Evaluation of *Faradayic*® Plating Method for Controlling Tin Whisker Growth

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Project Objectives:

- To study the effect of electroplating parameters on the propensity of tin whisker growth
- To determine if graded stress coatings help mitigate whisker formation in pure tin electrodeposits
- To compare Faraday's electrically mediated electrodeposition process with a commercially-available matte tin electrodeposition process

What Causes Tin Whiskers?

Plating Chemistry
- Pure Sn Most Prone
- Some Alloys (Sn-Cu, Sn-Bi, rarely Sn-Pb)
- Use of "Brighteners"
- Incorporated Hydrogen
- Codeposited Carbon

Substrate
- Material (Brass, Cu, Alloy 42, Steel, etc.)
- Substrate Stress (Stamped, Etched, Annealed)
- Intermetallic Compound Formation
- Substrate Element Diffusivity into Sn

Plating Process
- High Current Density
- Bath Temperature
- Bath Agitation

Deposit Characteristics
- Grain Size/Shape
- Crystal Orientation
- Deposit Thickness
- Sn Oxide Formation

Environment
- Temperature
- Temperature Cycling (CTE Mismatch)
- Humidity (Oxidation, Corrosion)
- Applied External Stress
  (Fasteners, bending, scratches)

In General, Factors that Increase STRESS In Tin Deposit

GREATER WHISKER PROPENSITY

HOWEVER….

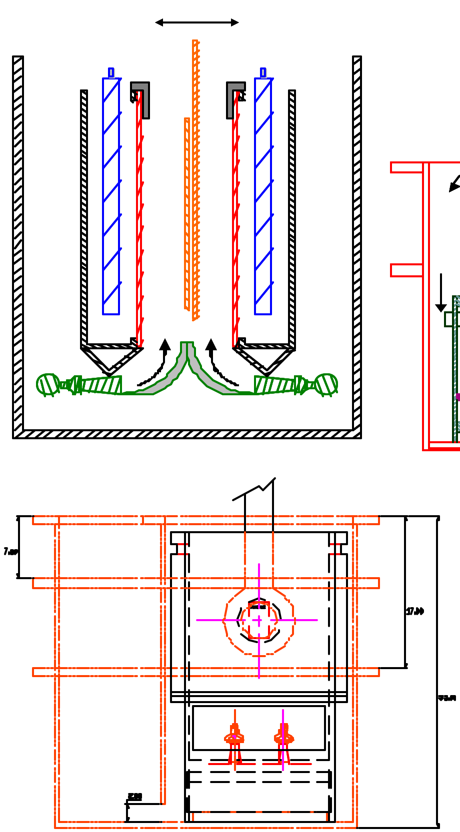
Many Experiments Show Contradictory Results For These Factors

*** Courtesy of Jay Brusse, NASA GSFC**

Faraday Technology Inc.,

- Faraday Technology Inc., utilizes an electrically mediated deposition process for pure tin.
- This process relies on non-steady state electric fields to control physical properties of the deposited tin, such as grain size, grain structure, surface finish and stress type/magnitude.
- The process is currently still under development. The initial work was completed in a Ph. I SBIR contract sponsored by the National Science Foundation.
- In the current work, Faraday submitted coupons of graded stress type/magnitude along with a pure tensile stress deposits to evaluate whisker propensity.

Key Factors for Uniform Plating



Cell Geometry

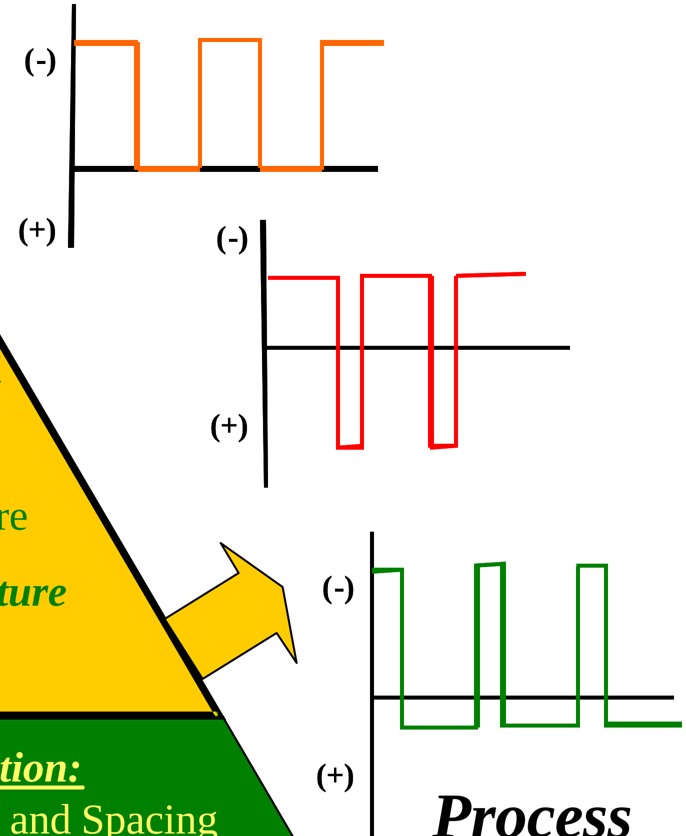
<u>*Secondary and Tertiary Current Distribution:*</u>
Chemistry/Waveform Parameters, Temperature

→ Throwing Power, Feature Size/Shape

<u>*Primary Current Distribution:*</u>
Agitation, Anode-Cathode Design and Spacing

→Panel Uniformity

→Must be Optimized Before Implementing Process



Process Parameters

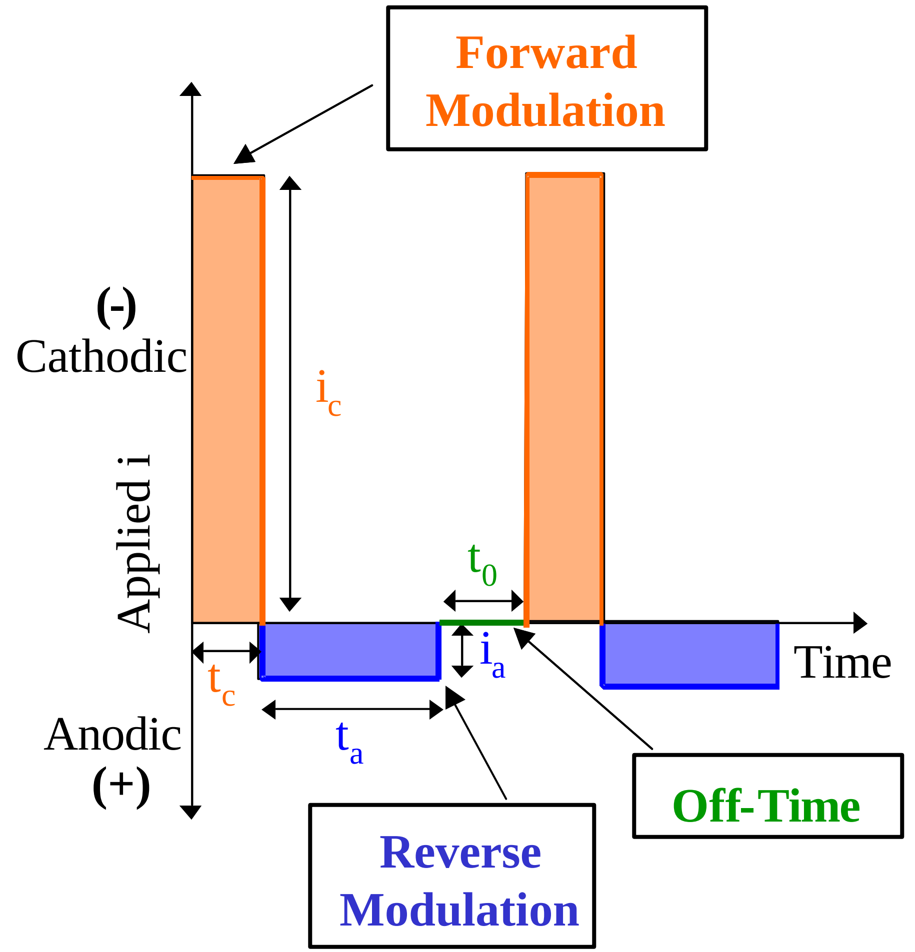
Pulse/Pulse-Reverse Processes

Cathodic Modulation – *Metallization*

- Tin reduction
- Potential hydrogen evolution → *surface defects, compressive tin deposit*

Anodic Modulation – *Leveling*

- Tin oxidation
- Replenishment of tin ions in direct vicinity of cathode for subsequent cathodic pulses.

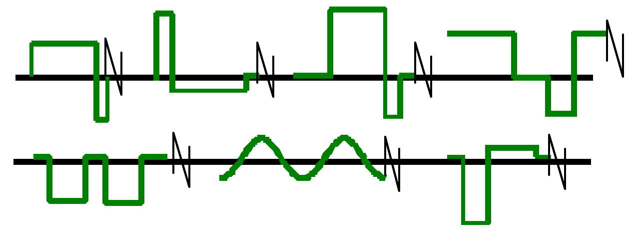


Off-time – *No current*

- Replenishment of tin ions in direct vicinity of cathode for subsequent cathodic modulations.

Benefits of Pulse/Pulse Reverse Plating

By properly tailoring waveform parameters for a specific process, the following benefits may be realized (in comparison to DC plating):



1. Enhancement of ***mass transport***

2. Control of ***current distribution***

3. Control of ***nucleation*** and therefore crystal structure/grain size of the deposit, which dictates deposit properties

4. Control of alloy composition

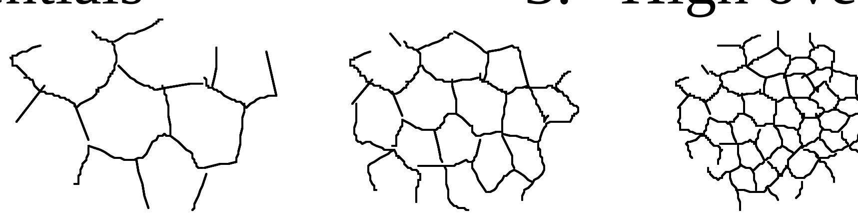
5. Elimination of hydrogen effects (i.e. hydrogen embrittlement may be eliminated).

Crystallization in Pulse/Pulse-Reverse Processes

Crystallization is dependent on:

- Surface Diffusion Rates
- Adatom/Adion Population at Cathode Surface
- Overpotential

<u>Conditions for Crystal Growth</u>	**vs.**	<u>Conditions for Nucleation</u>
1. High surface diffusion rates		1. Low surface diffusion rates
2. Low population of adatoms		2. High population of adatoms
3. Low overpotentials		3. High overpotentials



DC ← → **PC/PRC**

Faradayic® Tin Plating Process

- Tin whiskers ***may*** be mitigated or completely eliminated by controlling the physical properties of the electrodeposit.

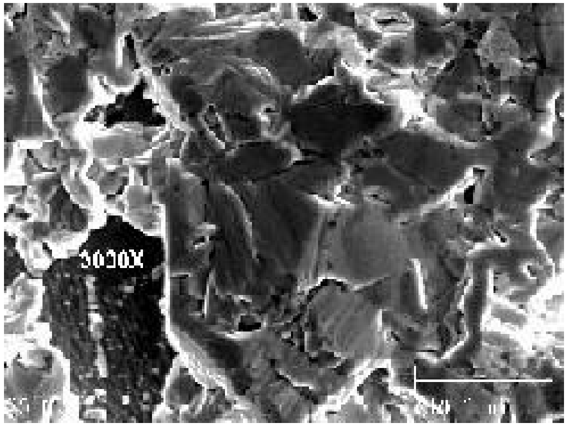
- Pure tin electroplating utilizing pulse/pulse-reverse process allows for the control of:

  - Stress Type (tensile vs. compressive)/Magnitude
  - Desired Grain Size (1-8 μm)
  - Desired Grain Structure
  - Surface Finish (matte vs. bright)
  - Surface Defects (pores, etc.)

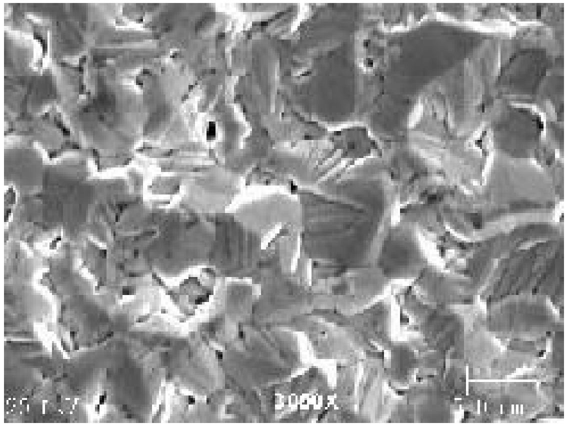
Phase I Feasibility Results

Effect of Waveform Parameters on Topography - SEM

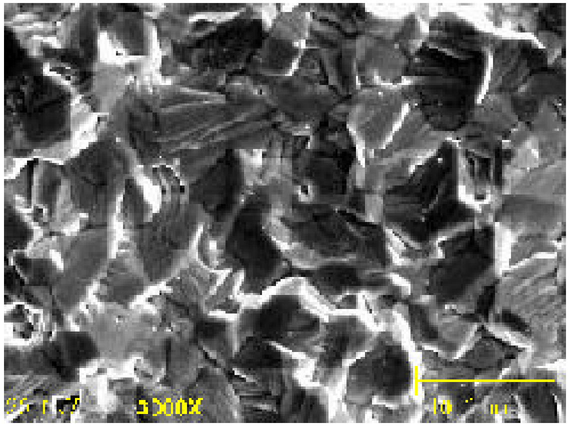
DC: High Compressive



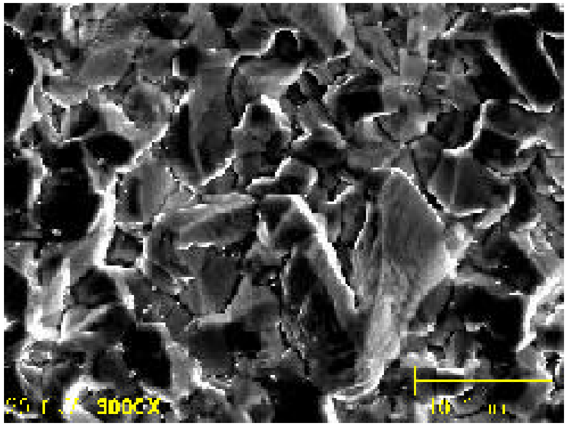
PC: High Tensile



PRC: Low Compressive

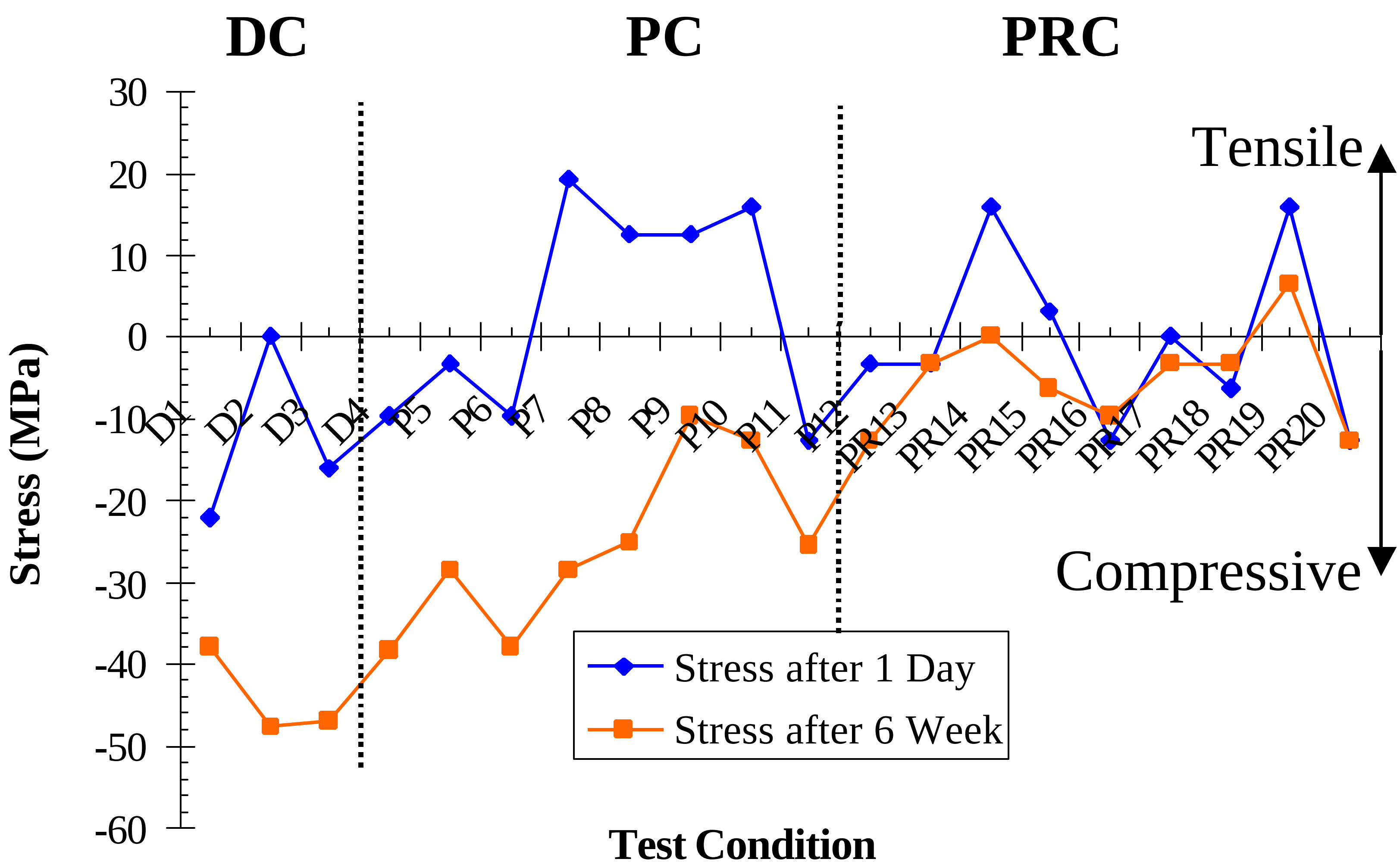


PRC: Low Tensile



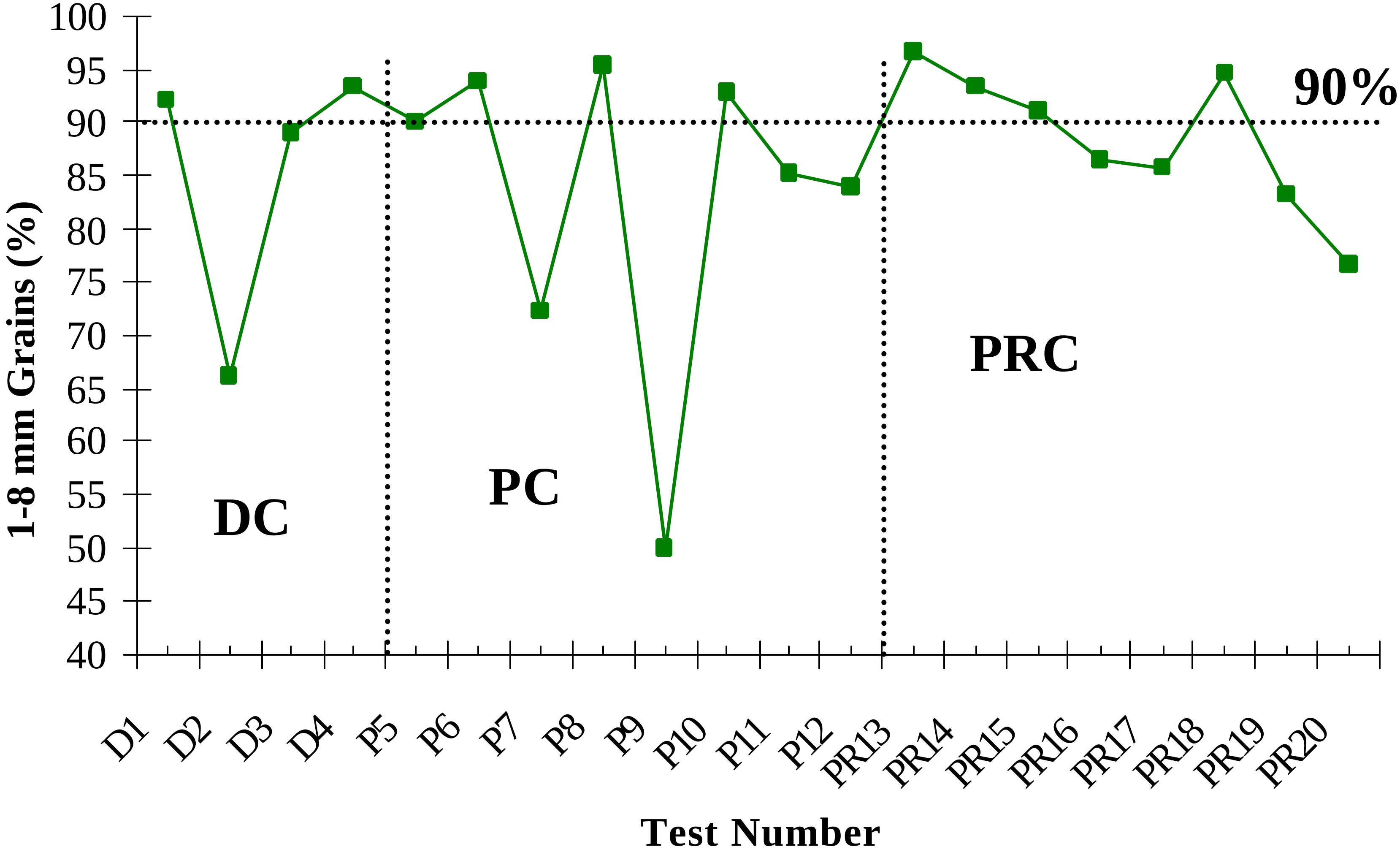
Phase I Feasibility Results

Effect of electrically mediated waveforms on internal stress



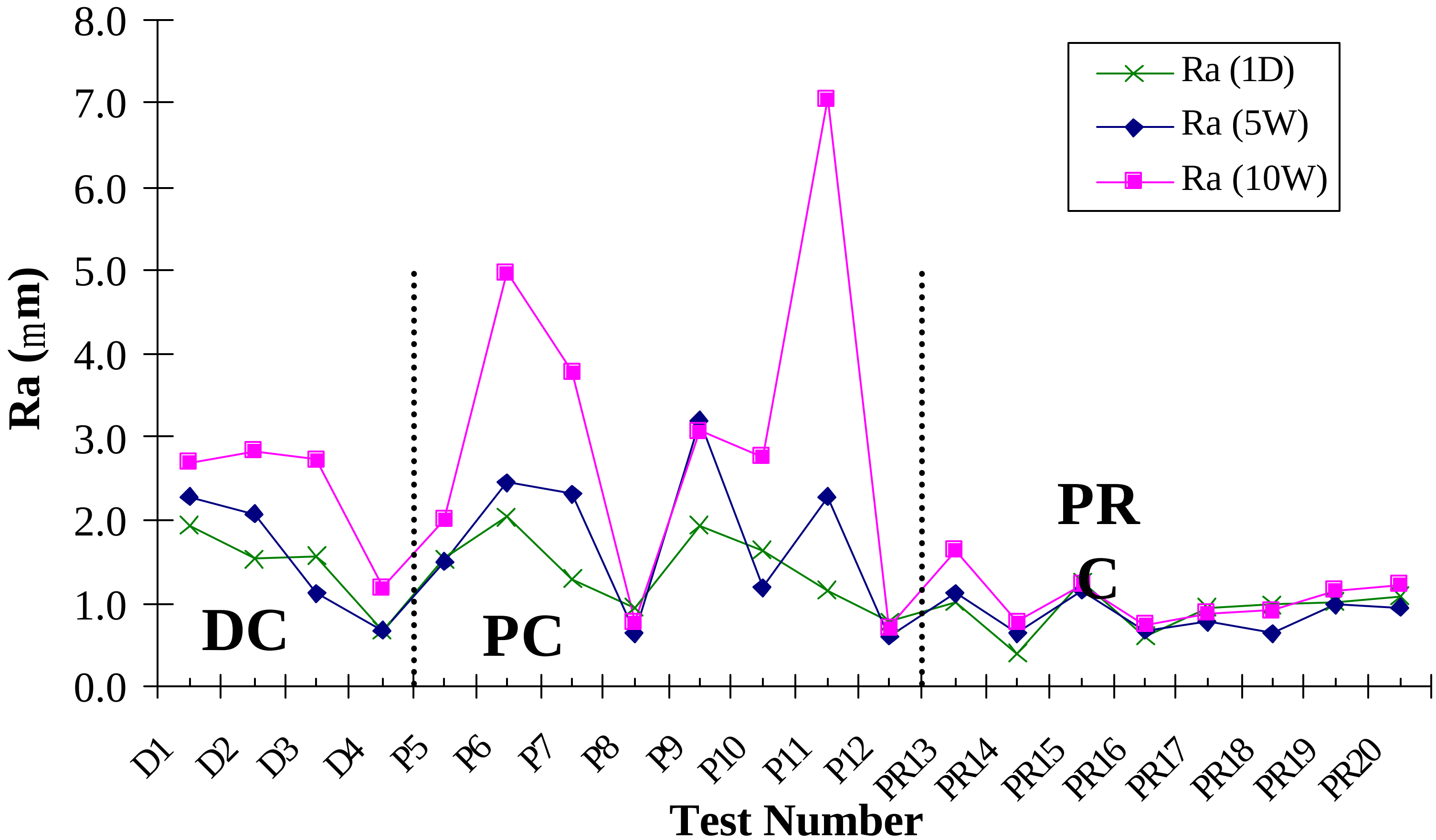
Phase I Feasibility Results

Percentage of grains in the desired 1-8 mm range



Phase I Feasibility Results

Surface Roughness as a Function of Aging Time for Various Electroplating Processes



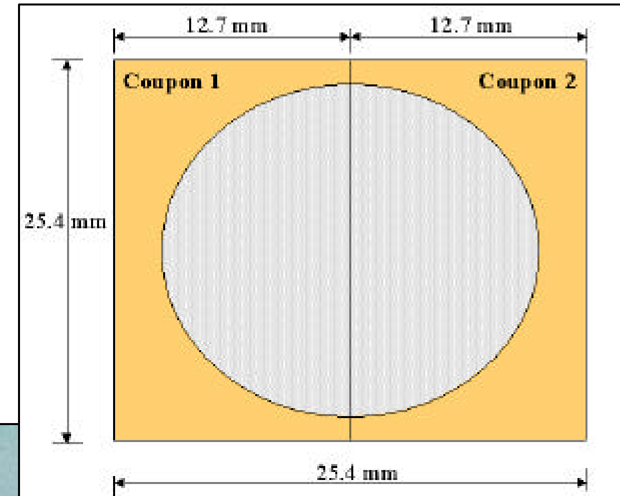
JEDEC Test Conditions [1]

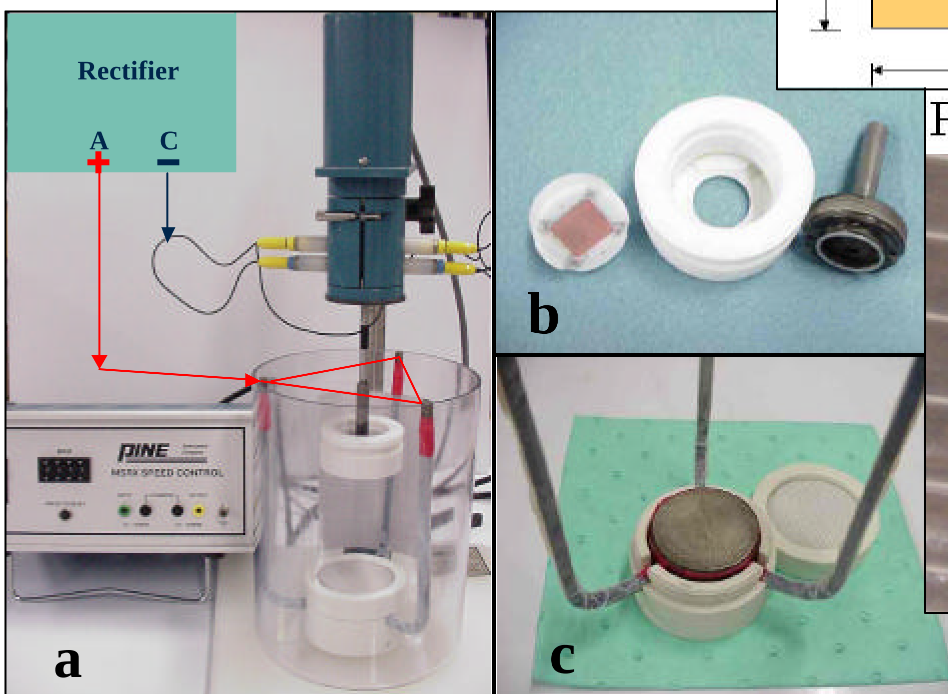
Stress Type	Test Conditions	Inspection Intervals	Minimum Duration
Ambient temperature/ humidity storage	30°C / 60% RH	1000 hours	3000 hours
High temperature/ humidity storage	60°C / 85% RH	1000 hours	3000 hours
Temperature Cycling	-55°C to 85°C ~3 cycles / hour (5 –10 min dwell)	500 cycles	1000 cycles

- Minimum of 3 coupons per test condition.
- Minimum total number of inspection areas = 3 on each coupon.
- Minimum area on each coupon = 25 mm^2
- Minimum total inspection area of at least 75 mm^2 on 3 coupons per test condition

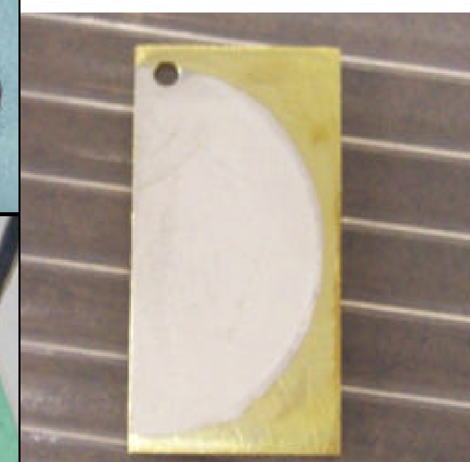
Test Samples

- Brass coupons are used in this study for accelerated whisker growth.
- Coupon dimensions are 25.4 x 12.7 x 1.6 mm with semicircular tin plated area of 200 mm^2.
- A simple RDE system was utilized for plating in a simple MSA based electrolyte.





Plated area = 200 mm^2



Faraday’s Strategy

• Faraday submitted coupons for six distinct types of coating, four of which had graded stress, achievable by sequenced waveform deposition.

Coating A

Low Tensile Stress

BRASS

Coating C

High Tensile Stress

Low Tensile Stress

BRASS

Coating E

High Tensile Stress

Low Tensile Stress

Low Compressive Stress

High Compressive Stress

BRASS

Coating B

High Tensile Stress

BRASS

Coating D

High Tensile Stress

Low Tensile Stress

Low Compressive Stress

BRASS

Coating F

Low Tensile Stress

High Tensile Stress

Low Compressive Stress

High Compressive Stress

BRASS

Test Matrix

Finish and Substrate	Plating Process	Plating Thickness (µm)	Number of Coupons for Test Conditions		
			60^{o}C / 85% RH	Temp Cycling (-55 to 85 C)	Total
Matte Tin over Brass	Process A	5	3	3	6
	Process B	5	3	3	6
	Process C	5	3	3	6
	Process D	5	3	3	6
	Process E	5	3	3	6
	Process F	5	3	3	3
Total			18	18	36

Pre-Plating Observations

- Substrate Surface:
  - Surface of coupons had scratches and gouges visible to the unaided eye
- Substrate Pretreatment:
  - No standard procedure for precleaning/pretreatment of samples.
  - Faraday manually polished samples (improve adhesion, buff out substrate defects) followed by chemical cleaning.

→ Plating process is not the only variable between Faraday's process and the commercially available tin plating process. What are effects of substrate defects and pretreatment on whisker propensity?

Pre-Test Observations

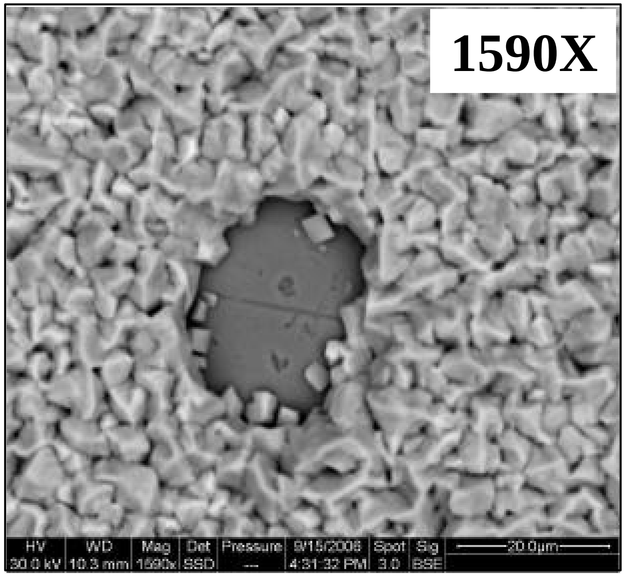
- **Pores**: Many of the coupons displayed pores in the plated area with an average size of 20 µm with a spacing of ~ 500 µm or less; in some cases the brass substrate was exposed.
- **Uneven Plating**: Half of the test coupons were plated unevenly; brass substrate was exposed in some areas.
- **Scratches**: Many of the coupons had scratches in the plated area; only a few of these scratches exposed the underlying brass.
- **Other Surface Defects**: One of the processes had a lower process efficiency and resulted in the hydrogen side reaction at the cathode and resulted in surface defects from H_2 bubbles on the surface of plated tin. One coupon from another process resulted in the same inefficiency.

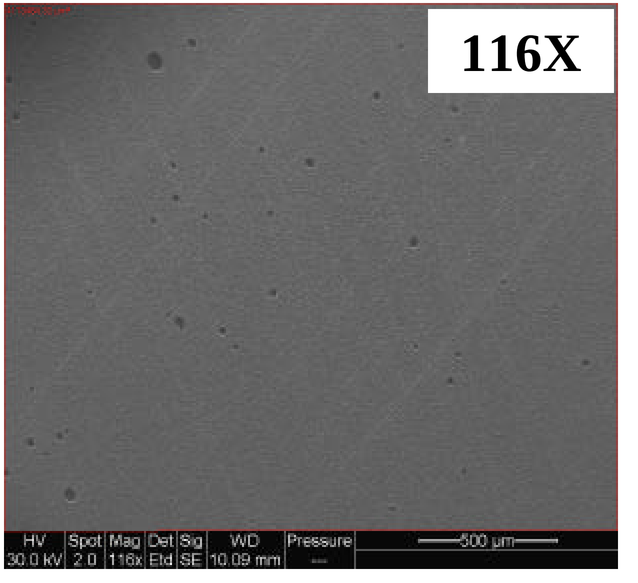
Porosity

• Porosity is obvious on some of the submitted coupons

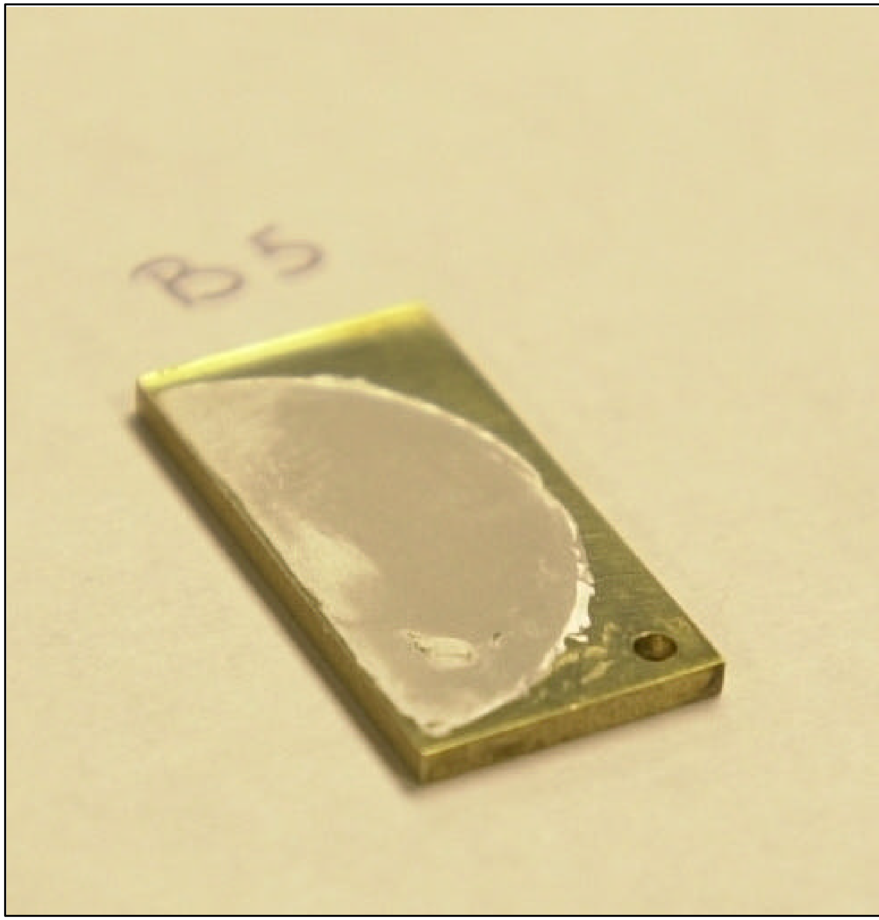
• Transverse porosity depends on the following[4]:

  • Substrate roughness
  • Surface defects on the substrate
  • Bath parameters
  • Hydrodynamics
  • Thickness of the deposit
  • Current density

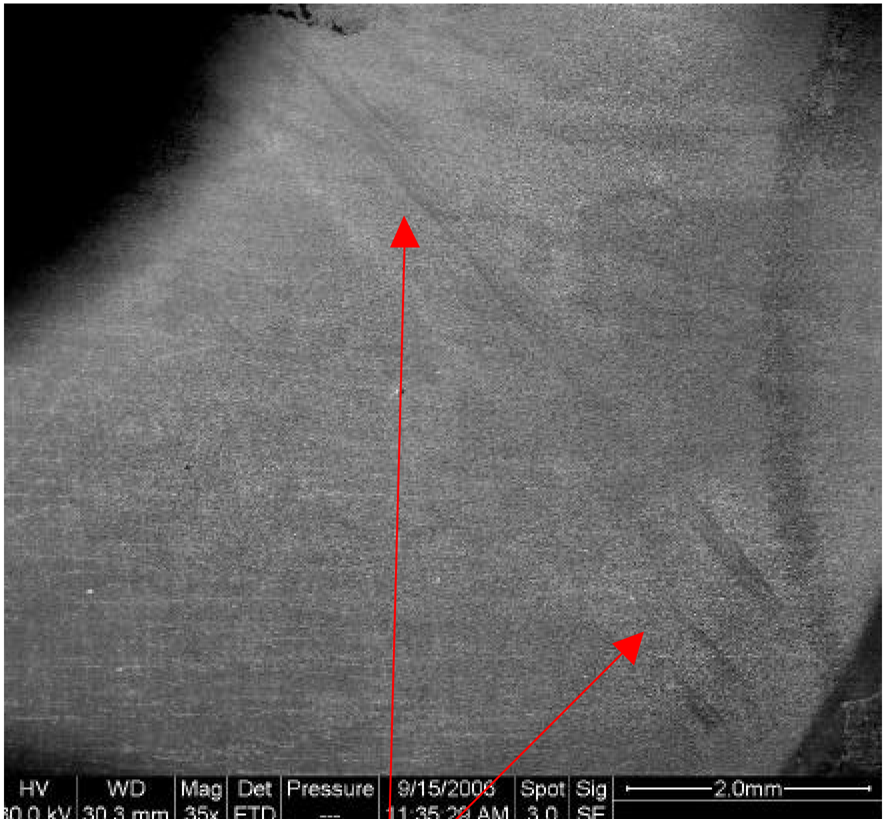




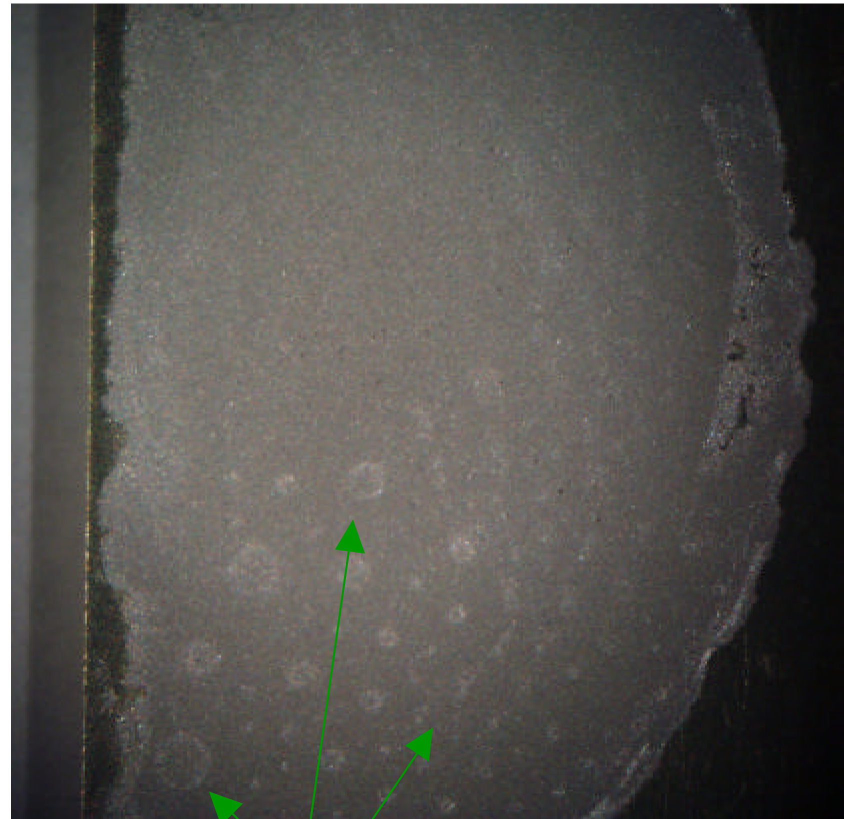
Example of Uneven Plating



Example of Other Surface Defects



Scratches



Voids from H_2 Evolution

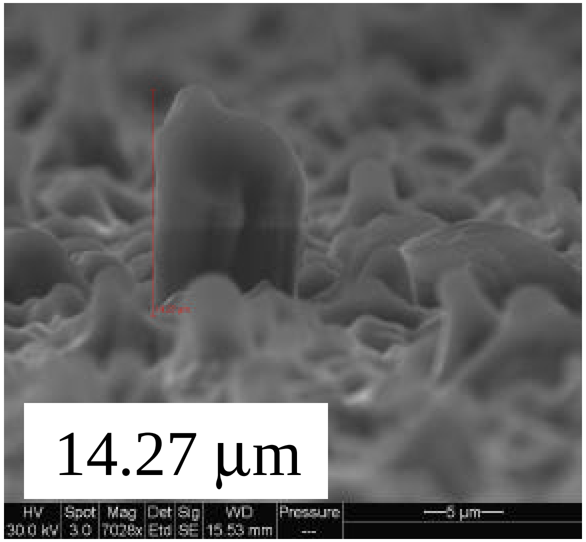
Pre-Test Observations

Summary of Coupons Displaying Surface Defects

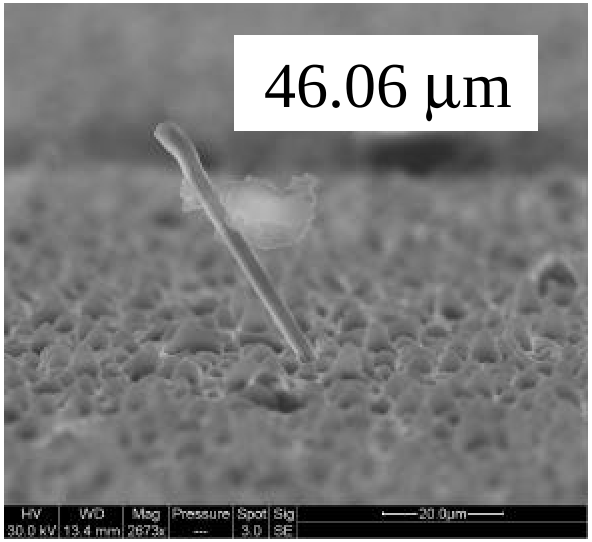
Number of Samples Affect by (out of 6):				
Process	Porosity	Uneven Plating	Scratches in Deposit	Bubbles
A	3	2	4	0
B	4	6	1	3
C	0	1	2	0
D	2	1	2	1
E	4	3	3	0
F	1	1	3	0

1000 Cycles of Temperature Cycling

- Coating A:
  - Very few whiskers
  - Average length: 10 μm
  - Average density: 1 per mm^2
  - Max length: 14.27 μm

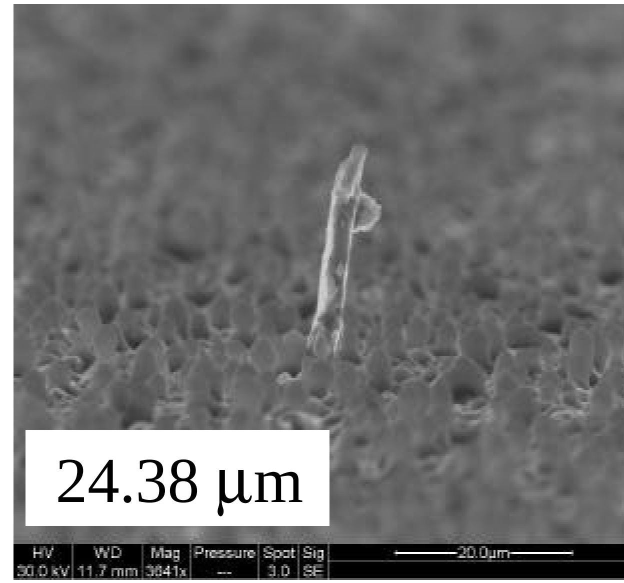


- Coating B:
  - Few whiskers
  - Average length: ~ 14 μm
  - Average whisker density: 1 per mm^2
  - Max length: 46.06 μm



1000 Cycles of Temperature Cycling

- Coating C:
  - Few whiskers
  - Average length: ~ 15 μm
  - Average whisker density: <1 per mm^2
  - No whiskers found on two of the three samples (Very few found on the third sample)
  - Max length: 24.38 μm



- Coating D: No whiskers on any of the samples
- Coating E: No whiskers on any of the samples
- Coating F: No whiskers on any of the samples

* No whiskers observed on any of the coupons after 500 hours of temperature cycling.

Comparison with a Commercial Process: Temperature Cycling

* A commercially available matte-tin plating was also tested. The test results from the commercial samples (NC Samples) are presented here for comparison.

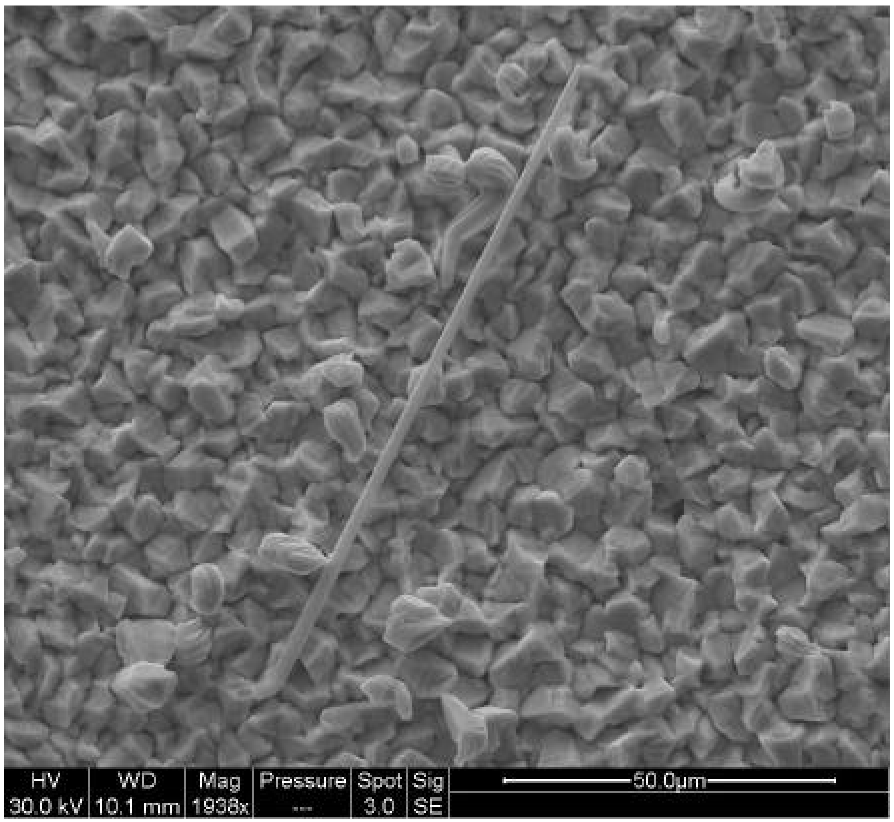
	Density (#/mm^2)		Length (µm)		
Sample	Av	STD	Av	STD	Max
FT-A	1		10		14.27
FT-B	1		14		46.06
FT-C	<1		15		24.38
FT-D	0		0		0
FT-E	0		0		0
FT-F	0		0		0
NC-14	45	35.4	5	3.9	13.34
NC-15	137	70.5	6	2.4	11.50
NC-18	16	1.3	3	2.2	7.00

5 Months of Temp/Humidity Storage

- Observations:
  - Many whiskers were found on each type of deposit.
  - For Coatings C, D, E and F, only two of the three coupons were documented due to lack of time, although all three were inspected.
  - The densities and lengths from the 2 coupons reported are representative of those seen on the third coupon.

Coating A: After 5 Months of Temp/Humidity (60/85) Storage

* Longest whisker found on an "A" Sample after 5 months storage:

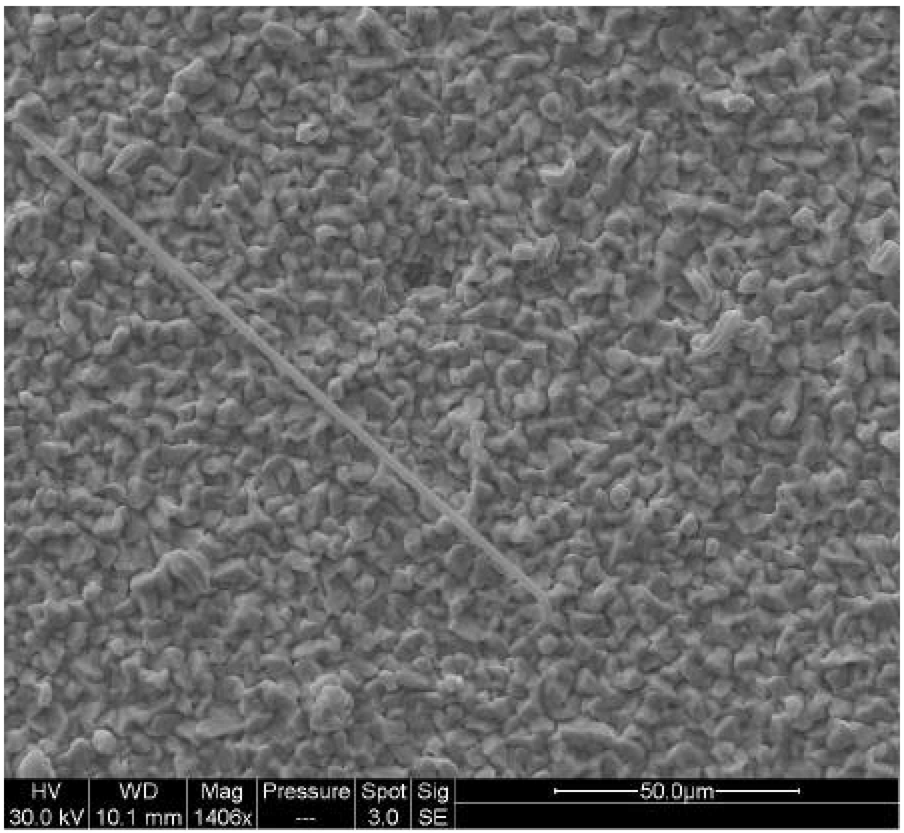


Coating A2

Length: 161.12 µm

Coating B: After 5 Months of Temp/Humidity (60/85) Storage

* Longest whisker found on a “B” Sample after 5 months storage:

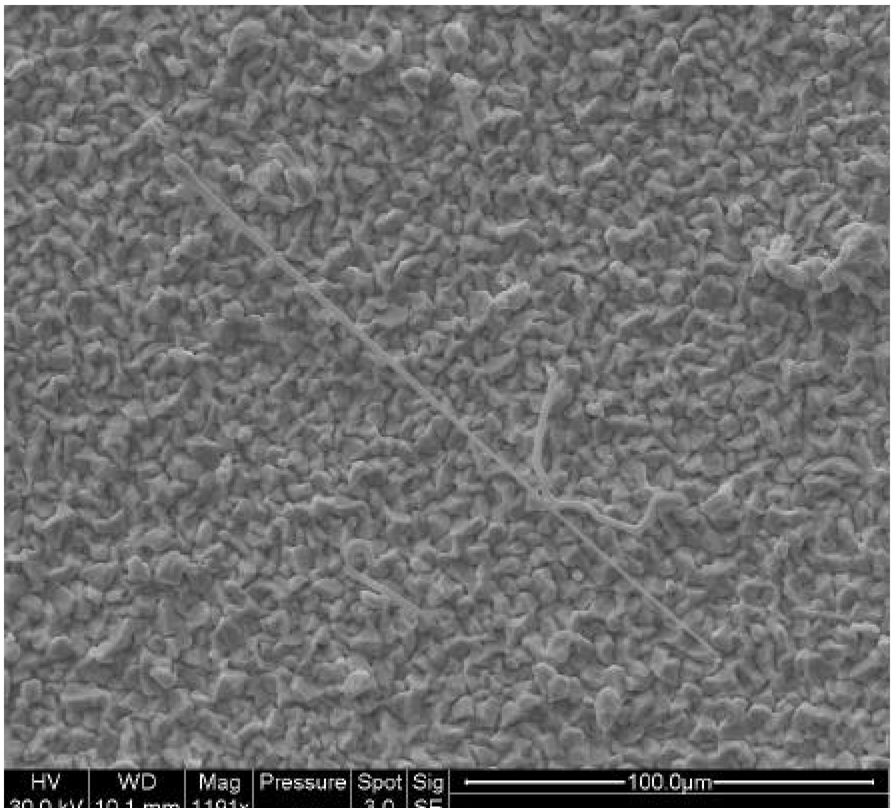


Coating B5

Length: 149.33 µm

Coating C: After 5 Months of Temp/Humidity (60/85) Storage

* Longest whisker found on a “C” Sample after 5 months storage:

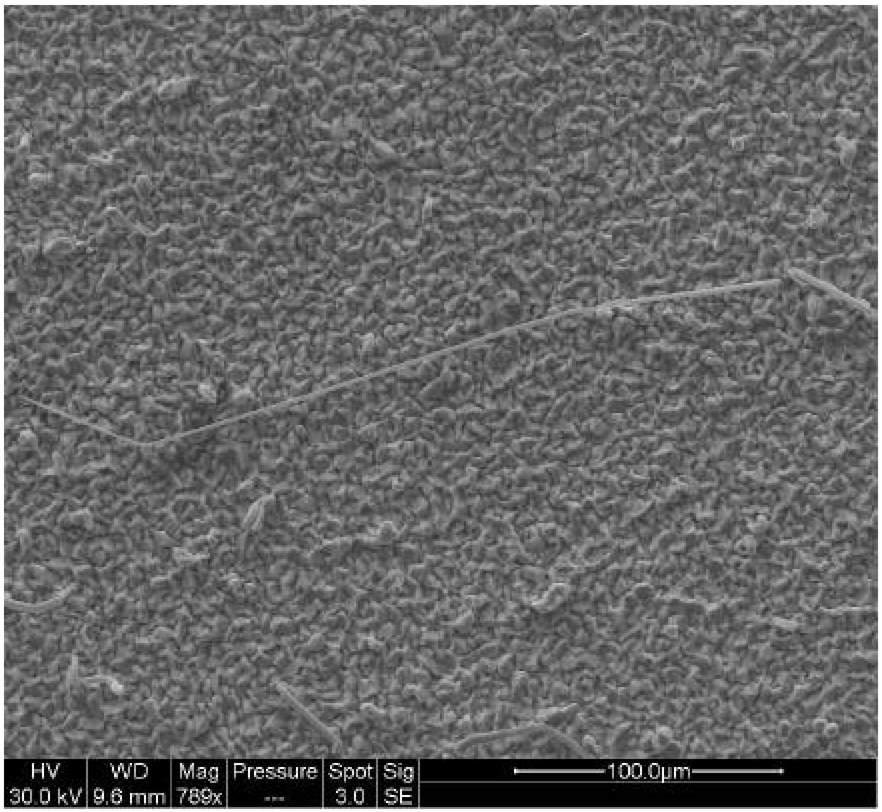


Coating C1

Length: 179.68 µm

Coating D: After 5 Months of Temp/Humidity (60/85) Storage

* Longest whisker found on a “D” Sample after 5 months storage:



High Tensile Stress

Low Tensile Stress

Low Compressive Stress

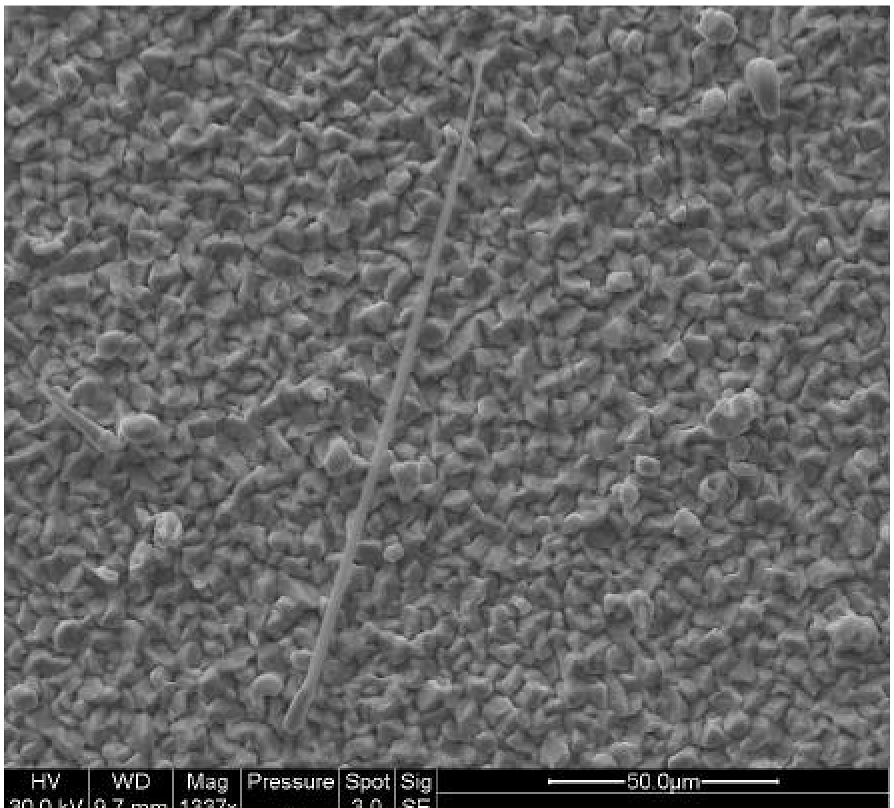
BRASS

Coating D3

Length: 295.26 µm

Coating E: After 5 Months of Temp/Humidity (60/85) Storage

* Longest whisker found on an "E" Sample after 5 months storage:



High Tensile Stress

Low Tensile Stress

Low Compressive Stress

High Compressive Stress

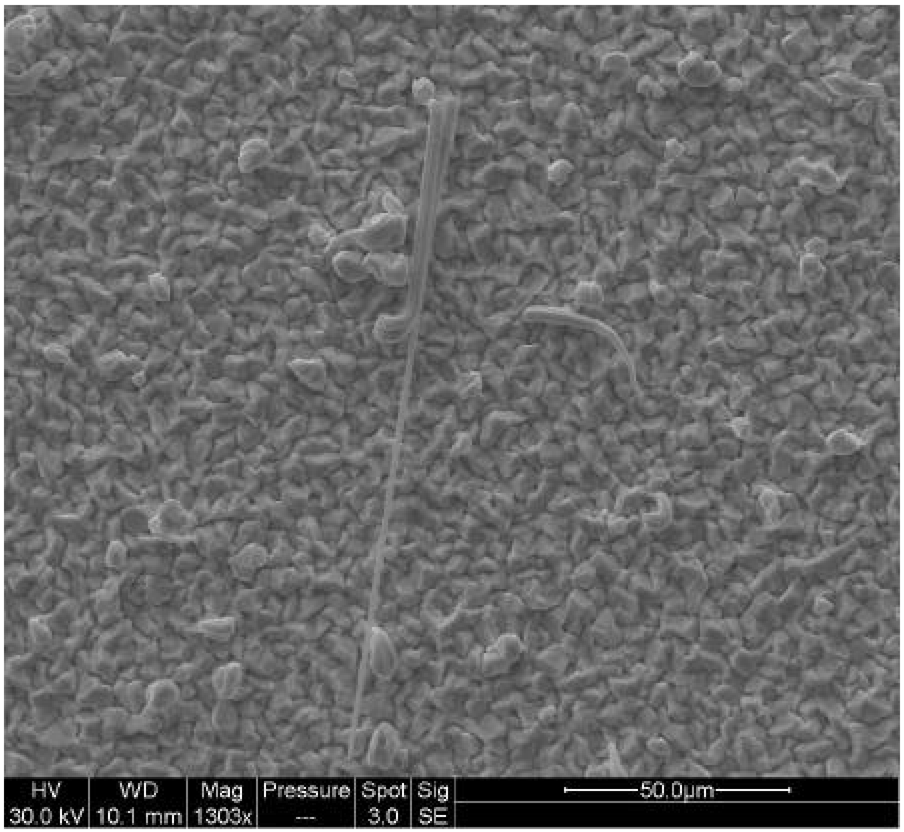
BRASS

Coating E2

Length: 152.78 µm

Coating F: After 5 Months of Temp/Humidity (60/85) Storage

* Longest whisker found on a “F” Sample after 5 months storage:



Low Tensile Stress

High Tensile Stress

Low Compressive Stress

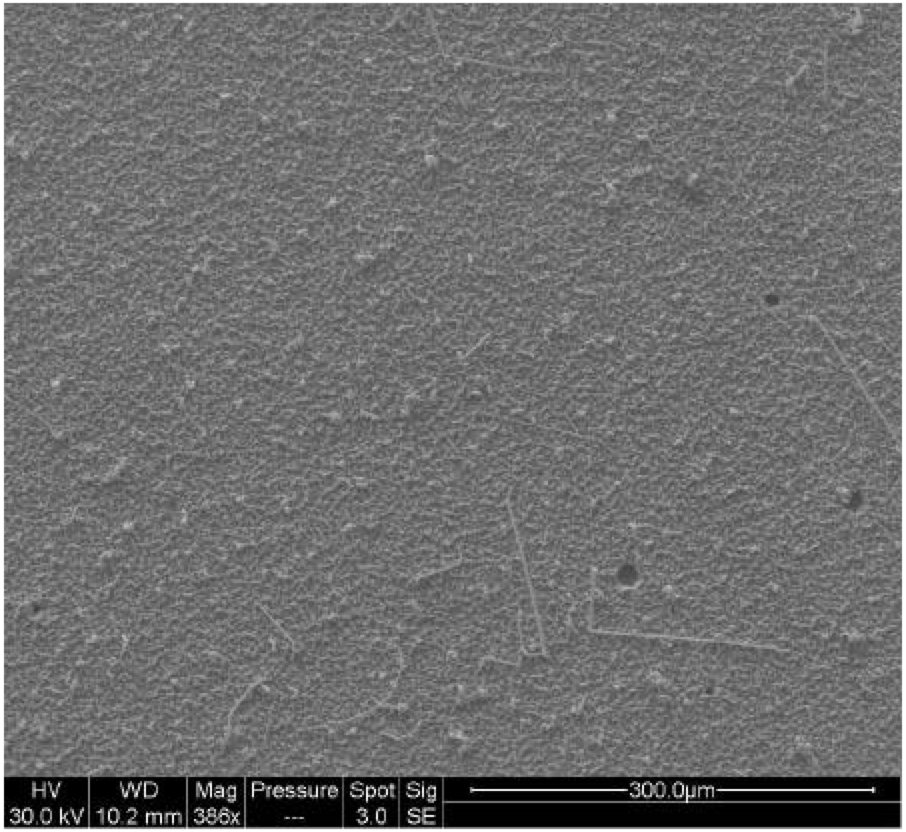
High Compressive Stress

BRASS

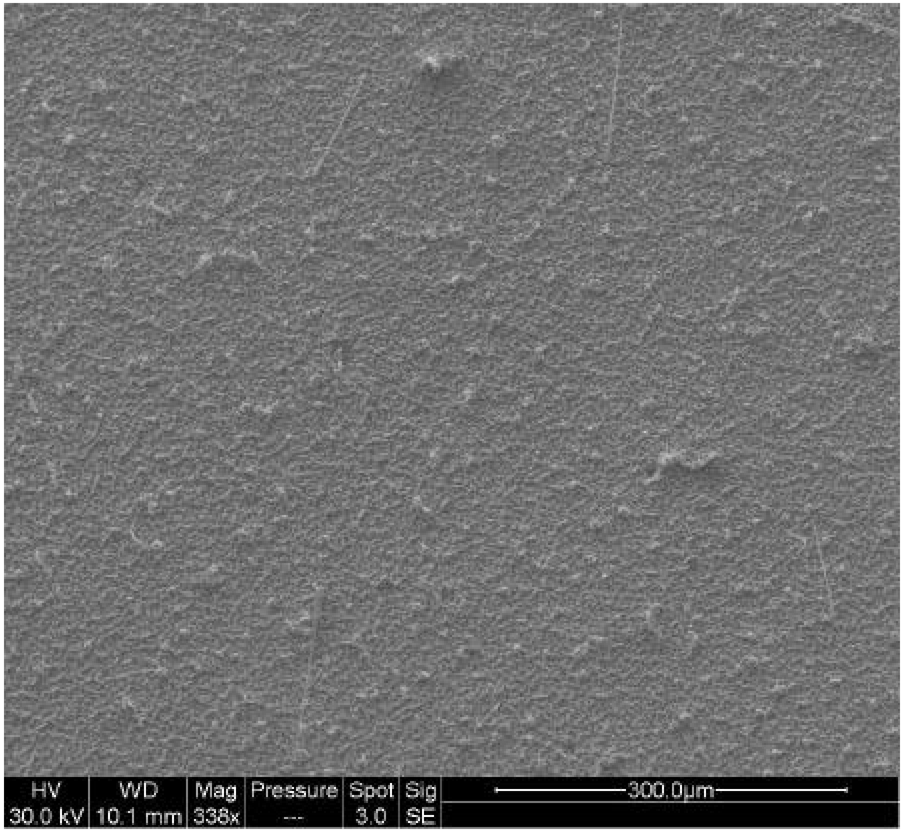
Coating F1

Length: 146.43 µm

Density: After 5 Months of Temp/Humidity (60/85) Storage



Sample D1



Sample F1

Comparison with a Commercial Process: Temp/Humidity Testing

* A commercially available matte-tin plating was also tested. The test results from the commercial samples (NC Samples) are presented here for comparison.

	Density (#/mm^2)		Length (μm)		
Sample	Average	STD	Average	STD	Max
FT-A2	236	26.1	19.3	25.9	161.1
FT-B1	268	23.3	20.7	23.4	99.2
FT-C2	266	4.1	27.2	36.7	130.5
FT-D3	281	7.9	30.7	57.5	295.3
FT-E2	309	21.9	22.8	36.4	152.8
FT-F1	406	22.6	22.9	30.0	146.4
NC-10	19	7.2	6.7	4.9	18.8
NC-11	26	8.2	3.0	2.4	7.6

Future Work

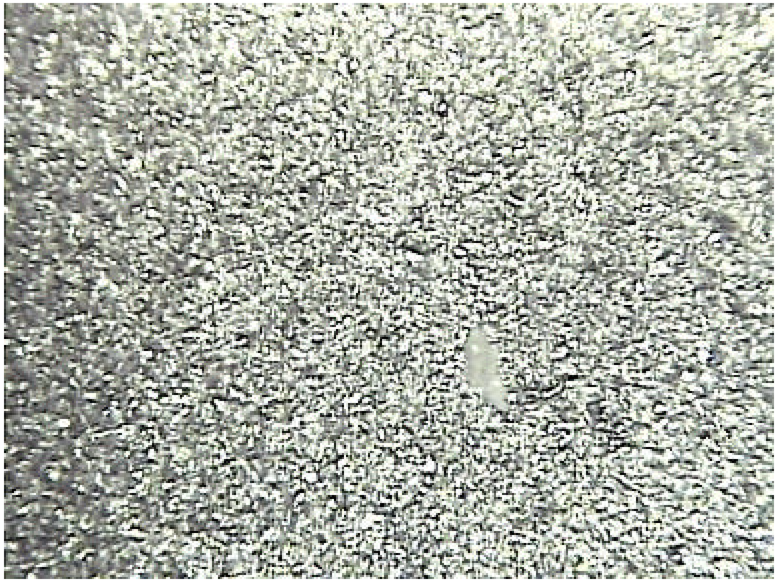
- Temperature Cycling
  - Completed
- Temperature Humidity
  - All coupons in the temperature/humidity chamber will be taken out from the chamber after 9 months for evaluation
  - Further evaluation after 1 year
  - Test will be stopped after 1 year

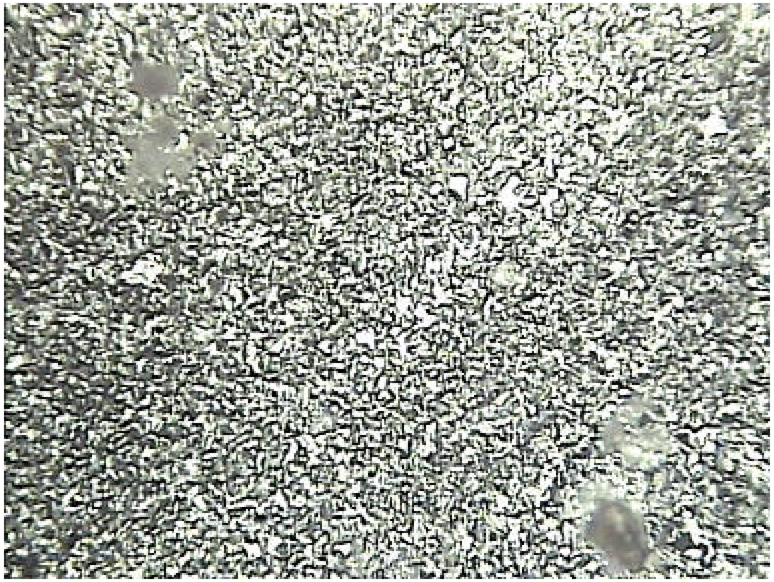
Whisker/Hillock Assessment: Samples Aged 3 Years

• Pure tin deposits plated with pulse/pulse reverse electrodeposition were aged for 3 years and then examined for whiskers (photos under 200X magnification)

• The pure tin deposits were 10 μm thick on copper substrates plated with RDE

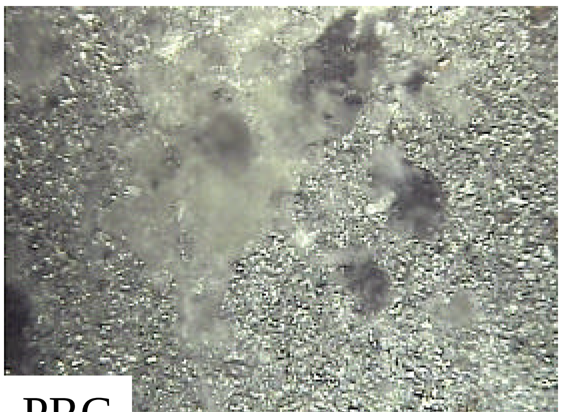
• The coupons with the lowest density of whiskers/smallest defect size were both plated utilizing high frequency and low duty cycle (PC), perhaps driving nucleation over crystal growth although, peak current density did not seem to have an effect





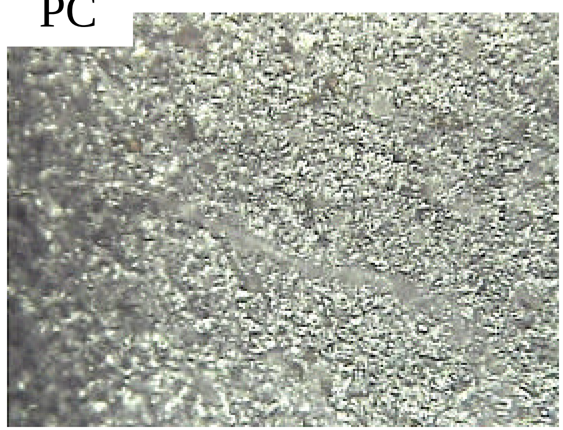
Whisker/Hillock Assessment: Samples Aged 3 Years

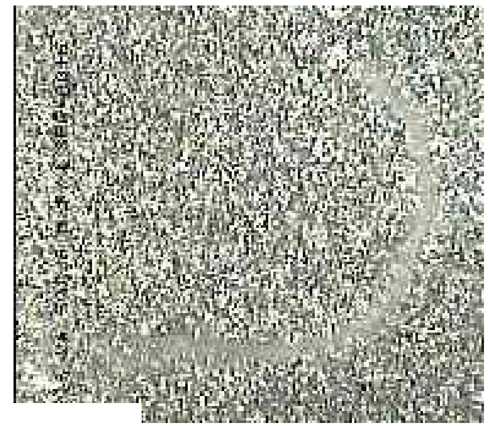
- The deposits with highest density/largest defect size seem to have been plated with a high duty cycle (both PRC and PC), although no real trend is observed



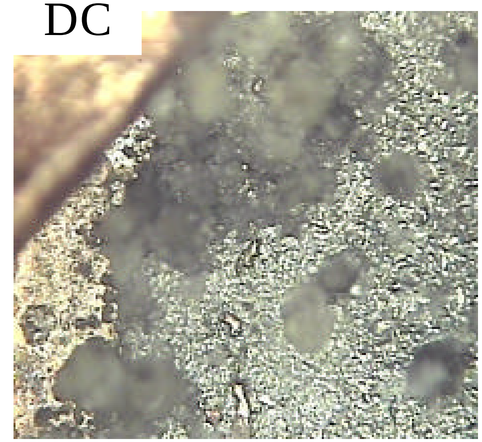
PRC

PC





DC



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"Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation."

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