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Pesky Stubble: Recent Progress and Remaining Challenges in Controlling Sn Whiskers

Edmund B. Webb III

Project Team: D. F. Susan, J. R. Michael, P. T. Vianco, C. V. Robino, W. G. Yelton, B. Mckenzie, A. Kilgo, G. L. Bryant, M. Rye, F. M. Hosking

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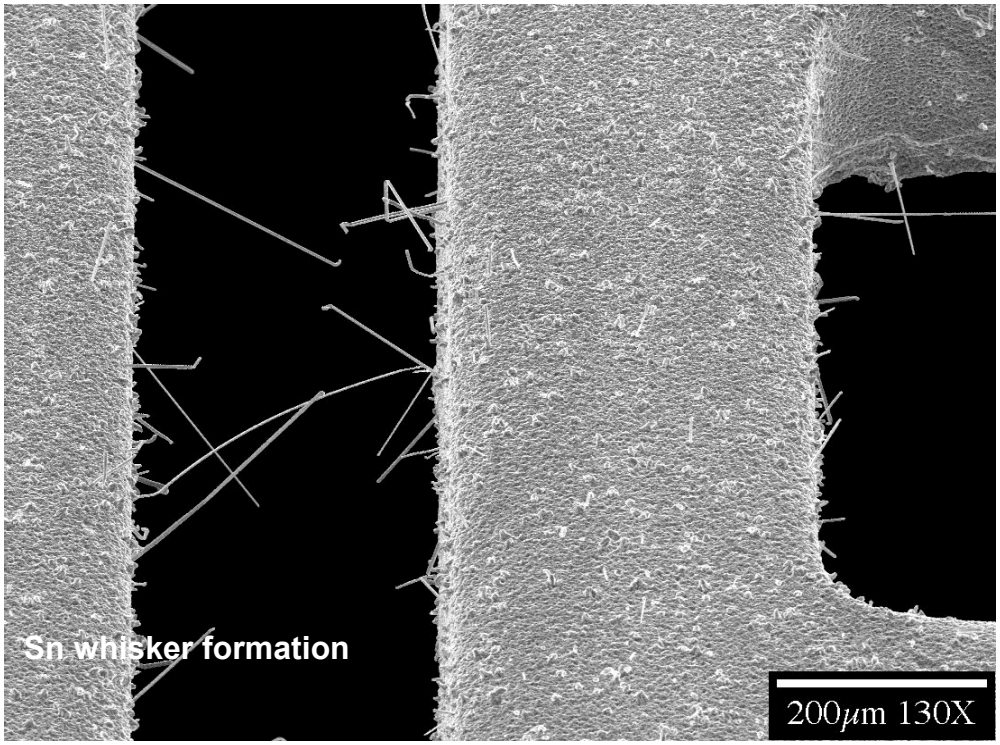
Boulder, CO; August, 2009

Pesky Stubble: Unwanted Whiskers

… not that …

Pesky Stubble: Unwanted Whiskers



… that.

Photo from NASA website, originally courtesy of Peter Bush (SUNY Buffalo)

Progress and Challenges in Predicting Sn Whisker Growth: *Outline*

- Introduction
  - Disclaimer
  - Sn thin films in technology (whisker impact)
  - Stress in Sn thin films (growth stress, chemical effects)
  - Whisker growth (rates, density, crystallography)

- What do we know about Sn whiskers
  - Stress versus stress gradients
  - Film thickness

- Outstanding questions and (some) suggested solutions
  - Role of crystallography
  - 3D stress state

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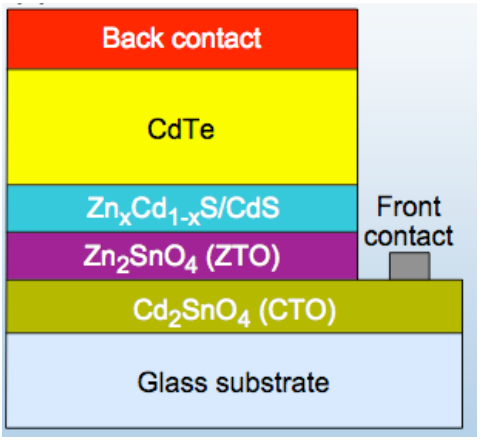
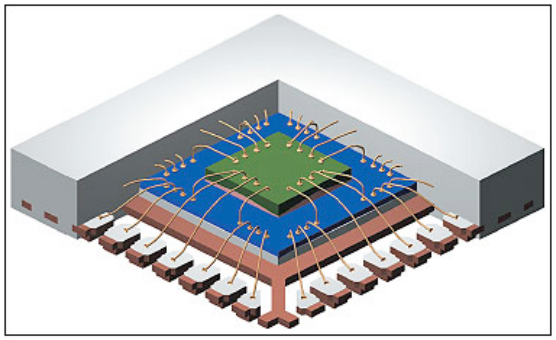
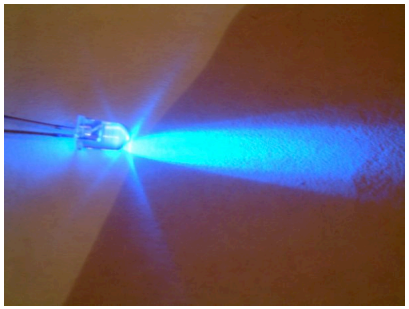
Sn Thin Film Technology

- Sn thin films abound in microelectronics (leadframe finishes)
- Especially true with the push toward Pb free
- Potential to impact a vast array of technology that depends on microelectronics



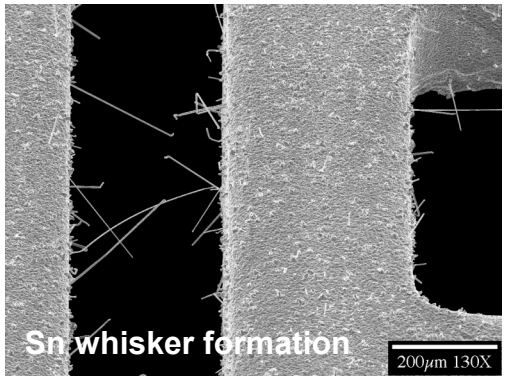




Potential Impact of Sn Whiskering

- Mitigation strategies have brought this to an acceptable level for low consequence applications (cell phones, computers, personal electronics)

- High consequence/reliability applications still subject to unacceptable risk



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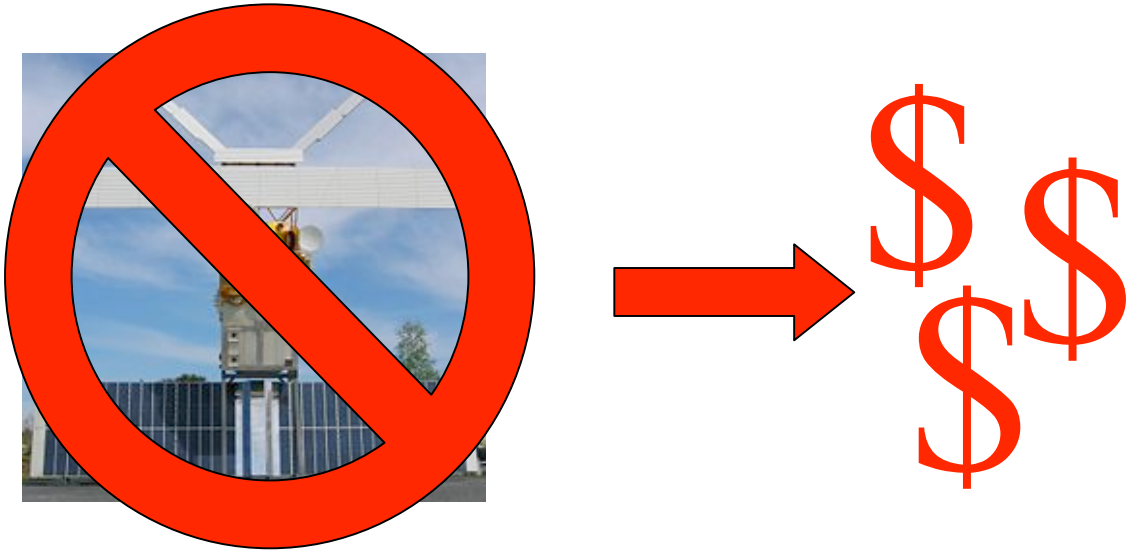
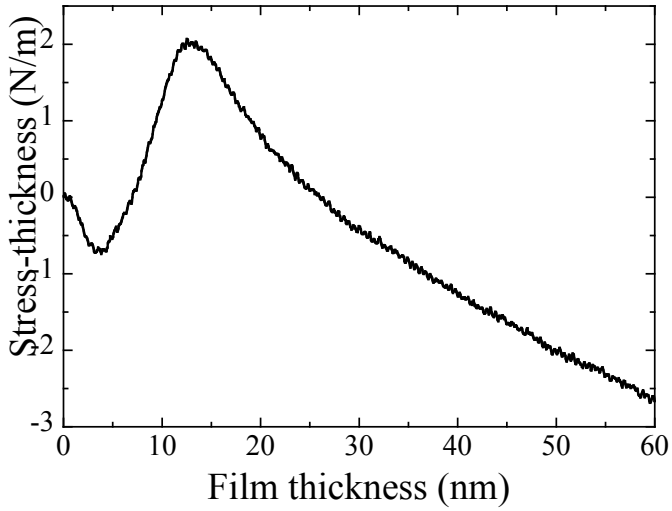
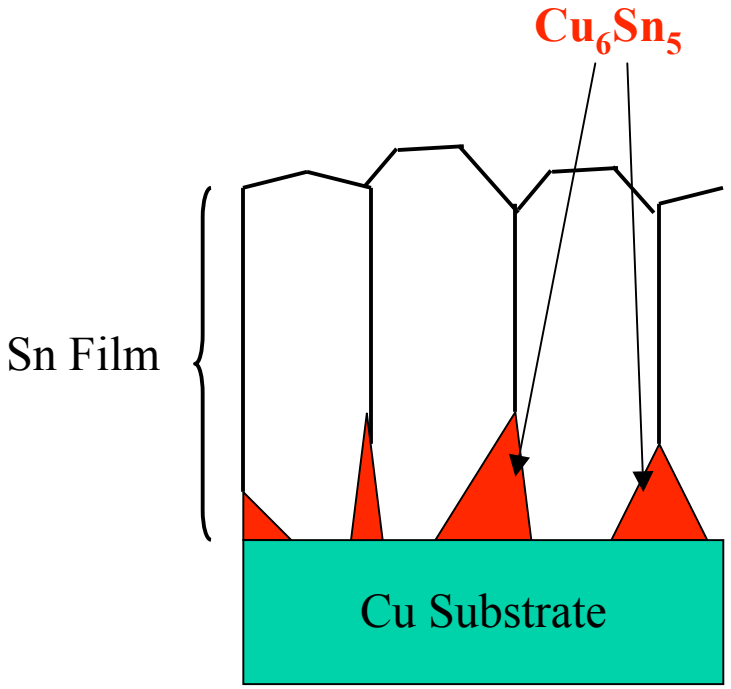
- Component failure ….



Stress Evolution in Sn thin films



Growth stresses



Chemical stresses

- Additional stress generation mechanisms: externally applied stress, oxide growth, etc

Whisker Growth in Sn

- May grow to several millimeters in length
- Have diameters of order 1-10 um
- Remarkable growth rates have been observed (1 um/s in presence of externally applied stress)
- Grow via addition of material at the base of the whisker
- Essentially perfect single crystals
- Driven by stress (gradients)
- Does not happen in presence of Pb
- Happens at ambient conditions

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Recent Results/Theories / Conjectures

• When hillocks form, their lateral growth sweeps the underlying substrate crystallography to be single crystal (i.e. grain boundary lateral motion); when whiskers form, grain boundaries remain fixed
• Recrystallization for hillocks versus no for whiskers?

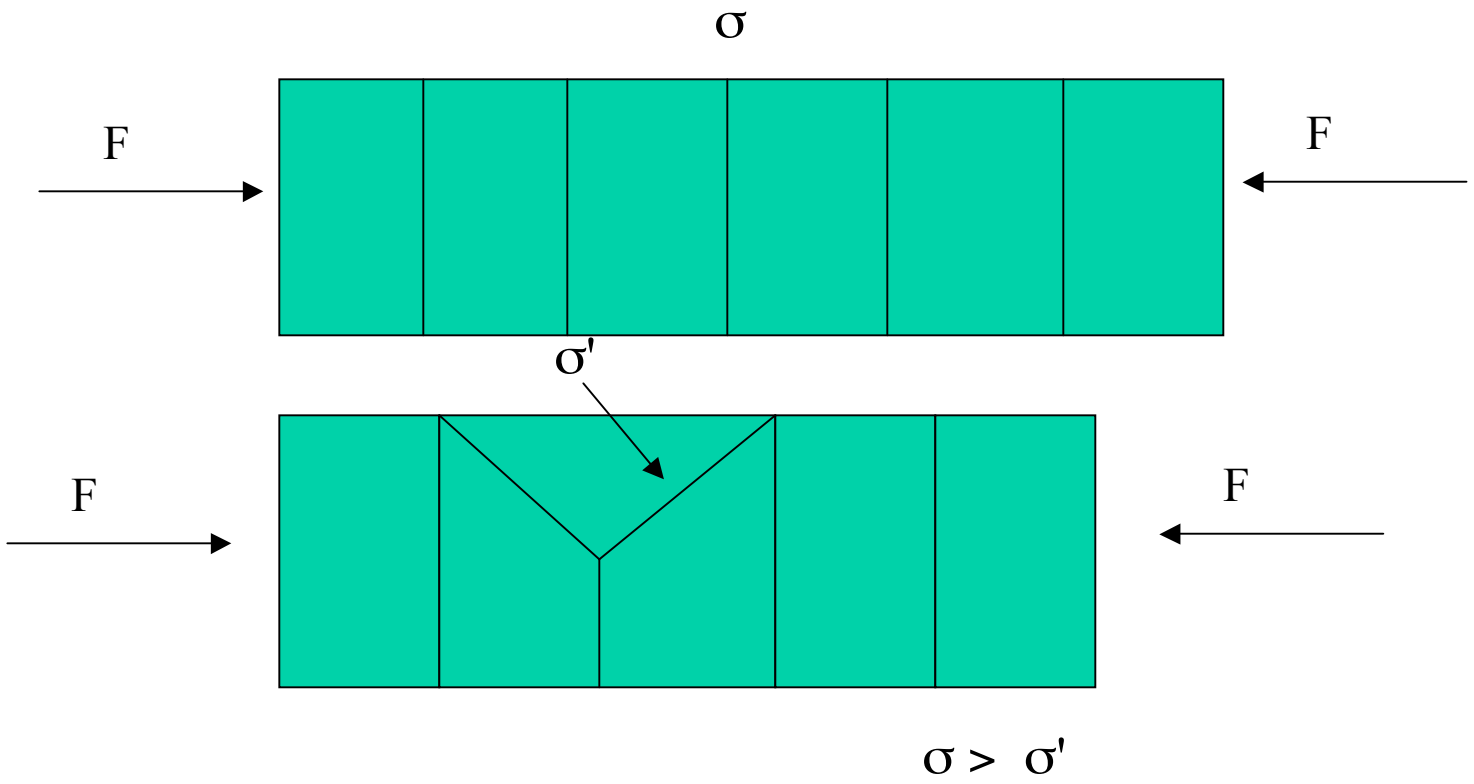
• An oxide layer seems critical: it prevents dislocation and defect annihilation at the free surface; where a whisker grows, the Sn grain is being forced upward with sufficient stress to break the oxide layer

• Boettinger, et al. observed that Pb additions resulted in more equi-axed grains, compared to columnar grain in pure Sn films.

• Chason, et al.: IMC is relatively localized growth and resulting stress may not be sufficient to drive whisker nucleation at a "far away" free surface; However, IMC growth generates dislocations and point defects which are capable of extending the range of the stress generated by localized IMC growth throughout the Sn film; nucleation only occurs at the free surface where stress is large enough to break the oxide layer

Recent Results/Theories / Conjectures

• J. Smetana (IEEE Trans. Electronic Packaging Manufac., vol. 30, pp. 11-22, 2007):



• Recrystallization, or simply the shape put down while plating, gives inclined boundaries relative to the largely columnar growth
• Generates local stress gradients for atoms at boundaries

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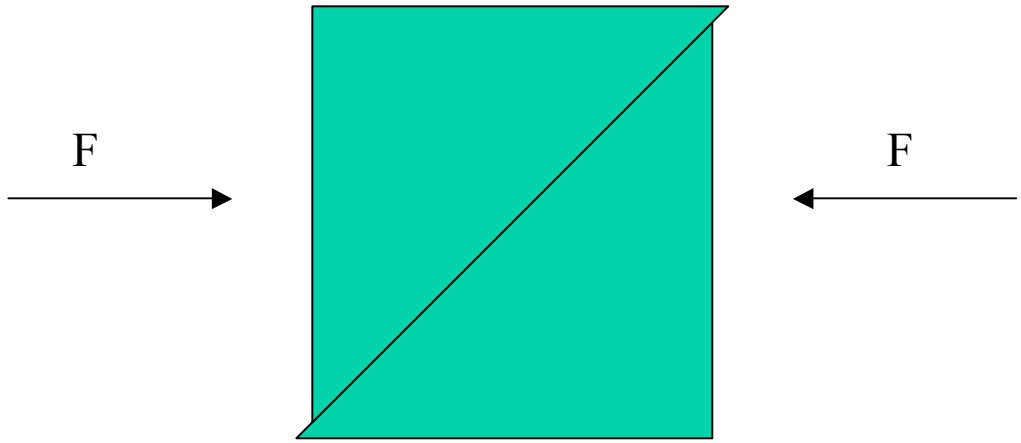

- Oblique geometries give rise to shear force
- High homologous T: GB sliding (i.e. creep mechanisms)

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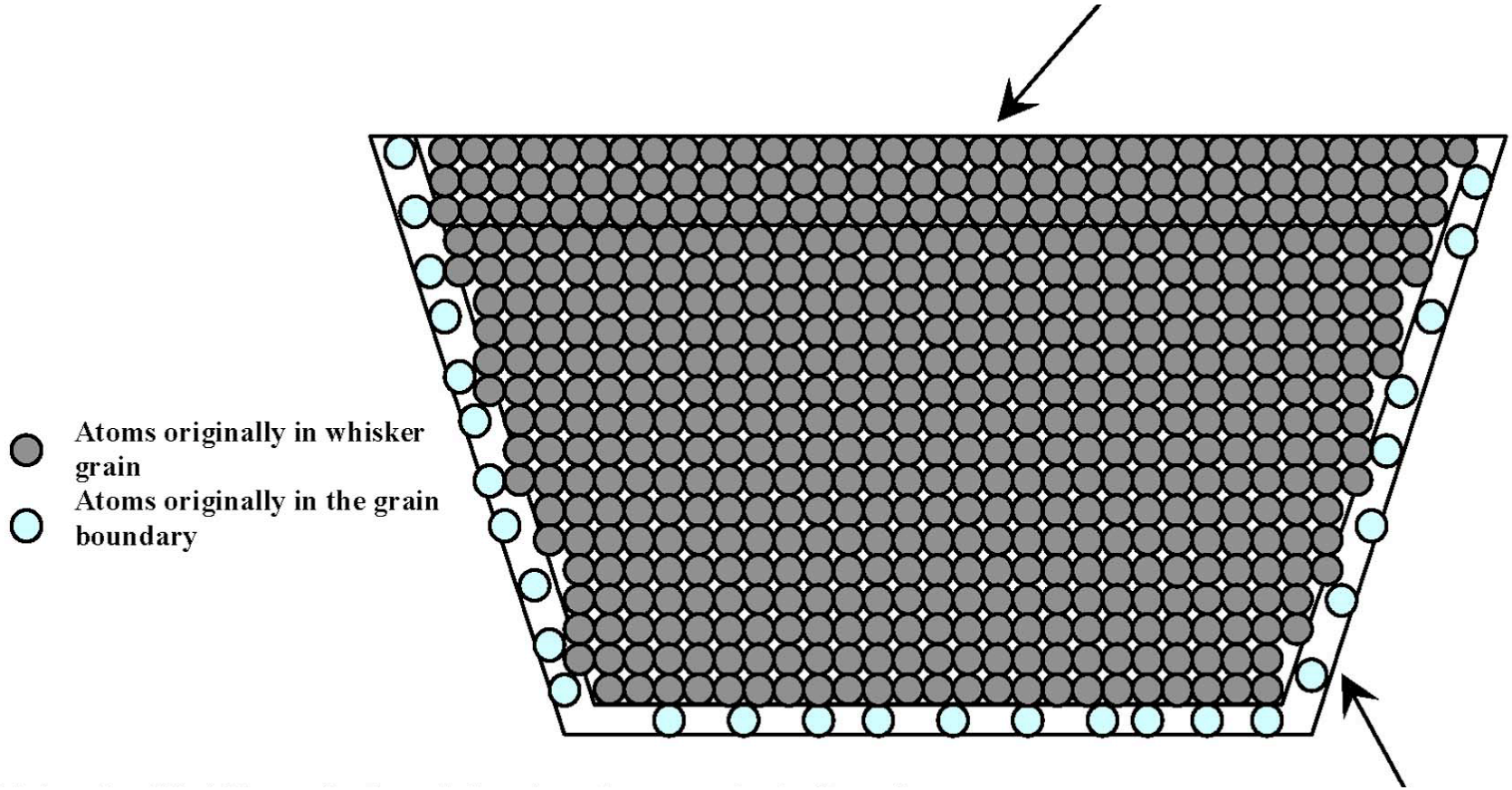

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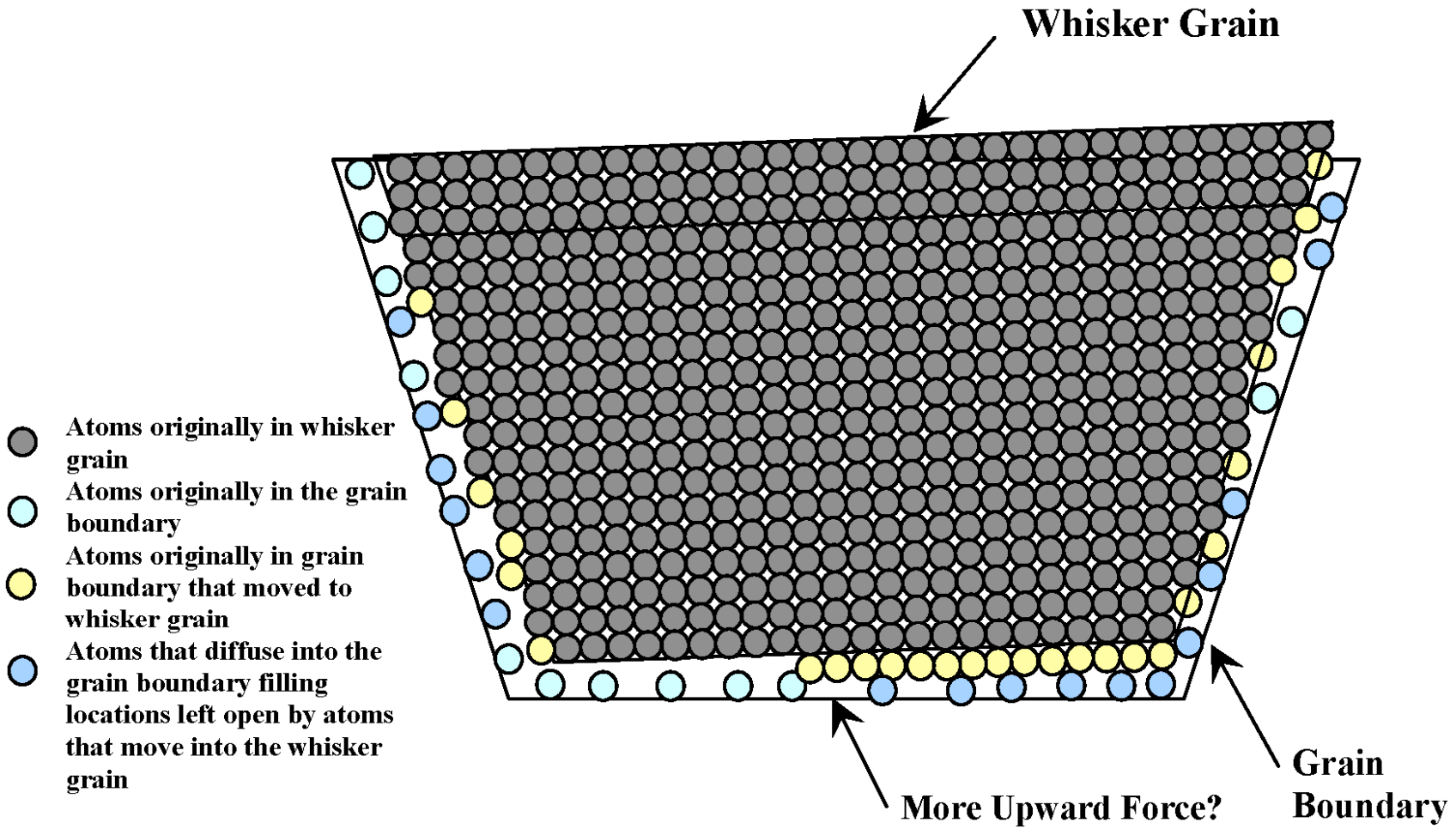

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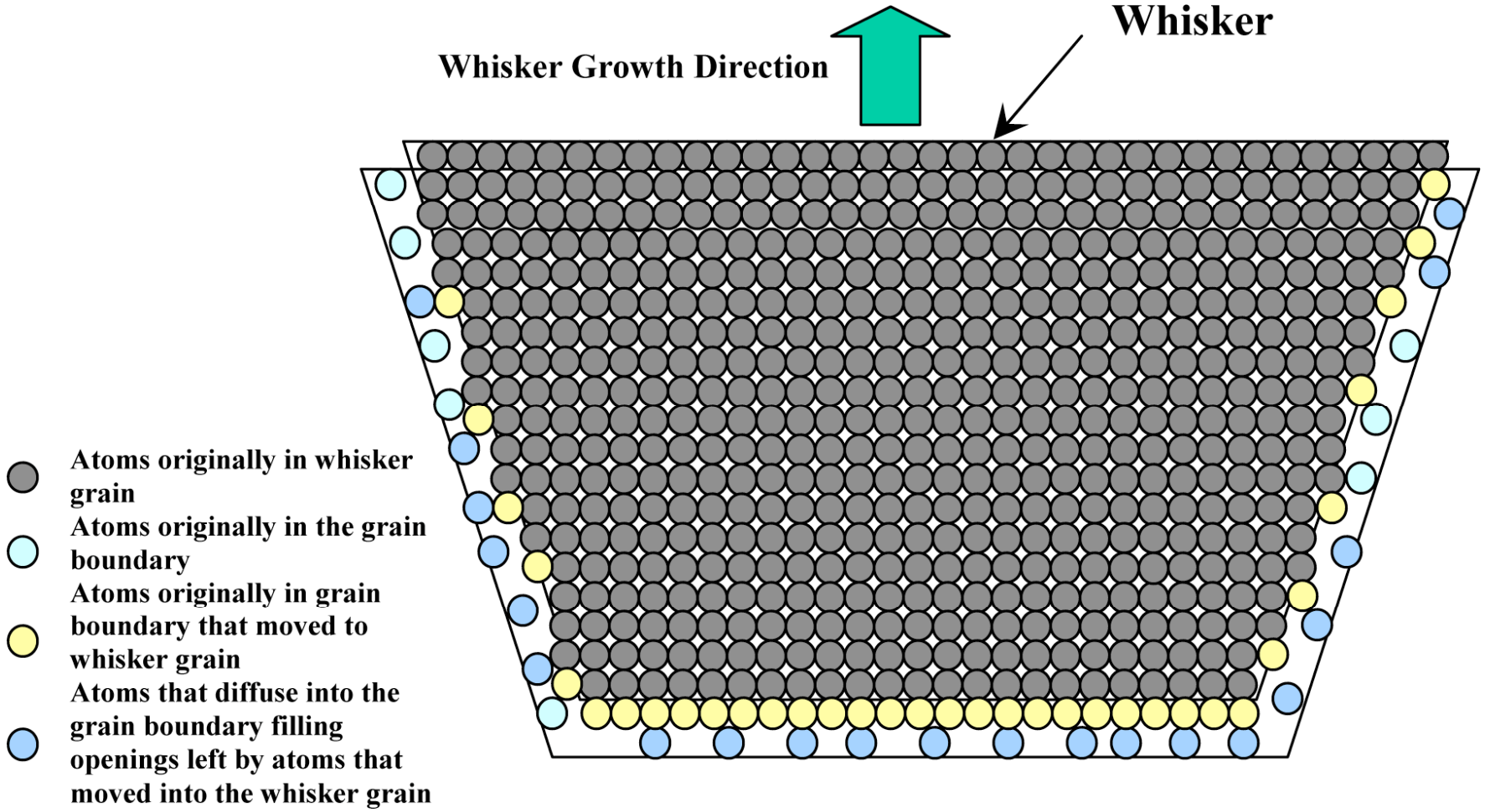


Some Thoughts / Questions

- How do atoms diffuse into growing grain (i.e whisker base)?
    - GB -> bulk -> GB -> bulk, etc?
    - all GB?

- Smetana dismisses as secondary the role of crystallography and focuses on morphology (oblique GBs is what is relevant … not necessarily the nature of the GBs themselves)

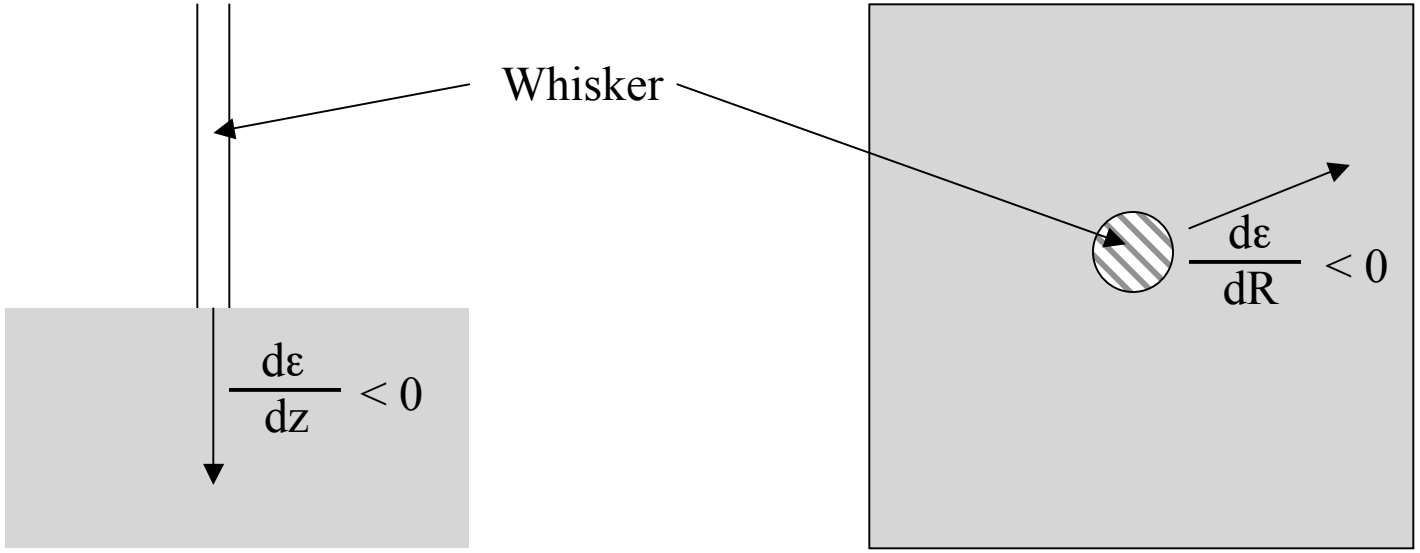
- He (and many others) recognize that processes like GB sliding, creep, GB diffusion, stress assisted diffusion, etc may be influenced by crystallography

- Whiskers form where stress builds up sufficiently to break the overlying oxide layer
    - local weakness in the oxide (stress build up near free surface is relatively uniform)?
    - local build up of diffusing atoms to sub-surface grain (stress build up is localized)?

- What determines kinetics of growth? Thought of as a diffusion problem, what is the rate limiting step or hop? For different GBs, do intrinsically different barriers exist for hopping from a bulk into the GB and for hopping from the given GB back into the bulk?

Recent Results/Theories / Conjectures

- M. Sobiech, *et al.* (Appl. Phys. Lett., vol. **93**, #011906 (2008); *ibid.*, vol. **94**, #221901 (2009):
  - compressive strains are not prerequisite to whisker growth
  - rather, a negative strain gradient is the necessary driving force
  - used synchrotron techniques to demonstrate strain gradients both radially and with depth from whisker roots

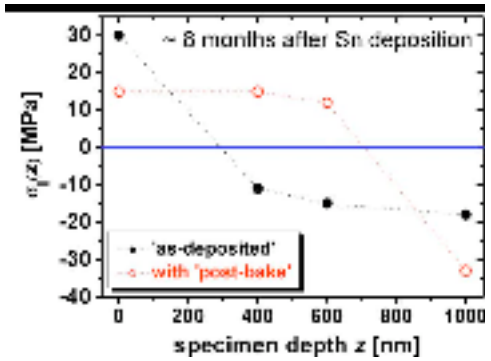


Some Thoughts / Questions

• Can information about strain gradients be incorporated into an atomic scale model that predicts whisker growth based on underlying diffusive transport?

• M. Sobiech, *et al.* (Appl. Phys. Lett., vol. **93**, #011906 (2008); *ibid.*, vol. **94**, #221901 (2009)):

• within ~2.5 μm of whisker root, estimate change of in-plane strain with respect to distance from the whisker root dε/dR ~ -0.008%/μm



• dσ/dz ~ -80 MPa/μm

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An Atomistic Model Idea

- Build an on-lattice kMC model of whisker growth

- Represent multiple grains as rotated lattices with model grain boundaries between them

- Site E depends upon coordination to 2nd NNs

    - use consistent approach for defining sites in GBs
    - define defect sites (interstitials) in lattice?
    - define a sliding (creep) mechanism?
    - barriers could be directionally biased based on input data for stress gradients?
        - stress distribution data from experiment? from simulation?
    - barriers for diffusing into and out of GB sites?
    - surface oxide effect?

An Atomistic Model Idea

• For an assumed, idealized stress state surrounding a given grain structure, what are the kinetics of growth; how does this vary for systematic variations in the grain boundary structure?

• For a given grain boundary structure, how do predicted kinetics vary with varying stress distribution in the sample?

Conclusions and Outlook

- *Mitigation strategies for dealing with Sn whiskering have been successful for a vast range of technology*

- *High reliability/consequence applications are still at unacceptable risk*

- *Can an atomic scale model incorporating information about the grain structure provide insight into the role of crystallography in Sn whisker growth?*

- *What inputs are required for baseline accuracy in such a model?*

- *What methods exist for generating such inputs?*