Repressing the Growth of Tin Whiskers

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ABSTRACT

A brief summary is offered of the results of studies concerned with reduction of metal whisker growth from electroplated tin. It has been found that lead, of the order of one per cent in a tin coating, either completely prevents the formation of tin whiskers or reduces growth to a degree that would eliminate any hazard of short circuits caused by whiskers even where components are closely spaced. Higher lead-tin alloys are equally effective.

Over a period of several years, in studies concerned with the growth of whiskers from electrodeposited metals,[1–3] one of the objectives has been the development of a method of preventing this type of growth. Throughout the work, however, the lack of reproducibility in the amount of whiskers which form on similarly prepared test specimens has been a major problem. Specimens plated at different times, under conditions as nearly identical as possible, have shown wide variations in their tendencies to form whiskers. In fact, occasionally a group of specimens have developed no whiskers at all, while others "prepared identically" have developed heavy deposits. Not only are there variations in density of growth and length of individual whiskers on similar specimens, but there are great differences in induction period, the interval between specimen preparation and the first visible indication of whisker formation. This may range from a matter of weeks or months to a period of years. The variability in amount of growth could not be related to differences in the physical characteristics of the coatings themselves.

Because the underlying reasons for this lack of reproducibility in the behavior of electrodeposited coatings are not understood, it has not been possible to correlate the method of specimen preparation with the tendency to develop whiskers. Therefore, to determine the effect of a change in any one variable, it has been necessary to repeat many of the studies, preparing similar specimens at different times.

Variations in detail in the preparation and cleaning operations prior to electroplating, rinsing and drying must be expected. In addition, details in plating procedure vary with regard to time, temperature, bath composition, current density, geometry and spacing of the electrodes, and the work load distribution itself. There also are unavoidable differences in the character of the individual parts with regard to surface structure, composition and residual stresses.

It is known, for instance, that relatively minor changes in plating procedure may result in significant differences in the amount and character of the stress in a deposited film. As a consequence, the film may be highly stressed in tension or in compression, depending on the deposition details. Day to day variation in the plating operation cannot be avoided. Changes in bath composition as a result of use and exposure to the atmosphere, work load, filtration and circulation operations, make-up and corrective additions, all are reflected in the characteristics of the deposited metal.

A number of studies have been made of factors which possibly might affect the amount of whisker growth from an electrodeposited coating. A few of these studies will be referred to briefly in order to indicate several of the variables which have been considered and what has been determined to date. Among the test specimens used in the program, there are some which now have been under observation for as long as 13 years, and it is believed that there is enough evidence at hand to indicate a means of minimizing the growth of tin whiskers.

SUMMARY OF EARLY WORK

Density of whisker growth conceivably may be affected by factors such as physical condition of substrate surface, thermal expansivity differences of various basis materials, deposit thickness and character of electroplate as modified by variations in plating bath and plating current density.

A number of these variables were considered in the very early studies. It was found that the roughness or surface condition of the substrate before plating did not make an appreciable difference in whisker growth. Nor did thermal expansivity differences between substrate and electroplate. Coating thickness had much greater influence, enhanced growth being associated with the thinner coatings.

It was realized that the character of an electrodeposited coating is largely dependent on the plating procedure itself. Adhesion, grain size and internal stress—believed to be closely related to whisker growth—vary with the plating current density. Keeping coating thickness constant but varying time and plating current, it was observed that differences in whisker growth were minor, varying only in degree.

Plating bath compositions and types of additives also were considered. Here again whiskers developed on tin deposited from a wide range of bath compositions and additive concentrations.

Various types of exposure have been used but whiskers

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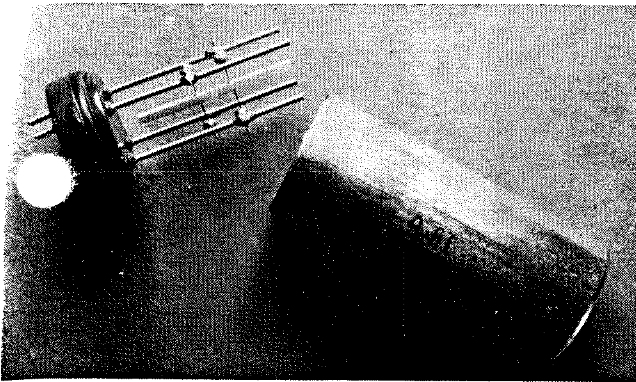

Fig. 1. Quartz crystal assembly and cover—Original magnification 2X.

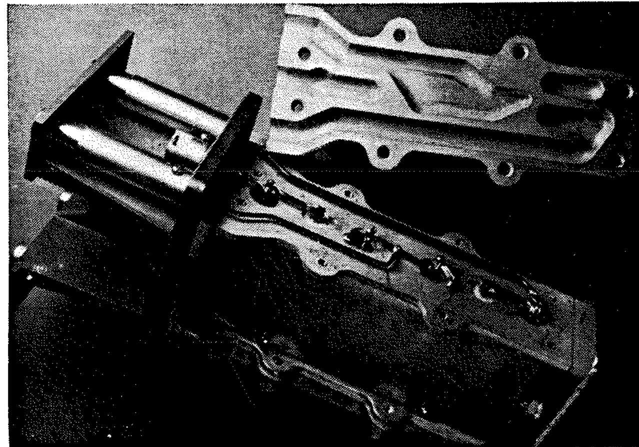

Fig. 3. Automatic switch unit and cover—Original magnification 1.2X.

have developed under all conditions ranging from high vacuum to high relative humidity. Figures 1 through 4 illustrate whisker growths found on tin plated surfaces in quartz crystal frequency filters and in automatic switch units. The parts involved were either inside evacuated containers or exposed to an atmosphere of dry nitrogen. An increase in relative humidity is frequently associated with increased whisker growth but this is believed to be a secondary effect and not due to humidity per se. When corrosion of the basis metal occurs, corrosion products are formed and as a result stresses in the coating are increased. This increase in stress in turn will accelerate the development of whiskers.

When, in spite of precautions taken to maintain close control over the plating operation, pronounced variations in w[illegible] growth were observed, contamination of the bath was suspected. A few of the most likely contaminating metals were introduced and codeposited with the tin. Some made very little difference but others, like copper, reduced whisker growth markedly.

Many samples of tin-coated copper wire were then examined. Only short whiskers, relatively few in number, were found. It was thought that possible diffusion of the copper into the tin was responsible for this reduction in whisker growth. Codeposition of copper and tin then should be beneficial and this proved to be the case over a 12-year test period.

TIN ALLOYS

In the meantime, other alloy coatings were electrodeposited and eventually all of the metals in the periodic table which could be electroplated were included. After four and one-half years, it has been found that, when present to the extent of one to two per cent, a number of metals will reduce to a negligible amount the growth of whiskers from tin. Other metals had little or no effect. Among those which appeared to be the most promising were antimony, cobalt, copper, germanium, gold, lead and nickel.

Glazunova[4] believes that metal impurities, particularly zinc and copper, in concentrations as low as 0.0001 per cent in the plating bath, affect metal whisker growth. However, variations in growth from specimen to specimen masked any such effect in our work at these low concentrations.

Because it is difficult to electroplate some metals simultaneously with tin, the effect of a thin metal film, deposited either before or after deposition of the tin, has been studied. In addition, a number of metals which could not be plated readily from aqueous solution have been vacuum deposited.

It was found that not only did alloying of certain metals with tin reduce whisker growth, but also that films of a few metals, when in contact with tin, were similarly effective, particularly when the second metal film was used as a substrate.

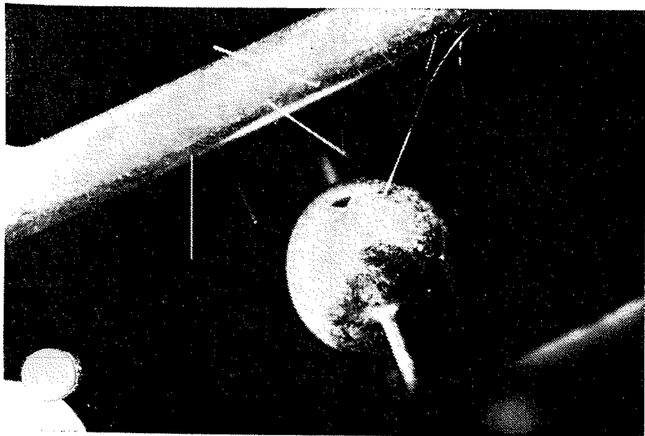

Fig. 2. Whisker growths on quartz crystal mounting wires—Original magnification 30X.

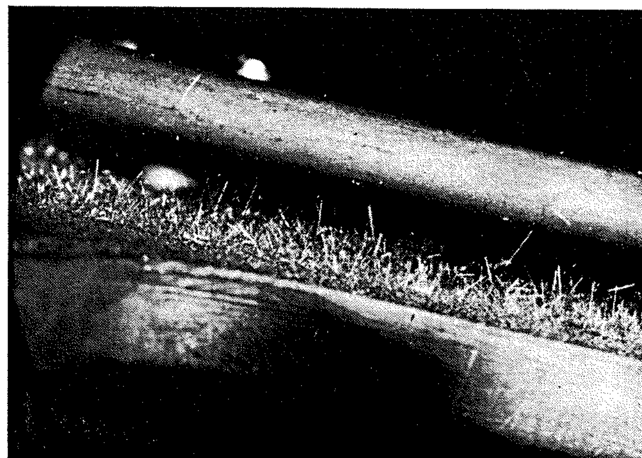

Fig. 4. Whisker growths on switch surfaces—Original magnification 14X.

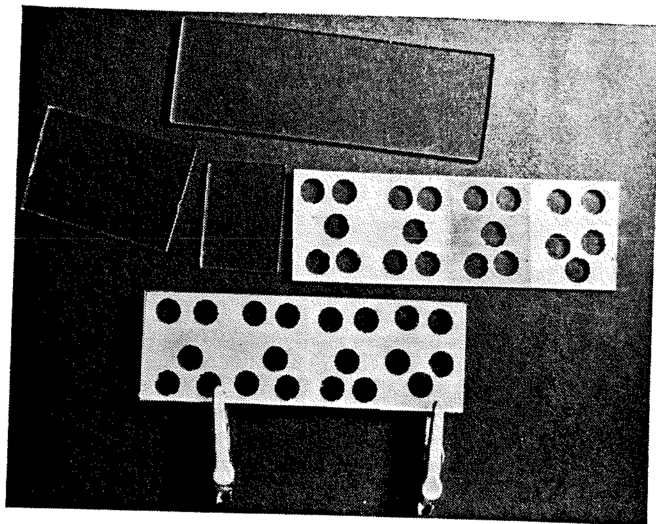

Fig. 5. Mask and slides used in vacuum deposition study—Original magnification 1.6×.

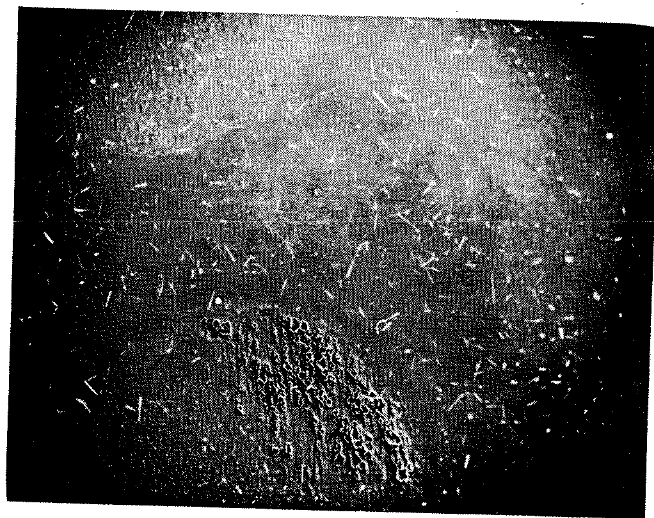

Fig. 7. Whisker growths on tin in contact with glass and with iron—Original magnification 24×.

This reduction in the growth of whiskers from tin in contact with certain other metals is illustrated in Figs. 5 through 8. Figure 5 shows a mask by means of which several metals were individually vacuum deposited to form a pattern of islands on a microscope slide such as that shown in Fig. 6. The entire slide was then coated with tin, leaving a film of tin in direct contact with glass and with the several metals of interest. In Fig. 7 may be noted the growing whiskers of tin, both on glass and iron substrates, while in Fig. 8 there is no evidence of whisker growth on the tin over gold.

The influence of the substrate has been noted by others also[4–6] but, as there is some disagreement among the various authors, more extended work along these lines will be required to resolve the issue.

In addition to the need to reduce whisker growth from electrodeposited coatings, however, another requirement must be kept in mind where electrical components are concerned. This is the all-important factor of solderability. Although, as has been pointed out, a number of metals reduced whisker growth from tin, solderability was degraded. For instance, some tin-nickel alloys have remained free of whiskers for more than nine years. However, when enough nickel is added to tin to reduce whisker growth, the alloy becomes more difficult to solder without the use of an active flux.

TIN-LEAD ALLOY COATINGS

When most of the various factors are considered, including ease of plating, cost, control, appearance, solderability and reduction in whisker growth, probably the best results are obtained by incorporating a small amount of lead in the tin.

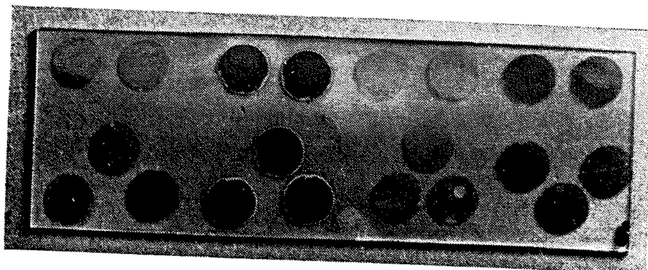

Fig. 6. Pattern of vacuum deposited metals on glass slide—Original magnification 1.6×.

Numerous tin-lead coatings are presently in test, some of them now with a background of 12 years of observation. Even under exposure conditions of 95 per cent relative humidity where gross corrosion of the substrate has taken place, only a few short whiskers have been found. As indicated in a previous paper,[7] an occasional whisker was found when one series of tin-lead coated test specimens was examined. However, the maximum length observed of approximately 20 mils is not comparable with that commonly attained by whiskers on electrodeposited tin and, therefore, would be of much less consequence in normal circuitry. More recently, in an attempt to obtain a broader picture of what will happen to such coatings prepared at different times under different conditions, additional specimens have been included in the test program. Data from this part of the study will not be available in their entirety for several years. Up to the present time, these tin-lead coatings have remained free of whisker growths.

Figures 9 and 10 are typical of the differences observed. In Fig. 9 is shown a tin-coated specimen after an exposure period of approximately one year at 80C. In Fig. 10 is shown a similar specimen coated with tin-one per cent lead, exposed

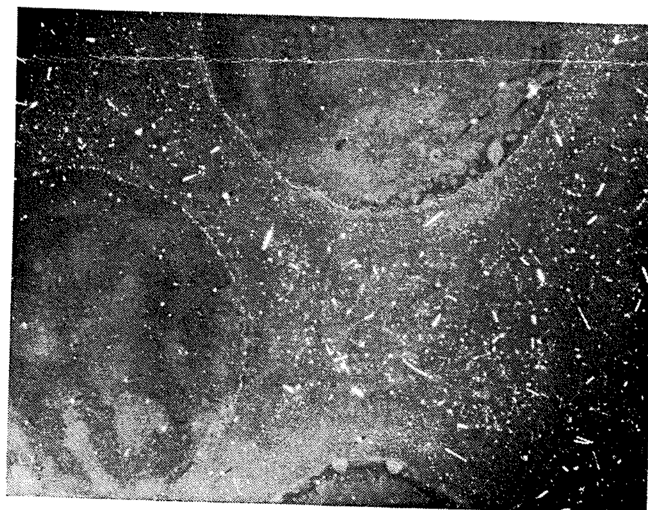

Fig. 8. Whisker growths on tin in contact with glass. Tin in contact with gold free of whisker growths—Original magnification 24×.

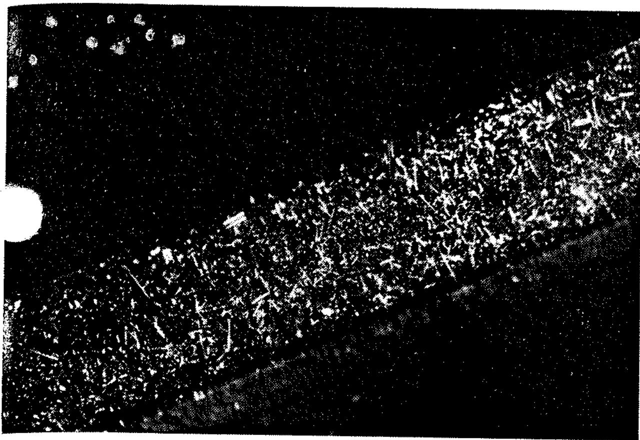

Fig. 9. Whisker growths on tin after 11 months—Original magnification 8×.

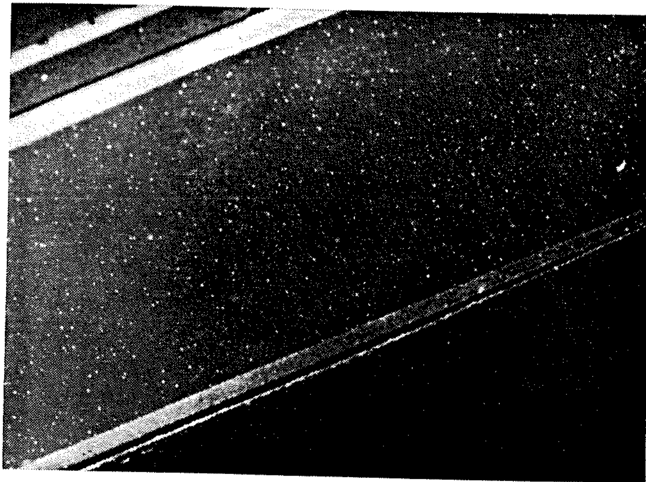

Fig. 10. Surface of tin-one per cent lead after 11 months—Original magnification 8×.

for the same time in the same container. The light-colored areas on this latter surface are not whiskers but very tiny rounded protuberances, not present when the specimens were first prepared. Such formations have been observed before on various electroplated coatings. They develop only to the extent shown, never attaining lengths of more than three-four mil or creating the short circuiting hazard of a whisker.

Deposition of the various tin-lead alloys was accomplished without difficulty at room temperature in fluoborate baths containing bone glue as an additive. Because a range of compositions was desired, dual anodes were used, whereas normally only a single anode of specific composition would be required. A current density of 3 amp/dm² (30 amp/ft²) was employed with one-eighth of the current being passed through [illegible] in anode. The bath composition was adjusted according [illegible] ie alloy desired. Recommended practices for this type of plating are available in most shops.[8, 9] These same references also contain information regarding sources of necessary chemicals.

CONCLUSIONS

Based on results of work extending over some 12 years, it appears that lead of the order of one per cent or more incorporated in electrodeposited tin minimizes the growth of whiskers. A higher lead content, such as that present in a solder alloy, is not necessary but is equally effective in reducing whisker formation. No exceptions have been noted with regard to this improved resistance to whisker growth when tin-lead has been used in place of tin, as long as areas of the coating have not been subjected to high compressive stresses. At the edges of bolt heads or washers, for instance, "squeeze" whiskers may develop regardless of the coating composition. Hence, electroplated solder alloys or tin alloys containing as little as one per cent lead are satisfactory substitutes for tin coatings where whisker growth could be a problem, provided other requirements of the coating are met.

ACKNOWLEDGMENT

Many of the specimens included in the metal whisker studies were prepared by Gustav Bittrich. This involved electrodeposition of numerous metals and alloys on some four thousand specimens. His contribution is gratefully acknowledged.

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Discussions of this paper are invited for publication in the Discussions Section of a future issue of PLATING.

CORRECTION

Figure 12 was published incorrectly in the paper by S. S. Frey and G. A. Lux of Oakite Products, Inc. entitled "Creation of Anodic Films in the Cleaning of Zinc Die Castings" which appeared on page 1278 of the December 1965 issue of PLATING. The photomicrograph shown in Fig. 12 should have been turned 90 degrees to the right. In that correct position, the effects of the before and after treatment can properly be evaluated.