UNIVERSITY OF CALIFORNIA, IRVINE

Department of Materials Science and Engineering

Heterogeneous Stress Relaxation in Tin Thin Films: Whiskers, Hillocks, and Beyond

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Thursday, May 27, 2021, 2:00-3:00 p.m.

Zoom: **https://uci.zoom.us/j/98066455796?pwd=ODBUbUxySm9ObHRYWUFEaVlJMFo5UT09**

Meeting ID: 980 6645 5796, Passcode: 974689

Abstract: When tin polycrystalline thin films are stressed, the film microstructures can become unstable, leading to the formation of long, single crystal whiskers that can create short circuits in electronic circuits and destroy MEMS devices in electronic assemblies. The conditions for whisker formation are inherently local as indicated by their low frequency: there is typically 1 whisker for every 10^3 -10^6 film grains. Relaxation of compressive stresses occurs by diffusion to the base of specific grain boundaries in the plane of the film and leads to growth of that individual grain out of the plane of the film. Hillocks form when grain boundary migration accompanies growth out of the plane of the film and whiskers in the absence of grain boundary migration. Experiments in tin whisker formation at low strains and strain rates allowed us to develop a simple model of whisker growth based on stress gradients between the base of shallow grains and the compressively stress columnar grains and on grain boundary sliding limited diffusional creep. However, many features of whisker growth, even under these conditions, cannot be explained by this simple model or with these film geometries. These include grain rotation and tilting of pre-existing grains, nucleation of new grains, incubation times before whiskers start growing suggesting changes in sub-surface features, such as grain boundary structures and geometries, and whiskers that stop growing. The mechanisms underlying some of these phenomena have been isolated by changing the film microstructure to pseudo-bicrystal films with millimeter-scale in-plane grain sizes and using other stressing conditions, such as cyclic bending, rapid thermal cycling, and thermal cycling using in-situ SEM. Finite element models of elastic and thermoelastic anisotropy, finite deformations and elasto-plastic anisotropy were used to simulate the mechanical response of polycrystalline thin films, including the formation of sub-grains due to lattice rotation. Finally, our research on stress relaxation in β-Sn can be put into the broader context of stress relaxation processes in Ag, Au, and Al thin films as a function of microstructure, film geometry, and stress conditions, and can start to be used as the basis for constructing microstructure-dependent deformation maps.

Bio: Carol Handwerker is the Reinhardt Schuhmann, Jr. Professor of Materials Engineering and Environmental and Ecological Engineering at Purdue University, West Lafayette. Before joining Purdue in 2005, she served as the Chief of the NIST Metallurgy Division where she started her career as an NRC Postdoctoral Fellow following her Ph.D. in materials science and engineering from MIT. Her research areas include: Developing innovative technologies for next-generation microelectronics and solar cells; Improving the reliability of Pb-free solder interconnects, particularly for high performance, military, and aerospace electronic systems; Integrating sustainability in the design of new materials, processes, and products; Understanding the thermodynamics and kinetics of moving interfaces, particularly for sintering and grain growth; Identifying and implementing strategies to move R&D into manufacturing and commercialization, using roadmapping, techno-economic analysis, and formation of self-assembling socio-ecological systems. She is co-PI in a major DOD program on workforce development for advanced microelectronics, and is leading a recently announced $40M, 5-year DoD program in facilitating the transition to Pb-free electronics in defense systems She was the Director of the Purdue-Tuskegee NSF Integrative Education and Research Traineeship program (IGERT) on Globally Sustainable Electronics (supporting 28 two-year fellowships from 2012-2019), served as a member of the iNEMI Environmental Leadership Steering Committee, along with Intel, Dell, Lenovo, and others, co-led the iNEMI project on Value Recovery for End-of Life Electronics – Phase 1 and Phase 2. Until last month, Prof. Handwerker was a member of the DoE Critical Materials Institute leadership team, focusing on accelerating technology transition of CMI R&D in recycling, reuse, and remanufacturing. She is a Fellow of TMS, ASM, MRS, and the American Ceramic Society, and received the TMS Leadership Award, the TMS Applications to Practice Award, the TMS/FMD John Bardeen Award, the Federal Laboratory Consortium Award for Excellence in Technology Transfer, and the Department of Commerce Gold, Silver, and Bronze Medals.