

LETTERS

LEAD-FREE TRANSITION FOR THE EUROPEAN SPACE SECTOR

The Tin Whiskers Challenge

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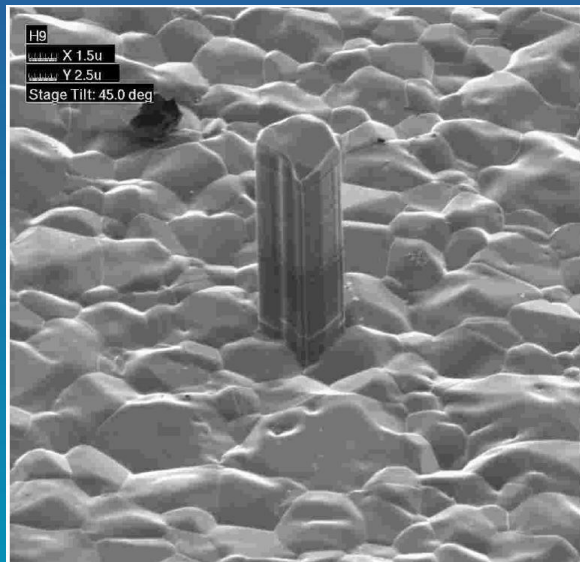
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Outline

- Background
- Influencing Factors
- LETTERSS



Zinc whiskers on steel pipe [1]



SEM image of tin whisker [2]

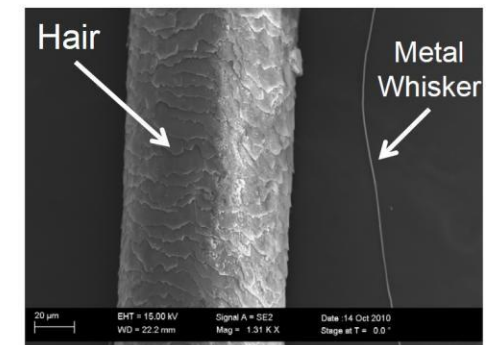
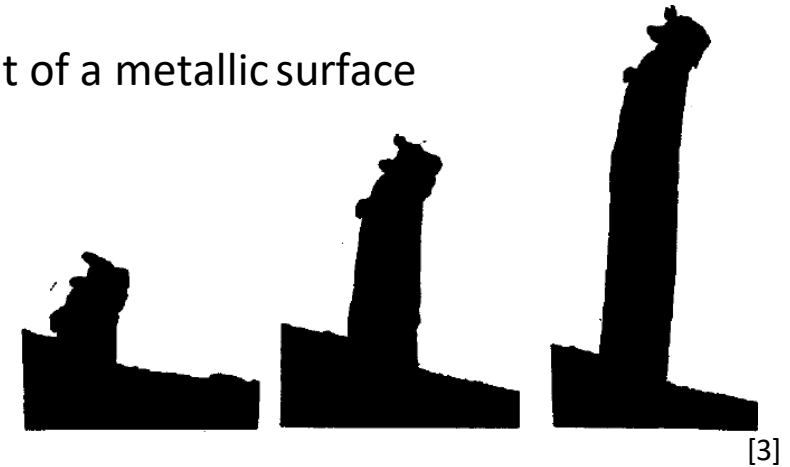
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Background

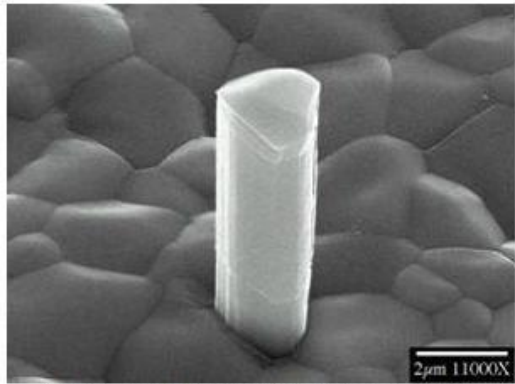
Definition

- Metal whiskers = electrically conductive, crystalline filaments, growing out of a metallic surface
 - Length: from some microns to millimeters
 - Thickness: some microns
 - Variable cross section
 - Incubation time: from hours to years
 - Growth rate from 0.1 to 100 nm/s
 - Addition of coating material to the root
- Metallic materials reported to grow whiskers
 - Mainly: Cd, Sn, Bi, Zn
 - But also: Ag, Au, Al, Sb, Mg, Ta, Mo, W, Fe, Ni, Pd, Pt, Pb, In
- 16th century: first observation of „hair silver“ after cutting, scratching or heating silver objects

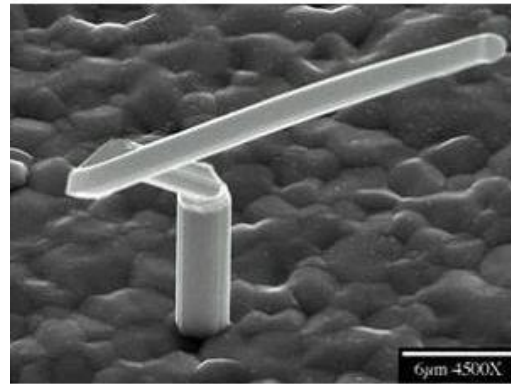


Background Appearance

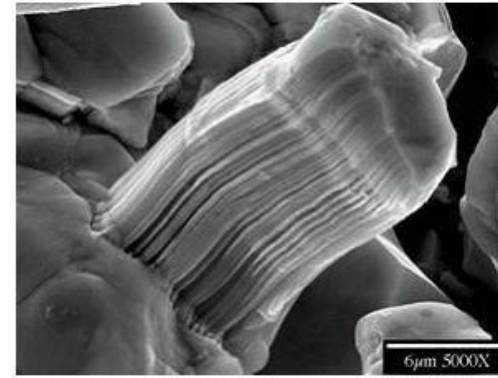
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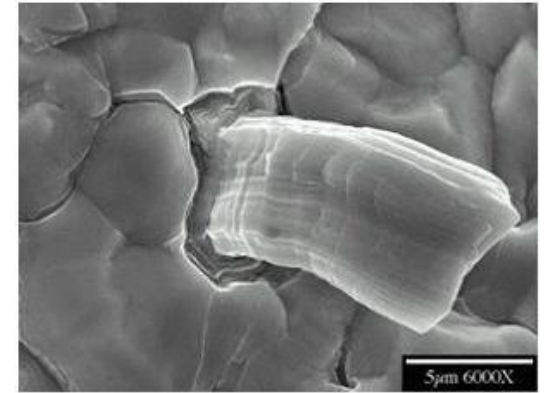
Whisker with a consistent cross section.



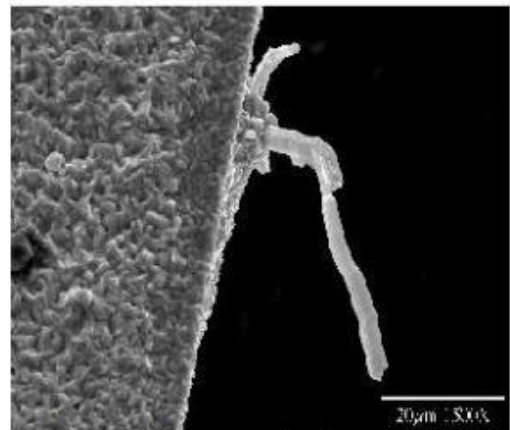
Kinked whisker.



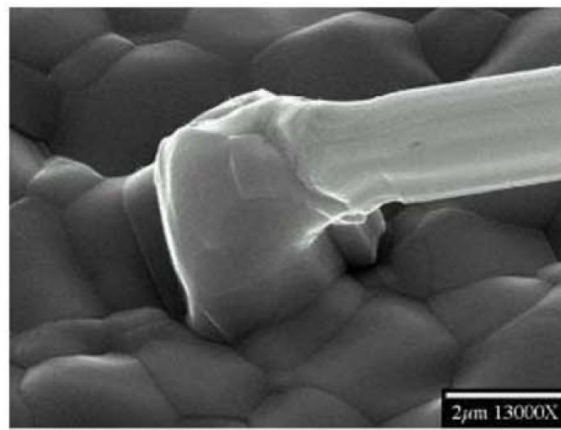
Tin whisker filament with striations.



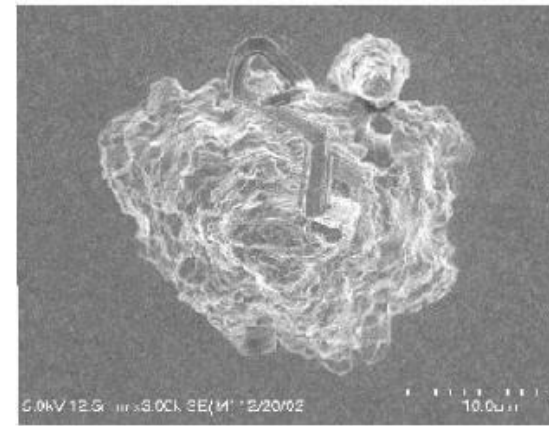
Tin whisker with rings.



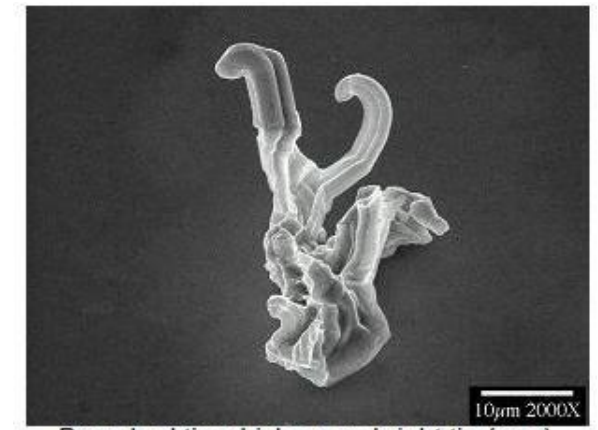
Kinked whiskers growing from a nodule.



Whisker initiating from a hillock.



Kinked whisker on odd-shaped eruptions.

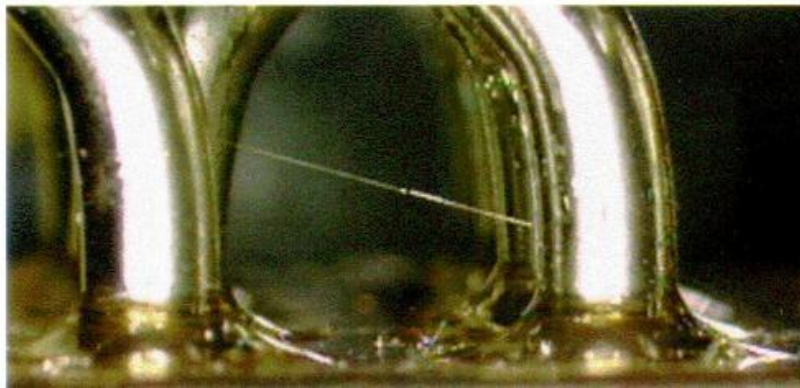


Branched tin whiskers on bright tin (rare).

Background

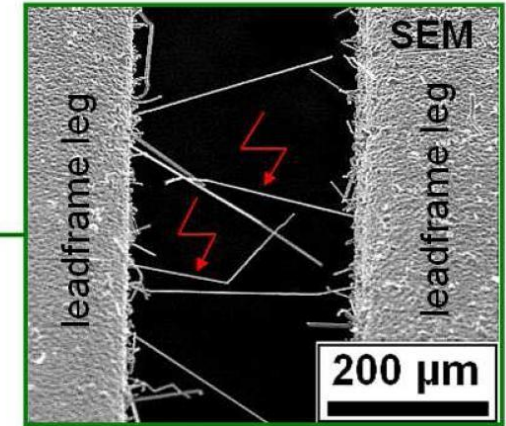
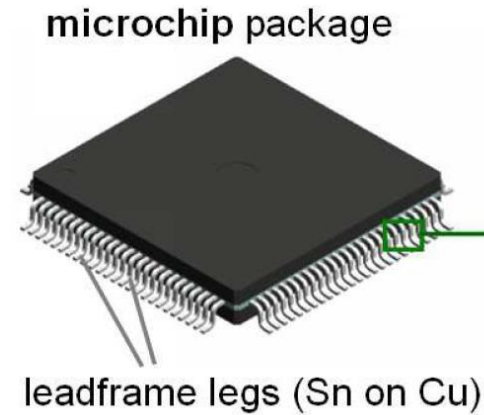
Dangers

- Creation of conducting bridges
 - Permanent or temporary short circuit



[1]

- Metal vapor arcing
 - Whisker vaporized and gas ionized
 - Current conduction over plasma



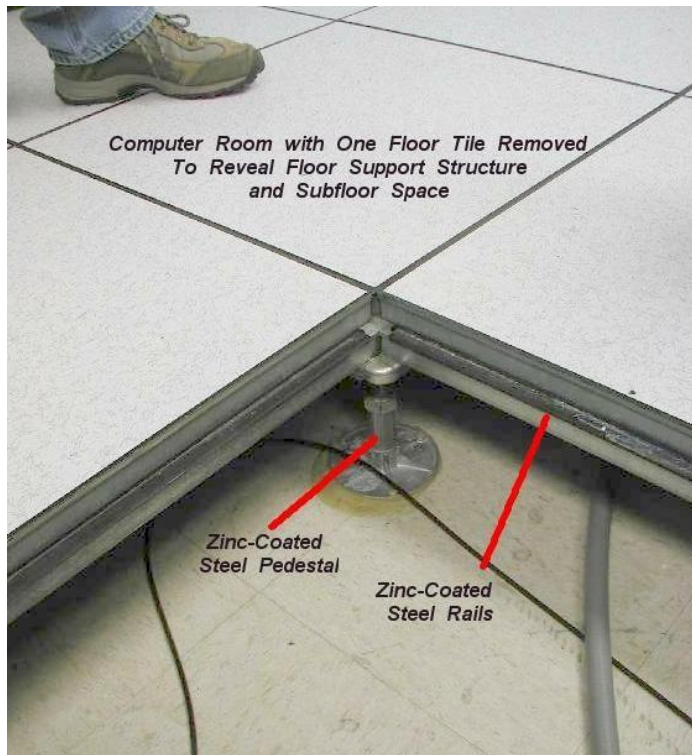
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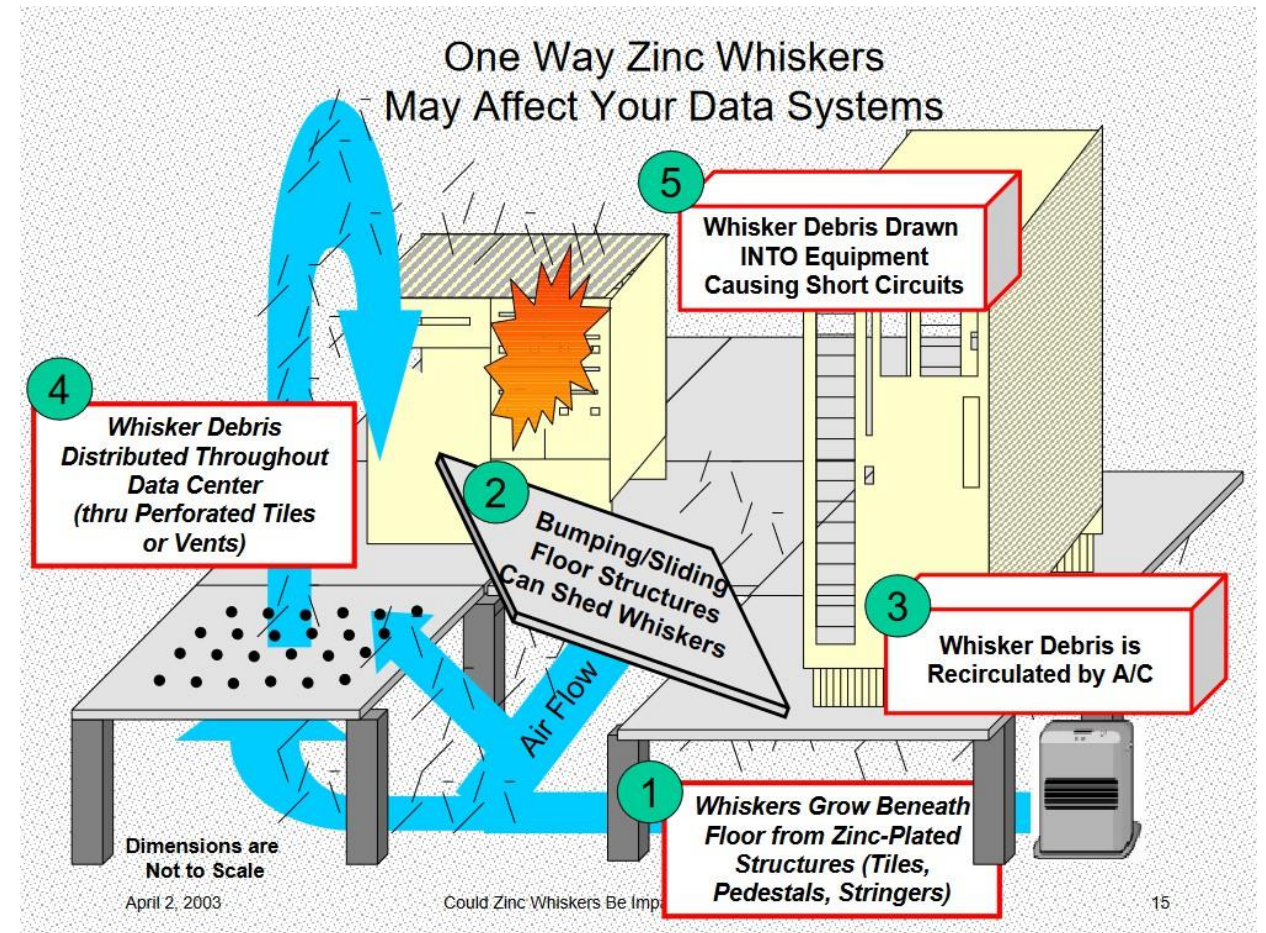
[7]

Background Dangers

- Debris contamination of other components



[1]



[8]

Background

Whisker-related Events

- First whisker-related failures:
 - WWII - short-circuit of electrical systems
 - Cd whiskers identified by Cobb in 1946
- Known whisker-related issues
 - Military equipment (missiles, radars, satellites)
 - Medical equipment (pace-maker, rotary switches)
 - Watch oscillators
 - Power plants (shutdown, alarms, relays)
- Estimated losses since first notice
 - Over 1 billion dollars in 2002 (CALCE)
 - Over \$10 billion in 2007 (Associated Press)

| Year | Satellite | Failure cause | Component affected |
|------|--------------------------------------|---------------|--------------------|
| 1998 | DBS1 (Side 1) | Tin whiskers | Relays |
| 1998 | GALAXY IV (Side 2, complete loss) | Tin whiskers | Relays |
| 1998 | GALAXY VII (Side 1) | Tin whiskers | Relays |
| 1998 | PAS-4 (Side 1) | Tin whiskers | Relays |
| 1999 | SOLIDARIDAD I (Side 1) | Tin whiskers | Relays |
| 2000 | GALAXY VII (Side 2), complete loss | Tin whiskers | Relays |
| 2000 | SOLIDARIDAD I (Side 2) complete loss | Tin whiskers | Relays |
| 2001 | GALAXY IIIIR (Side 1) | Tin whiskers | Relays |
| 2002 | DIRECT TV 3 (Side 1) | Tin whiskers | Relays |
| 2005 | OPTUS B1 | Tin whiskers | Relays |
| 2006 | GALAXY IIIIR (Side 2) | Tin whiskers | Relays |

[1]

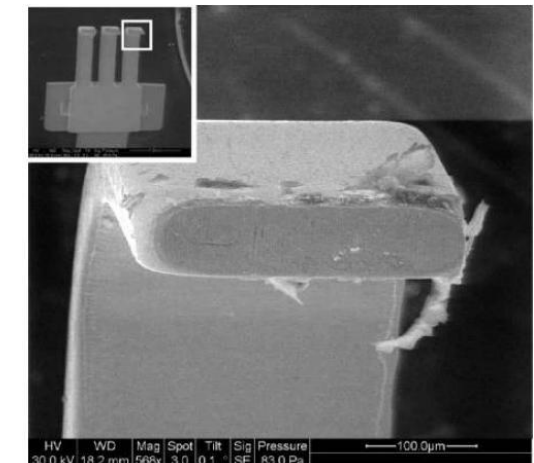
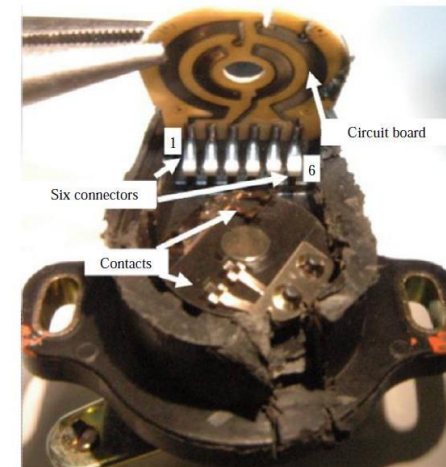
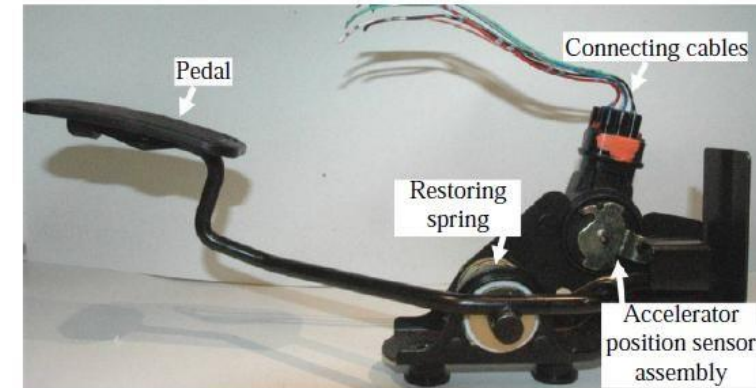
Background

Whisker-related Events?

Issue with Toyota engine control unit on several Toyota models

[9]

- Vehicle not starting or stalling while driving
➔ 1.33 million vehicles recalled
- Tin whiskers up to 1.9 mm found in pedal assemblies
➔ Partial short-circuit between pedal and signal output
- Whisker not held for responsible in the official version

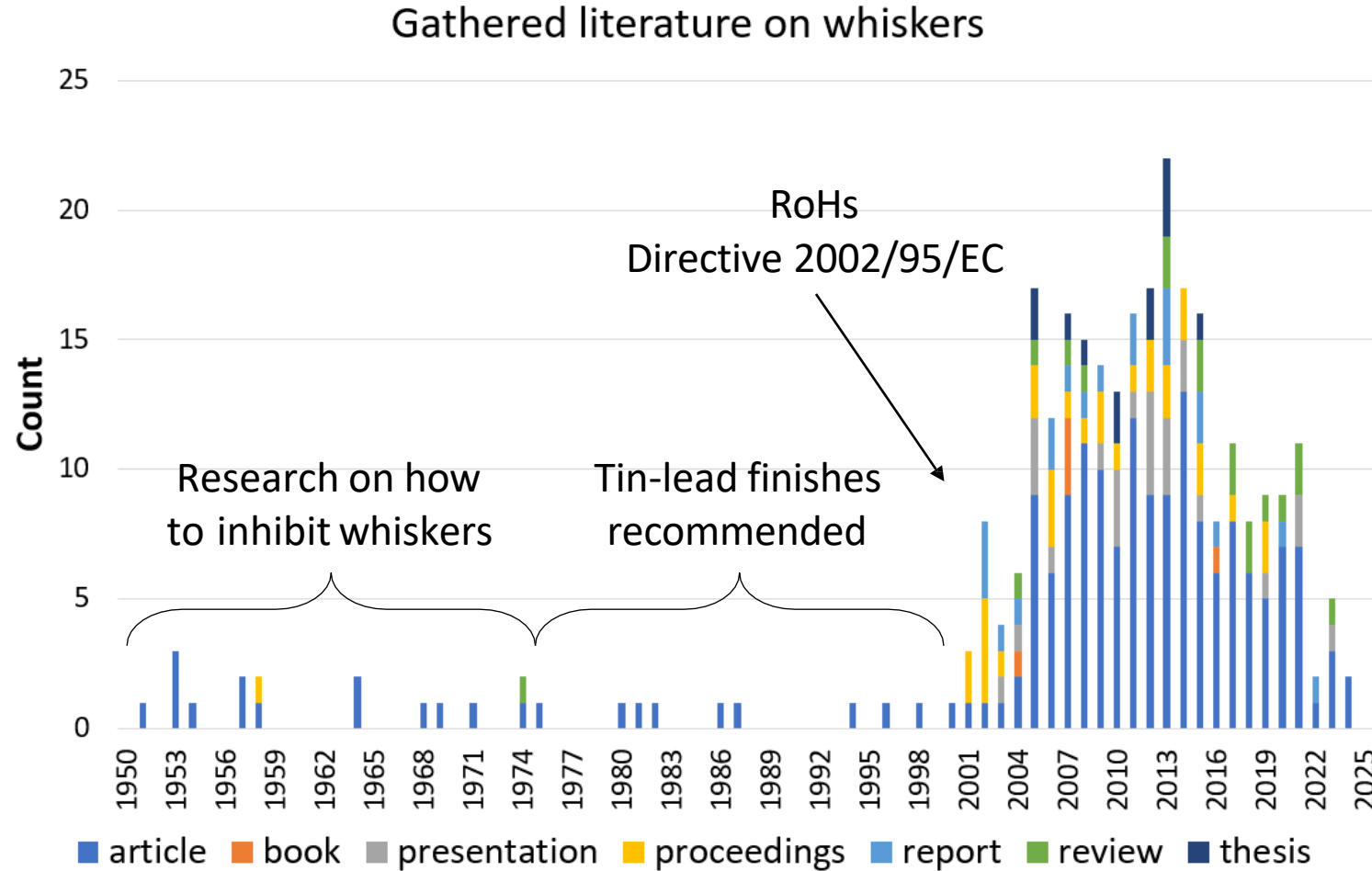


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Influencing Factors

70 Years of Whisker Research

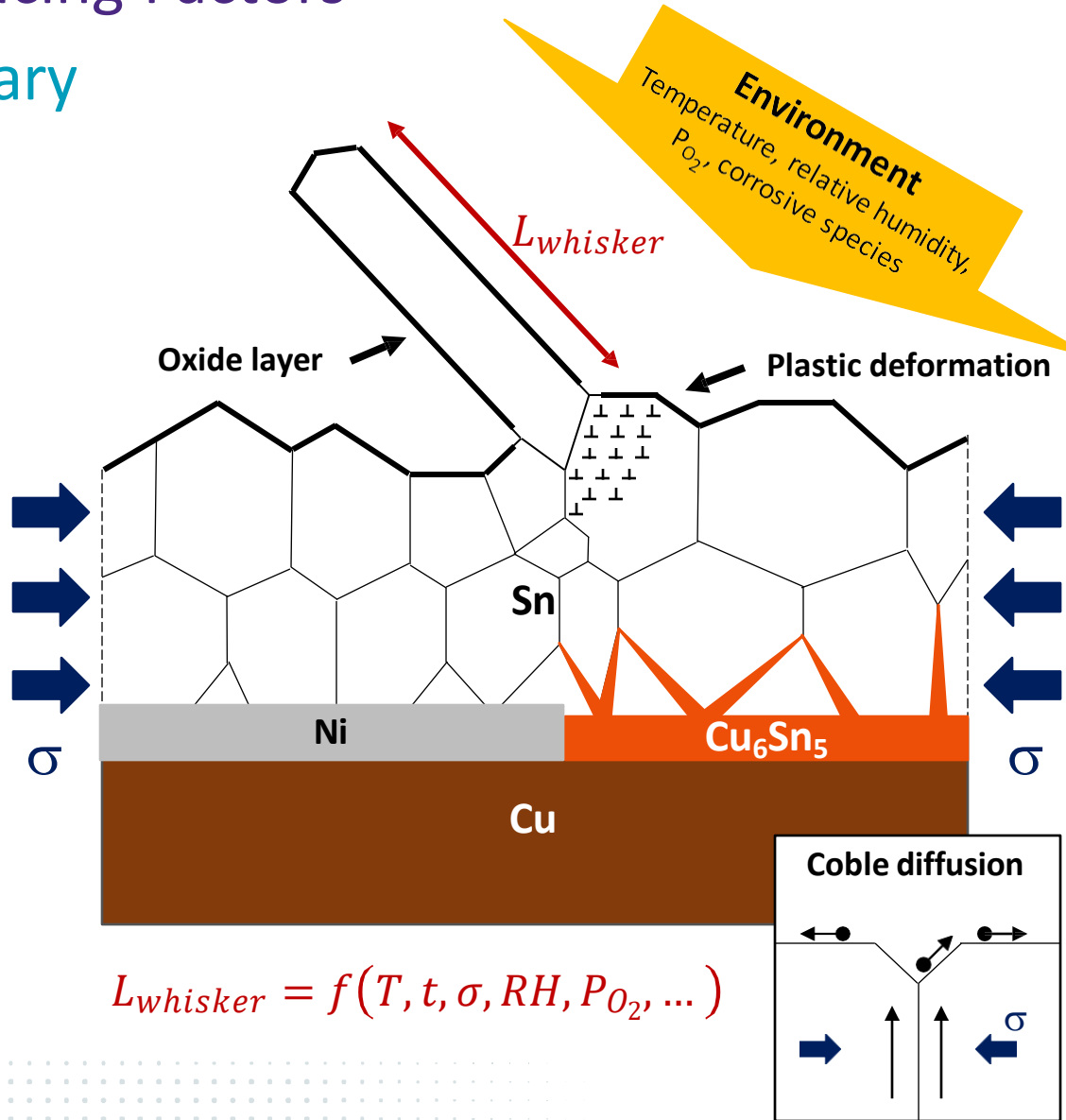


Influencing Factors Summary

- Coating**
- Coating conditions
 - Residual stresses
 - Thickness
 - Grain size
 - Texture
 - Composition
 - Impurities

- Interface**
- Intermetallic phases
 - Diffusion barrier

- Substrate**
- Diffusion into coating
 - Roughness
 - CTE mismatch



- Interaction of multiple processes
 - Stress generation & relaxation
 - Phase transformation
 - Diffusion
 - ...
 - Numerous processing variables
 - Involved materials
 - Layer thickness
 - Microstructure (grain size, texture, orientation)
 - Processing & operating conditions
 - Time
 - ...
- ➔ Underlying mechanism not identified
- ➔ No generally valid predictive models

Influencing Factors

Challenges

- Intricate problematic due to combined parameters interacting with each other
 - All variables not known, not always (and systematically) reported
 - No universal theory → whisker phenomenon depends on operating conditions
- Industrial standards are no norms
 - Require „critical engineering judgment“ ^[10]
 - „No way to relate these tests to field conditions with any reasonable degree of certainty“ ^[10]
- Challenges
 - Correlation between test and field conditions & long-term predictions
 - Why do whisker nucleate, grow and stop growing?
 - Whisker = whisker?
 - Whisker growth scenario

→ The influence of each factor must be investigated separately in a systematic manner

Outline

- Background
- Influencing factors and theories
- **LETTERSS**

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Whisker Workpackage

- Objectives

- Advance the understanding on the correlations between the growth rates of whiskers and the temperature, stress state within the samples and chemical composition of substrate / solder systems
- To analyse the interplay between influencing factors on the whisker formation and growth rate
- Provide a heat map for whisker growth risk
- Establish an accelerated test strategy for whiskers formation & mitigation approaches in space application
- Own / European database with comparable & systematic parameter variation

- Model experiments

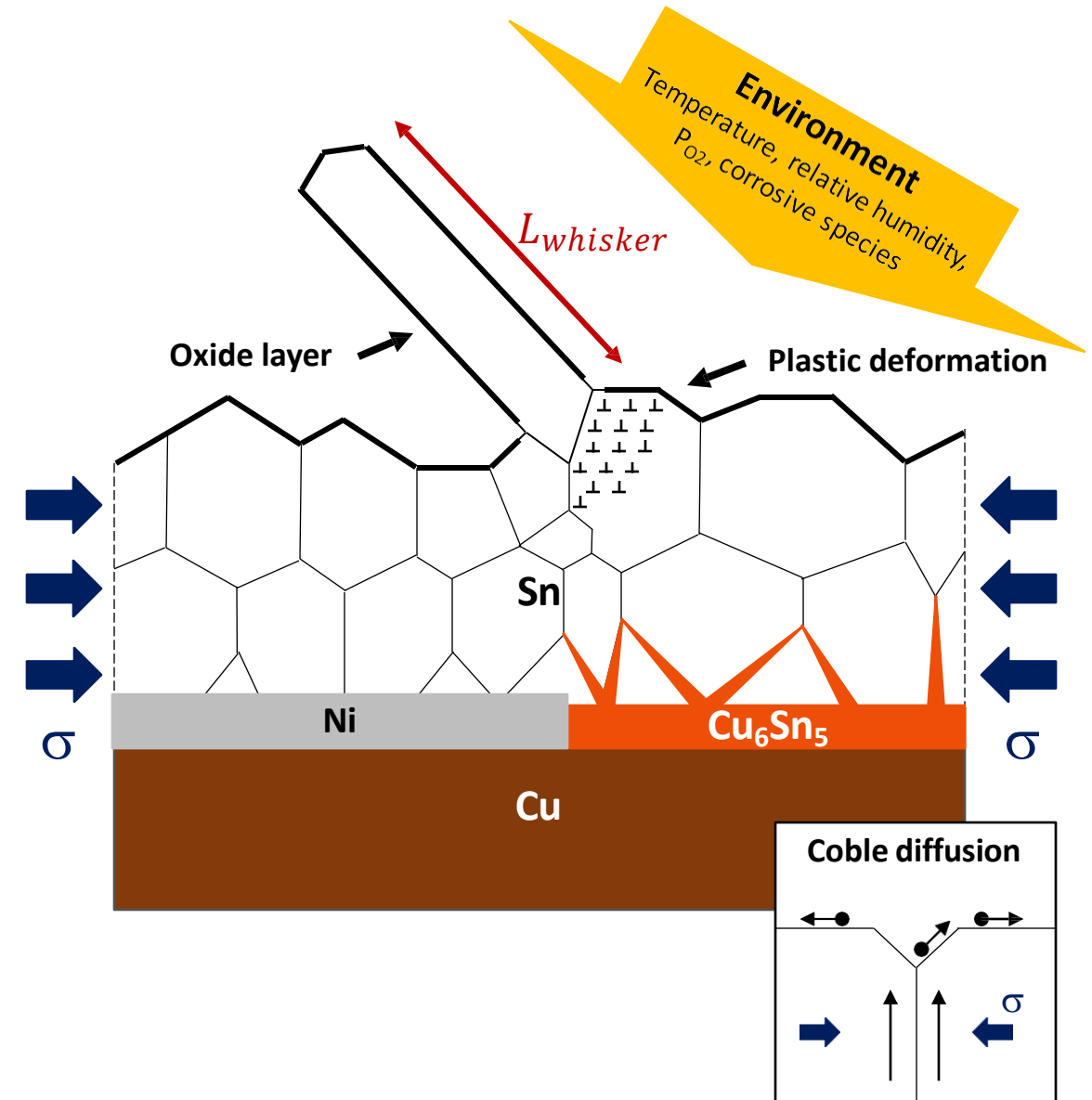
- Parameters changed independently of each other to replicate conditions, under which the highest growth rates of whiskers are found
- Lab conditions / model samples vs. real components



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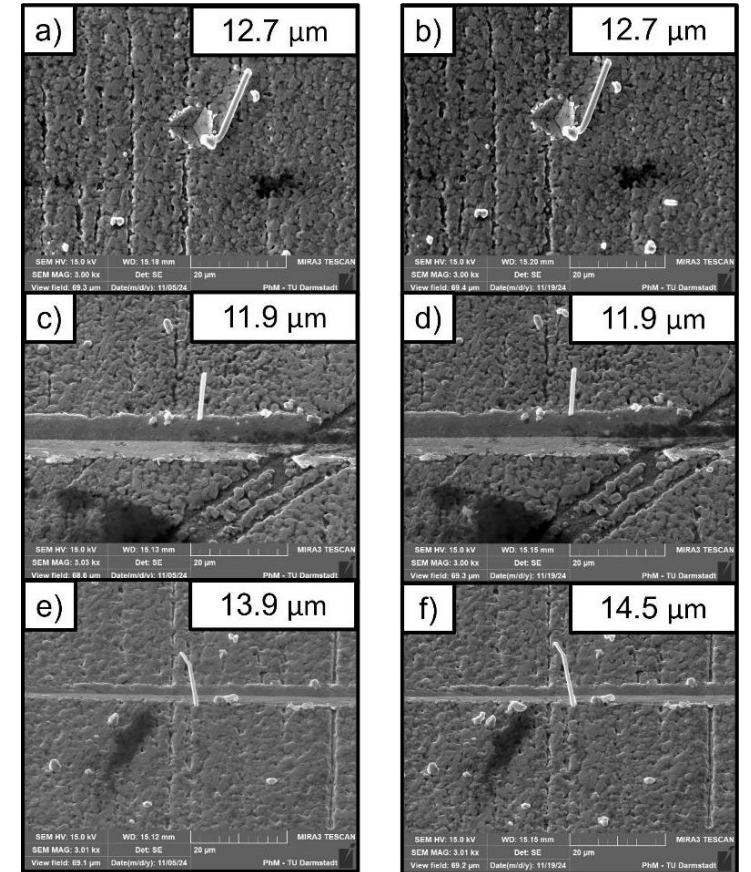
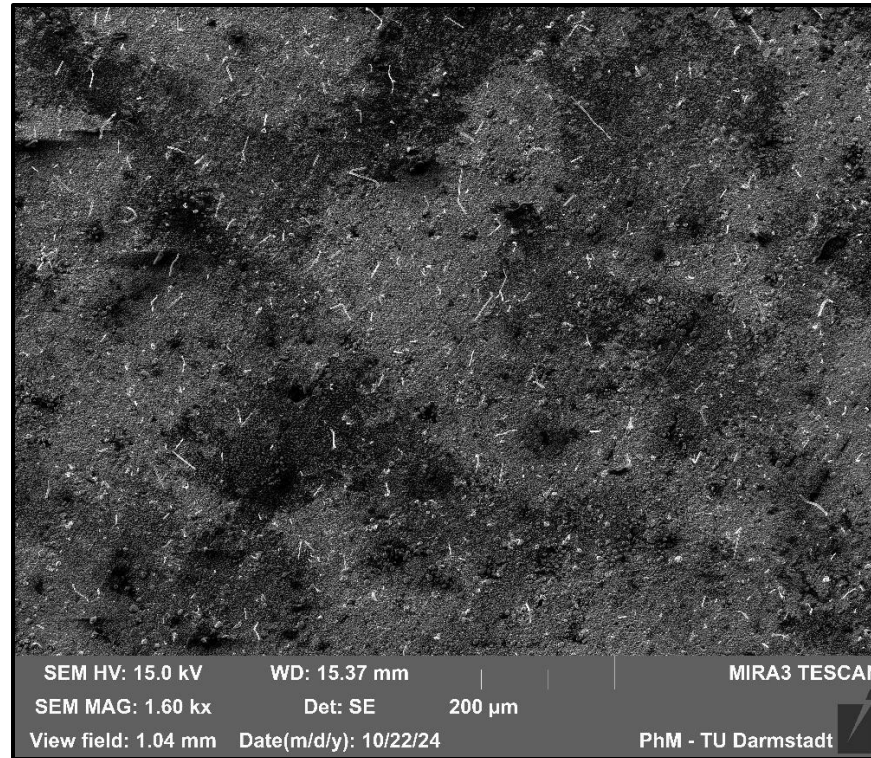
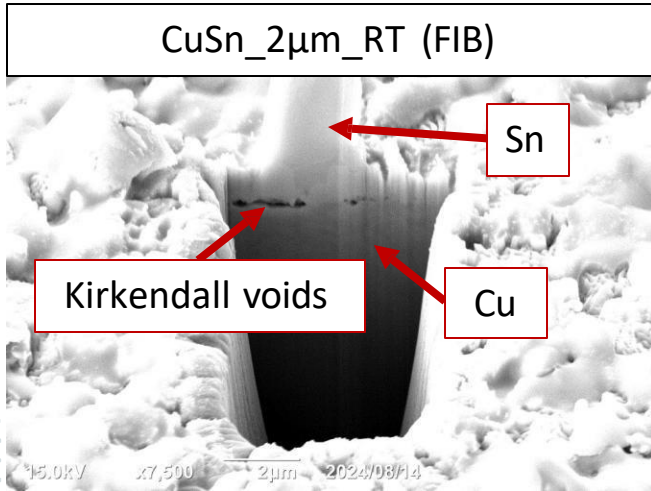
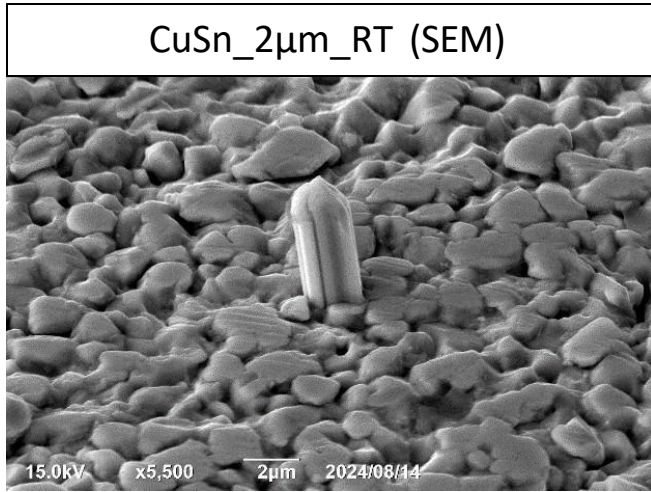
Investigated Parameters

- Layer system
 - Sn on Cu foils: residual stresses assessment
 - Sn on Cu sheets: IMC influence
 - Ni underlayer: influence of diffusion barrier
- External stresses
 - 4-point bending: stress gradients simulation
 - Nano-indentation & scratches: severe plastic deformation
- Environment
 - Ageing at constant temperature
 - Thermal cycles / thermal shock
 - Heat treatment
 - Controlled atmosphere



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Preliminary Results



Outline

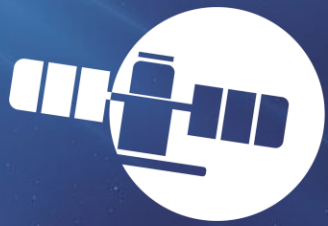
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Thank you for your attention

Any questions?

References

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