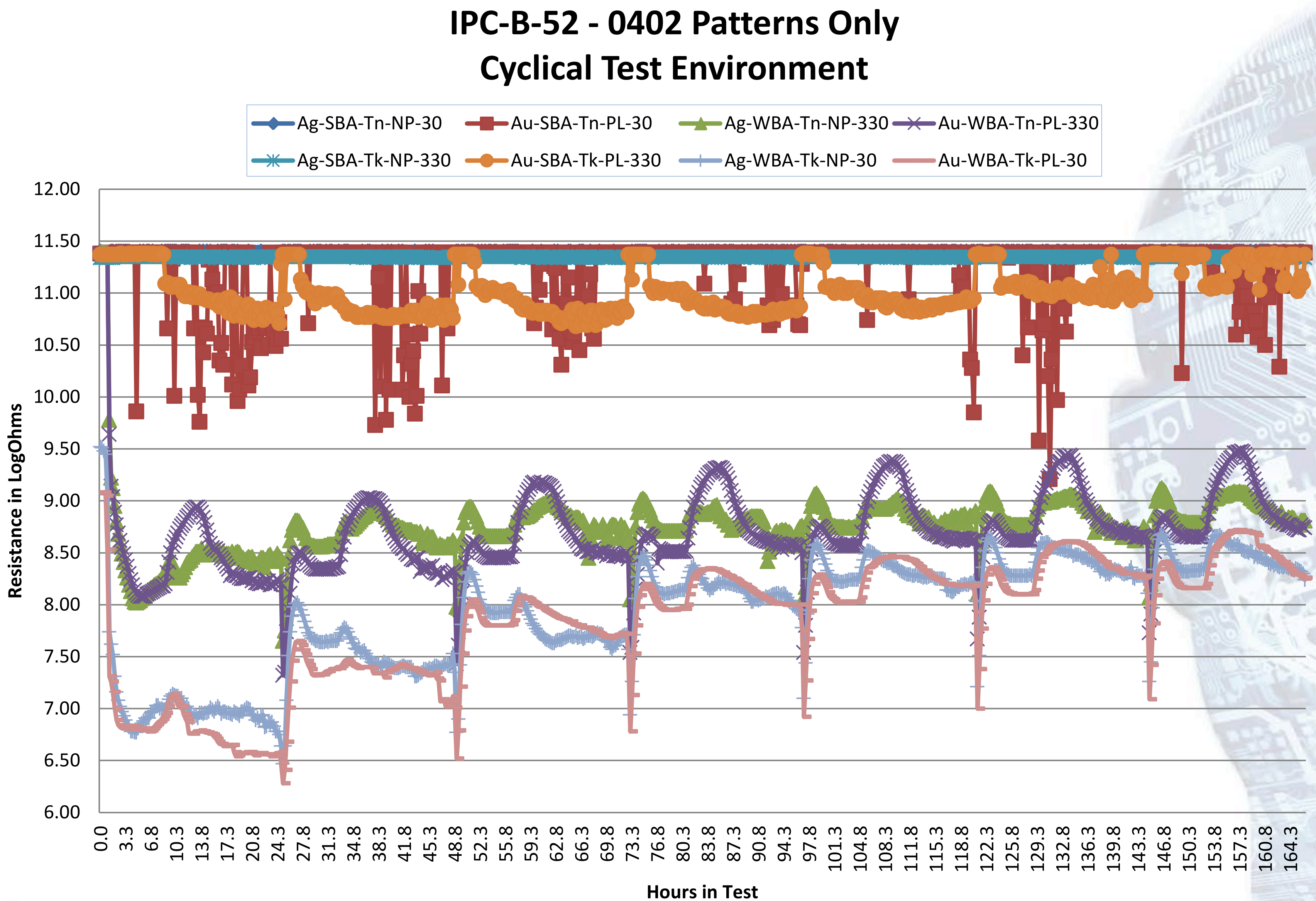
Characterization Tests

- You could repeat the tests found in MIL-I-46058 or CC-830
  - Don't recommend this – save your money on material use tests
  - The published vendor data is usually reliable
- Concentrate on determining acceptable parameters for the application method, thickness, and curing methods chosen
- Recommend using the IPC-B-52 Standard Test Assembly
  - Base Substrate for IPC-9202
  - IPC-9203 is the companion document
  - This test assembly has multiple test patterns
    - BGA, 2 QFPs, SOICs
    - SMT and through hole connectors
    - Capacitors: 0402, 0603, 0805, and 1206
  - Additional designs and patterns being considered (QFNs)

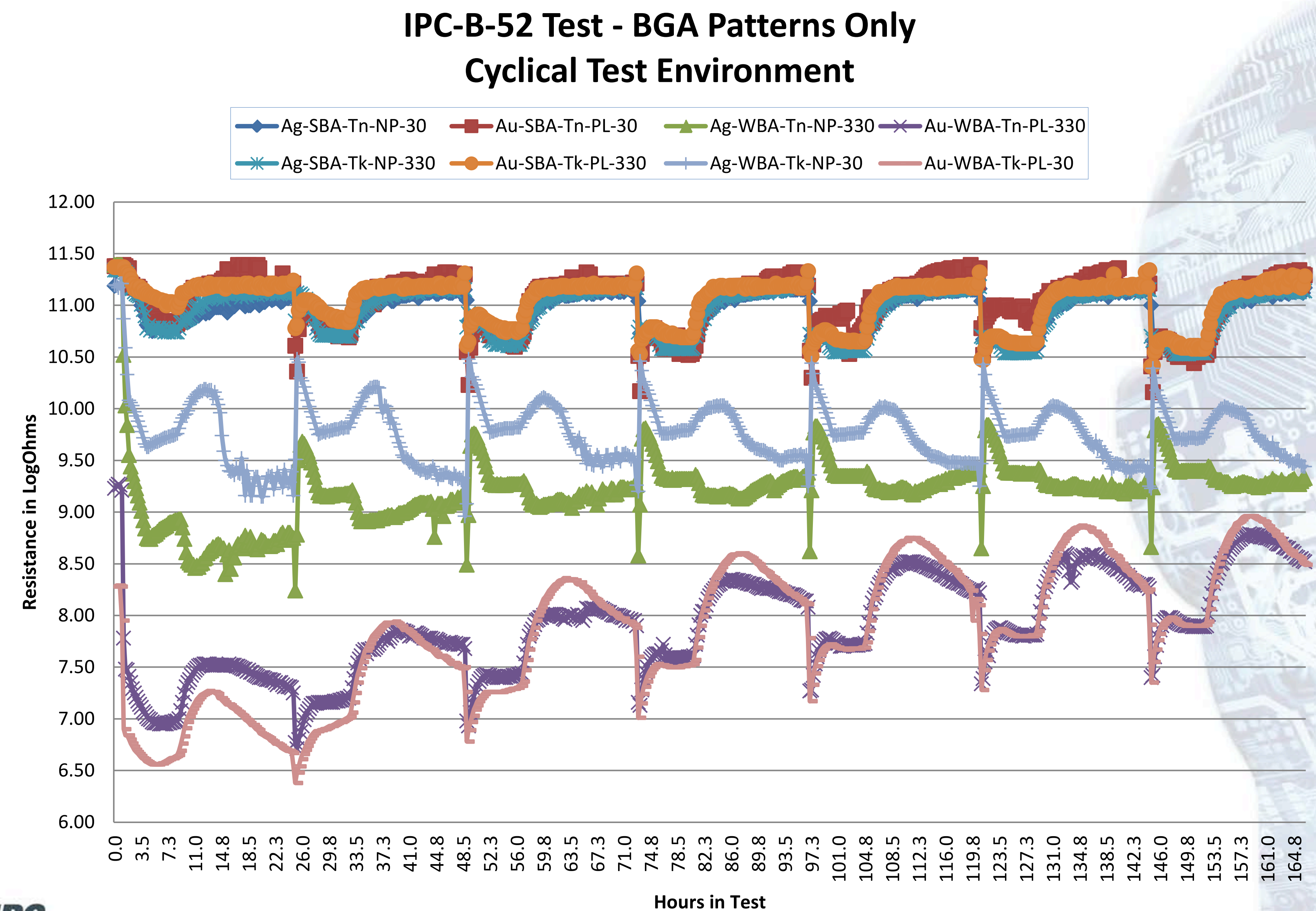
IPC-B-52 Assembly



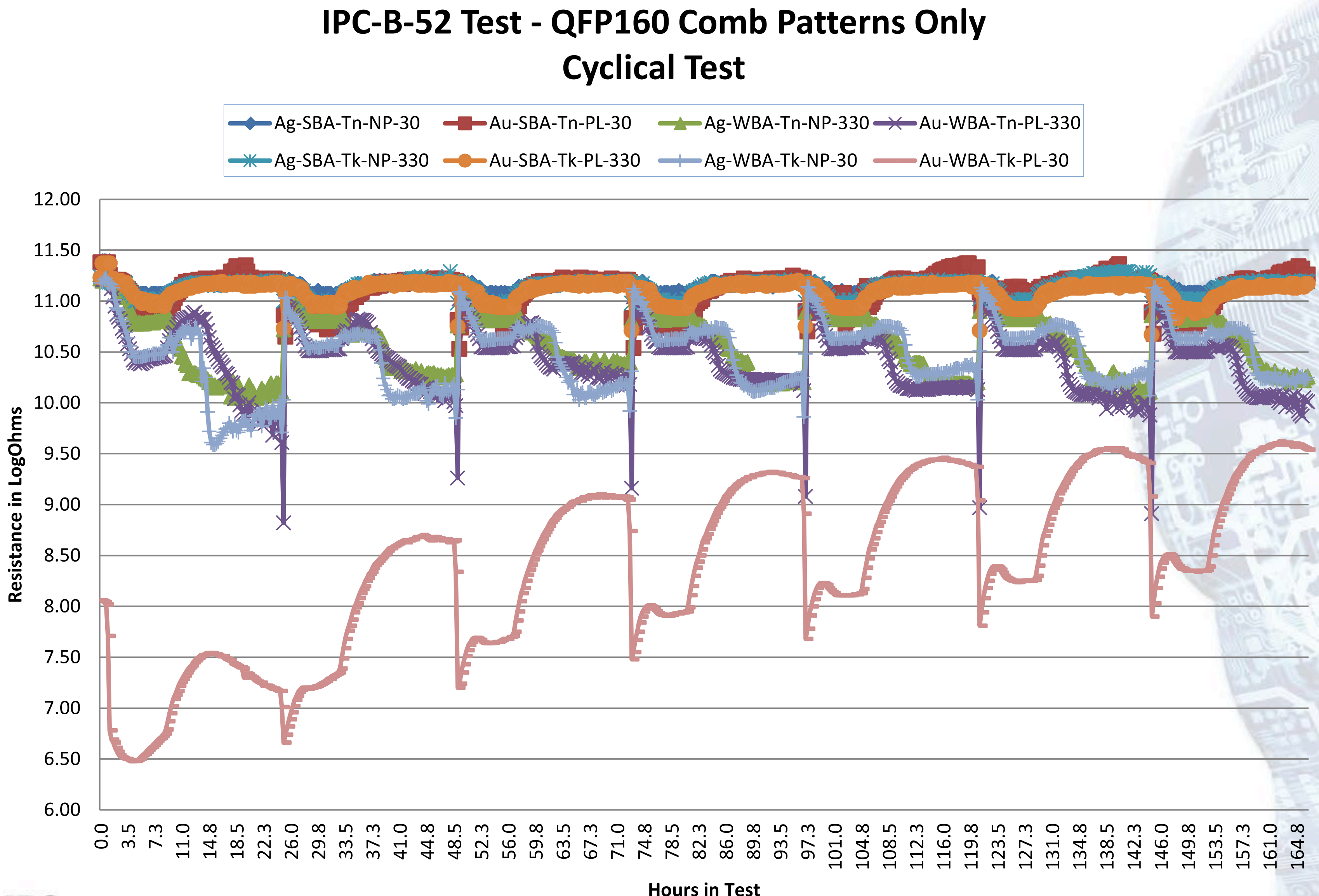
Performance in a Cyclical Environment



Performance in a Cyclical Environment



Performance in a Cyclical Environment



How These Tests Are Different

- Film characterization tests are essentially two dimensional
- These test examine the three dimensional characteristics of coatings
  - Multiple cure states
  - Conformal coating can have different characteristics depending on thickness, the method of application, method of cure, and length of cure
  - You see effects on an actual assembly that you don't see on flat test boards
    - Close spaced parts – webbing, bridges, bubbles
    - Shadowed parts
    - Cumulative process effects from other materials and contaminants
    - Areas shielded from heat or UV light

Questions?

'You've never been lost until you've been lost at Mach 3.'
- Paul F. Crickmore (SR71 test pilot)-