Atomic Layer Deposition (ALD) for Tin Whisker Mitigation on Pb-free Surfaces

Project: 4000113005/14/NL/PA

EMPS-7

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Outline

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1. Introduction
2. Background
3. Observations
4. Summary
5. Questions

1.1.Programme partners

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1.2.Goals of the project

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- Primary goal: to assess how well an ALD coating prevents initiation and growth of tin whiskers
- Final goal: to develop a coating process and equipment for industrial use
- Further: ALD as conformal coating for electronics assemblies
  - environmental protection
  - corrosion prevention
  - enhancement of polymer packages
  - coating for devices requiring rework

2.1.What are metal whiskers?

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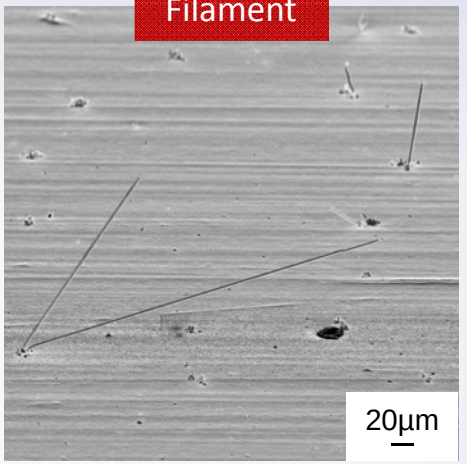
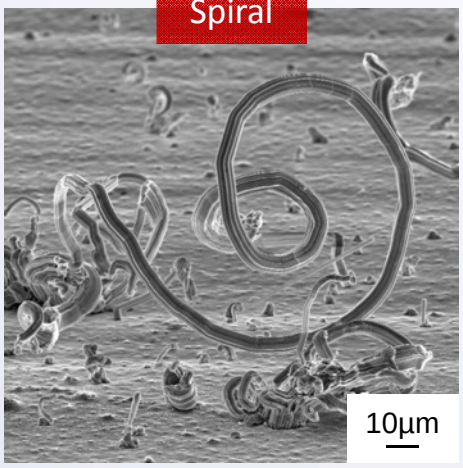
- Crystalline growths from a metal surface (e.g. Sn, Zn and Cd)
- Uncertain incubation period before growth
- Numerous growth morphologies possible
- A few micrometres in diameter and up to several millimetres in length
- Although investigated for ~70 years, whisker related problems are increasing due to environmental legislation and device miniaturisation

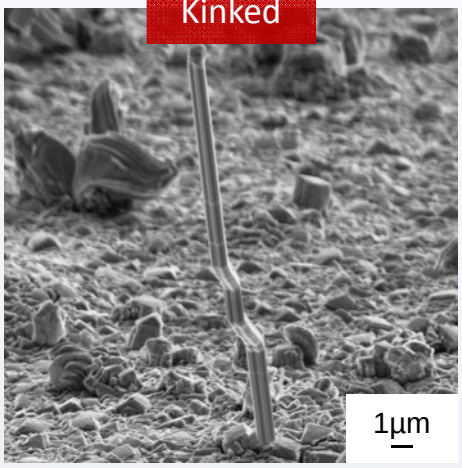
Filament



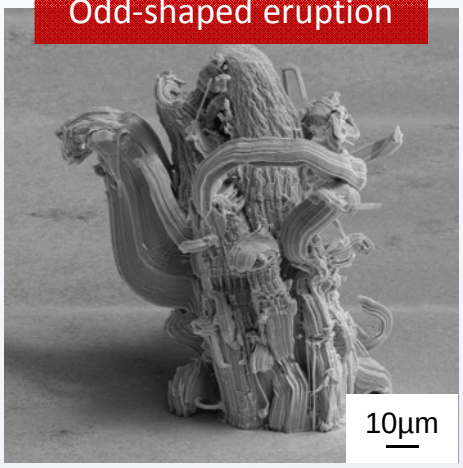
Spiral



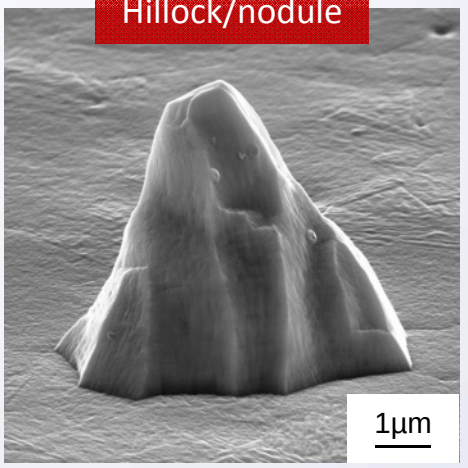
Kinked



Odd-shaped eruption



Hillock/nodule



2.2.Documented failures due to tin whiskers

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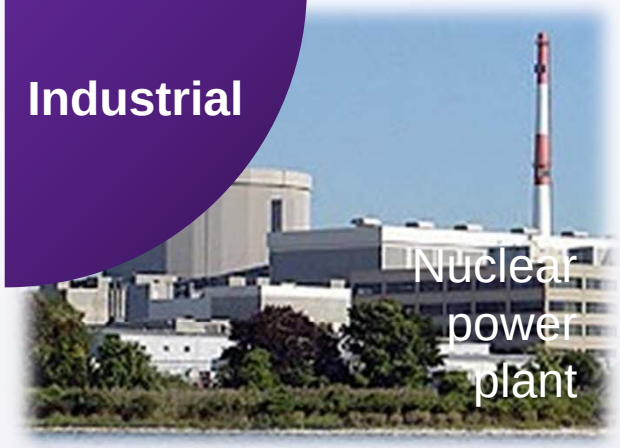
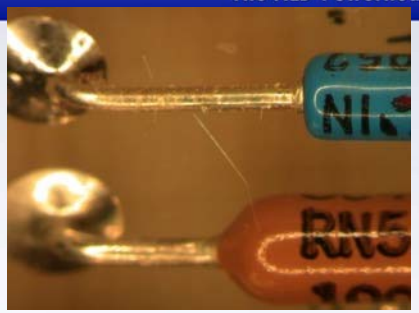
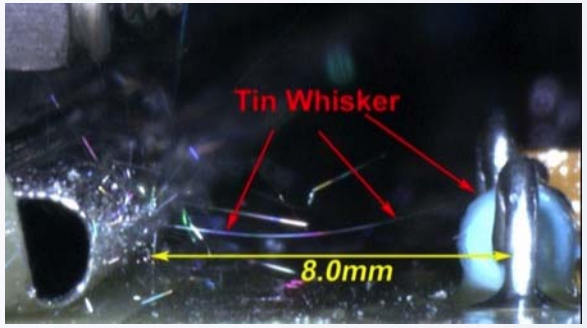
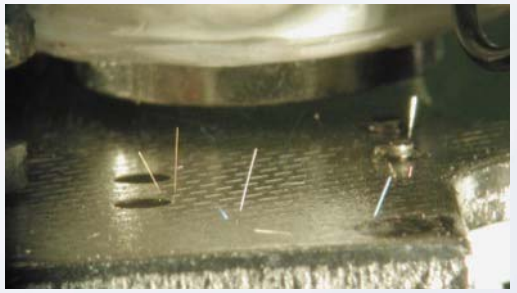
Aerospace | Military | Medical | Industrial





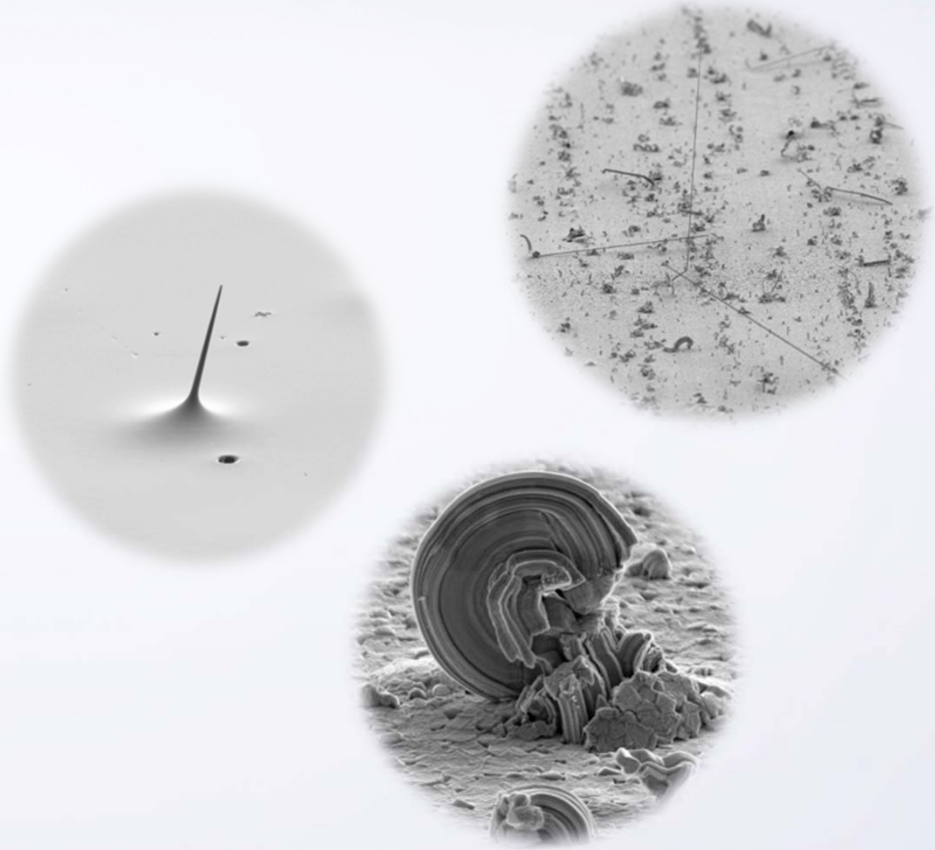




http://nepp.nasa.gov/whisker/

2.3.Whisker mitigation strategies

- Alloy tin with lead
- Avoid pure Sn finishes (alloy with Ag or Bi)
- Ni underlay coatings
- Conformal coatings
- Annealing treatments
- Component reflow
- **Atomic layer deposition**



2.4.ALD process

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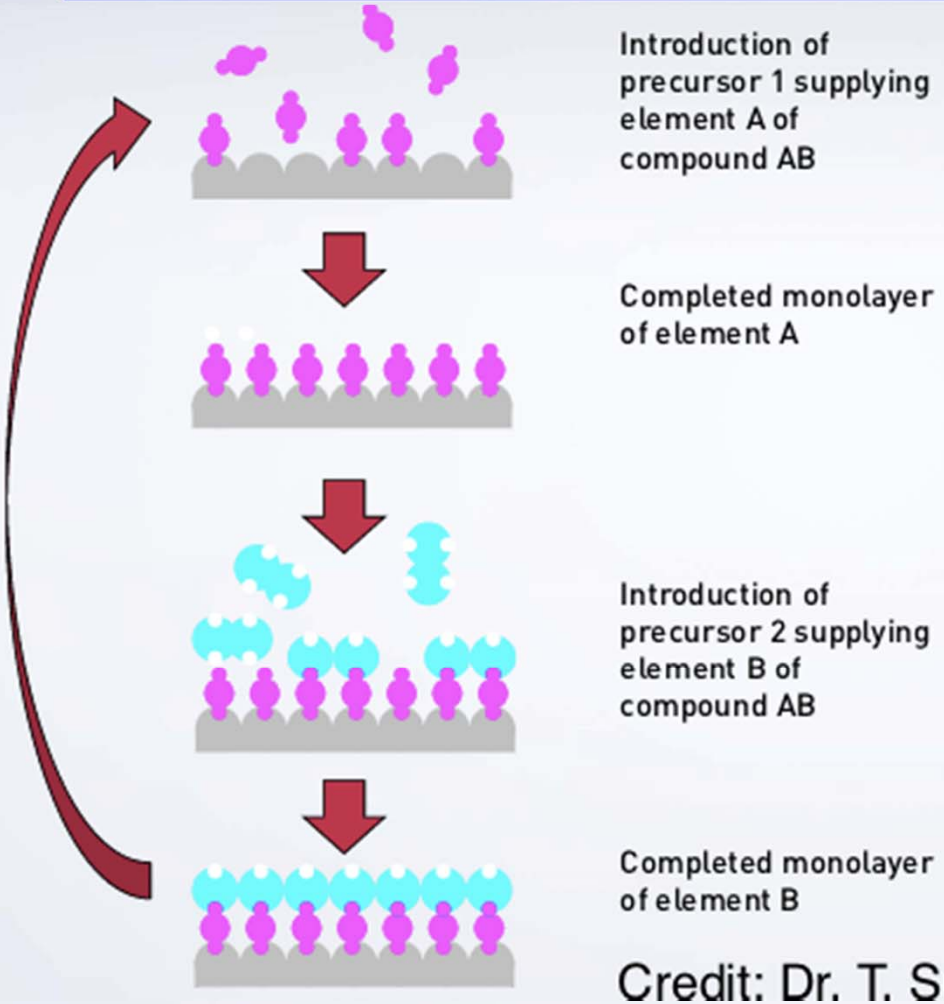
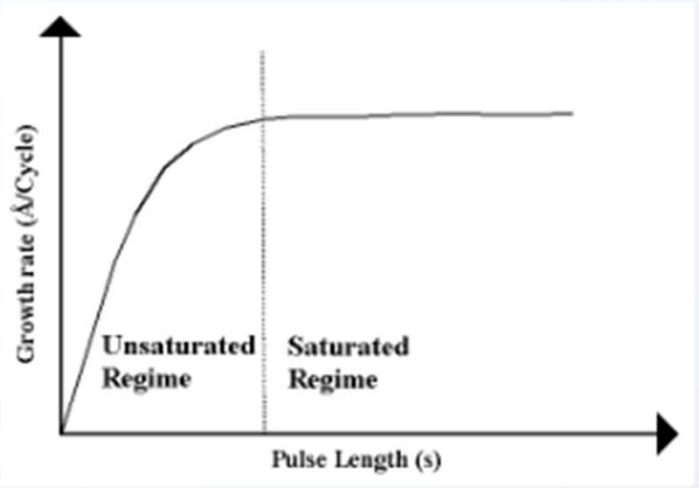


Credit: Dr. T. Suntola

ALD, using self-limiting surface chemistry and AB binary reaction sequence



http://www.picosun.com/binary/file/-/id/3/fid/4/

2.5.ALD for semiconductor manufacturing

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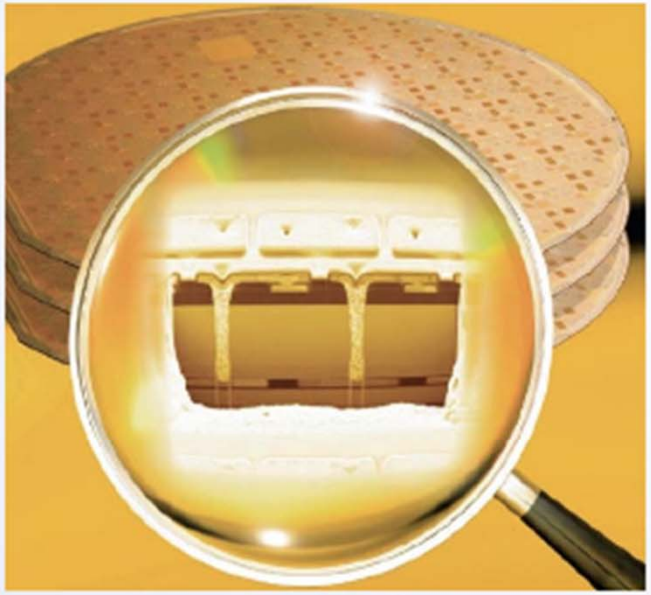
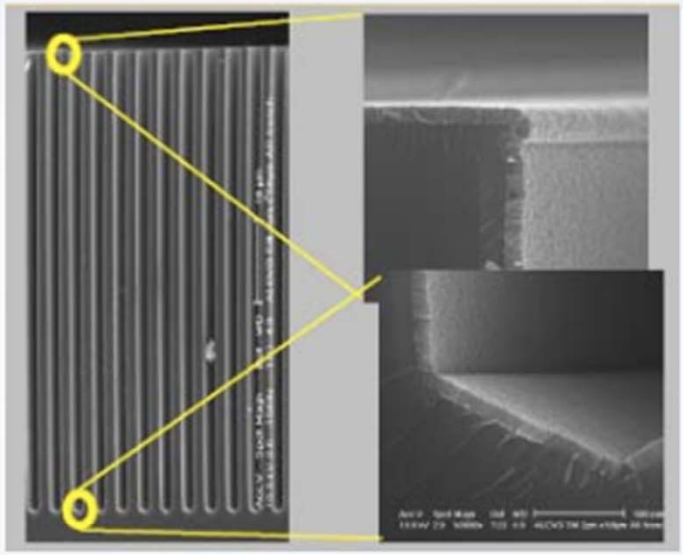
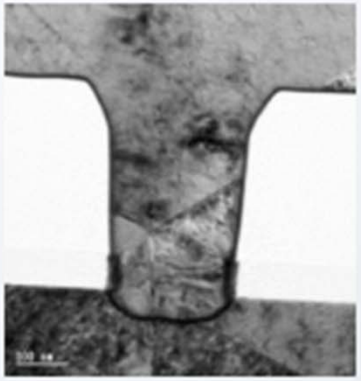
- **ALD has been used in microprocessor, memory, and 3D-WLP in IC industry for years**







Source: Solid State Technology, November 2007;
IEEE Spectrum 2007

http://www.picosun.com/binary/file/-/id/3/fid/4/

2.6.Uniform ALD-layer in deep trenches

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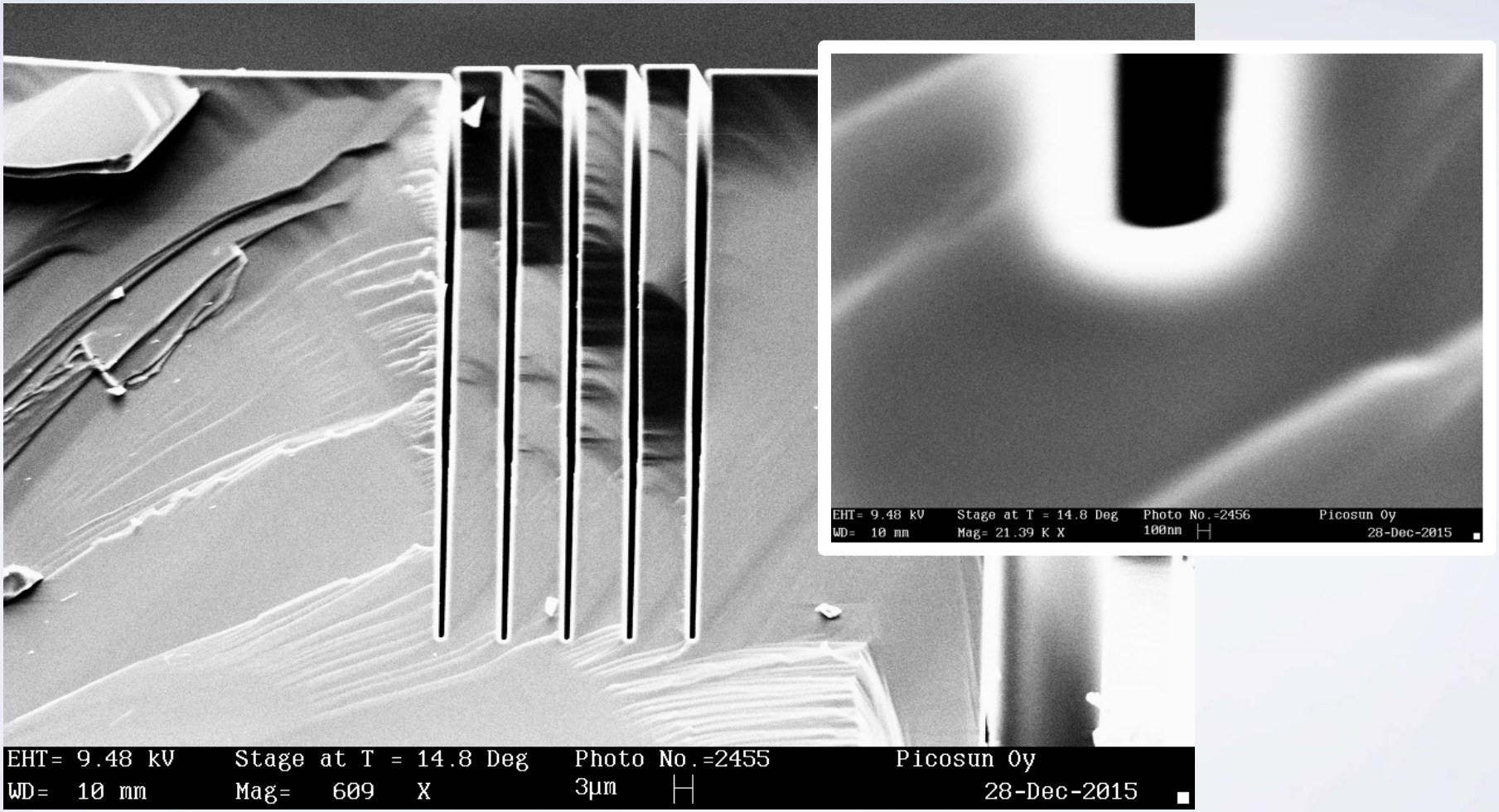

2.7.Coating coverage, CALCE study 2012

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Materials Under Test

Test Specimens: 184 Quad Flat Packages (QFP)

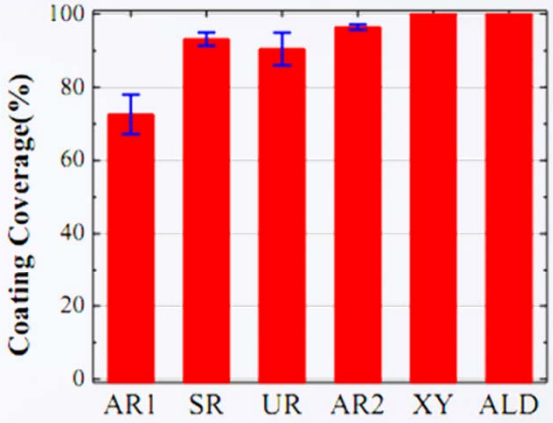
- Alloy42 lead material
- Sn surface finish
- 0.34 mm lead spacing
- Assembled with Sn-Pb solder paste.

Six conformal coatings were applied

- Acrylic (AR): Type 1 and Type 2 by machine spray
- Silicone (SR) by machine spray
- Polyurethane (UR) by hand spray
- Parylene (XY) by vapor deposition
- ALD-Cap O5TA200 (ALD) by vapor deposition

Some were uncoated for a control

Quantitative Analysis of Coating Coverage



- The result from the quantitative image analysis is consistent with the initial inspections.
- The Acrylic type 1 (AR1) showed the lowest coating coverage at 72.6 % compared to other coatings, while the Parylene C and ALD coating had 100% coating coverage.

http://www.calce.umd.edu/tin-whiskers/presentations/CALCE-conformal-coating-study.pdf, pages 9, 20

3.1.Effect of storage time on whisker growth (Batch 4)

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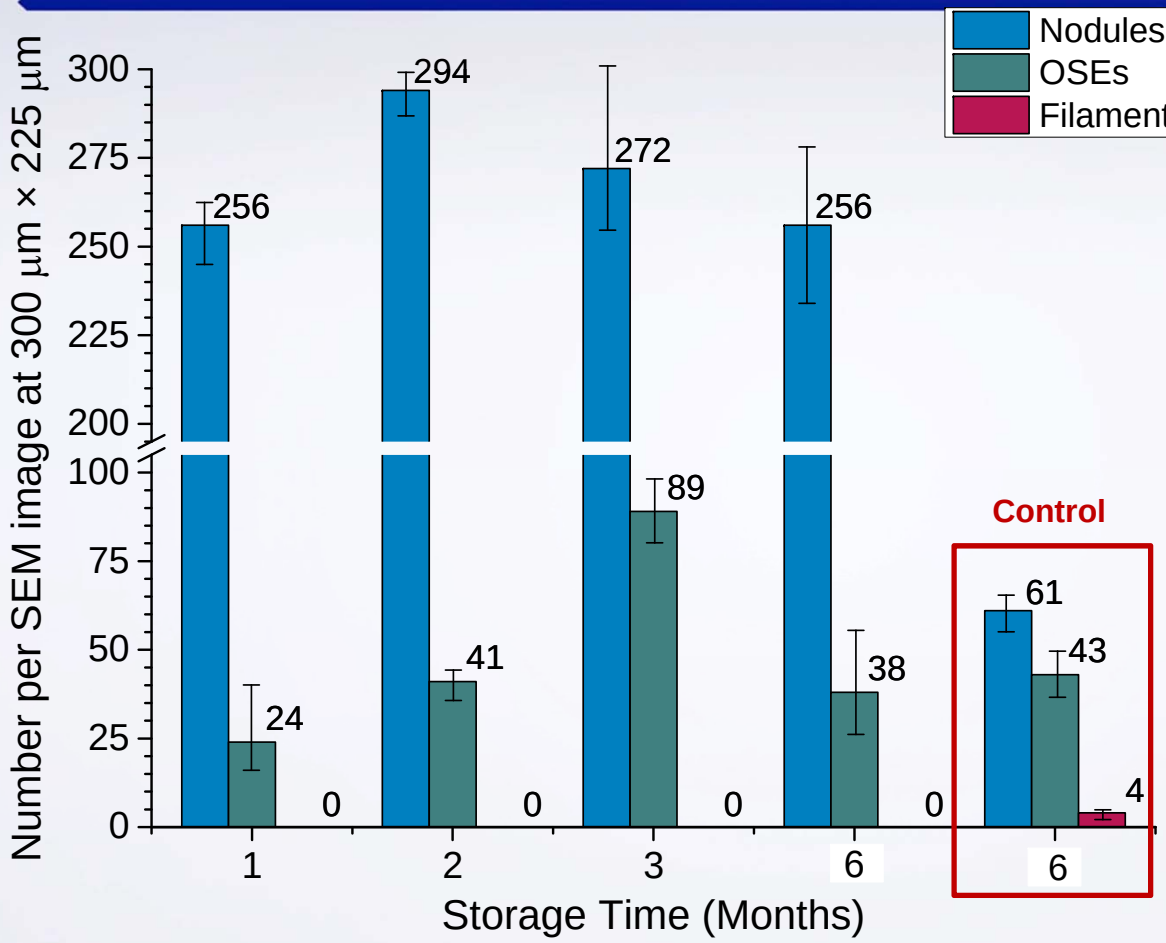

Whisker growth data for **batch 4** samples

- No apparent increase in whisker density with increasing storage time
- No filament whiskers observed on ALD coated samples
- Filament whiskers observed on control sample examined after 6 months

3.2.Effect of ALD coating on filament whisker growth (Batch 4)

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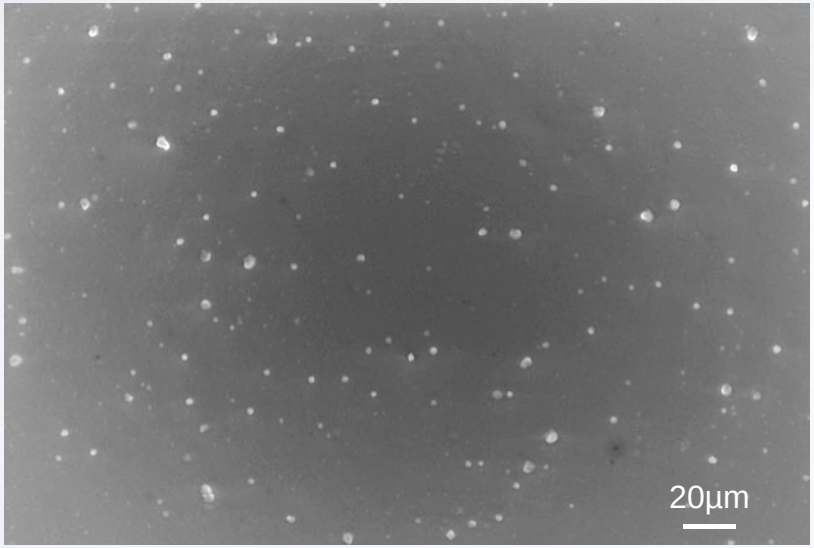
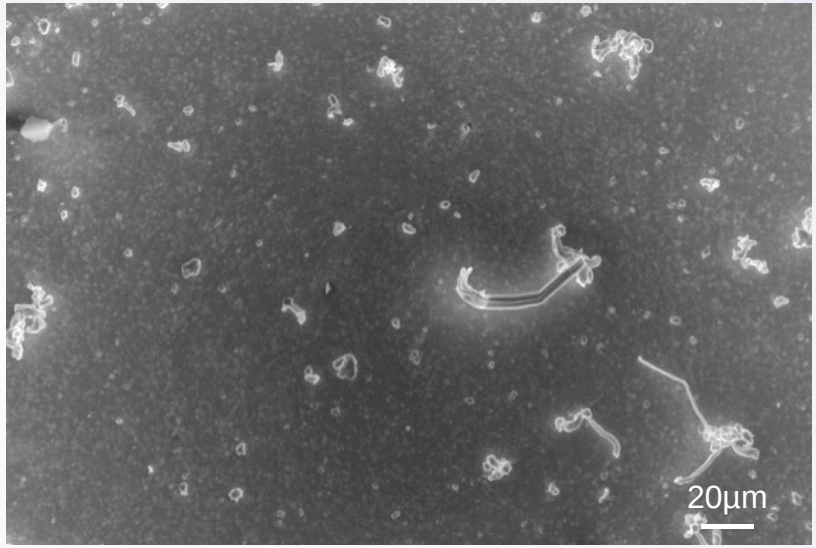
ALD coated sample

- No filament whiskers present



Uncoated control sample

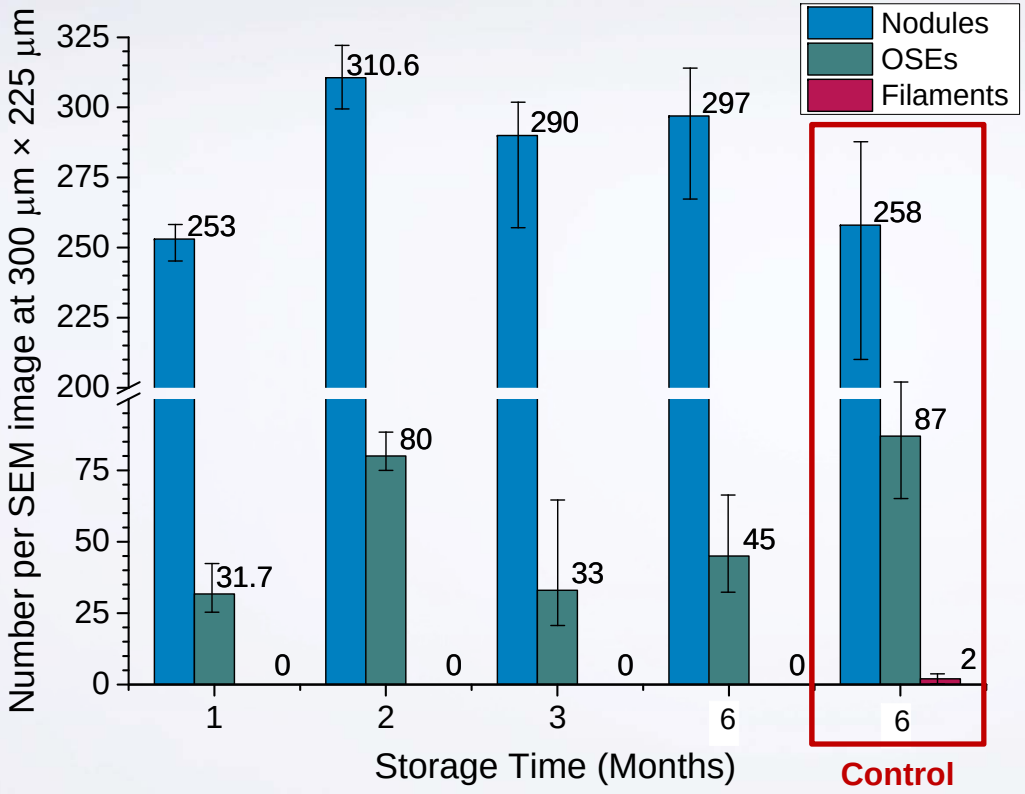
- Filament whiskers 10's of µm in length present



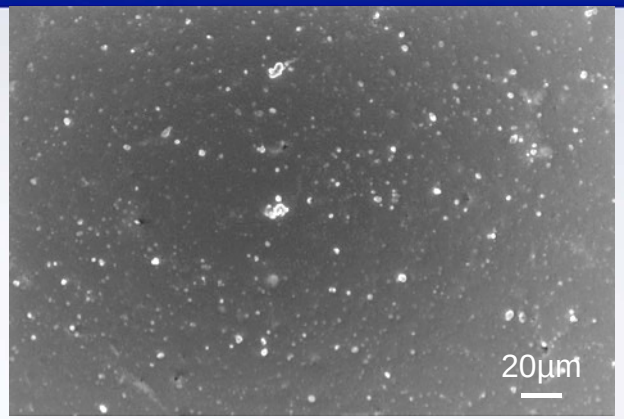
SEM images showing reduced filament whisker formation on an ALD coated sample compared with an uncoated control sample

6 months storage at room temperature

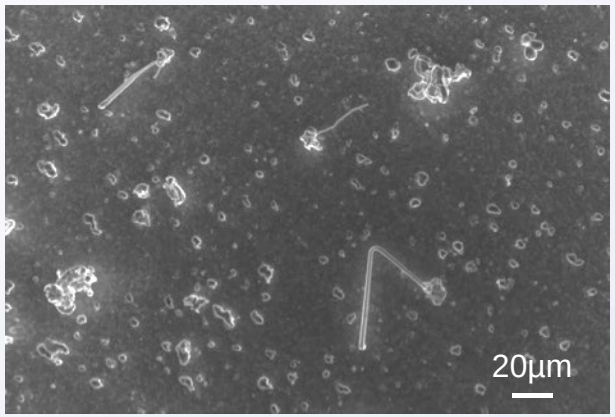
3.3.Effect of ALD coating on filament whisker growth (Batch 6)



Whisker growth data for **batch 6** samples

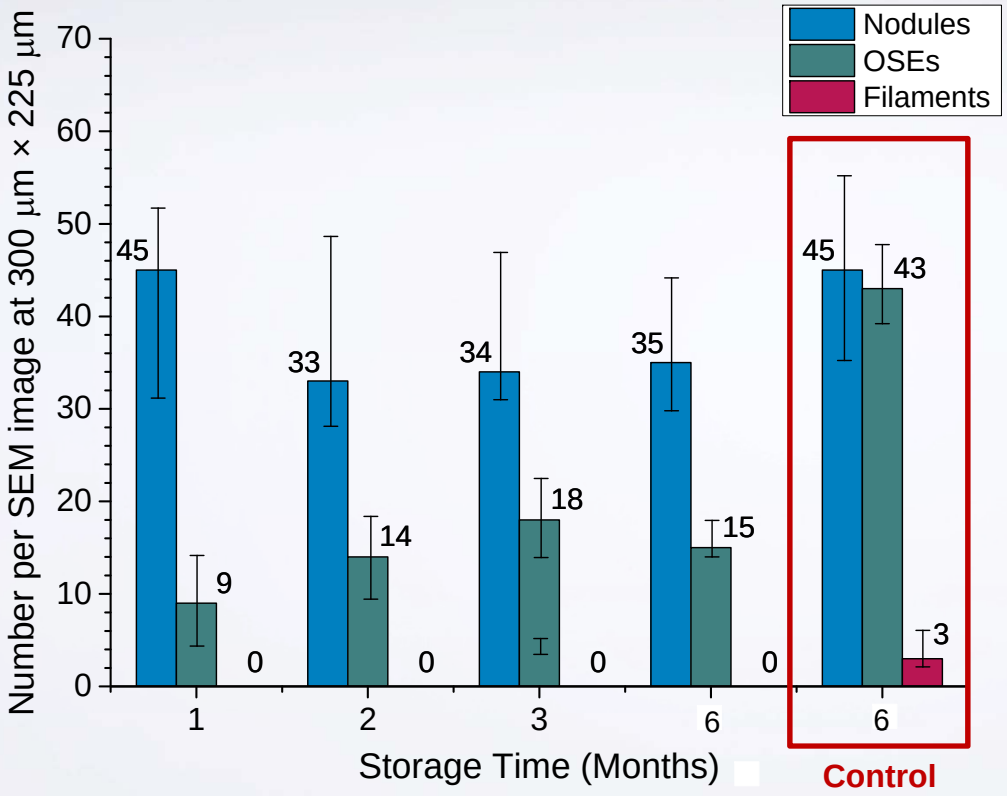


SEM image showing whisker growth on ALD coated sample after 6 months

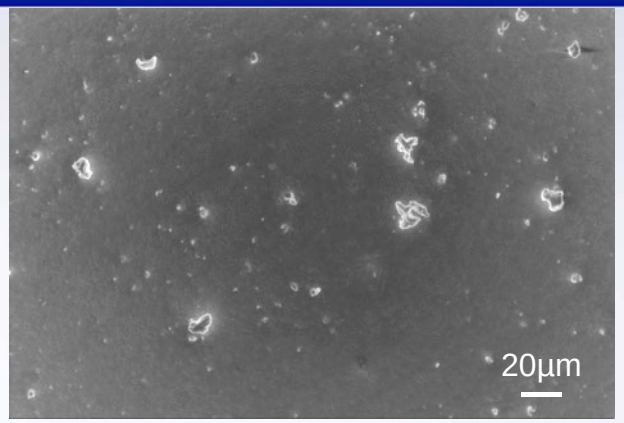


SEM image showing filament whisker growth on uncoated control sample after 6 months

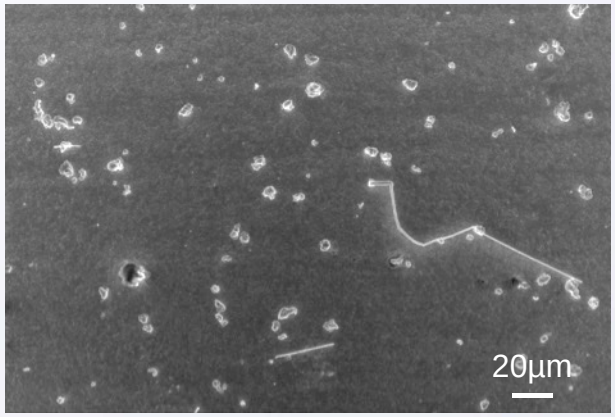
3.4.Effect of ALD coating on filament whisker growth (Batch 7)



Whisker growth data for **batch 7** samples

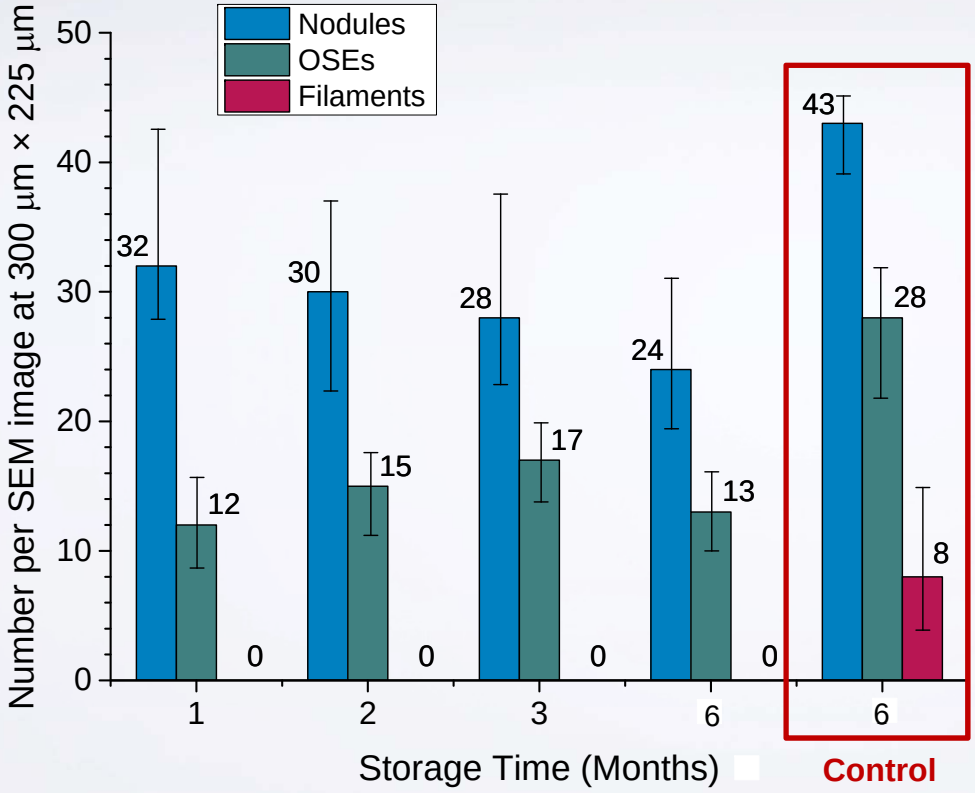


SEM image showing whisker growth on ALD coated sample after 6 months

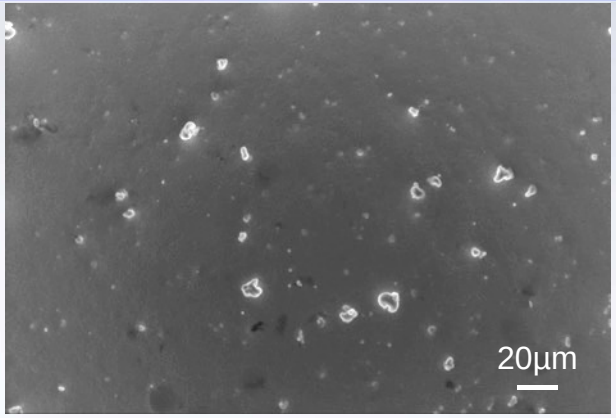


SEM image showing filament whisker growth on uncoated control sample after 6 months

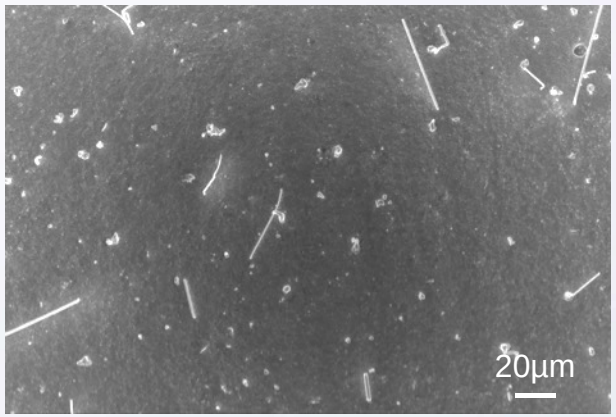
3.5.Effect of ALD coating on filament whisker growth (Batch 8)



Whisker growth data for **batch 8** samples



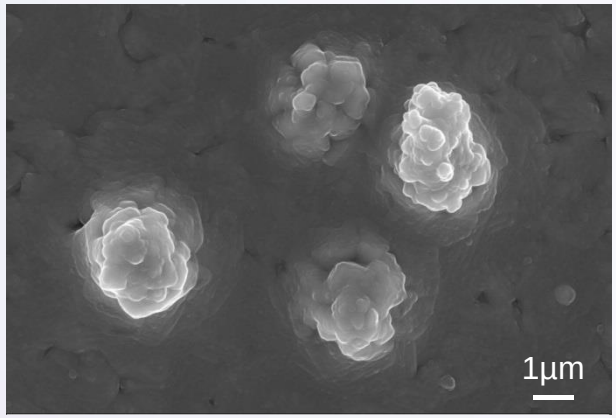
SEM image showing whisker growth on ALD coated sample after 6 months



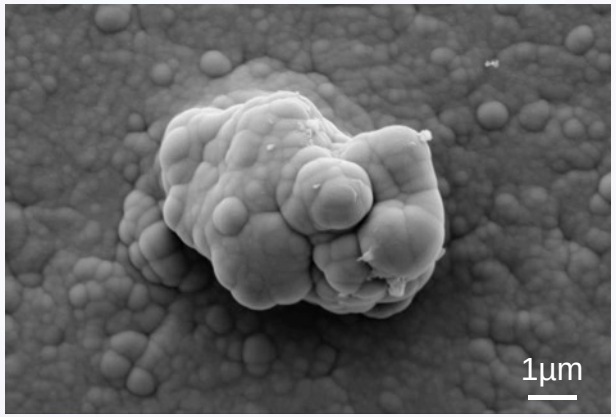
SEM image showing filament whisker growth on uncoated control sample after 6 months

3.6.When does whisker growth occur?

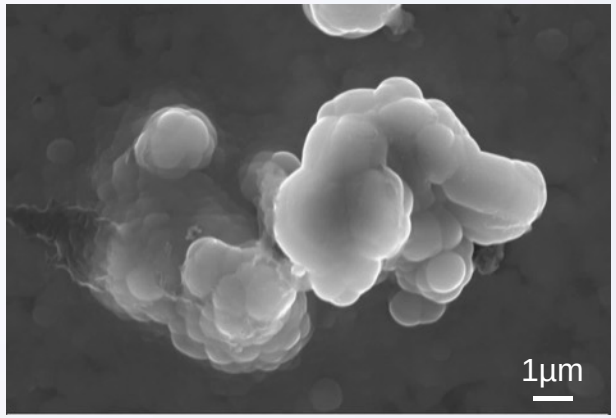
- SEM analysis indicates that many of the whiskers that are present are encased within an oxide shell, i.e. whisker growth occurred prior to ALD coating



Batch 3 – 3 months



Batch 6 – 2 months



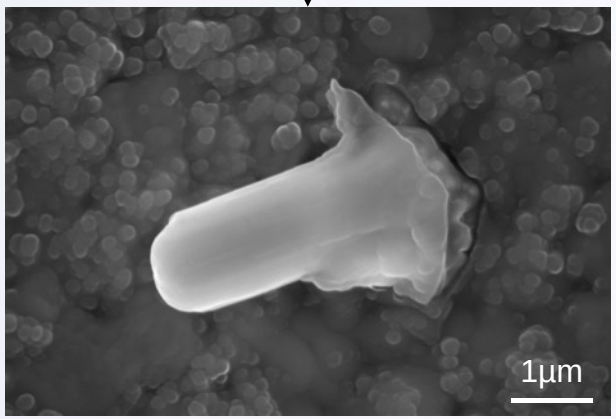
Batch 6 – 6 months

SEM images showing examples of whiskers that are encased within the ALD coating

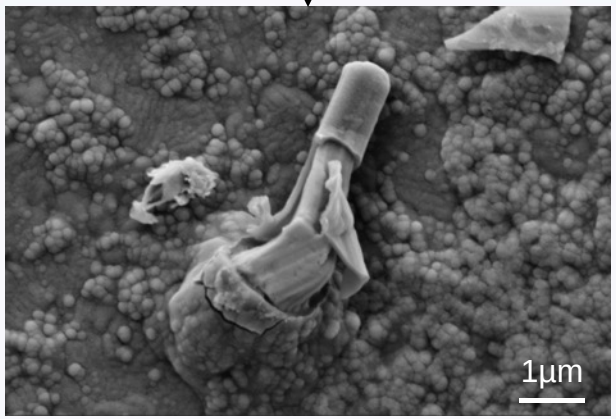
3.7.Whisker growth post ALD coating?

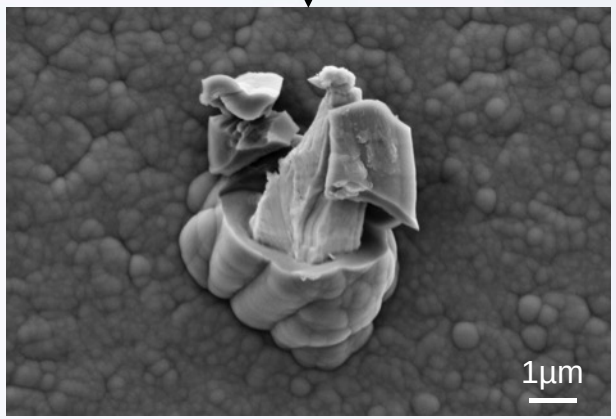
Samples examined after 3 months storage

Batch 2



Batch 5

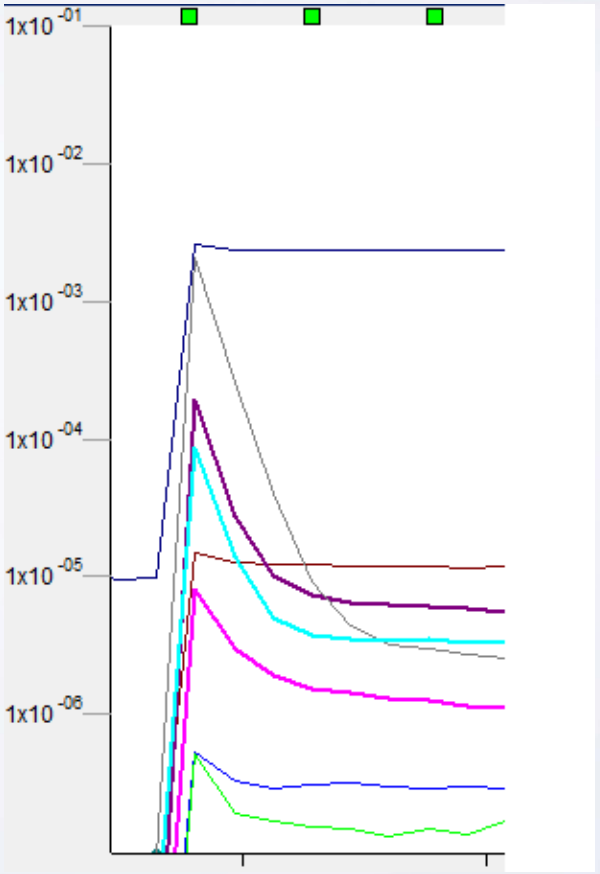




SEM images showing examples where the ALD coating has been fractured – possibly by post coating whisker growth

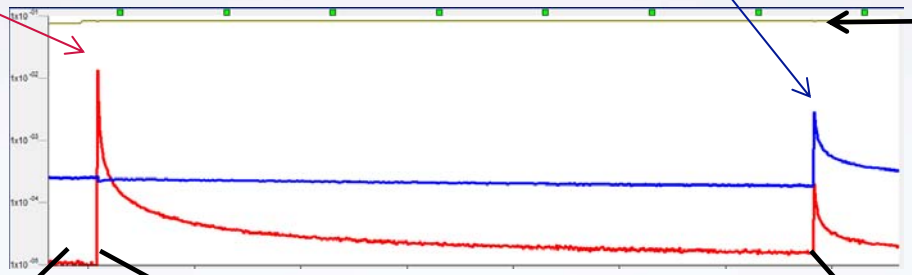
3.8.Residual gas analysis (RGA)

- Mass spectrometry for gasses coming out from the ALD reactor
- Mass-to-charge (m/z) vs. time of chemicals, decomposition and reaction products
- Degassing:
  - Gasses that may react with ALD gasses
  - Remainders of solvents
  - Oils evaporating from PCB
  - Effect of heating
- <u>Batch specific drying bake time</u>



3.9.An example of RGA

- TMA (TriMethylAluminium) & H2O pulses



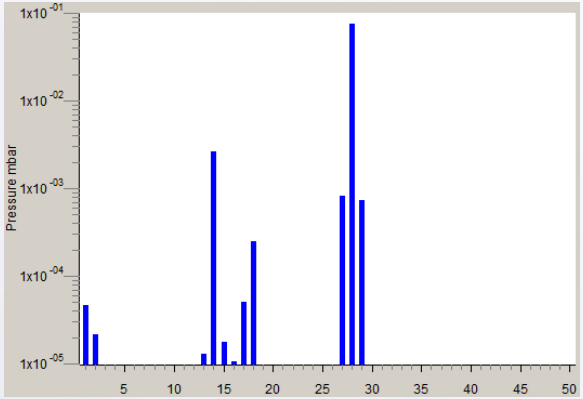
N2 carrier gas

Intensity 5 orders of magnitude

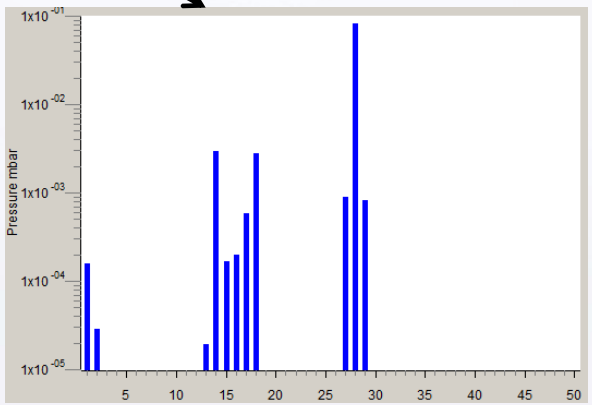
m/z 18 = Water

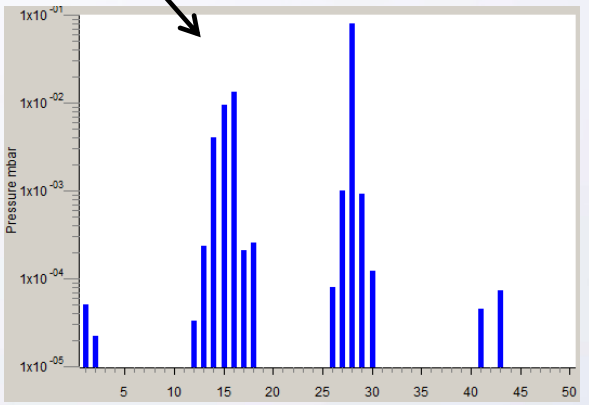
m/z 16 = Oxygen (by-product)

Time



Background





4.1.Summary

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- The density and length of filament type whiskers is greater in unprocessed control samples than those that have undergone ALD coating
- Filament whiskers, typically 10's of µm in length, are present on all the control samples analysed at the 6 month interval
- In general, whisker densities do not appreciably increase with increased storage time for the ALD processed samples
- SEM analysis suggests that whiskers had developed on the samples prior to ALD coating
- Printed circuits boards contain various substances requiring special attention in ALD process

5.1.Questions?

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Picosun Oy (www.picosun.com)

Picosun Oy, a limited liability company registered in Finland, is a leading provider of high quality ALD coating equipment and solutions to global industries. Picosun has over four decades of unparalleled, groundbreaking experience in the field of ALD, reaching back to the invention of the technology itself. Today, PICOSUN™ ALD systems are in production use in many of the world's largest microelectronics, sensor, semiconductor and various other industries. Picosun headquarters is located in Espoo, Finland and its production facilities in Masala, Finland. Picosun has subsidiaries in North America, Singapore, China, Japan, and Taiwan, and world-wide sales and support network.