Infineon

Tin Whisker Formation – Results, Test Methods and Countermeasures

ECTC New Orleans - May 29, 2003

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Outline

- Premises for whisker formation
- Whisker formation and countermeasures on copper based leadframes
- Whisker formation on FeNi42 leadframes
- Test conditions
- Conclusions / Summary

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Root cause for Whisker formation

Premises:

- The driving force for whisker formation is a compressive stress in the deposit
- Matt tin layer is stress free after deposition
- Copper based L/F material:
  Compressive stress is caused by irregular growth of intermetallics in grain boundaries (volume increase by diffusion of Cu into Sn)
- FeNi based Leadframes:
  Compressive stress is caused by temperature cycling only (due to cte mismatch)

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Whisker formation and countermeasures for tin plated copper-based leadframes

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Whisker on copper based leadframes

Countermeasures

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Symptomatic effects

- No influence on stress build-up
- Only stress release path or stress level is influenced

Increase layer thickness to 7.5 µm minimum

(stress distribution in bigger volume results in lower stress)

Causative effects

- Diffusion barriers prevent irregular formation of Cu_6Sn_5 intermetallic
- No stress build-up:

Effective diffusion barriers can be

Ni- underlayer

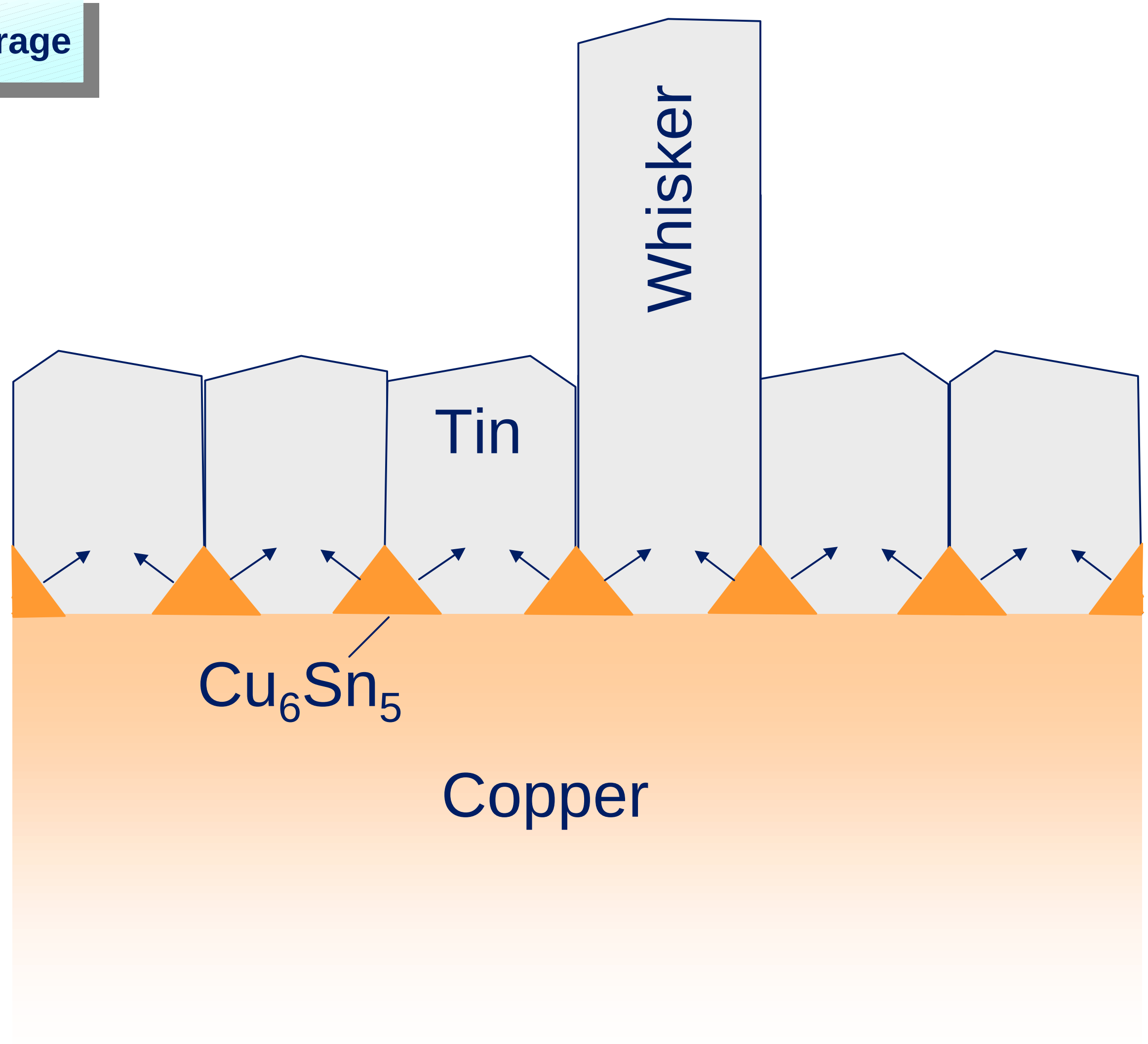
Ag-underlayer

Intermetallic layer (regular growth of intermetallic forced by baking)

Whisker on copper based leadframes

Theorie of whisker formation

Ambient storage



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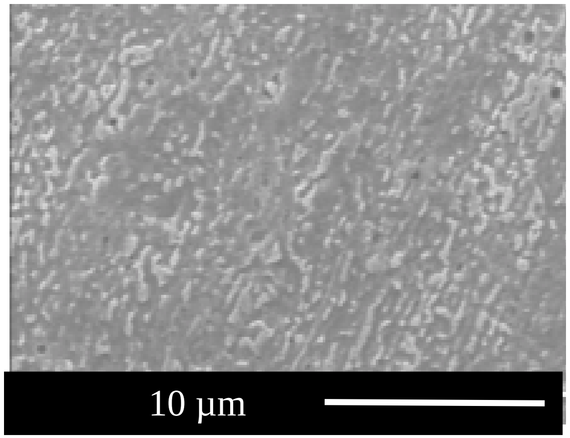
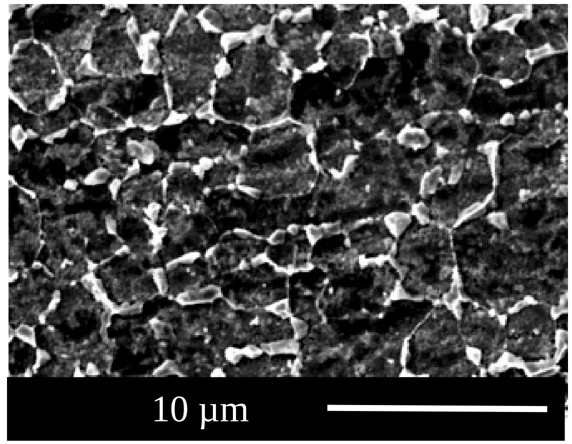
Theorie of whisker formation

Ambient storage

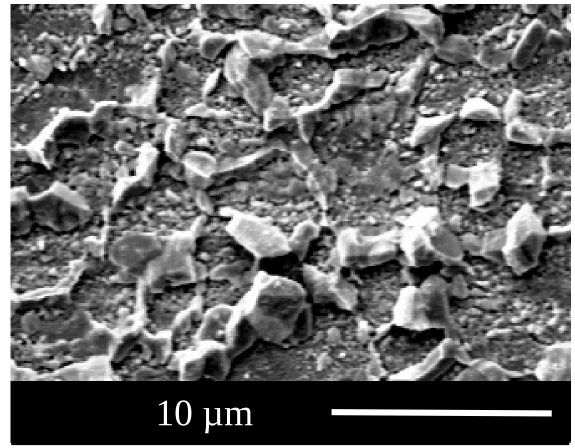
Selective etching of free tin exhibits intermetallics at former interface Cu-substrate / tin



1 h after plating



6 d after plating



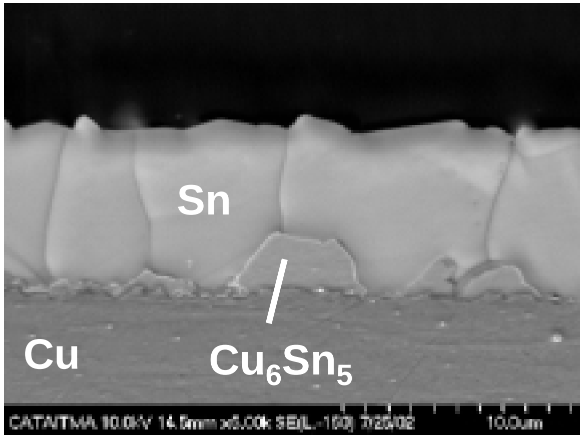
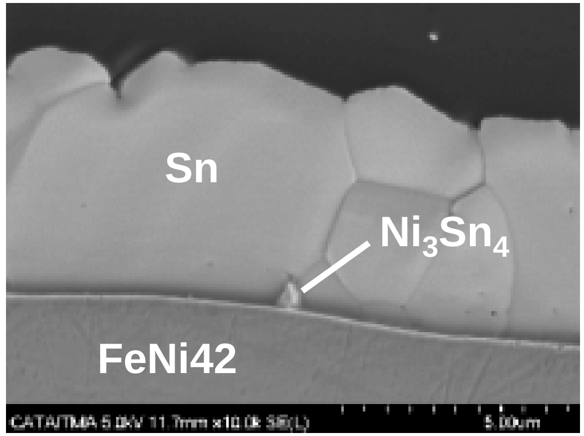
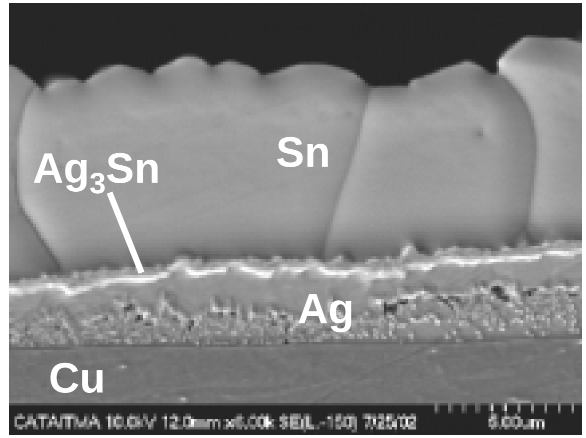
7 weeks after plating

- **Intermetallic formation is associated with volume increase of ~45 % in the tin layer**

Whisker on copper based leadframes

Intermetallic growth

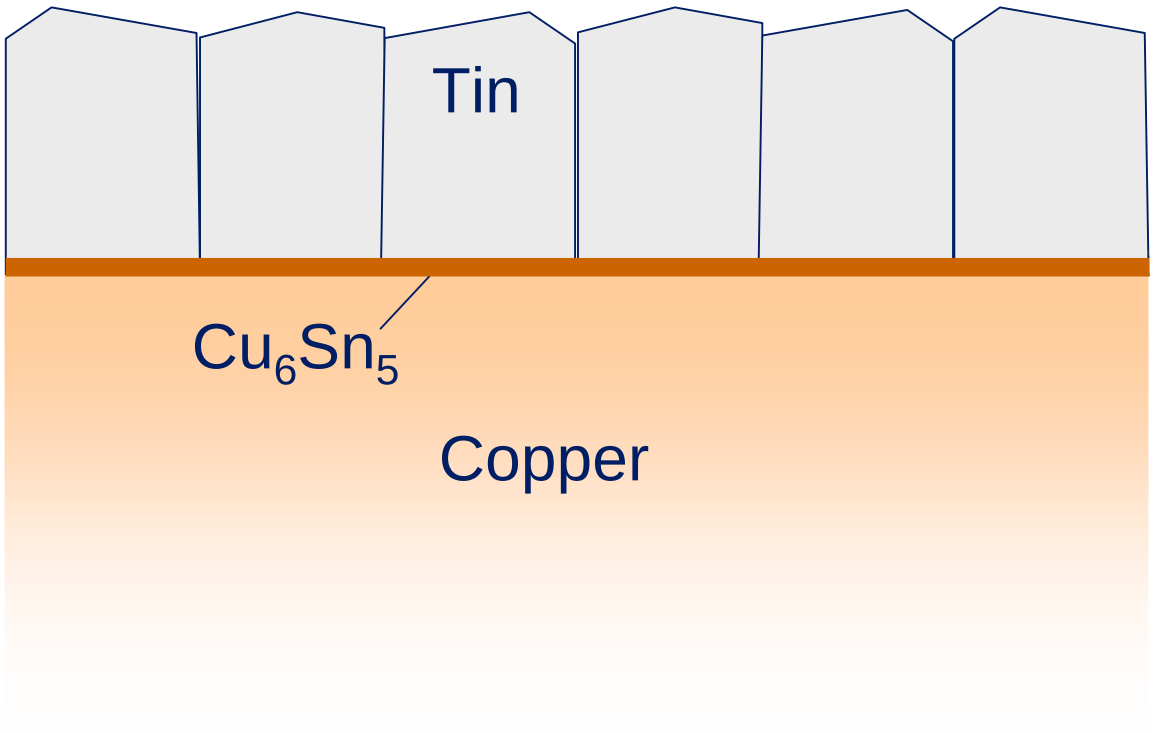
9 months storage in ambient atmosphere

Copper	FeNi42 or Ni	Silver
		
Excessive irregular growth of Cu_6Sn_5 (predominantly in grain boundaries) on Cu leadframe	**Little growth of Ni_3Sn_4 with some irregularities (predominantly in grain boundaries) on FeNi42 leadframe**	**Little growth of Ag_3Sn_4 on Ag-plated Cu-Leadframe**
Whisker!	**No whisker!**	**No whisker!**

Whisker on copper based leadframes

Theorie of whisker formation - baking

150 °C



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Whisker on copper based leadframes

Baking - intermetallic growth

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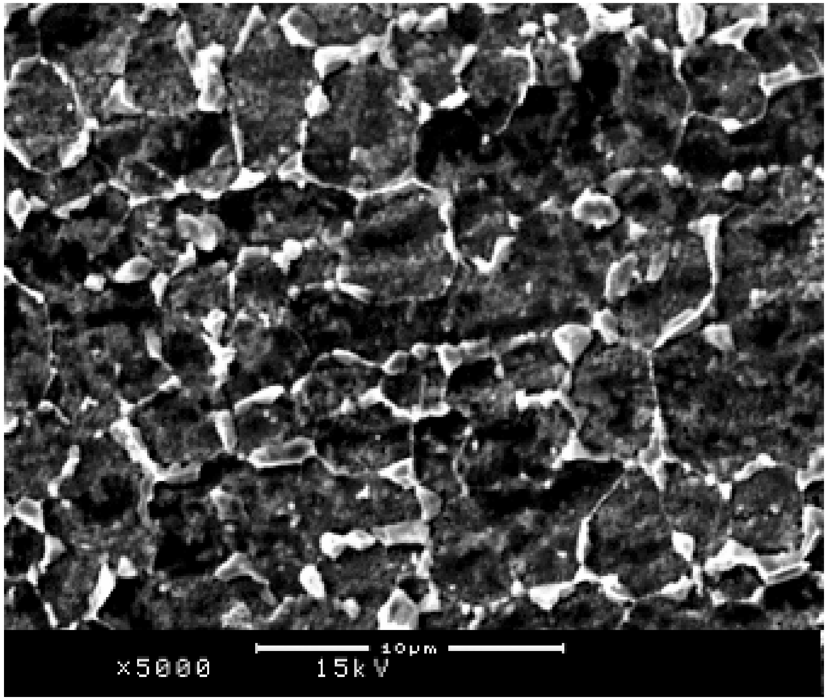
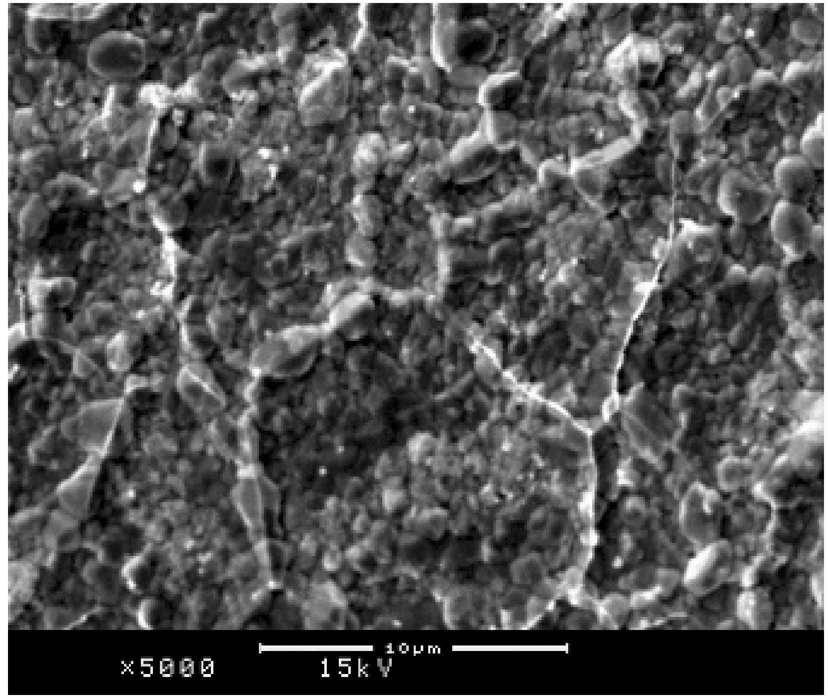
Pure tin on Wieland K75



Sn stripped 6 days ambient storage after plating (white grains Cu_6Sn_5, dark copper)



Sn stripped after baking 150 °C / 1h (copper completely covered with Cu_6Sn_5, significant Sn grain growth)

- Irregular growth of intermetallic at ambient storage
- Baking, e.g. 1 h / 150 °C causes dense and regular layer of intermetallic and stress release
- This effective diffusion barrier prevents further irregular growth of intermetallic
- No compressive stress --> no whisker

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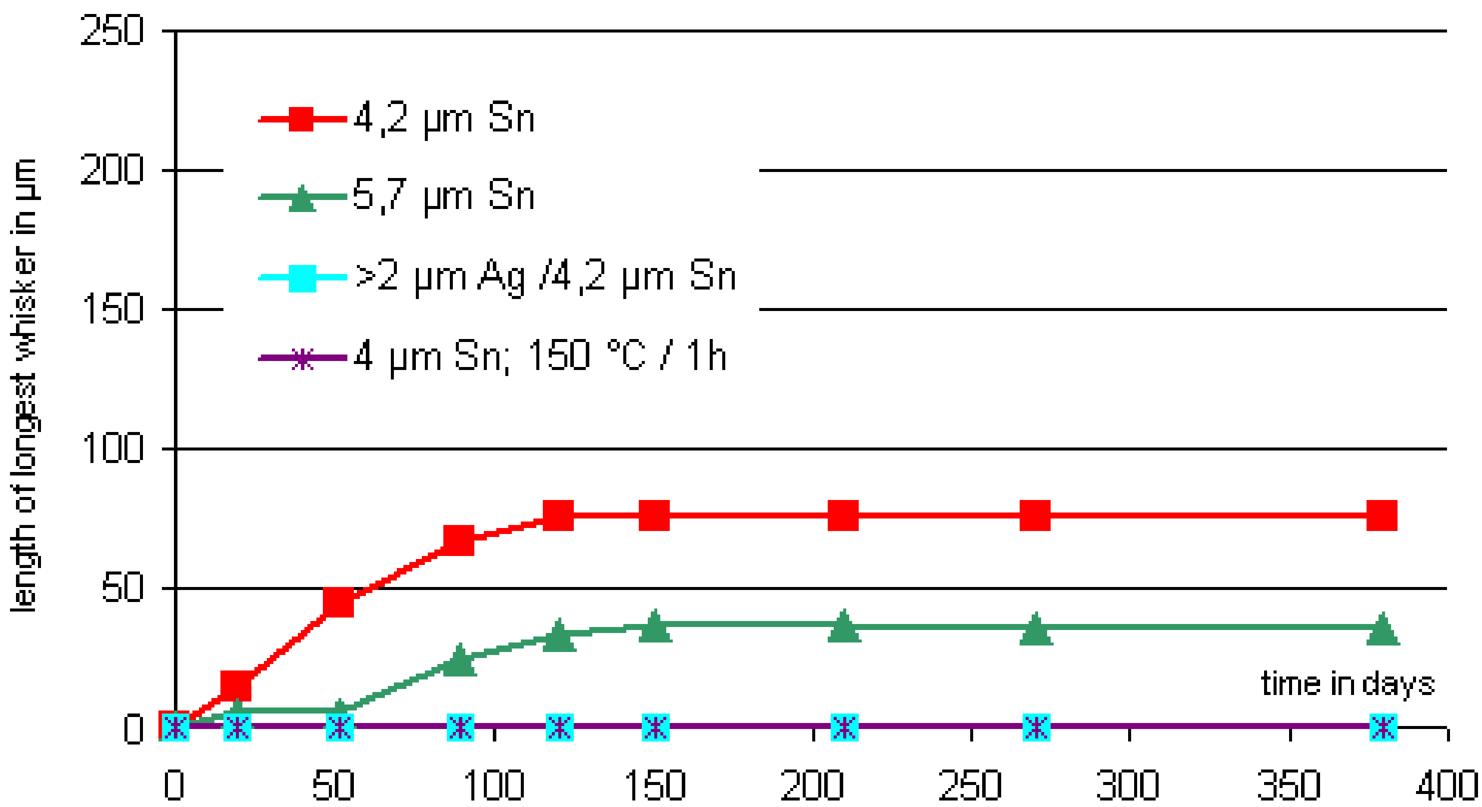
Whisker on copper based leadframes

Countermeasure - diffusion barrier



- **Ag-underlayer (proven for > 2 µm) prevents whisker growth**
- **Baking 1 h / 150 °C prevents whisker growth**

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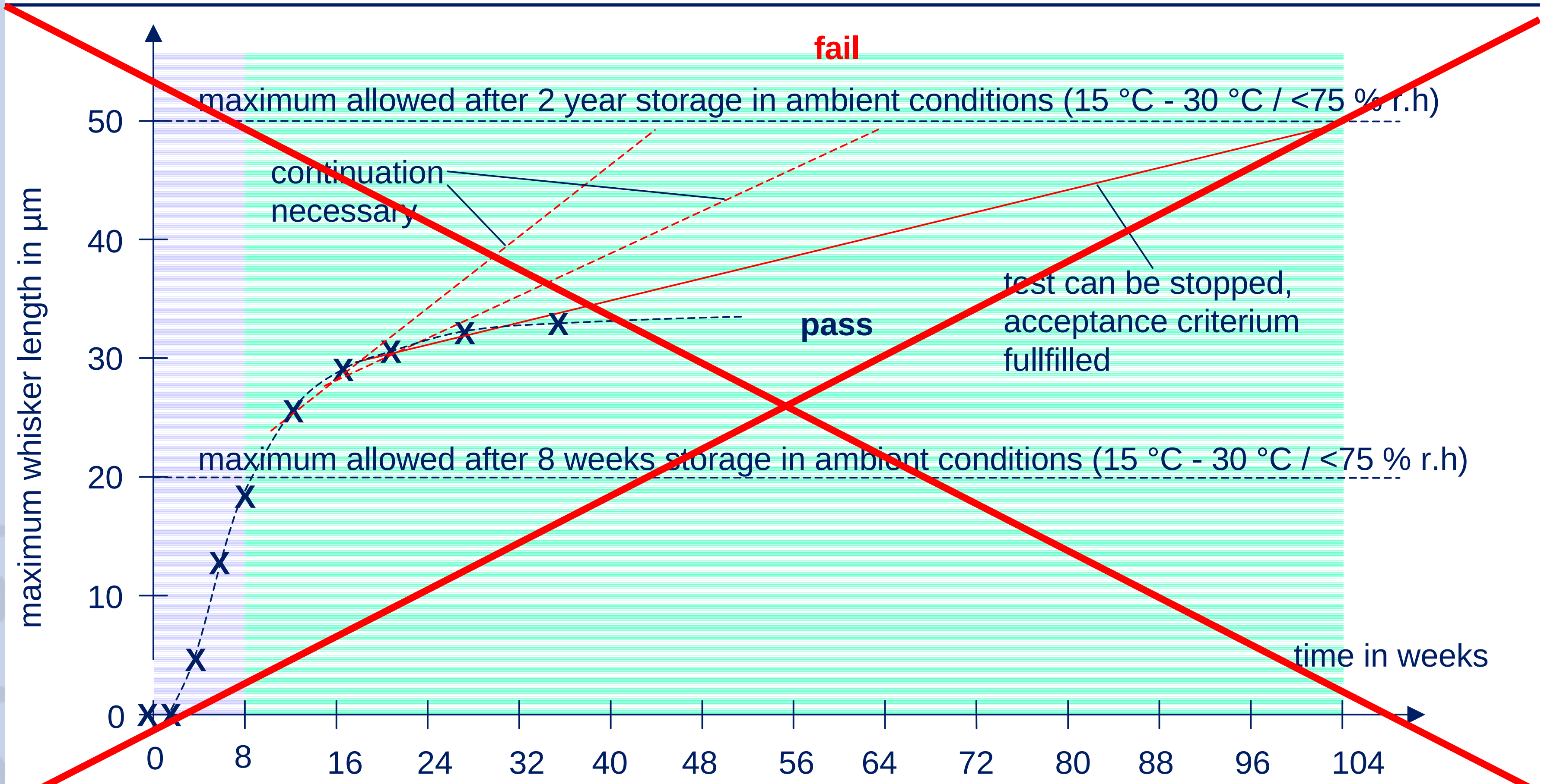
Whisker on copper based leadframes

Approach for qualification procedure



- **Qualification approach based on observation that growth rate reduces in time and reaches zero growth rate when stress induction and annealing is in equilibrium**

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Whisker on copper based leadframes

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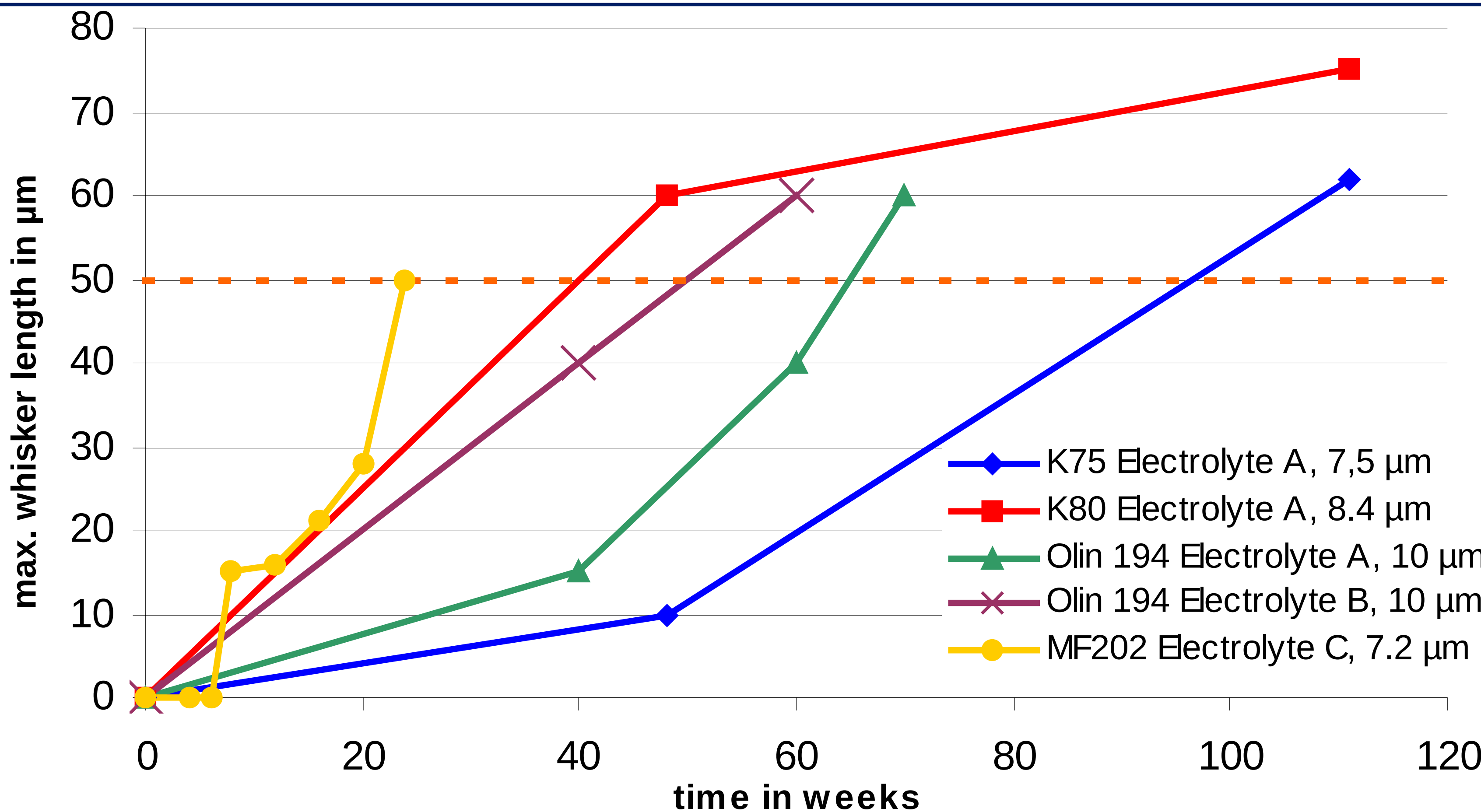
Example for spec excession (> 50 µm) and incubation effect



- **Latest results show excession of specified limit of 50 µm after two years storage and incubation effects**
  - **Thick layer (>7.5 µm) as countermeasure not reliable**

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Whisker on copper based leadframes

Conclusions

- **Diffusion barriers prevent <u>irregular</u> formation of Cu_6Sn_5 intermetallic**
- **No stress build up:**

Effective diffusion barriers can be

(Ni- underlayer)

Ag-underlayer

Intermetallic layer (regular growth of intermetallic forced by <u>baking</u>)

Qualification approach observing whisker growth rate unnecessary when appropriate countermeasures are applied.

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Whisker formation for tin plated FeNi42 leadframes

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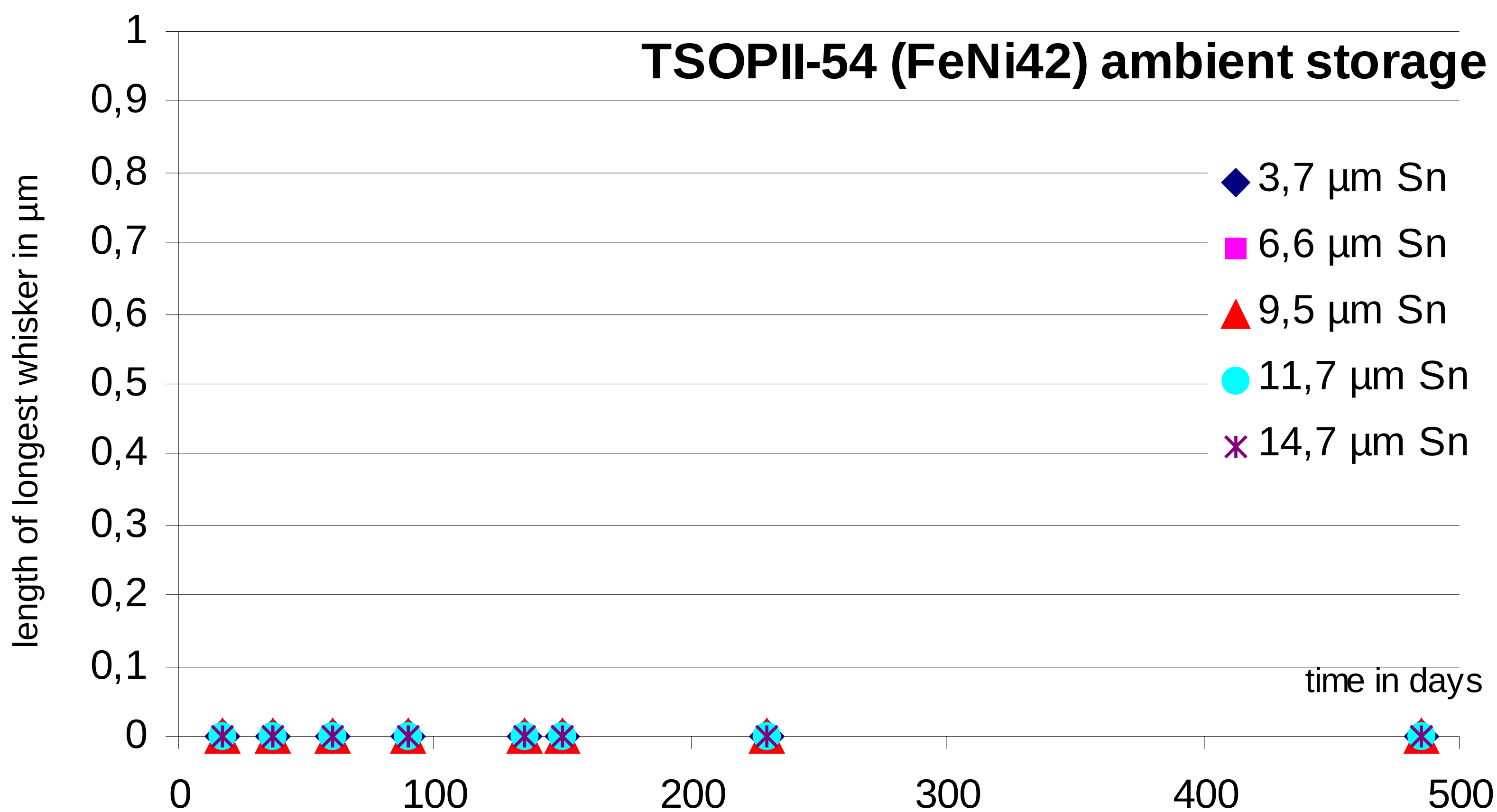
Whisker on FeNi42 leadframes

Ambient storage of tin plated FeNi42



In isothermal ambient storage no whisker on matt Sn plated FeNi42 based components

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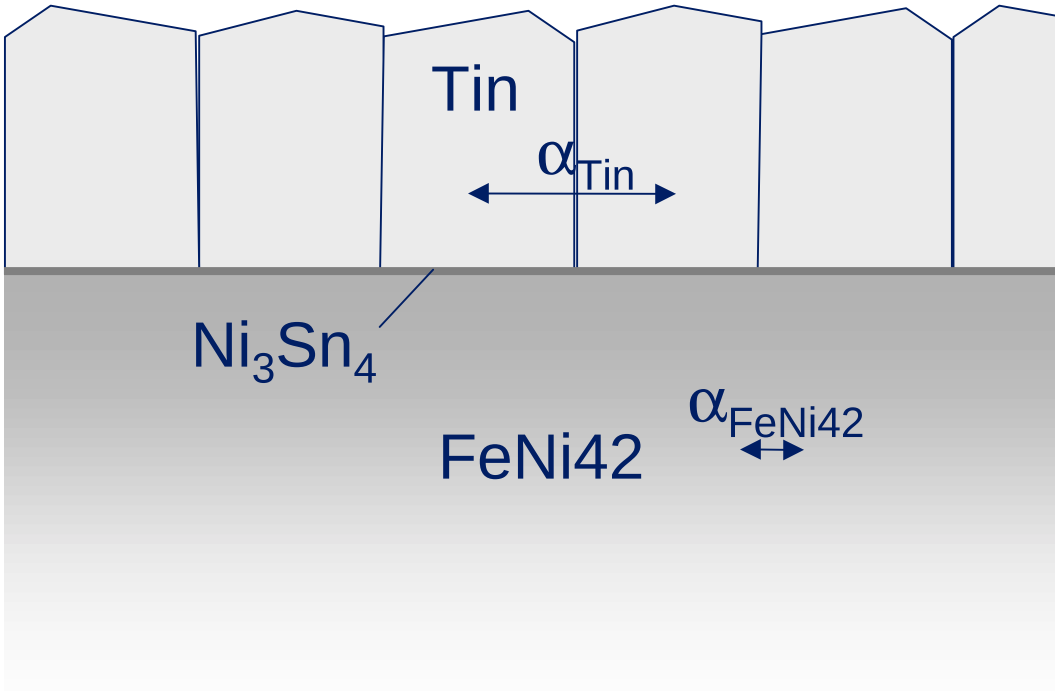
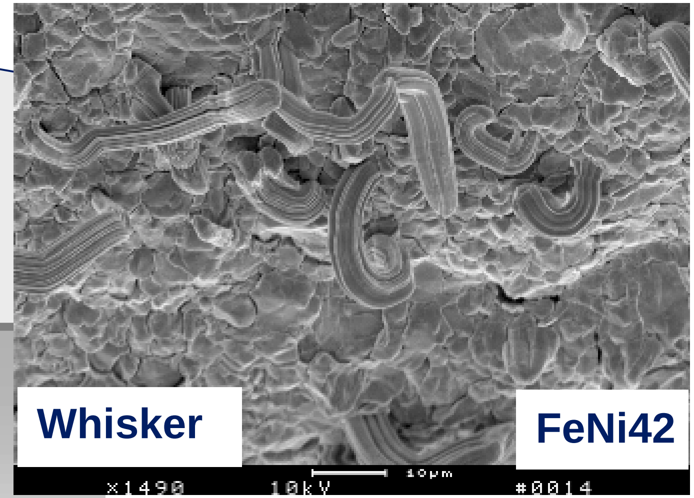
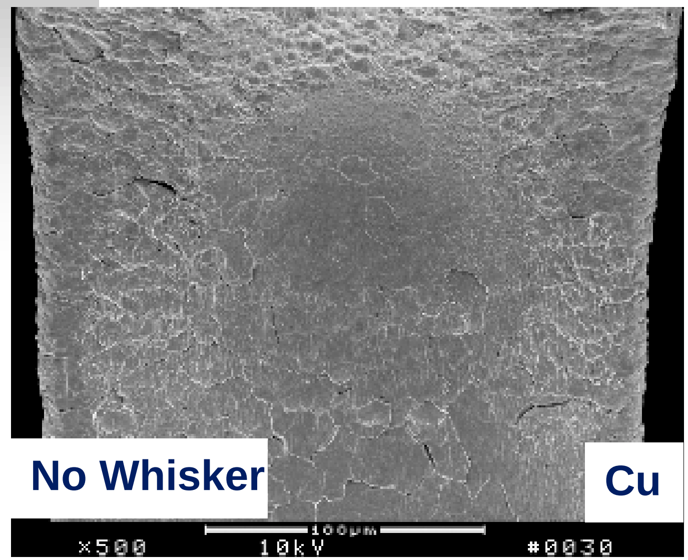
Whisker on FeNi42 leadframes

Effect of temperature cycling

500 T-cycles (-40 °C/ +125 °C)







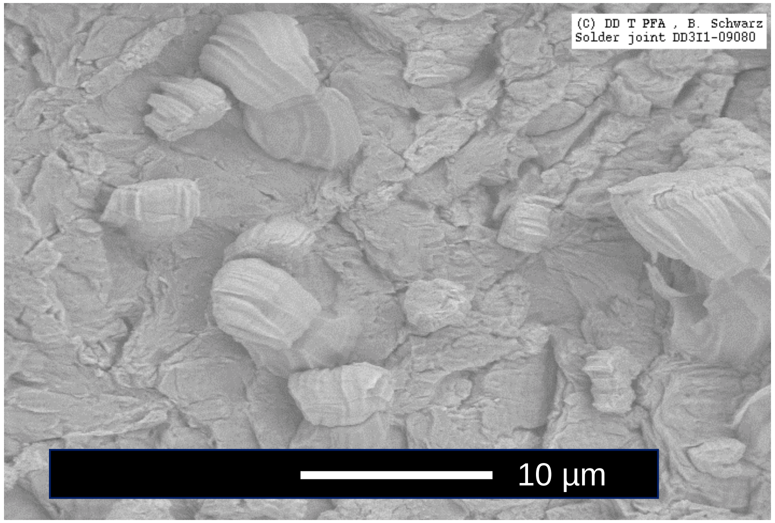
α_{FeNi42} = $4{,}3 \cdot 10^{-6}$/K

α_{Sn} = $23 \cdot 10^{-6}$/K

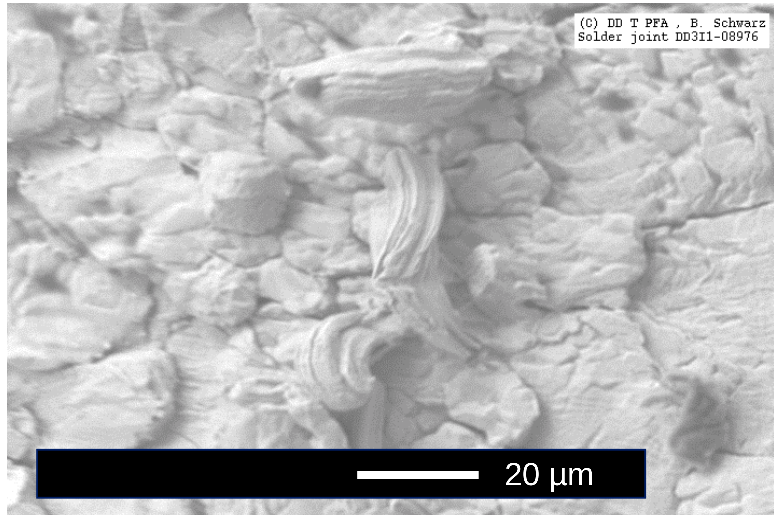
α_{Cu} = $17 \cdot 10^{-6}$/K

Whisker on FeNi42 leadframes

Temperature cycling (1000 cycles 0 / +100 °C)



SnPb plated components, SnPb-soldered



Sn plated components, SnPb-soldered

- **Whisker growth after temperature cycling of FeNi42 Leadframe components widely unknown phenomenon, but actual standard**
- **Whisker growth after TC comparable for SnPb plated and Sn plated components**

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Whisker on FeNi42 leadframes

Conclusion for FeNi42 base components

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- **Isothermal storage does not result in whisker formation**
- **Whisker grow during T-cycling due to thermal mismatch of plating and L/F material**
- **Whisker grow on all Sn-based platings (SnPb included) on FeNi42 L/F when T-cycled**

But:

- **T-cycling (fast T-change) induces more stress than service life (slow T-change)**
- **Whisker growth is limited to few 10 µm (even in fast T-cycling)**

- **Sn-plated FeNi42 leadframes are acceptable and will not result in higher risk than SnPb-plated FeNi42 based components**
- **Appropriate T-cycling test under investigation (focus on effect of ramp rate)**

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Whisker test

Conditions

Conditions tested by E3

- ambient atmosphere (uncontrolled)
- 55 °C / ambient humidity (uncontrolled)
- 55 °C / 60 % r.h.
- 85 °C % / 85 % r.h.
- 5 °C / ambient humidity (uncontrolled)
- TC -35 °C / +125 °C / 500 cycles (Sony)
- TC -40 °C / +125 °C / 500 cycles
- TC -55 °C / +85 °C / 500 cycles (Motorola)
- TC 0 °C / +100 °C / 1000 cycles

- **None of the tested conditions can accelerate whisker growth**
- **No correlation of test conditions to long time storage available**
- **No standardised test method available**

→ **E3 combine their knowledge in joint EU-project (PROTIN) to standardise test method and acceptance criteria**

E3 Acceptance criterion

Whisker length < 50 µm after 24 month ambient storage (15-30 °C, < 75 % r.h.)

Summary

- Acceptance criterion defined (max. 50 µm after two years)
- Theory of whisker formation proven
- Effective countermeasures for Cu identified
- Most effective countermeasures are diffusion barriers (Ni, Ag, regular intermetallics by baking)
- Two countermeasure technologies for Cu selected (Ag-underlayer, baking)
- FeNi42 L/F do not require countermeasure
- Appropriate test method for FeNi42 under evaluation

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Thank you !

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Acknowledgement: The authors like to thank the European Union for funding previous and ongoing work under the acronym PROTIN.

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