# Evaluation of Conformal Coatings as a Tin Whisker Mitigation Strategy

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**Abstract**
The objective of this ongoing study is to evaluate the ability of conformal coatings to mitigate the formation and growth of tin whiskers. Conformal coatings were chosen as a mitigation strategy because they are one of the few processes that are actually under the control of OEMs that manufacture high reliability electronics. Brass coupons were plated with bright tin and then conformal coatings were applied. The coupons were aged in a 50°C/50%RH (relative humidity) environment and observed for whisker formation and penetration of the coatings by whiskers. The results of this test suggest that conformal coatings can suppress the formation of whiskers and OSE's (odd shaped eruptions). With time, however, all of the coupons in this test began to grow whiskers under the coatings and once whisker growth began, most of the thinner coatings were penetrated. In contrast, the thicker coatings (3.9–6.0 mils) were not penetrated by whiskers or OSE's during the test. No obvious relationship was noted between the mechanical properties of the coatings and their ability to suppress whisker and OSE formation. Similarly, no obvious relationship was noted between the oxygen and water vapor permeability of the coatings and their ability to suppress whisker and OSE formation. Unusual formations of zinc ("zinc rings") were noted on the surface of the tin plating around some of the OSE's.

**Background**
The worldwide transition to lead-free electronics is forcing most major suppliers of components to convert their product lines from tin/lead to lead-free finishes. Their predominant choice for a lead-free component finish appears to be pure tin. The propensity of pure tin plating to form tin whiskers has been known for many years[1,2]. Tin whiskers have been found to form on a wide variety of tin-plated component types under a range of environmental conditions[3]. These whiskers are comprised of nearly pure tin and are therefore electrically conductive and can cause shorting of electronics. The growth of whiskers has caused, and continues to cause, reliability problems for electronic systems that employ components that are plated with tin. Manufacturers of high-reliability systems and government users have not been immune to these difficulties[1,4]. Field failures attributable to tin whiskers have cost individual programs many millions of dollars and have caused significant customer dissatisfaction.

What causes tin whiskers to grow is still under debate although it is generally accepted that stresses in the plating play a major role[1]. Several mechanisms for whisker growth have been postulated[5,6,7]. The effects of plating process parameters such as current density[8,9], temperature[10], substrate preparation[11], substrate material[10,12,13], and bath components[5,8,9,10] have been studied. In addition, the effects of plating thickness[10,14], underlayers[12,15], post-plating annealing[6,8,15], plating structure[8,17,18], and alloying agents[14,19,20,21] on whisker growth have been explored. The crystallographic structure of tin whiskers has also been well studied[6,13,16].

Although strategies have been identified to reduce the chances of growing whiskers, currently the only sure prevention strategy is to totally eliminate pure tin from a system. However, the growing use of tin by component vendors and the increasing use of COTS components in high-reliability systems makes this strategy increasingly difficult to implement. For these reasons, it is important that effective and low cost strategies for controlling tin whisker risks be developed so that tin-plated components can be used in high reliability electronics.

**Objective**
The objective of this ongoing study is to evaluate the ability of conformal coatings to mitigate the formation and growth of tin whiskers. Conformal coatings were chosen as a mitigation strategy because they are one of the few processes that are actually under the control of OEMs that manufacture high reliability electronics. Other processes (such as the actual tin plating process) can not be reliably controlled by the OEMs that purchase tin-plated components from vendors.

This study has been divided into two phases.

Phase I was a study to evaluate the ability of different test environments to promote the growth of tin whiskers[22]. The primary goal was to produce whiskers long enough to penetrate three mils of conformal coating (75 microns). Before you can evaluate mitigation strategies, you must be able to reliably grow whiskers in a controlled environment.

Phase II is ongoing and is evaluating the ability of conformal coatings to suppress whisker formation and growth. The results to date of the Phase II 50°C/50%RH testing will be reported here.

Few papers have been published on the ability of conformal coatings to suppress the formation and growth of tin whiskers. One exception is a study by NASA Goddard which is evaluating a polyurethane[23].

**Approach**

Test coupons were prepared from Brass 260 (70% Cu, 30% Zn) and were plated with approximately 150 microinches of bright sulfate tin. Brass was chosen as a substrate because it has been shown to promote rapid whisker growth[10,12,14]. Bright tin was chosen as the plating type as it has been shown to be conducive to whisker growth[9,14]. The thickness of the plating that was chosen (150 micro-inches) has been shown to be optimum for whisker growth on brass substrates[10].

UNS C26000 H02 temper (half hard) brass sheet (0.032 in. thick) was sheared into 1 in. by 4 in. test coupons. The coupons were degreased, cleaned in an alkaline cleaner, and then pickled in a sulfuric acid bath before plating.

The sulfate tin plating tank was filled with fresh plating solution immediately before processing of the coupons. No strike (e.g., copper) was applied prior to the tin plating process. The plating conditions were as follows:

Coupon surface area per load (sq. ft.): 2.78
Surface area of side robber electrodes (sq. ft.): 1.8
Total cathode surface area (sq. ft.): 4.6
Cathode current density (amps/sq. ft.): 10.9
Agitation: rocking bars
Temperature: 66°F
Anode: pure tin in Dynel bags

Microsections were done on three of the plated coupons and the thicknesses of the tin plating were measured. The average thickness of the plating was 154 microinches +/- 30 microinches.

The coupons were then coated with the six conformal coatings to be tested. The candidate coatings had widely varying physical properties. It was hoped that some of these properties, such as Young's modulus, hardness, tensile strength, oxygen permeability, and water vapor transmission, could be correlated with the ability of the coatings to suppress whisker formation and growth. It is not unreasonable to expect that a very hard coating with a high modulus might physically inhibit the formation of whiskers. In addition, oxygen and water vapor have been implicated as possible factors in whisker formation and the permeability of a coating to either might be an important factor[24,25]. The known physical properties of the coatings are given in Table 1. Coatings A, D and E were UV-cured urethane acrylic hybrids. Coating B was a silicone. Coating C was a non-crosslinked acrylic. The sixth coating was Parylene C applied by vacuum deposition. Prior to deposition of the Parylene, the coupons were lightly etched in a 4% solution of Vichem 600A (Interflux USA, Inc.) in order to improve adhesion of the Parylene. Coating C was applied to the coupons at Boeing. All of the other coatings were applied by Raytheon.

The coatings were applied to the test coupons as shown in Figure 1. One end of each coupon was coated with approximately 1 mil of coating and the opposite end of each coupon was coated with a thicker layer (4 – 6 mil) of coating. The middle of each coupon was left uncoated to serve as a control. The exceptions were the coupons coated with Coating B (the silicone) and Parylene. The silicone was applied in only one thickness (1.5 mils). The Parylene was applied over the entire surface of the coupons (0.8 – 1.0 mil) leaving no control areas. A separate coupon was used as the Parylene control. The control coupon was exposed to the Vichem 600A etching step but was not coated with Parylene.

The thickness of each coating was measured using a microscope with a vernier scale on the focusing knob. The difference in the readings obtained by focusing on the surface of the coating and then on the tin substrate was multiplied by the index of refraction of the coating to yield the coating thickness (see Table 2). Five measurements of each coating were taken at random spots on the coupon and then averaged.

The coated coupons were allowed to sit for 278 days in a laboratory environment (ambient temperature and humidity) which resulted in the formation of small nodules but no significant whisker growth. The coupons were then placed into a temperature/humidity test chamber held at 50°C/50%RH for an additional 419 days to accelerate whisker growth.

The test coupons were examined periodically with a visual microscope and/or a scanning electron microscope (SEM) and any growths were noted (see Table 2). Figure 2 shows how the different types of growths observed were classified, i.e. nodules; odd shaped eruptions (OSE's); and whiskers. Photographs were taken to document any changes in the tin plating during testing.

Several of the conformal coatings were also applied to PLCC68 (plastic leaded chip carrier) components soldered to test boards. The leads on the PLCC's were then probed with a digital ohmmeter to determine if the coatings failed to adequately cover the leads.

**Results and Discussion**

Aging of the test coupons in a laboratory environment (ambient temperature and humidity) for 278 days resulted in the formation of small nodules but no significant whisker growth. Placing the coupons into a temperature/humidity chamber held at 50°C/50%RH appeared to greatly accelerate the formation of tin whiskers. At the end of 63 days in the 50°C/50%RH environment, all of the uncoated control areas on the coupons exhibited significant whisker growth (see Table 2). On all of the coupons, whiskers grew first on the uncoated areas nearest the coated areas. This suggests that the coating is somehow promoting whisker formation on the uncoated portion of the coupons.

It was noted that some of the whiskers growing on the control areas were covered with unusual patches of a substance that traveled along with the whisker as it grew (Figure 3). This substance seemed to be exuded from within the tin plating and may be residual organics from the plating process. The presence of this substance was fortuitous as it allowed the growth rate of the whisker to be accurately measured (see Figure 4, measured growth rate of this whisker was approximately 10 Angstroms/minute). Additional work is ongoing to identify the composition of the substance.

After 63 days in the 50°C/50%RH environment, the acrylic coating (Coating C) had odd shaped eruptions (OSE's) and whiskers growing under both the thin and the thick coated areas. The whiskers pushed the conformal coating up to form "tents". Similarly, Coating E had a few whiskers under both the thin and the thick coated areas. Some of these whiskers were as long as 300 microns (see Figure 5).

In contrast, after 63 days in the 50°C/50%RH environment, Coatings A, B, and D had only nodular growths beneath the coatings but no whiskers. Parylene C had no growths underneath the coating (see Table 2).

After 119 days in the 50°C/50%RH environment, the thin acrylic coating (0.6 mils of Coating C) had been penetrated by whiskers (see Figure 6). Note the whisker whose tip is still covered with conformal coating that has ripped away from the bulk material (Figure 6, upper left hand photo). Also note that some whiskers appear to have re-penetrated the coating. The thicker acrylic coating (3.9 mils) was not penetrated by whiskers although there were many whiskers "tenting" the coating (Figure 7). The 1.1 mils of Coating D was penetrated by OSE's and whiskers (see Figures 8 and 9). The OSE's that penetrated the coating emanated from the serial number that was scribed onto the coupon before plating. This may be an example of how stresses induced into the substrate by mechanical means can trigger the formation of growths in a tin plating applied later. The 4.6 mils of Coating D had one whisker under, but not penetrating, the coating.

In comparison, after 119 days in the 50°C/50%RH environment, Parylene C had no growths underneath the coating. Coating B had only nodular growths beneath the coating but no whiskers. Coating A had many OSE's under both the thick and thin coatings. Some of these OSE's had formed "bubbles" around them where the coating had lifted off of the coupon surface. Photos of typical OSE's inside bubbles can be seen in Figures 10 and 11. Note the differences in appearance of the bubbles under optical microscopy and scanning electron microscopy

After 336 days in the 50°C/50%RH environment, the thinner applications of Coatings B, E, and Parylene C were also penetrated by whiskers and/or OSE's (see Figures 12-22). The Parylene had only a few growths under the coating (Figure 20) but several whiskers had formed and had penetrated the coating (Figures 21 and 22). Coating A was the only coating that was not yet penetrated by whiskers, however, there were many OSE's in bubbles under the coating and whiskers were growing on the OSE's (see Figure 23). Coating D also had many OSE's in bubbles at this point (Figure 24).

All of the conformal coatings tested suppressed the formation of tin whiskers when compared to the uncoated controls. The controls all grew massive amounts of whiskers that were long enough to penetrate the coatings in test (see Figures 12, 17, 25-28). The coating that best suppressed the formation of growths under the coating was Parylene C. At the end of 336 days of 50°C/50%RH, the tin plating under the Parylene was almost free of nodules, OSE's and whiskers. Coating B (the silicone) was also very good at preventing the formation of OSE's and whiskers. The worst coating for suppressing growths was the acrylic (Coating C) which had numerous whiskers severely "tenting" the thicker acrylic coating (Figures 29 and 30) and penetrating the thinner acrylic coating. All of the other coatings fell somewhere in between Parylene and the acrylic in their ability to suppress OSE and whisker growth.

However, once whiskers and OSE's had formed under the coatings, the thinner coatings (0.6–1.5 mils) were generally not effective at preventing penetration by the whiskers and/or OSE's. Close examination of Figures 13-15 and 19 reveal that the thickness of each coating penetrated appears to be less than the average coating thickness as measured optically. This suggests that the whiskers that penetrated were those that had found a weak spot in the thinner coatings.

In contrast, the thicker coatings (3.9–6.0 mils) were not penetrated by whiskers or OSE's during the test. Therefore, thick conformal coatings appear to be an effective mitigation strategy due to their ability to trap the whiskers.

No obvious relationship was noted between the physical properties (Table 1) of the coatings and their ability to suppress whisker and OSE formation. For example, Parylene C has the highest modulus, tensile strength and hardness. These properties suggest that the ability of Parylene to suppress whisker formation might be due to its ability to apply a mechanical resistance. However, Coating B (the silicone) was also fairly effective in suppressing whisker and OSE formation despite the fact that it has a very low modulus, a low tensile strength and is softer than Parylene.

Similarly, no obvious relationship was noted between the oxygen permeability of the coatings and their ability to suppress whisker and OSE formation. Oxygen has been implicated as a factor in promoting whisker growth[24, 25]. This suggests that the ability of Parylene to suppress whisker growth might be due to its low permeability to oxygen. However, Coating B (the silicone) was also fairly effective in suppressing whisker and OSE formation despite the fact that it has a much higher oxygen permeability than Parylene C (four orders of magnitude).

It is not clear if there is a relationship between the water vapor permeability of the coatings and their ability to suppress whisker and OSE formation. Parylene C has the lowest water vapor transmission when compared to the other coatings (by one order of magnitude) but it is not clear if this is enough to explain its performance.

A simple test was also performed to determine if the conformal coatings would actually coat component leads to a thickness sufficient to provide protection from whisker penetration. PLCC64's were soldered to test boards and the boards were then coated with conformal coatings (Figure 31). Three conformal coatings were evaluated (Coating D, Coating E and Parylene C). The electrical resistance of each coating on the PLCC leads was evaluated using a digital ohmmeter with blunt probes in order to determine if the coating had adhered to the lead or if it had run off during application of the coating. Coatings D and E were so thin on the leads that they provided no electrical insulation at all (on the front or backside of the leads, see Table 3). In contrast, the Parylene C provided a fully insulating barrier on both sides of the leads. It was obvious from this experiment that Coatings D and E were so thin on the leads that they would provide no protection if a whisker were to grow on the leads or if they came into contact with a whisker growing from an adjacent lead. This thinning of the coating on component leads will probably be encountered with most conformal coatings applied by spraying. Parylene C is unique in that it is applied by a vacuum deposition process which produces a very uniform coating on all surfaces.

When the coupons were removed from the 50°C/50%RH chamber for the last inspection, Coating E began to delaminate from the coupon. This provided the opportunity to better observe what was going on beneath the coating.

Some of the growths under Coating E were different in appearance from the typical odd shaped eruption. In some cases it looked as if whiskers had grown but had then coiled up when they were unable to penetrate the coating (Figures 32 and 33).

A piece of delaminated Coating E was sputtered with iridium and examined in the SEM. Figure 34 shows a bubble in the coating and how the coating has pulled material off of the tin plating. The bubble once enclosed an OSE on the surface of the coupon. EDS (energy dispersive x-ray spectroscopy) examination revealed an unusual formation of zinc around the perimeter of the bubble ("zinc ring", Figure 35). Figures 36 and 37 demonstrate that part of the OSE has been removed by the coating and is surrounded by the "zinc ring". Oxygen is intimately associated with the zinc.

The area on the coupon that mates with the coating shown in Figures 34-37 was located and examined (Figure 38). EDS again showed the presence of the "zinc ring" around the centralized OSE's (Figure 39). The "zinc ring" on the coupon has had most of the zinc removed on one side by adhesion to the coating. This demonstrates that the zinc is mostly on the surface of the tin. By comparison, no "zinc ring" was observed around OSE's on the uncoated control area of the coupon which suggests that the coating is essential for the formation of a ring.

Migration of zinc from a brass substrate (and through a tin plating) has been observed before[5] but no rings or other patterns were noted. The zinc was presumed to diffuse through the grain boundaries of the tin and onto the surface of the tin where it formed zinc oxide. In our case, we believe that the zinc was moving away from the OSE's in the center of the bubble in the coating. The zinc was then trapped by the polymer at the edge of the bubble to form the "zinc ring".

**Conclusions**

The results of this test suggest that conformal coatings can suppress the formation of whiskers and OSE's (odd shaped eruptions). With time, however, all of the coupons in this test began to grow whiskers under the coatings and once whisker growth began most of the thinner coatings were eventually penetrated. In contrast, the thicker coatings (3.9–6.0 mils) were not penetrated by whiskers or OSE's during the test. No obvious relationship was noted between the mechanical properties of the coatings and their ability to suppress whisker and OSE formation. Similarly, no obvious relationship was noted between the oxygen and water vapor permeability of the coatings and their ability to suppress whisker and OSE formation. In this test, Parylene C was the best coating for suppressing the formation of OSE's and whiskers. In addition, Parylene C will completely and uniformly coat component leads unlike other coatings applied by spraying. Additional studies need to be done to verify these findings.

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**Table 1. Physical Properties of the Conformal Coatings**

| | Coating A (Urethane Acrylic) | Coating B (Silicone) | Coating C (Acrylic) | Coating D (Urethane Acrylic) | Coating E (Urethane Acrylic) | Parylene C |
|---|---|---|---|---|---|---|
| Young's Modulus (psi) | 700 | 900* | 1000 | 60,000 | 178,000 | 400,000 |
| Tensile Strength (psi) | 250 | 435 | | 6,000 | 3,500 | 10,000 |
| Elongation @ Break (%) | 200 | 30 | | 5 | 9.5 | 200 |
| Hardness | Shore A55 | Shore D24 | | Shore D80 | Shore D70 | Rockwell R80 (approx. Shore D75) |
| Oxygen Permeability at 25°C ($cm^3$ (STP)•mil/(100 $in^2$/day•atm) | 200* | 50,000* | | 200* | 200* | 7.2 |
| Water Vapor Transmission at 90%RH, 37°C (gm•mil/(100 $in^2$•day) | 2* | 5* | | 2* | 1.8 | 0.21 |

***Estimated Values (Reference 26)**

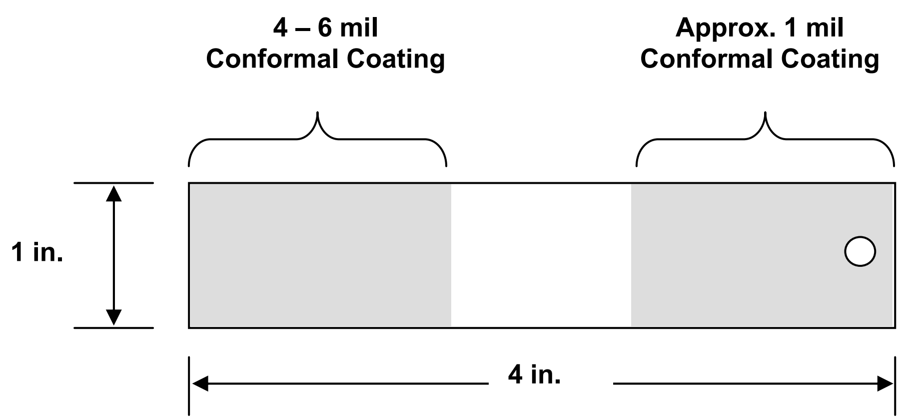
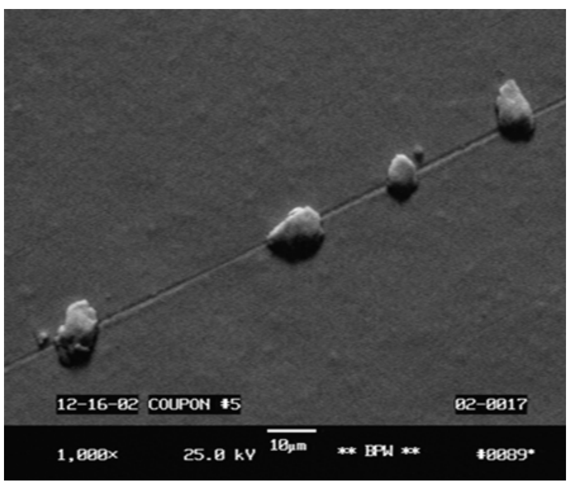



**Figure 1. Test Coupon (Brass 260 Plated with 154 Microinches of Bright Tin)**

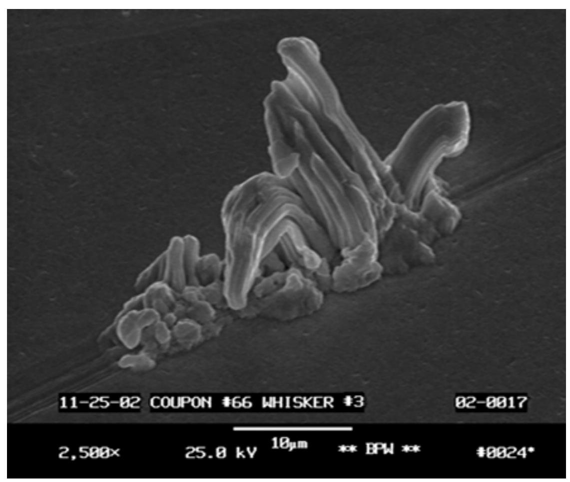
**Table 2. Test Results**

**OSE = Odd Shaped Eruption**

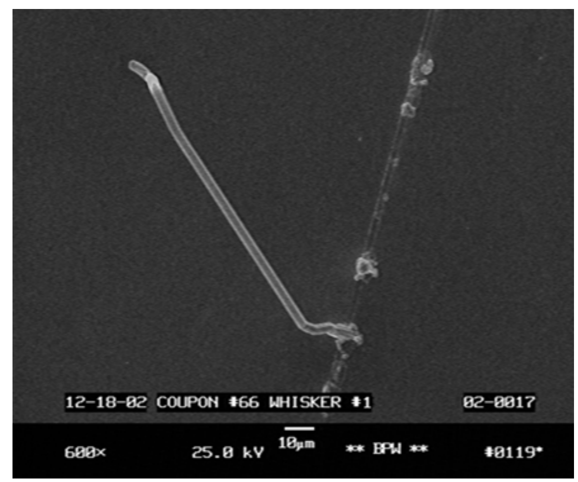
| | Coating A (Urethane Acrylic) | | | Coating B (Silicone) | | Coating C (Acrylic) | | | Coating D (Urethane Acrylic) | | | Coating E (Urethane Acrylic) | | | Parylene C | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Average Coating Thickness (mils)** | No Coating | 1.4 | 6.0 | No Coating | 1.5 | No Coating | 0.6 | 3.9 | No Coating | 1.1 | 4.6 | No Coating | 1.3 | 4.0 | Etched But Not Coated | 0.8 |
| **Coating Thickness Range (mils)** | No Coating | 1.2 - 1.7 | 5.4 - 6.5 | No Coating | 1.4 - 1.6 | No Coating | 0.4 - 1.0 | 3.1 - 4.3 | No Coating | 1.0 - 1.2 | 2.7 - 6.7 | No Coating | 1.1 - 1.5 | 3.2 - 4.5 | Etched But Not Coated | 0.8 - 1.0 |
| **After 278 Days at Ambient** | Small Nodules on Fine Scratches | Small Nodules on Fine Scratches | Small Nodules on Fine Scratches | Scattered Small Nodules | No Growths | Small Nodules on Fine Scratches; **2 Short Whiskers** | Small Nodules on Fine Scratches | Small Nodules on Fine Scratches; **1 Short Whisker** | No Growths | No Growths | No Growths | Nodules; **Whiskers** | Scattered Small Nodules | Scattered Small Nodules | | No Growths |
| **After 278 Days at Ambient + 63 Days in 50°C/50%RH** | Nodules on Scratches; **Scattered Whiskers** | Nodules on Scratches | Nodules on Scratches | Nodules on Scratches; **Scattered Whiskers** | Nodules on Scratches | **Many Whiskers** | OSE's + **Some Whiskers** | **Many Whiskers Tenting Coating** | **Many Whiskers (Some Very Long)** | Small Nodules on Scratches | Small Nodules on Scratches | **Many Whiskers** | **Scattered Whiskers (Some Very Long)** | **1 Whisker** | **Many Whiskers** (after 177 Days at Ambient + 84 Days in 50°C/50%RH) | No Growths |
| **After 278 Days at Ambient + 119 Days in 50°C/50%RH** | **Many Whiskers** | Many OSE's (Some in Bubbles) | Many OSE's (Some in Bubbles) | **Many Whiskers** | Nodules | **Many Whiskers** | **Coating Penetrated by Whiskers** | **Many Whiskers Tenting Coating** | **Many Whiskers** | Many OSE's in Bubbles; **Coating Penetrated by OSE's and Whiskers** | **1 Whisker under Coating** | | | | | No Growths |
| **After 278 Days at Ambient + 336 Days in 50°C/50%RH** | **Many Whiskers** | Many OSE's in Bubbles | Many OSE's in Bubbles; **Short Whiskers in Bubbles** | **Many Whiskers** | A few OSE's in Bubbles; **Coating Penetrated by Whiskers** | **Many Whiskers** | | **Many Whiskers Tenting Coating** | **Many Whiskers** | | Many OSE's in Bubbles; **Short Whiskers in a Bubble** | **Many Whiskers** | **Coating Penetrated by OSE's and Whiskers**; a Few OSE's in Bubbles | Many OSE's and **a Few Whiskers**; a Few OSE's in Bubbles | | **Very Few Whiskers but Coating was Penetrated** |




**Nodule**




**Odd Shaped Eruption (OSE)**




**Whisker**

**Figure 2. Different Types of Growths**

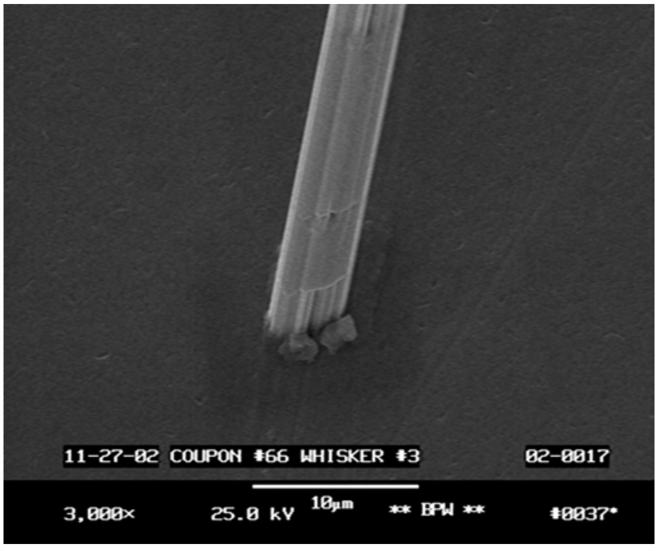



**Figure 3. Organic? Material on Whisker**

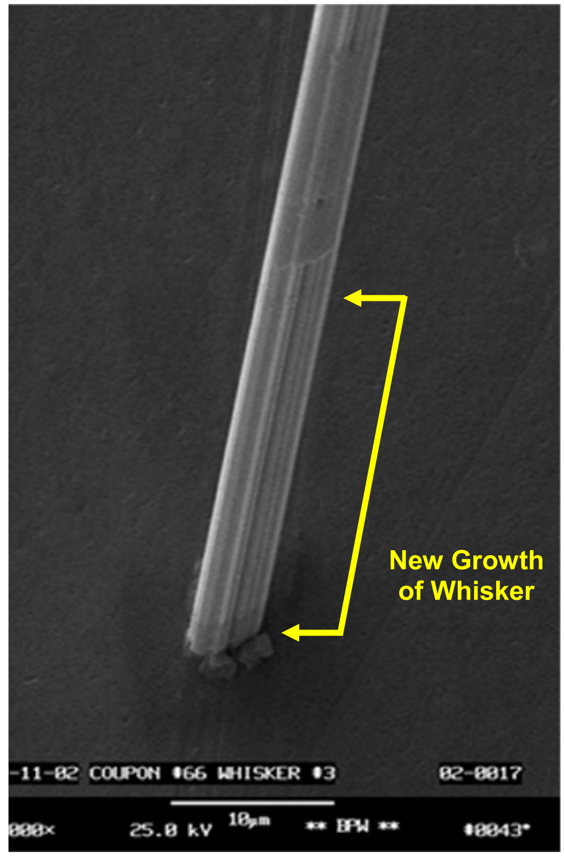



**Figure 4. Same Whisker as Shown in Figure 3. (Note New Growth of Whisker after 14 Days and that Organic? Material Moves with Whisker)**

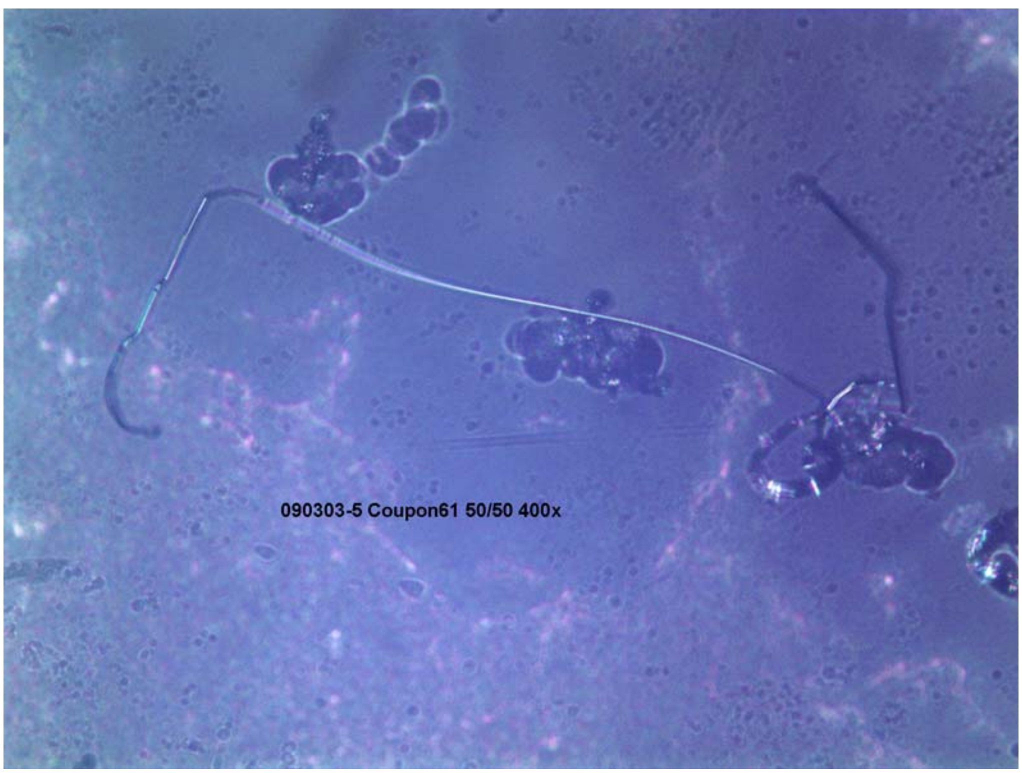



**Figure 5. 300 Micron Whisker Growing under Coating E – 1.3 Mils (278 Days at Ambient + 46 Days in 50°C/50%RH)**

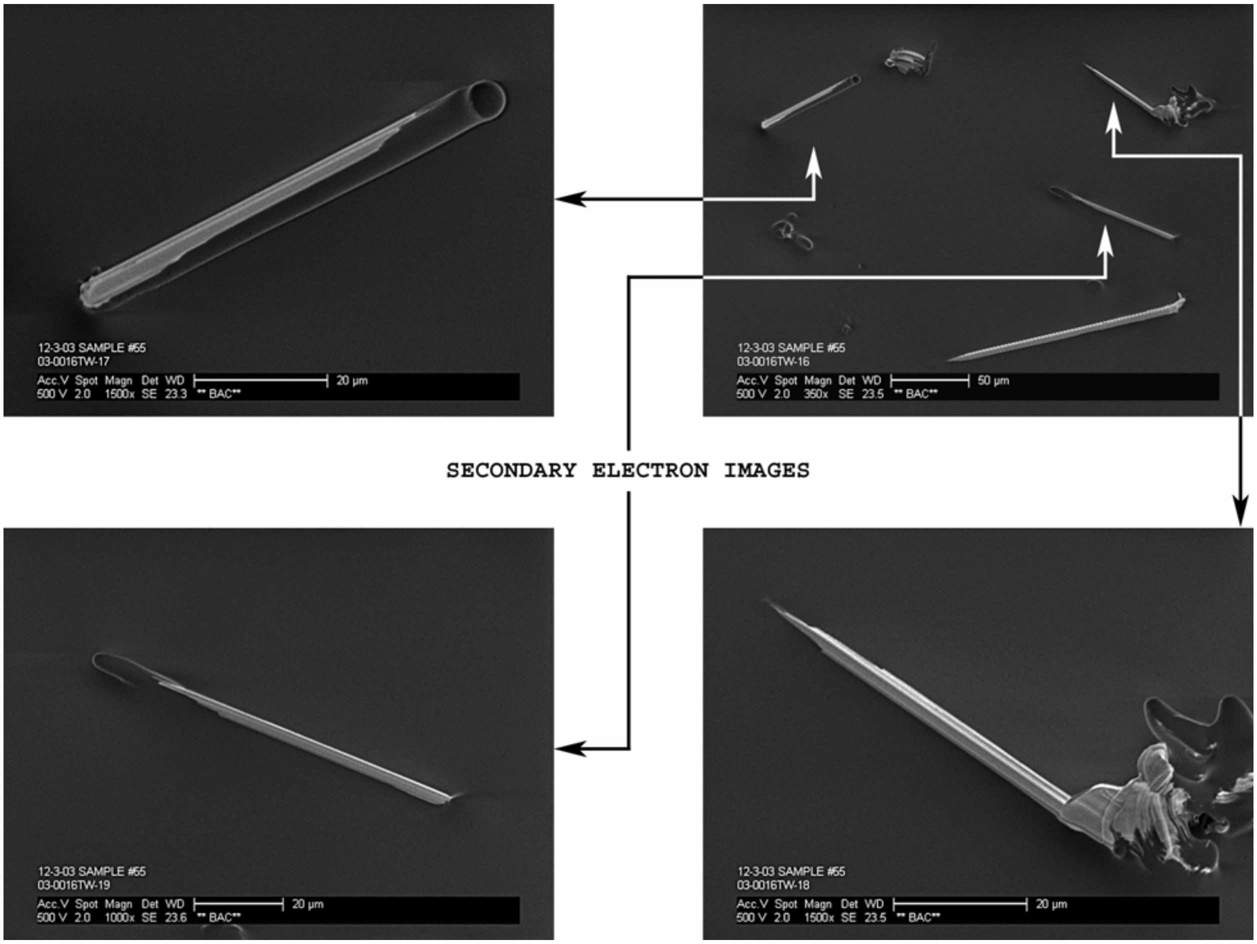



**Figure 6. Whiskers Penetrating Coating C – 0.6 Mils (278 Days at Ambient + 119 Days in 50°C/50%RH)**

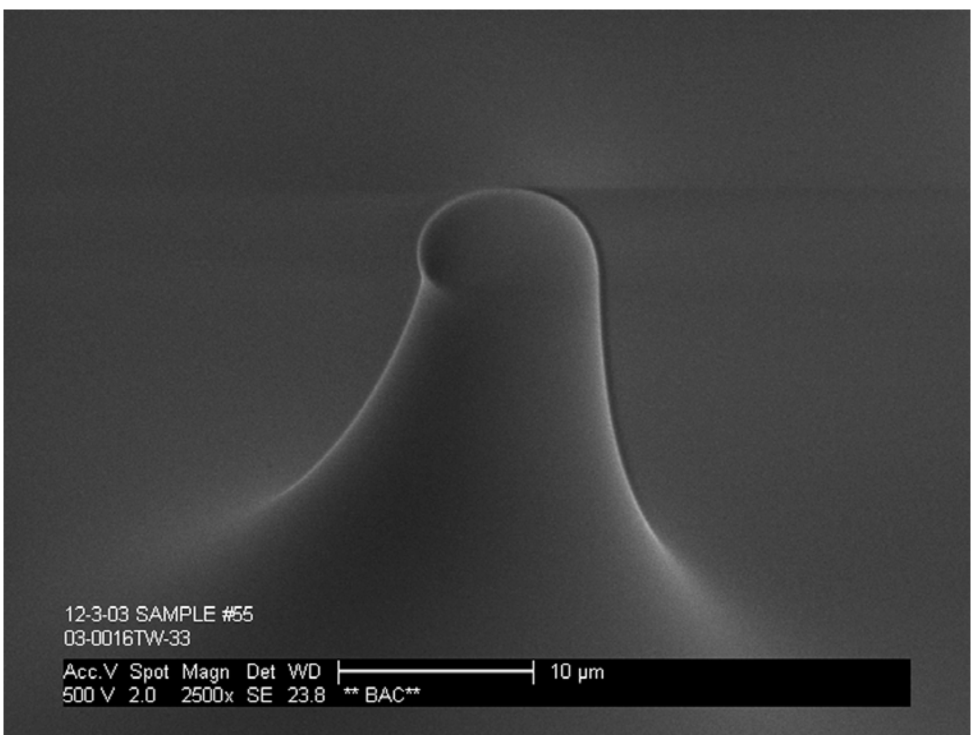



**Figure 7. "Tenting" of Coating C – 3.9 Mils (278 Days at Ambient + 137 days in 50°C/50%RH)**


**Figure 8. OSE's and Whiskers Erupting through Coating D – 1.1 Mils (278 Days at Ambient + 147 Days in 50°C/50%RH)**

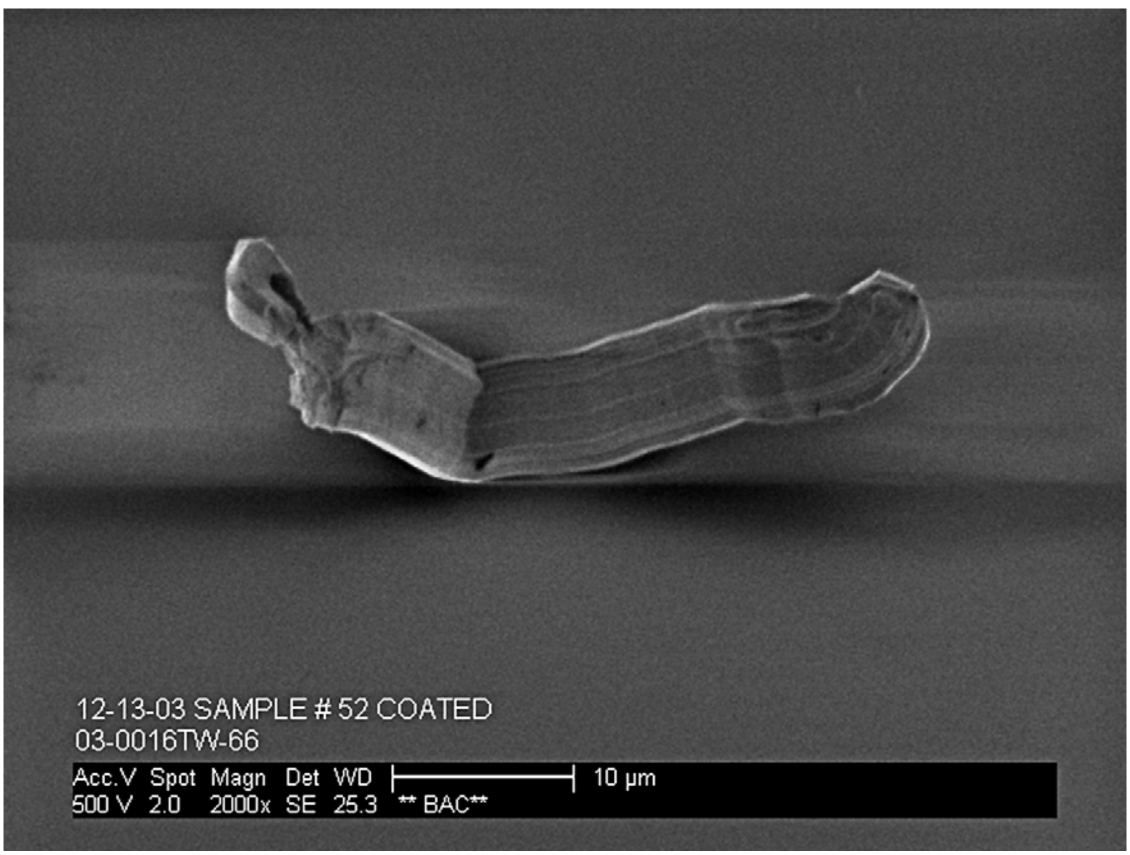



**Figure 9. Whisker Penetrating Coating D – 1.1 Mils (278 Days at Ambient + 147 Days in 50°C/50%RH)**

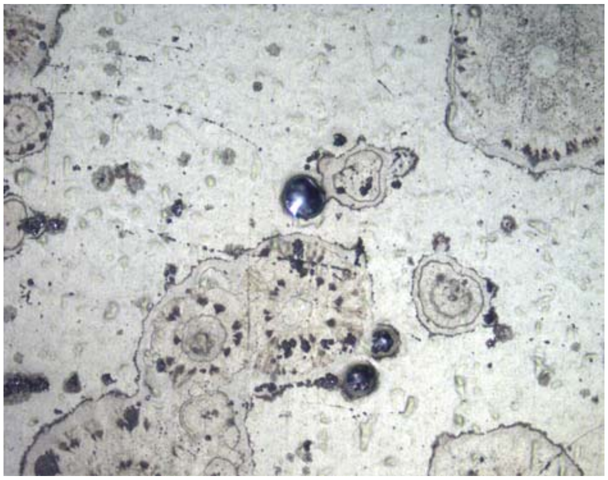


**Figure 10. Optical Microscope Image of Coating B Showing Example of OSE's in Bubbles – 1.5 Mils (278 Days at Ambient + 419 Days in 50°C/50%RH)**

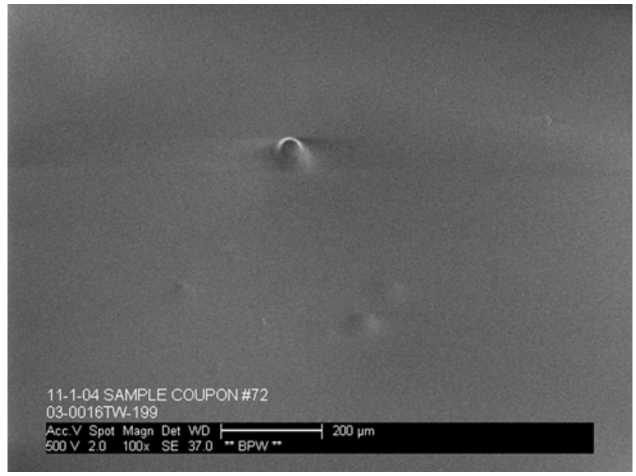



**Figure 11. SEM Image of Same Area as Figure 10**

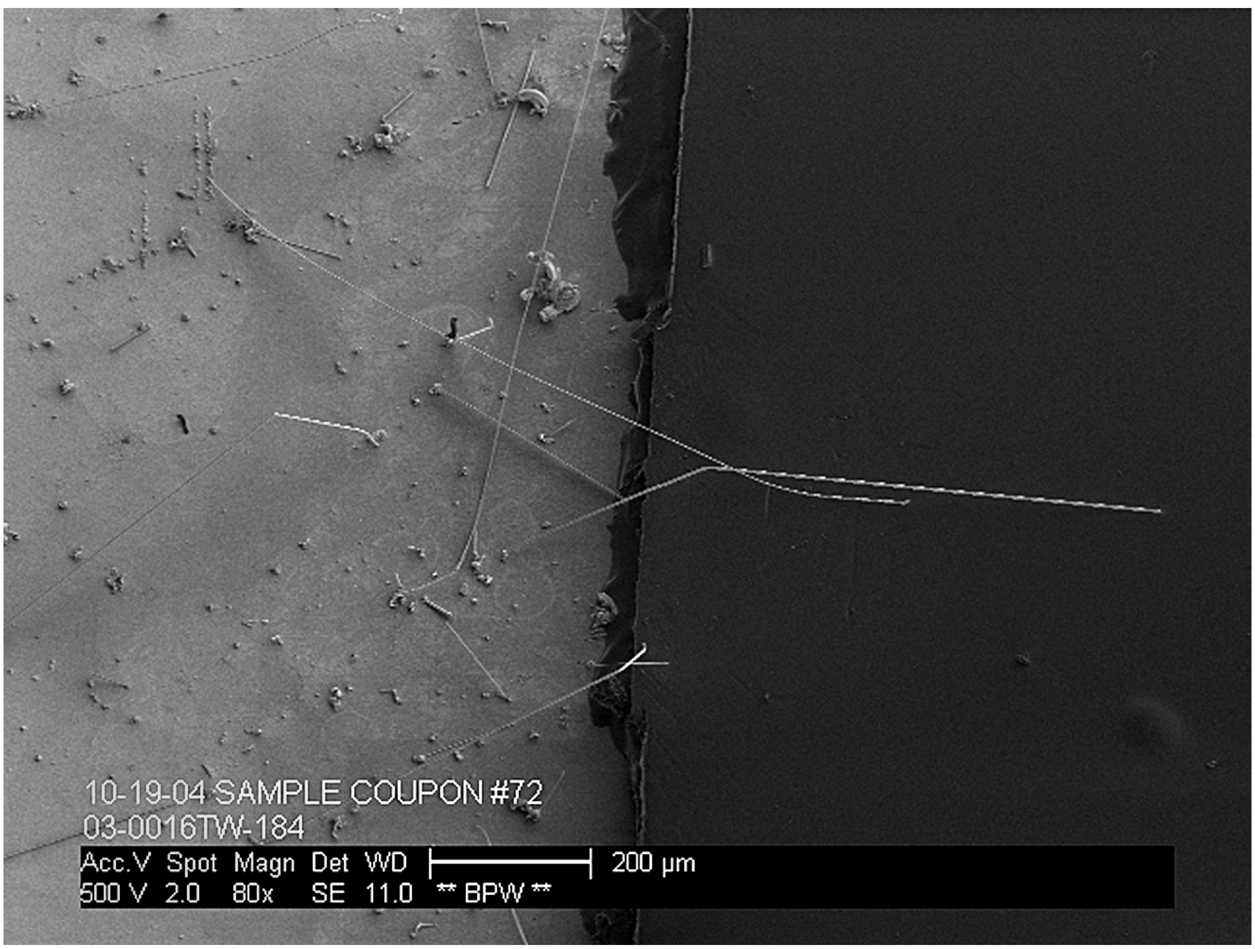



**Figure 12. Coating B – Demarcation Line between Coated Area (1.5 Mils) and Uncoated Control Area (278 Days at Ambient + 419 Days in 50°C/50%RH)**

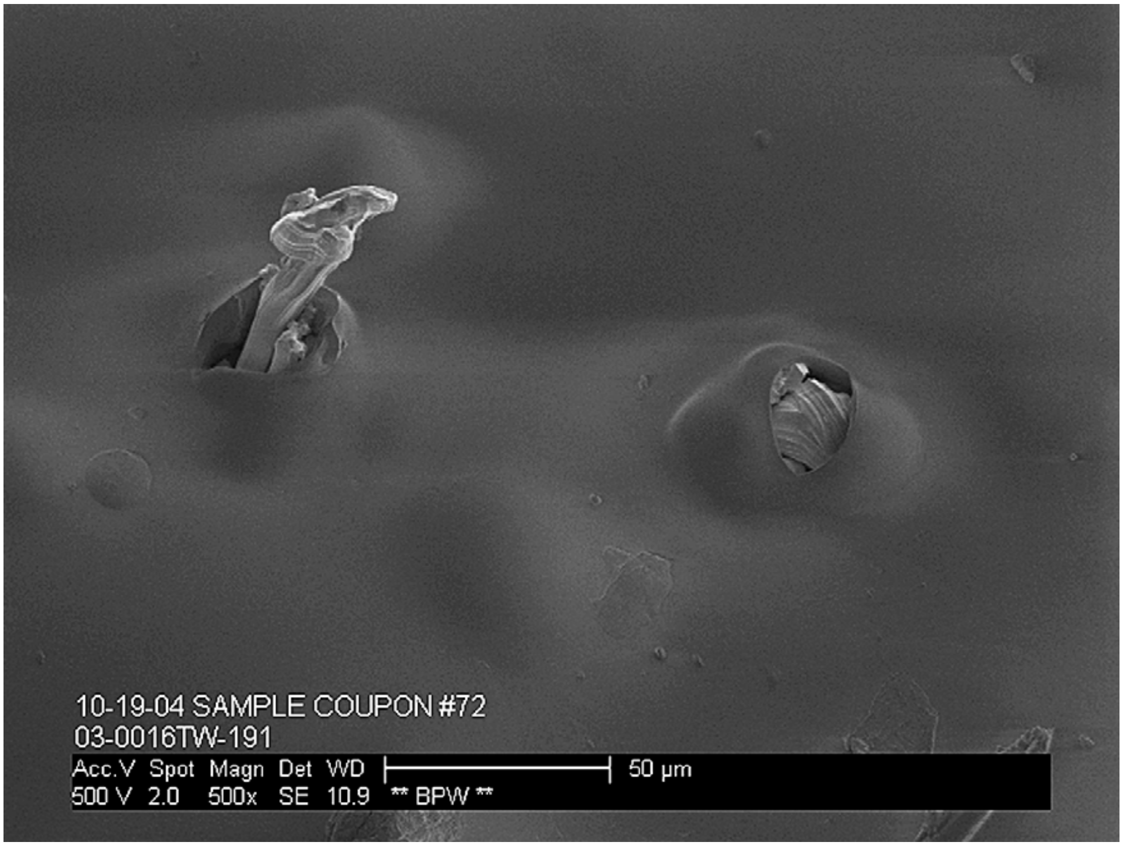



**Figure 13. Whisker Penetrating Coating B – 1.5 Mils (278 Days at Ambient + 419 Days in 50°C/50%RH)**

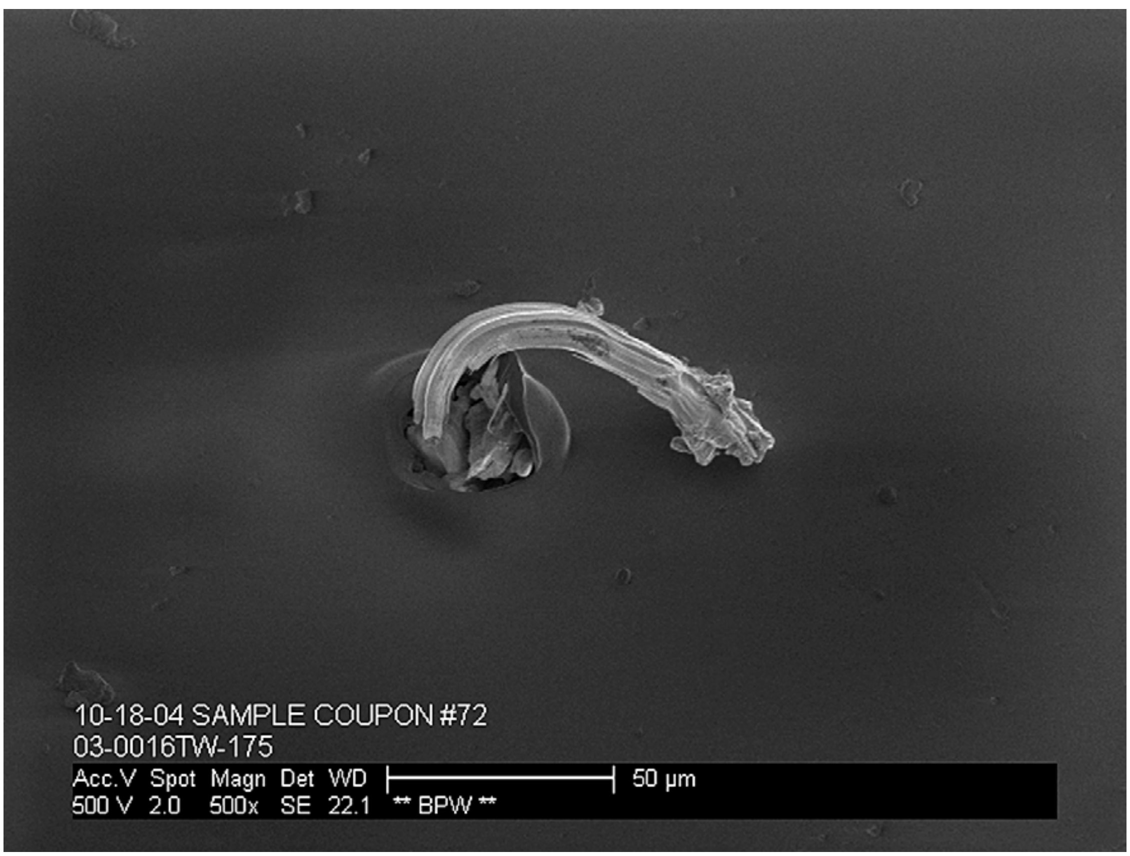



**Figure 14. Whisker Penetrating Coating B – 1.5 Mils (278 Days at Ambient + 419 Days in 50°C/50%RH)**

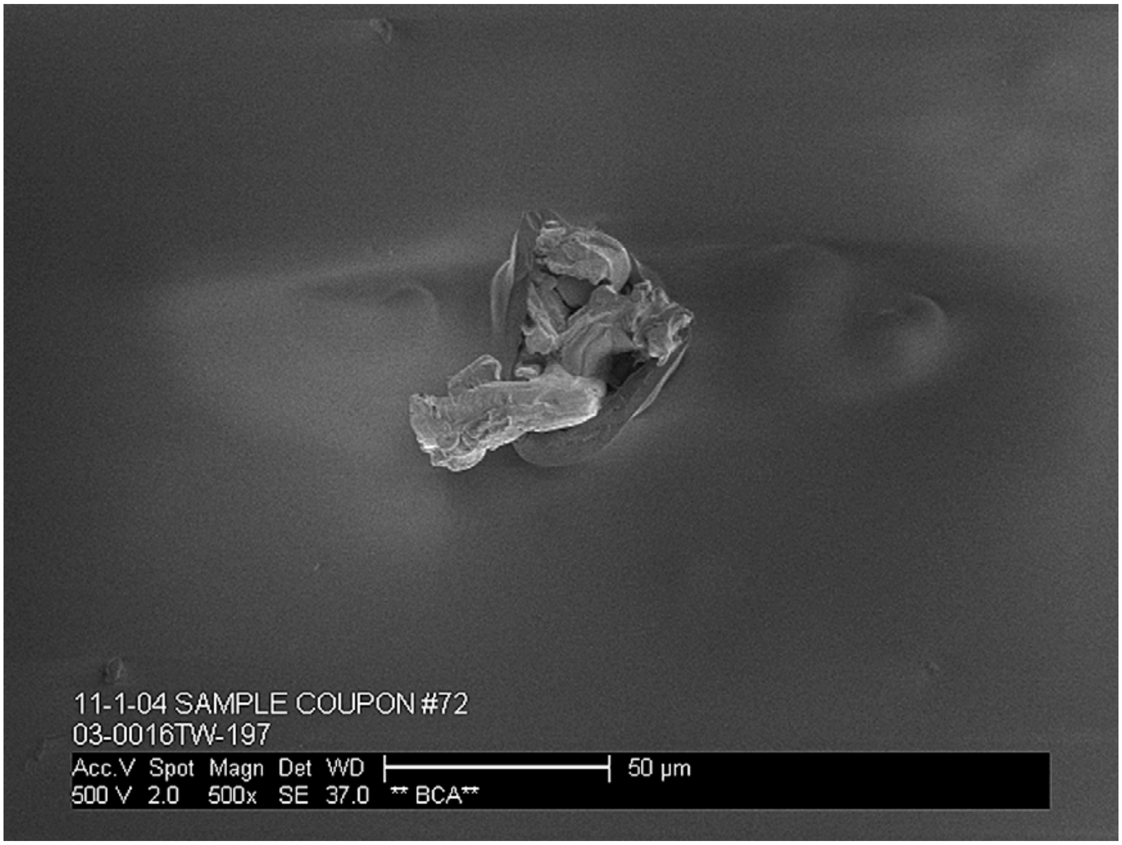



**Figure 15. Whisker Penetrating Coating B – 1.5 Mils (278 Days at Ambient + 419 Days in 50°C/50%RH)**


**Coated Side** **Uncoated Side**

**Figure 16. Coating B – 1.5 Mils (278 Days at Ambient + 336 Days in 50°C/50%RH)**


**Uncoated Side** **Coated Side**

**Figure 17. Control Area for Coating E (278 Days at Ambient + 419 Days in 50°C/50%RH)**


**Figure 18. Whisker Penetrating Coating E – 1.3 Mils (278 Days at Ambient + 419 Days in 50°C/50%RH)**

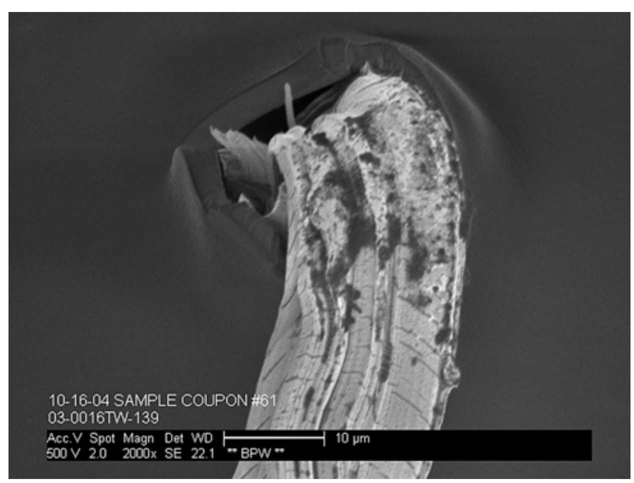



**Figure 19. Whisker Penetrating Coating E – Enlargement of Figure 18**

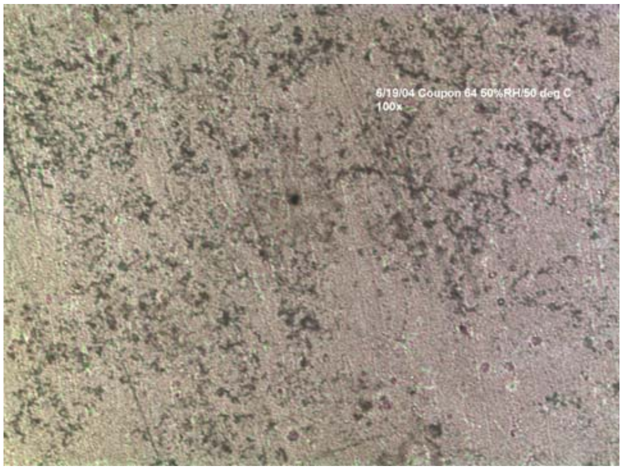



**Figure 20. Parylene C – 0.8 Mils, Note Mottling of Tin Plating but No Growths (278 Days at Ambient + 336 Days in 50°C/50%RH)**

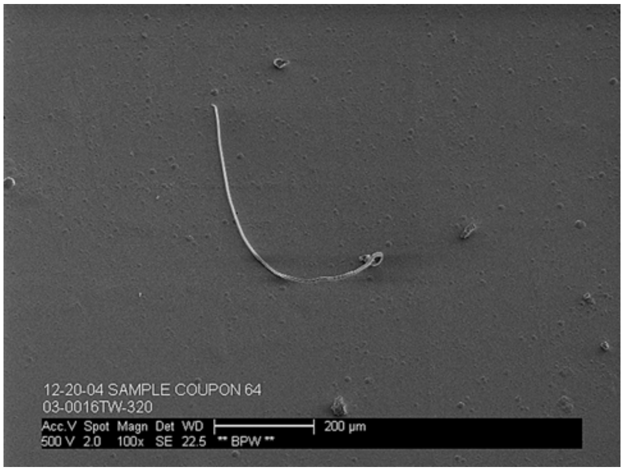



**Figure 21. Whisker Penetrating Parylene C – 0.8 Mils (278 Days at Ambient + 419 Days in 50°C/50%RH)**

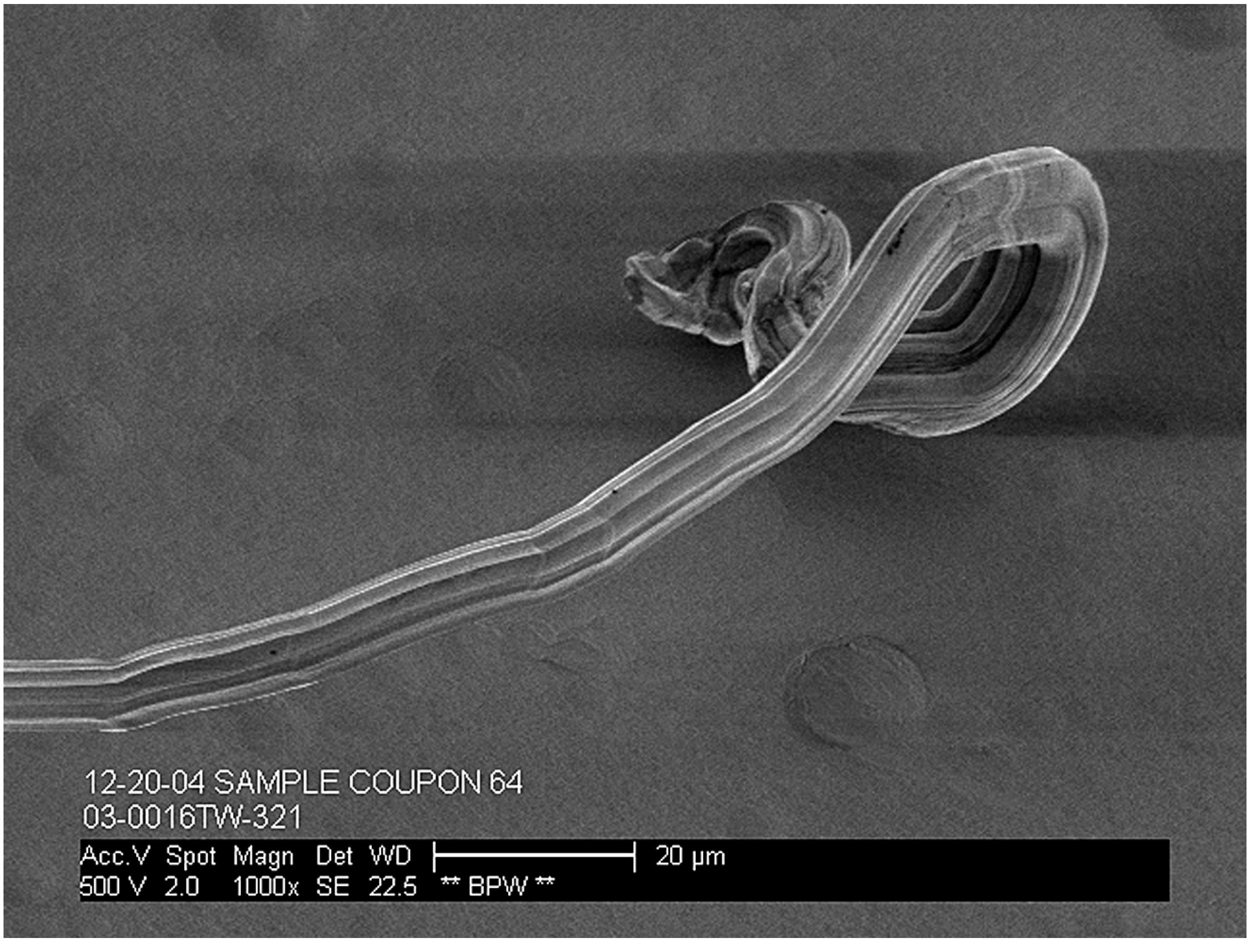



**Figure 22. Whisker Penetrating Parylene C – Enlargement of Figure 21**


**Figure 23. Coating A – 6.0 Mils (278 Days at Ambient + 336 Days in 50°C/50%RH)**


**Figure 24. Coating D – 4.6 Mils, OSE's and Whisker in a Bubble (278 Days at Ambient + 318 Days in 50°C/50%RH)**

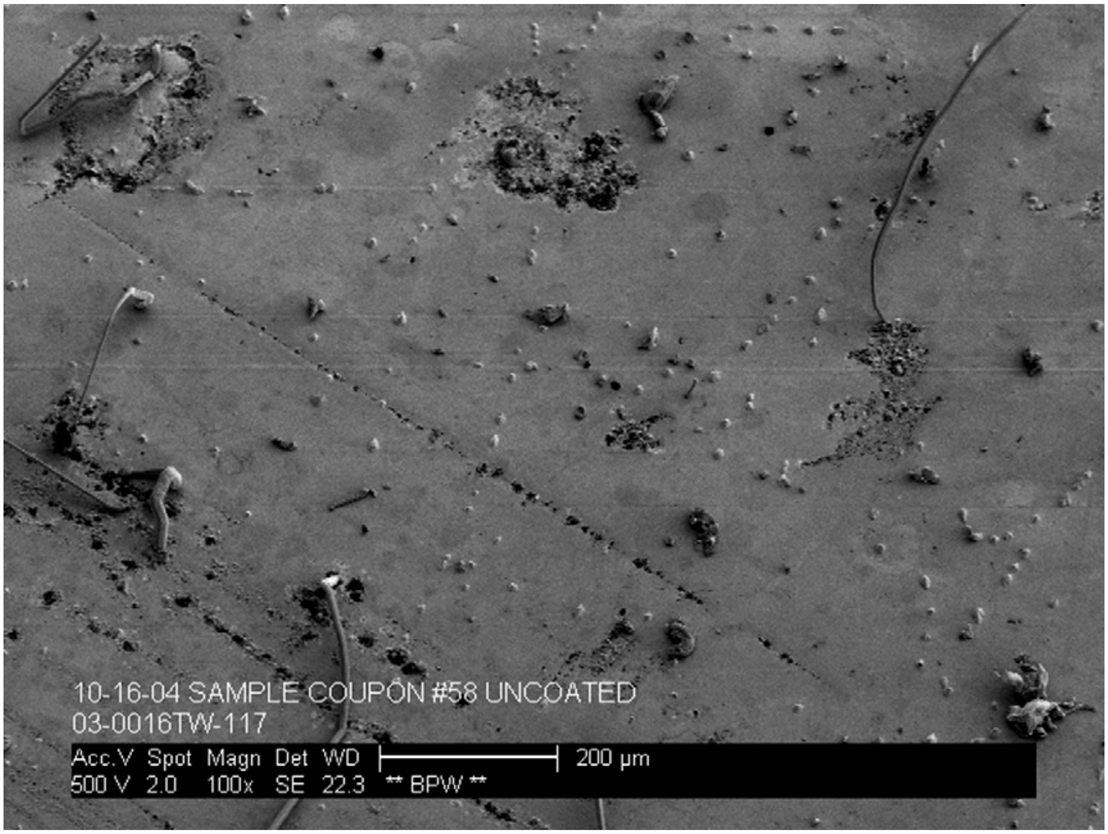



**Figure 25. Control Area for Coating A (278 Days at Ambient + 419 Days in 50°C/50%RH)**

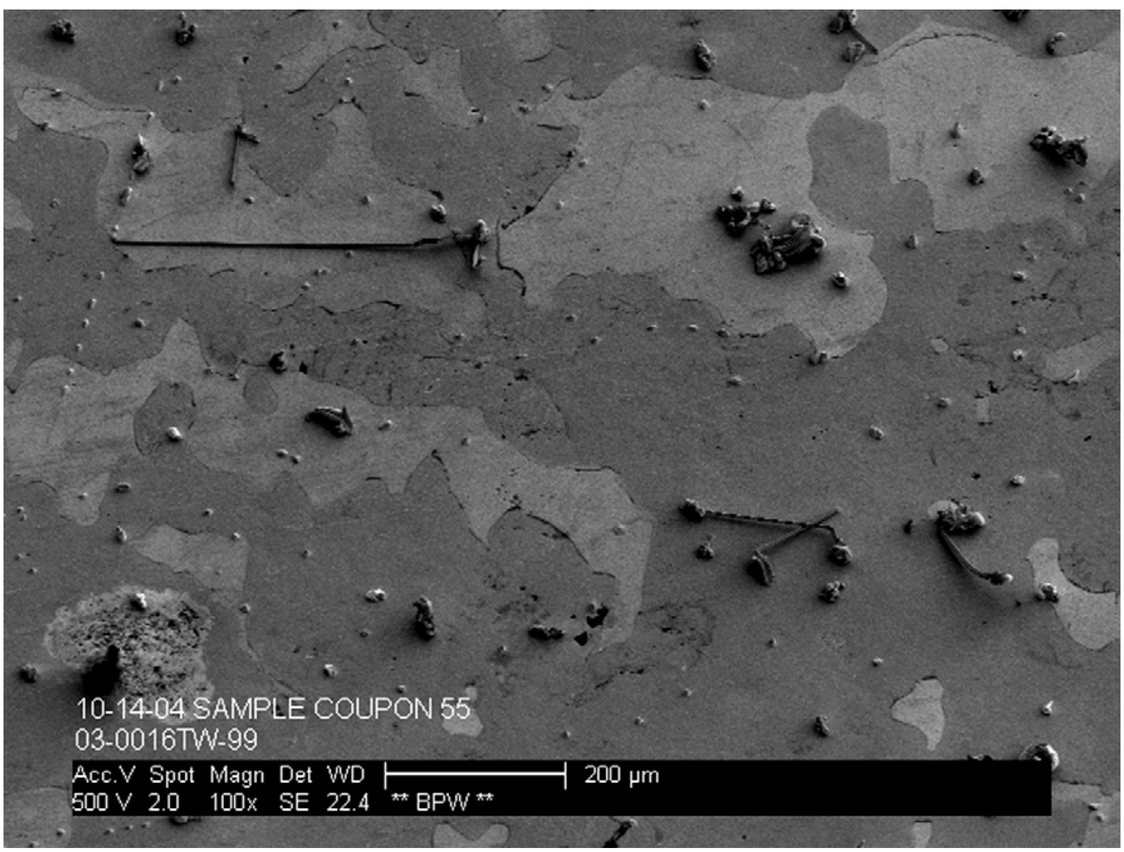



**Figure 26. Control Area for Coating C (278 Days at Ambient + 419 Days in 50°C/50%RH)**

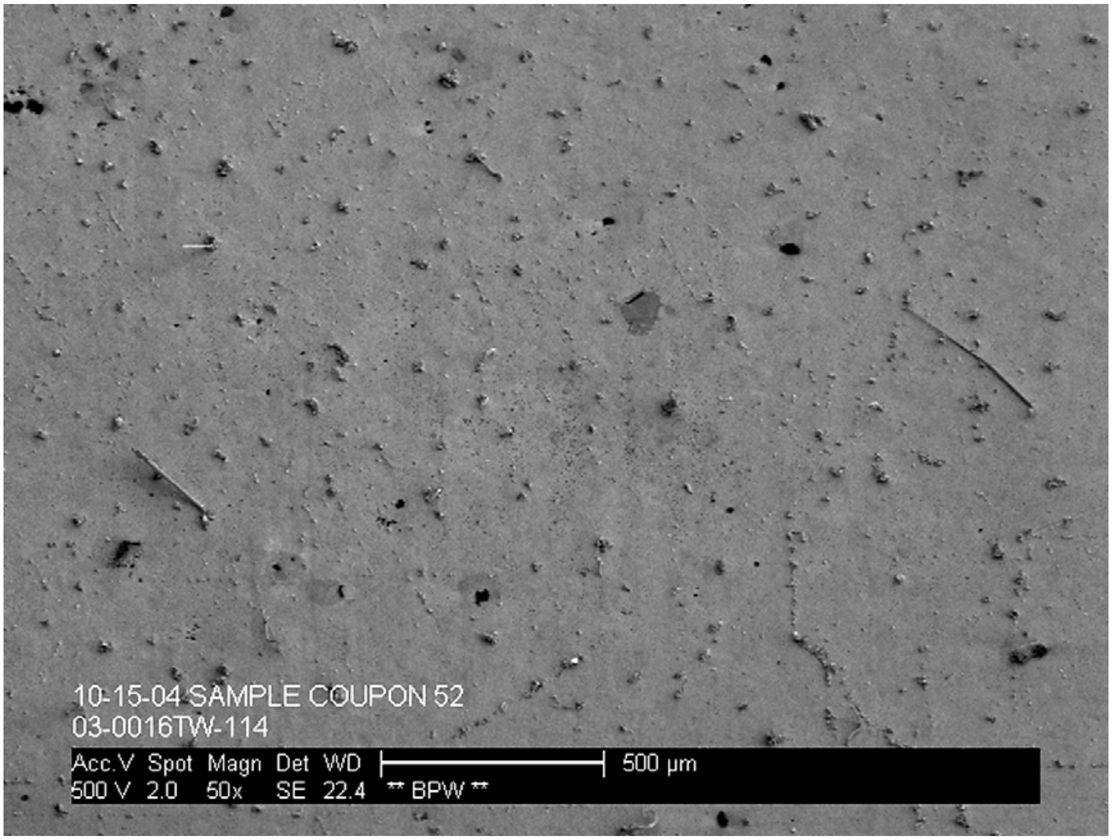



**Figure 27. Control Area for Coating D (278 Days at Ambient + 419 Days in 50°C/50%RH)**

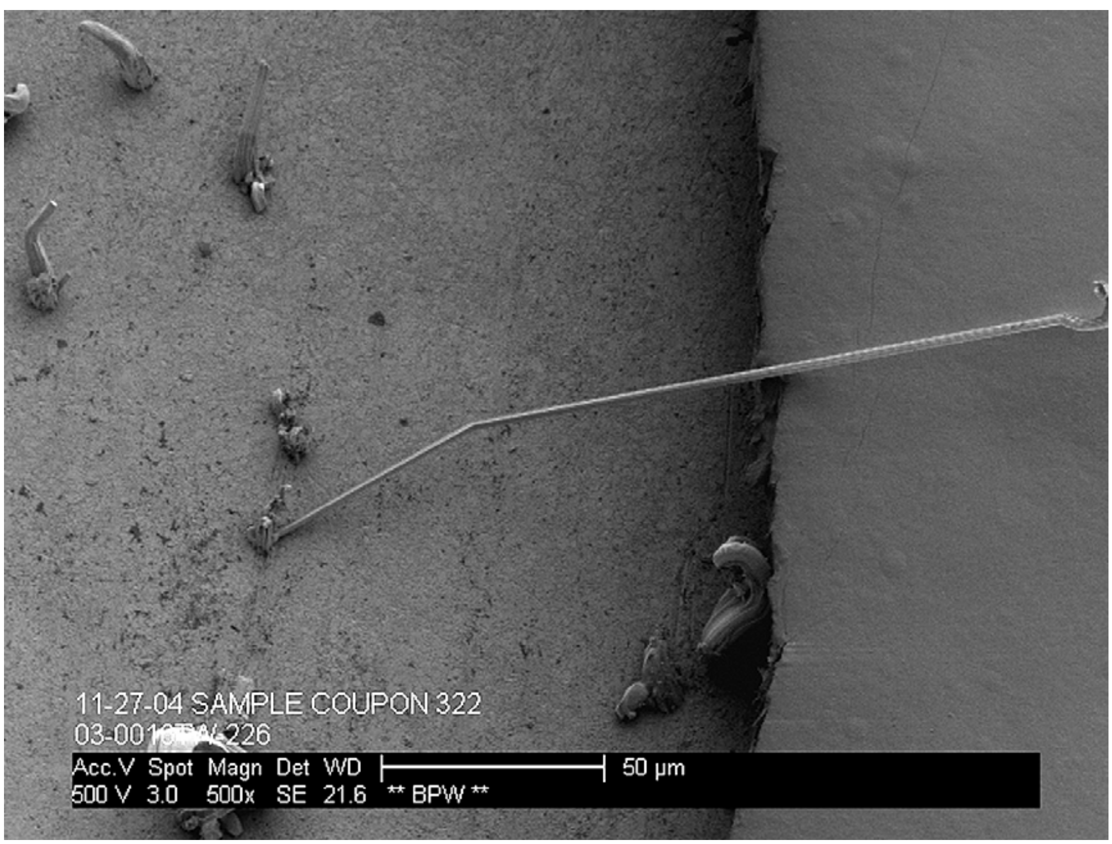



**Figure 28. Control Area for Parylene C – Chemically Etched but not Coated (177 Days at Ambient + 84 Days in 50°C/50%RH)**

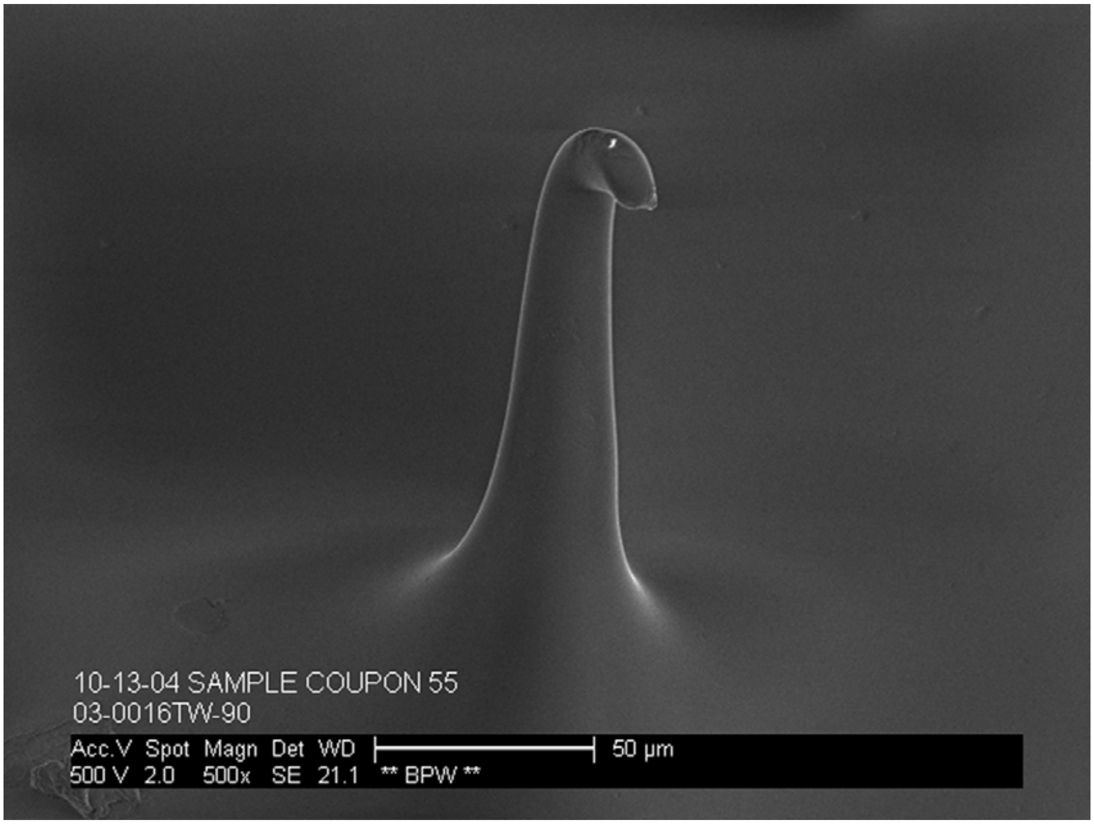



**Figure 29. Coating C – 3.9 Mils (278 Days at Ambient + 419 Days in 50°C/50%RH)**


**Figure 30. Coating C – 3.9 Mils (278 Days at Ambient + 336 Days in 50°C/50%RH)**

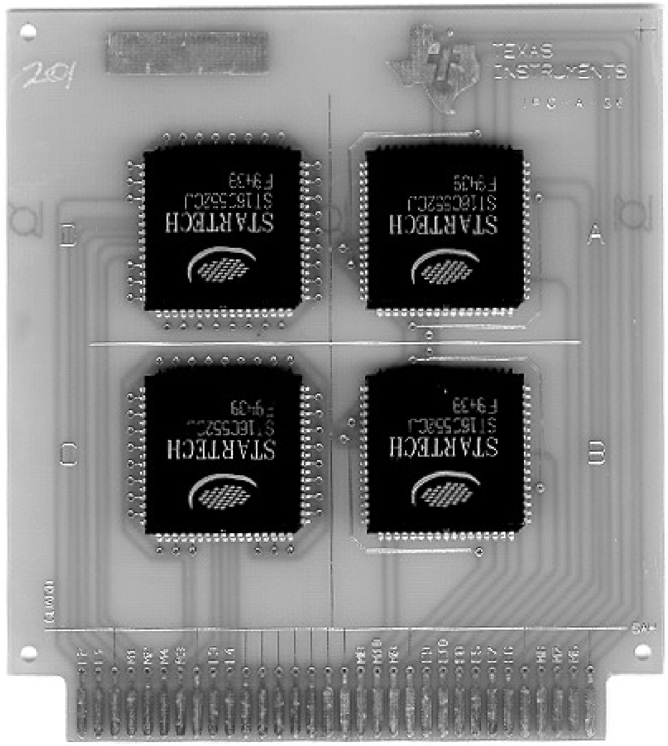



**Figure 31. PLCC64's Used to Evaluate Conformal Coating Coverage on Leads**

**Table 3. Evaluation of Lead Coverage using Resistance Measurements**

| | Coating D (Urethane Acrylic) | Coating E (Urethane Acrylic) | Parylene C |
|---|---|---|---|
| **Measured Thickness of Coating on Flat Area of Test Board (mils)** | 4.6 | 1.8 | 0.85 |
| **Sufficient Coverage on Front of PLCC64 Leads?** | No | No | Yes |
| **Sufficient Coverage on Back of PLCC64 Leads?** | No | No | Yes |

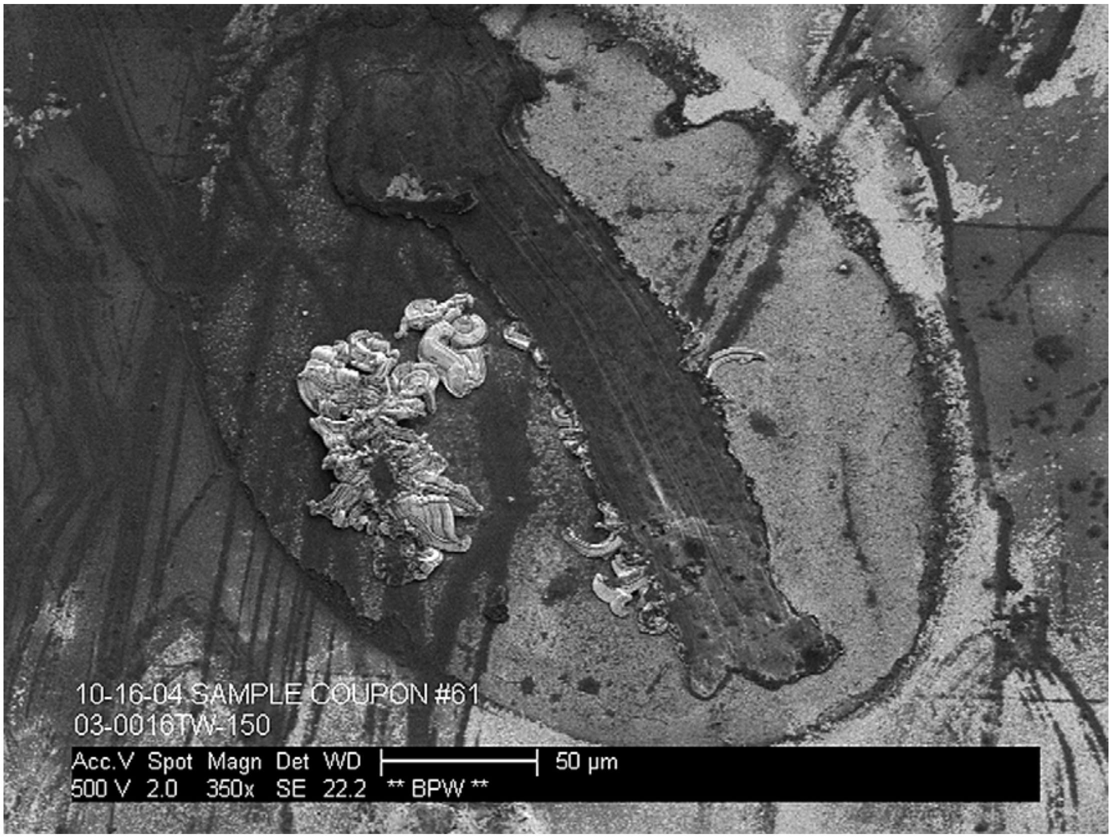



**Figure 32. Coupon after Removal of 1.3 Mils of Coating E (278 Days at Ambient + 419 Days in 50°C/50%RH), Note Oval Demarcation Line Where Bubble Was**

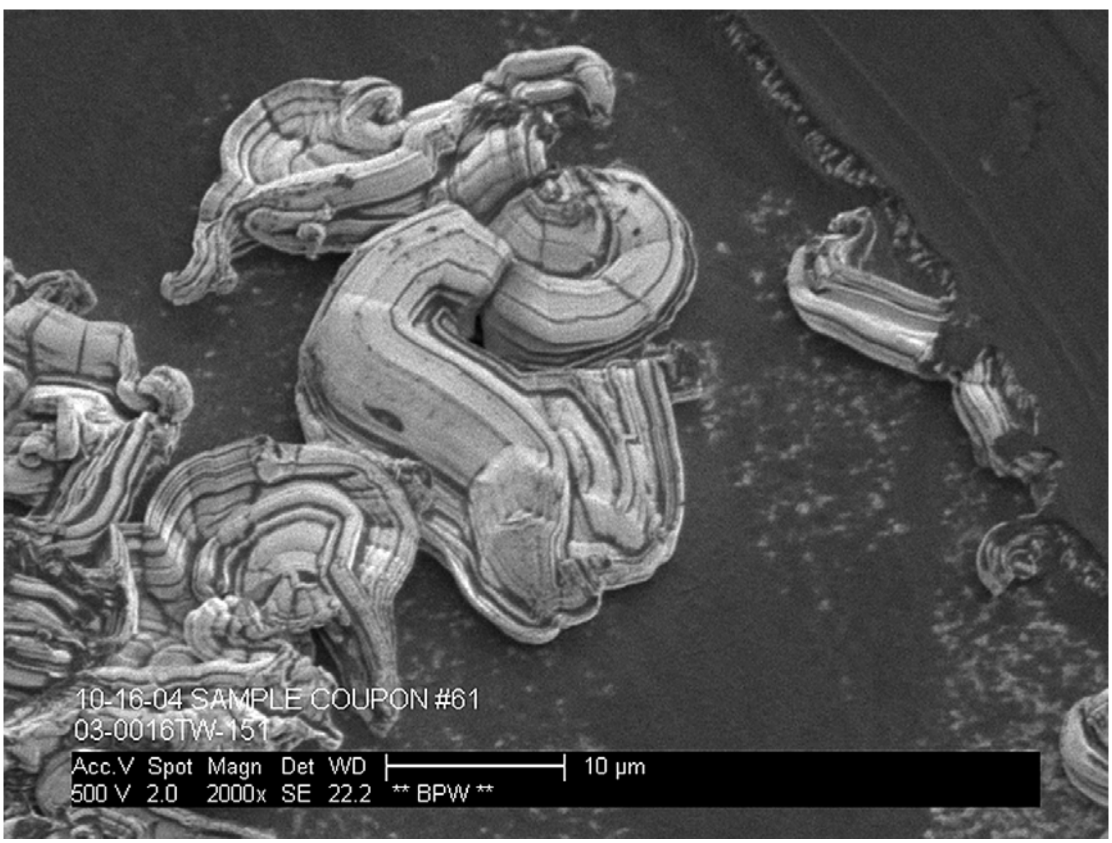



**Figure 33. Enlargement of Figure 32**

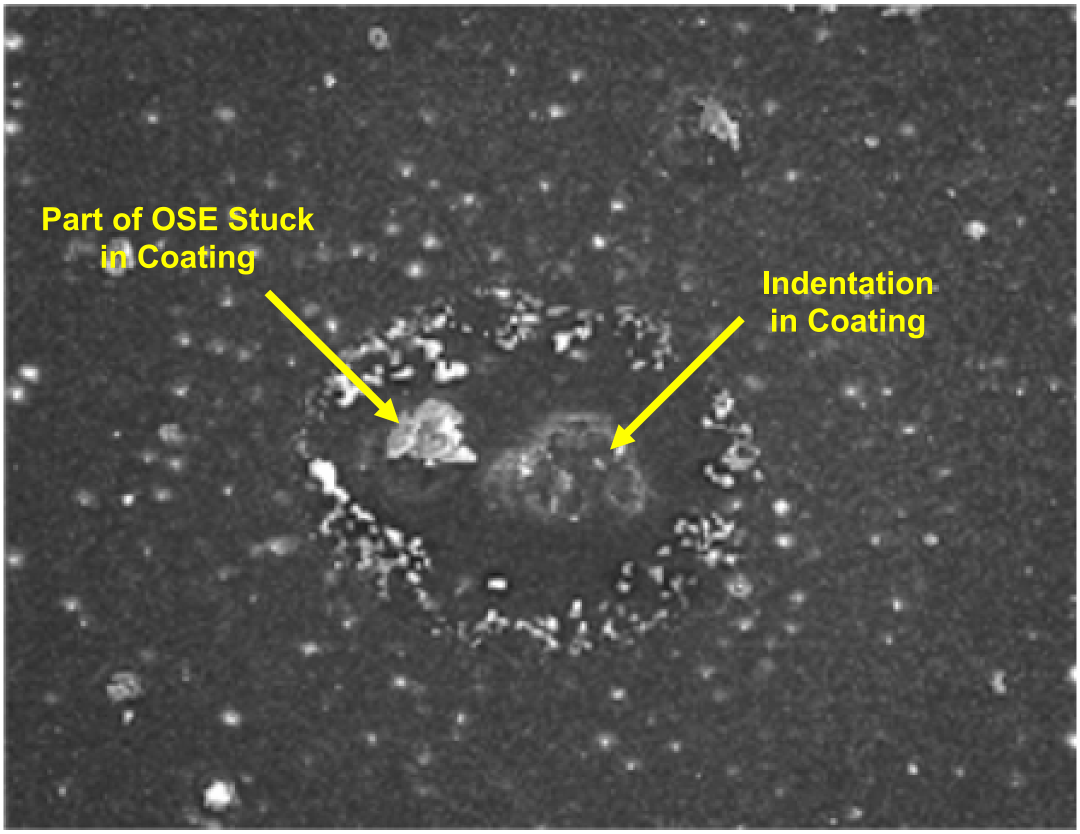



**Figure 34. Coating E (4.0 Mils Thick) after Removal from Coupon**

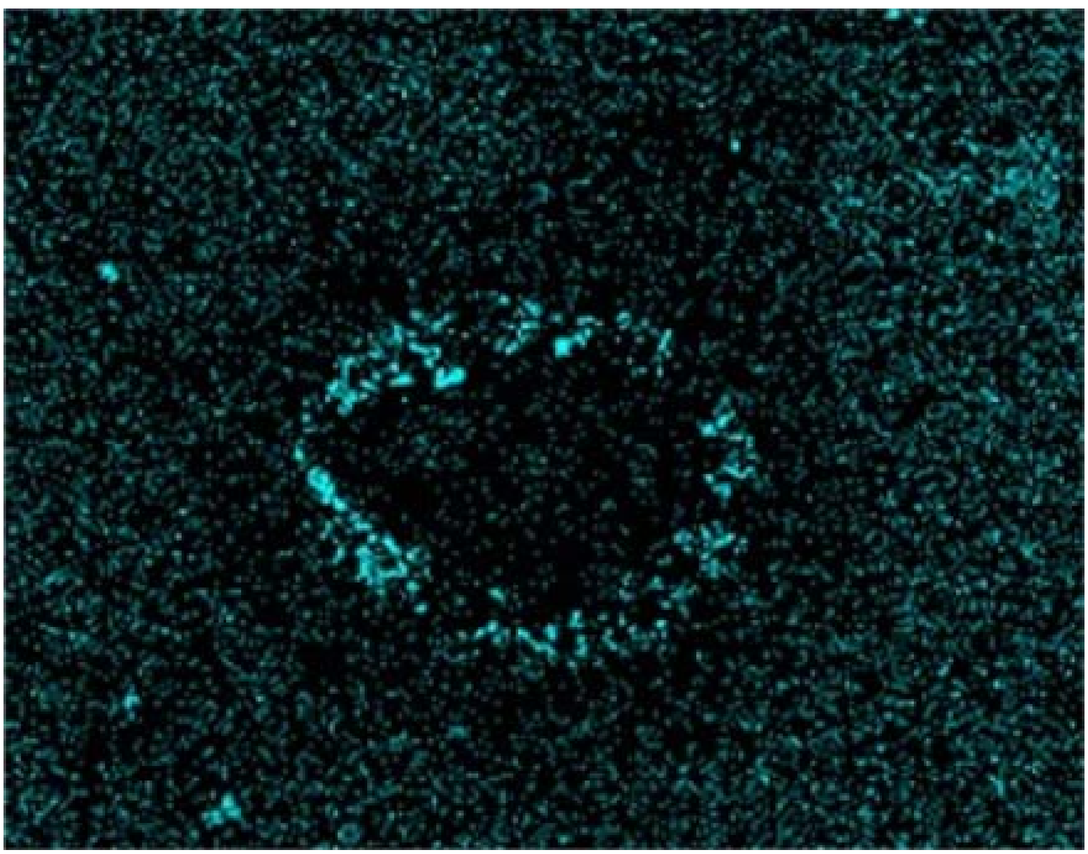


**Figure 35. Zinc EDS Map of Coating in Figure 34 Showing "Zinc Ring"**

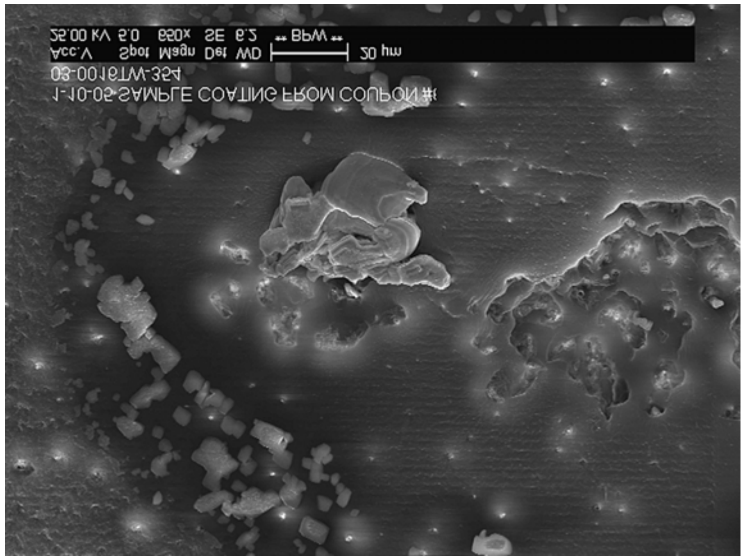


**Figure 36. Coating E after Removal from Coupon (Same as Figure 34)**

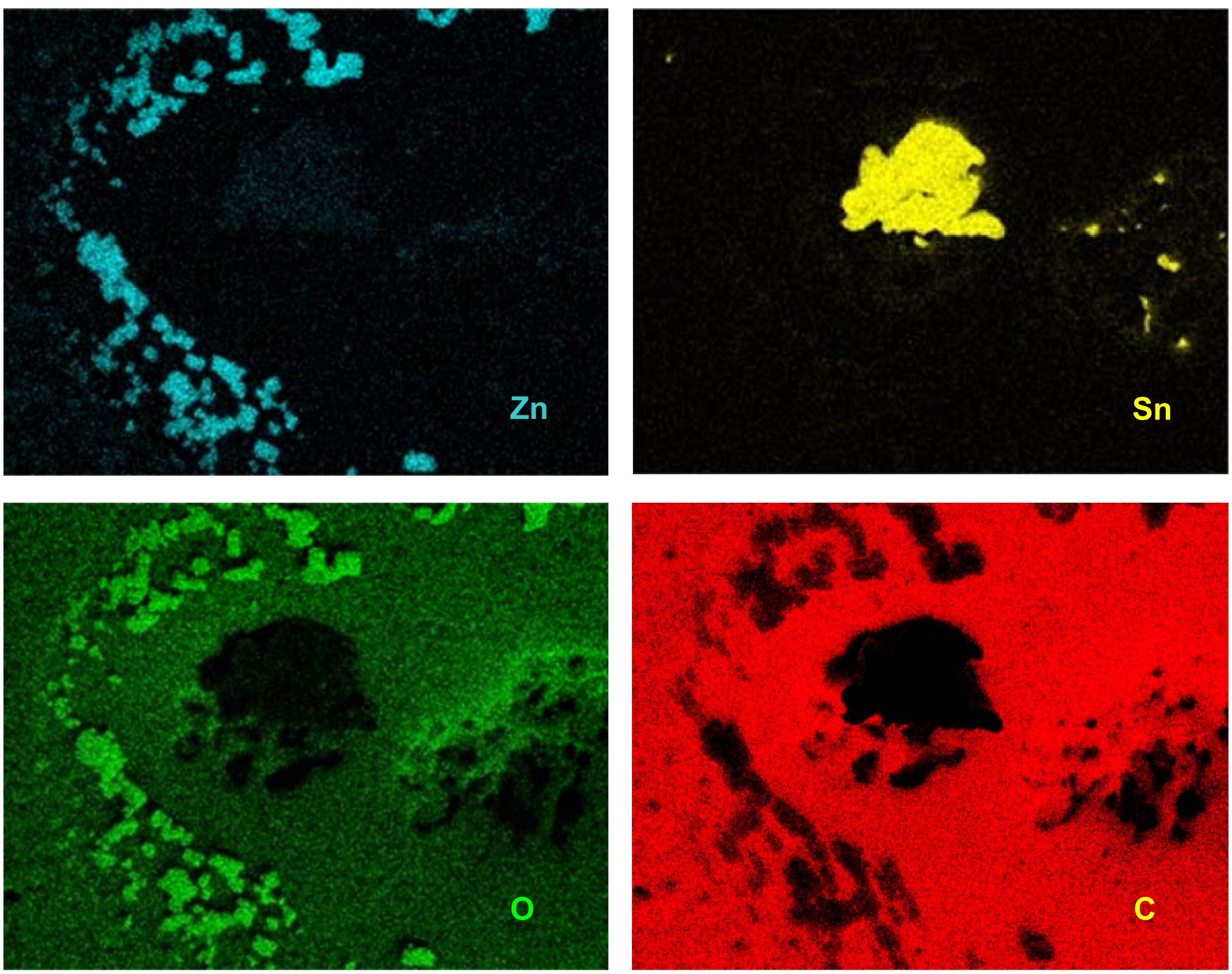



**Figure 37. EDS Elemental Maps of Coating E after Removal from Coupon (Same as Figure 36)**

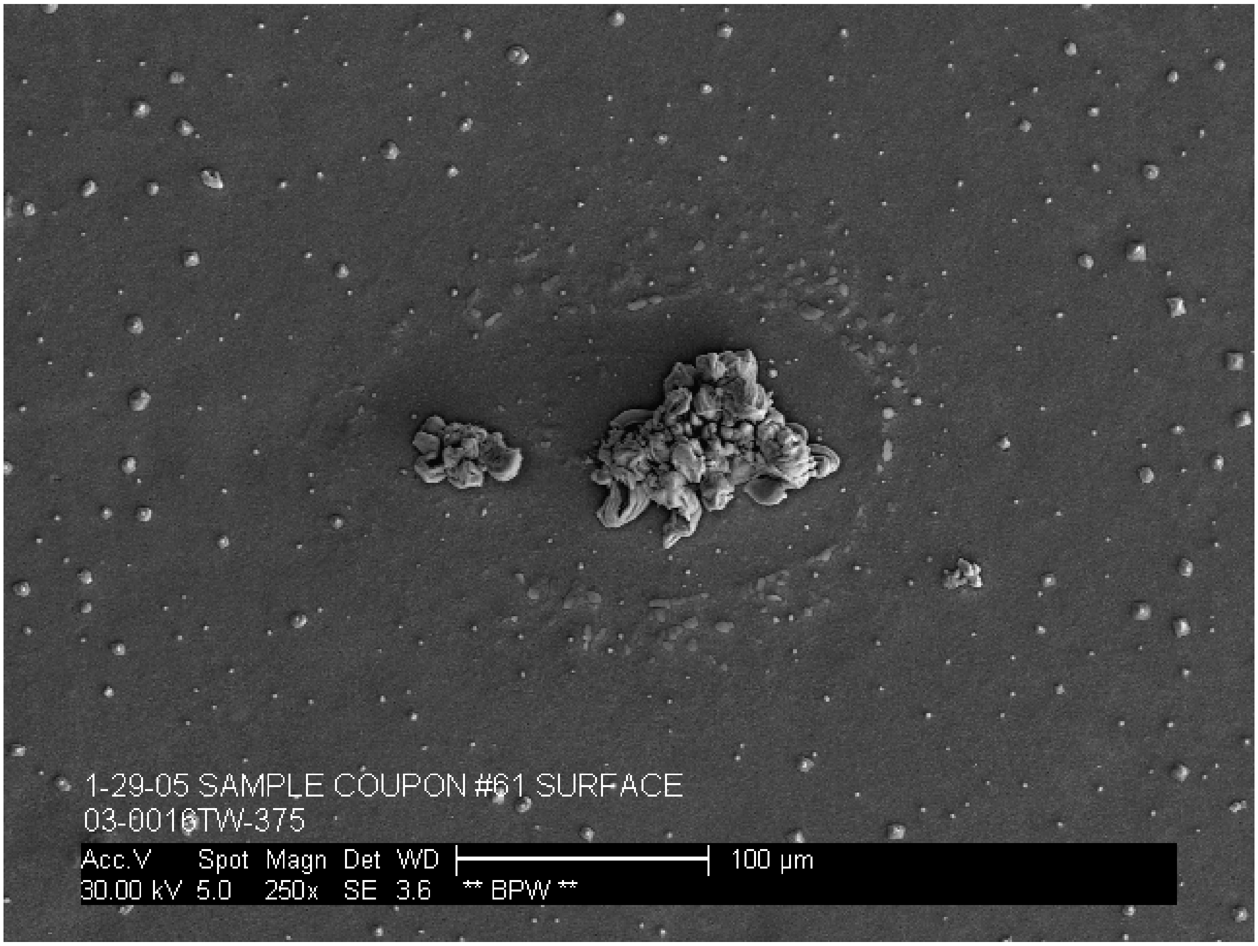



**Figure 38. Surface of Coupon that Matches Up with Coating in Figure 34**

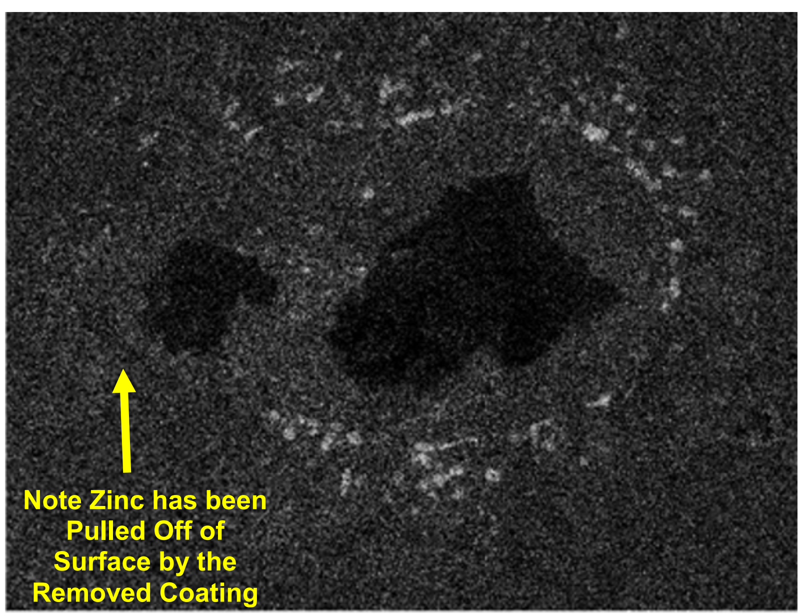



**Figure 39. Zinc EDS Map of Coupon in Figure 38 Showing "Zinc Ring"**