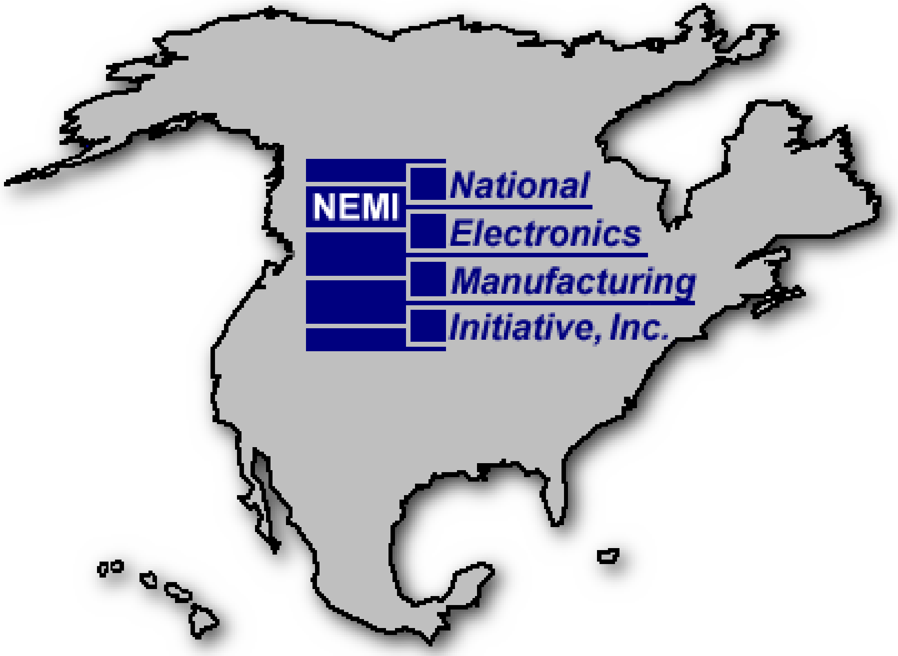


NEMI Sn Whisker Modeling Group
Part 2:Future Work

IPC/NEMI Meeting

Maureen Williams, NIST
Irina Boguslavsky, NEMI Consultant

November 7, 2002 New Orleans, LA

Capabilities of NEMI Modeling Group

- NEMI Fundamental Group has a unique set of expertise and capabilities and unbiased attitude necessary to resolve such a complex problem as whisker growth. It includes experts in the following areas:
  - Electroplating chemistries and processes
  - SEM characterization of whiskers (quantitative approach)
  - XRD for macro- and micro-stress measurements and crystal orientation
  - Crystal mechanics, modeling and computation
  - Metallurgy
  - Material science
  - Engineering/manufacturing

Problem – Identifying Growth Mechanisms and Test Methods

- “The Whisker Growth Mechanism” question has been around since ~1946.

- Exhaustive studies have identified many important factors, but the interaction of these factors has made it difficult to determine the underlying growth mechanism(s).

- The Modeling Group must identify the whisker growth mechanisms in order to develop a viable whisker test.

Future Work

- Determine deposit characteristics that affect whisker growth.
- Develop techniques for their measurements.
- Develop a model for whisker growth mechanism.
- Based on the modeling, predict long-term whisker performance:
  - Incubation period, growth rate, and maximum length
- Use the knowledge of whisker growth mechanism to identify accelerated test conditions and determine accelerating factors.
- Coordinate activities and cooperate with other groups (e.g JEITA, ITRI) on experiments, minimize duplication of effort and maximize knowledge collection.

Modeling Group DOE 2:
a Study of Deposit Characteristics
and Their Influence on Whisker Growth

Fixed Factors in the Test Matrix

Fixed Factors:

- Bath chemistry
- Bath temperature and agitation
- Filtration of plating bath (fine 0.2 um)
- Substrate degreasing

Variables in the Test Matrix

Variables:

- Current Density during plating
  - 5 ASD and 15 ASD
- Substrate pretreatment
  - acid dip and electropolishing
- Substrate 194
  - without Ni underlayer and with 2.5 um Ni underlayer
- Plating thickness of Sn deposit
  - 3 um and 10 um
- As a separate set of experiments: vary thickness of Ni underlayer:
  - 0.25, 1.0, and 5.0 micron

Post Plating Test Conditions

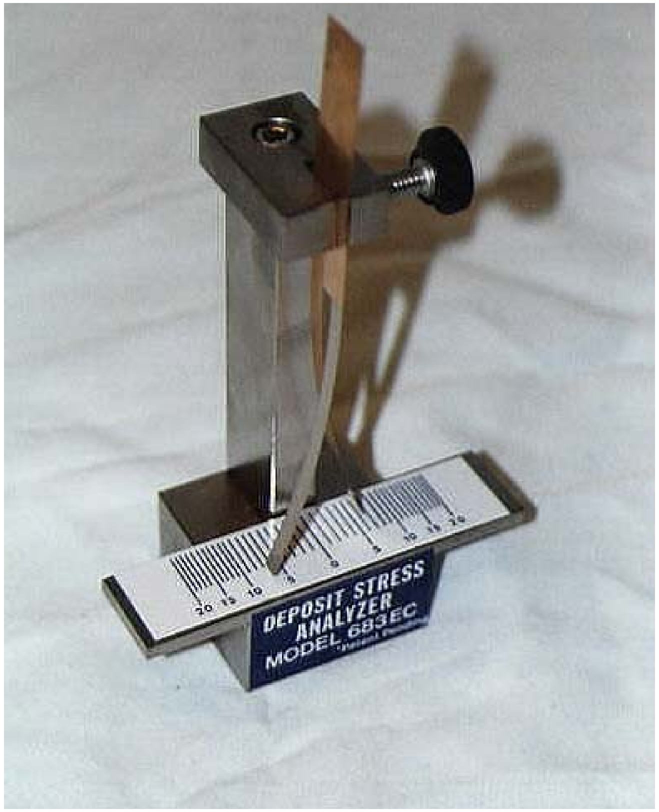
- Ambient
- Annealing + Ambient
- 500 thermal cycles + Ambient
- 1500 thermal cycles + Ambient

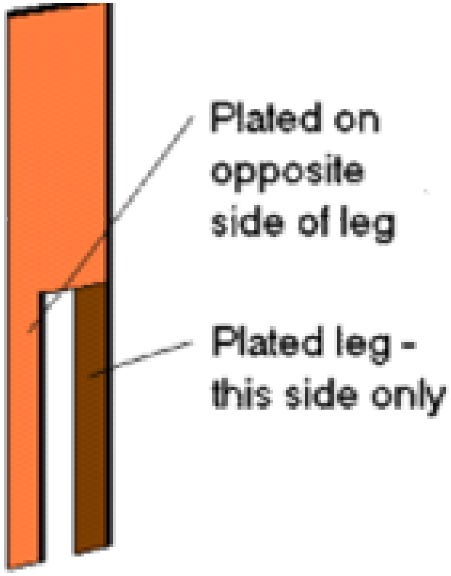
All tests will be followed by long-term monitoring of whisker growth

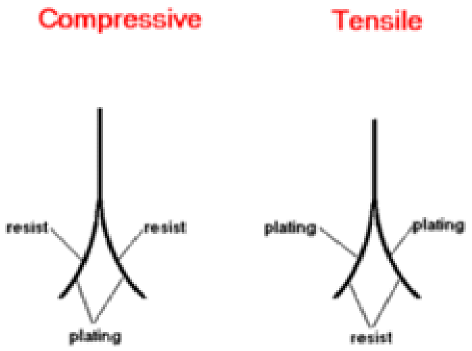
Deposit Characteristics as Responses in DOE 2 and Methods for their Measurements

- Internal Stress monitored with conventional dual beam test coupon and XRD (microprobe).
- IMC thickness and IMC distribution in the deposit measured by metallographic cross sectioning and FIB. Both techniques followed by SEM/EDS to identify the structure and composition of IMC.
- Crystallographic orientation by standard XRD and localized grain orientation with micro XRD or EBSD.
- Whisker performance (density and length) by SEM inspection.

Internal Stress Measurement by Conventional Dual Beam







Monitor internal stress with convention coupon (dual beam made of alloy194)

Slide Courtesy of Specialty Testing & Development Co. Jacobus, PA

Internal Stress Measurement by XRD Techniques

- Powder Diffraction XRD
  - looks at a large number of grains and gives average properties of the deposit.
- XRD microprobe
  - preferred orientation, stored deformation energy, and strain.

Sn Coating Properties

Note: 1 ksi = 6.895 MPa

40 u inches = 1 um

- Anisotropic material - properties are not the same in all directions
- Low bulk modulus compared to Ni
  - (Sn ~58 GPa and Ni ~ 180 GPa)
- Very low stress ~ 10 MPa
  - (Ni ~100 MPa)
- Textured Structure - crystalline distribution not random
- Thin coatings < 10 um to 15 um may still be influenced by substrate structure (epitaxy)

Problems with XRD Measurements for Sn

- Measuring strain in soft metals (Sn)
  - Three major problems
    - Error starts to dominate the measurement because of lower sensitivity to strain (error +/- 50%)
    - Large grain size
    - Preferred orientation
      - Substrate can influence pf and will also influence modulus causing a larger error in the stress calculations
- To calculate the strain must know the Modulus
  - In randomly oriented Sn ~42GPa
  - Modulus does change for a particular hkl
    - (001) ~ 85 GPa
    - (110) ~ 25 GPa
      - Metals handbook , vol. 11, 9th Ed, p.811

Comments from Dr. Mayo's invited discussion on XRD to the Modeling Group 2-26-02

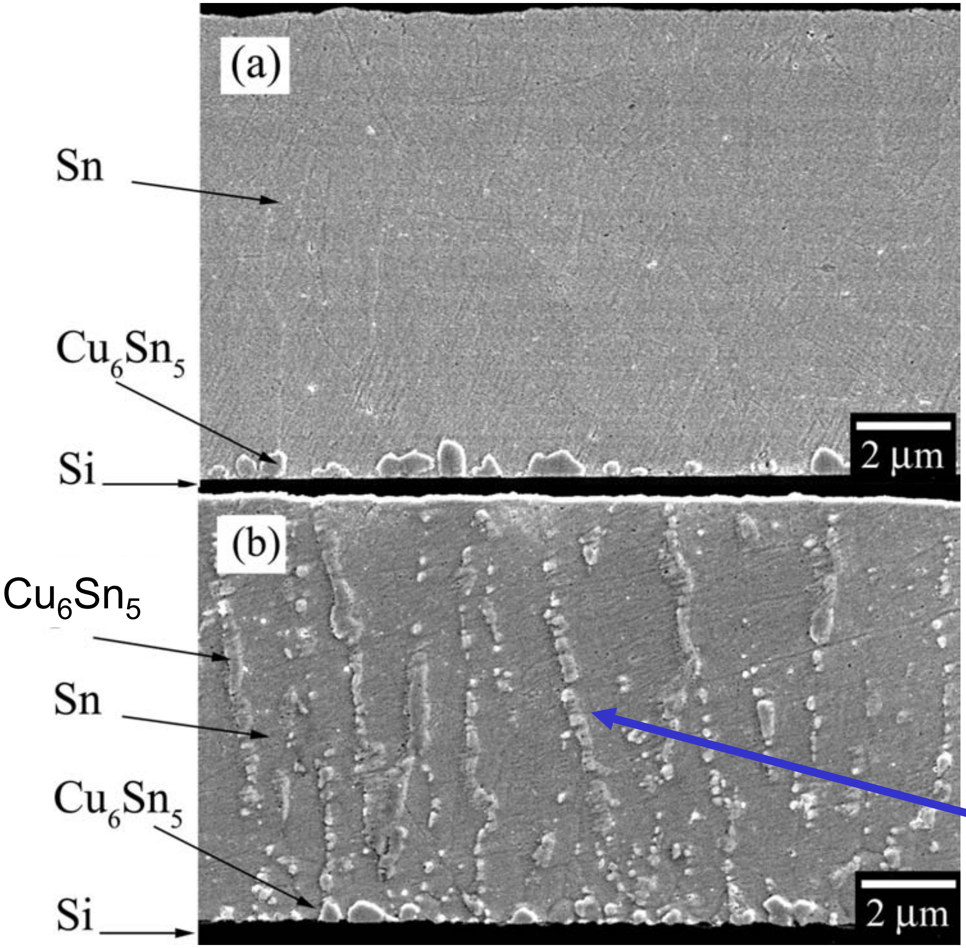
Accuracy, Reproducibility, and Statistical Significance of Measurements

- XRD
  - “Conventional Sine squared PSI (Sin$^2\psi$) measurement is based on a model of an isotropic solid material. To use this method with textured material you need to determine the reflection specific x-ray elastic constants for the textured material”
    - (Quote from Arild Christensen – Scintag, Inc)
  - Handbook Measurements of Residual Stress published by the Society for Experimental Mechanics (Oxford Press) quotes the usual precision for XRD residual stress measurements as “*plus or minus 20 MPa*”
  - Depth of penetration
    - Dependent on wavelength of radiation
    - Internal Stress maybe unevenly distributed across Sn deposit
- Conventional Dual beam
  - Average stress of deposit
  - IMC formation influencing the substrate and complicating the interpretation of the stress measurement results

Verification of Stress Measurement Methods

- Must do experiments to determine experimental error and correlate the results of the three methods
  - Conventional Dual Beam Method will provide standard interpretation of average internal stress in the deposits
  - XRD may only be able to show stress trend and not stress level
  - XRD microprobe can supply measurement of localized strain energy

Polished Cross Sections



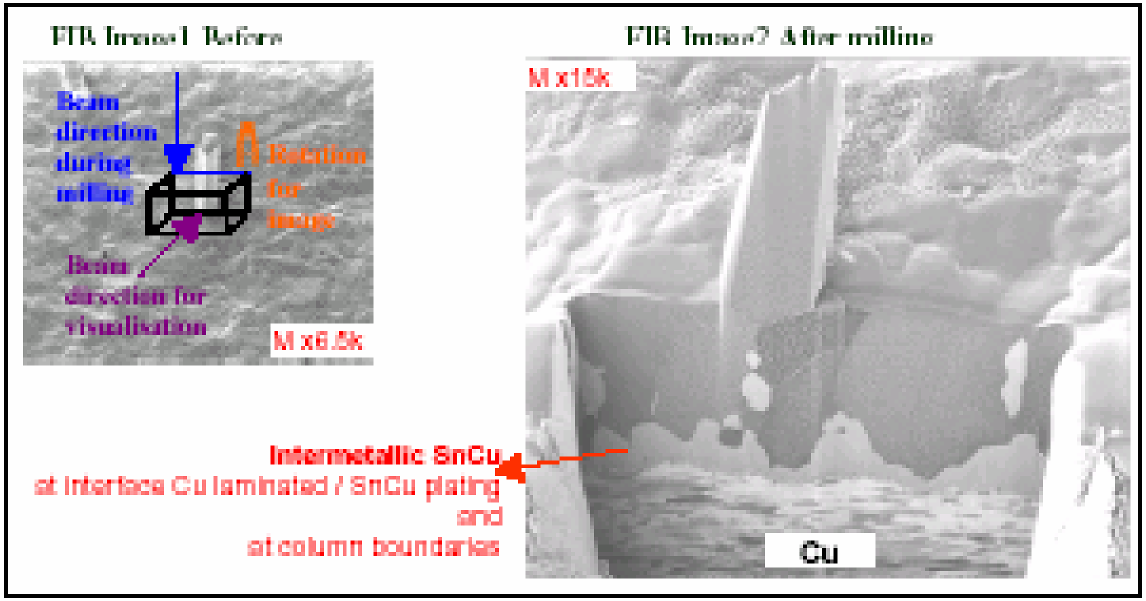
Pure Sn deposit

Sn-0.67 wt% Cu deposit

Intermetallic decorates grain boundaries

Slide courtesy of Kil-Won Moon at NIST

Focused Ion Beam (FIB)



Images 1 and 2 are obtained by FIB before and after milling respectively.
Image 2 shows the structure of a tin copper 2%wt plating on a copper base, the texture of one whisker and the copper distribution. The laminated copper is easily recognized by the orientation of the grains. The intermetallics are concentrated at the interface and at the grain boundaries.
Grains width vary from 3 to 6 µm.

Slide Courtesy Isabelle BAUDRY, Grégory KERROS STMicroelectronics, Grenoble, France
From SOLDERING & Assembly Technology, Issue 3, 2001
“Focused Ion Beam in Microelectronics Packaging Applications, Leadfree Plating Analysis”

EBSD

- Electron Backscatter Diffraction (EBSD)
  - very good spatial resolution (0.05 - 0.5 µm) and can look at submicron area comparable with a grain size.
  - can map the orientation of the surface grains.

EBSD Diagram and Pattern

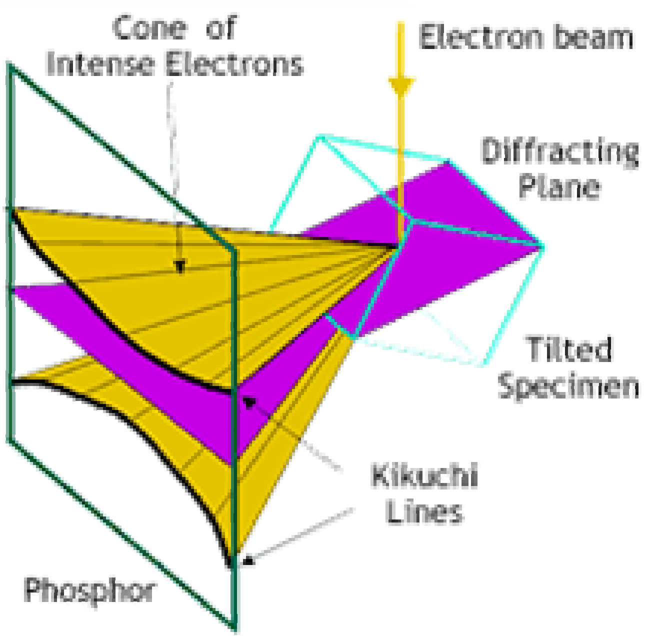
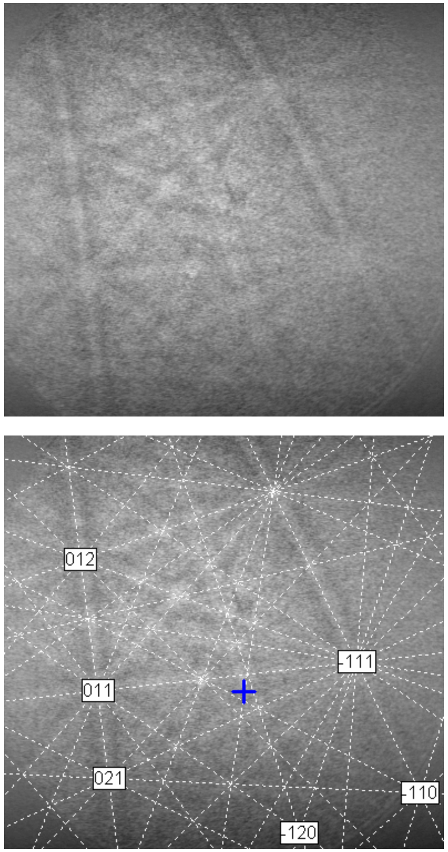


Diagram courtesy HKL Technologies, Inc
Danbury, CT



Kikuchi bands from Sn electroplating

Collection of an Electron Backscatter Diffraction Pattern (EBSP) in the SEM

- A polished sample is tilted to a relatively high angle (typically 70°)
- initial elastic scattering of the incident beam causes the electrons to diverge from a point just below the sample surface and to impinge upon crystal planes in all directions.
- Wherever the Bragg condition for diffraction is satisfied by a family of atomic lattice planes in the crystal, 2 cones of diffracted electrons are produced. These cones are produced for each family of lattice planes.
- These cones of electrons can be imaged using a phosphor screen attached to a sensitive camera.
- Where the cones of electrons intersect with the phosphor screen, they appear as thin bands. These are called "Kikuchi bands", and each one corresponds to a family of crystal lattice planes. The resulting EBSP is made up of many Kikuchi bands.

Slide courtesy HKL Technologies, Inc Danbury, CT

Modeling Approach

- Combination of the Monte Carlo technique with finite element modeling of microstructure deformation.
- The mobility and energy of the boundary depends on the misorientation between adjacent grains.
- Look at the microtexture of the surface in the early stages of whisker growth and see if there is a correlation between a certain orientation grain and the propensity to whisker.
- Test the model on existing deposits with known whisker performance. Optimize the model to correlate with real life performance.
- Predict long term whisker performance from model.

The objective of our future work is to identify what factors are dominant and how to measure and control them.