

# Technical Paper

## Tin Whisker Testing: Hot Air Leveled Tin and Electroplated-Reflowed Tin

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## **Abstract:**

Hot air leveled tin and electroplated reflowed tin have been used in the electronics industry for 15 to 20 years. This note examines the whisker performance of these coatings. Samples aged 11.5 years are analyzed for whisker growth. Whiskers do not grow on these surfaces in the as coated state or after severe forming of the coating.

## **Introduction:**

The elimination of lead from electronics has generated substantial interest in the risk evaluation for tin whisker growth. Scientists around the globe struggle to determine the fundamental route causes for tin whisker growth, accelerated test methods and more importantly, the best mitigation practices.

Accelerating the test methods is of particular interest since the existing best practices for tin whisker testing, JESD 201 and iNEMI Tin Whisker Test Method<sup>1</sup>, require a minimum of 7 months to complete. Further, the test results are only an indication of the final performance of the part – we won't know for sure how these new tin platings will perform until they have been in the field for a decade or more.<sup>2</sup>

Alternatives to tin plating are somewhat limited hence tin plating is typically the finish of choice.<sup>3</sup> Gold, silver and palladium nickel are all high performance coatings but are generally too expensive for the interconnect marketplace. Two coatings that have often been overlooked for whisker mitigation is hot air leveled tin or electroplated reflowed tin.

This report considers the whiskering performance of HALT and reflowed tin layers. Previous results are considered as well as some new testing and observations.

## **History**

The two coatings of interest are fundamentally very similar. Hot air leveled tin (HALT) or hot tin dip (HTD) are created by passing a copper strip through a molten bath of tin. The tin wets the surface of the strip and is cast upon the copper strip in a reel to reel manufacturing process. As the strip exits the tin bath the thickness of the tin coating is controlled by either an air knife (in the case of HALT) or a mechanical wiper (in the case of HTD). After wiping, the tin coating solidifies on the copper strip. The resulting microstructure is tin over copper-tin intermetallic over copper. The intermetallic is

primarily  $\text{Cu}_6\text{Sn}_5$  and the growth rate of the intermetallic is well documented.<sup>4</sup> A nickel barrier is not practical in this coating process since the coating is a casting process not a plating process. Adding a nickel layer would require substantial capital investment and capability enhancement by the HALT coaters in order to add an electroplating station prior to HALT coating.

Electroplated-reflowed tin processing results in a very similar metallurgical structure when compared to HALT. The reflow process uses a standard tin plating process. Since the tin will be reflowed, the organic content of the tin is kept as low as possible; organic compounds in the tin can volatilize during the reflow process to generate blisters, voids and surface blemishes that are unacceptable. Tin is plated onto copper strip which is subsequently passed through a reflow oven where the tin is melted and recast onto the copper strip. The resulting microstructure is tin over  $\text{Cu}_6\text{Sn}_5$  copper-tin intermetallic over copper. While a nickel barrier layer is technically possible between the tin and the copper it is not normally used nor needed. The nickel plating process is inherently slow and therefore costly. The sample examined in this particular study included a 0.5um thick copper preplate under the tin plating.

While these two coatings are similar in structure and appearance there are some differences in the general availability and preference based on the geographic region of manufacturing.

These two coatings have been in use for several decades. HALT was first introduced to the market around 1985 and reflow tin was introduced a few years later. Tyco Electronics/AMP have been using these materials since their introduction.

### **Whiskering History**

For the last 20 years, we have been using HALT coatings in a variety of product applications. Since HALT is a preplated product<sup>5</sup> there are certain engineering limitations to its use. As a result, the applications for HALT in the industry of electronic components has been focused on automotive contacts, external shells, external shells and mechanical contacts. The electronics industry<sup>6</sup> shows general acceptance of HALT and reflowed tin as an excellent tin whisker mitigation practice.<sup>7</sup>

In 20 years of use Tyco Electronics has experienced no reports of whiskering on HALT or electroplated-reflowed tin coatings. A whiskering study was performed on HALT in 1989 by researchers at AMP using the best know whisker testing at the time.<sup>8</sup> In this study, HALT coatings were stored at 23 C or baked at 50 C for up to one year then examined for whisker growth. In order to further accelerate the whiskering effect, the parts were placed under a state of continuous mechanical compression by bolting the samples to a substrate – the fastener providing a compressive stress. The results were clear – no whiskers.

### **Experimental Procedure**

In 1995 Amp performed internal research on a variety of tin based coatings.<sup>9</sup> The samples used in this research have been preserved in our laboratory and were used for

this analysis. The storage conditions are typical for an air-conditioned laboratory environment in Pennsylvania. Temperature is maintained between 22 and 24 C with relative humidity maintained between 20 and 45%. The parts were stamped and stored on manufacturing reels.

The tin plated parts were available in three part configurations. Each of these were stamped and formed after the tin coating process:

1. Flat coupon, 12 x 25mm x sheet thickness, nominally 0.4mm
2. Hemispherical dome, 6mm dome formed into the surface of the sheet.
3. Hemispherical dome with a Hertz dot on the top. The standard 6mm dome is embossed with an additional Hertz dot with an outside diameter of 1mm. This represents a bending severity on the inside radius of  $R/t = 1$ .

These three configurations represent a variety of configurations typical of the type of forming we would expect to see in connector applications using HALT or reflow tin.

Details on the two coated samples are provided in Table 1. The coatings are typical of the production coatings used in the connector industry. Both samples were produced 1Q96 and were stamped and formed on April 4, 1996. Thus, at the time of inspection, the parts were about 11.5 years old.

Table 1. Tin Coated Samples for Whiskering Inspection

Sample Code	Tin	Underplate	Supplier	Base Metal
M12	HALT, 1.25um	None	Marjan	C51100 Phosphor bronze
M14	Reflow, 1.75um	0.5um Cu	Summit	C51100 Phosphor bronze

### Examination/results

Samples from each type of coating were removed from storage and inspected for evidence of whisker growth. The formed parts could have a complex residual stress state due to the forming process. Thus, the domes were inspected in the live bug and dead bug configuration in order to better visualize the convex and concave portions of the formed shape. Samples were mounted to carbon tape for SEM evaluation. The SEM is an Amray field emission 1850 FE operating at either 15 or 20 kV.

HALT

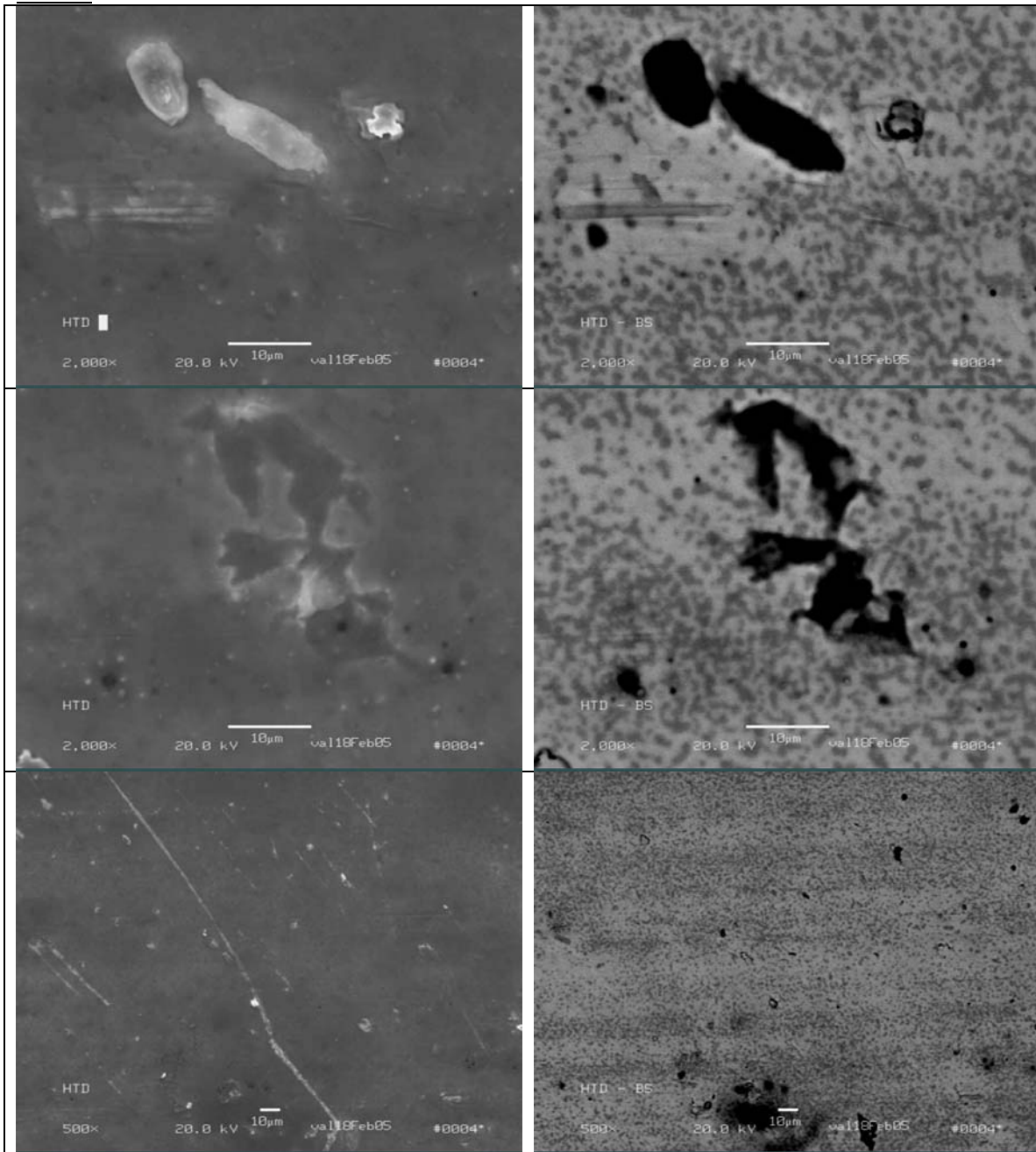


Figure 1. SEM inspections of flat surface of HALT (February 2005). Left side shows surface contaminants (Secondary Electron Mode). Right side shows the same location (Back Scatter electron Mode).

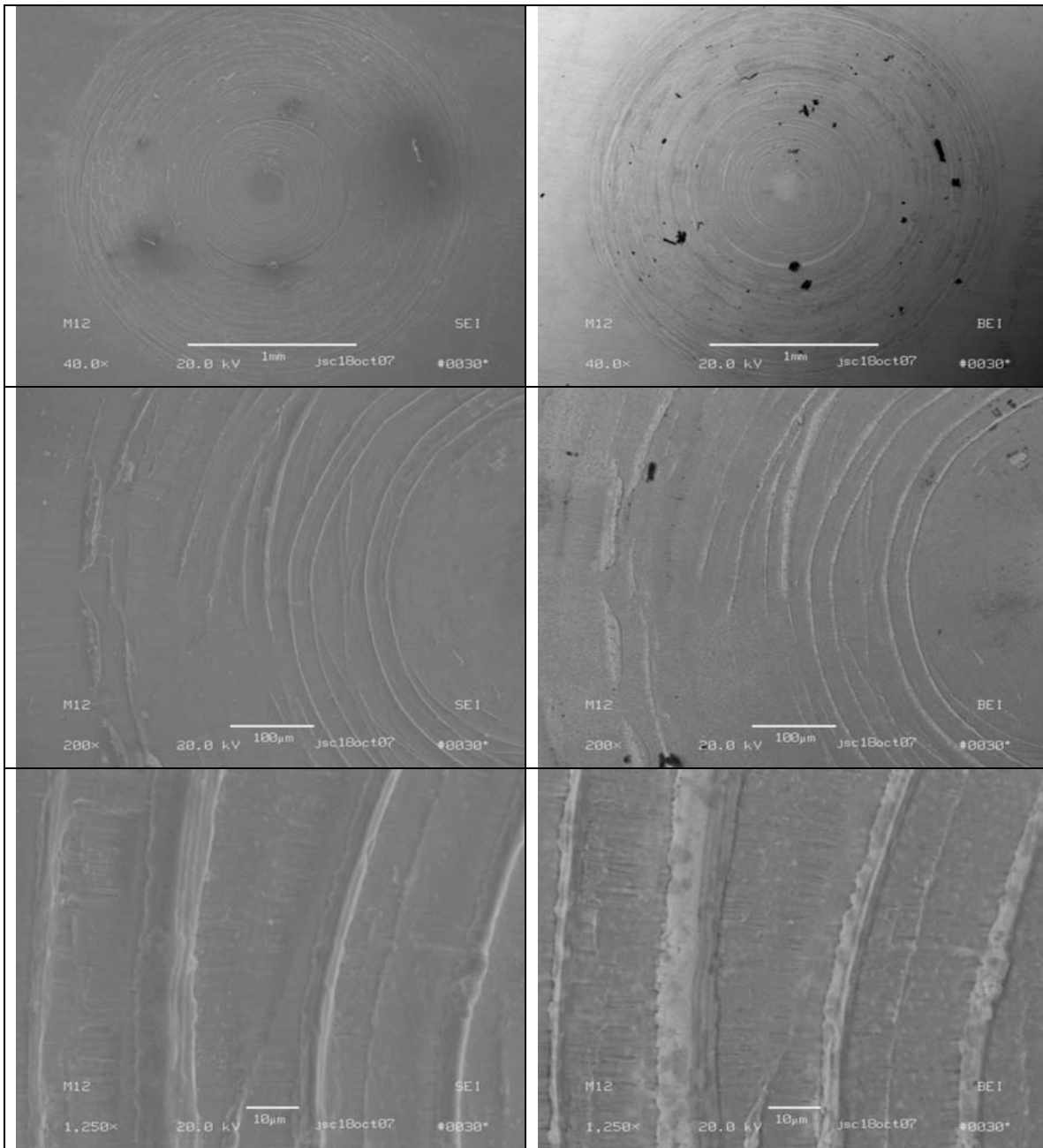


Figure 2. SEM inspections of inside surface of Hertz dot inside 6mm dome formed with HALT coating. Left side shows surface contaminants (Secondary Electron Mode). Right side shows the same location (Back Scatter electron Mode). Images are of same location at increasing magnification. No whiskers seen on any samples.

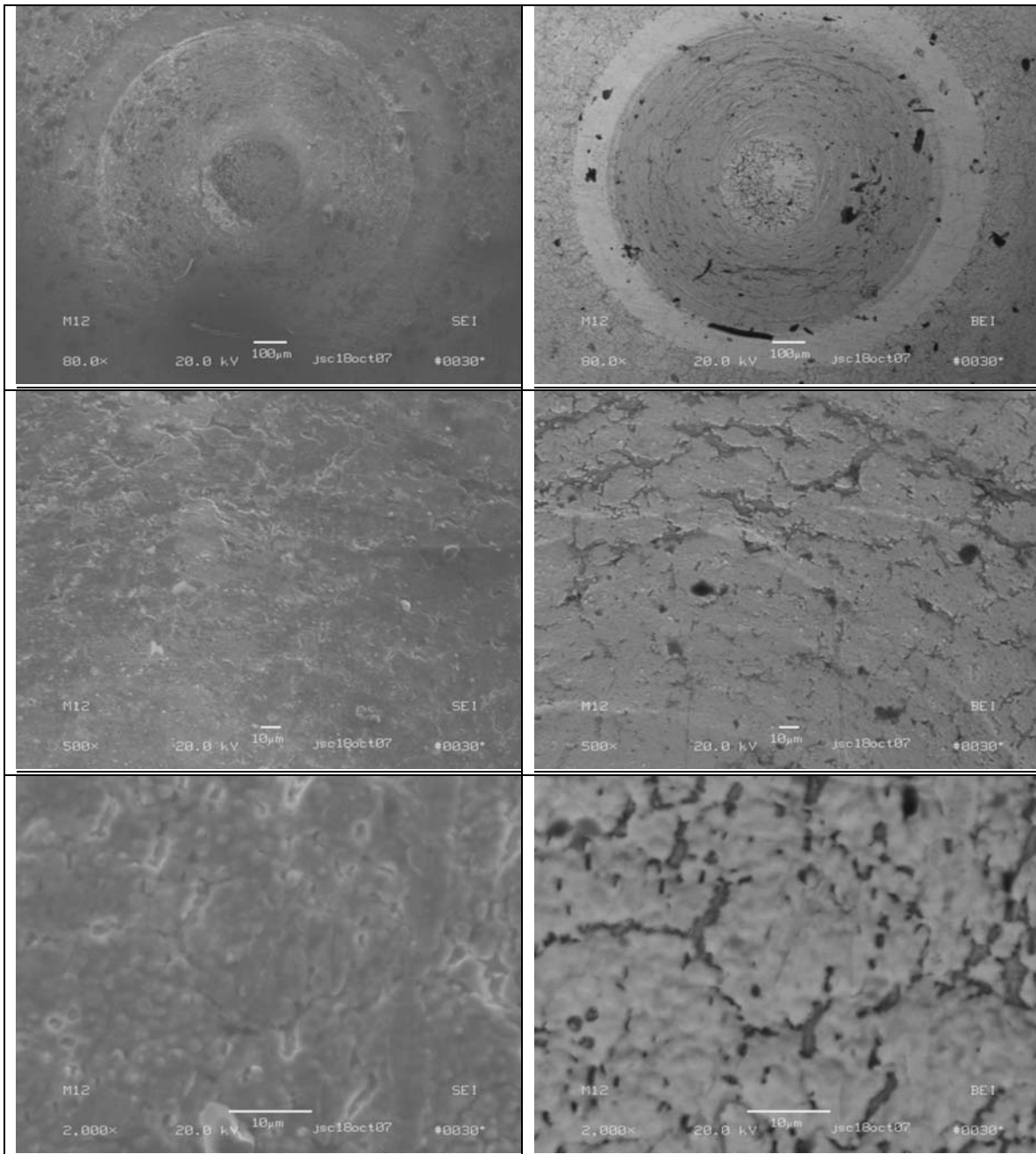


Figure 3. SEM inspections of outside surface of Hertz dot on top of 6mm dome formed with HALT coating. Left side shows surface contaminants (Secondary Electron Mode). Right side shows the same location (Back Scatter electron Mode). No whiskers seen on any samples. Some cracking of the tin layer can be seen in areas of extreme deformation. The BSE images show preferential diffusion of Cu in the cracked regions.

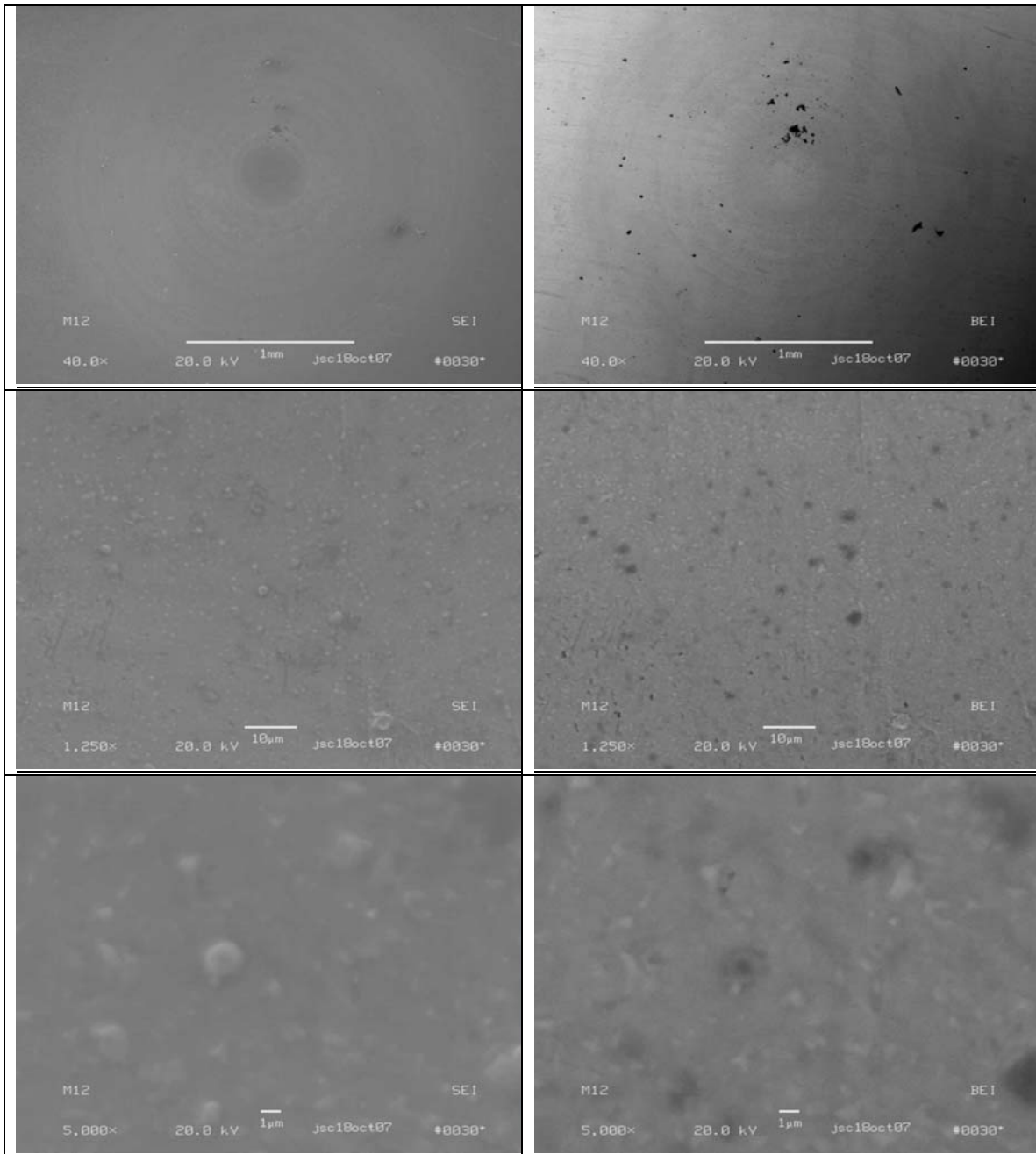


Figure 4. SEM inspections of inside surface of 6mm dome formed with HALT coating. Left side shows surface contaminants (Secondary Electron Mode). Right side shows the same location (Back Scatter electron Mode). No whiskers seen on any samples. Images are of same location at increasing magnification.

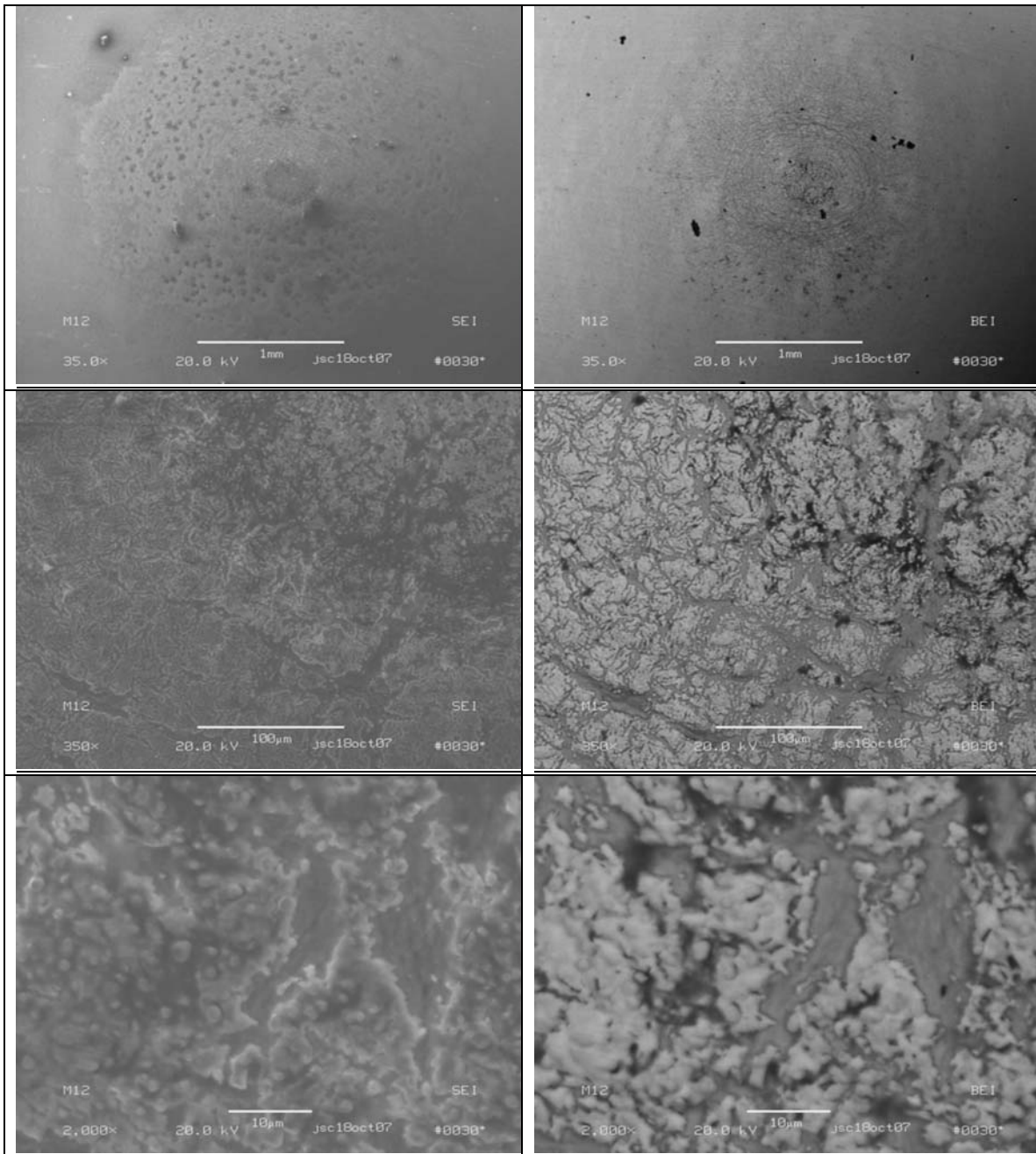


Figure 5. SEM inspections of outside surface of 6mm dome formed with HALT coating. Left side shows surface contaminants (Secondary Electron Mode). Right side shows the same location (Back Scatter electron Mode). No whiskers seen on any samples.

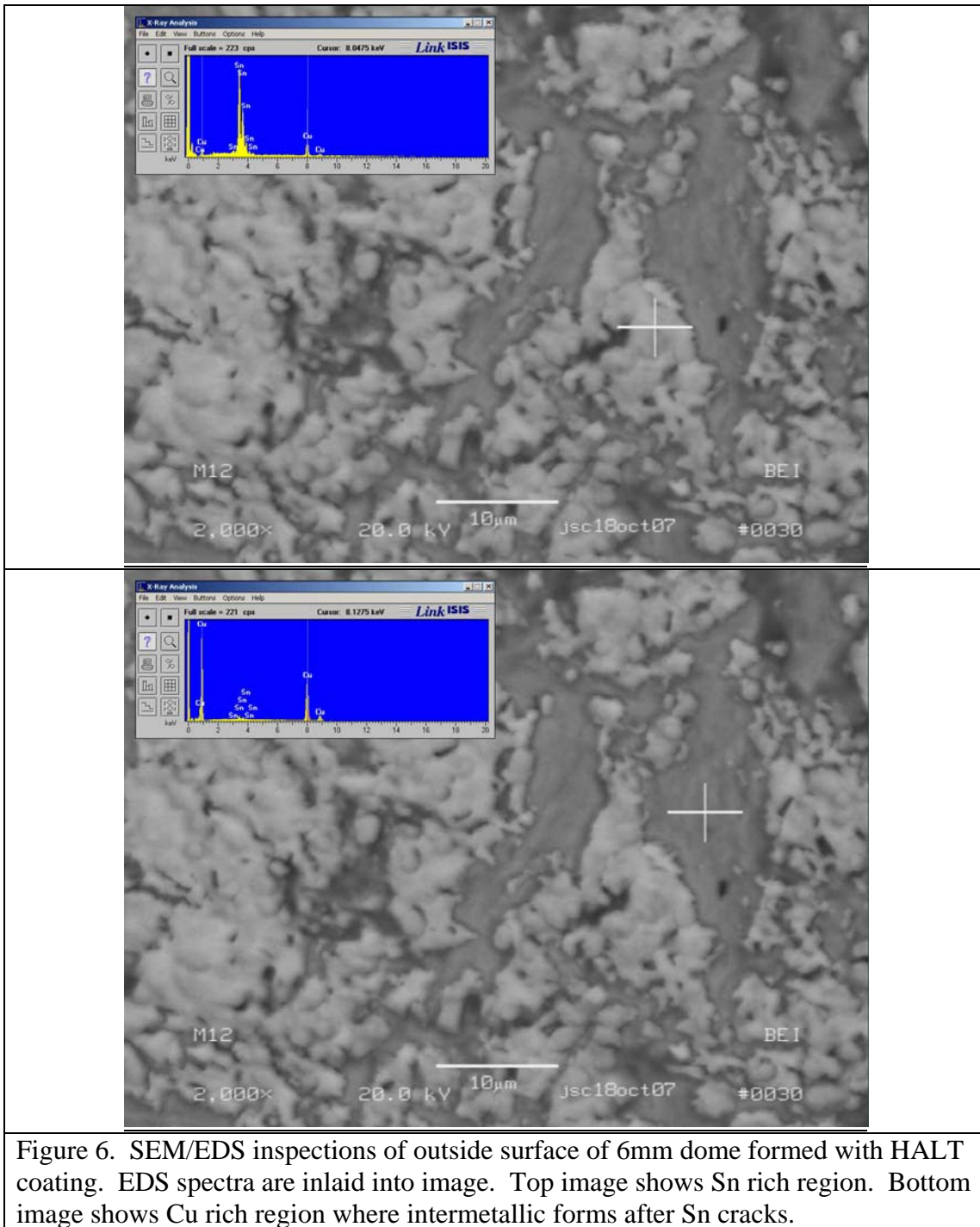


Figure 6. SEM/EDS inspections of outside surface of 6mm dome formed with HALT coating. EDS spectra are inlaid into image. Top image shows Sn rich region. Bottom image shows Cu rich region where intermetallic forms after Sn cracks.

Electroplated & Reflowed Tin

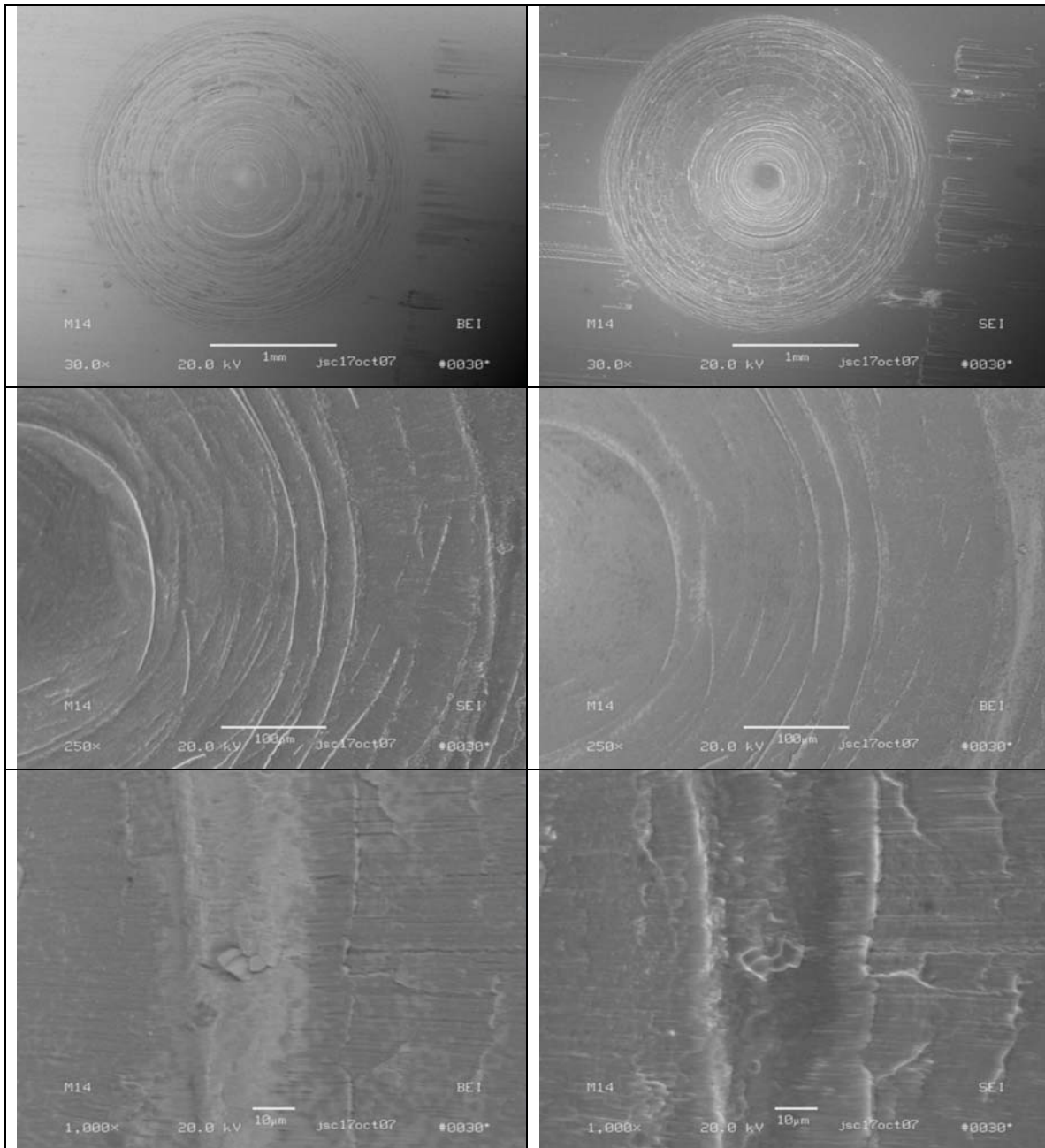


Figure 7. SEM inspections of inside surface of Hertz dot inside 6mm dome formed with Electroplated Reflowed Tin coating. Left side shows surface contaminants (Secondary Electron Mode). Right side shows the same location (Back Scatter electron Mode). Images are of same location at increasing magnification. No whiskers seen on any samples.

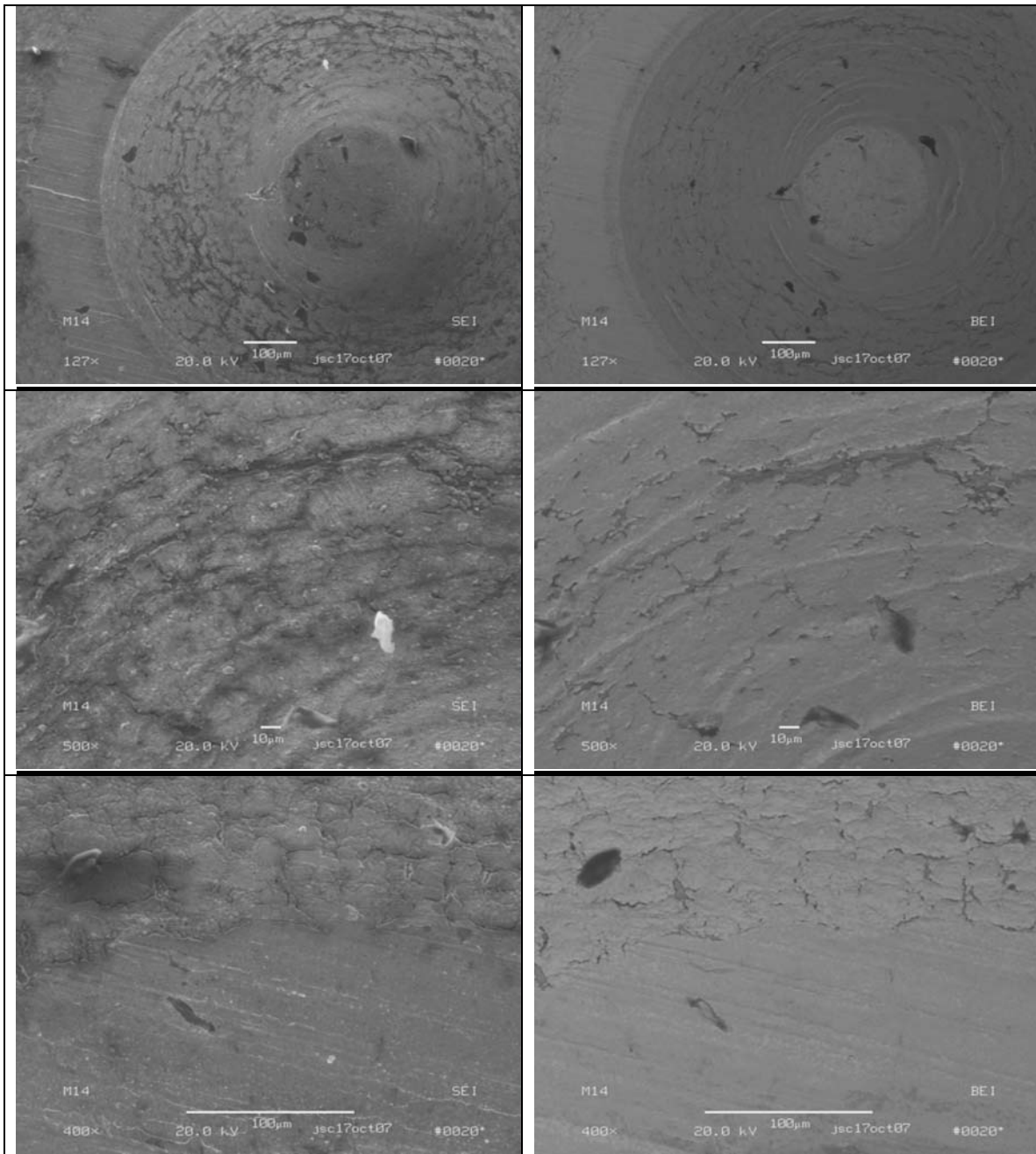


Figure 8. SEM inspections of outside surface of Hertz dot on top of 6mm dome formed with Electroplated Reflowed Tin coating. Left side shows surface contaminants (Secondary Electron Mode). Right side shows the same location (Back Scatter electron Mode). No whiskers seen on any samples. Some cracking of the tin layer can be seen in areas of extreme deformation.

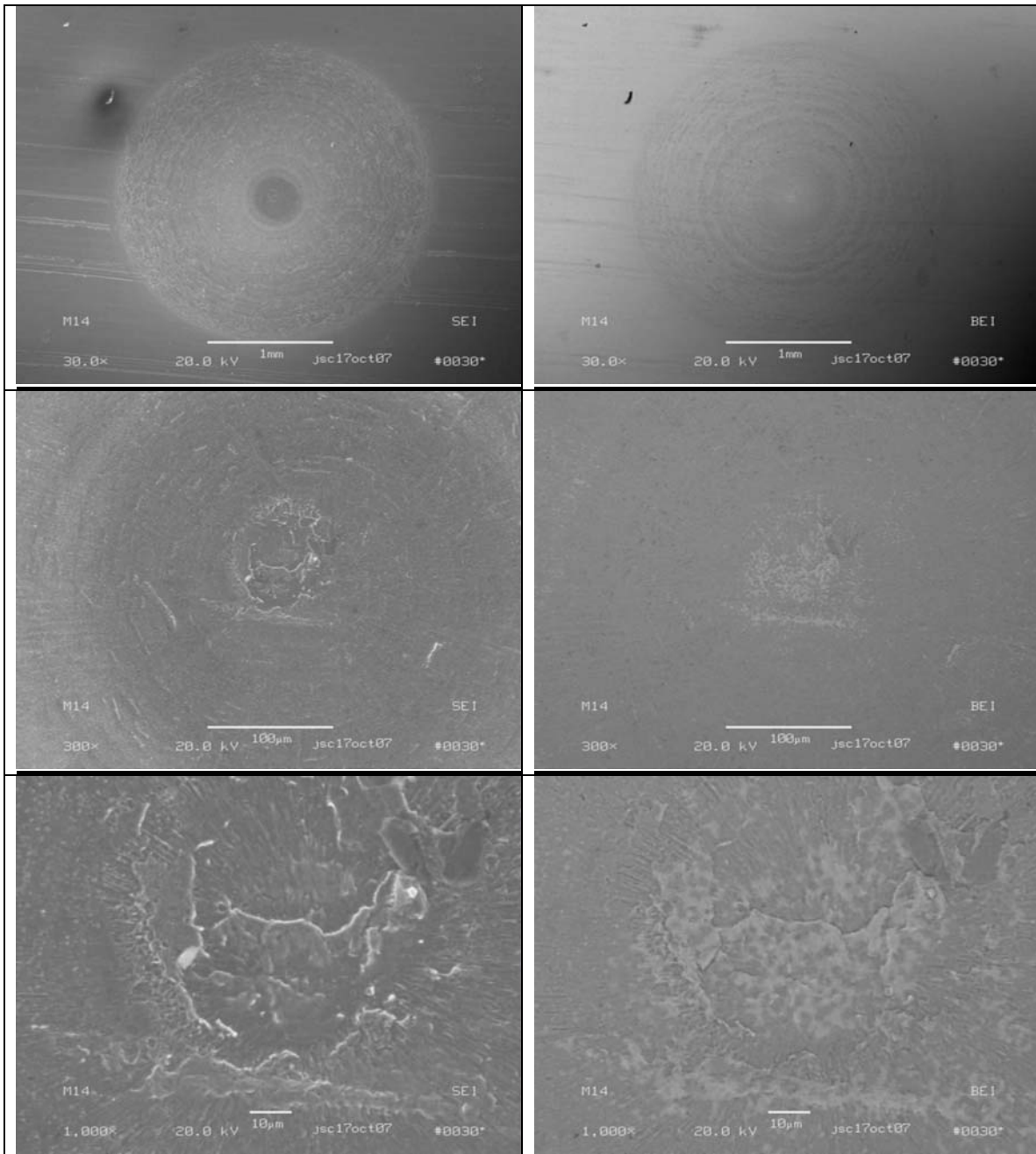


Figure 9. SEM inspections of inside surface of 6mm dome formed with Electroplated Reflowed Tin coating. Left side shows surface contaminants (Secondary Electron Mode). Right side shows the same location (Back Scatter electron Mode). No whiskers seen on any samples. Images are of same location at increasing magnification.

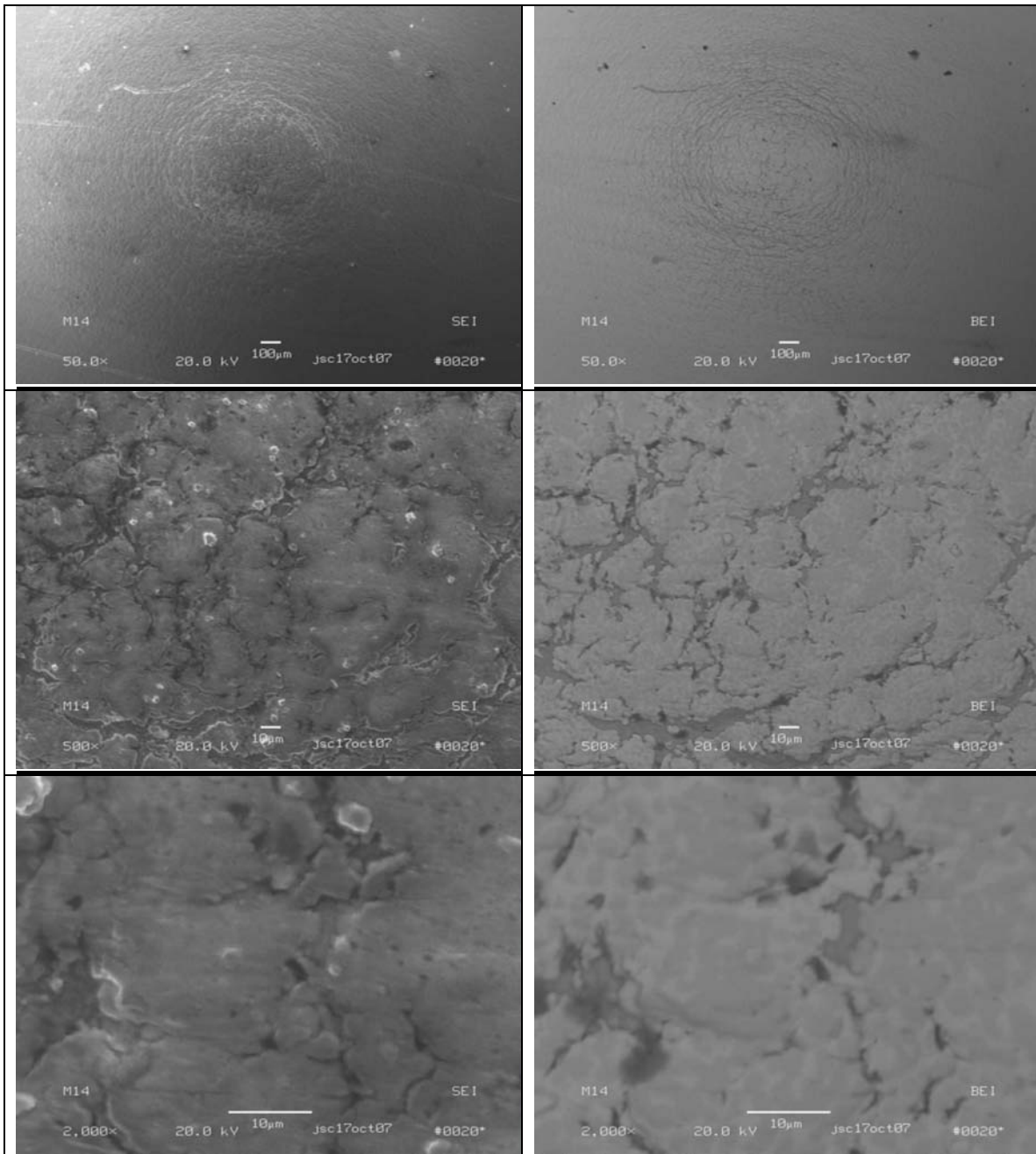


Figure 10. SEM inspections of outside surface of 6mm dome formed with Electroplated Reflowed Tin coating. Left side shows surface contaminants (Secondary Electron Mode). Right side shows the same location (Back Scatter electron Mode). No whiskers seen on any samples. Images are of same location at increasing magnification.

## **Discussion**

The results shown here demonstrate that the HALT and Electroplated Reflowed Tin coatings do not grow whiskers after very long exposures. This is in agreement with long standing performance of these products in the field. The results can be tempered somewhat since these results only apply to parts stored at room temperature and the environmental storage conditions are not the same as those specified by JESD201. While heat/humidity testing and thermal cycles testing have not been included in this test program, the room temperature parts have a very long controlled storage period, well beyond any reported whisker incubation period.

## **Conclusions**

1. HALT and Electroplated Reflowed Tin samples that are about 11.5 years old show no evidence of whisker growth.
2. Forming of the HALT or reflowed tin samples appears to have no impact on whisker growth.
3. A nickel barrier layer is not required to mitigate whisker growth on reflowed or HALT samples.

## **Acknowledgements**

The author would like to acknowledge the skilled assistance of Dr. George Chou for SEM/EDS analysis.

## **References**

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- <sup>1</sup> INEMI Tin Whisker Acceptance Test Requirements, INEMI Tin Whisker Users Group, July 28, 2004, available at [www.iNEMI.org](http://www.iNEMI.org)
  - <sup>2</sup> Tyco Electronics has been in high volume production of new lead free tin plating finishes since February 2002.
  - <sup>3</sup> Elmgren, P., Dixon, D., Hilty, R. D., Moyer, T., Lal, S., Nitsche, A., Teuber, F., "Pure Tin – The Connector Finish of Choice", IPC/JEDEC 4th International Conference on Lead-Free Electronic Components and Assemblies, October 2003.
  - <sup>4</sup> Haimovich, J., "Cu-Sn Intermetallic Compound Growth in Hot-Air-Leveled Tin at and below 100°C", AMP Journal of Technology Vol. 3 November, 1993. Also available at: [http://www.tycoelectronics.com/documentation/whitepapers/pdf/3jot\\_7.pdf](http://www.tycoelectronics.com/documentation/whitepapers/pdf/3jot_7.pdf)
  - <sup>5</sup> Preplated stock is when the copper strip is coated prior to stamping and forming the product into its desired shape. The counterpart to preplated stock is post-plated contacts where the copper strip is stamped and formed, then subsequently plated.
  - <sup>6</sup> iNEMI Tin Whisker Users Group.
  - <sup>7</sup> Hamman, T., "Electrical and Frictional Performance of Tin-Coated Contacts Exposed to Wear and Fretting Corrosion", Uppsala University Dissertations, Faculty of Science and Technology, 147, 2006.
  - <sup>8</sup> Haimovich, J., "Hot-air-leveled tin: solderability and some related properties," Proceedings of the 39th Electronic Components Conference (Houston, TX, 1989), pp. 107-112.
  - <sup>9</sup> Schuetz, T., AMP Incorporated Research Report 266.