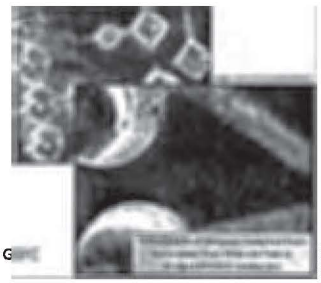
Long Term Investigation of Urethane Conformal Coating Against Tin Whisker Growth



Lyudmyla Panashchenko – NASA GSFC
Jay Brusse – Dell Perot Systems at NASA G
Dr. Henning Leidecker – NASA GSFC

Mitigations Against Tin Whiskers

- Mitigation is not elimination – *it is reduction in severity*
  - Whiskers may still form after application of a mitigation strategy
  - Effective mitigation strategies severely reduce risk of whisker formation and/or whisker-induced harm
- The most effective whisker mitigation strategies:
  - Application of tin (Sn) with lead (Pb)
    - Typically 3%wt Pb or more is required
    - Past studies indicate that as low as 0.5%wt Pb may be adequate [1]
  - Placing physical barriers to prevent whisker bridging
    - Conformal Coating
    - Potting
    - Tape wrap

Subject of this talk

How can Conformal Coat Help

1. Will conformal coat inhibit nucleation of whiskers?
2. Will conformal coat inhibit outward escape of whiskers?
3. Will conformal coat inhibit inward penetration of whiskers?
4. Will conformal coat protect against loose (i.e. detached) whisker debris?

Subjects of this talk

Research on Whiskers vs Conformal Coating (1/2)

	Boeing [2][3][4]	Schlumberger [5]	Lockheed Martin [6][7]	NPL [8]	Raytheon [9]
Acrylic	1 and 3mil thick OK in ambient. Penetrated in 25°C/95%RH	–	1,2,3 mil thick. 5 years 50°C/50%RH – penetration and tenting of 1mil coating	5-20μm thick. OK after 150days in ambient	–
Silicone	1 and 3mil thick OK in ambient. Penetrated in 25°C/95%RH		–	14-588μm thick. OK after 150 days in ambient.	
Parylene C	0.4mil thick OK in ambient. Penetrated in 25°C/95%RH	–	0.5mil thick. 5 years 50°C/50%RH – no tenting or penetration	–	–

Research on Whiskers vs Conformal Coating (2/2)

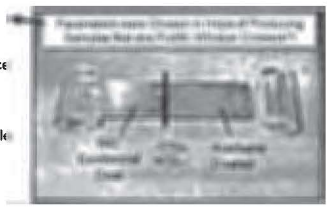
	Boeing [2][3][4]	NASA [10][11][12]	Lockheed Martin [6][7]	NPL [8]
Urethane (Polyurethane)	--	2mil thickness fully effective after 9 years of ambient	1,2,3 mil thick. 5 years 50°C/50%RH – penetration and tenting of 1mil coating	9-57µm thick. OK after 150 days in ambient
Urethane Acrylate	1 and 3mil thick. OK in ambient. Penetrated in 25°C/95%RH	--	--	13-79µm thick. OK after 150 days in ambient

NASA GSFC Conformal Coating Experiment

- Objective:
  - Evaluate the effectiveness of Arathane 5750 (now Arathane 5750) conformal coating as a whisker mitigation strategy
  - Arathane 5750 is a common conformal coating used for aerospace applications due to its low outgassing properties
- Approach:
  1. To obtain samples that are prone to grow whiskers
  2. Apply conformal coat
  3. Store in ambient conditions
  4. Monitor for whisker nucleation and penetration through coating

Conformal Coat (Arathane 5750* Polyurethane) ~11 Years of Office Ambient Storage

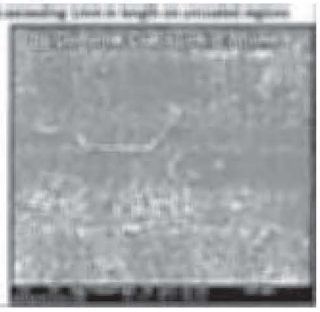
- **Specimens: 14 total**
  - 1" x 4"x 1/16" Brass 260
  - Tin-Plated 200 microinches
  - A few intentional scratches created after plating to induce localized whisker growth
- **Conformal Coating:**
  - Arathane 5750 on ¼ of sample
  - Nominal Thickness = 2 mils
  - Locally THIN Regions also examined
- **Storage Conditions:**
  - Office Ambient ~ 11 years



*Arathane™ 5750 was previously known as Uralane™ 5750

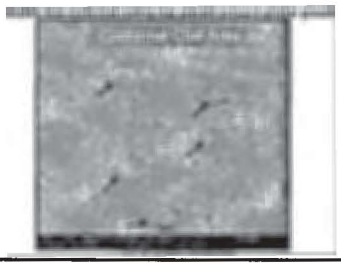
Control Areas – No Conformal Coat 11-Years of Office Ambient Storage

- Control Areas Grew Whiskers Abundantly within the First Year.
- 11 years after plating, control area grew substantial number of whiskers
- Some



Arathane 5750 – 2 Mils Thick 11-Years of Office Ambient Storage

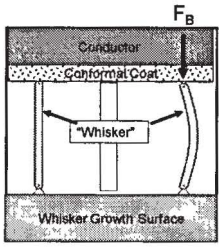
- Whiskers nucleated under the conformal coating within the first year
- HOWEVER, 11 years after coating, no whiskers found to penetrate nominal 2mil thickness of conformal coating
- SEM and optical inspection reveal 'tenting' of conformal coat caused by whiskers forming beneath the coating and lifting it up
- Following slides



Euler Buckling Axial Force Required to Buckle a Metal Whisker

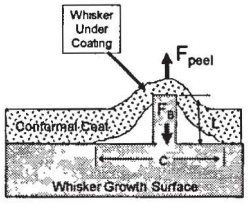
$$F_B = \frac{\pi^2 EI}{(KL)^2} \approx \left(\frac{\pi^3 \cdot E}{32}\right)\left(\frac{d^4}{L^2}\right)$$

E = Young's Modulus of whisker material,
I = Area Moment of Inertia,
(e.g. $I = \pi d^4 / 64$ for circular cross section)
L = Length of whisker,
K = Column Effective Length Factor
K = 0.5 for whisker fixed at both ends
K = 0.7 for fixed at one end, pinned at other



Whiskers Lift and Peel Conformal Coat Until Whisker Buckles OR Coating Fails (F_{peel} vs. F_{Buckle})

- As whisker first emerges it is short and stiff thus $F_B > F_{peel}$ and whisker begins to lift the coating forming a "circus tent" with height L = length of whisker;
- "Tent" joins the surface at a circle of circumference $C \sim 2\pi QL$,
  - Q describes the details of tent-like shape
- To peel conformal coating up and away from the surface, one needs to apply a force (F_{peel}) proportional to the circumference:
  - $F_{peel} = \Phi * C = 2\,pi\,Q\,\Phi\,L$
    Φ = peel strength of material which describes the adhesion of the coating to the tin, and the effect of the separation angle. It also depends on the rate at which the coating is peeled away

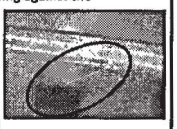


Arathane 5750 has better self-cohesion than adhesion to a tin surface

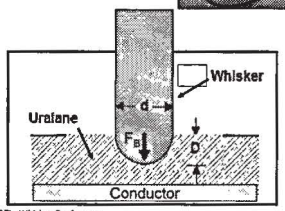
Will Whiskers Buckle Before Puncturing the Coating on a Distant Surface?

- The displacement of the conformal coat due to a whisker pushing against the coating is:

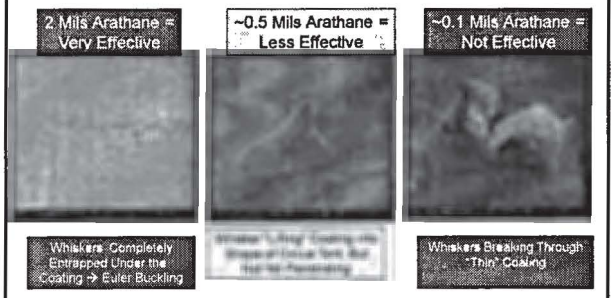
$$D = \left(\frac{1-\nu^2}{E_{coat}}\right)\left(\frac{F_B}{d}\right) \approx \left(\frac{\pi^3}{32}\right)\left(1-\nu^2\right)\left(\frac{E_W}{E_{coat}}\right)\left(\frac{d^3}{L^2}\right)$$



Where
D = Displacement of conformal coat
ν = Poisson's ratio
E_{coat} = Young's Modulus of coating
E_W = Young's Modulus of Whisker
d = "Diameter" of whisker
L = Length of whisker
F_B = Euler Buckling Strength of the whisker



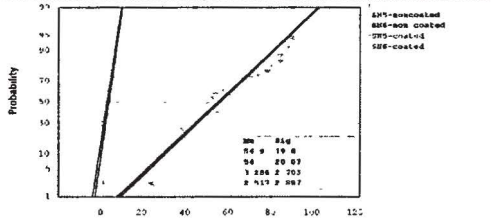
Arathane 5750 Conformal Coat - 11-Years of Office Ambient Storage



Change pictures, keep the idea

Comparing Whisker Densities (#/area) Coated vs Uncoated

- Two samples were examined using SEM both on coated and uncoated regions to compute number of whiskers per area
  - 30 areas each 0.64mm² on uncoated regions
  - 30 areas each 0.9mm² on coated regions
- 'Tenting' was counted on coated side as sign of whisker nucleation
  - SEM does not 'see' into conformal coating, thus only whiskers that are lifting the coating are counted

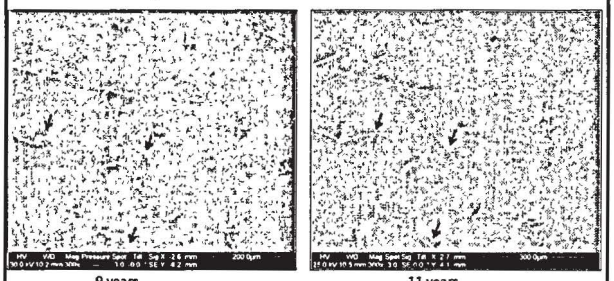


Effects of Conformal Coating

- Conclusion 1: *No whiskers have penetrated 2 mils of Arathane 5750 after 11 years*
  - Despite samples being capable of forming approximately 50 whiskers/mm² on coated areas greater than 600mm²
- Conclusion 2: *Whiskers are able to penetrate when coating is thinner (~0.1mil)*
  - Conformal coating processes can leave "weak zones"
    - Shadowing effects may prevent complete coverage when applying coating
    - Coating may flow/thin prior to completion of cure
  - Thinner coatings are more prone to whisker puncture
- Conclusion 3: *Even "Poor" Coatings Can Offer Some Protection*
  - Long whiskers bend easily (Euler Buckling) and are less likely to re-penetrate even thin conformal coat applied on a distant conductor.
  - Conformal coat protects against a conductive bridge from detached whiskers lying across a pair of coated conductors

Continuous Whisker Growth

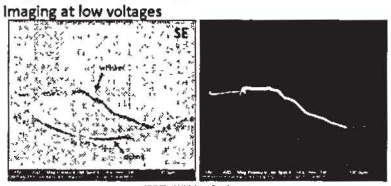
Whisker growth continues even a decade after initiation



9 years 11 years

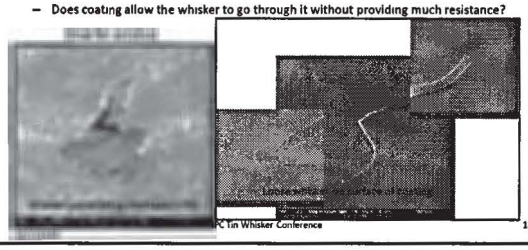
SEM Observation Methods

- Use of Secondary electron (SE) and Backscattering electron (BSE) detectors
  - SE provides higher image resolution and gives topographical view
  - BSE relates image contrast to atomic number of elements viewed. This allowed easy distinction between metallic whiskers and carbon dust fibers
- Use of low voltages (1-2kV) for imaging of highly non-conductive areas with conformal coating
- Use of stage tilting to improve signal accumulation at SE detector for better imaging at low voltages



Distinguishing Penetrating and Loose Whiskers on Conformal Coating

- Whiskers identified on the surface of conformal coating may be
  - Penetrating the coating by growing from the substrate below the coating
  - Settled on the surface of the coating after being dislodged from their original place of growth
- Know how the coating should be behaving if a whisker is growing
  - Does the coating stretch out and form a 'tent' with whisker as center pole? (true for Urethanes)
  - Does coating allow the whisker to go through it without providing much resistance?

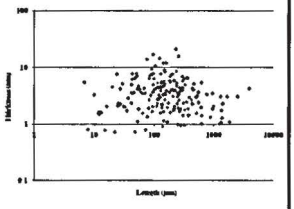


Tin Whisker Growth Statistics

- Whisker density was measured on randomly located 30 uncoated areas ~0 64mm² each
- Whisker lengths and thicknesses were measured for 187 whiskers randomly picked from whiskers growing on areas used for density measurements

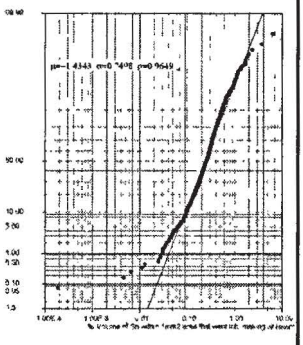
Whisker growth metric (units)	Distribution type	μ	σ	Median
Density (#/mm²)	Normal (Gaussian)	54	20	50
Length (μm)	Lognormal	5 01	1 15	150
Thickness (μm)	Lognormal	1 17	0 67	3 38

- Graph represents lack of correlation between whisker length and thickness
  - Meaning that whiskers of any thickness can grow to any length



Volume of Sn in Whiskers

- Although whiskers are made of tin that came from surrounding surface, no depletion of tin is observed around the whisker
- To evaluate how much tin has been used up in making of whiskers in comparison to total volume of Sn within a given area, 1000 areas of 1mm2 each were simulated with whiskers modeled through parameters described in previous slide
- Results indicate that median % of Sn available within 1mm2 area used up in whiskers is 0.24%
- This agrees with lack of visual depletion of Sn



Conclusions

- Arathane 5750 applied at a nominal 2mil thickness prevented outward growth of tin whiskers after 11 years of ambient storage
  - Non-coated areas grew ample whiskers
  - Areas with coating significantly thinner (~0.1mil) showed whisker penetrations through the coating
  - 'Tenting' was observed in areas of 2mil thick coating, where whiskers are pushing the coating up
- Whiskers are still growing a decade after tin electroplating
- Growth statistics indicate no correlation between whisker thickness and whisker length
  - Median whiskers thickness was 3.4μm
  - Median whisker length was 150μm
- Volume of tin consumed in whiskers is only a fraction of a percent of tin available in the surrounding area of whisker growth

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