ALD Atomic Layer Deposition for space applications

PCB-Assembly protection *Tin whiskers mitigation *COTS use in space

Finnish Space Industry Days 04.04-05.04.2019

DICSUN

AGILE ALD

ALD – Atomic Layer Deposition

- Is a batch coating process with surface chemistry
- Wide range of material, e.g. Al₂O₃, TiO₂, M-, M-C,M-N
- Typical; **100 nm** up to ~0,5 μm
- True 3D down to nanopores, no pinholes
- Vacuum deposition process
 - Substrates are degassed & heated (degas analyzed)
 - ~40 C **125C -** 400 C
- Mature IC manufacturing process
- Extremely repeatable in thickness & quality over time
- Chemical adhesion; will not peal off/flake
 - Dense
 - Pinhole- and defect-free films
 - Digitally repeatable process

THE PRINCIPLE OF ALD



Introduction of molecules containing element A.



Adsorption of the molecules on the surface.



Introduction of molecules containing element B and reaction with element A on the surface.



Completion of one monolayer of compound AB.

Repeat cycle till desired film thickness is reached.



Widely applied for example in IC industry, corrosion protection, moisture barriers...

Benefits of ALD for different areas on space application

THIN FILM GROWTH BY CONSECUTIVE ATOMIC LAYERS

- <u>Tin whiskers mitigation;</u> Main objective for ongoing ESA-funded activity
 - <u>Reworkable:</u> Components can be changed and the substrate re-coated
- <u>Corrosion protection</u>; ALD or PVD+ALD most durable corrosion resistance; 600 h/salt spray
- Excellent gas & moisture barrier; 4 x10⁻⁵ g/m²/d, (PEN/PET ~10⁻¹ g/m²/d);
 - Can be used for Sulfur & Creep Corrosion barrier, now used for coins; Creep corrosion or similar test needs?
 - <u>Prevent oxidation</u> (of e.g. mirrors)
 - <u>Degas</u> COTS plastic packages / boards -> ALD coat -> No moisture intake, nor release
 - Tests to be carried out at ESTEC
 - Prevent gas leak from fuel/gas containers
- Optical filters, mirrors-layers, black-surfaces (~100 nm thickness)
- Possible mitigation of surface charging with (weakly) conductive transparent conformal coating







PCBA protection by ALD

Conformal PCB assembly coating with a difference

- Blocks tin whiskers*
- Excellent moisture (&gas) barrier
- Corrosion barrier even against some liquids
- Can be reworked
- Can be patterned



- and in some cases not needed for patterning for contacts
- Can be combined with other coating methods
- Ensuring high surface insulation resistivity, no RF changes
 - Obtain higher environmental reliability with even while decreasing conductor spacing (decreased side)
 - With <u>"~0 added weight"</u>

* Tin whiskers growth prevented in model substrates, see later







Problem: Tin Whiskers



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

Problem: Tin Whiskers

Metal whiskers

- 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

SAC instead of SnPb

ROHS regulation drives industry to use leadfree solders that are more prone to whiskering than tin-lead alloys. Despite excempted for some industries, commercial reasons limit the availability of lead containing component finishes and soldering processes.



Atomic Layer Deposition for conformal coating of PCB assemblies and components

• funded; Evaluation of Atomic Layer Deposition (ALD) Conformal Coating to Mitigate Tin Whiskering - 4000113005/14/NL/PA, 2015

- Testing and validation planning of ALD for complete PCB(A) conformal protection
- 1st stage has demonstrated *
 - Mitigation of tin whiskers
 - **Conformal** applicability ALD for PCBA, >80 V breakthrough voltage;
 - even higher voltage with increased layer thickness; Reworkable
 - Deposition and testing processes were evaluated; best in use, ALD tool available

- funded; Atomic Layer Deposition for Tin Whiskers Mitigation and Cure on Space Electronics Manufacturing (4000122745/18/NL/LvH/gp), 2018

2nd stage started 1/2018 *

Cesa

- Verification of 1st stage experiment & Route planning to establish validation of ALD coating for suppliers
- Testing of ALD-encapsulation of plastic packages for space use and increased lifetime in ambient
- Test boards with relevant space grade AND off-the-shelf components (polymer packages)

What are your critical components to be validated? Your required test board?

Parallel B2B projects for automotive, medical...

* In collaboration with Loughborough Univercity and Oy Poltronic Ab





Test board

Multi purpose test board:

- 1. Surface Insulation Resistance SIR
- 2. Daisy Chain in QFP
- 3. SIR under QFP
- 4. Tin Whisker Test Matrix
- 5. Plate Capacitor with Prepreg as Dielectric
- 6. Temperature Sensors
- 7. SIR pattern for Humidity Detection
- 8. Indicator LEDs
- 9. Micro Controller
- 10. Regulator



Notes:

- Finger patterns on backside only for balancing the board.
- Connector not assembled.

What are your critical components to be validated? Your required test board?



ESA-funded; Atomic Layer Deposition for Tin Whiskers Mitigation and Cure on Space Electronics Manufacturing (4000122745/18/NL/LvH/gp), 2018



BIASED CORROSION

Drop of salt water on *Imm*-Ag coated electrodes, 3.3v bias



PCBA protection by ALD



Figure 9 Legs cut and component removed



Figure 10 Regulator was removed using Weller repair tool

Rework by RUAG Space Finland Oy Ab

• No coating removal required



Components after rework

ENVIRONMENTAL CHAMBER TESTS

85/85 (C/RH%) have been made with bias voltage upto 1400 V/mm

- All samples survived 1000h **MFG test**
- Non-coated samples showed signs of corrosion in optical analysis.



| Parameter | Value |
|-------------------|-----------------------------|
| H ₂ S | 200 ppb |
| NO ₂ | 200 ppb |
| Cl ₂ | 30 ppb |
| Temperature | 40°C |
| Relative Humidity | 75% |
| Test duration | 48 hours |
| Corrosion rate | 3.5 μg/cm ² /day |







ACCELERATED SN-WHISKERS GROWTH PROCESS

ALD prevents the whiskers growth – Status Mar 2019

- Upto 180 days test time done
- 7 different ALD materials tested*



- Thermal refence; no whiskers observed yet
- 1st stage project samples show that growth will start later!



ALTERNATIVE FOR SOLDER MASK

= Metal oxide thin-film to replace solder mask

'Plastic' solder mask - not wide used in space applications

Sn-coat the Cu; + Prevent oxidation, + Prevent air borne contamination,

- Tin whiskers, - no coating ~ short circuit from 'dirt'

ALD deposition conformally; openings for soldering

+ Prevent oxidation (best process), + Prevent air borne contamination,

+ Tin whiskers + conformal coating + more processes later + rework





How to do it

Roadmap

- Tin whiskers mitigation preliminary demonstrated and evaluated, now repeating experiment using a wider test matrix
 - Equipment available
- Plastic package encapsulation now used in tests
- 3rd Phase; Validation
 - Validation planned, expected to start in ~1 year

Tool examples **P300**; 27 x 27 x 27 cm3



(other, **P1000**; diam 60cm, h70 cm)

- Flight representative board assemblies for validation proposals for boards / components? Interested partners?
- Parallel use for down to earth applications (reliability), aka. industrial drivers

 We are searching partners!
- Demonstration / development now in process; next (e.g. EMS) collaborator, who can provide the coating service (should be requested by 'OEM')



Quick questions?

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Thank you!

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Multiple patents granted and pending, including but not limited to US8211235, US8741062, US8753716, WO2014080067, FI20195173.