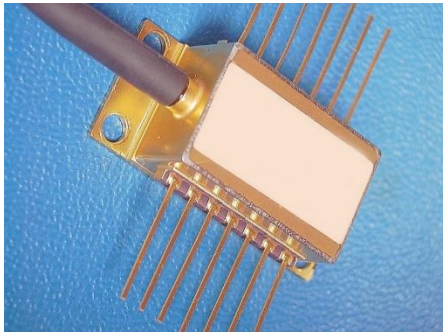
Tin Whisker Growth on Sn77.2-In20-Ag2.8 Solder

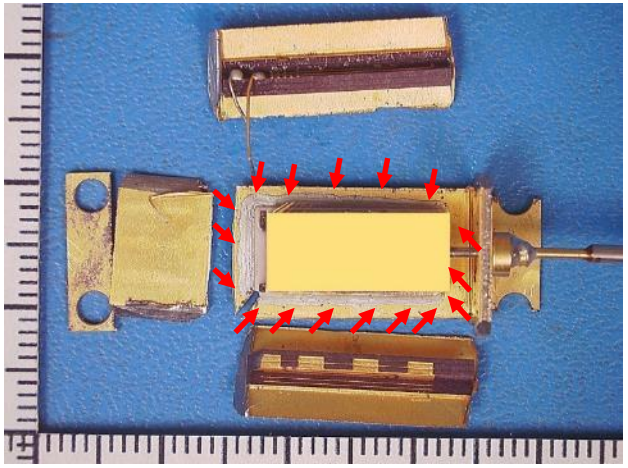
Lyudmyla Panashchenko

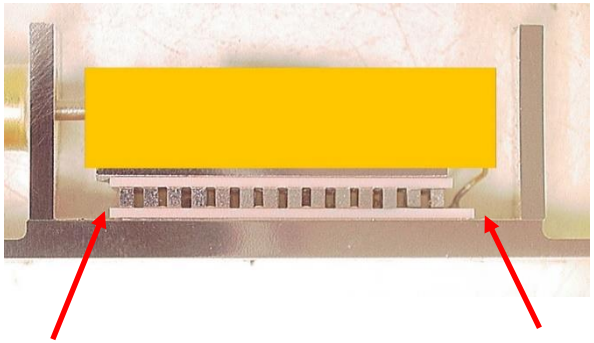
NASA Goddard Space Flight Center

Presented by Lyudmyla Panashchenko at the 2018 CMSE Components for Military & Space Electronics Training & Exhibition, Los Angeles, CA, May 7-10, 2018.

Butterfly Package with an Internal Short







- Internal short between package body and columns of the thermo-electric cooler (TEC)
- Resistive short is due to tin whiskers growing from the Sn77.2-In20-Ag2.8 solder used for attaching TEC to the Au-plated package
  - Resistive shorts in 100-400Ω range
  - Normally the connection is electrically open
  - Tin whiskers bridged ~1.3mm gap

Device background:

Au-plated Cu-W package

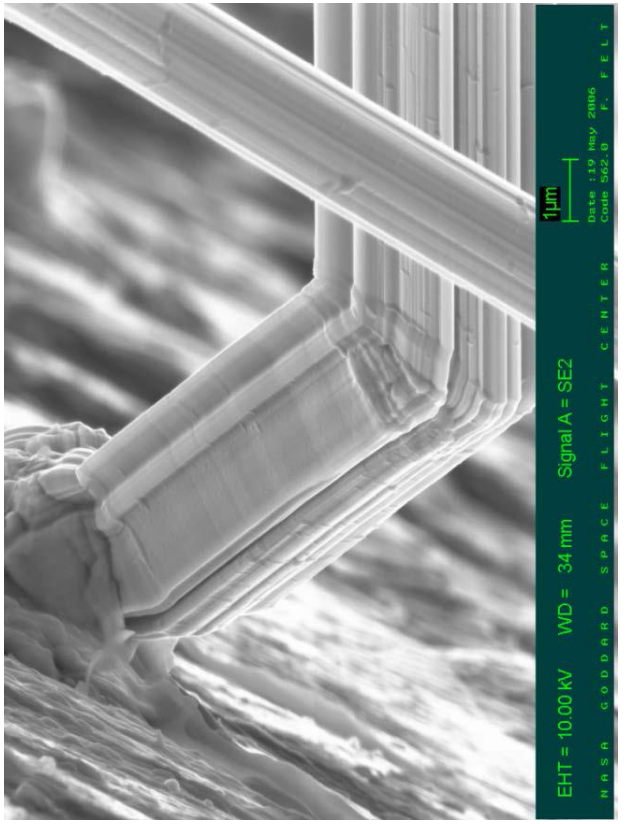
Package is hermetically sealed with nitrogen backfill

Electrical check-out post-manufacturing

2 years of non-operational storage

What are whiskers

- Hair-like metal structures that erupt outward from a grain or several grains on a metal surface
  - May be straight, kinked, or odd-shaped eruptions
- Coatings of *Tin, Zinc and Cadmium* are especially able to develop whiskers; but, whiskers have been seen on Indium, Gold, Silver, Lead, and other metals too



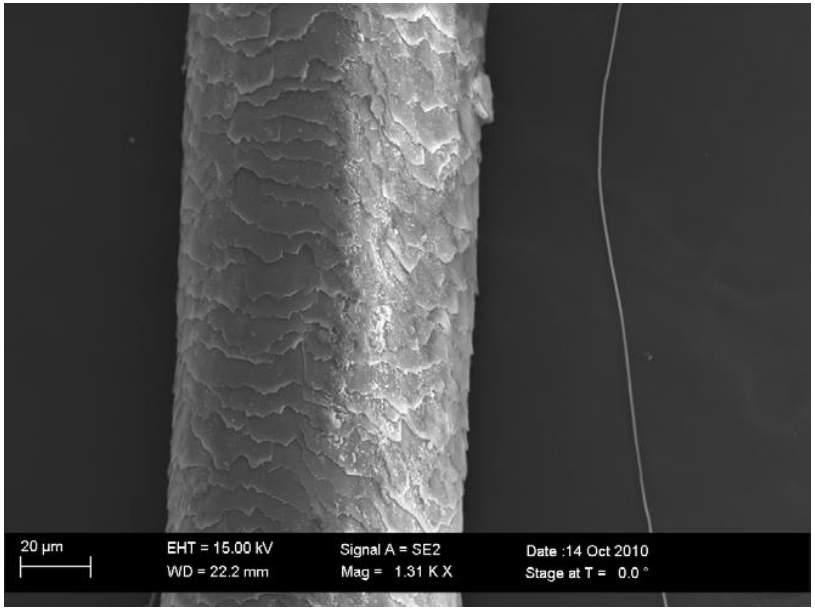
Source Material	→	atoms of the metal itself
Transport Mechanism	→	primarily grain boundary diffusion
Transformation	→	diffusing atoms aggregate at the root (NOT the tip) of the forming whisker

Human Hair vs. Metal Whisker

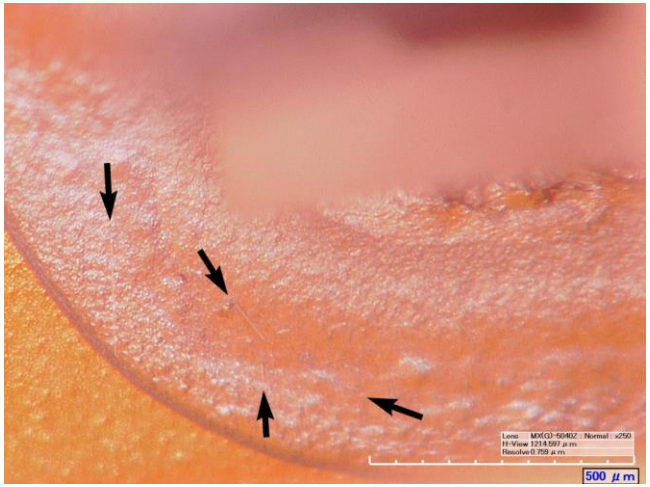
Metal Whiskers are commonly 1/10 to <1/100 the thickness of a human hair

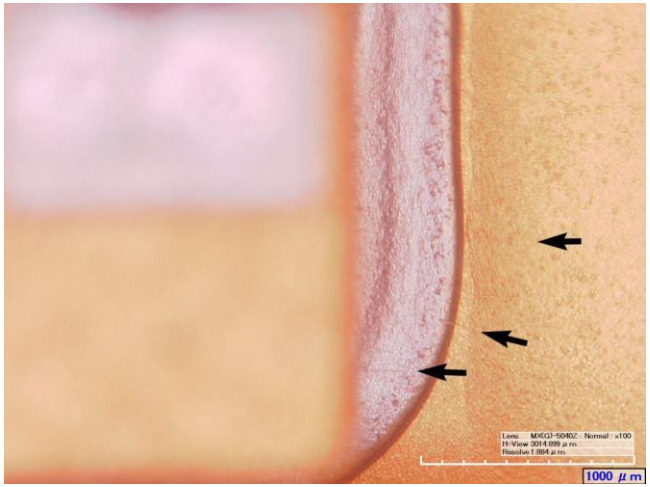
Optical comparison of Human Hair vs. Tin Whisker

SEM comparison of Human Hair vs. Metal Whisker

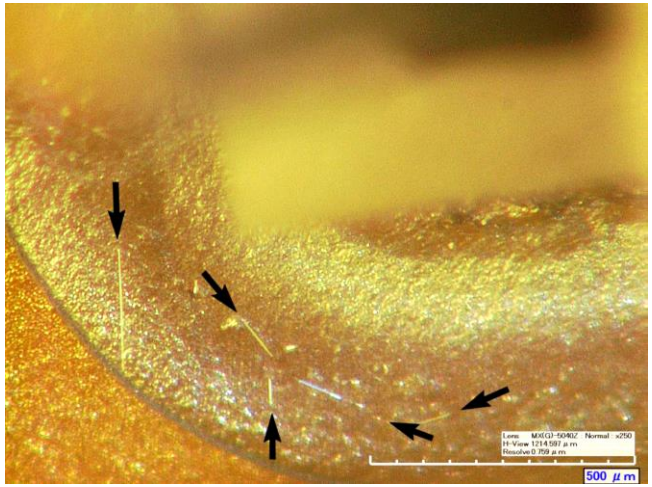


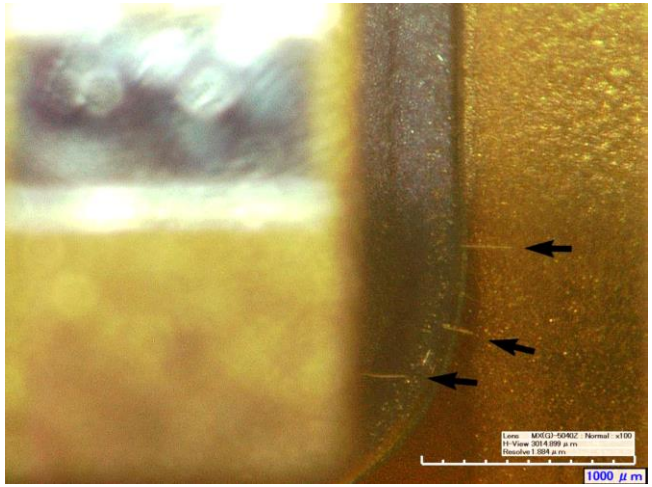
Effect of Optical Illumination



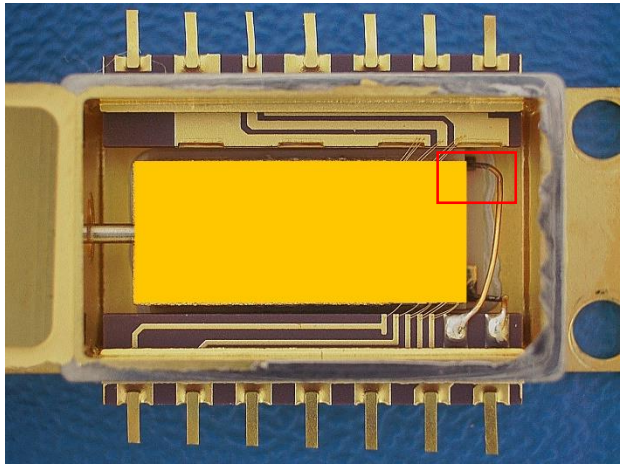


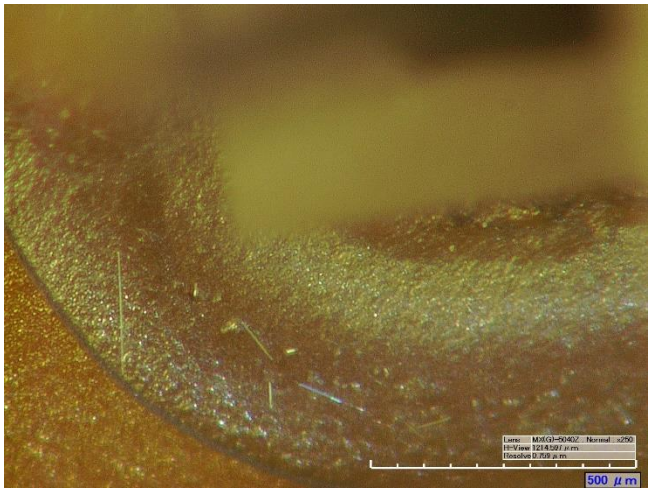
Change in Illumination

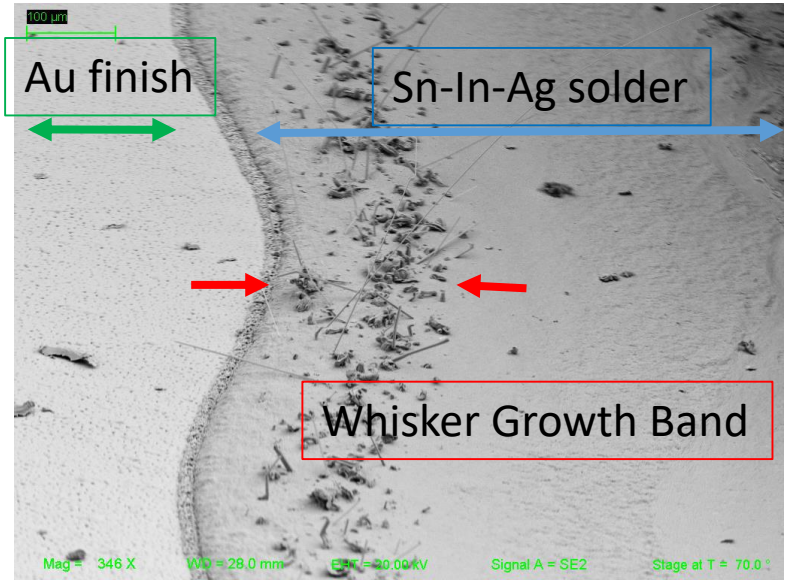


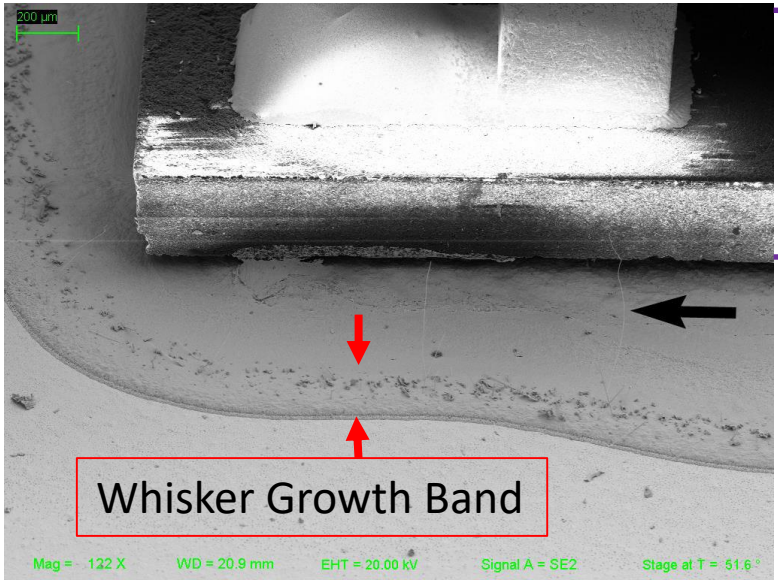


Whiskers Only Present in a Narrow Band

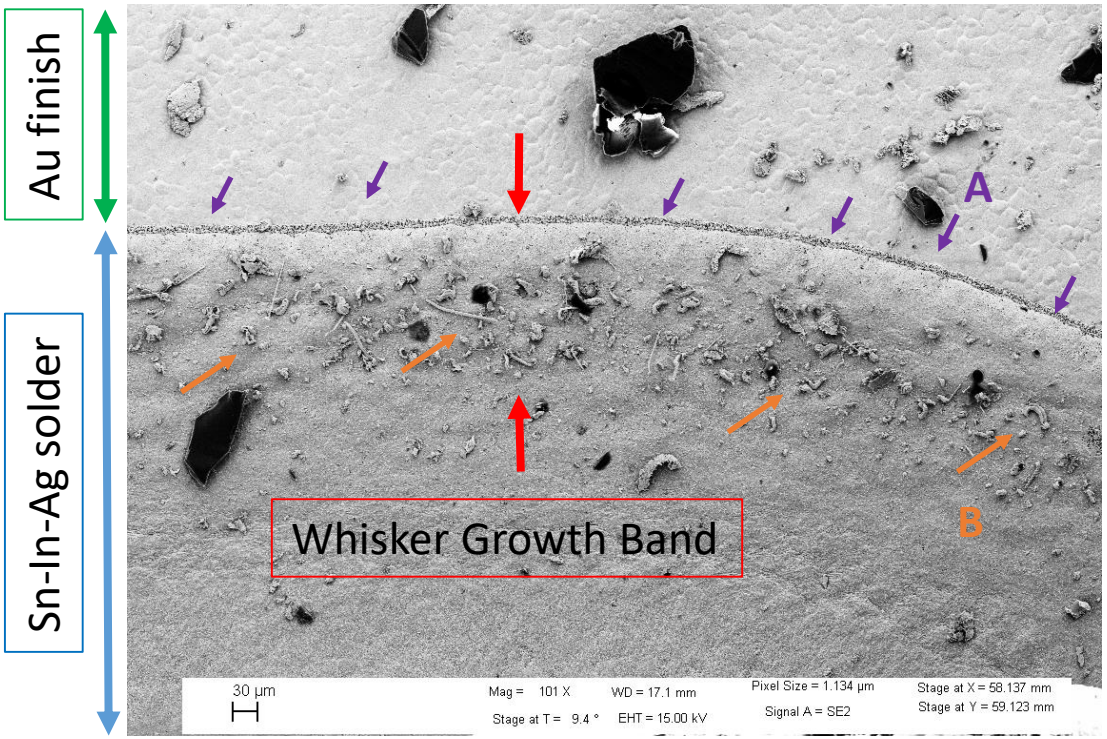








Whiskers Only Present in a Narrow Band



- Whiskers growth fully contained within a band around the solder edge
- The band varied from sample to sample: 100-250µm from the edge
- Whiskers <20µm in length present continuously around the perimeter of the solder (**A**)
- Whiskers >100µm typically present 25µm or further from the edge (B)

Tin Whiskers' Lengths, Diameters and Resistance

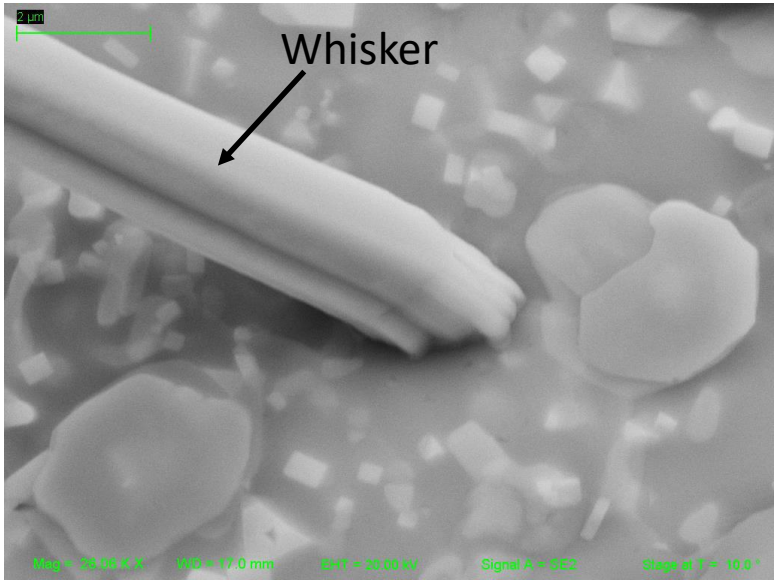
Calculated Whisker Resistance Based on Thickness and Length

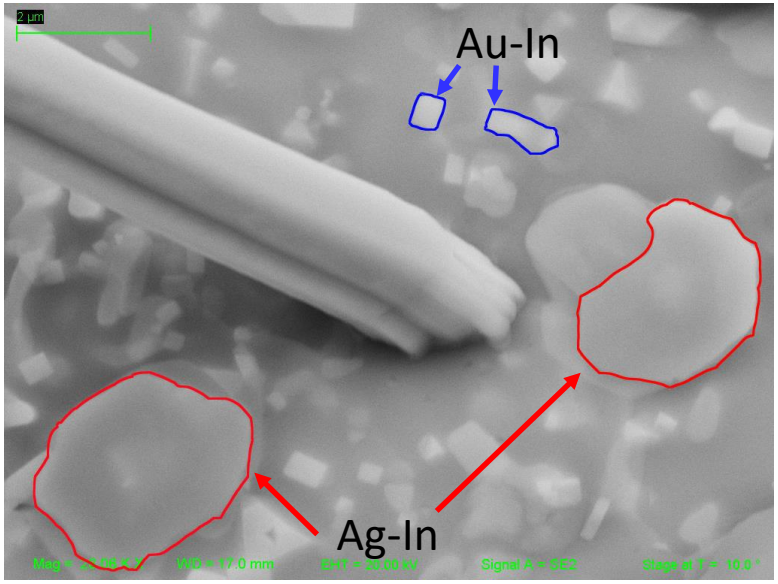
	Whisker Length (mm)			
	0.5	1	2	5
Whisker Diameter (µm)				
0.5	293Ω	586Ω	1171Ω	2928Ω
1	73Ω	146Ω	293Ω	732Ω
2	18Ω	37Ω	73Ω	183Ω
5	3Ω	6Ω	12Ω	29Ω

Resistivity of tin: 1.15E-7 Ω-m

Whiskers in this range caused electrical shorts in this device

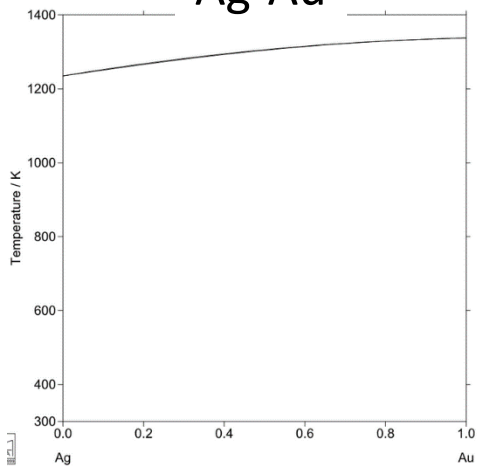
Whisker-Growing Region has Lots of Intermetallic Compounds (IMCs)



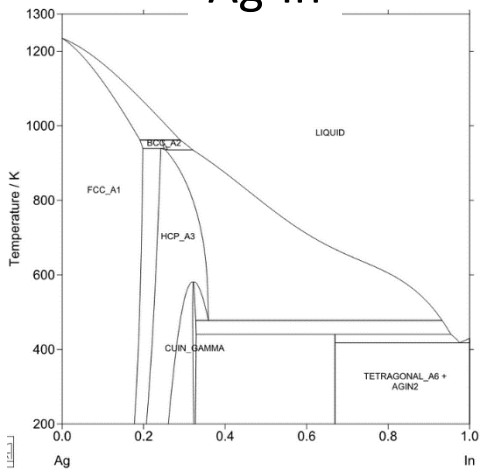


Intermetallics between Ag, Au, In and Sn – Binary Diagrams Only

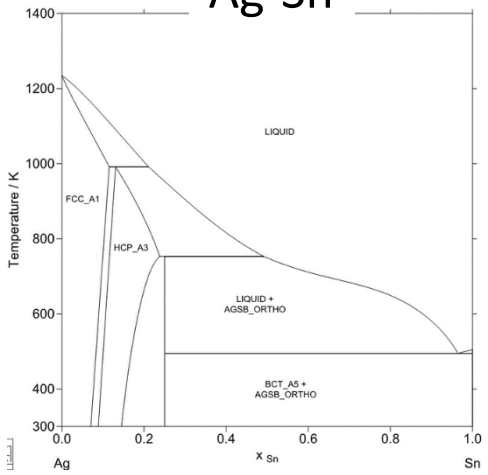
Ag-Au



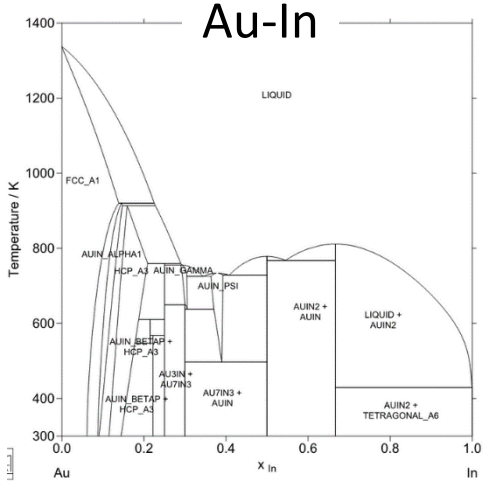
Ag-In



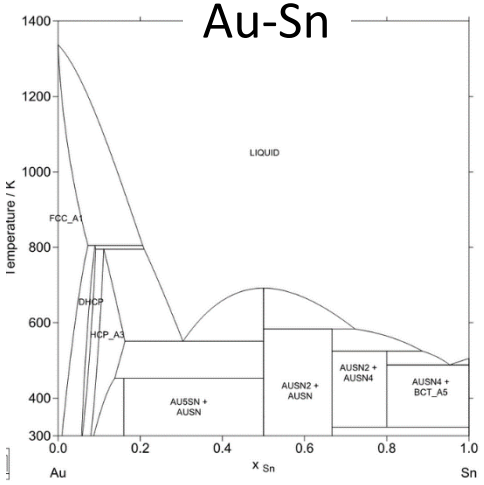
Ag-Sn



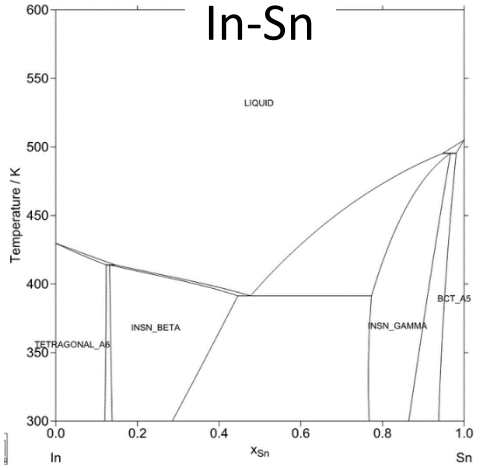
Au-In



Au-Sn

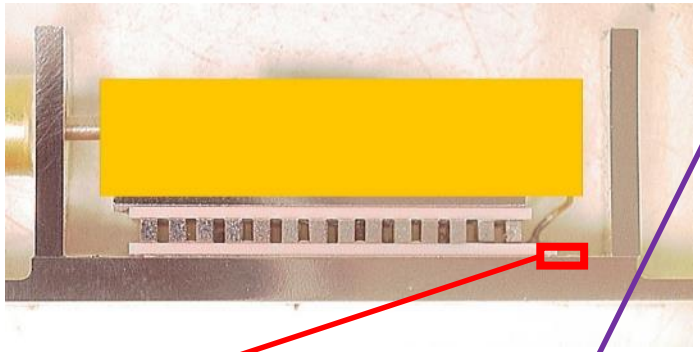


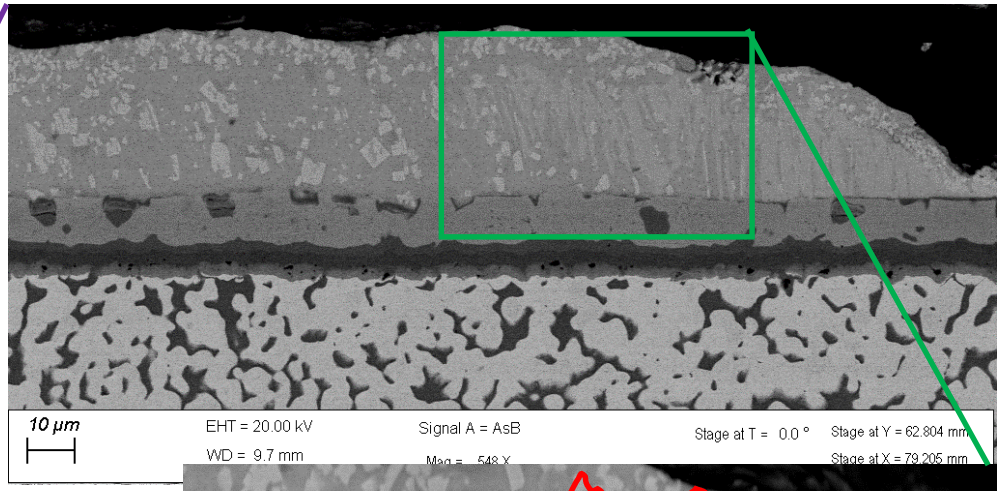
In-Sn

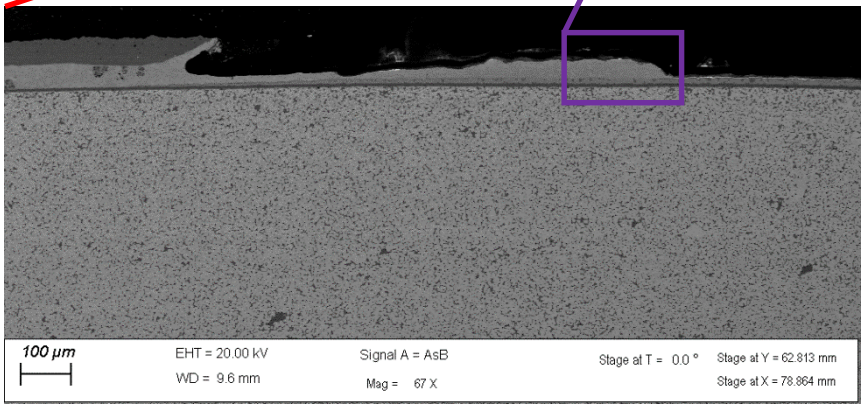


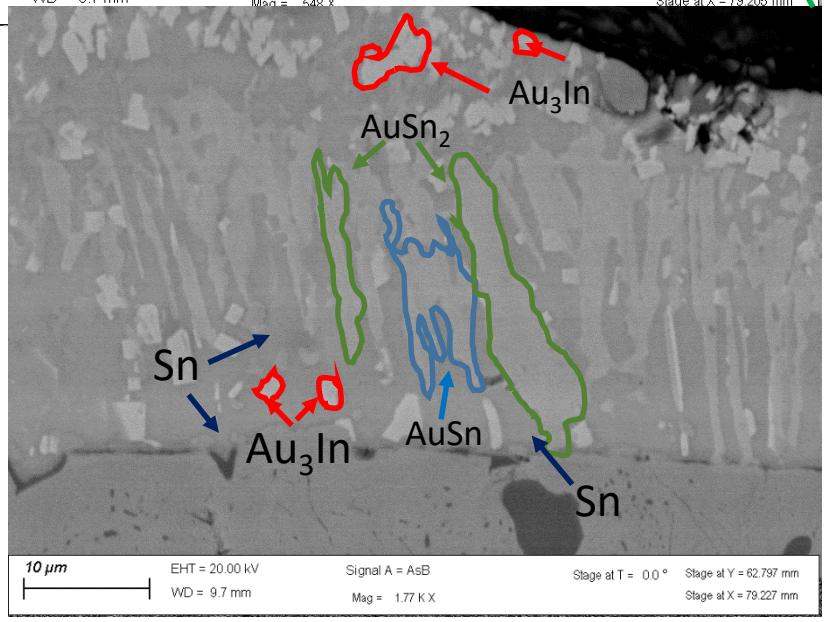
Source: npl.co.uk

Intermetallic Compounds in Cross Section: Au_3In, AuSn, $AuSn_2$

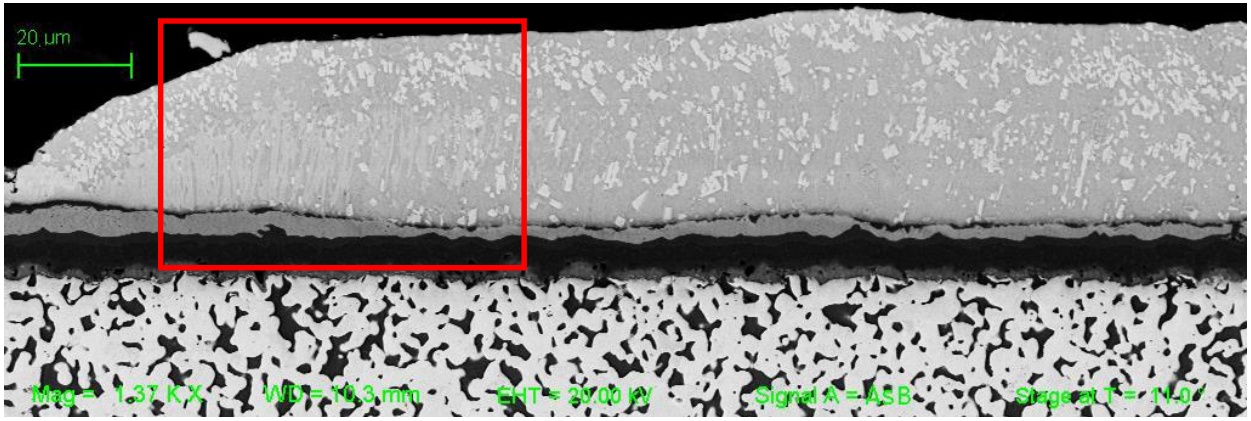


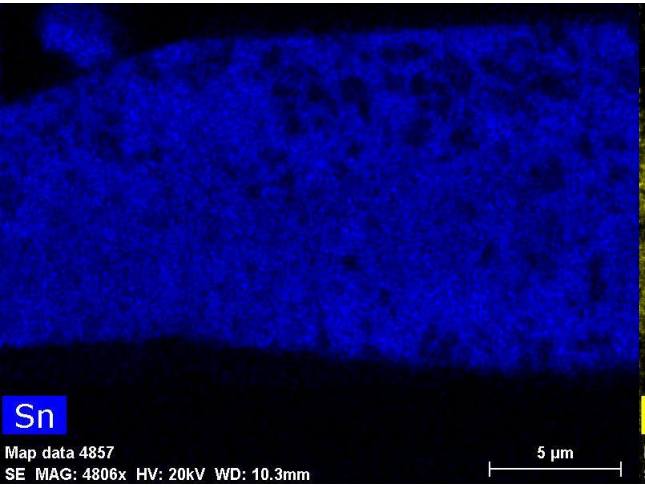


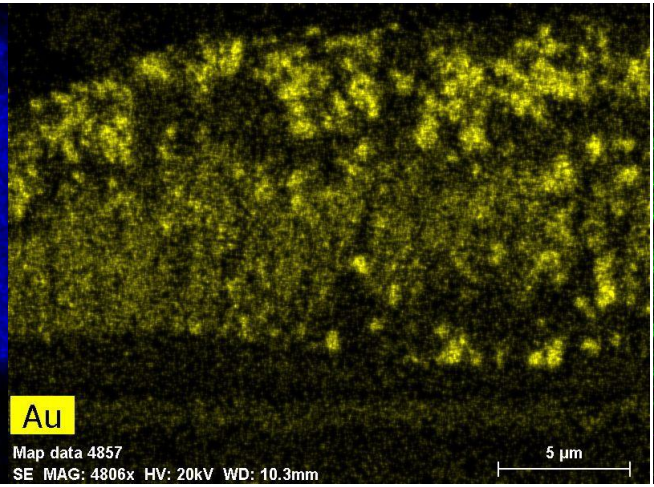


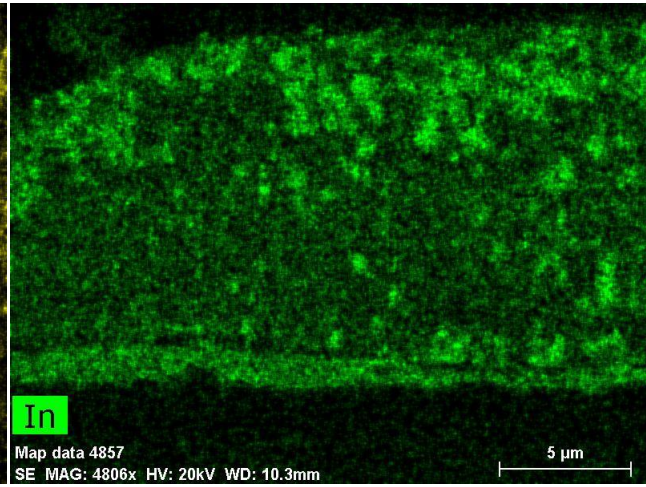


Whisker Growth Band Corresponds to Presence of Au-Sn Intermetallics









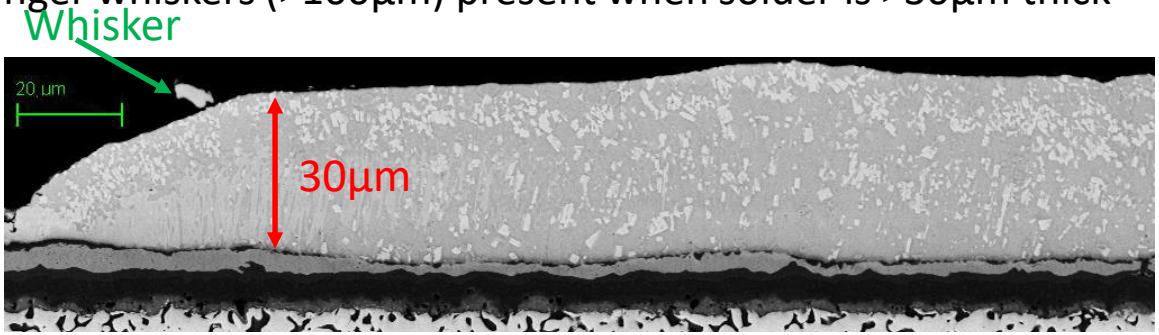
Past Publication with Similar Experiences

- Li, Qingqian, Y. C. Chan, and Zhong Chen. "Tin whiskers growth of SnAgIn solder on Kovar substrate with Au/Ni plating." *Journal of Materials Science: Materials in Electronics* 25.3 (2014): 1222-1227.
  - Observed tin whisker growth from 77.8SnIn20Ag2.8 solder reflowed on Au/Ni/Kovar. Au thickness of 1.8µm
  - Whiskers grew in narrow strip where solder thickness was between 7.9µm and 18.8µm

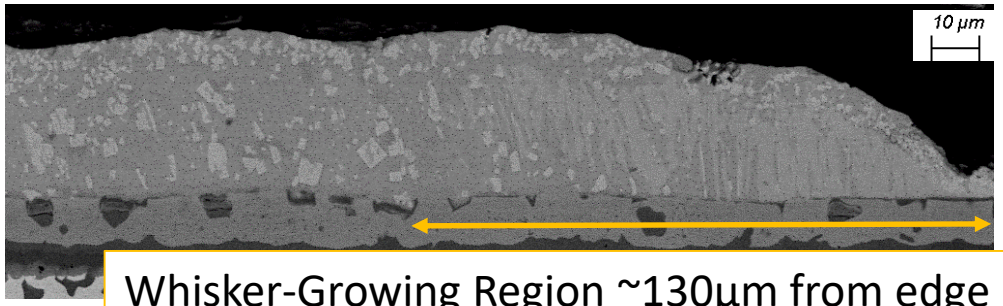
- Fukuda, Mitsuo. "Reliability and Degradation of Semiconductor Lasers and LEDs." *Boston: Artech House*, 1991. ISBN 0890064652. Sections 4.4.2.2 and 9.1.1
  - Observed tin whisker growth from Sn and SnPb solders used to bond Au-plated heat sink to Au-plated package
  - Whisker growth in areas that are not electrically stressed
  - No whiskers observed with eutectic Au-Sn (80Au-20Sn) solder used

Whisker-Growing Region

- Solder thickness
  - Li's observations point to solder thickness of 7.9µm and 18.8µm corresponding to whiskering region
  - In our case, whiskers were observed from solder thickness up to 30µm
  - Shorter whiskers (<25µm) present when solder is <30µm thick
  - Longer whiskers (>100µm) present when solder is >30µm thick



- Intermetallic compounds correspond to whisker-growing region
  - AuSn, $AuSn_2$ observed 100µm-250µm from edge, depending on sample



Public Standards Mostly Focus on Finishes, and Less on Solders

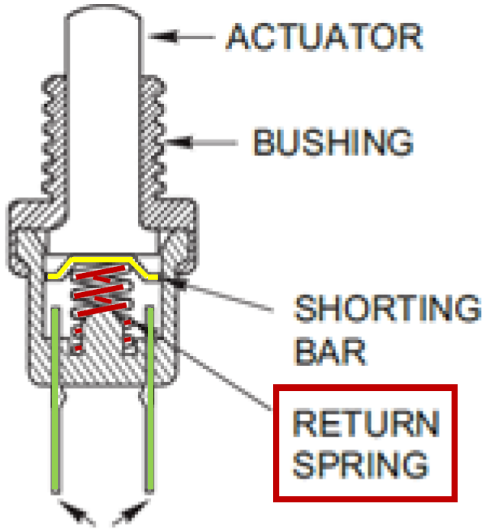
- GEIA-STD-0005-2
  - The majority of requirements in this standard apply to Pb-free tin finishes, not Pb-free solders. This is because the level of understanding for tin whiskers growing from finishes is much higher than from solders. However, the data on the dangers of tin whiskers growing from Pb-free and SnPb solders when there are rare earth elements (REE) present is sufficient to consider these solders a risk
  - Annex E titled "Whiskers Growing from Solder Joint Fillets and Bulk Solder"
    - Scenario 1: Corrosion Effects
    - Scenario 2: Rare earth element additions
- JESD 201: "Environmental Acceptance Requirements for Tin Whisker Susceptibility of Tin and Tin Alloy Surface Finishes"
  - This specification does not apply to components with bottom-only terminations where the full plated surface is wetted during assembly (for example: QFN and BGA components, Flip Chip bump terminations)
- JESD 22A121: Test Method For Measuring Whisker Growth On Tin and Tin Alloy Solder Finishes
  - Pure Sn and Sn-based alloy electrodeposits and solder-dipped finishes may grow tin whiskers, which could electrically short across component terminals or break off the component and degrade the performance of electrical or mechanical parts

Conclusion

- Tin Whisker growth along Sn77.2-In20-Ag2.8 solder reflowed over Au-finished package
  - Observed whiskers over 1mm in length
  - Experienced electrical shorts due to whiskers in 100-400Ω range
- Whisker growth is in a narrow band of the solder along the preform edge
  - 100-250µm from the edge
  - Does not correspond to change in solder thickness
  - Corresponds to presence of large AuSn and AuSn2 intermetallic crystals in the solder
- Underlying mechanism(s) of whisker growth from Sn77.2-In20-Ag2.8 solder are not understood
- Conventional wisdom and past experience would not have predicted whiskers growing from this combination of metals
  - Reflowed solder tends to not grow whiskers
  - Presence of alloying constituents in tin tends to correlate to less whisker growth

P.S. – Field Failure of a Push Button Switch

- Non-NASA entity contacted us regarding intermittent behavior of a timing relay box in a chemical processing plant
- The box would intermittently trigger
- Box could be reset through percussive maintenance (aka: hitting the front panel)
- The problem was electrically isolated to the push button switch on the front panel



Switch Closed

Switch Opened

P.S. – Field Failure of a Push Button Switch

- Internal spring is a “tinned music wire” according to data sheet. Material analysis shows a variety of alloys
- Whiskers found on spring of the push button switch, explaining intermittent closure of the switch

Lot Date Code	Composition of Internal Spring	Final Surface Finish thickness (um)	Metal Whiskers Growing?	Comments
0223	Tin over Iron alloy	0.49	Yes	Tin Whiskers
0810	Tin over Copper over Iron alloy	0.47	Yes	Tin Whiskers
0952	Tin over Copper over Iron alloy	0.67	Yes	Tin Whiskers
1452	Zinc over Iron Alloy	2.3	No	Note the spring uses Zinc Coating instead of Tin
1637	Zinc over Iron Alloy	2.2	No	Note the spring uses Zinc Coating instead of Tin