Understanding and Predicting Metallic Whisker Growth

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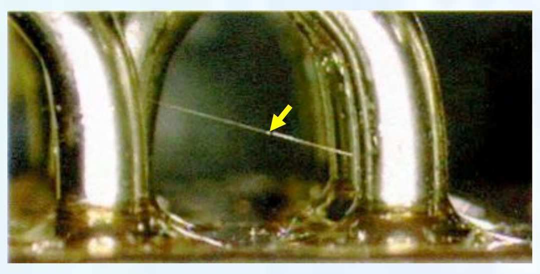
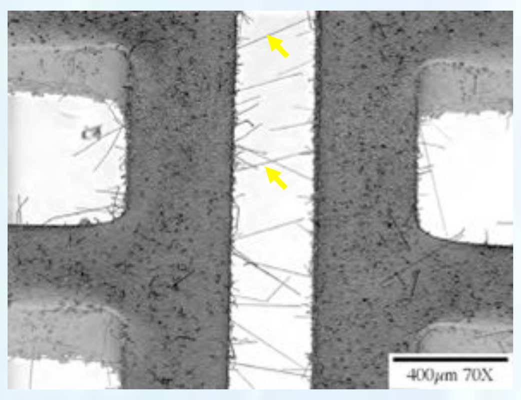
Problem

Background:
Whiskers are conductive filaments that can span between conductors and cause shorting failures. They grow spontaneously, often after long and unpredictable incubation periods. Tin surface finishes on Pb-free electronics are more prone to whiskering than their Sn-Pb counterparts. Recent push is toward Pb-free electronics in COTS parts; possible future requirement to be placed upon DOE electronics as well.

A science-based understanding is needed to predict whiskering and to determine margins and uncertainty due to the risk of whisker formation.





Photos: http://nepp.nasa.gov/whisker/

Project Goals

- Obtain whisker growth kinetics as a function of temperature; Determine an activation energy for whisker growth.
- Characterize the whisker growth phenomenon from the "bottom up." Use unique characterization tools: electron backscatter diffraction (EBSD), Focused-Ion Beam (FIB), TEM, confocal microscopy, etc.
- Computational materials modeling: *predict whisker nucleation density and whisker growth rate.*

Approach

Combined experimental characterization and computational modeling

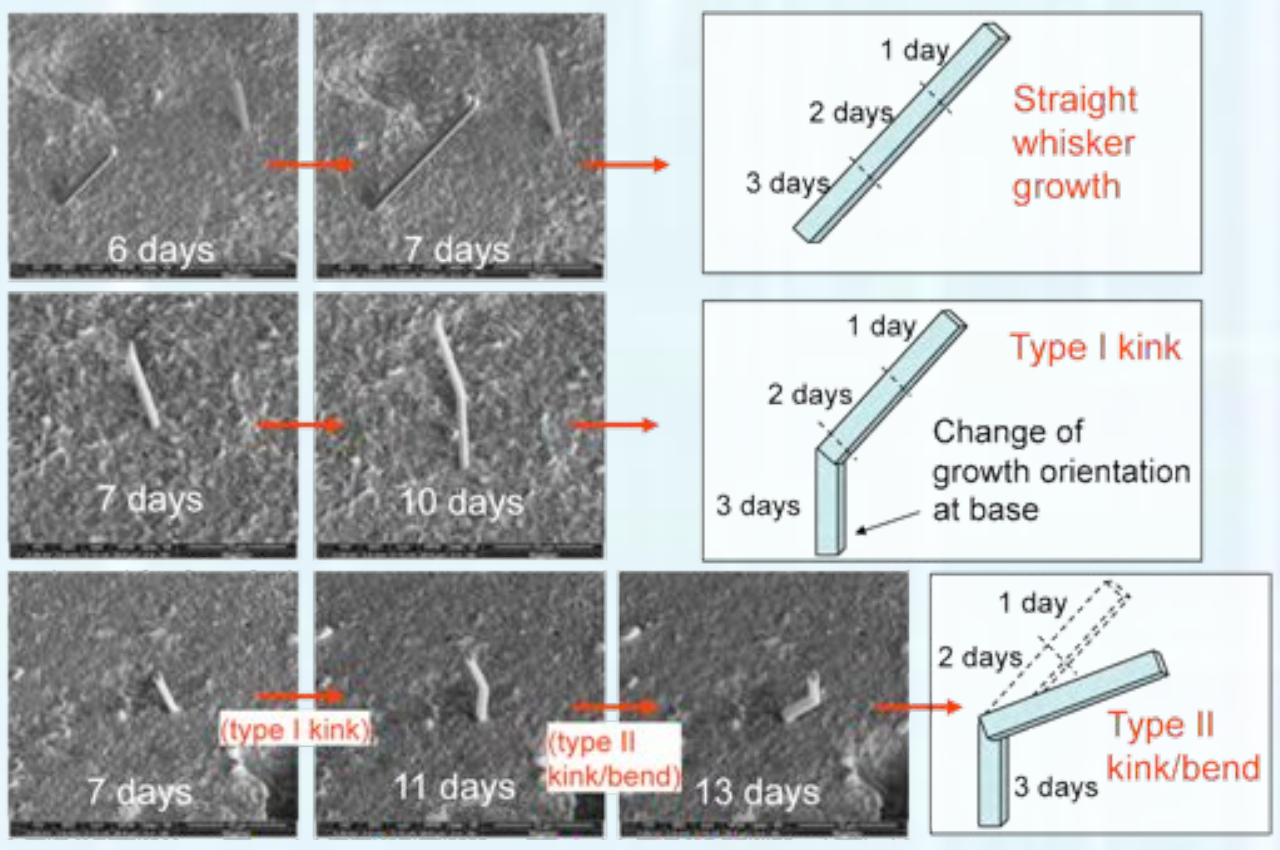
Deposition of bright Sn, matte Sn, and Sn-Cu on Cu-alloy substrates → Long-term holds at a series of temperatures → Measure whisker growth kinetics with temp and time

SEM/EBSD of Sn *surface* → FIB cut → SEM imaging → EBSD; FIB cut → TEM sample extraction → TEM imaging → Atomistic diffusion modeling and kinetic modeling of whisker growth

Overall morphology and crystallography of Sn layer → *Characteristics of specific whiskers and "whisker-root grains"* → *Unique g.b. structures, fast diffusion paths, etc.*

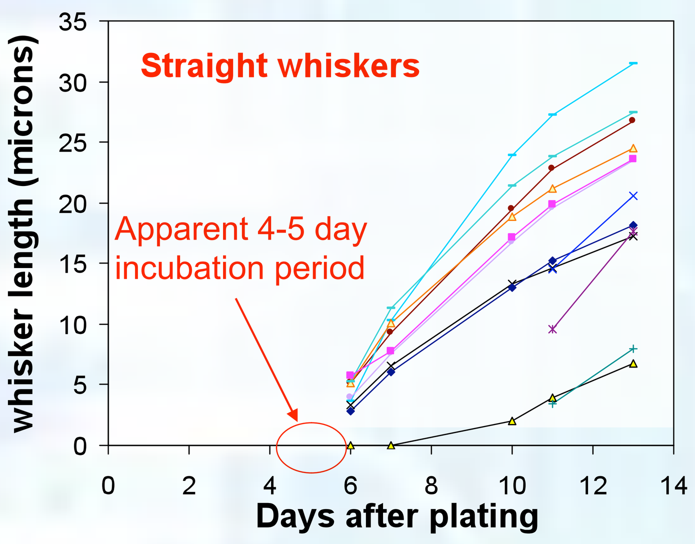
Results

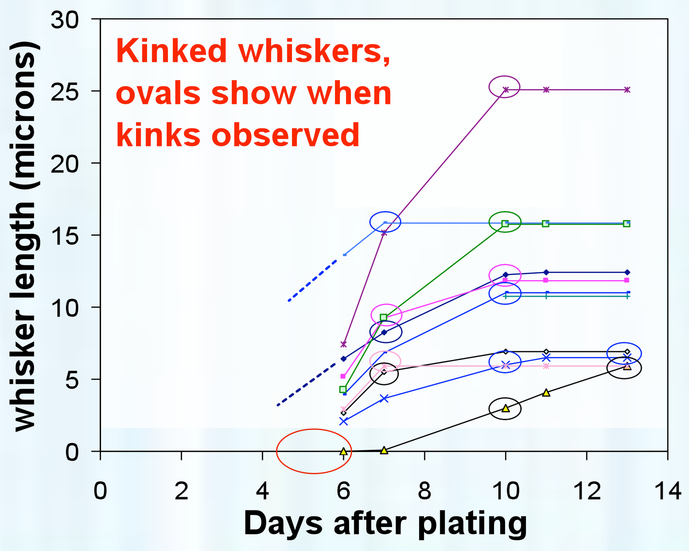
In-Situ SEM studies of whisker growth show complex behavior



Results

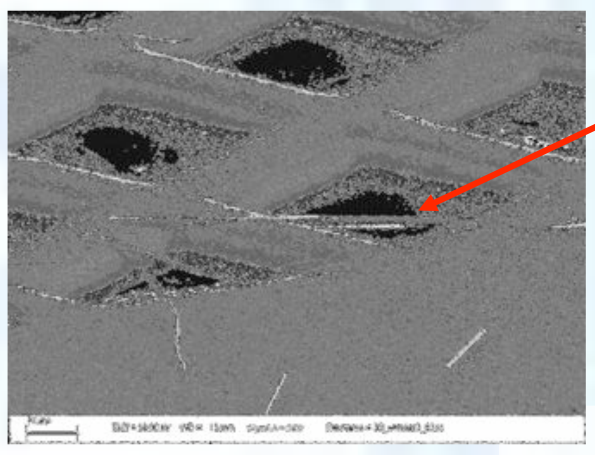
Tin Whisker Growth Kinetics





- Straight whiskers: Growth rate ~3 microns per day (Room Temp), slightly decreasing with time. This is very fast growth when compared with typical Sn diffusivity values.
- Kinked whiskers: Growth rate decreases or *growth completely stops when kinks occur.* Is this related to a change in the crystallographic orientation?

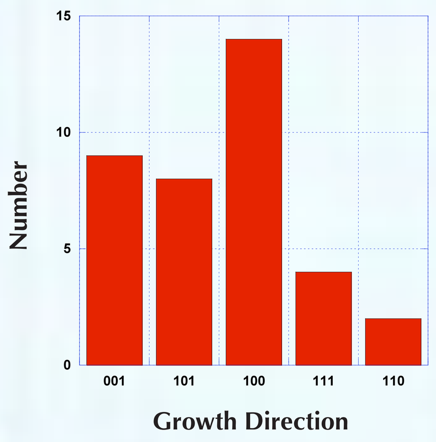
Tin whisker crystallography — Whisker growth axis measurement



Whiskers mounted on TEM support – obtained by wiping grid over sample surface.

Electron Backscatter Diffraction in the SEM was used to determine the growth direction of 37 whiskers.

EBSD showed all whiskers are single crystals.
Whiskers grow with low index directions parallel to the growth axis.
The most common direction of growth is <100> or along the primary a-axis in the tetragonal crystal.



Sn Whisker Modeling Approach

- Our goal is to be able to predict whisker/hillock nucleation density and whisker growth rate
- Input information includes film composition, deposition method, and film surface finish
- **Residual stress in film (stress distribution) is physical driving force**

Atomic Scale Studies

- Analytical models describing whisker growth kinetics require information about the underlying mass transport mechanisms and magnitudes
  - dislocation core diffusion, grain boundary diffusion, dislocation and grain boundary mobility, anisotropic transport effects
- Existing atomic force fields for Sn are not sufficiently accurate to model relevant behavior
- University leveraging (N.C. State) to obtain improved Sn interatomic force field
- Goal: grain boundary diffusivity calculations with accurate Sn model

Kinetic Modeling

- Nucleation theory assumes supersaturation as driving force (i.e., chemical composition)
- Adapt standard theory to have stress/strain super-saturation act as nucleation driving force
- Currently working with existing growth rate model:

$$\frac{dh}{dt} = \frac{2}{\ln(b/a)} \frac{\sigma_0 \Omega s D}{kT a^2}$$

h – length of whisker
t – time
b – whisker separation distance
a – whisker radius
σ_0 – stress in Sn film
Ω – atomic volume
s – crystalline step height
D – diffusivity
kT – thermal energy

Significance

- Direct observation of Sn whisker growth has not been done previously in this detail: ~40 individual whiskers observed over period of weeks.
- Growth kinetics information gained from these studies will provide valuable input for modeling effort.
- Careful characterization of crystallographic orientation helps clear up confusion in the whisker literature.
- Measurement of in-film stress and the effects of temperature on whisker growth will continue next FY. Also, laser confocal microscopy, FIB sectioning, and TEM analysis next FY will build on previous detailed characterization of Sn whiskers.

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