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Date	

Presenter

a Estimating the Probability of Electrical Short Circuits from Tin Whiskers – Part I

Presented to the NASA-DoD Lead-Free Electronics Project Consortium December 16, 2008

Presenter

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Dr. Shihab Asfour, University of Miami Jon Bayliss, NASA-Kennedy Space Center Larry Ludwig, NASA-Kennedy Space Center Clara Wright, NASA-Kennedy Space Center





2

Page

huttle —	NASA Johnson Space Center, Houston, Texas	Presenter Karim	Courey	
ogram	Outline	Date December 3, 2008	Pag	

- Notice
- Publication
- Tin Whisker Phenomenon
- Risk Models
- Contact Resistance
- Objective
- The First Experiment
- The Second Experiment
- Limitations
- Conclusion
- Future Work
- Acknowledgments
- References





uttle		Presenter Karim Cour	rey	·
gram	Notice	Date December 3, 2008	Page	3

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Publication

Date December 3, 2008 P

Karim Courey

Presenter

- Page 4
- This presentation summarizes the research presented in the article titled:

Tin Whisker Electrical Short Circuit Characteristics— *Part I,* Courey, K. J.; Asfour, S. S.; Bayliss, J. A.; Ludwig, L. L.; Zapata, M. C.; Electronics Packaging Manufacturing, IEEE Transactions on, Volume 31, Issue 1, Jan. 2008 Page(s): 32 - 40

Copies are available through the KSC Library IEEE *Xplore*® link below:

http://ieeexplore.ieee.org/search/searchresult.jsp?query1=courey&scope1=au&queryText=+ %28%28courey%29%3Cin%3Eau+%29+&history=yes&menu1=&query2=&menu2=&scope 2=&query3=&menu3=&scope3=&op1=&op2=&queryblock=&reqloc=basic&py1=1950&py2= 2008&submit=Run+Search



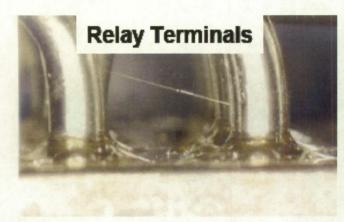
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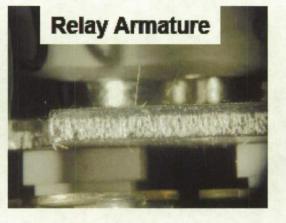
> Tin Whiskers on Components (Source: Leidecker & Brusse, 2006)

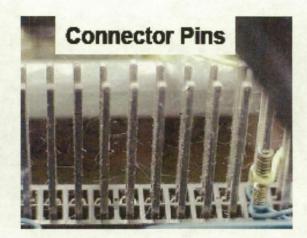


Presenter Karim Courey
Date
December 3, 2008 Page 5

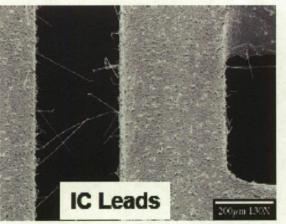
Optical Microscopy

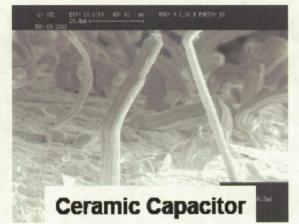






Scanning Electron Microscopy











Current Assumption in Risk Models

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- In the published simulations it is assumed that physical contact between a whisker and an exposed contact results in an electrical short
- This conservative assumption was made because the probability of an electrical short circuit from free tin whiskers had not yet been determined



Contact Resistance (Source: R. Holm & Holm, 1967)



7

Date December 3, 2008 Page

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- Contact resistance is the sum of the constriction resistance and the film resistance
 - When two surfaces touch, only a small portion of the area actually makes contact due to unevenness in the surfaces
 - Current flow is constricted through the smaller area resulting in a constriction resistance
 - Film resistance is due to the build up of tarnish films (oxides, etc.) on the contact surfaces that act in a nearly insulating manner





Shuttle		Presenter Karim Courey		!	
rogram	Objective	Date December 3, 2008	Page	8	

 To develop an empirical model to quantify the probability of occurrence of an electrical short circuit from tin whiskers bridging adjacent contacts as a function of voltage





Presenter	Karim Cou	ırey	
Date Decemb	er 3, 2008	Page	9

- To determine when a tin whisker's contact resistance breaks down the voltage level at the transition to metallic conduction current must be recorded
- To determine the breakdown voltage of a tin whisker a micromanipulator probe was brought into contact with the side of the tin whisker growing from a tin-plated beryllium copper card guide

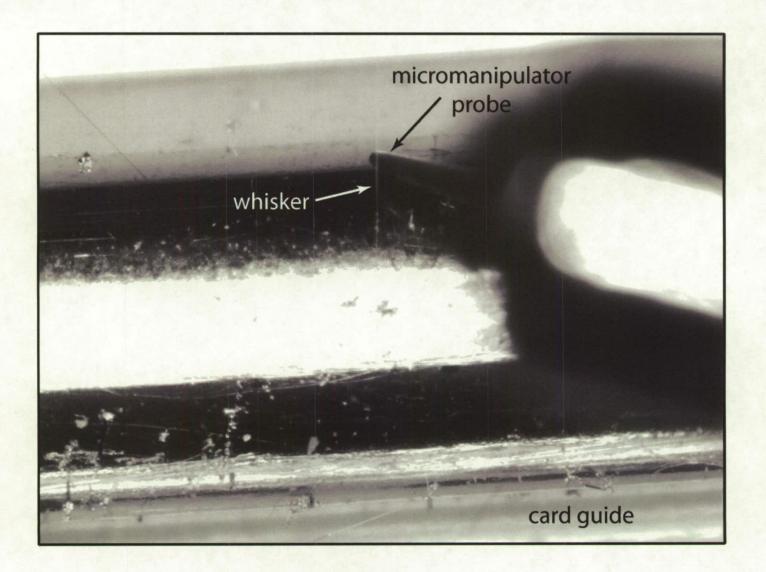


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 First Experiment - Micromanipulator probe
 Presenter
 Karim Courey

 touching tin whisker growing from the card guide.
 Date
 Date
 December 3, 2008
 Page 10



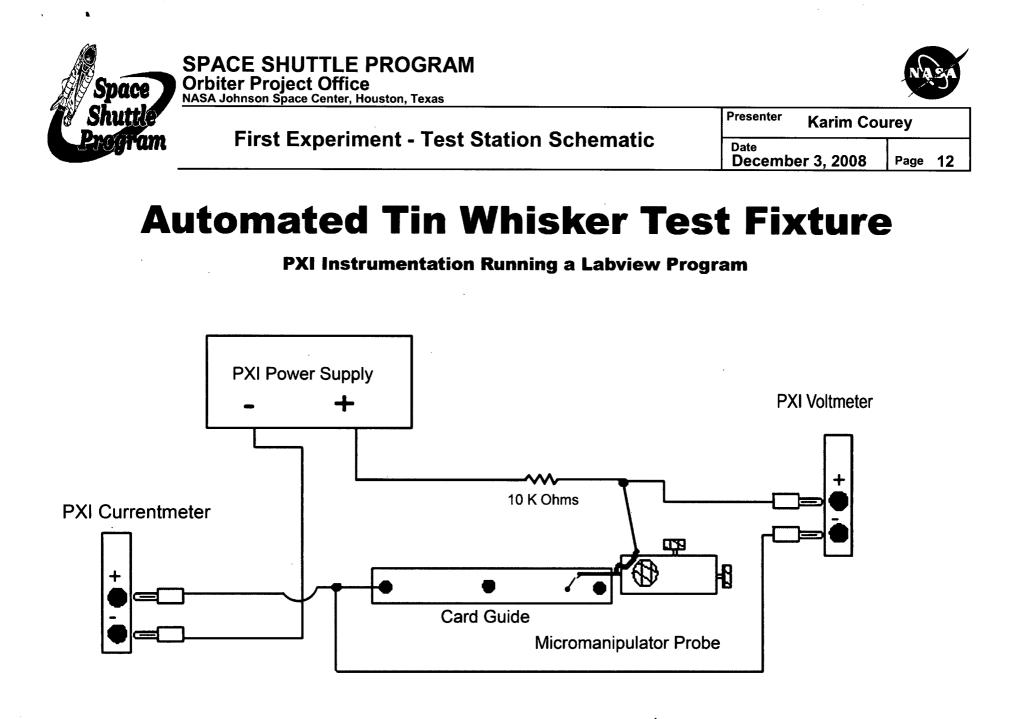




First Experiment – Methods Cont.

resenter	Karim Cou	irey	
Date Decembo	er 3 2008	Page	11

- Data Acquisition (DAQ) software was written using LabVIEW® to automate both the incrementing of power supply voltage changes as well as the gathering and recording of the voltage and current data for each of the tin whiskers
- Once contact was established, as determined with an optical microscope, the power supply voltage was increased from 0 to 45 volts direct current (vdc) in 0.1 vdc increments
- Validation of the automated test station was performed by substituting a calibrated resistor decade box for the micromanipulator, whisker and card guide



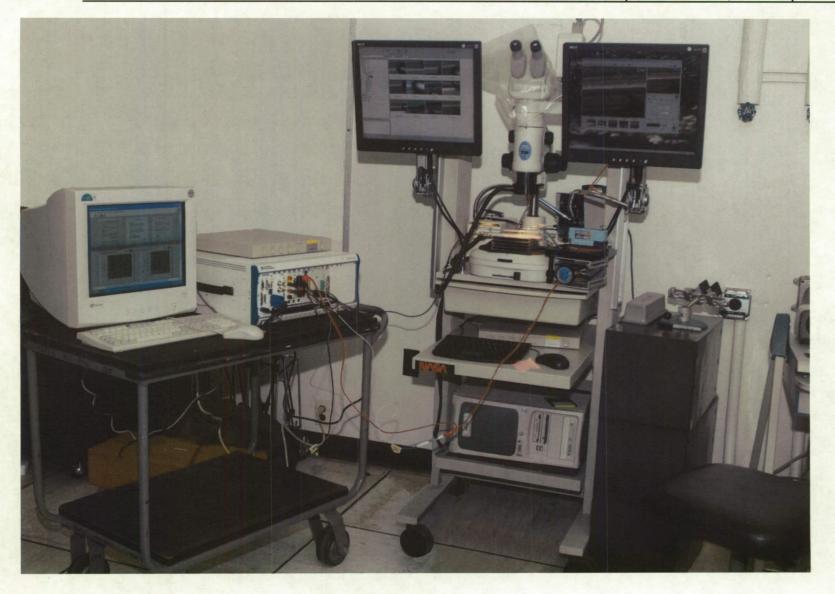


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First Experiment - Tin Whisker Test Station

Presenter Karim Courey Date December 3, 2008 Page 13







First Experiment – Results

Presenter Karim Courey
Date
December 3, 2008 Page 14

- The breakdown voltage for each whisker was determined from the graphs of recorded current and voltage data
- There were three different transition categories: Single, Multiple, and Multiple with intermittent contact





First Experiment – Results (Continued)

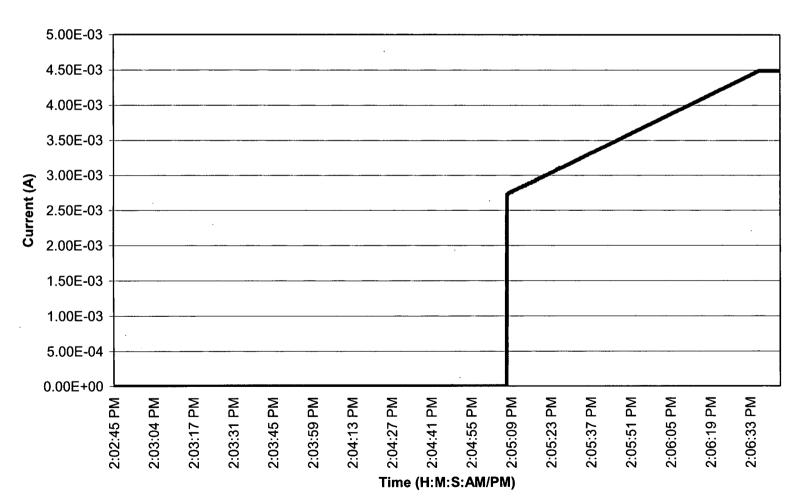
Date **December 3, 2008** Page 15

Karim Courey

Presenter

Tin Whisker Number 32 - Single Transition

Whisker Current







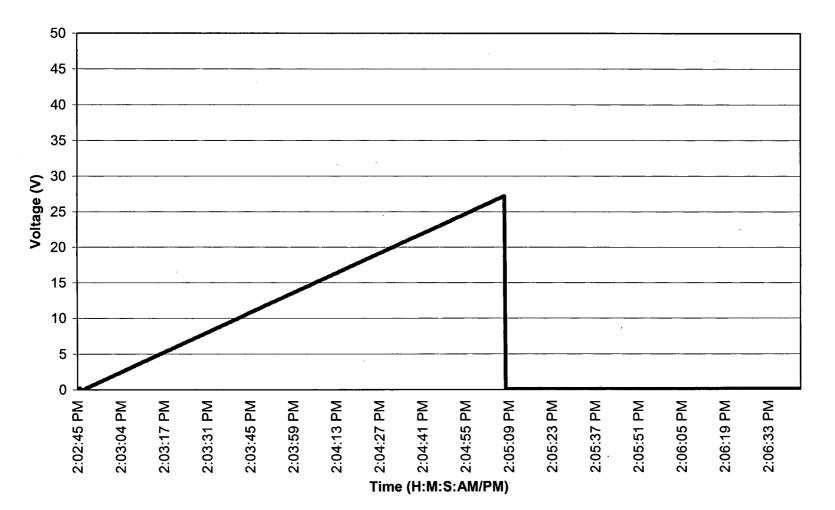
First Experiment – Results (Continued)

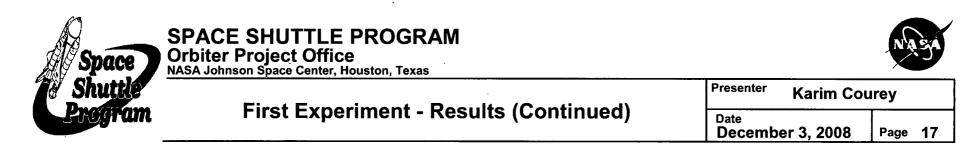
Date **December 3, 2008** Page 16

Karim Courey

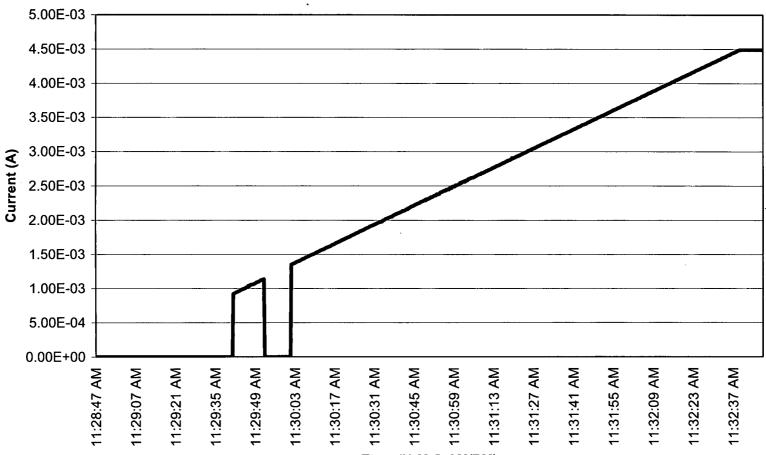
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Tin Whisker Number 32 - Single Transition Whisker Voltage





Tin Whisker Number 4 - Multiple Transition Points



Whisker Current

Time (H:M:S:AM/PM)





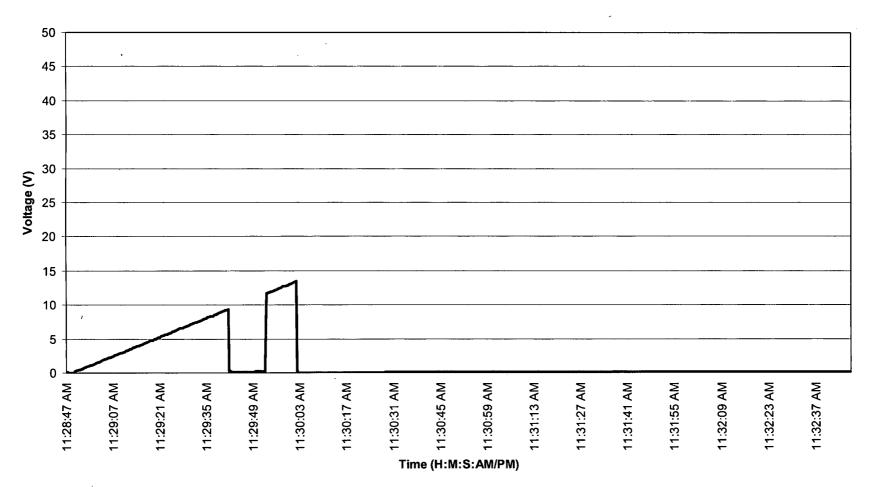
First Experiment - Results (Continued)

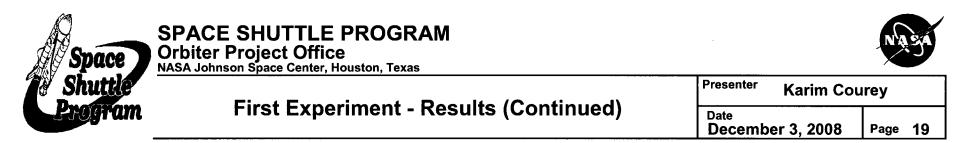
Karim Courey Date **December 3, 2008** Page 18

Presenter

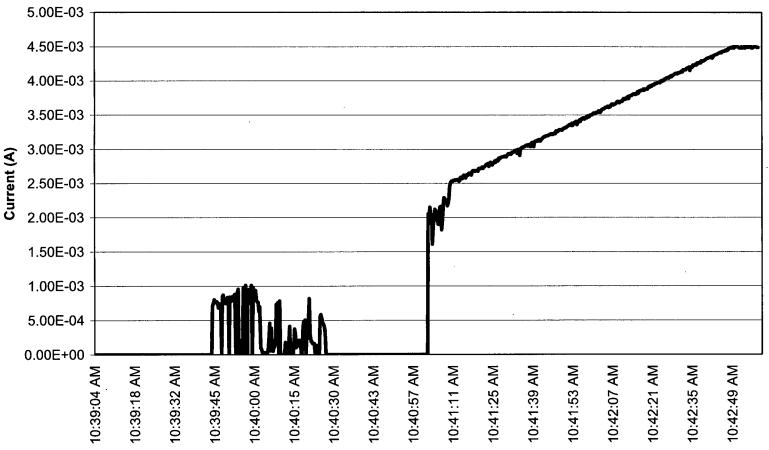
Tin Whisker Number 4 - Multiple Transition Points

Whisker Voltage



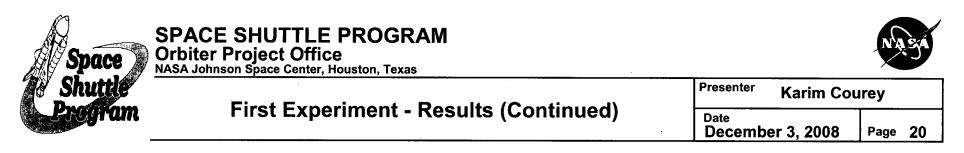


Tin Whisker Number 2 - Multiple Transition Points with Intermittent Contact



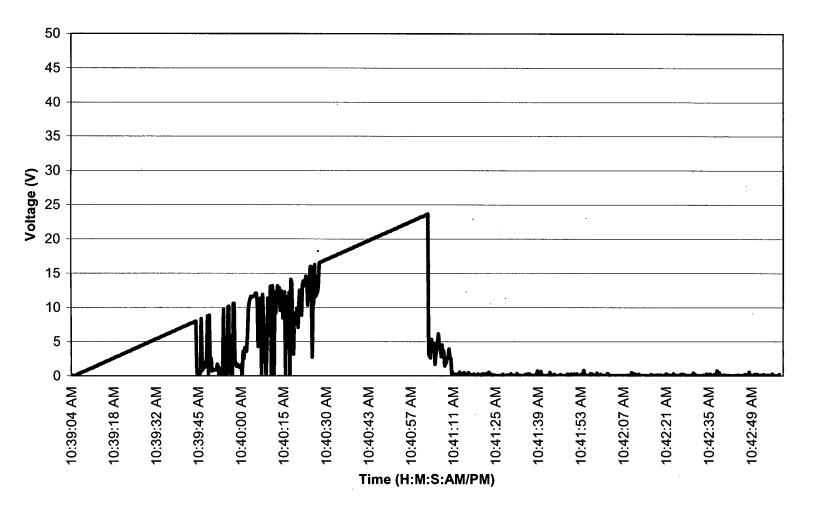
Whisker Current

Time (H:M:S:AM/PM)



Tin Whisker Number 2 - Multiple Transition Points with Intermittent Contact

Whisker Voltage







First Experiment - Results (Continued)

Presenter Karim Courey
Date
December 3, 2008
Page 21

- Although the software had originally been written to stop recording data after the film resistance broke down as determined by the change in whisker current, it was decided to run 35 whiskers to the full range of the test, 0 45 vdc, to observe their behavior
- An interesting benefit of running the test from 0 45 vdc for all of the whiskers was the opportunity to witness the difference in transitions
 - Single Transitions in 20 of 35 whiskers (~57%)
 - ➢ Multiple Transitions in 9 of 35 whiskers (~26%)
 - Multiple Transitions with intermittent contact in 6 of 35 whiskers (~17%)





First Experiment - Results (Continued)

December 3, 2008 Page 22

- Current Carrying Capacity
 - 33 of the 35 tin whiskers (~94%) tested conducted up to 4.5 mA
 - With a 10 KΩ current-limiting resistor in place, the test station was limited to a maximum of 4.5 mA at 45 Vdc
 - 2 of the 35 tin whiskers (~6%) only conducted up to 3.06 mA and 2.00 mA before metallic conduction ceased





First Experiment - Data Analysis

Date December 3, 2008 Page 23

Karim Courev

- Probability-Probability (P-P) plots were used to determine how well a specific model fits the observed data
- The Kolmogorov-Smirnov test was used to further analyze the best fit
- The EasyFit® distribution fitting software tested over 40 different distributions before selecting the 3-Parameter Inverse Gaussian as the best fit



First Experiment - Three Parameter Inverse Gaussian Distribution



Page 24

Karim Courey

Presenter

December 3, 2008

Date

• The values for the Three Parameter Inverse Gaussian Distribution are $\lambda = 31.977$, $\mu = 17.571$, $\gamma = -1.9716$. The Probability Density Function for the Three Parameter Inverse Gaussian Distribution is shown in the following equation:

$$f(x) = \sqrt{\frac{\lambda}{2\pi(x-\gamma)^3}} \exp\left(-\frac{\lambda(x-\gamma-\mu)^2}{2\mu^2(x-\gamma)}\right)$$

 The Cumulative Distribution Function for the Three Parameter Inverse Gaussian Distribution is shown in the following equation, where Φ () is the normal cumulative distribution function:

$$F(x) = \Phi\left(\sqrt{\frac{\lambda}{x-\gamma}}\left(\frac{x-\gamma}{\mu}-1\right)\right) + \Phi\left(-\sqrt{\frac{\lambda}{x-\gamma}}\left(\frac{x-\gamma}{\mu}+1\right)\right)\exp(2\lambda/\mu)$$



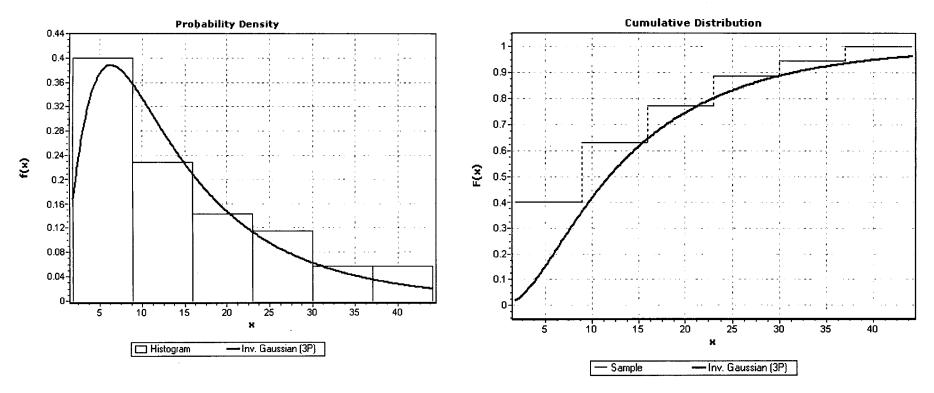


First Experiment - PDF and CDF

Karim Courey Date **December 3, 2008** Page 25

Presenter

Probability Density Function and Cumulative Distribution Function for the Three Parameter Inverse Gaussian Distribution



X = applied voltage



First Experiment - Film Resistance and the Oxide Layer



Karim Courey **December 3, 2008** Page 26

Presenter

Date

- One of the factors that contributes to film resistance is the oxide layer that forms on the tin whisker
- To study the oxide layer, it was necessary to section a few tin whiskers



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First Experiment - Whisker Materials Analysis



	Presenter Karim Courey		12	
100	Date Decemb	er 3, 2008	Page	27

- Whisker thickness: 2 to 5 µm
 - Analysis of whisker structure required high-resolution microscopy
- Conventional techniques for cross sectional microstructural and oxide thickness evaluation not adequate

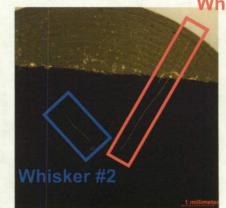






Image of penny at same magnification as whiskers #1 and #2

Whisker #1





First Experiment - Scanning Electron Microscopy

December 3, 2008 Page 28

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 A scanning electron microscope (SEM) was used for higher-magnification imaging and elemental analysis



Fluted appearance

Presenter

Date





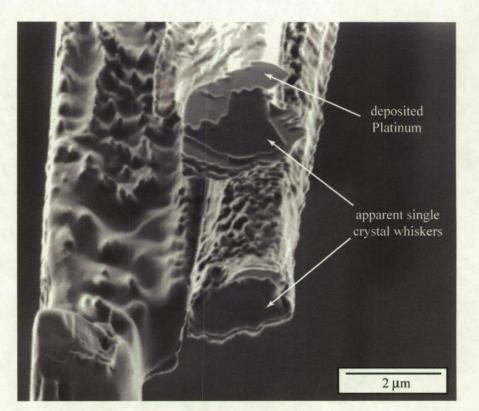
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First Experiment - Focused Ion Beam (FIB)	Presenter
Analysis	Date Decem

Date Karim Cou		urey	
	er 3, 2008	Page	29

- The gallium ion beam was used to mill away sufficient whisker material to obtain a cross section normal to the whisker's growth direction
- The FIB cross section facilitated the examination of the crystallographic orientations



FIB image of two as-sectioned tin whiskers that exhibited the expected single-crystal cross section. Image was taken 52° from horizontal (NASA/UCF)

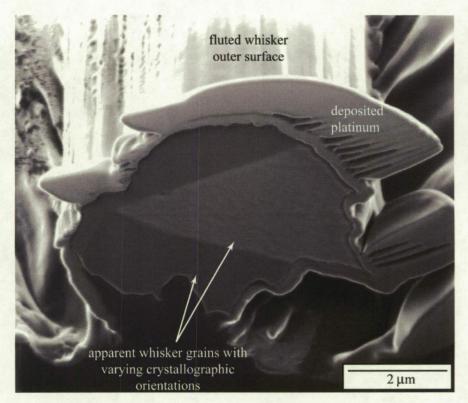


Nasa

First Experiment- Focused	lon	Beam
(FIB) Analysis		

Presenter	Karim Co	urey	-
Date Decemb	er 3, 2008	Page	30

- One of the three tin whiskers studied here was found with what appeared to be grains with varying crystallographic orientations
 - While polycrystalline tin whiskers have been seen before, in the majority of literature tin whiskers were described as single crystals



FIB image of as-sectioned Tin whisker shows apparent variation in grain orientation within the cross-section. Image was taken at a 52° angle from horizontal (NASA/UCF)



First Experiment- Focused Ion Beam (FIB) Analysis



Date		
December 3, 2008	Page	31

Karim Courey

- We were not able to identify the oxide layer as originally planned with the techniques and equipment that were used
- However, we were able to find what appeared to be a rare polycrystalline tin whisker





Second Experiment

Date December 3, 2008	Page	32
	•	

Karim Courey

- The following improvements were added to the second experiment
 - ➤ A larger sample size of 200 whiskers
 - Experimental process improvements
 - Transmission Electron Microscopy (TEM) was used to determine if the tin whisker examined in the first experiment was truly polycrystalline
 - FIB cross-section of the card guides was used to verify whether the tin finish was bright tin or matte tin.
- The second experiment has been completed and the results will be presented in our next KEA presentation





 Presenter
 Karim Courey

 Date
 December 3, 2008
 Page
 33

- Limitations of the first experiment included:
 - The number of conducting surfaces
 - The difference and variation between force applied by gravity and the force applied by the micromanipulator probe
 - Sample size (35 Tin Whiskers)





Conclu	ision
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- In the first experiment, an empirical model to quantify the probability of occurrence of an electrical short circuit from tin whiskers as a function of voltage was developed
- This model can be used to improve existing risk simulation models
- FIB images of a tin whisker show an apparent polycrystalline structure on one of the three whiskers studied





Future Work

Date December 3, 2008 Page 35

Karim Courey

- Effect of the following variables on tin whisker shorting:
 - > Applied Pressure
 - ➤ Acceleration
 - > Whisker Shape
 - Oxidation Layer Thickness
- Free Whisker Test
- Metal Vapor Arcing
- Fusing Current





Acknowledgments

Date December 3, 2008 Pa

Presenter

Karim Courey

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- Mike Madden of United Space Alliance





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Kariin Courey			
Date Decembe	er 3, 2008	Page	37

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