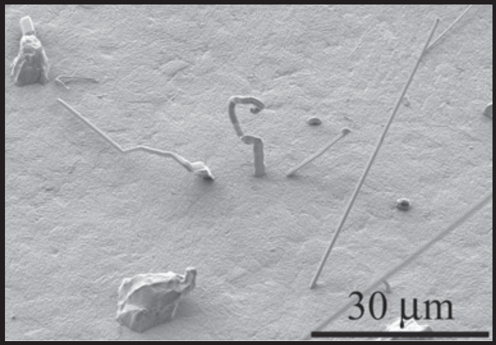
Lead-Free Surface Finishes for Electronic Components: Tin Whisker Growth

Objective

This project will provide data and materials measurements necessary to improve the reliability of solder interconnects degraded by the switch to lead-free technology. In particular, the state of compressive stress and the localized creep response (whisker growth) of tin-based lead-free electrodeposits are being measured. Molecular dynamics simulations aimed at understanding the conditions (stress, temperature, grain boundary diffusion, surface diffusion) at which the hillock/whisker growth processes can be initiated are being utilized to examine how stress and creep drive whisker growth. Industry will use these measurement methods and data to modify processing conditions to prevent the formation of tin-whiskers.



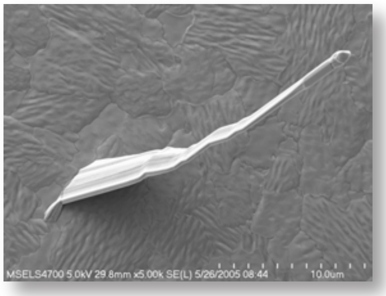
METALS

Impact and Customers

- The 2007 International Electronics Manufacturing Initiative (iNEMI), and IPC technology roadmaps clearly articulate the U.S. microelectronics industry's need for research and measurement to predict and prevent tin (Sn) whisker formation.
- There is a clear industrial consensus that more information is required regarding the influence of electroplating conditions, grain structure, compressive stresses, intermetallic compound (IMC) formation, diffusion of Sn, and thermal cycling effects on electroplated components.
- We maintain multilevel interactions with industry/government/university groups, including iNEMI, Aerospace Industries Association (AIA), Government Electronics and Information Technology Association (GEIA), and the UMD - Center for Advanced Life Cycle Engineering (CALCE).
- iNEMI has asked the NIST Metallurgy Division to establish a standard technique for measuring the stress in electroplated Sn films, using the $\sin^2\psi$ X-ray diffraction method.

Approach

Tin is widely used as a coating in the electronics industry because it provides excellent solderability, ductility, electrical conductivity, and corrosion resistance. Unfortunately, tin whiskers often grow spontaneously from tin electrodeposits and short-circuit finely pitched electrical components. Adding a few percent of lead inhibits whisker growth, but environmental concerns have resulted in a demand for lead-free (Pb-free) surface finishes, and consequently, a demand for whisker mitigation strategies.

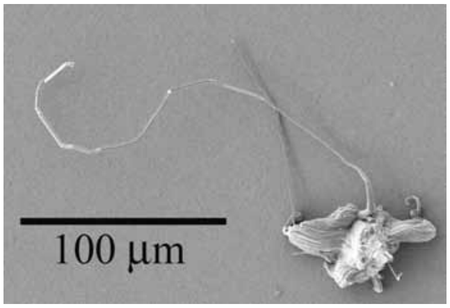


Two conditions in the tin coating are necessary, but not sufficient, requirements for whisker growth. First, a compressive stress must exist in the film. Second, energy relaxation mechanisms such as grain growth and recrystallization must be impeded, e.g., by grain boundary pinning. We have focused on the measurement of stress using cantilever beam bending and X-ray diffraction methods, and the development of dynamic molecular models to understand initial hillock/whisker formation. We are also investigating pulse deposition techniques to eliminate the columnar grain shape of tin as a strategy to prevent tin whisker formation.

Accomplishments

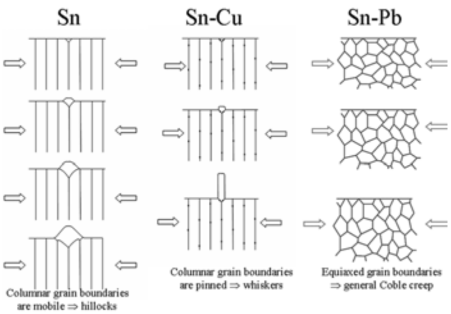
NIST sponsored a workshop in April 2008 to assess the state of the art residual stress measurement methods in Pb-free electrodeposits. Thirty researchers from industry, government labs and universities attended. The benefits and difficulties with both X-ray diffraction (sine squared psi) and wafer/beam curvature methods of stress measurement were discussed. Topics included: precision and accuracy of measurements; interpretation of measurements, e.g. spatial resolution, macro- and micro- stress; orientation (texture) effects; grain shape effects, stress gradients in the deposit; and Sn-Cu intermetallic (IMC) growth induced stress. Although it is easy to obtain stress values from these techniques, understanding the source of measurement errors and the interpretation of the results is underdeveloped.

We are measuring the stress of electrodeposited Sn as a function of time with two different techniques: $\sin^2\psi$ X-ray diffraction, and cantilever beam deflection. The deflection of the cantilever beam is a measure of the average stress in the film.



Tin whiskers

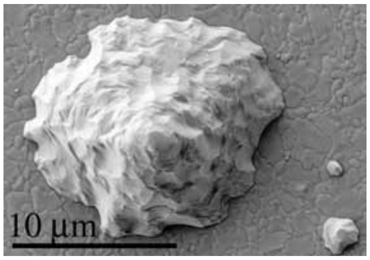
The X-ray diffraction method measures the lattice strain in a volume of Sn near the surface of the electrodeposit. The preferred orientation of the deposits and the low stress levels (~ 10 MPa) presented many challenges for this technique. A protocol for simultaneous stress measurements using both methods is being developed. A detailed analysis of errors in the measurement method as it applies to Sn has been performed. Also, a major summary of whisker/hillock growth in response to intrinsic electrodeposition stress and IMC generated stress has been published.



Effect of grain shape and mobility on whisker and hillock formation

The mechanisms of hillock and whisker growth remain largely unknown. Molecular dynamic simulations are aimed at understanding the conditions (stress, temperature, grain boundary diffusion, surface diffusion) under which the hillock/whisker growth processes can be initiated. In stressed solids, surface evolution is often driven by grain boundary diffusion and can result in growth of hillocks and whiskers. The simulated geometries include a single boundary normal to the surface and a tricrystal with a wedge shaped surface grain, both under an applied stress parallel to the surface.

To mitigate the growth of whiskers we are working on grain structure modification. Results show that the columnar grain structure of Sn electrodeposits can be modified to an equiaxed structure by pulsed deposition combined with the addition of 3 at.% Bi. Pulsed deposition is used to selectively turn on and off the Sn deposition reaction. Bi is more noble than Sn; thus, during the off cycle a displacement reaction between metallic Sn on the electrode surface and Bi^{3+} in solution selectively dissolves Sn and deposits Bi, effectively terminating the growth from the previous cycle and forcing the Sn to nucleate a new grain on the Bi-enriched surface. The grain size is tuned by varying the pulsing conditions, and an equiaxed structure can be obtained. This surface enrichment of Bi by pulsed deposition is similar to that which occurs naturally during Sn-Pb deposition, and provides an avenue for breaking up the columnar grain structure inherent to pure Sn. An equiaxed grain structure enables uniform creep, and rapid stress relaxation, thus preventing whisker and hillock formation.



A tin hillock

Learn More

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Publications

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