AN INVESTIGATION OF THE ELECTRICAL SHORT CIRCUIT CHARACTERISTICS OF TIN WHISKERS

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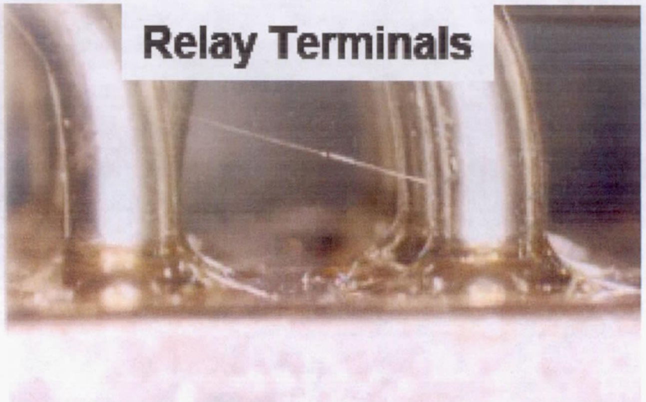
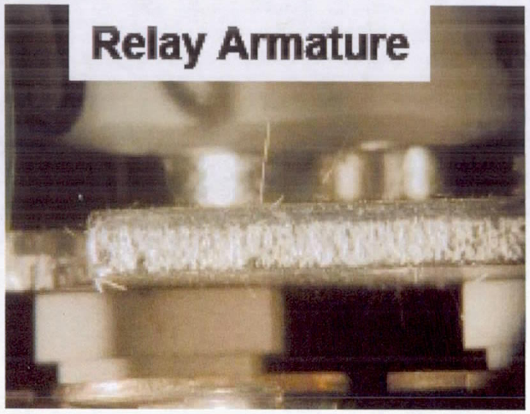
Outline

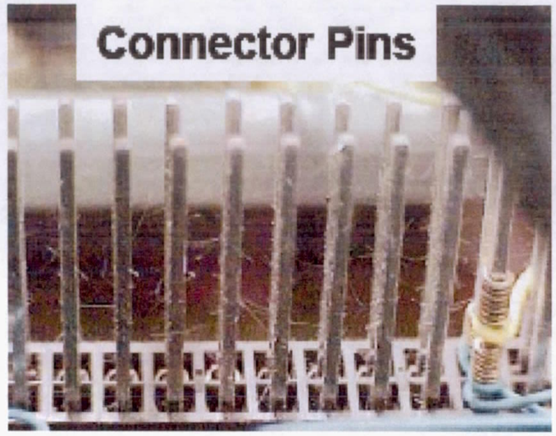
- Tin whisker phenomenon
- Risk models
- Contact resistance
- Objective
- The first experiment
- The second experiment
- Comparison of results
- Limitations
- Conclusion
- Future work

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

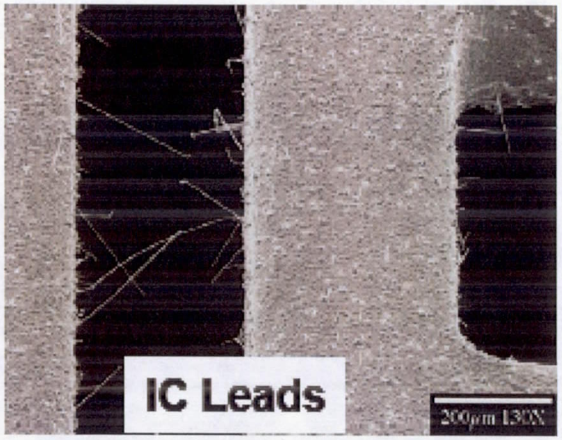
Optical Microscopy

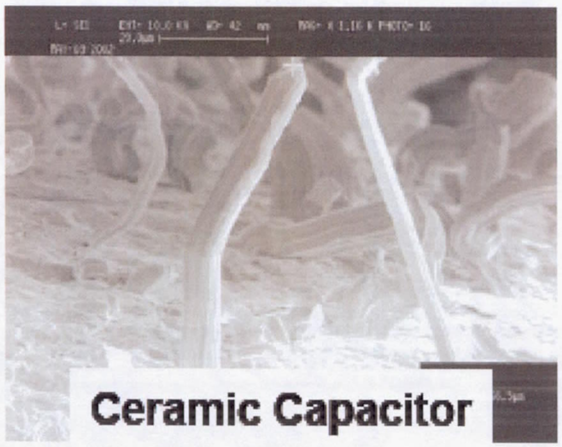






Scanning Electron Microscopy





Current Assumption in Risk Models

- 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 has been made because the probability of an electrical short from free tin whiskers has not yet been determined

Contact 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
- Contact resistance is the sum of the constriction resistance and the film resistance (Source: R. Holm & Holm, 1967)

Objective

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

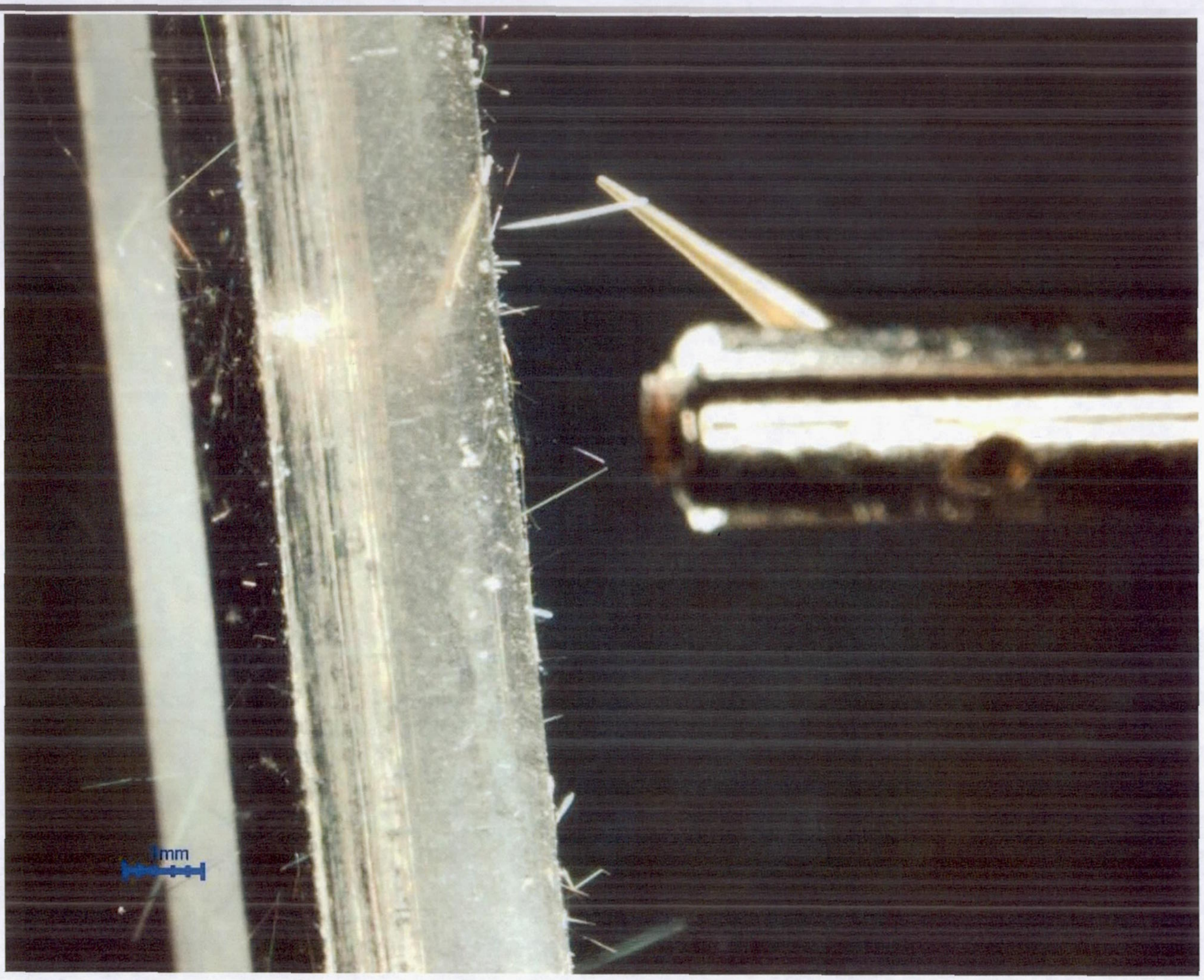
First Experiment - Methods

- The voltage level at the transition to metallic conduction current, is the voltage level at which the contact resistance breaks down
- To determine the break down voltage a micromanipulator probe was brought in contact with the side of a tin whisker growing from a tin-plated beryllium copper card guide

First Experiment – Methods Cont.

- 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 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

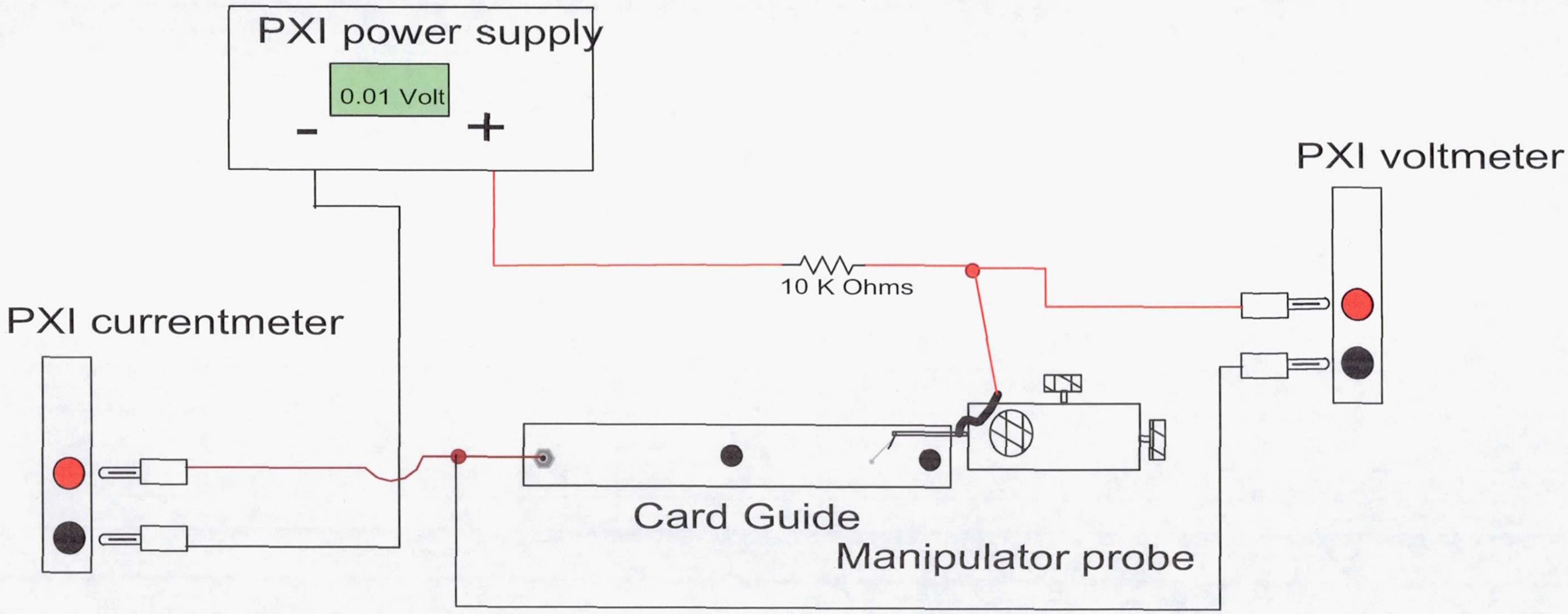
Tin Whiskers



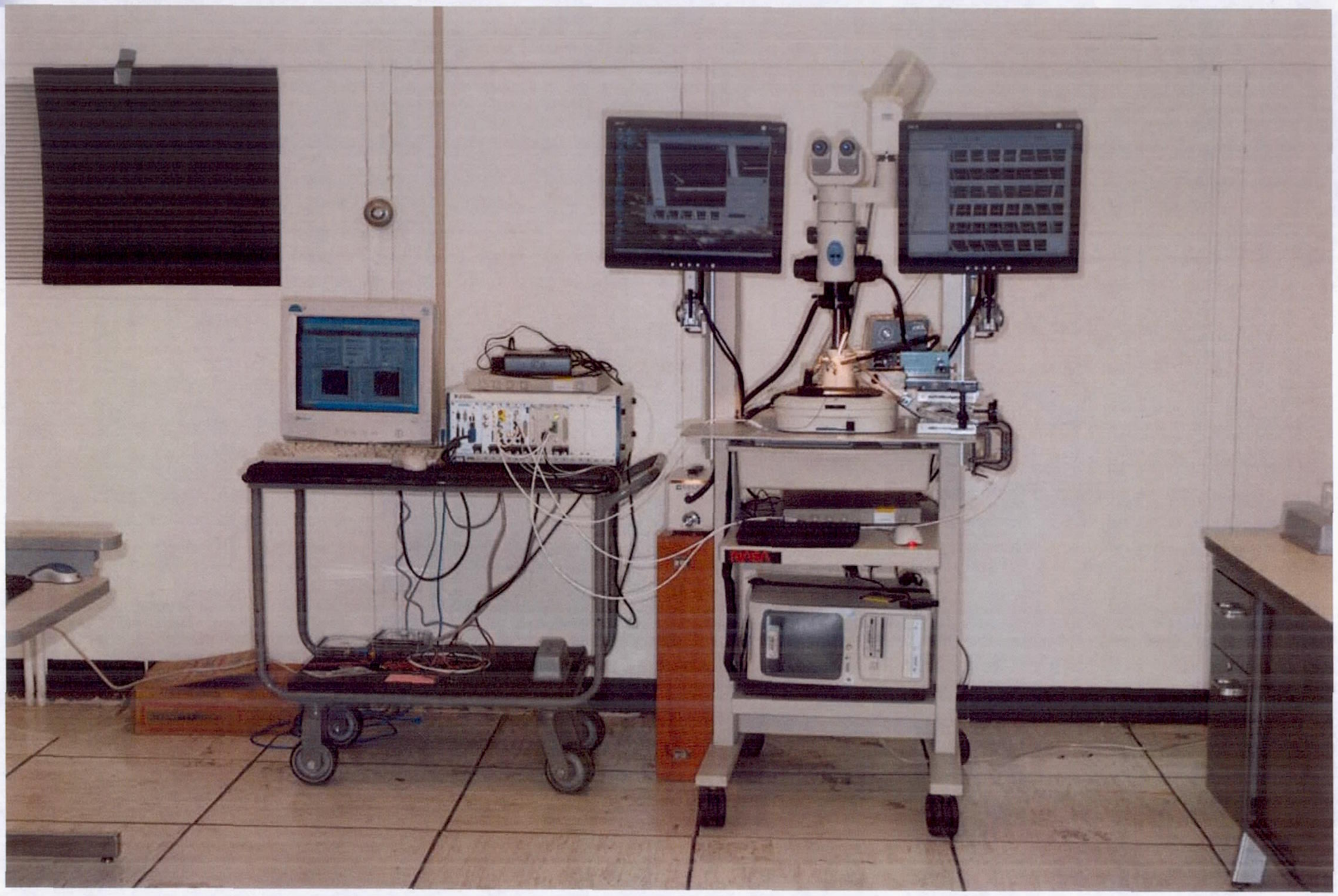
Test Station Schematic

Automated Tin Whisker Test Fixture

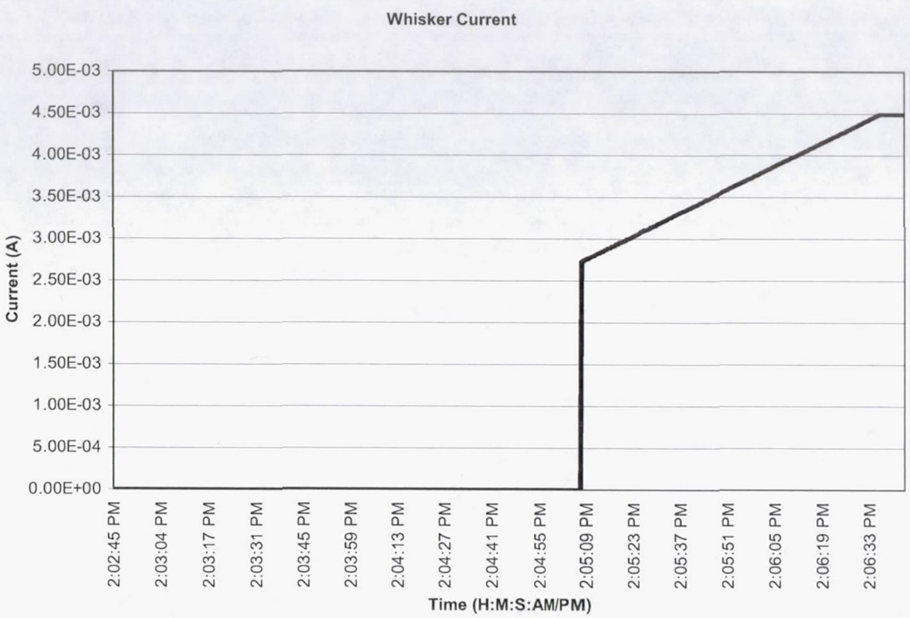
PXI instrumentation running a Labview program

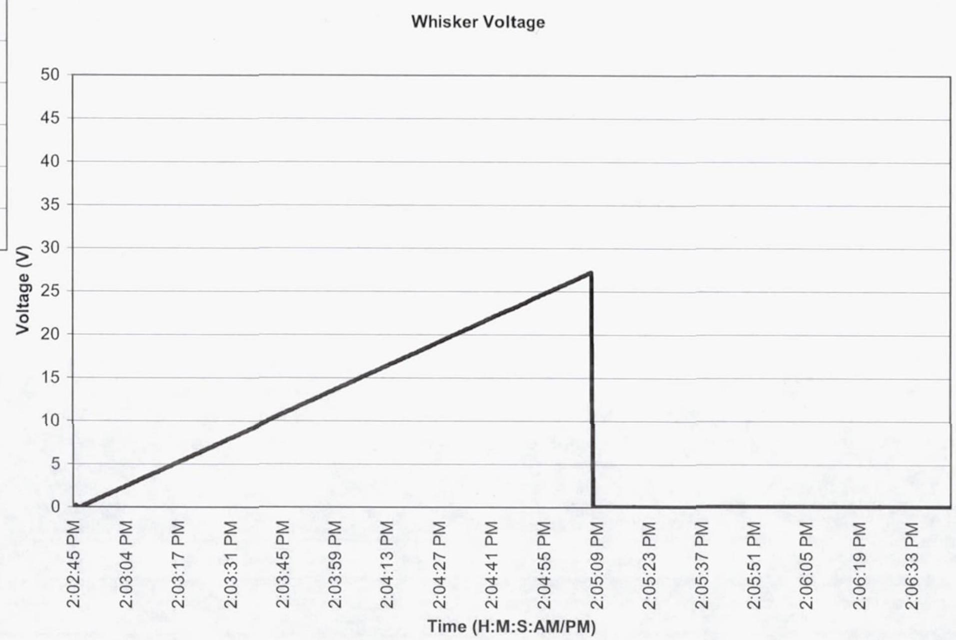


Tin Whisker Test Station



First Experiment - Results Whisker Current and Voltage - Single Transition Point





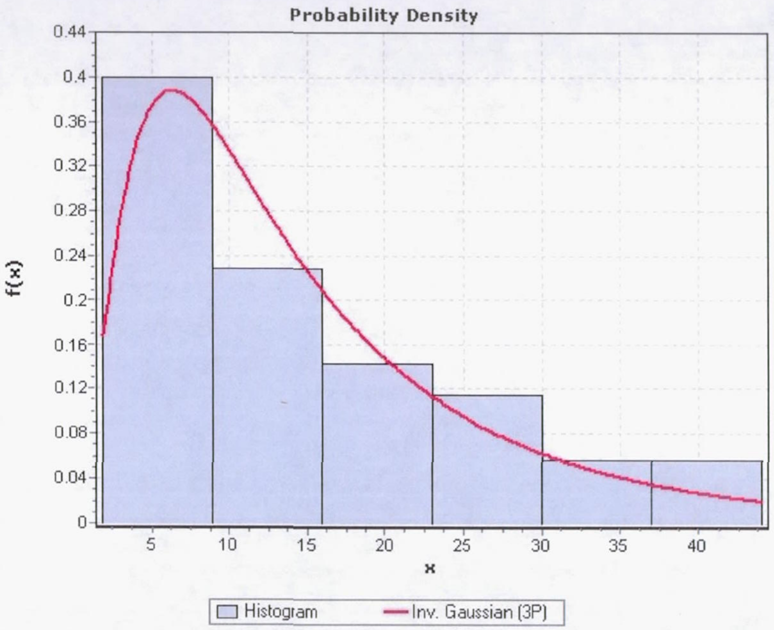
First Experiment – Results Cont.

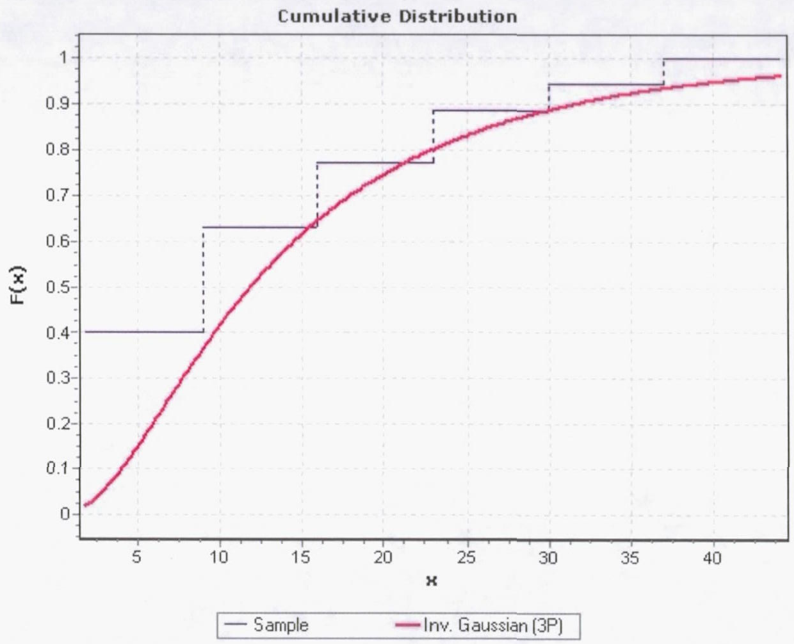
- The breakdown voltage for each whisker was determined from the graphs and recorded current and voltage data
- There were three different transition categories: Single, Multiple, and Multiple with intermittent contact

First Experiment - Data Analysis

- 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 - PDF and CDF

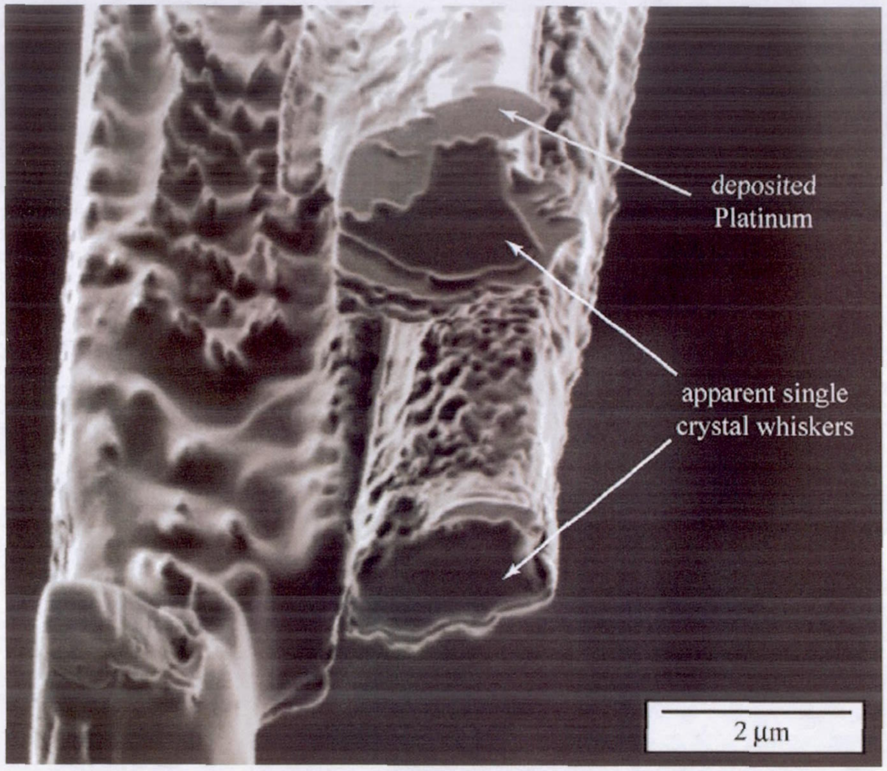




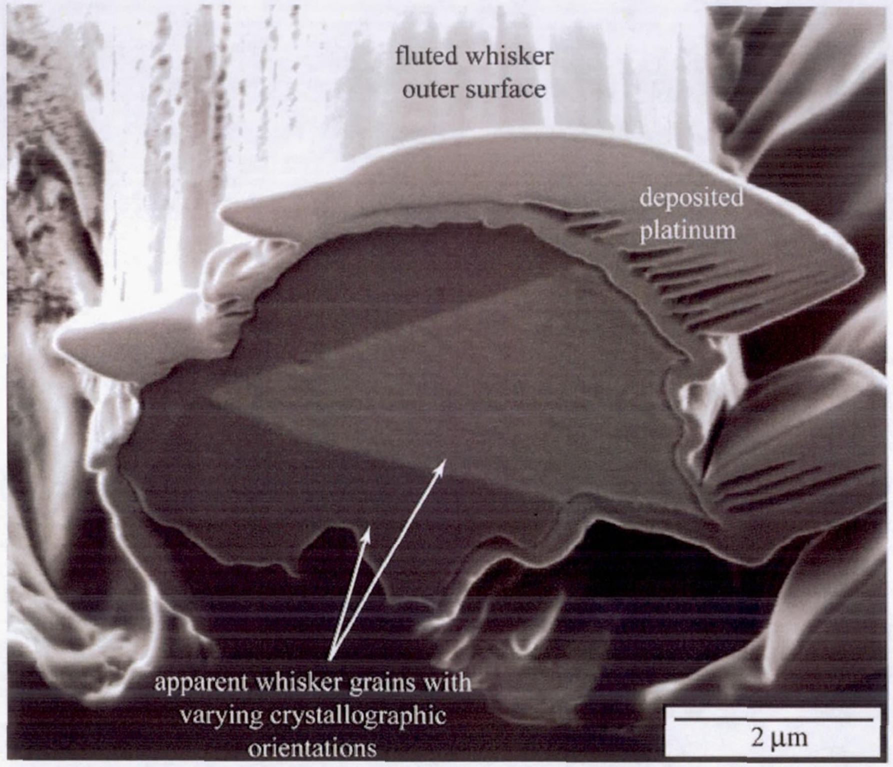
First Experiment - Focused Ion Beam (FIB) Analysis

- The Gallium ion beam was used to mill away whisker material until the desired region of interest to obtain a cross section normal to the whisker's growth direction
- The FIB cross section facilitated the examination of the crystallographic orientations
- In the majority of literature, tin whiskers were described as single crystals

Focused Ion Beam (FIB) Analysis



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



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).

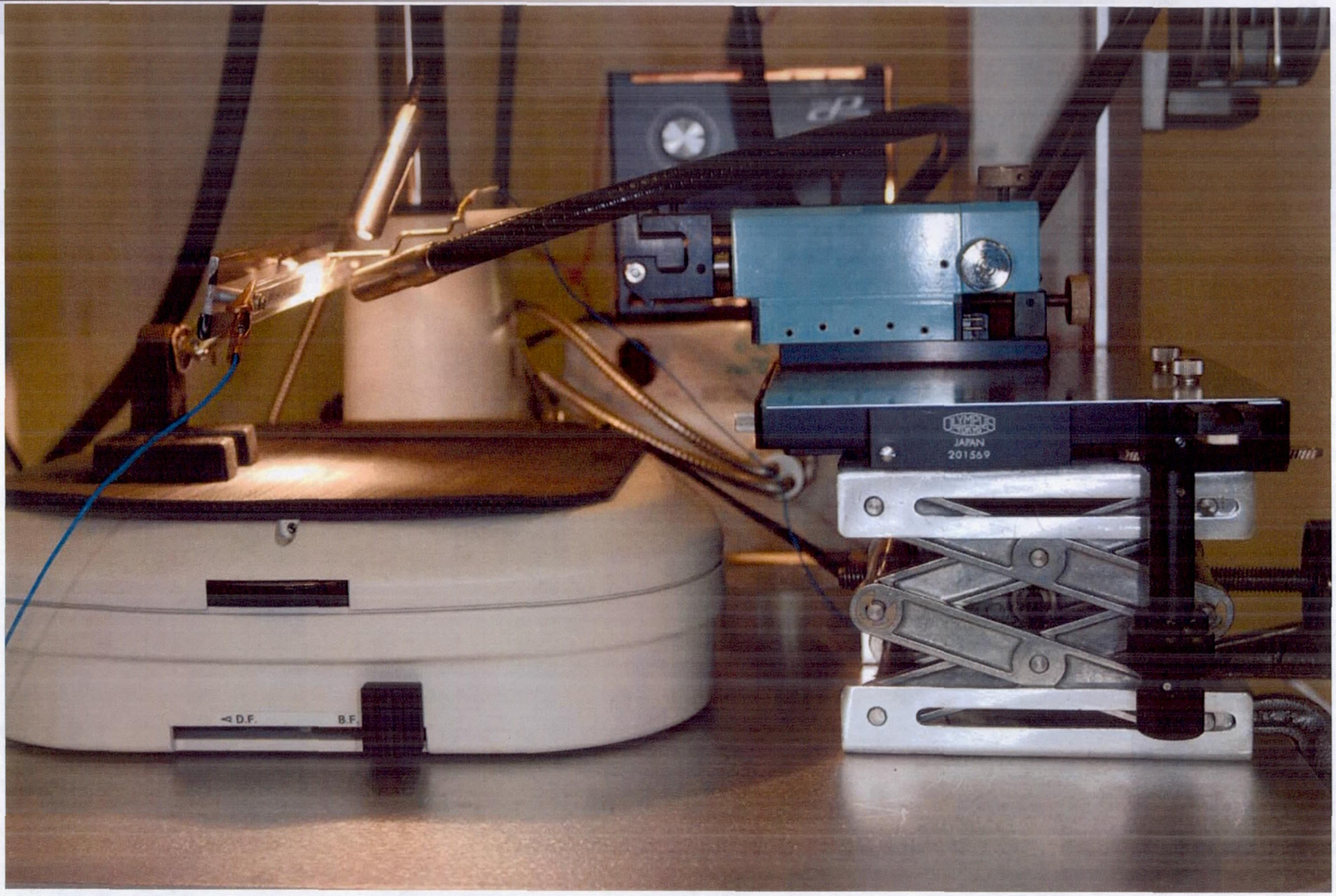
Second Experiment - Improvements

- The following improvements were added to the second experiment
  - A larger sample size of 200 whiskers
  - Random card guide selection
  - Improved grounding
  - Added shielding to wires
  - Gold plated tungsten micromanipulator tips
  - Minimize applied pressure

Second Experiment – Improvements (Continued)

- Probe cleaned at regular intervals
- Software will be written to select the breakdown voltages to ensure consistency
- Fabricated and extension platform for microscope
- Fabricated a ferrous metal top for lab jack
- Fabricated a card guide holder for solderer's helper
- Air duct diverters

Second Experiment - Test Station Close up



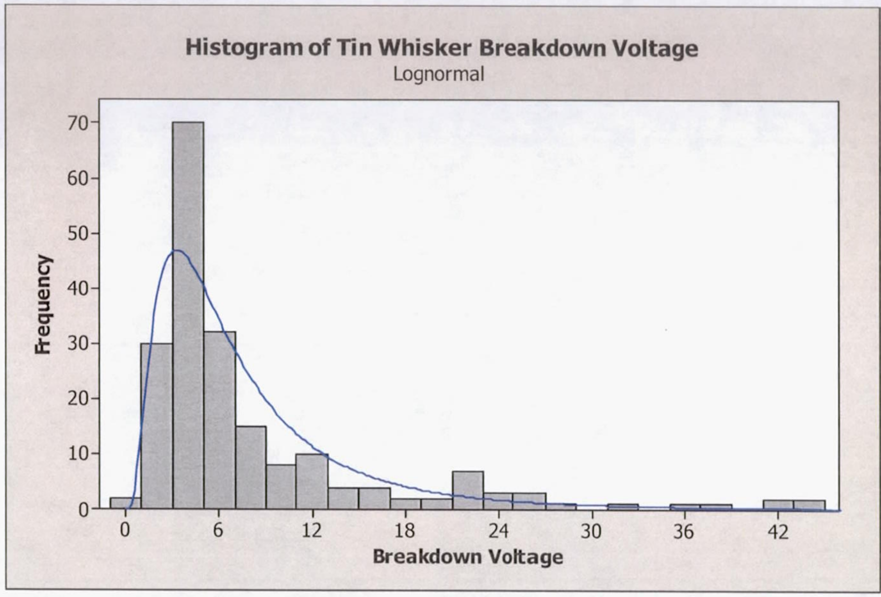
Second Experiment - Data Analysis

- Minitab was used instead of EasyFit since it could handle censored data
- Probability-Probability (P-P) plots were used to determine how well a specific model fits the observed data
- The Anderson-Darling test and the Correlation Coefficient were used to further analyze the best fit
- The Minitab distribution tested 11 different distributions. The lognormal was selected as the best fit

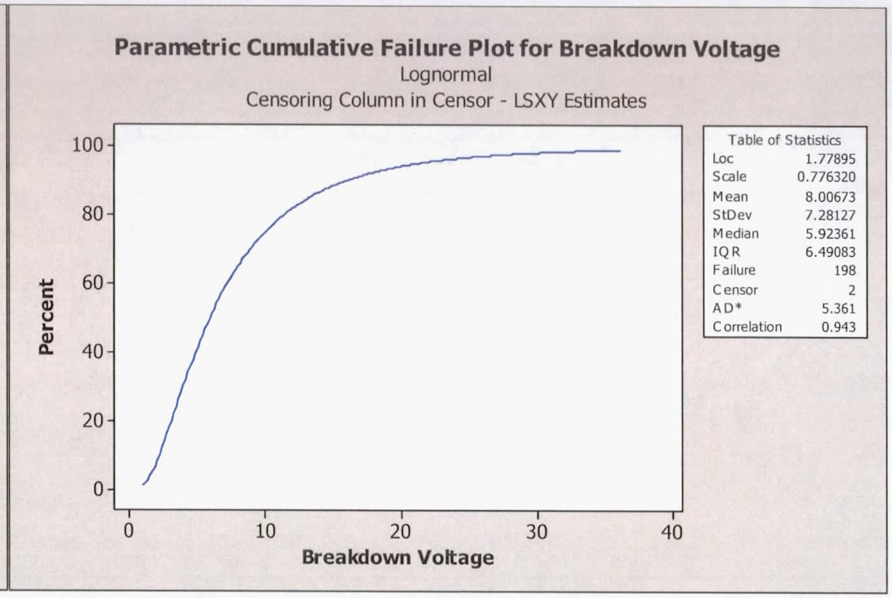
Second Experiment - Data Analysis

- The effect of outliers was examined
- Residual Plots
- ANOVA- examined possible sources of variability such as the differences across the LRUs, card guides, top and bottom of card guides
- Applicability of two best fitting distributions – loglogistic and lognormal
- Hazard Plot

Second Experiment-DPF and CDF



Histogram tin whisker breakdown voltages with lognormal distribution



Tin whisker CDF of breakdown voltage for lognormal distribution

Comparison of results Characteristics

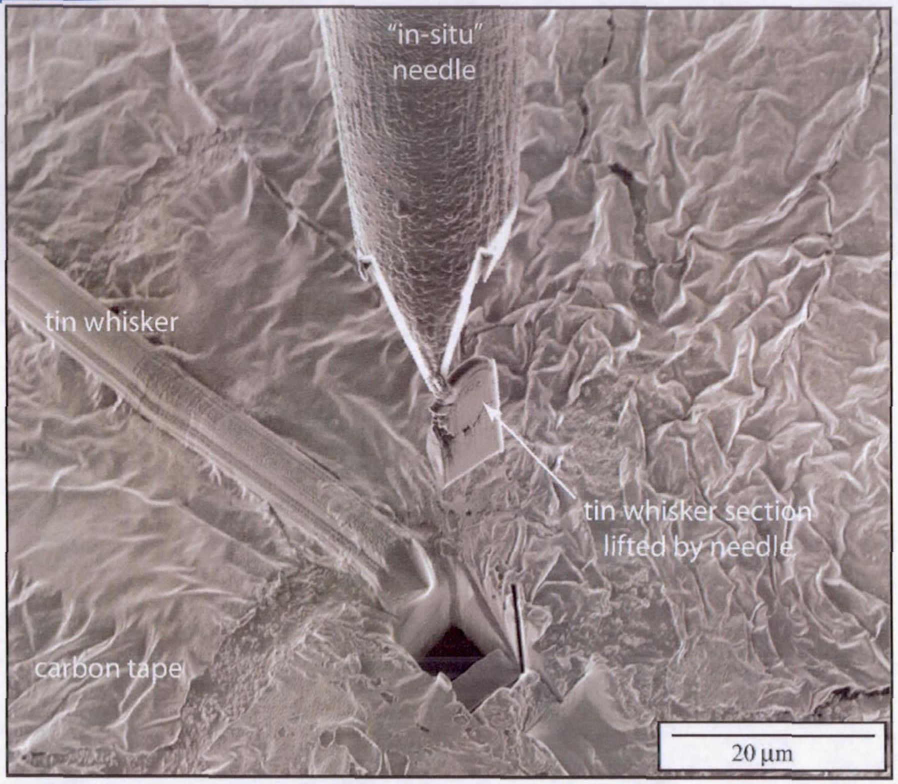
- First Experiment – mean voltage were a short will occur is 15.59 vdc, median tin whisker breakdown voltage is 11.89
- Second Experiment - mean voltage were a short will occur is 8.01 vdc, median tin whisker breakdown voltage is 5.92 vdc
- Inverse Gaussian and lognormal are similar in shape
- Analyzed data from first experiment using Minitab and lognormal was best fit – both experiments are consistent
- First Experiment - 33 of the 35 tin whiskers tested conducted up to 4.5 mA
- Second Experiment – 158 of the 200 tin whiskers tested conducted up to 4.5 mA

Second Experiment – Transmission Electron Microscopy

- A focused ion beam (FIB) was used to prepare a sample for TEM examination

- TEM analysis determined that the tin whisker examined in the first experiment was truly polycrystalline

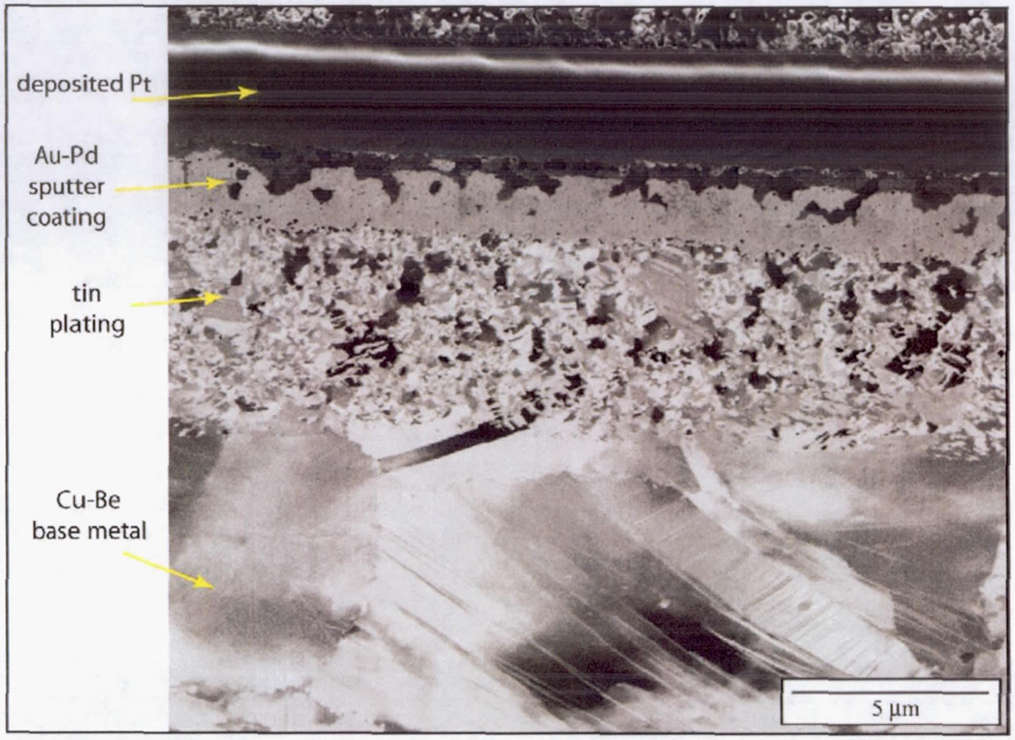
FIB Preparation and TEM Examination



FIB image showing removal of tin whisker section using the in-situ needle

TEM Image of the polycrystalline tin whisker and nomenclature used to identify the various grains (A-D)

Card Guide FIB Cross-section



FIB ion channeling image of card guide 16 (ATVC S/N 31) cross section showing the distinct layers studied: the expected Cu-Be substrate with larger grains, the Sn plating with nm-sized grains, the Au-Pd sputter coating and finally the deposited Pt used to protect the region during FIB (NASA/UCF)

Experiment Limitations

- Limitations of the this experiment included:
  - The number of conducting surfaces
  - The difference and variation between force applied by gravity and the force applied by the micromanipulator probe
  - Power supply range 0-45 vdc
  - Sample size
  - Whisker characteristics (thickness, length, shape)
  - Oxide layer thickness

Conclusion

- In this 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 and TEM images of a tin whisker confirm the rare polycrystalline structure on one of the three whiskers studied

- FIB cross-section of the card guides verified that the tin finish was bright tin

- *NOTE: Please refer to dissertation for the acknowledgements and references*

Future Work

- 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