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EVALUATION OF CONFORMAL COATINGS AS A TIN WHISKER MITIGATION STRATEGY, PART II

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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 25°C/97%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, all of the coatings were penetrated regardless of the coating thickness. These observations differ from a prior study in which the coupons were aged in a 50°C/50%RH environment. In that study, only the thinner (less than 1.5 mil) coatings were penetrated by whiskers or OSE's during the test. In this current study, unusual eruptions of tin were observed that were capped with a thick crust of material. Auger analysis suggested that the crust was a mixture of tin, tin oxide and zinc oxide.

Key Words: tin whiskers, conformal coatings, mitigation

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 (75 microns) of conformal coating. 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 of the Phase II 25°C/97%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 (approximately 3 mil) of coating. The middle of each coupon was left uncoated to serve as a control. The exception was the coupon coated with Parylene C. The Parylene C was applied over the entire surface of the coupon (0.4 – 0.5 mil thick) leaving no control area.

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). Six measurements of each coating were taken at random spots on the coupon and then averaged.

The coated coupons were allowed to sit for 401 days in a laboratory environment (ambient temperature and humidity). Most of the coated areas had only nodules forming under the coatings with no significant whisker growth. The coupons were then placed into a dessicator over saturated potassium sulfate solution mixed with solid potassium sulfate. At 25°C, the relative humidity in the dessicator remained constant at 97%. The coupons were allowed to sit in the dessicator at 25°C for an additional 347 days in an attempt to accelerate whisker formation and 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.

RESULTS AND DISCUSSION

Aging of the test coupons in a laboratory environment (ambient temperature and humidity) for 401 days resulted in the formation of nodules and whiskers on the uncoated control areas. In contrast, Coatings A, B, C, and D had only nodules growing under the coatings. Coating E had nodules and several whiskers growing under the coating. Parylene C had no growths of any kind under the coating at this point (see Table 2).

Placing the coupons into a dessicator held at 25°C/97%RH appeared to accelerate the formation of tin whiskers on the control areas and (to a lesser extent) underneath the coatings. The high humidity environment also caused the growth of

fungus on the coupons but the fungus filaments were easily distinguishable from tin whiskers.
At the end of 347 days in the 25°C/97%RH dessicator environment, all of the uncoated control areas on the coupons exhibited significant whisker growth (see Table 2 and Figures 3, 11, 19, 24, and 31).

After 347 days in the 25°C/97%RH dessicator environment, all of the coatings had numerous nodules and OSE's growing under them. In many cases, the OSE's caused the coatings to delaminate from the coupon and form a bubble (Figures 9 and 10). **Most significantly, all of the coatings (thin and thick) had been penetrated by whiskers and OSE's (Figures 5-8, 13-18, 20-23, 27-30 and 32-35).**

These results contrast with test results from aging the coupons for 336 days in a 50°C/50%RH environment[26]. During that test, only the thinner coatings (0.6–1.5 mils) were penetrated by whiskers and/or OSE's. Thicker coatings (3.9–6.0 mils) were not penetrated by whiskers or OSE's during the test. This suggests that the high humidity conditions used in this current test facilitated penetration of the coatings either by promoting growth of larger OSE's/whiskers or by changing the material properties of the conformal coatings so that they became easier to penetrate.

The number of whiskers penetrating each coating was not quantified since the primary intent of the study was to see if the coatings could be penetrated by even a single whisker. However, it was apparent from visual examination that Coating D had the fewest growths under the coating and Coating C had the most OSE's/whiskers actually penetrating the coating (compare Figures 4, 12, 20, 26, 36 and 39).

Close examination of Figures 13, 23, 27, 28 and 33 reveal that the thickness of each coating penetrated appears to be less than the average coating thickness as measured optically. This suggests that these whiskers were able to penetrate because they had found a thin spot in the coatings. This same phenomenon was observed in the prior 50°C/50%RH test[26].

In contrast, Figure 14 shows an OSE that appears to have penetrated a thicker spot in the coating.

Figures 8, 18, 23 and 30 show OSE's and whiskers erupting through the coatings where the brass coupon had been scribed prior to plating. It is not clear if the scribing promoted OSE and whisker growth by providing nucleation sites or if the scribe marks created thin spots in the coating because the coating ran off of the raised areas while being sprayed. These thin spots could then allow whiskers to penetrate. Note that the scribe marks covered by Parylene C do not have OSE's and whiskers on them (Figure 37). Since Parylene is applied by a vacuum deposition process, the coating tends to be very uniform regardless of surface imperfections. This observation suggests that OSE's and whiskers tend to grow on the scribe marks because the coating is thin and not because nucleation sites have been generated by the scribing process.

Thinning of the coatings will also occur on component leads as noted in the prior conformal coating test[26]. In that test, conformal coatings applied to PLCC leads by spraying yielded coatings so thin that they provided no electrical insulation. Parylene C, on the other hand, provided excellent insulation on all sides of the leads because it was applied by a vacuum deposition process which gave a uniform coating on all surfaces.

In summary, during 401 days of exposure to ambient conditions, all of the conformal coatings tested suppressed the formation of tin whiskers when compared to the uncoated controls. During subsequent exposure to high humidity, the control areas all grew large amounts of whiskers that were potentially long enough to penetrate any of the coatings being tested. The coating that best suppressed the formation of growths under the coating was Coating D. The worst coating for suppressing growths was the acrylic (Coating C) which had numerous growths under the coating and was penetrated by numerous OSE's and whiskers All of the other coatings fell somewhere in between Coating D and the acrylic in their ability to suppress nodule, OSE and whisker formation. All of the coatings (both thick and thin) were eventually penetrated by whiskers which indicates that these coatings can not be depended on as a foolproof mitigation strategy.

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, the highest tensile strength and is relatively hard. These properties suggest that Parylene C might suppress whisker formation the best due to its ability to apply the largest mechanical resistance. However, Coating D was the most effective in suppressing nodule and OSE formation in this test despite the fact that it has a lower modulus and a lower tensile strength than Parylene C.

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.

On some coupons, a thick "crust" appeared to have formed. It was thought that it might be a thick oxide layer formed by the high humidity test conditions. Figure 38 shows a piece of "crust" that has been forced up and over by an OSE.

When the coupons were removed from the 25°C/97%RH environment 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.

Many of the OSE's growing under Coating E were capped with a large platelet of "crust" (see Figures 39 – 41). EDX analysis of this "crust" showed the presence of tin, zinc, and oxygen (Figure 42). Figure 43 shows a side view of an OSE capped with "crust". The "crust" is surprisingly thick, i.e., it is approximately as thick as the original tin plating.

The "crust" was sputtered with an argon ion beam to a depth of approximately one micron. Auger Electron Spectroscopy (AES) analysis was done periodically during the sputtering and the results are shown in Table 3. The results are consistent with a "crust" composition of metallic tin, tin oxide and zinc oxide. Small amounts of copper may also have been present near the surface but overlap of Auger peaks inhibited the measurement of copper in the presence of zinc. Iridium was present on the surface because the sample was coated with iridium for taking SEM photos. Note that AES is a semi-quantitative analytical technique with the atomic percent numbers being accurate to approximately +/- 20% (relative error).

The tin plating on the Coating E coupon was fractured by scoring the underside of the coupon and then bending it. SEM examination of the fractured plating shows the columnar structure of the plating grains (Figure 44). Small microvoids can be seen within the grains (Figure 44, lower left photo).

Another interesting observation was the presence of tin whiskers growing from the microsections used to determine the thickness of the tin plating on the brass coupons (Figure 45). The diameter of the whiskers are approximately the same as the thickness of the plating.

CONCLUSIONS

During 401 days of exposure to ambient conditions, all of the conformal coatings tested suppressed the formation of tin whiskers when compared to the uncoated controls. During subsequent exposure to high humidity, the controls all grew large amounts of whiskers that were long enough to penetrate the coatings in test. The coating that best suppressed the formation of growths under the coating was Coating D. The worst coating for suppressing growths was the acrylic (Coating C) which was penetrated by numerous OSE's and whiskers. All of the other coatings fell somewhere in between Coating D and the acrylic in their ability to suppress nodule, OSE and whisker formation. All of the coatings (both thick and thin) were eventually penetrated by whiskers which indicates that these coatings can not be depended on as a foolproof mitigation strategy.

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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 27)**

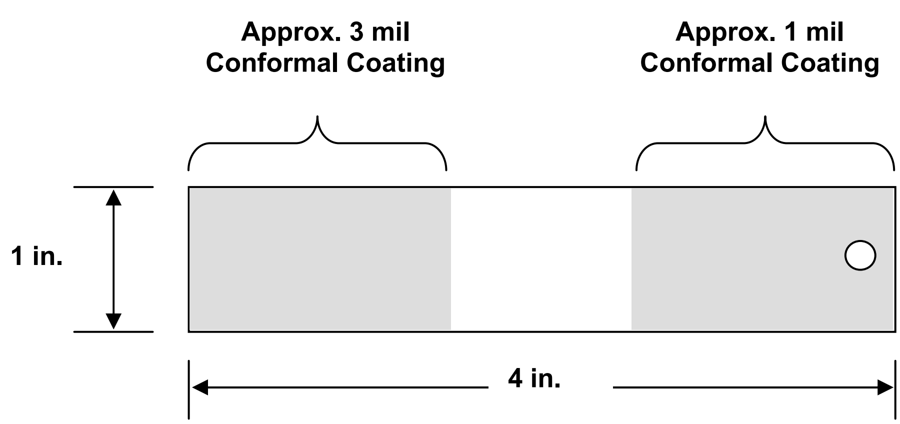
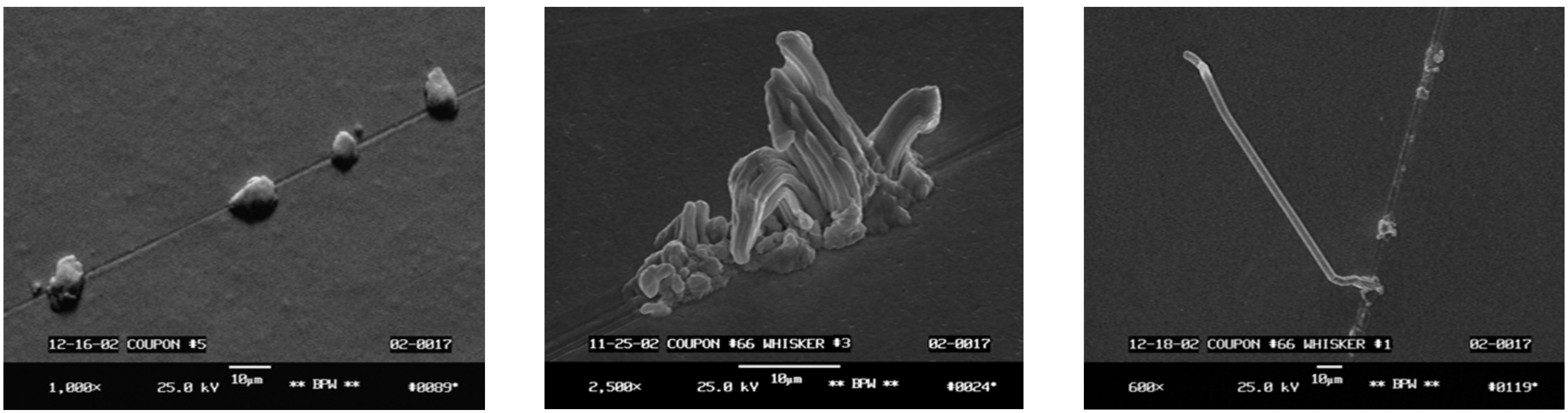


Figure 1. Test Coupon (Brass 260 Plated with 154 Microinches of Bright Tin)

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	1.1	3.2	No Coating	0.7	2.9	No Coating	1.1	2.8	No Coating	1.2	3.3	No Coating	1.1	2.9	0.4
Coating Thickness Range (mils)	No Coating	1.0 - 1.2	2.9 - 3.5	No Coating	0.6 - 0.8	2.3 - 4.4	No Coating	0.9 - 1.3	1.8 - 3.5	No Coating	1.1 - 1.4	1.8 - 4.6	No Coating	1.0 - 1.1	2.3 - 3.5	0.4 - 0.5
After 107 Days at Ambient	Many Nodules	Many Nodules	Many Nodules	No Growths	No Growths	No Growths	Many Nodules; **a Few Whiskers**	Many Nodules	Many Nodules	Small Nodules	Small Nodules	Small Nodules	Small Nodules on Scratches; **Several Whiskers**	Small Nodules on Scratches	Small Nodules on Scratches; **Several Whiskers**	Some Bubbles in Coating; No Growths
After 401 Days at Ambient	Many Nodules, OSE's and **a Few Short Whiskers**	Many Nodules	Many Nodules	Nodules; **Whiskers**	A Few Nodules	Nodules on Scratches	Many Nodules; **Many Whiskers**	Many Nodules	Many Nodules	Some Nodules, OSE's and **a Few Whiskers**	Small Nodules on Scratches	Small Nodules on Scratches	Many Nodules; **Many Whiskers**	Small Nodules on Scratches; **Several Whiskers**	Small Nodules on Scratches; **Several Whiskers**	Some Bubbles in Coating; No Growths
After 401 Days at Ambient + 347 Days at 25˚C/97%RH	**Many Whiskers**	Many OSE's in Bubbles; **Coating Penetrated by Whiskers and OSE's**	Many OSE's in Bubbles; **Coating Penetrated by Whiskers and OSE's**	**Many Whiskers**	Many OSE's Pushing Up Coating; **Coating Penetrated by Whiskers and OSE's**	Many Nodules; **Coating Penetrated by Whiskers and OSE's**	**Many Whiskers**	**Coating Penetrated by Many Whiskers and OSE's**	**Coating Penetrated by Whiskers and OSE's**	**Many Whiskers**	A Few OSE's in Bubbles; **Coating Penetrated by Whiskers and OSE's**	A Few Nodules; **Coating Penetrated by OSE's**	**Many Whiskers**	ManyOSE's in Bubbles; **Coating Penetrated by Whiskers and OSE's**	ManyOSE's in Bubbles; **Coating Penetrated by Whiskers and OSE's?**	Many OSE's; **Coating Penetrated by Whiskers and OSE's**



Nodule **Odd Shaped Eruption (OSE)** **Whisker**

Figure 2. Different Types of Growths

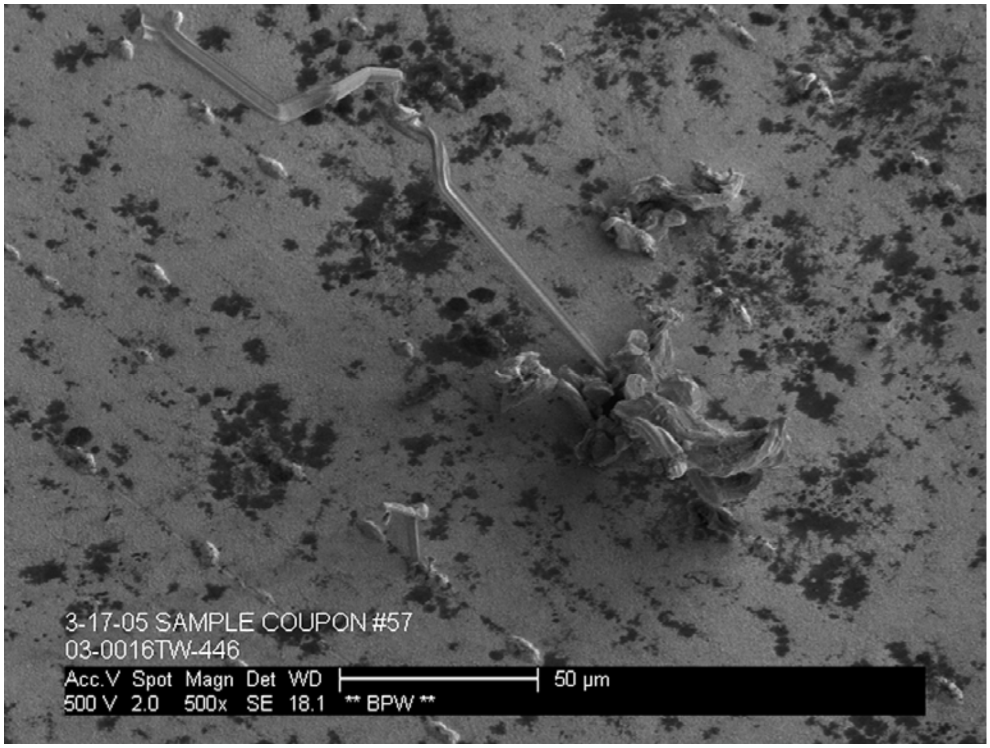


Figure 3. Control Area for Coating A (401 Days at Ambient + 347 Days in 25°C/97%RH)

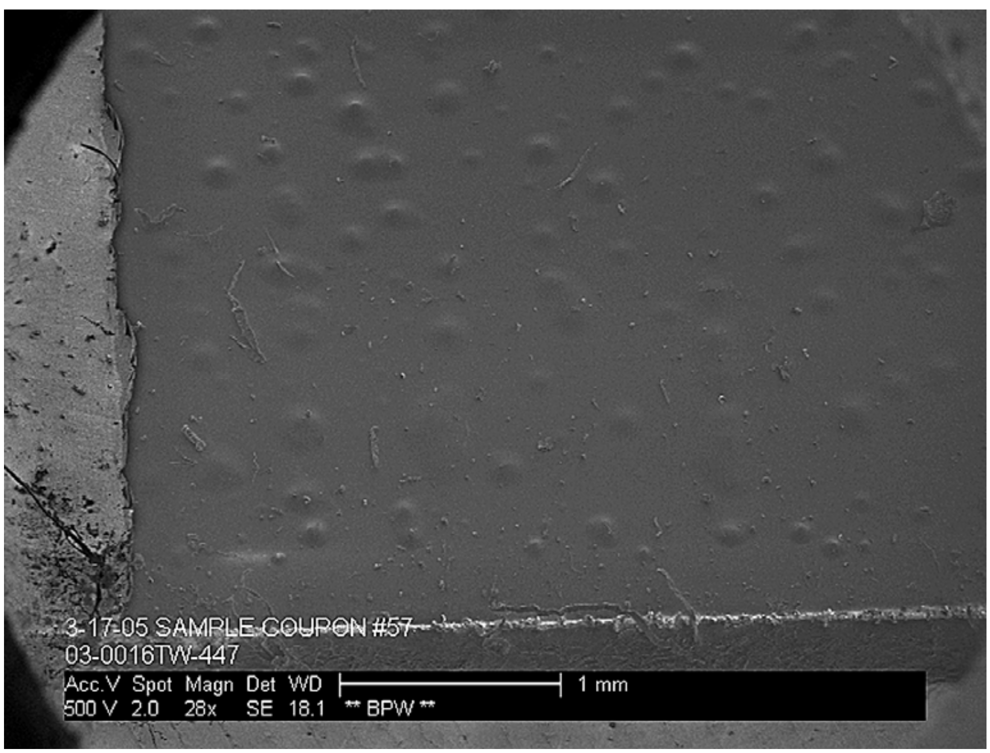


Figure 4. Coating A – Demarcation Line between Coated Area (1.1 Mils) and Uncoated Control Area (401 Days at Ambient + 347 Days in 25°C/97%RH). Note Tenting of Coating by OSE's and Whiskers.

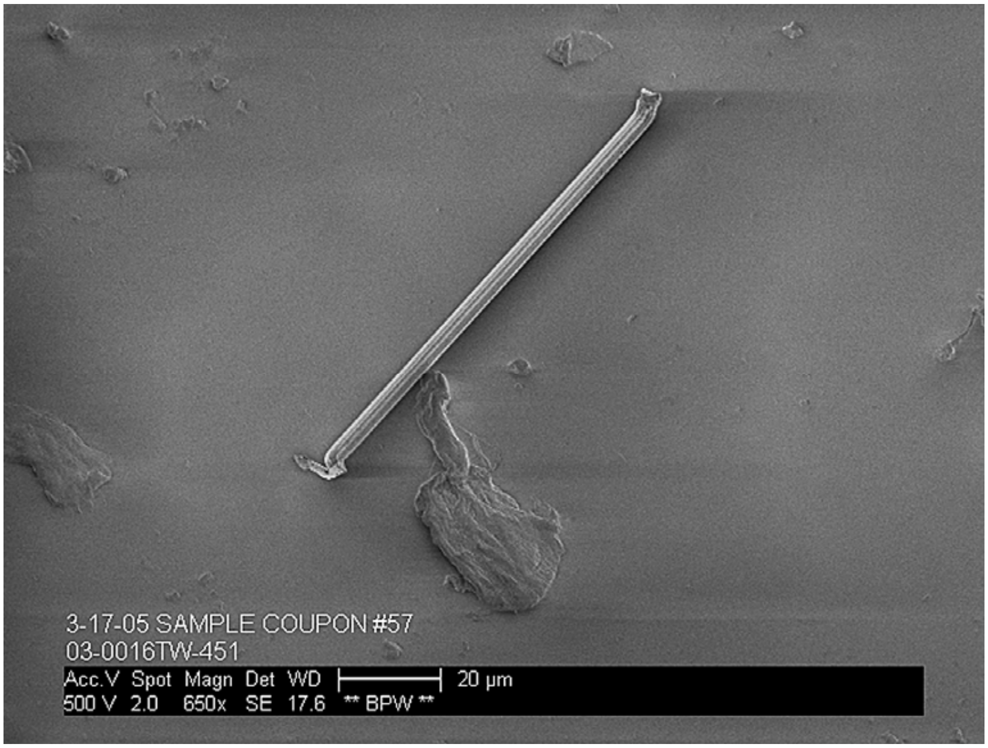


Figure 5. Whisker Penetrating Coating A – 1.1 Mils (401 Days at Ambient + 347 Days in 25°C/97%RH)

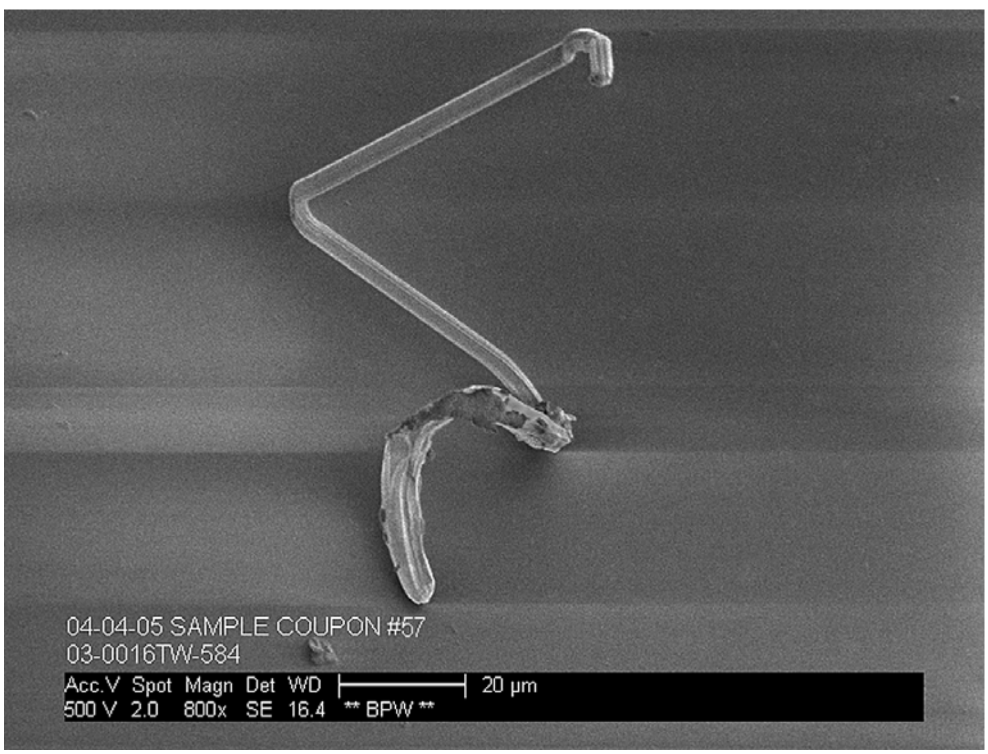


Figure 6. Whisker Penetrating Coating A – 3.2 Mils (401 Days at Ambient + 347 Days in 25°C/97%RH)

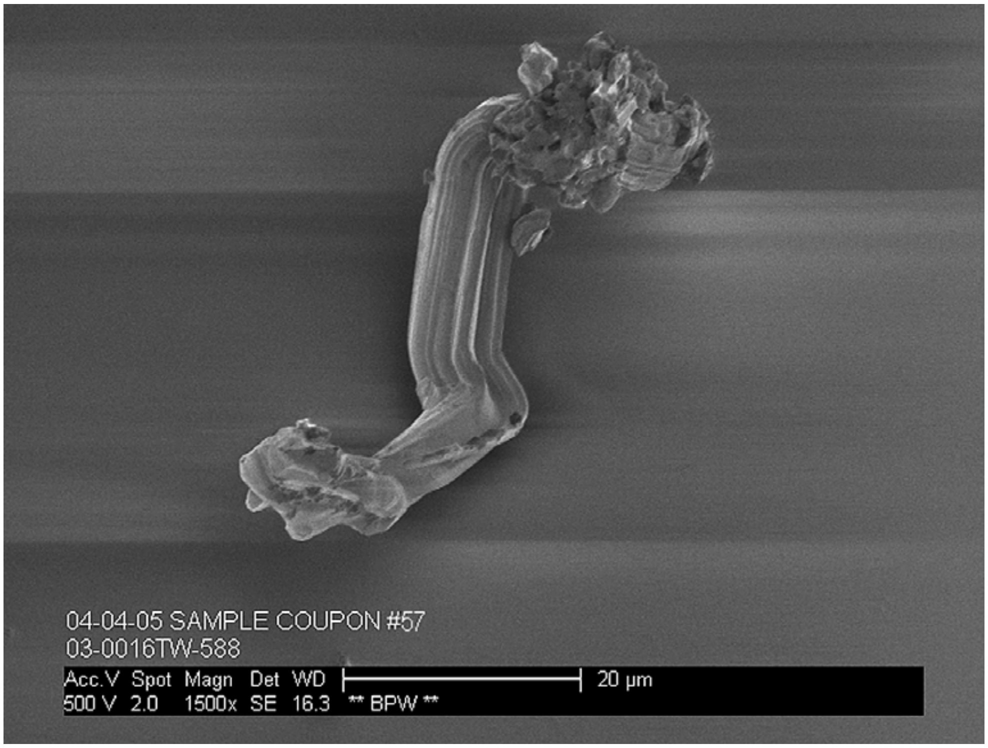


Figure 7. Whisker Penetrating Coating A – 3.2 Mils (401 Days at Ambient + 347 Days in 25°C/97%RH)

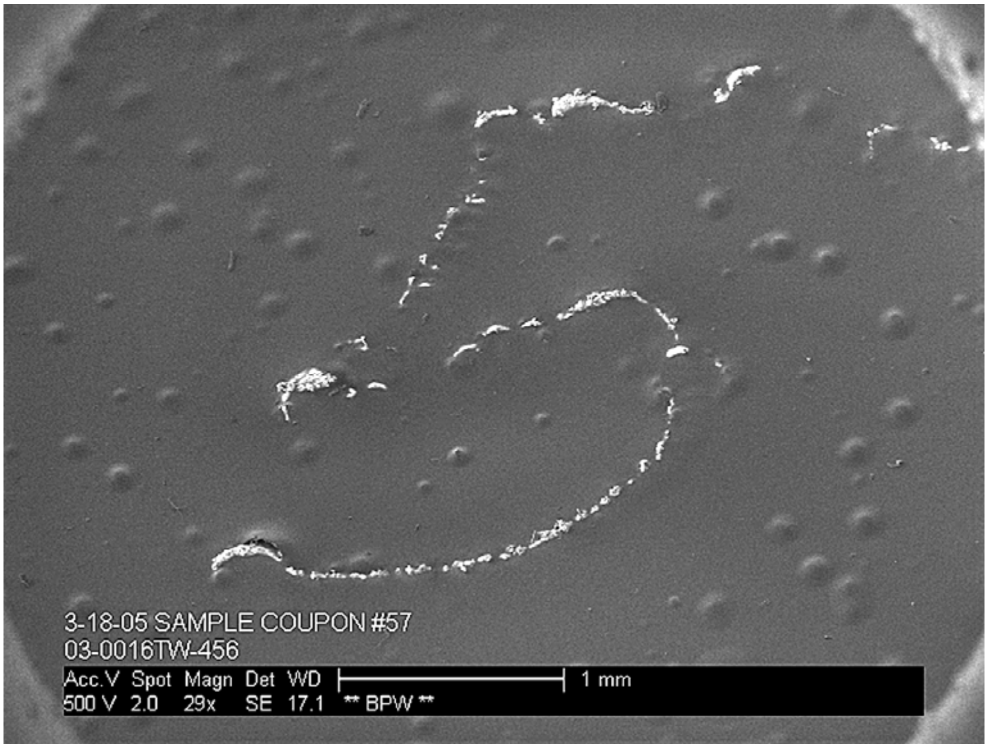


Figure 8. Short Whiskers and OSE's Penetrating Coating A on Scribe Mark - 1.1 Mils (401 Days at Ambient + 347 Days in 25°C/97%RH)

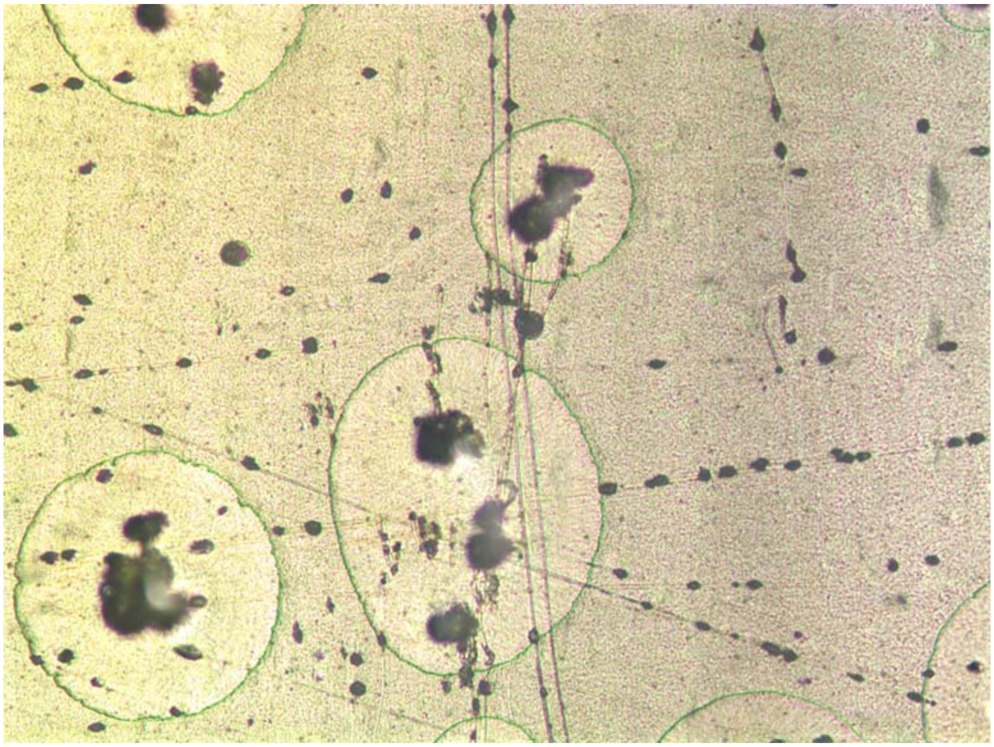


Figure 9. Coating A – 1.1 Mils (401 Days at Ambient + 347 Days in 25°C/97%RH), 200x. Note Delamination of Coating by OSE's.

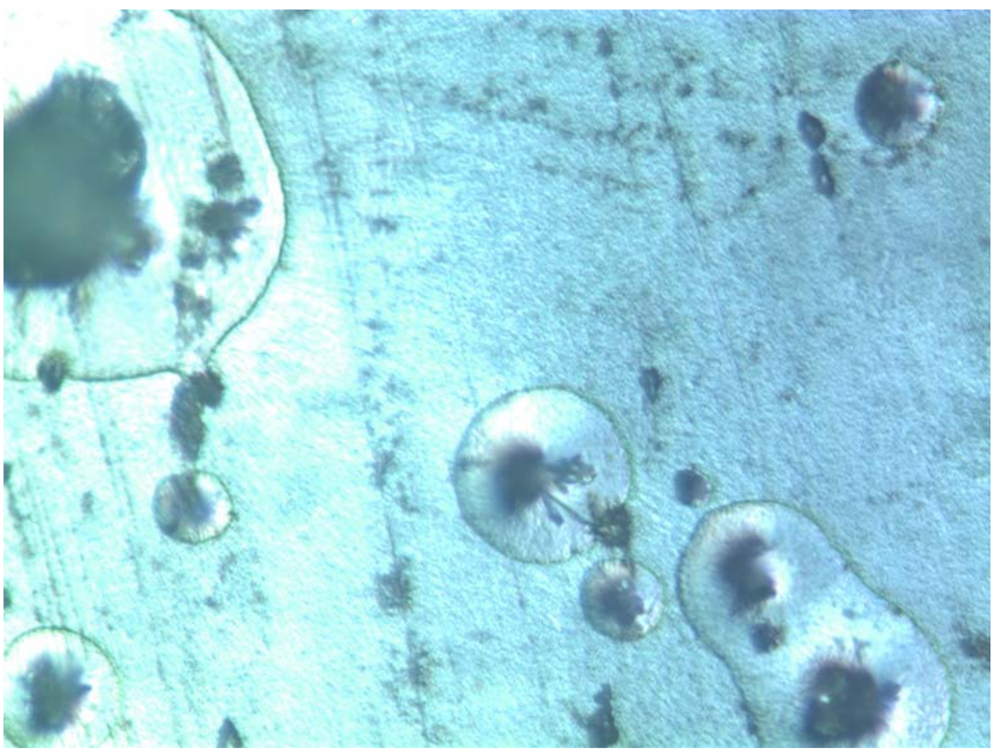


Figure 10. Coating A – 3.2 Mils (401 Days at Ambient + 347 Days in 25°C/97%RH), 200x. Note Delamination of Coating by OSE's.

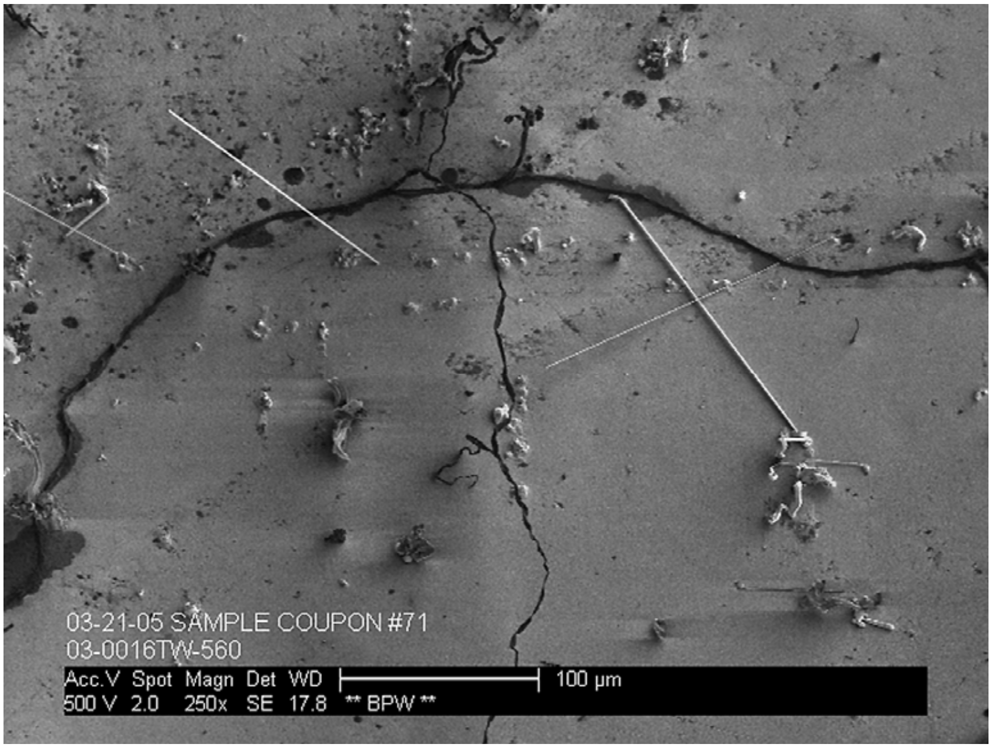


Figure 11. Control Area for Coating B (401 Days at Ambient + 347 Days in 25°C/97%RH). Note: Dark Fibrous Material is Fungus.

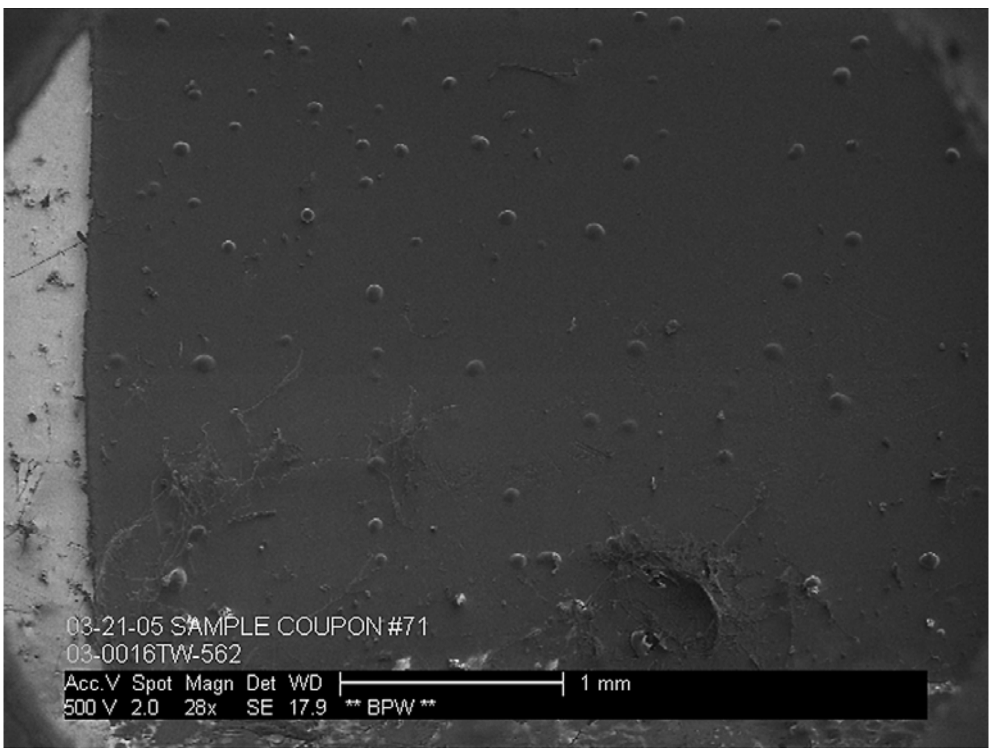


Figure 12. Coating B – Demarcation Line between Coated Area (0.7 Mils) and Uncoated Control Area (401 Days at Ambient + 347 Days in 25°C/97%RH). Note Tenting of Coating by OSE's and Whiskers. Note: Fibrous Material at Bottom is Fungus.

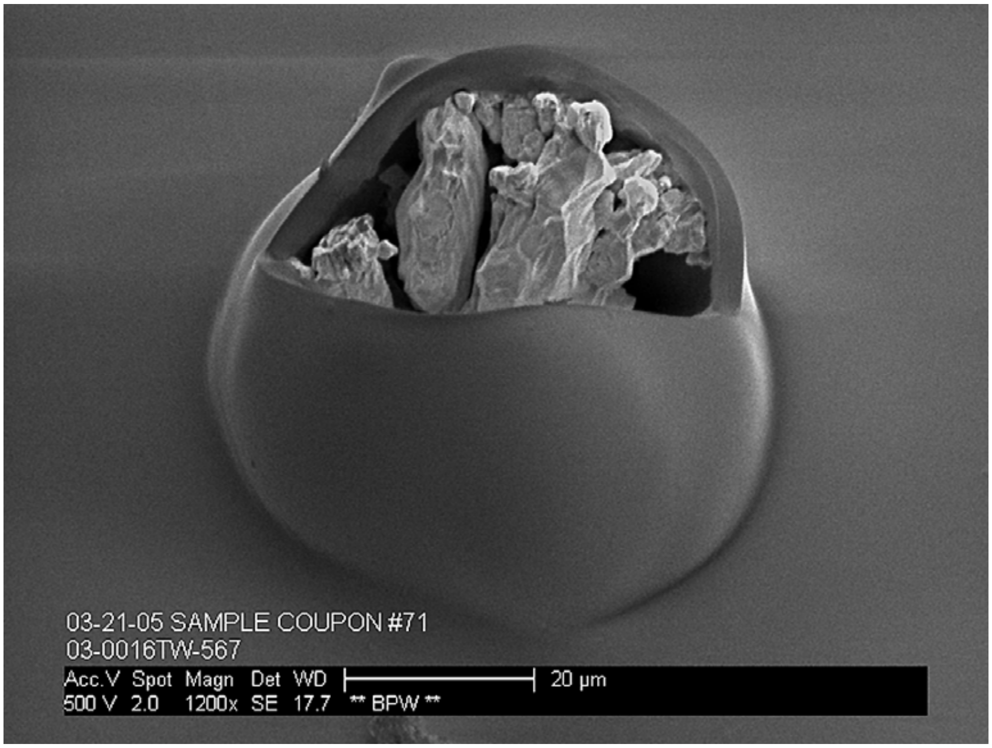


Figure 13. OSE Penetrating Coating B – 0.7 Mils (401 Days at Ambient + 347 Days in 25°C/97%RH)

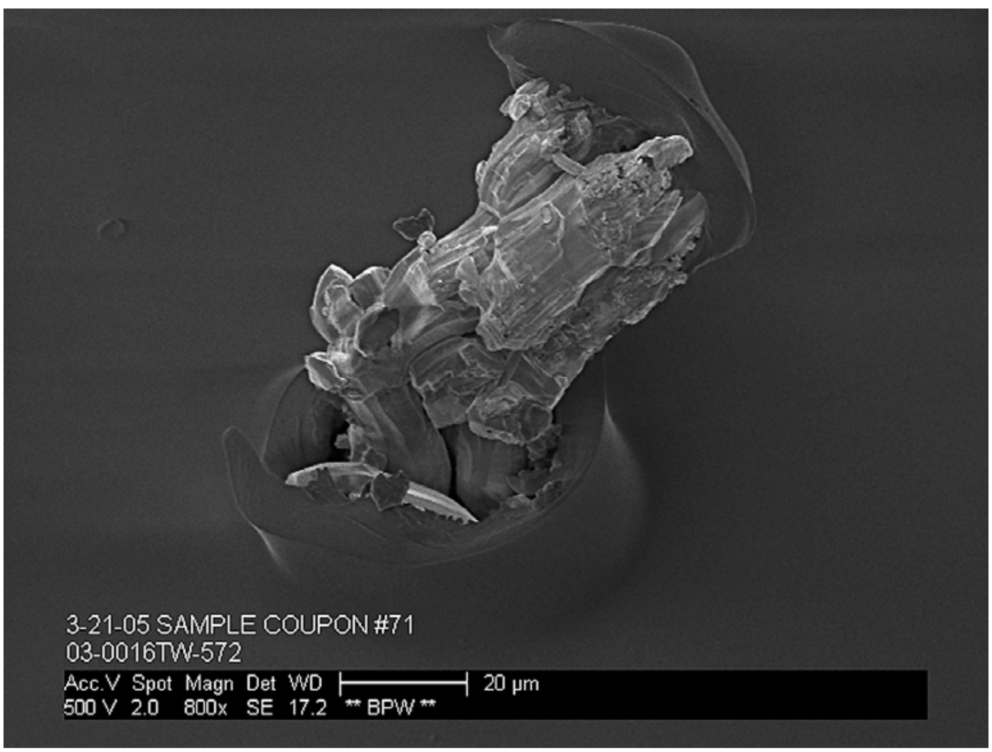


Figure 14. OSE Penetrating Coating B – 0.7 Mils (401 Days at Ambient + 347 Days in 25°C/97%RH)

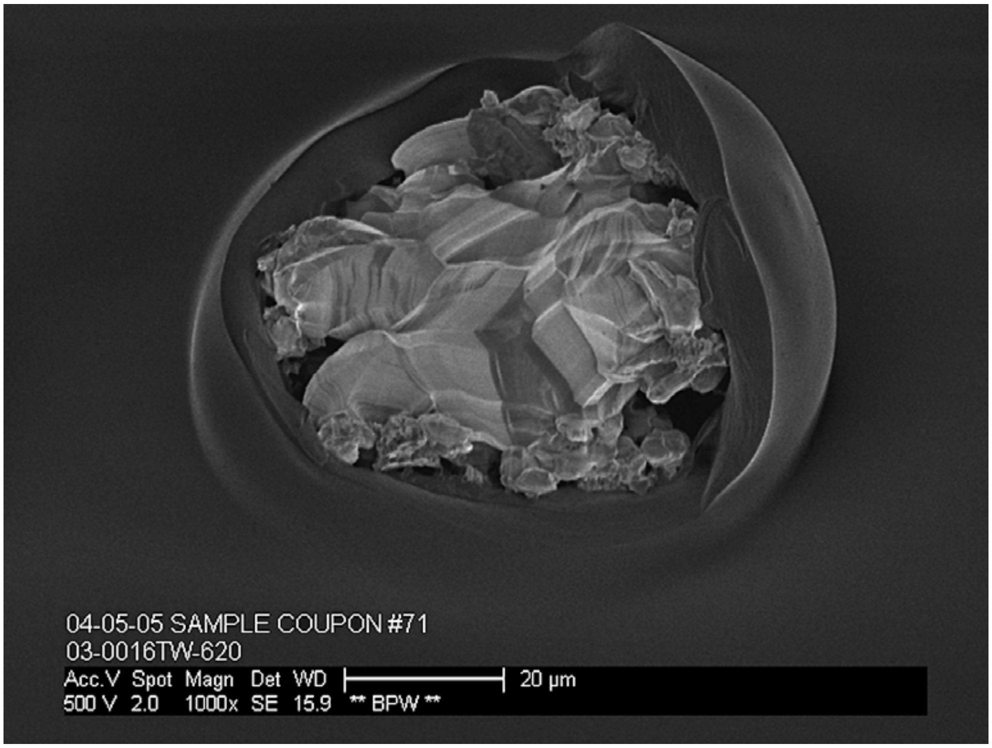


Figure 15. OSE Penetrating Coating B – 2.9 Mils (401 Days at Ambient + 347 Days in 25°C/97%RH)

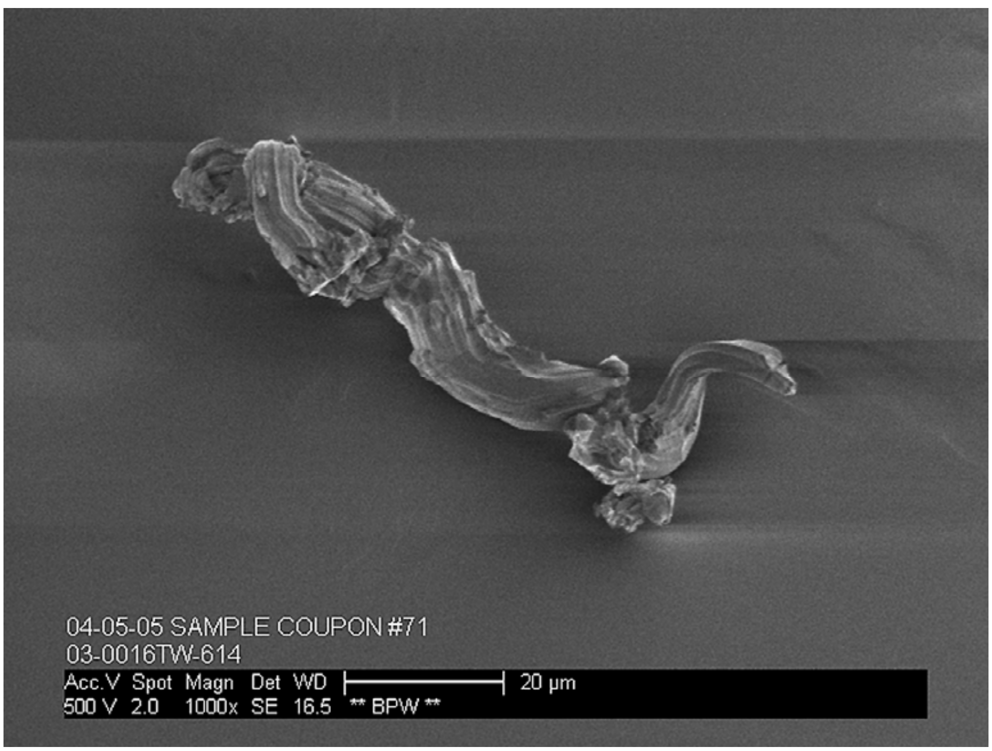


Figure 16. Whisker Penetrating Coating B – 2.9 Mils (401 Days at Ambient + 347 Days in 25°C/97%RH)

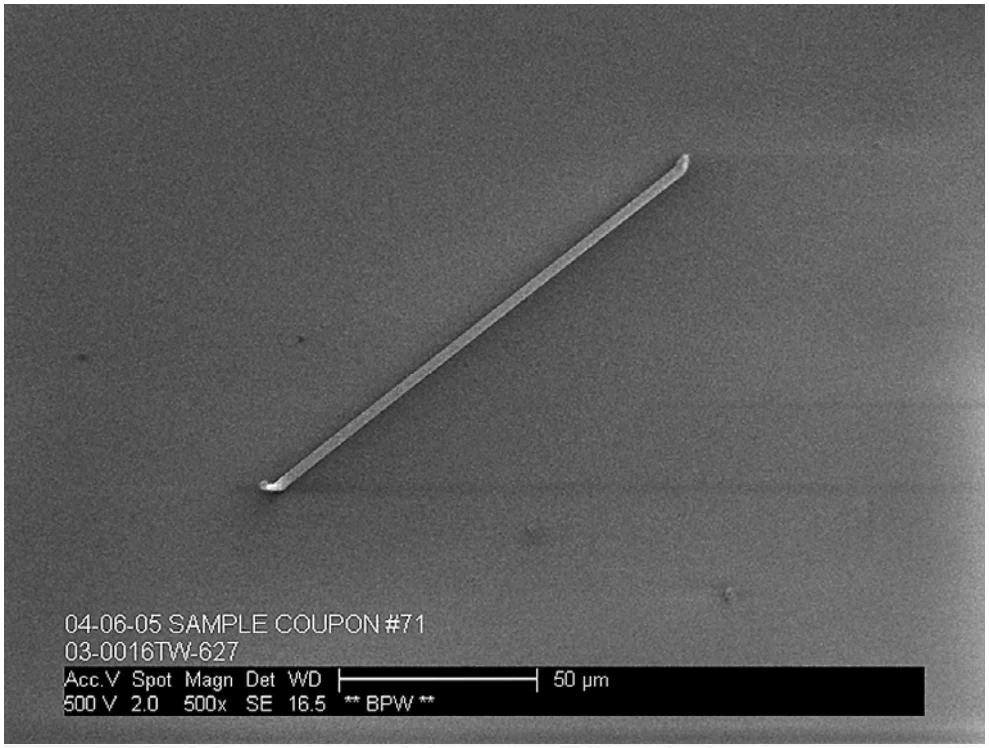


Figure 17. Whisker Penetrating Coating B – 2.9 Mils (401 Days at Ambient + 347 Days in 25°C/97%RH)

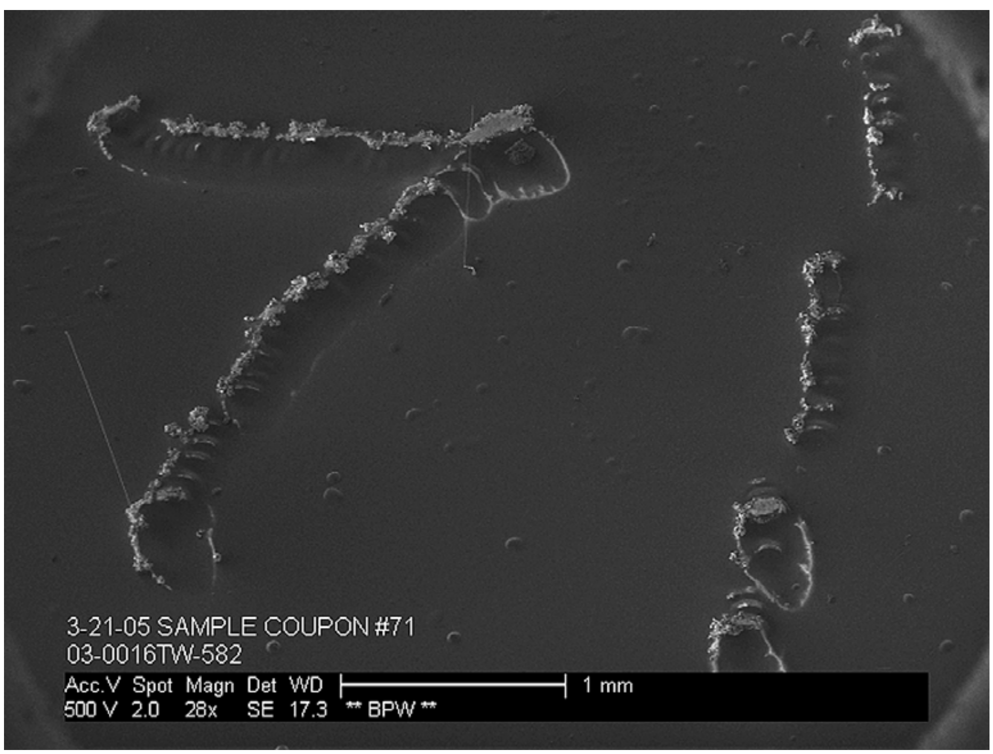


Figure 18. Whiskers and OSE's Penetrating Coating B on Scribe Mark – 0.7 Mils (401 Days at Ambient + 347 Days in 25°C/97%RH)

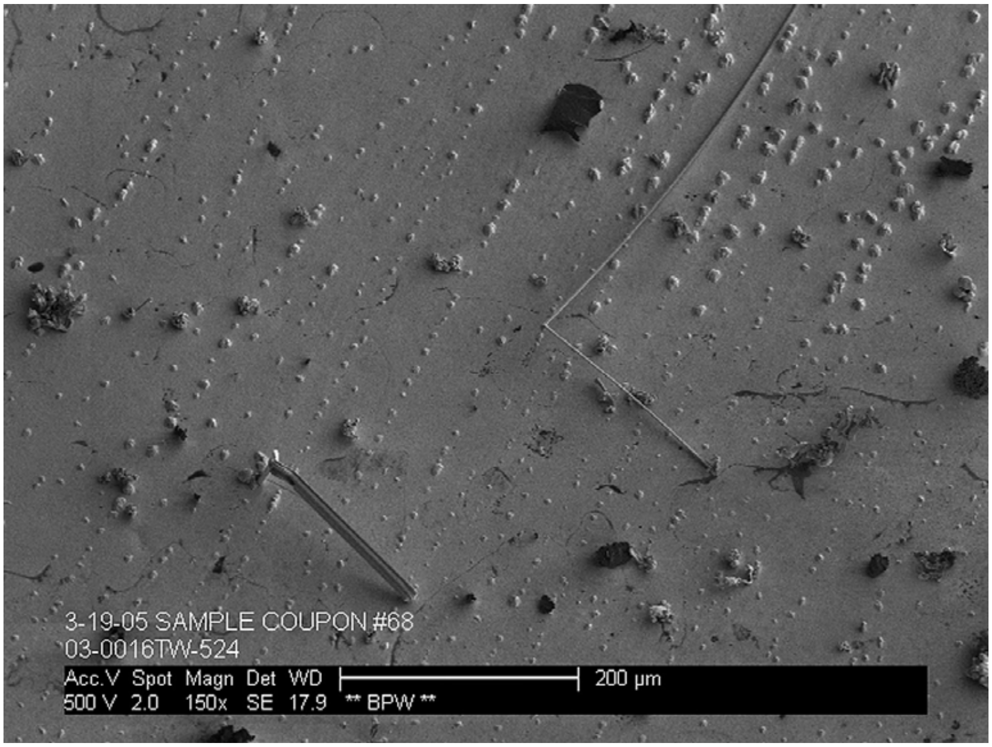


Figure 19. Control Area for Coating C (401 Days at Ambient + 347 Days in 25°C/97%RH)

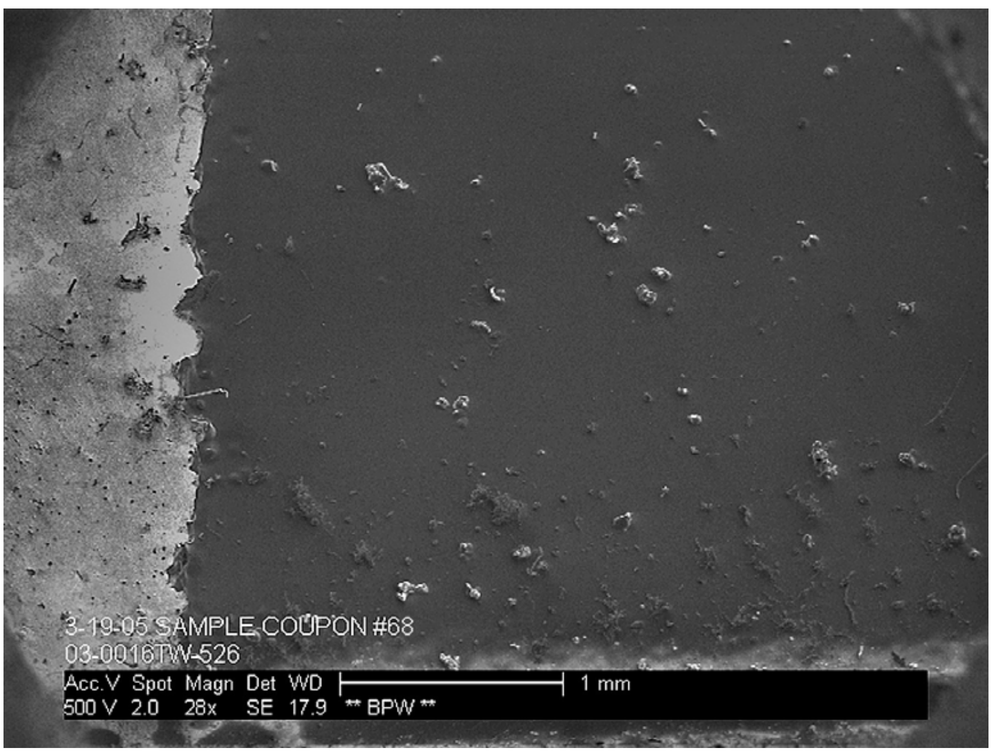


Figure 20. Coating C – Demarcation Line between Coated Area (1.1 Mils) and Uncoated Control Area (401 Days at Ambient + 347 Days in 25°C/97%RH). Note Penetration of Coating by OSE's and Whiskers.

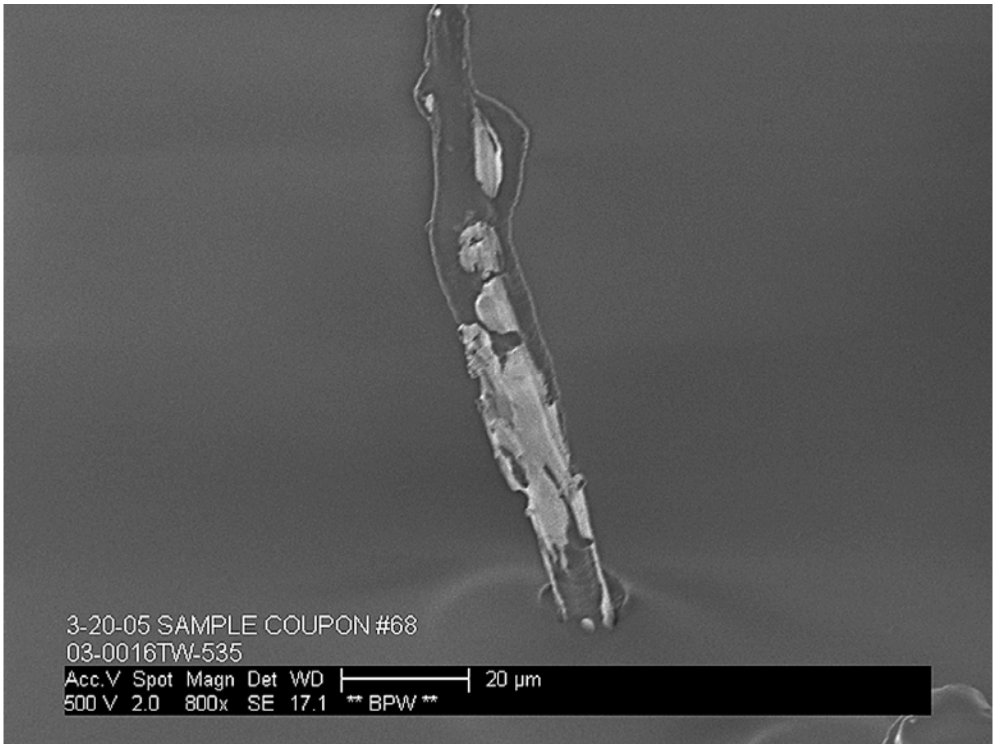


Figure 21. Whisker Penetrating Coating C – 1.1 Mils (401 Days at Ambient + 347 Days in 25°C/97%RH)

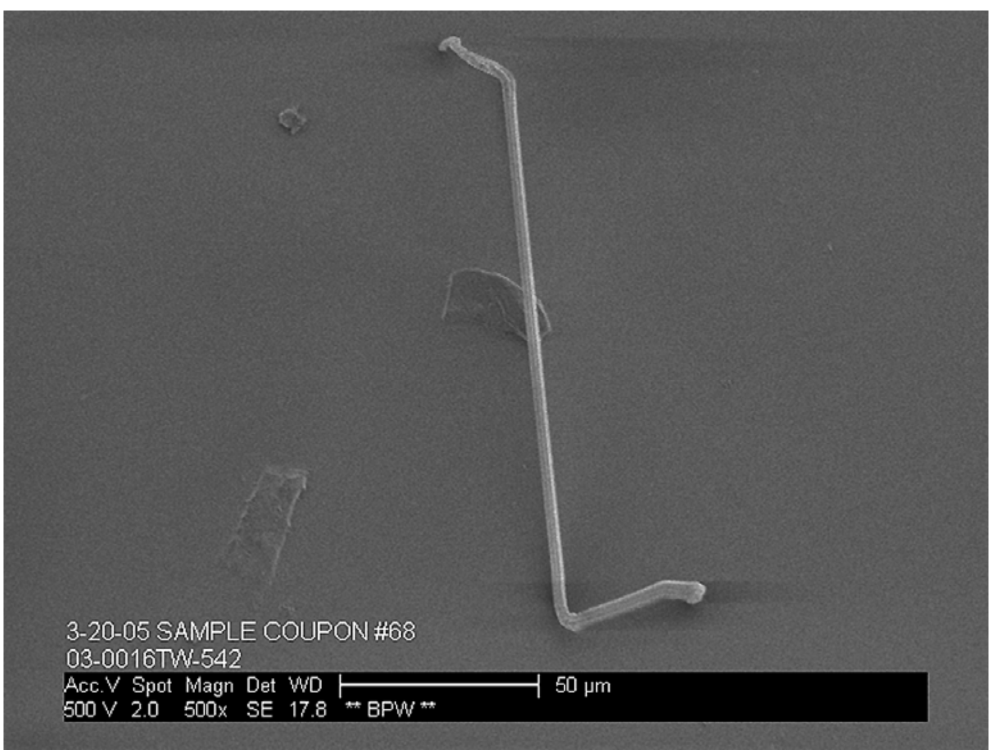


Figure 22. Whisker Penetrating Coating C – 2.8 Mils (401 Days at Ambient + 347 Days in 25°C/97%RH)

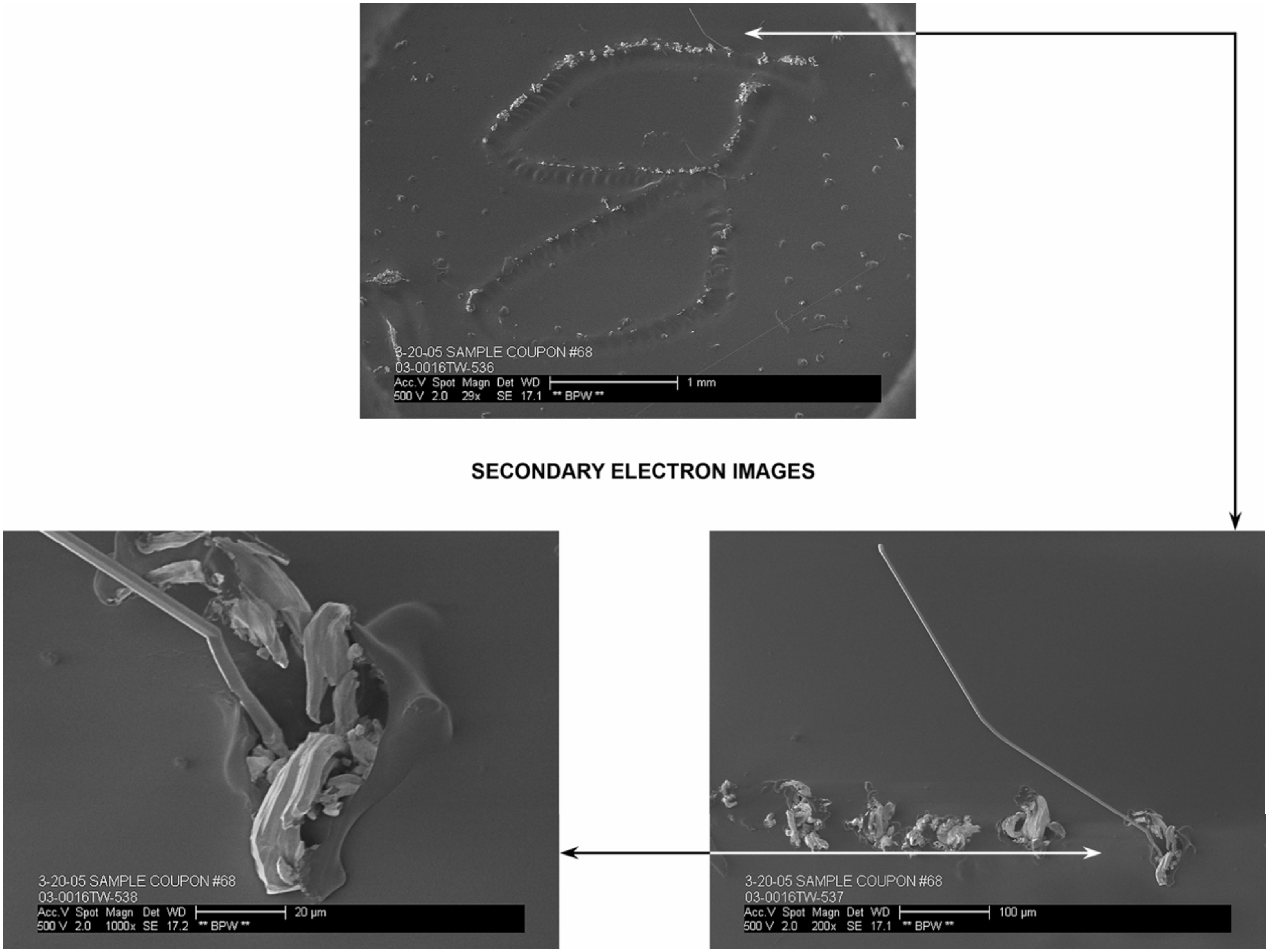


Figure 23. Whiskers and OSE's Penetrating Coating C on Scribe Mark – 1.1 Mils (401 Days at Ambient + 347 Days in 25°C/97%RH)

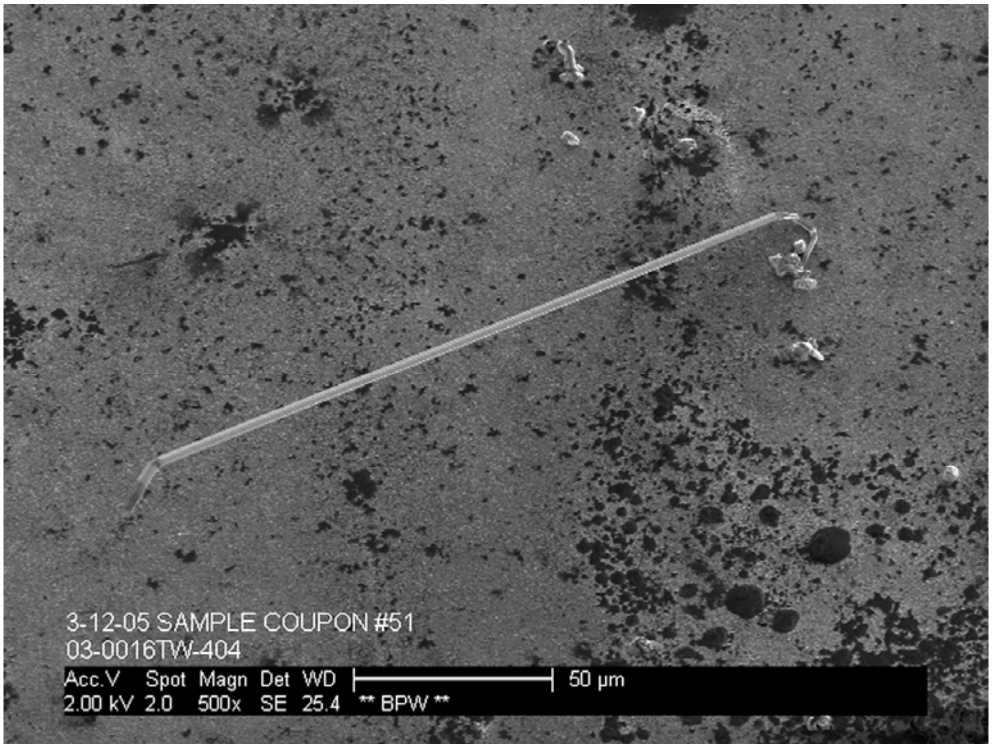


Figure 24. Control Area for Coating D (401 Days at Ambient + 347 Days in 25°C/97%RH)

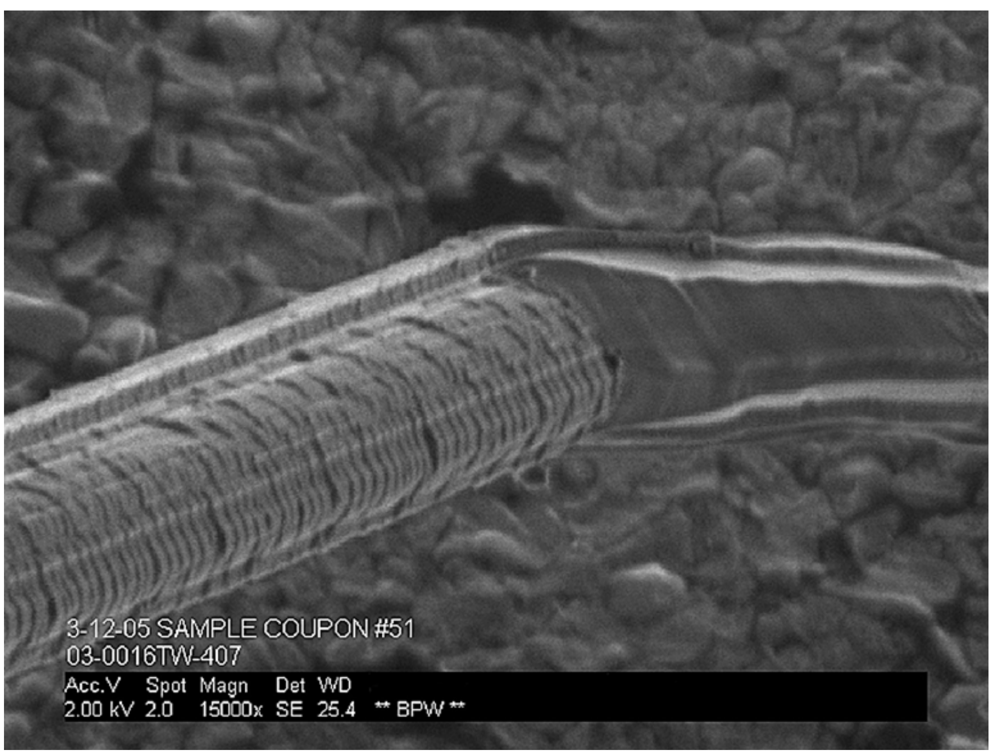


Figure 25. Magnification of Whisker Shown in Figure 24. Note Circumferential Rings.

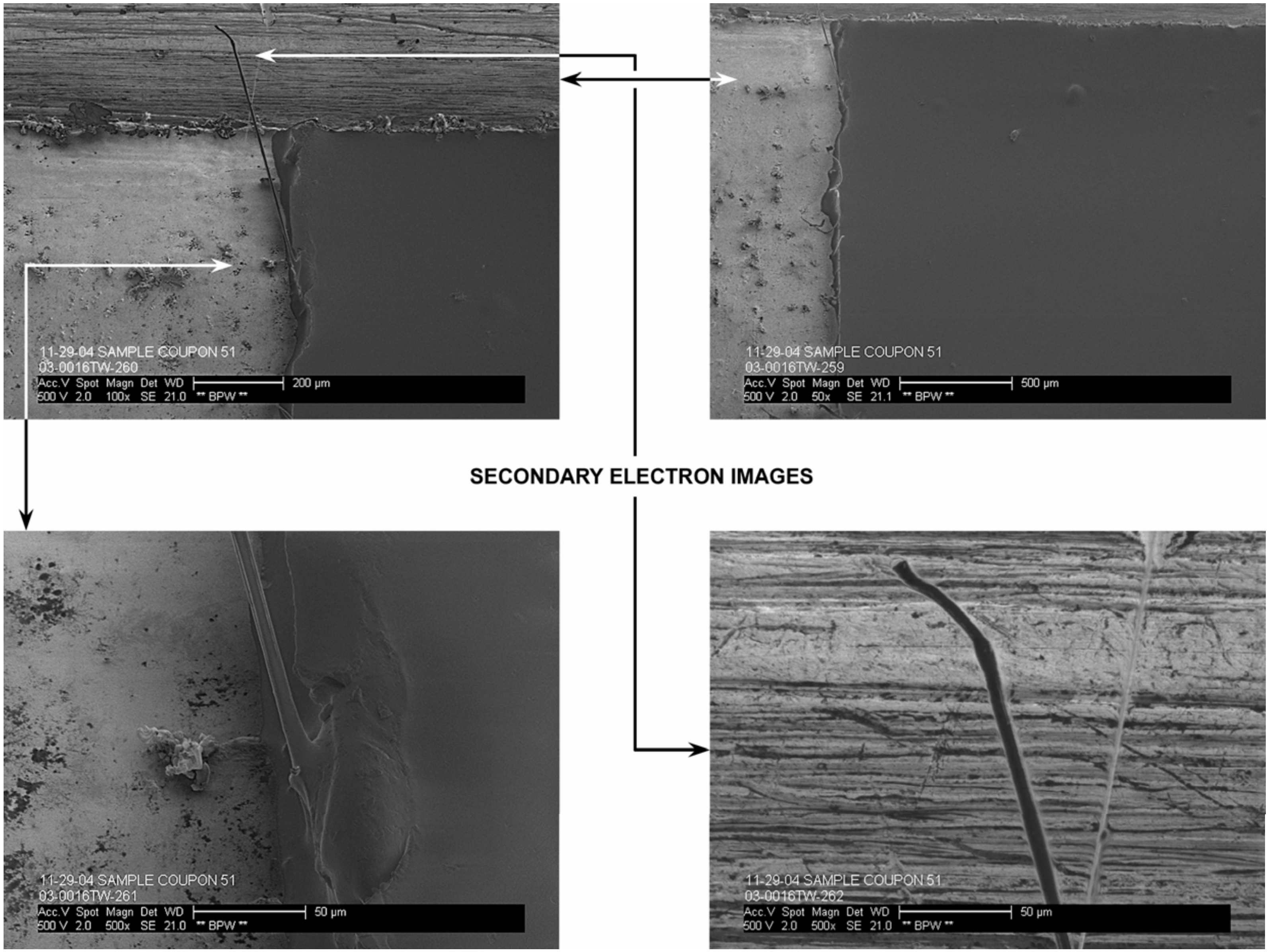


Figure 26. Coating D – Demarcation Line between Coated Area (1.2 Mils) and Uncoated Control Area (401 Days at Ambient + 347 Days in 25°C/97%RH). Note Long Whisker-like Structure Covered with Coating.

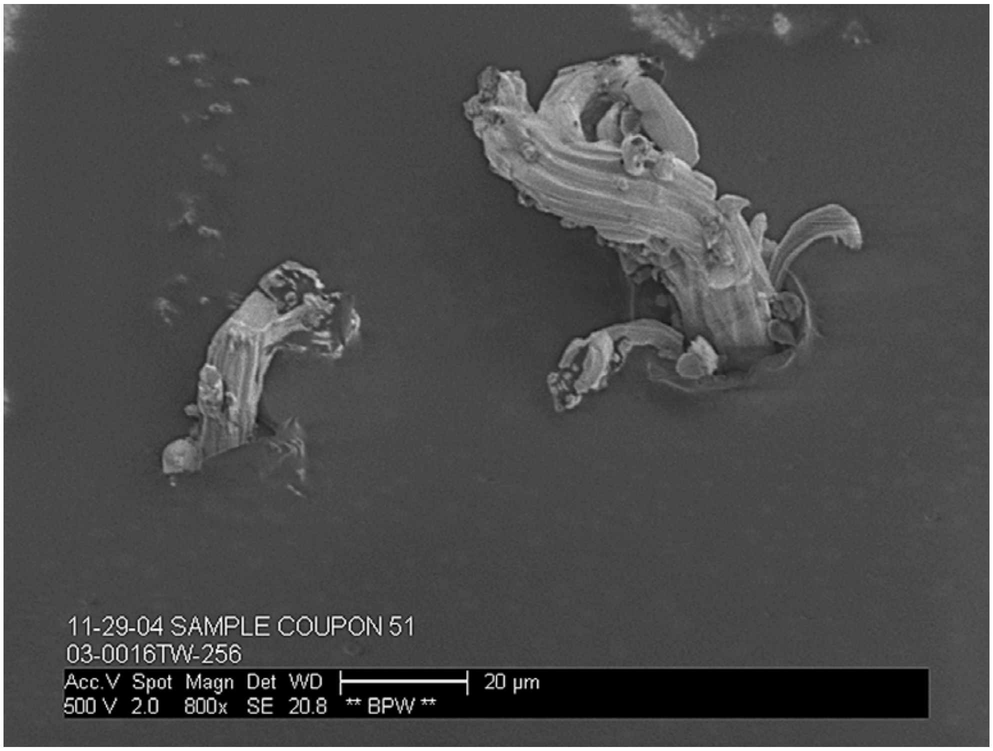


Figure 27. Whiskers Penetrating Coating D – 1.2 Mils (401 Days at Ambient + 347 Days in 25°C/97%RH)

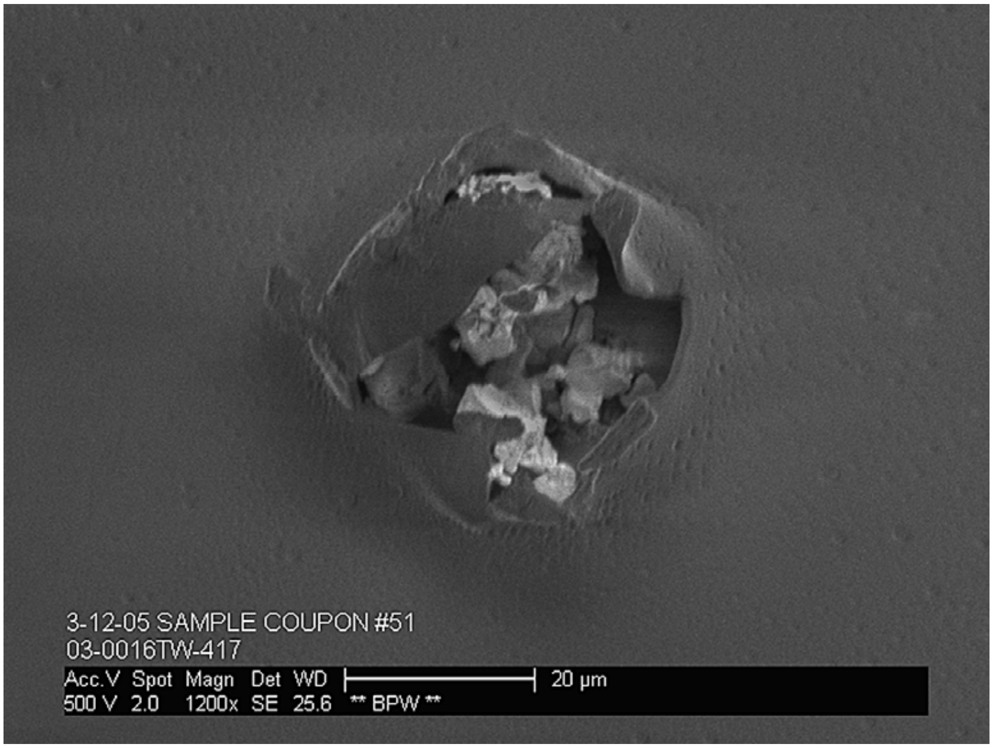


Figure 28. OSE Penetrating Coating D – Thin Spot in 3.3 Mil Thick Coating (401 Days at Ambient + 347 Days in 25°C/97%RH)

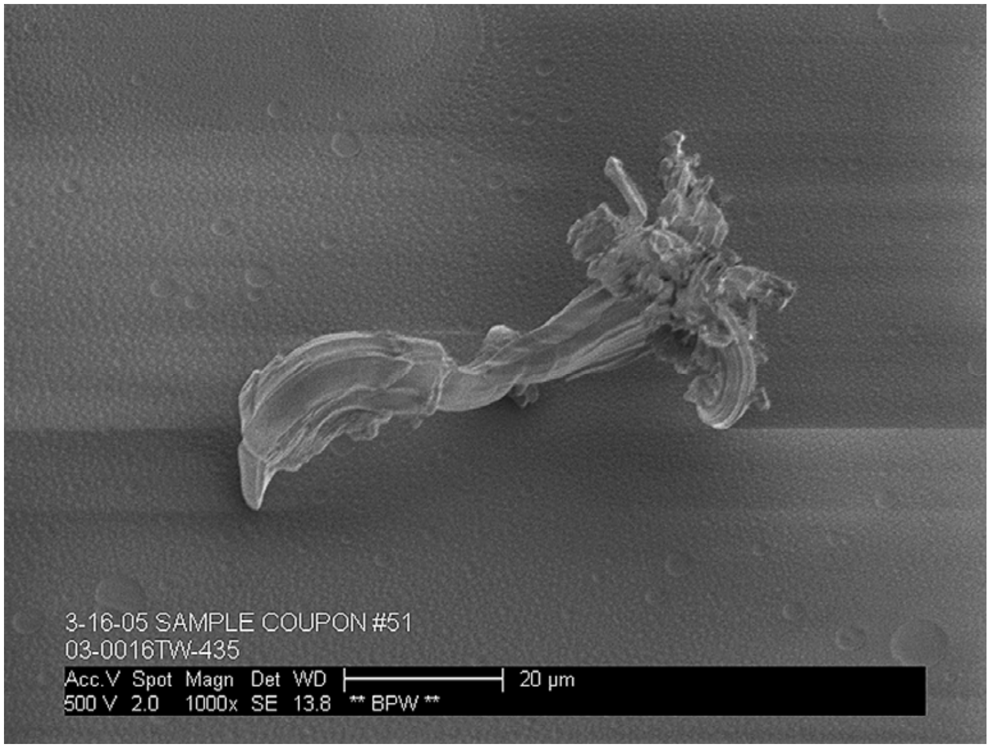


Figure 29. Whisker Penetrating Coating D – 3.3 Mils (401 Days at Ambient + 347 Days in 25°C/97%RH)

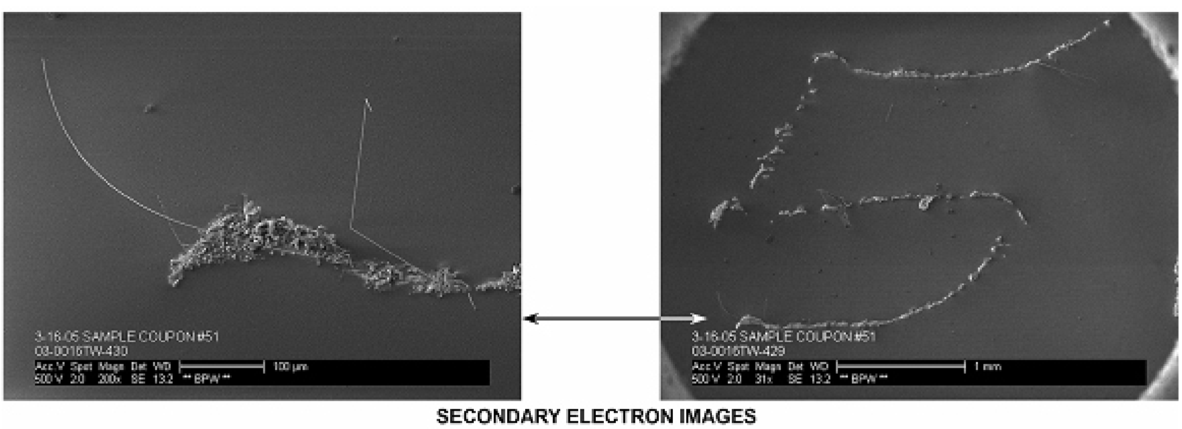


Figure 30. Whiskers and OSE's Penetrating Coating D on Scribe Mark – 1.2 Mils (401 Days at Ambient + 347 Days in 25°C/97%RH)

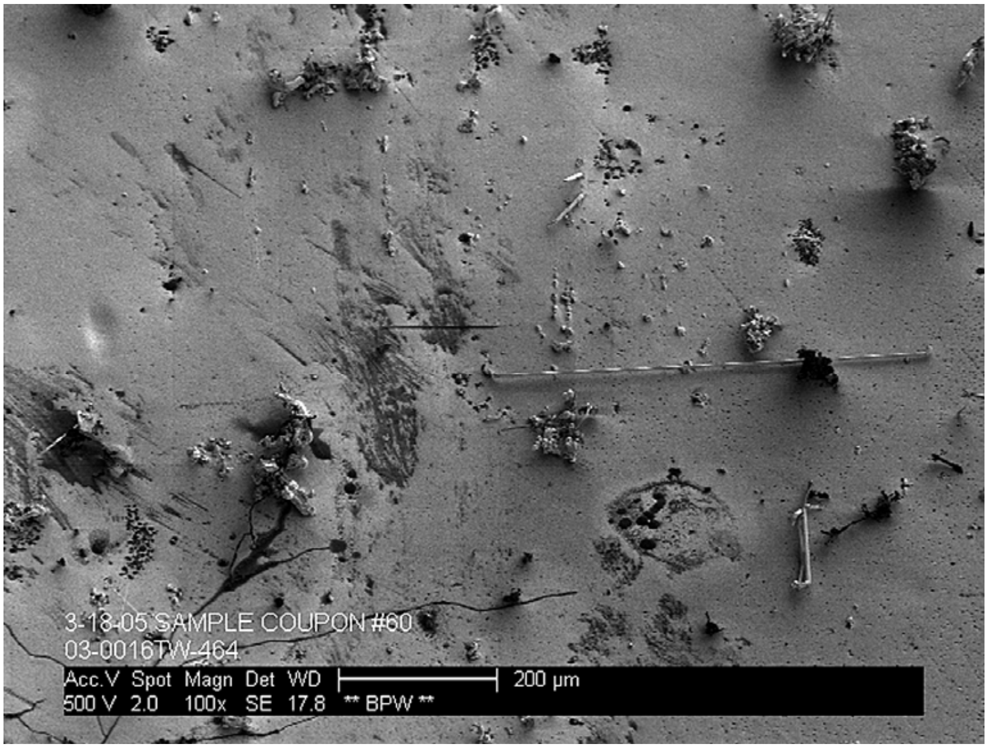


Figure 31. Control Area for Coating E (401 Days at Ambient + 347 Days in 25°C/97%RH)

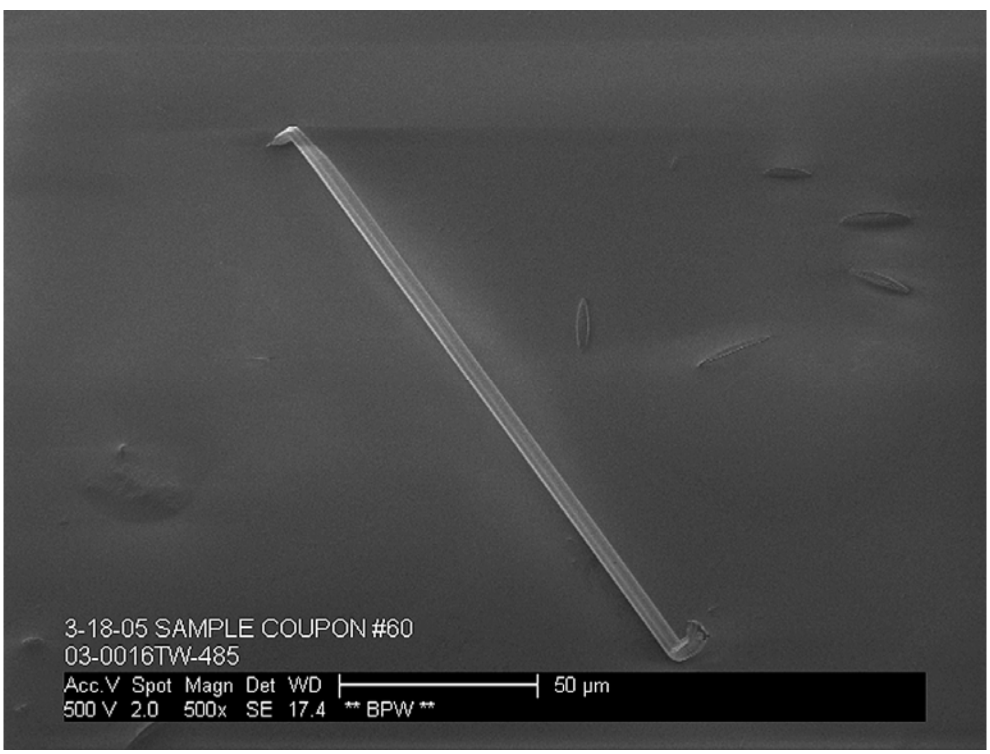


Figure 32. Whisker Penetrating Coating E – 1.1 Mils (401 Days at Ambient + 347 Days in 25°C/97%RH)

Figure 33. OSE Penetrating Coating E – 1.1 Mils (401 Days at Ambient + 347 Days in 25°C/97%RH)

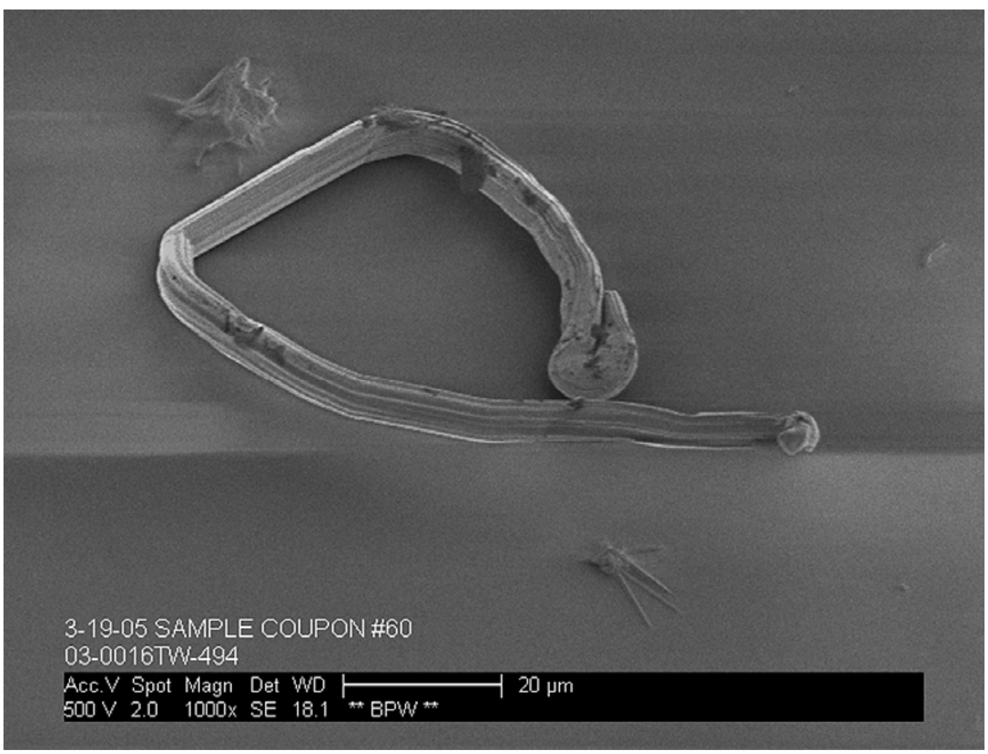


Figure 34. Whisker Penetrating Coating E – 2.9 Mils (401 Days at Ambient + 347 Days in 25°C/97%RH)

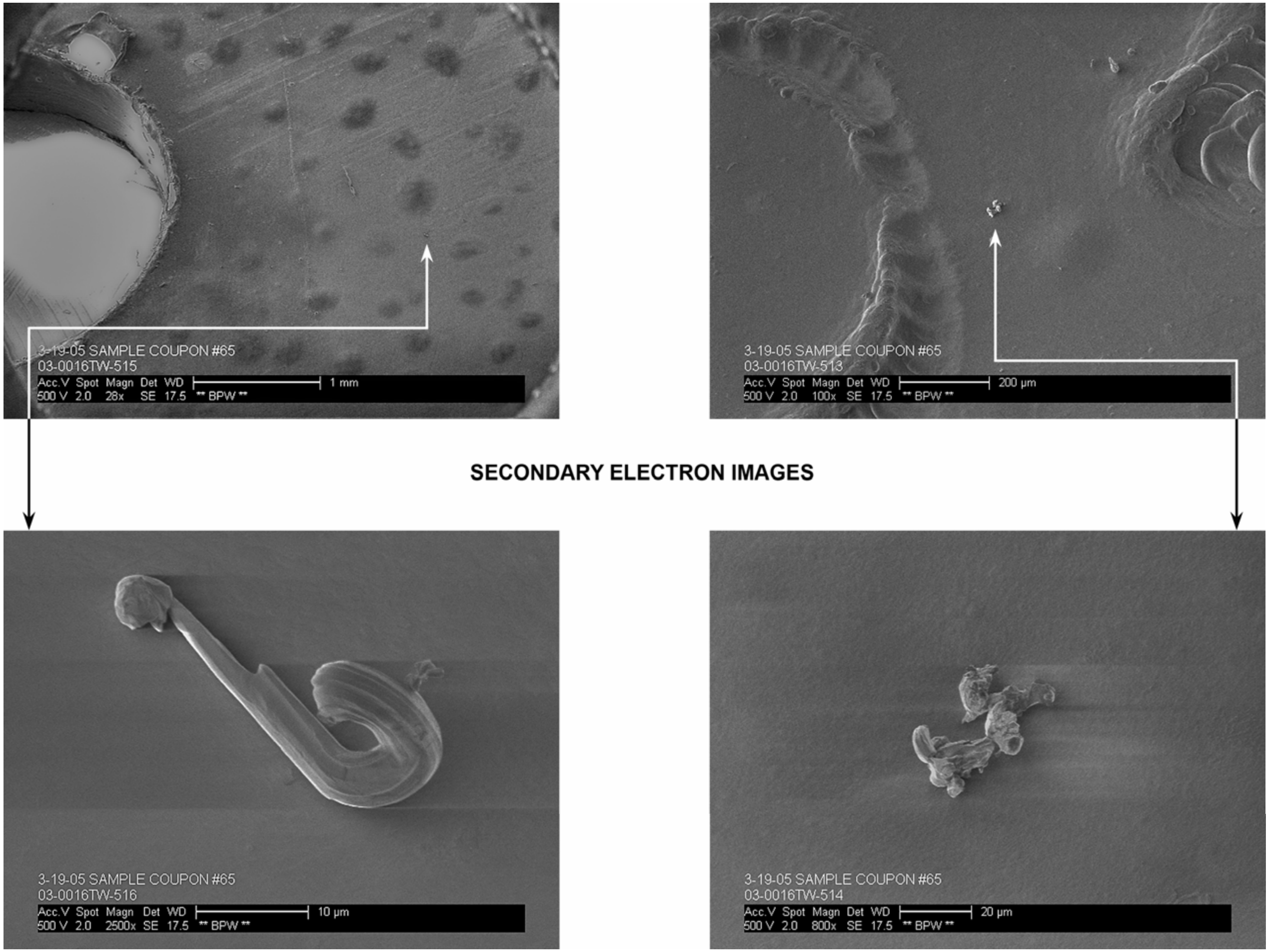


Figure 35. Whiskers Penetrating Parylene C – 0.4 Mils (401 Days at Ambient + 347 Days in 25°C/97%RH). Note Tenting of Parylene C due to OSE's (Upper Left Photo).

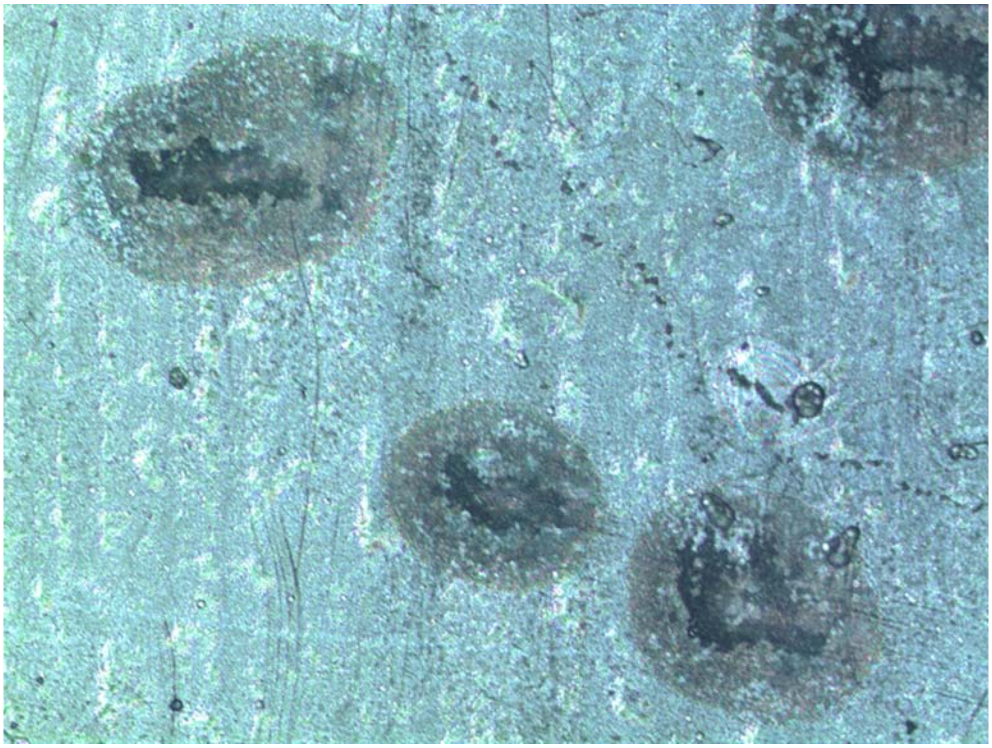


Figure 36. OSE's under Parylene C – 0.4 Mils (401 Days at Ambient + 347 Days in 25°C/97%RH)

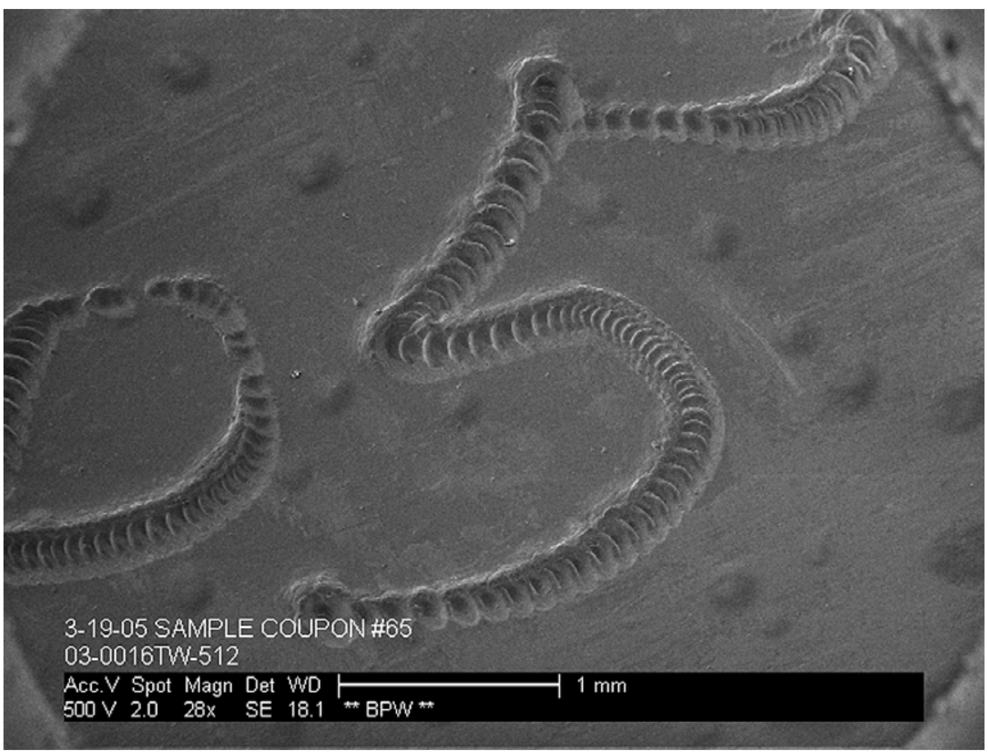


Figure 37. Scribe Mark under Parylene C – 0.4 Mils (401 Days at Ambient + 347 Days in 25°C/97%RH). Note Absence of Whiskers or OSE's on Scribe Mark.

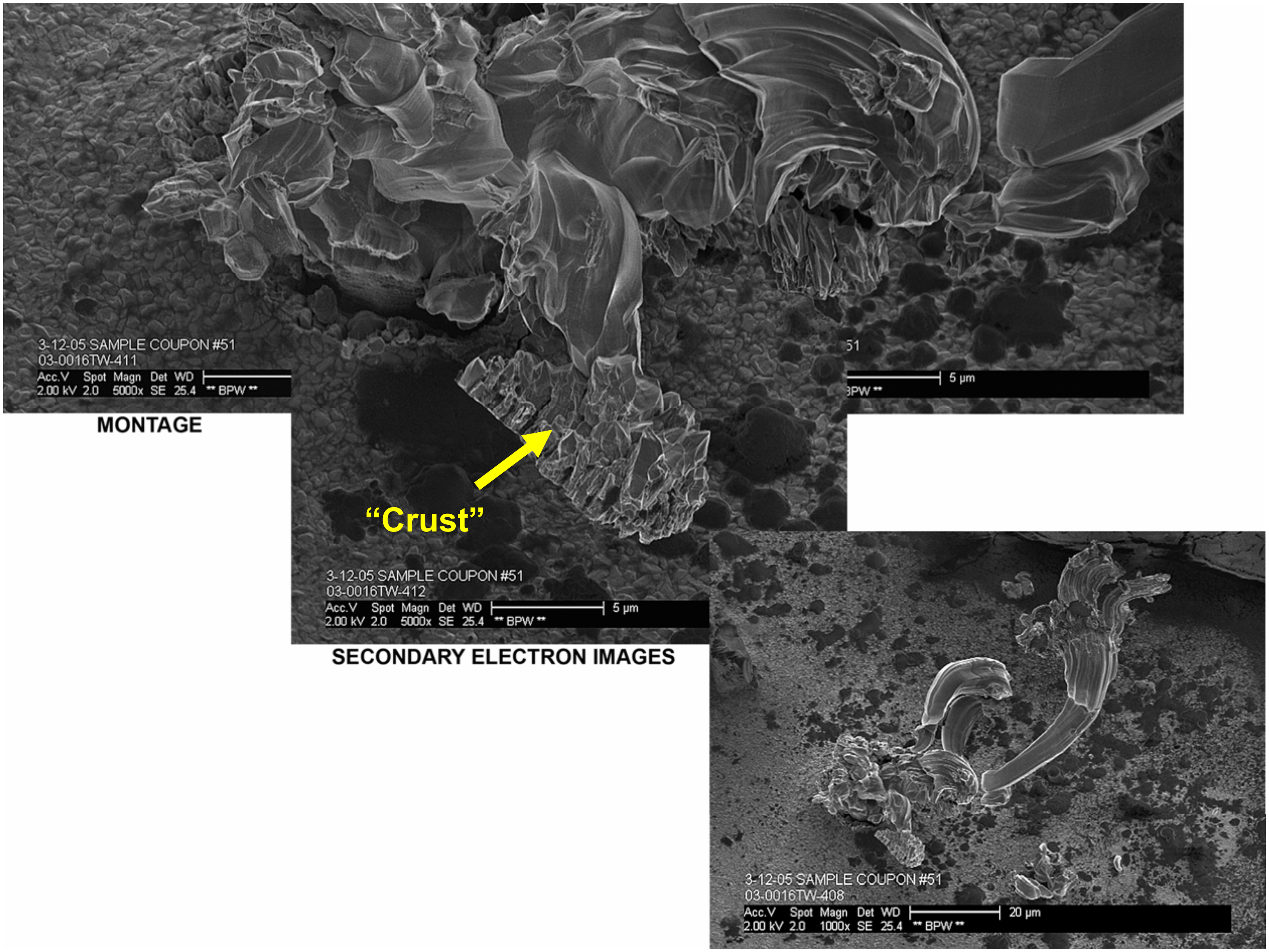


Figure 38. Control Area for Coating D (401 Days at Ambient + 347 Days in 25°C/97%RH). Note "Crust" Pushed Up and Over by an OSE.

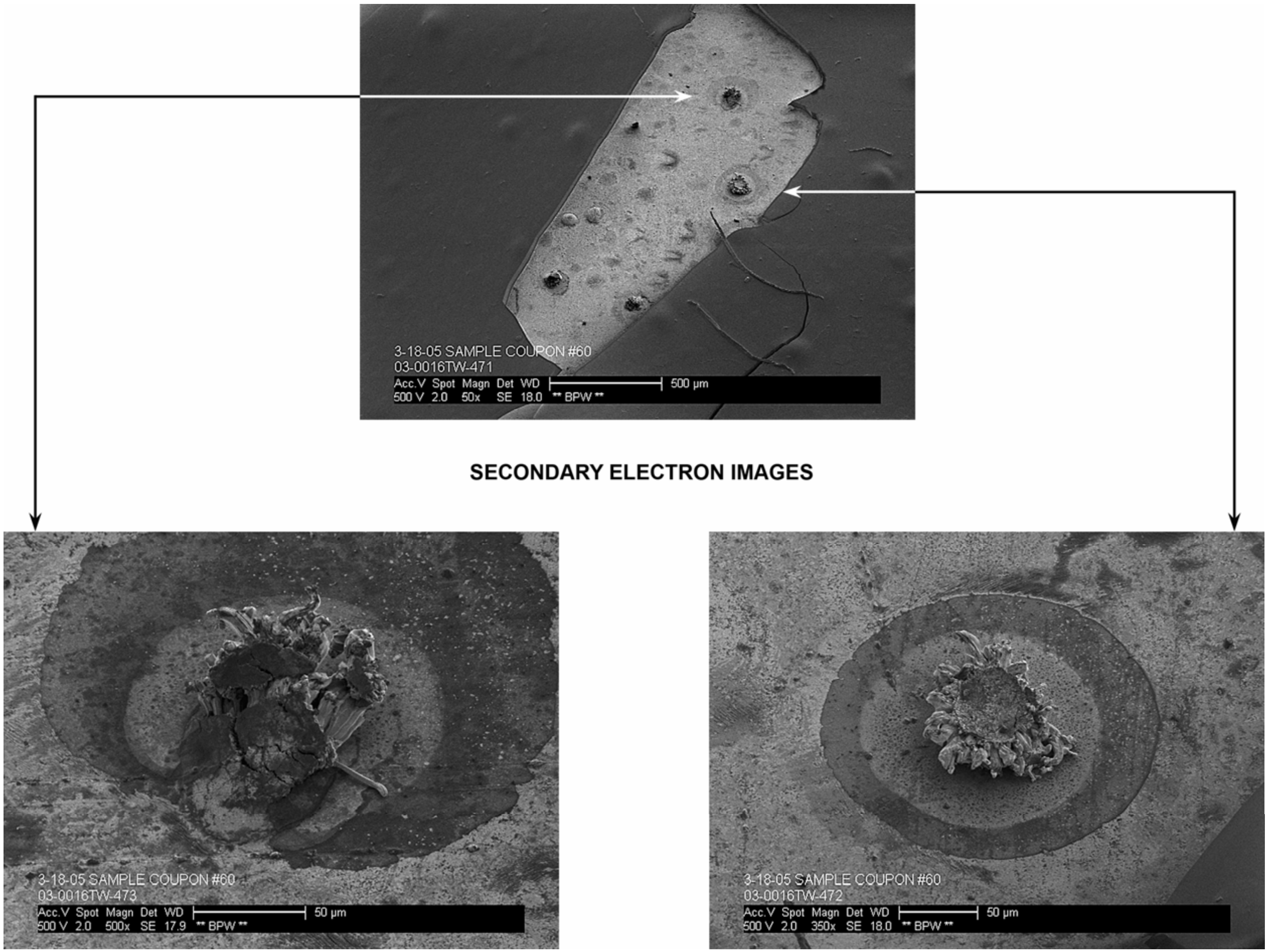


Figure 39. Coupon after Removal of 1.1 Mils of Coating E (401 Days at Ambient + 347 Days in 25°C/97%RH). Note Demarcation Lines Where Bubbles Were.

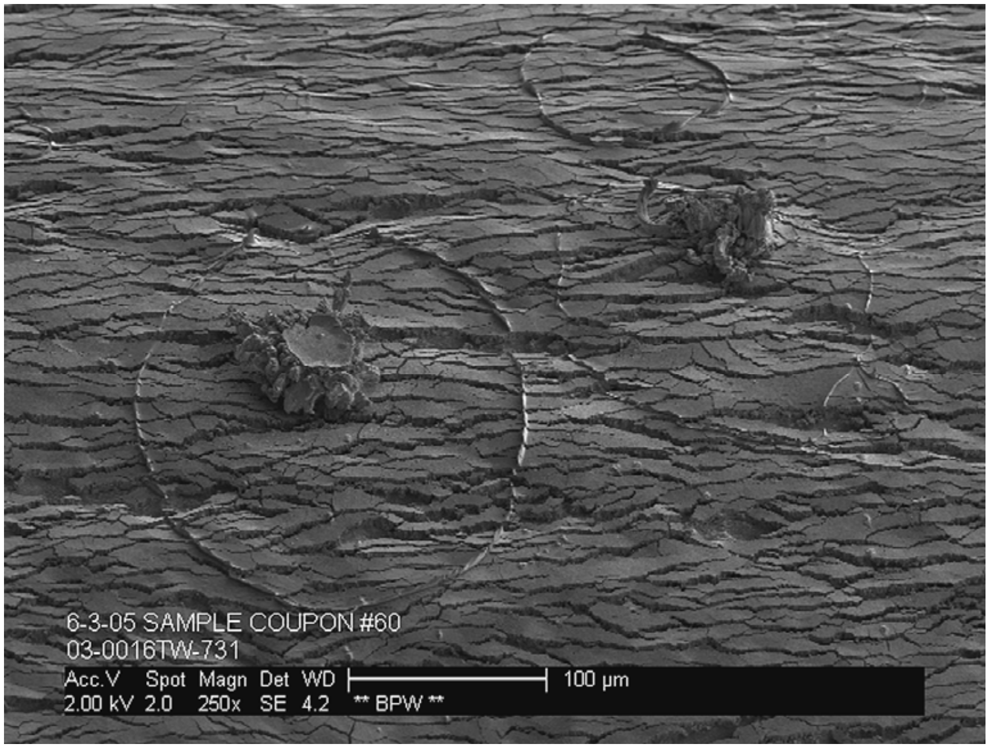


Figure 40. Coupon after Removal of Coating E (401 Days at Ambient + 347 Days in 25°C/97%RH). Note Demarcation Lines Where Bubbles Were (Circular Ridges are Organic Material). Tin Plating Has Been Intentionally Fractured.

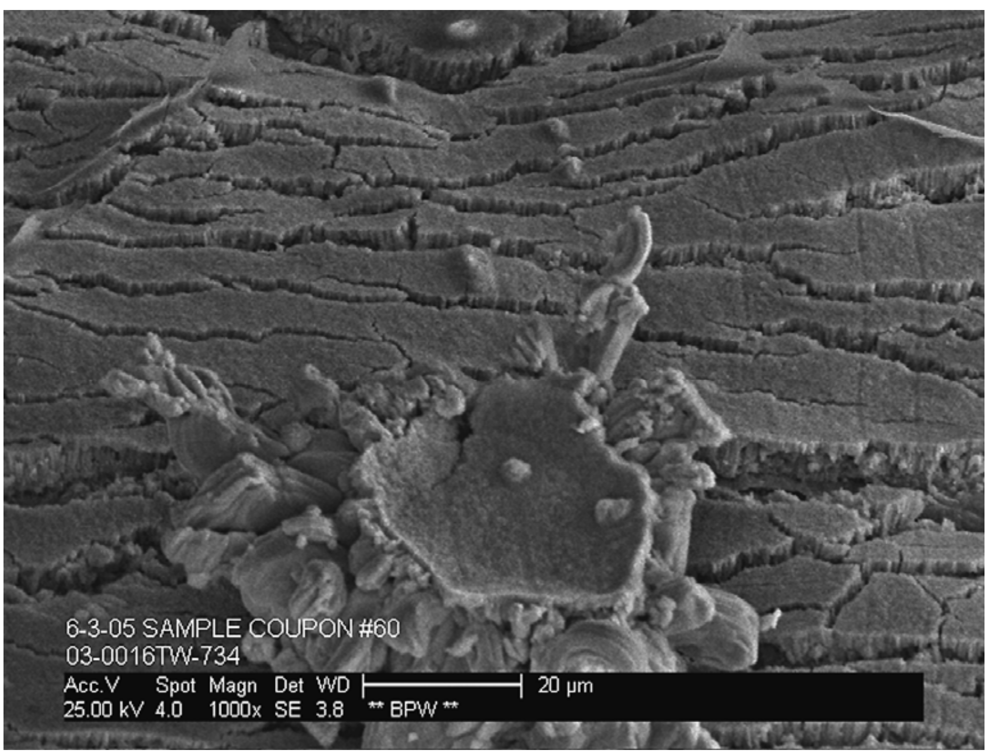


Figure 41. Close Up of the OSE from Figure 40

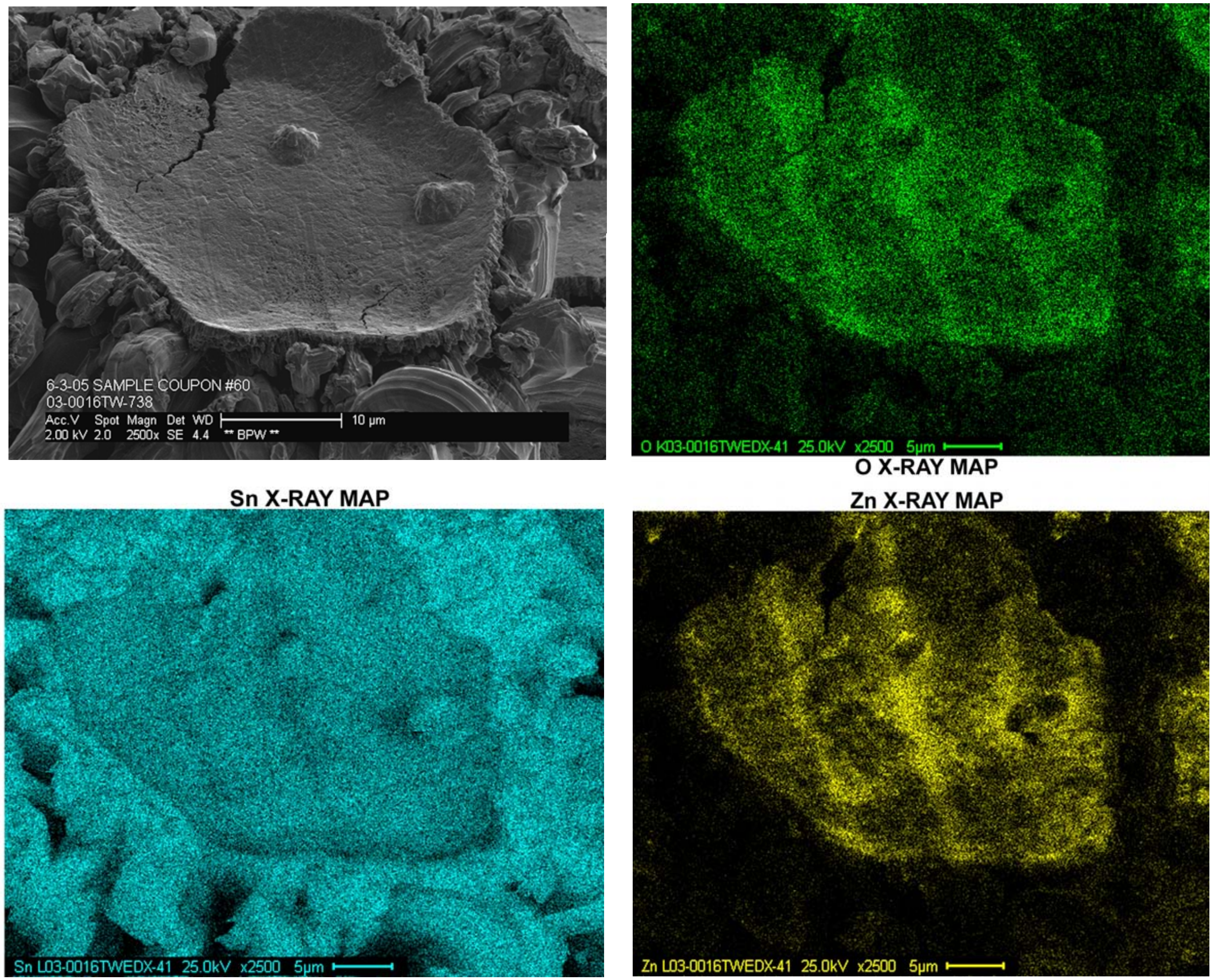


Figure 42. EDX Analysis of the OSE from Figure 41

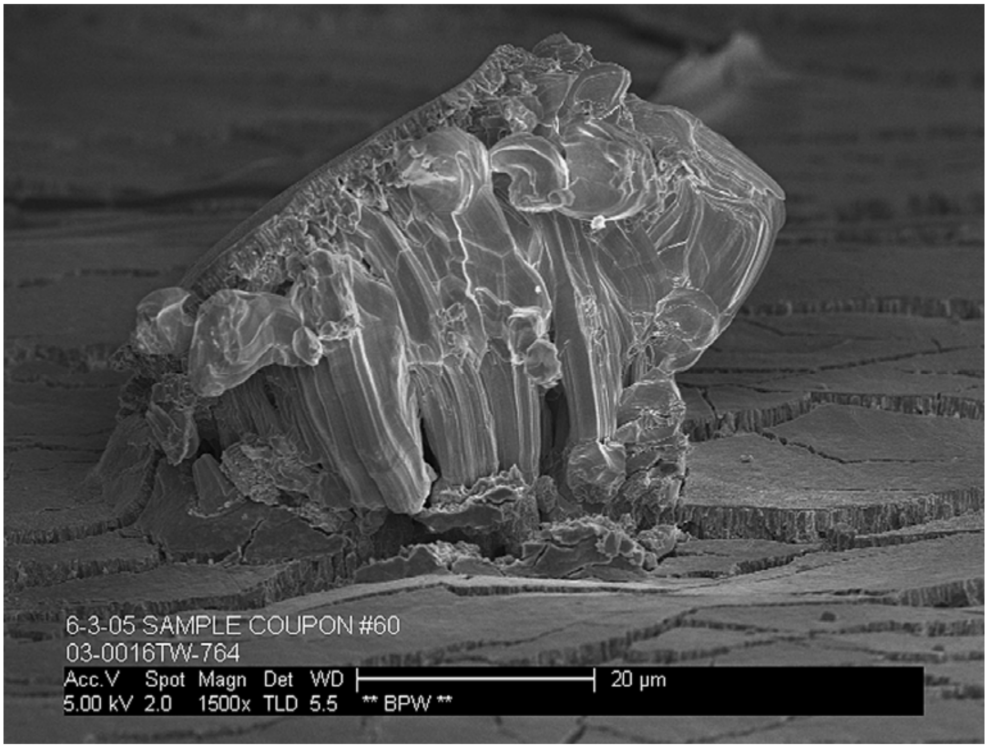


Figure 43. Coupon after Removal of Coating E (401 Days at Ambient + 347 Days in 25°C/97%RH). Tin Plating Has Been Intentionally Fractured. Note "Crust" on Top of the OSE.

Table 3. AES Analysis of "Crust"

	Atomic %					
Sputter Time* (min)	C	N	O	Zn	Sn	Ir
0	43.8	5.3	4.7	2.0	-	44.2
1.2	13.7	-	33.0	28.0	20.1	5.2
6	-	-	20.1	15.6	64.3	-
12	-	-	17.3	10.9	71.8	-
23.5	-	-	17.1	7.0	75.9	-
35	-	-	14.9	5.2	79.9	-
59	-	-	14.2	5.9	79.9	-

**Sputter Rate= 170Å/Minute Relative to SiO_2*

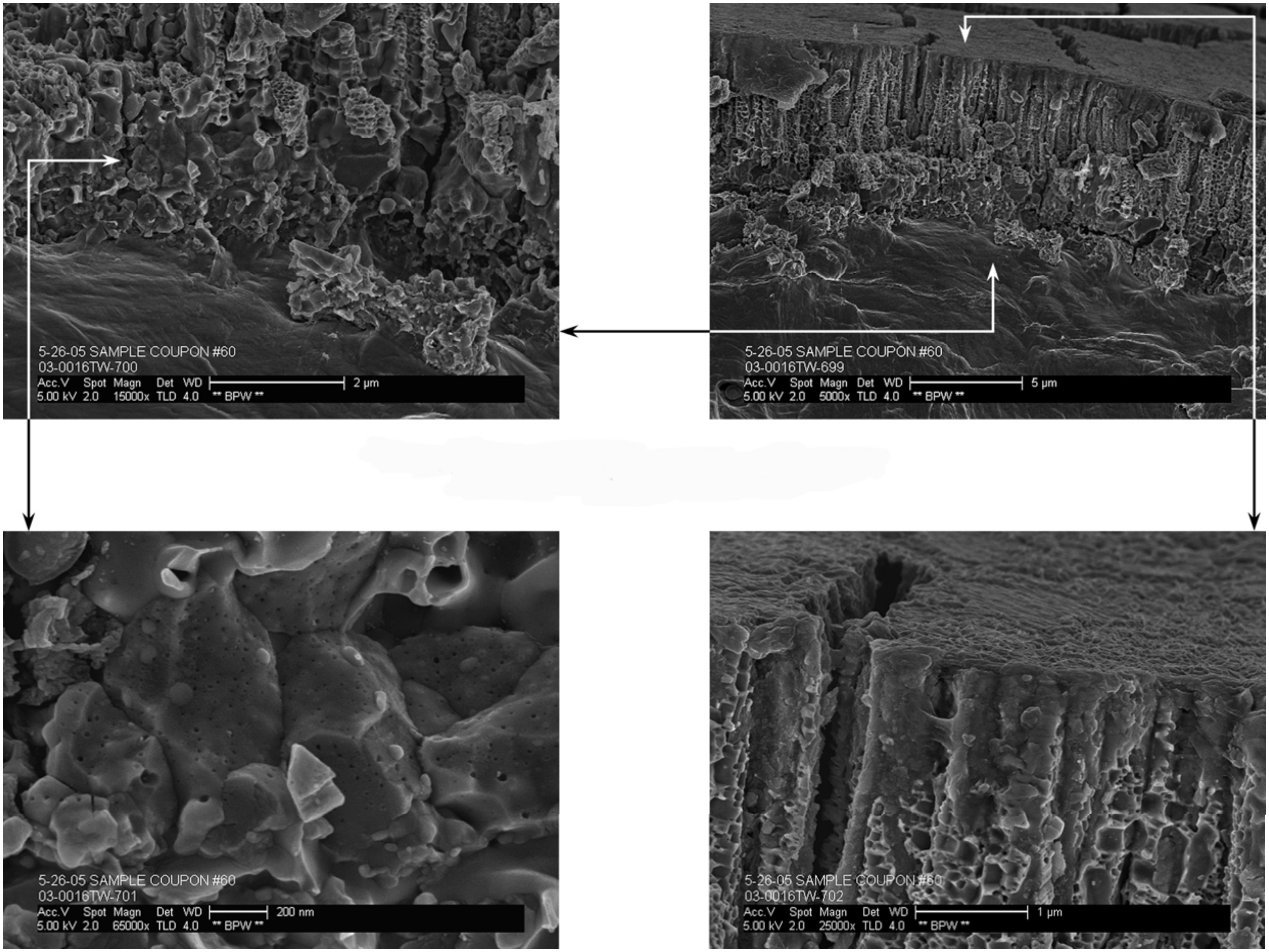


Figure 44. Coupon after Removal of Coating E (401 Days at Ambient + 347 Days in 25°C/97%RH). View is of Tin Plating that Has Been Intentionally Fractured.

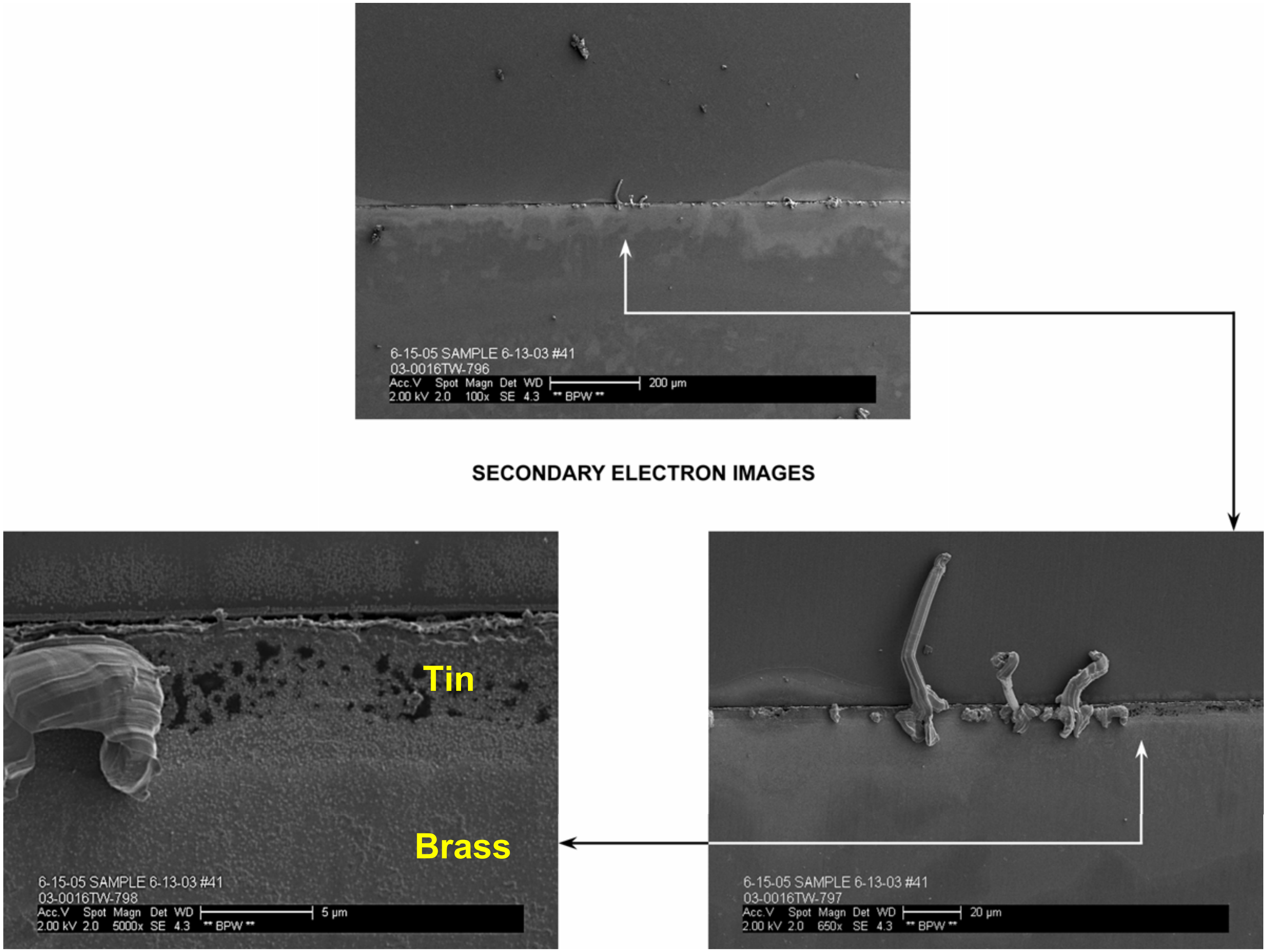


Figure 45. Whiskers Growing from a Microsection (4.4 Microns of Tin Plating on a Brass Substrate, 974 Days after Plating)