Arcing Enabled by Tin Whiskers

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Whiskers can grow spontaneously from metallic coatings such as tin, zinc, and cadmium. This phenomenon was first discovered over 60 years ago in cadmium electroplated components [1]. Whiskers can grow to lengths upwards of 10 mm with diameters ranging from 1 µm to 10 µm. The physical growth mechanism is still not completely understood, so it is difficult to reproduce whisker growth consistently; however, it has been established that growth is induced by compressive mechanical stress in the coating [2, 3]. Failure modes caused by whiskers include transient (high voltage) or permanent (low voltage) short circuits due to bridging of adjacent conductors, as well as plasma arcing [4].

Tin whiskers have received the greatest attention due to the ubiquitous use of tin coatings on electronic components and mechanical hardware used in electrical systems. Generally, the only mitigation method known to consistently reduce the maximum size and density of whiskers in tin coatings is the addition of greater than 1 weight percent lead. Reduced use of lead due to implementation of the Restriction of Hazardous Substances (RoHS) Directive has led to a re-emergence of concern regarding tin whisker growth [5].

The risk assessment algorithm developed by David Pinsky at Raytheon for military and aerospace components ranks the potential for whisker growth on a scale of 1 to 10, where 1 is a very low risk and 10 is a very high risk for whiskers to bridge connections at different potentials [6,7,8]. This rating is not a probability for whisker growth because the mechanism of whisker growth is not understood. Instead, the values from the algorithm reproduce the opinion of subject matter experts (SME), and the net result is that all of the documented failures yield a score of 8.99 or higher, but applications where the SMEs generally agreed that tin was suitable for use score below the range of 7.0-7.5. Additional complexities of arcing, plasmas, and coronas are not explicitly included in the Pinsky rating but the discussion below provides insight into the relevance of tin whisker initiated arcing in high voltage electrical systems.

The following calculations estimate the increased likelihood of arc faults when tin whiskers are present. The dielectric breakdown field of air is ~3 kV/mm and depends on environmental conditions. The maximum electric field between two perfectly flat, parallel plates at a potential difference of 208 VAC will be 3 kV/mm when the plates approach a separation distance of less than approximately 69 µm. Non-idealities, such as roughness or particles on the surface of the plates, however, will cause higher electric fields locally, and thus increase the separation distance at which dielectric breakdown occurs. Whiskers protruding from parallel plates decrease the effective distance between the parallel plates and also greatly enhance the electric field strength at the whisker tips due to their narrow geometry.

The electric field enhancement resulting from whisker geometry is exemplified by Equation 1. The maximum electric field, E_{MAX}, for a narrow whisker tip (approximated as a paraboloid of revolution of radius R), oriented perpendicular to a flat conductor at a separation distance of d (provided $d >> R$), held at a potential difference of V is

$$E_{MAX} = \frac{2V}{R \ln\left(\frac{2d}{R}\right)} \qquad 1$$

This formula [9] indicates that, for a potential difference of 208 V, a breakdown field of 3 kV/mm between a whisker tip with radius of curvature equal to 0.02 mm and a nearby flat conductor can be achieved given a separation distance of 10.2 mm.

Failures linked to the presence of whiskers in electrical systems likely will continue to present themselves in applications because of the RoHS requirements. This paper provides a brief overview of tin whisker formation, a method used to rate the likelihood of tin whisker formation and a model illustrating the risk of arcing caused by tin whiskers.

References

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