

Final Presentation

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22nd Sept 2021

Assessment of Automotive EEE Components Suitability For Space Applications

Introduction



Background:

- ESA awards two parallel contracts to assess potential suitability of automotive EEE COTS components for use in space applications.
- One contract awarded to TAS-E with Tyndall as sub-contractor (4000126343/19/NL/hh).
- Work commenced in 2019, tests completed in early 2021, final analysis of data in progress.

Objectives:

- To identify the additional testing (“delta testing”) to align automotive qualified (AEC-Q) EEE parts with space standards.
- To identify & procure suitable candidate components based on market analysis and review of published data.
- To define and carry out the “delta test” programme on the selected components.
- To evaluate the test programme results and formulate recommendations on the suitability of the selected component families for space use.

Project Tasks



WP1: AEC-Q MAPPING



- Compile an AEC QPL list based on the state of the art.
- Compile a list of the most demanded devices for Space applications.
- Generate an update of the AEC PPL for Space applications.
- Select candidates for test from the AEC PPL.

WP2: COMPARE AEC-Q & SPACE



- Compare AEC standards and flow versus Space standards (ESCC, MIL, ECSS and NASA).
- Define recommended delta-approval tests
- Procured 3 lots of each candidate within a 3 years of date code

WP3: TESTS



- Check for variability Lot-to-Lot and Part-to-Part:
 - *Detailed Construction Analysis*
- Reliability “Delta” Test Programme:
 - *Thermal Cycling, THB & HTOL Tests*
 - *Inspection & Electrical Test (Before/After Stress)*

WP4: RECOMMENDATIONS



Component Selection



■ ST Microelectronics Operational Amplifier:

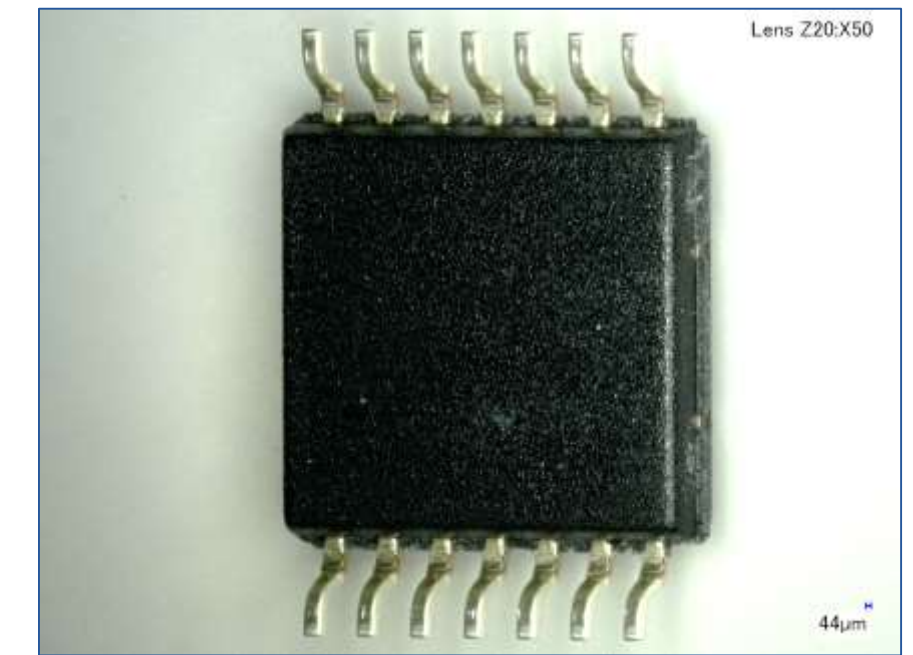
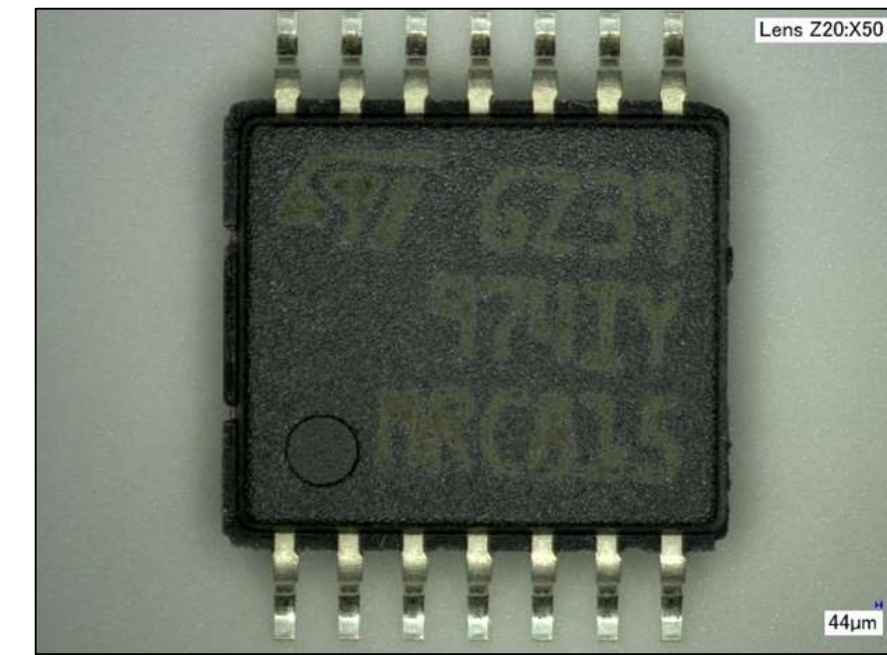
- *Low-Noise Op-Amp, AEC-Q100.*
- *Part No.: 511TS9741YPT.*
- *Lots: 1647, 1706, 1816.*
- *TSSOP-14 Package.*

■ Infineon Switching Diode:

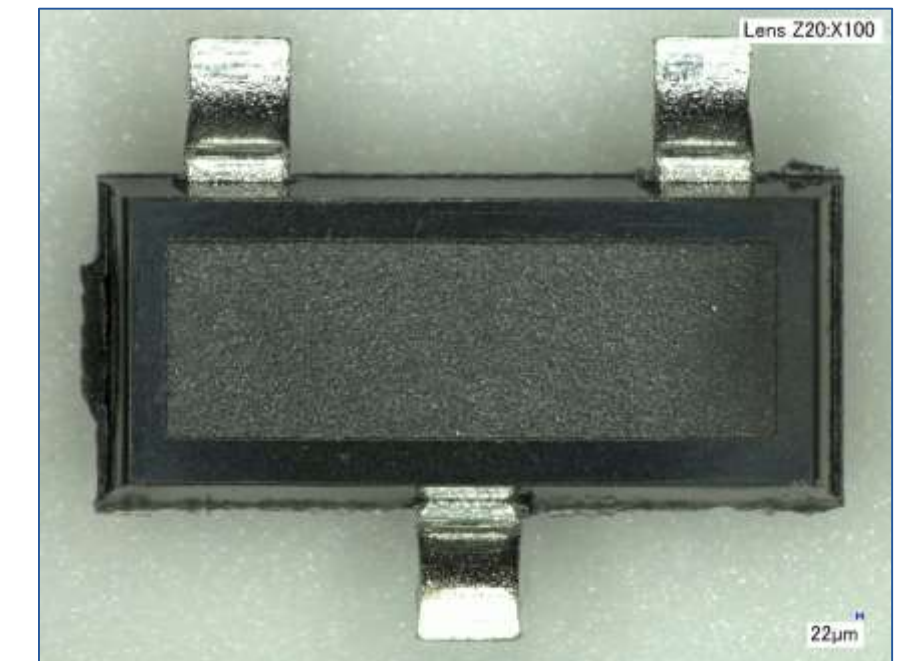
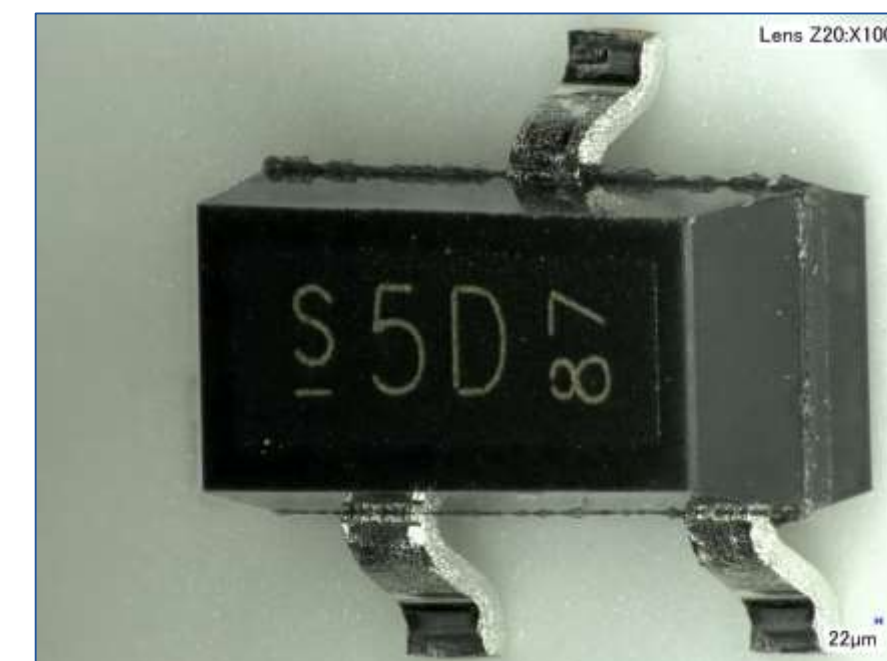
- *High Speed Silicon Switching Diode, AEC-Q101.*
- *Part No.: SMBD914E6327HTSA1.*
- *Lots: 1536, 1829, 1831.*
- *SOT-23 Package.*

■ AVX Ceramic Capacitor

- *Ceramic Capacitor, 4.7 μ F, 50V, X7R, Type II, AEC-Q200.*
- *Part No.: 12105C475KAZ2A.*
- *Lots: 1820, 1927, 1937.*
- *1210 Form Factor.*



Op-Amp (lot 1816) – Top & Bottom Views



Diode (lot 1829) – Top & Bottom Views



Capacitor (lot 1927) – End & Side Views

Physical Analysis – Active Components (ST-Micro Op-Amps & Infineon Diodes)

■ Detailed Construction Analysis (CA) 5 samples x 3 lots x 3 types:

- External Visual Inspection (based on Mil-Std-883K, Method 2009.12).
- Dimensional Measurement (based on Mil-Std-883K, Method 2016).
- Radiographic Inspection (based on Mil-Std-883K, Method 2012.9 / Mil-Std-750, Method 2076).
- Radiographic CT-Scan (3D imaging).
- Scanning Acoustic Microscopy (SAM).
- Marking Permanence Test / Resistance to Solvents.
- Energy Dispersive X-ray (EDX) Analysis of termination finish.
- Solderability Test (based on Mil-Std-883K, Method 2004.7 / Mil-Std-750, Method 2077 but with SAC305 & Sn63Pb37).
- Termination Strength Test (Mil-Std-883K, Method 2004.7, Condition A).
- Chemical de-cap
- Internal Visual & SEM Inspection (based on ESCC 2045000, 2045010, 2059000 & Mil-Std-883K, Method 2018.6).
- Ball Shear Test (JEDEC JASD22-B116).
- Glassivation Integrity Test - active components (Mil-Std-883K, Method 2021.3).
- Cross-sectioning.
- SEM Measurement of internal dimensions.
- EDX analysis of all materials.
- Determination of Tg & Outgassing for plastic-encapsulated components (active samples).
- Determination of CTE for all component types (using TMA)

Physical Analysis – Passive Components (AVX Capacitors)

■ Detailed Construction Analysis (CA) 5 samples x 3 lots x 3 types:

- *External Visual Inspection (based on Mil-Std-883K, Method 2009.12).*
- *Dimensional Measurement (based on Mil-Std-883K, Method 2016).*
- *Radiographic Inspection (based on Mil-Std-883K, Method 2012.9 / Mil-Std-750, Method 2076).*
- *Radiographic CT-Scan (3D imaging).*
- *Energy Dispersive X-ray (EDX) Analysis of termination finish.*
- *Solderability Test (based on Mil-Std-883K, Method 2004.7 / Mil-Std-750, Method 2077 but with SAC305 & Sn63Pb37).*
- *Microsectioning (to enable inspection and analysis of internal structure).*
- *Internal Visual & SEM Inspection, Measurements of Internal Layer Dimensions*
- *EDX elemental analysis of materials.*
- *Determination of CTE.*

External Visual Inspection

- ESCC-Q-ST-60-13C, Table H2.
- Based on Mil-883, TM2009 & Mil-750, TM 2009.
- Methods not ideally suited to plastic-encapsulated ICs.
- Inspection focussed on:
 - *Package Markings – legibility & correctness.*
 - *Overall Structure – chip-outs, voids, cracks, foreign inclusions, moulding quality.*
 - *Deformation / warpage.*
 - *Termination Finish – peeling, blistering, corrosion, solder protrusions, isolation.*
- *Carried out with Keyence VHX 2000 system up to 200X.*



- Keyence 3D Digital Microscope
- Solves depth-of-focus problem
- Combines multiple photos at different focal points to give fully focussed image.

External Visual Inspection

■ ST-Microelectronics Operational Amplifiers:

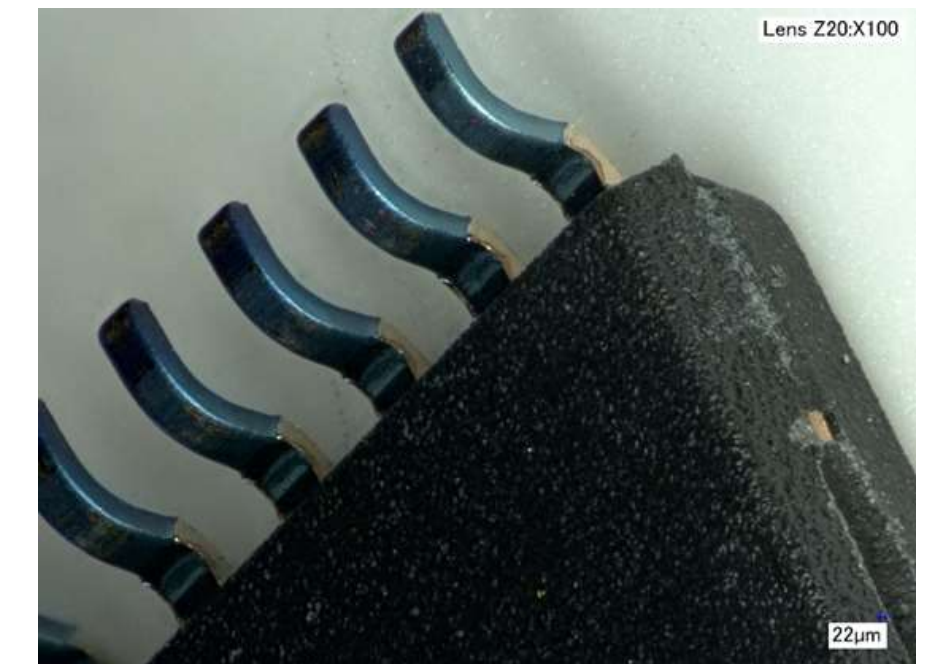
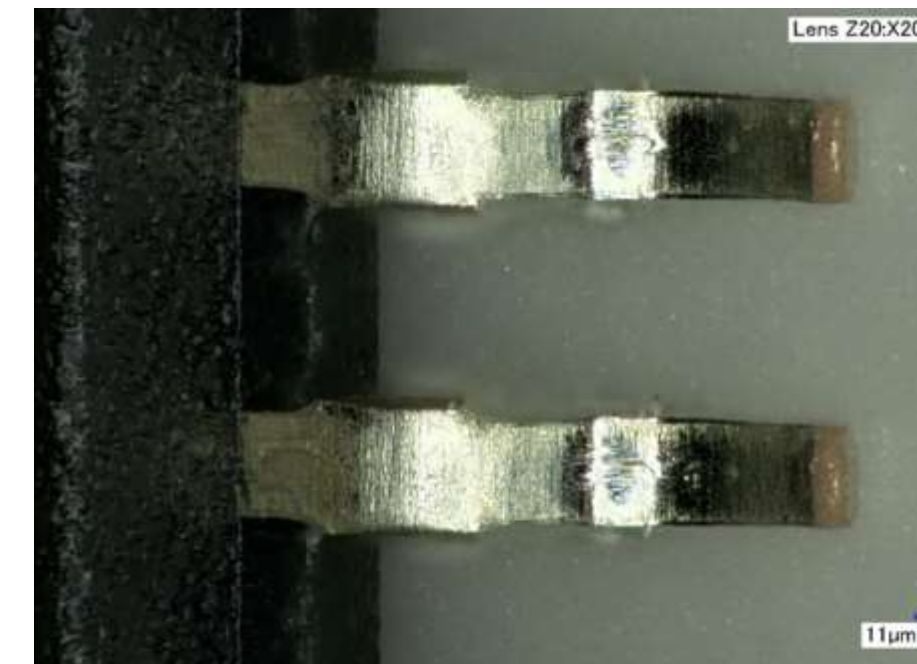
- *All samples generally in good condition.*
- *Oldest lot (1647) had discoloration on terminations.*
- *All show features typical of plastic components (e.g. mould lines, excess plastic, exposed base metal due to cutting of the lead frame)*
- *No external construction differences found between lots.*

■ Infineon Diodes:

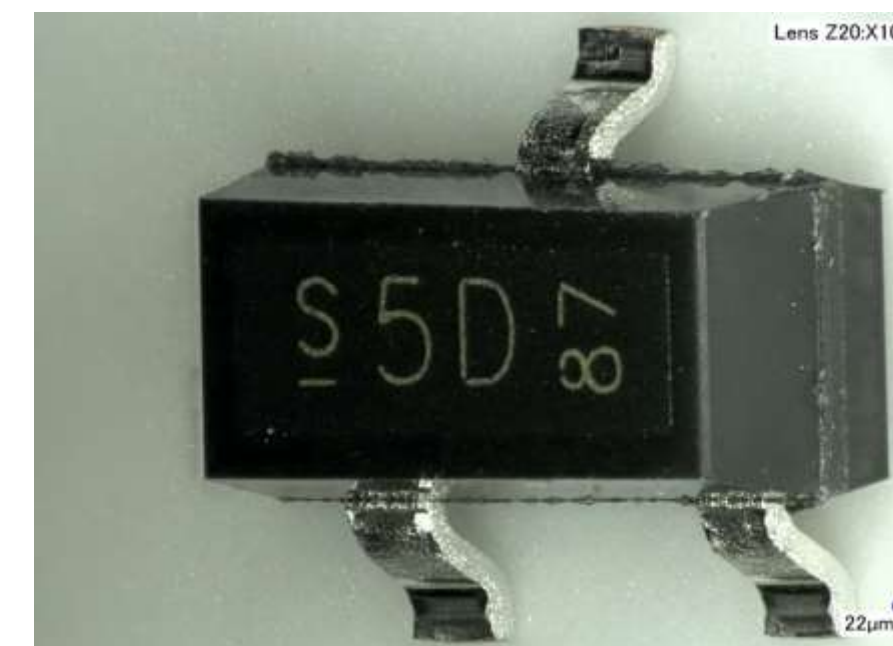
- *All samples in good condition.*
- *No external construction differences found between lots.*
- *Oldest Lot (1531) has different marking.*

■ AVX Capacitors:

- *All samples in good condition.*
- *No external differences between lots.*



ST Microelectronics Operational Amplifier – Discoloured Leads on oldest lot (1647).



Infineon Diode – Marking “59” on oldest lot (1531).



AVX Capacitor – No external differences between lots.

Dimensional Measurements

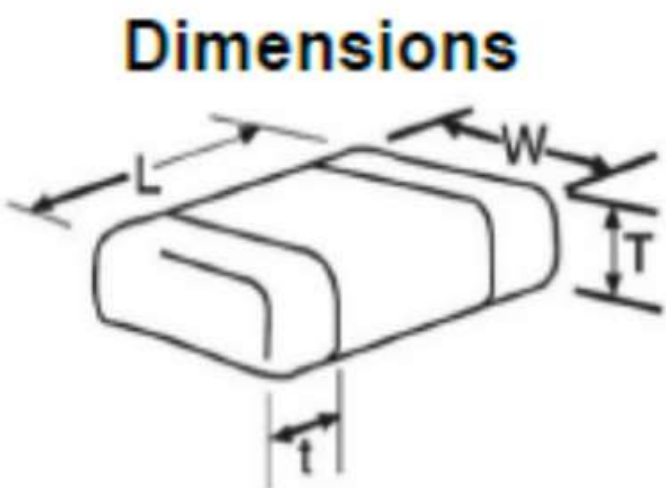
- Mil-Std-883K, Method 2016.
- Low lot-to-lot variance.

| ST Microelectronics TS974 Operational Amplifier Component | | | | | |
|---|---------------|---------------|---------------|-----------------|---------------|
| Device No. | L (mm) | W-body (mm) | W-total (mm) | Lead Width (mm) | H (mm) |
| 1647 | 5.092 ± 0.011 | 4.278 ± 0.008 | 6.394 ± 0.005 | 2.272 ± 0.008 | 0.948 ± 0.004 |
| 1706 | 5.082 ± 0.004 | 4.288 ± 0.008 | 6.396 ± 0.005 | 2.252 ± 0.008 | 0.942 ± 0.004 |
| 1816 | 5.092 ± 0.008 | 4.274 ± 0.005 | 6.390 ± 0.010 | 2.270 ± 0.009 | 0.950 ± 0.001 |

Dimensions - ST Microelectronics Operational Amplifier Lots

| Infineon SMBD914 High Speed Switching Diode | | | | | |
|---|---------------|---------------|---------------|-----------------|---------------|
| Device No. | L (mm) | W-body (mm) | W-total (mm) | Lead Width (mm) | H (mm) |
| 1536 | 3.006 ± 0.005 | 1.390 ± 0.012 | 2.430 ± 0.007 | 0.432 ± 0.004 | 1.044 ± 0.005 |
| 1829 | 3.002 ± 0.004 | 1.388 ± 0.008 | 2.442 ± 0.008 | 0.438 ± 0.004 | 1.048 ± 0.004 |
| 1839 | 3.004 ± 0.005 | 1.376 ± 0.005 | 2.446 ± 0.005 | 0.428 ± 0.004 | 1.050 ± 0.001 |

Dimensions – Infineon Diode Lots



| | millimetres | inches |
|--------|-------------|---------------|
| L | 3.3 ± 0.4 | 0.13 ± 0.016 |
| W | 2.5 ± 0.3 | 0.098 ± 0.012 |
| T max. | 2.79 | 0.11 |
| t | 0.5 ± 0.25 | 0.02 ± 0.01 |

| AVX 12105C475KAZ2A Capacitor | | | |
|------------------------------|---------------|---------------|---------------|
| Device No. | L (mm) | W (mm) | H (mm) |
| 1820 | 3.254 ± 0.005 | 2.460 ± 0.007 | 2.656 ± 0.011 |
| 1927 | 3.258 ± 0.008 | 2.448 ± 0.008 | 2.652 ± 0.008 |
| 1937 | 3.248 ± 0.008 | 2.458 ± 0.008 | 2.660 ± 0.007 |

Dimensions – AVX Capacitor Lots

Radiographic Inspection

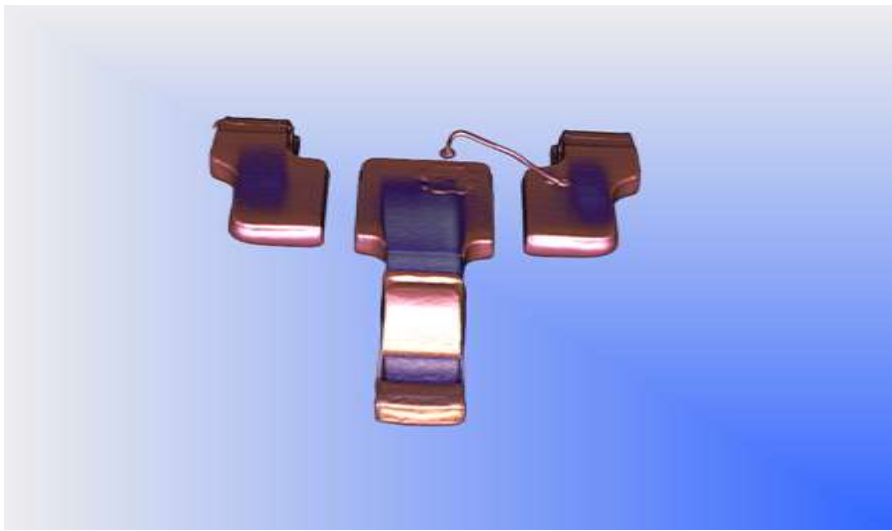
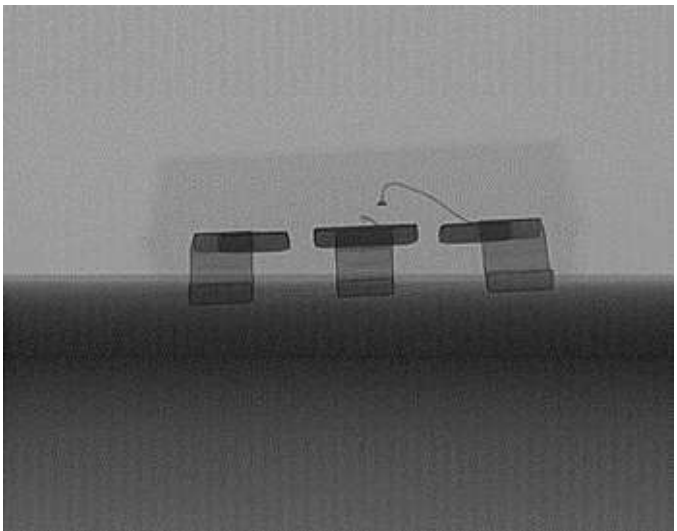
- Based on Mil-883, TM2012 & Mil-750, TM 2076.
- 2D (Three axes) & 3D (CT-Scan) Inspections.
- Objectives:
 - *Determine the internal layout.*
 - *Check for gross defects (major cracks / voids).*
 - *Foreign materials / inclusions.*
 - *Inspect wire bonds (shape, clearances, etc).*
 - *Evaluate die-attach quality.*
- Equipment:
 - *Nordson-Dage Diamond II XD7600NT.*
 - *Siemens CERA CT-Stage*



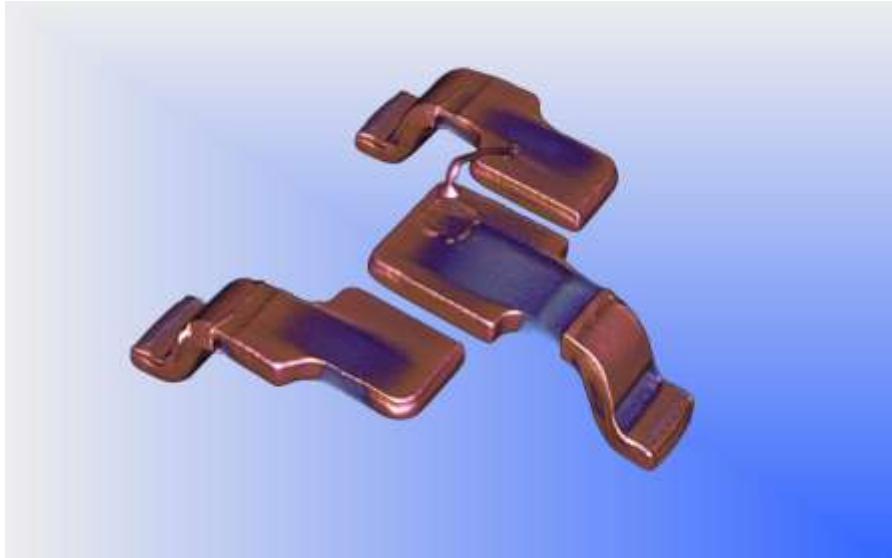
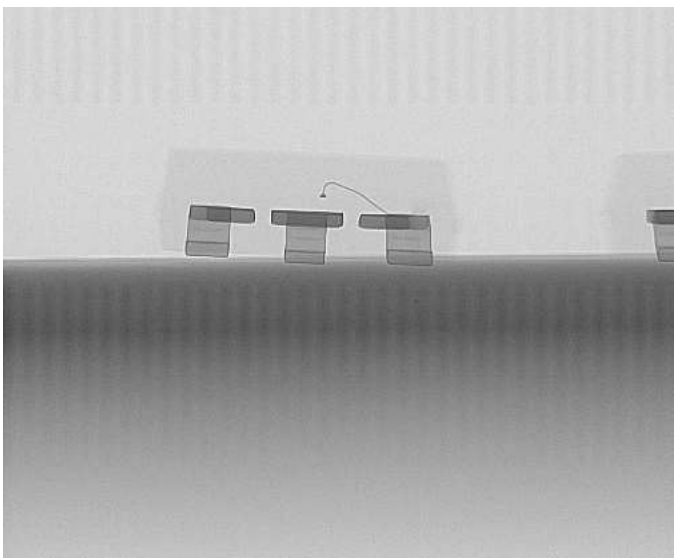
Nordson Dage Diamond II XD7600NT X-ray Imaging System at Tyndall National Institute

- X-ray Source 30KV – 160 KV, 10W
- Up to 2,500X magnification.
- Inspection area: 50cm x 44cm
- 0.1µm feature recognition.
- X-plane & Micro CT capability.
- Automated inspection.

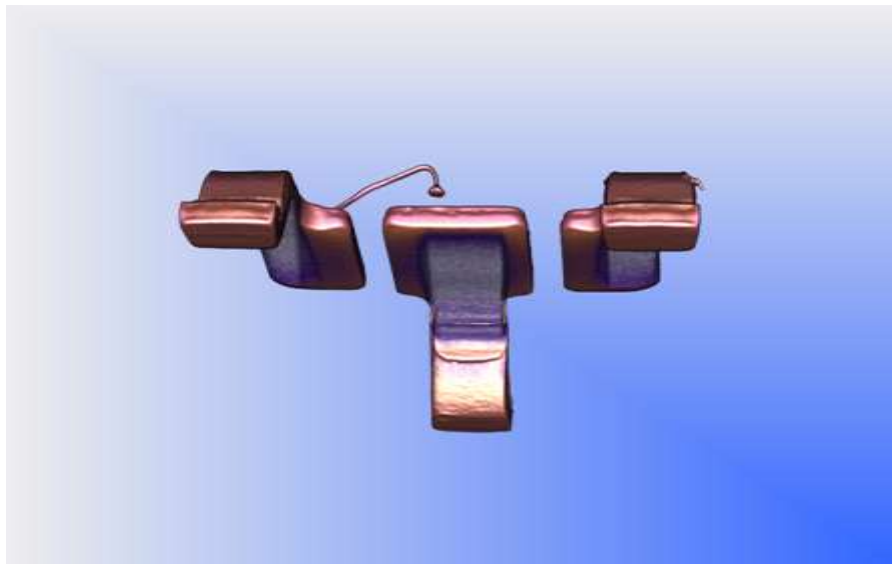
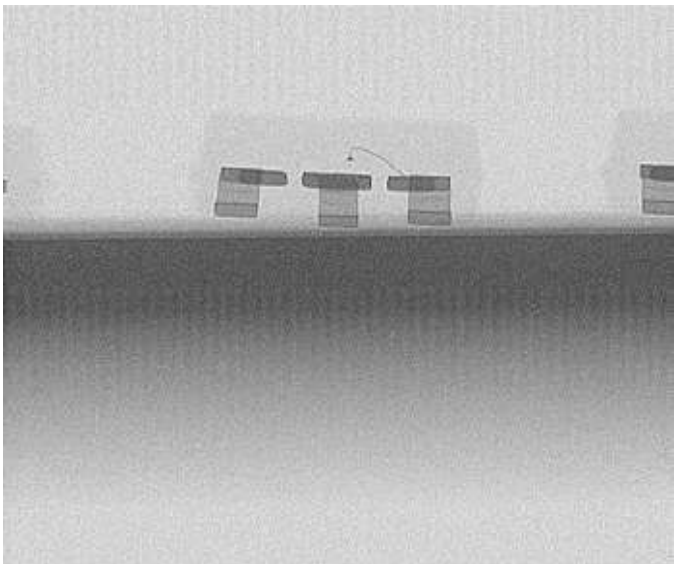
Radiographic Inspection



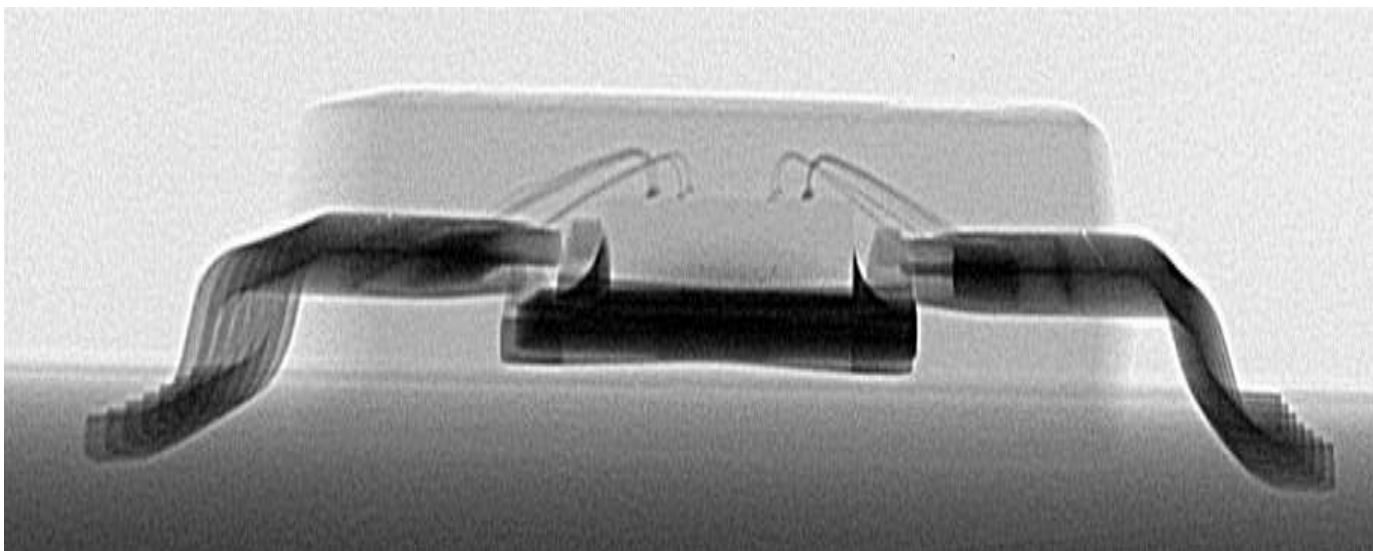
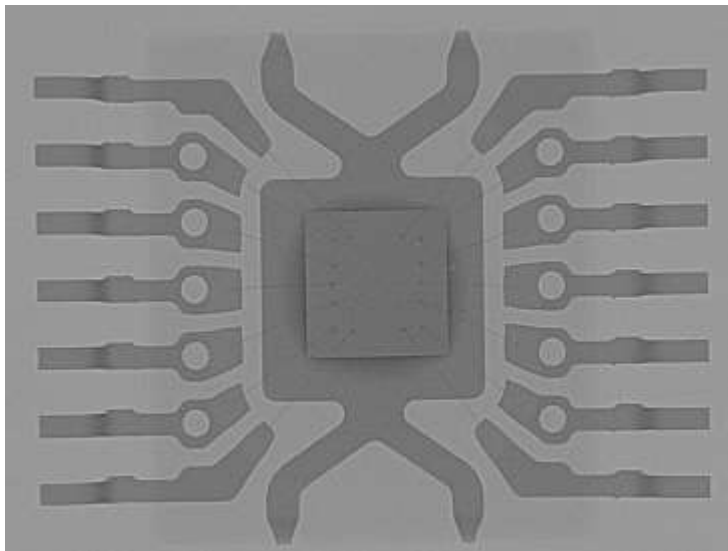
Infineon Diode (1536)



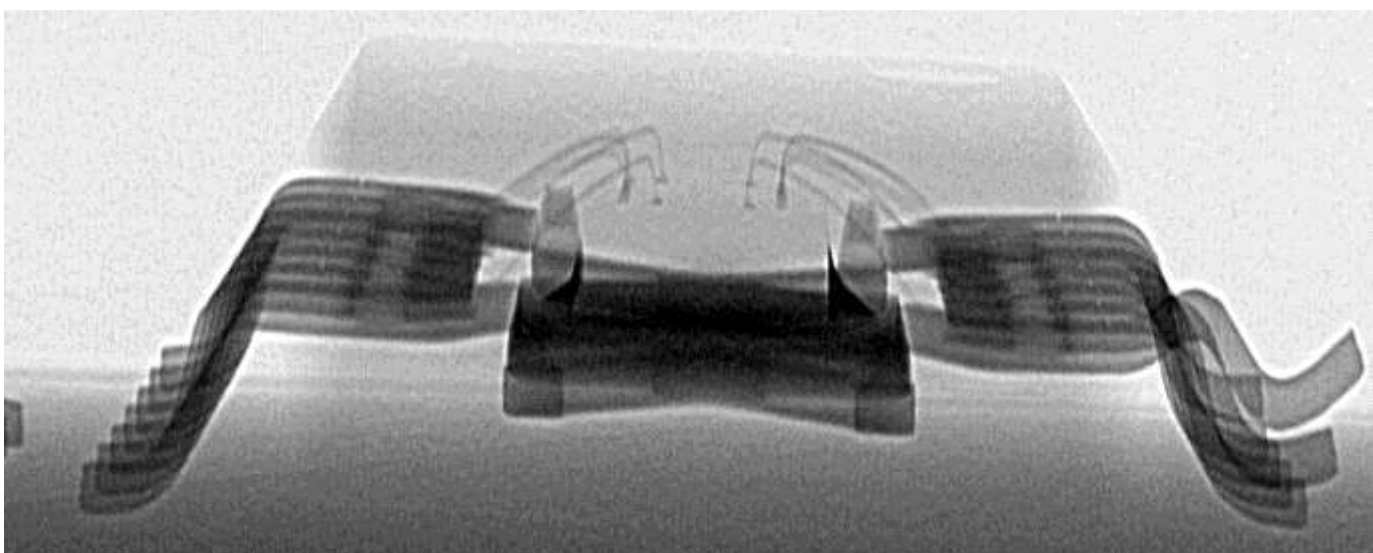
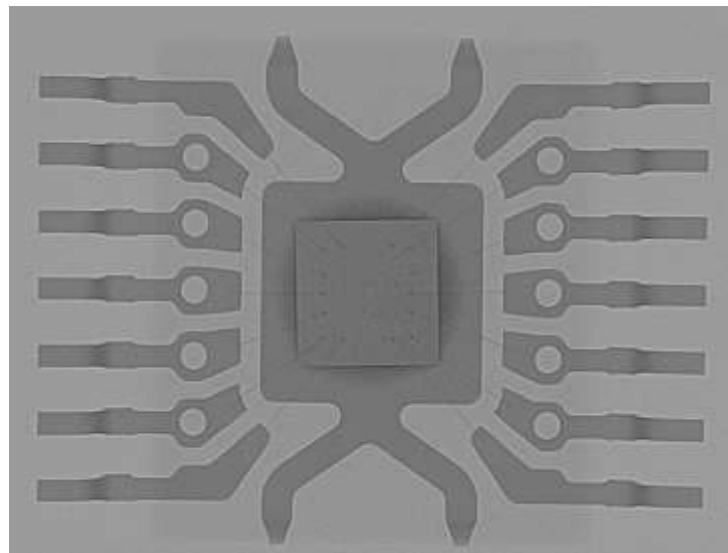
Infineon Diode (1829)



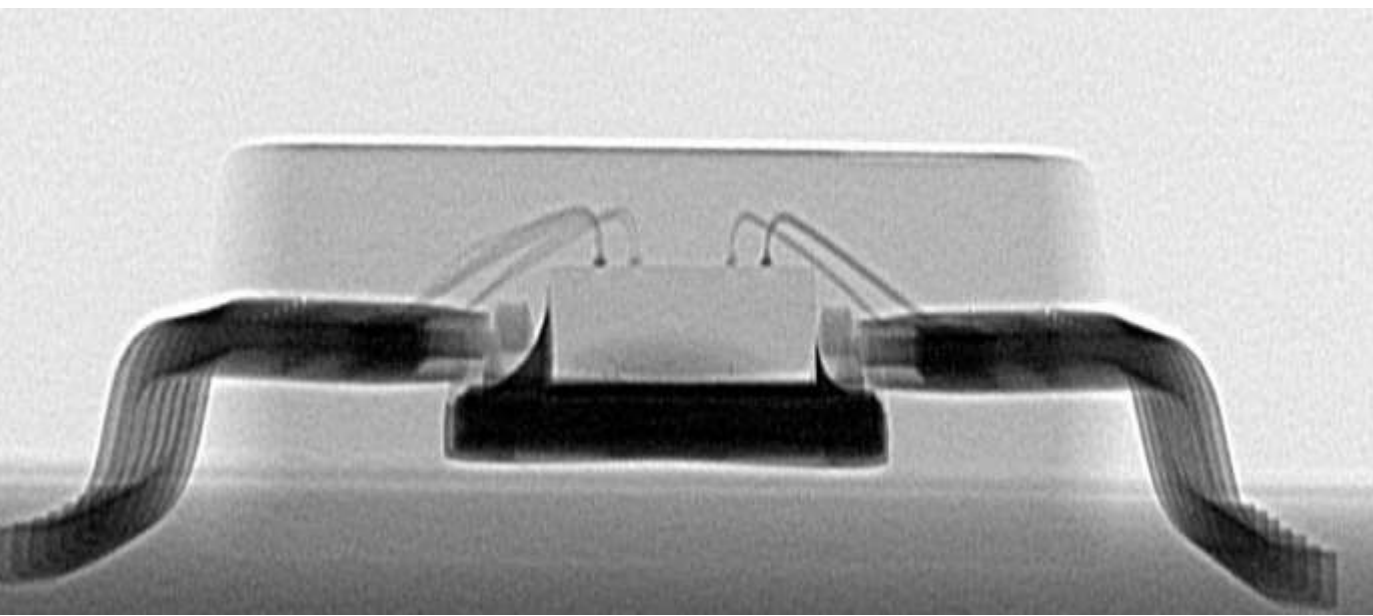
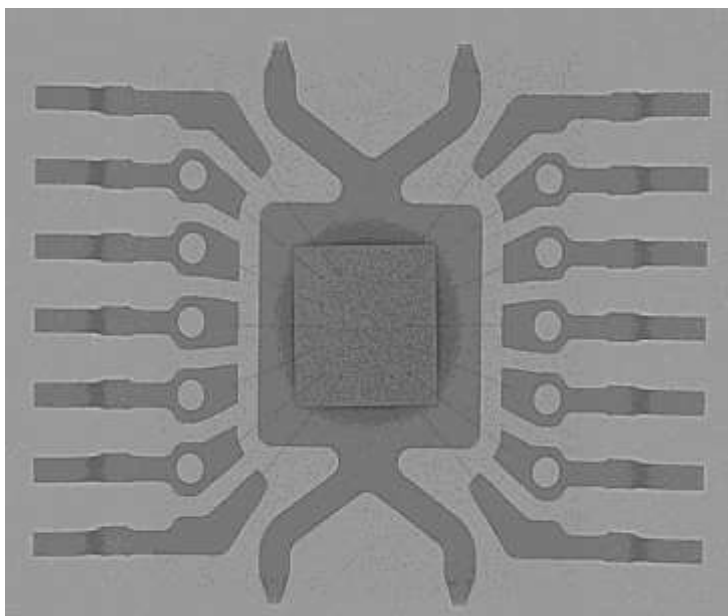
Infineon Diode (1831)



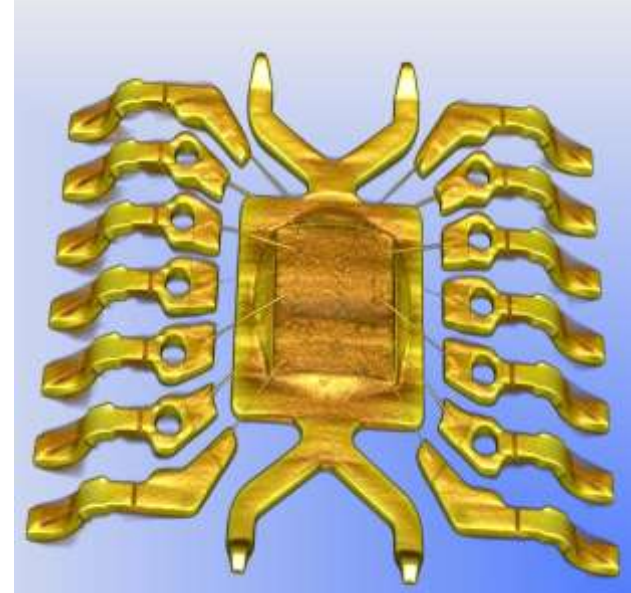
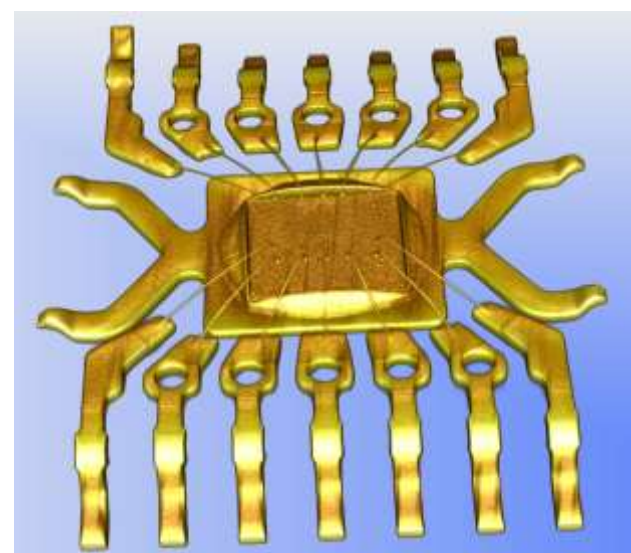
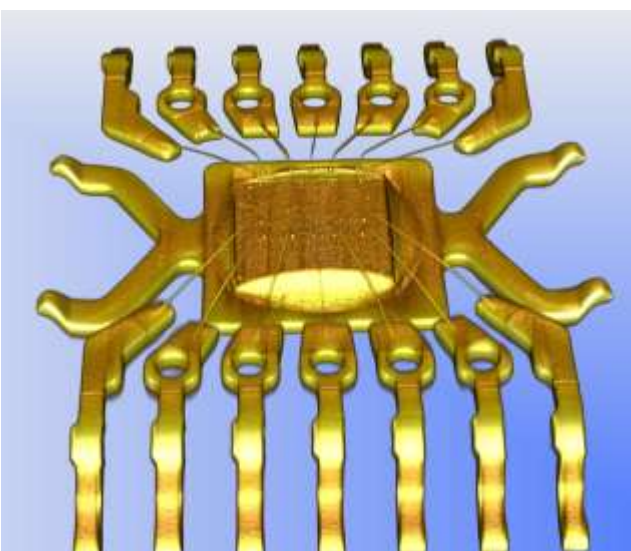
ST Microelectronics Operational Amplifier (1647)



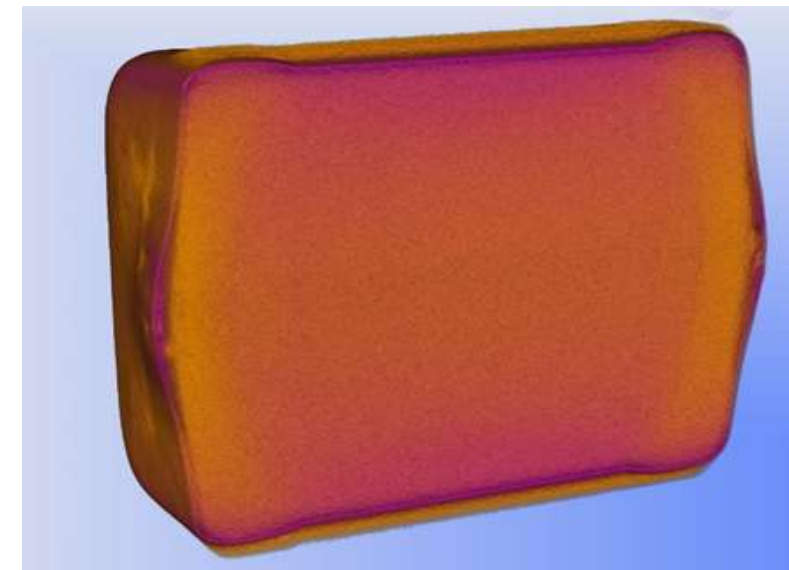
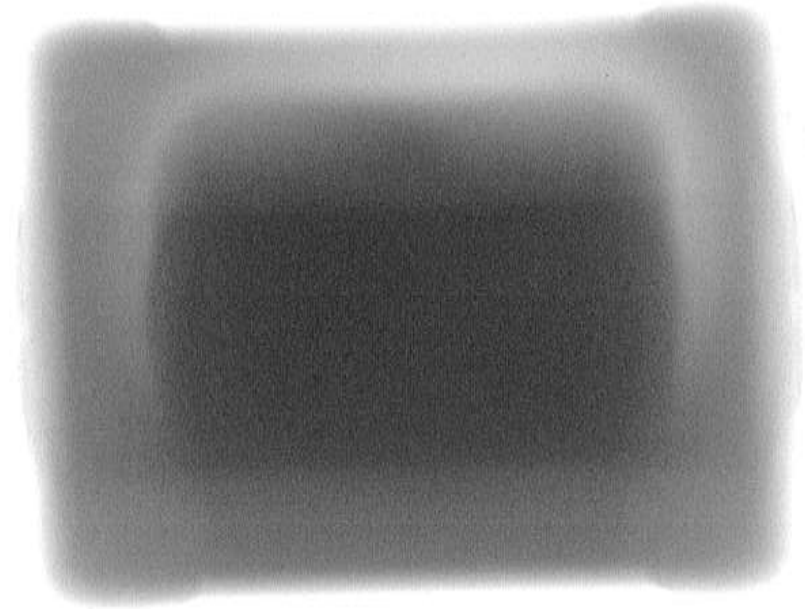
ST Microelectronics Operational Amplifier (1706)



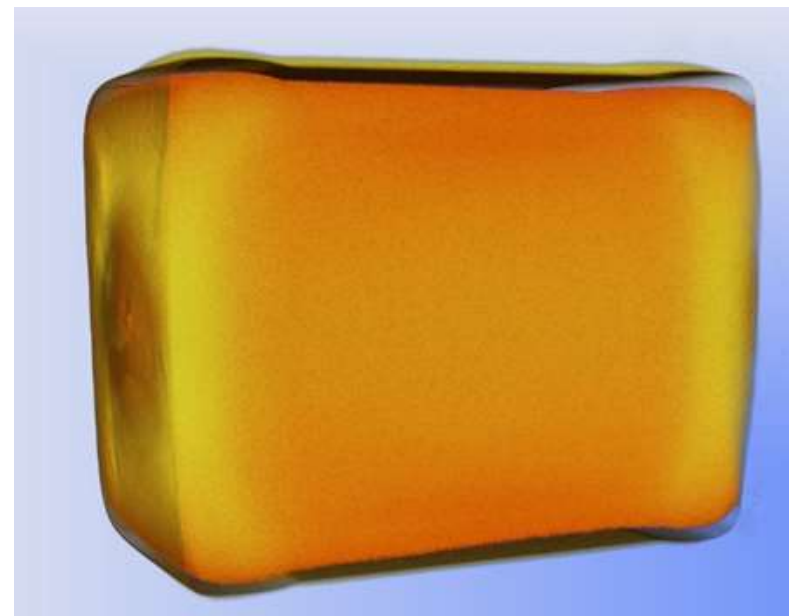
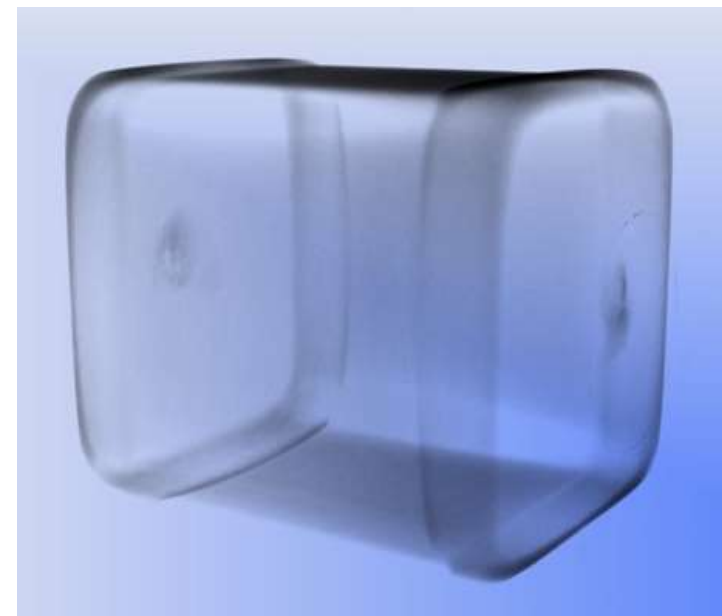
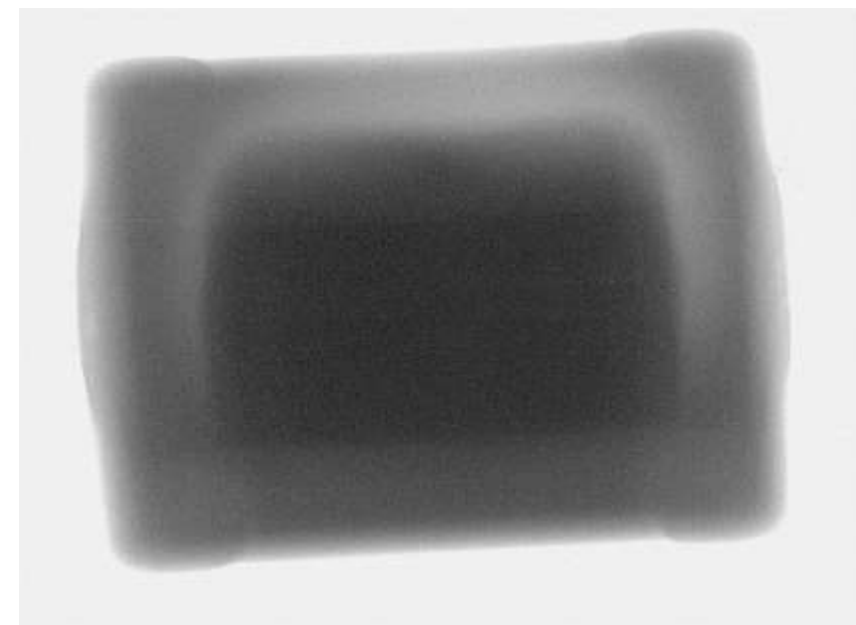
ST Microelectronics Operational Amplifier (1816)



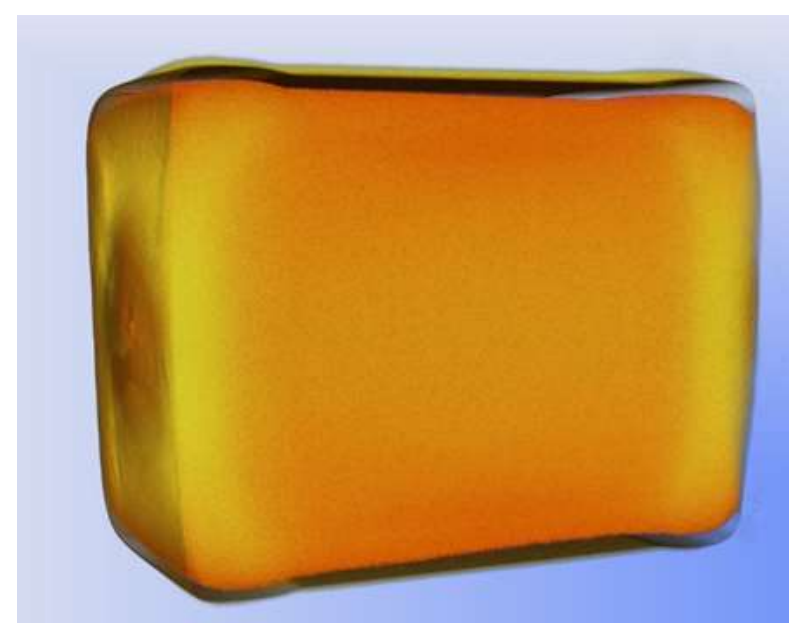
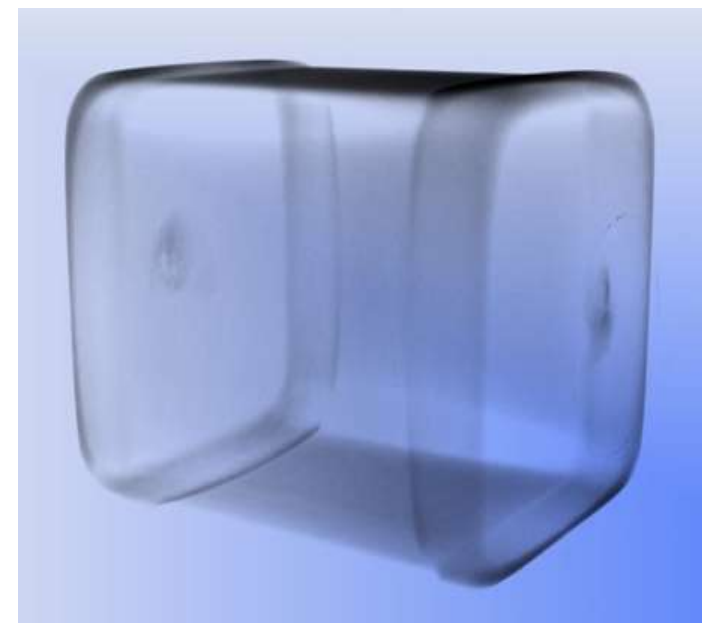
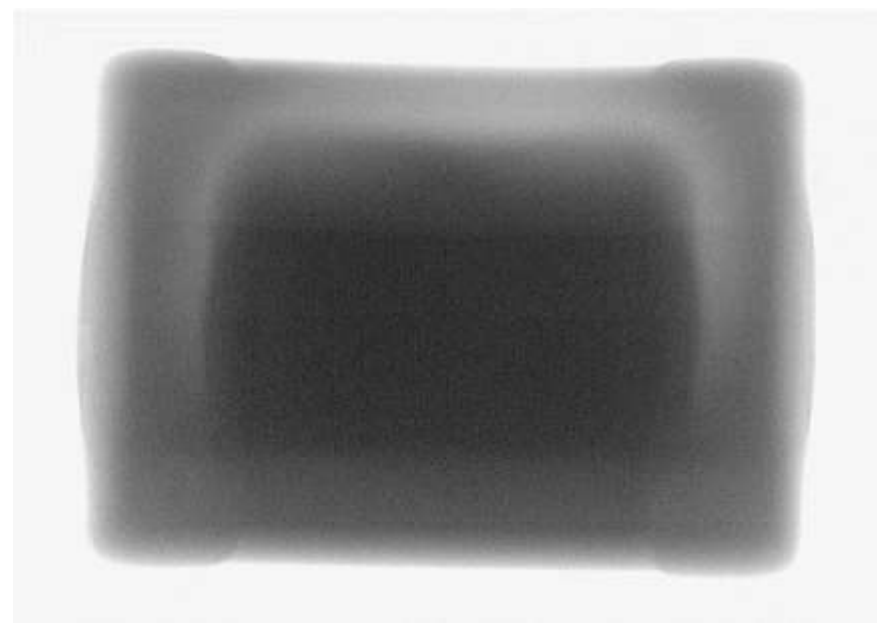
Radiographic Inspection



AVX Capacitor (1820)



AVX Capacitor (1927)



AVX Capacitor (1937)

■ ST-Microelectronics Operational Amplifiers:

- *No defects observed / No differences between lots.*
- *Lead frame, wire bonds & die-attach visible.*
- *Wire bonds are Cu.*

■ Infineon Diodes:

- *No defects / No differences between lots.*
- *Lead frame, wire bonds & die-attach visible.*
- *Wire bonds are Au.*

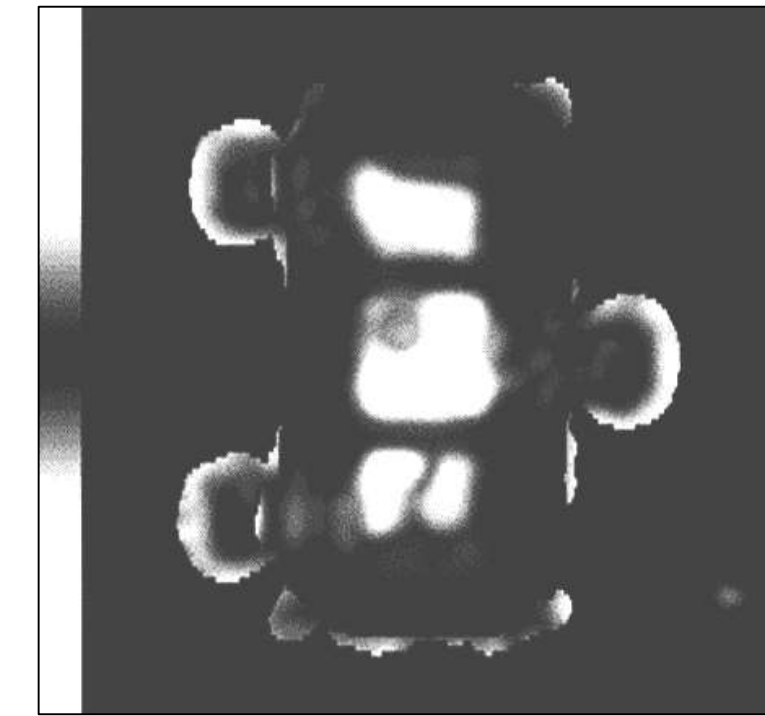
■ AVX Capacitors:

- *Detail difficult to observe due to dense ceramic construction.*
- *No apparent defects or differences between lots.*

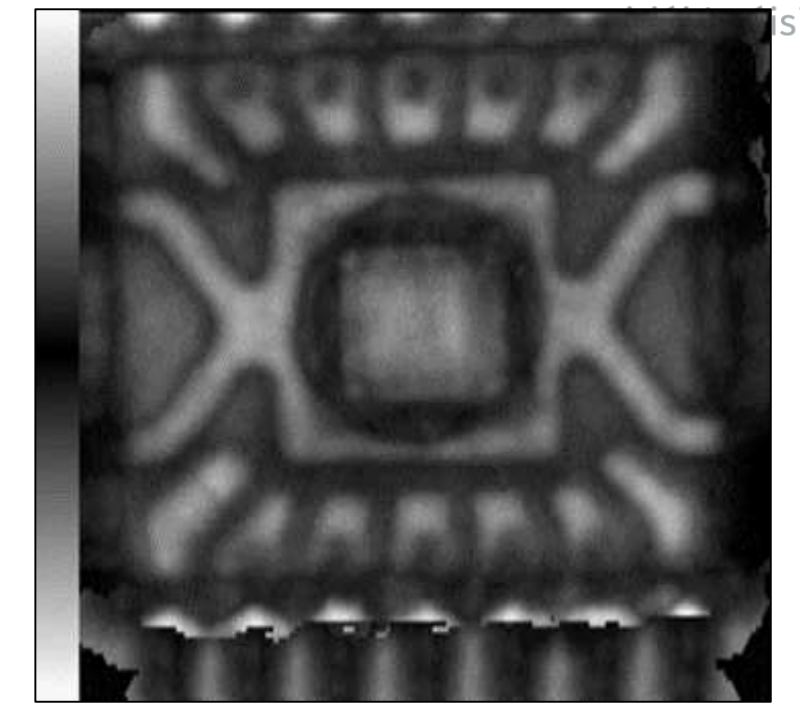
Scanning Acoustic Microscopy



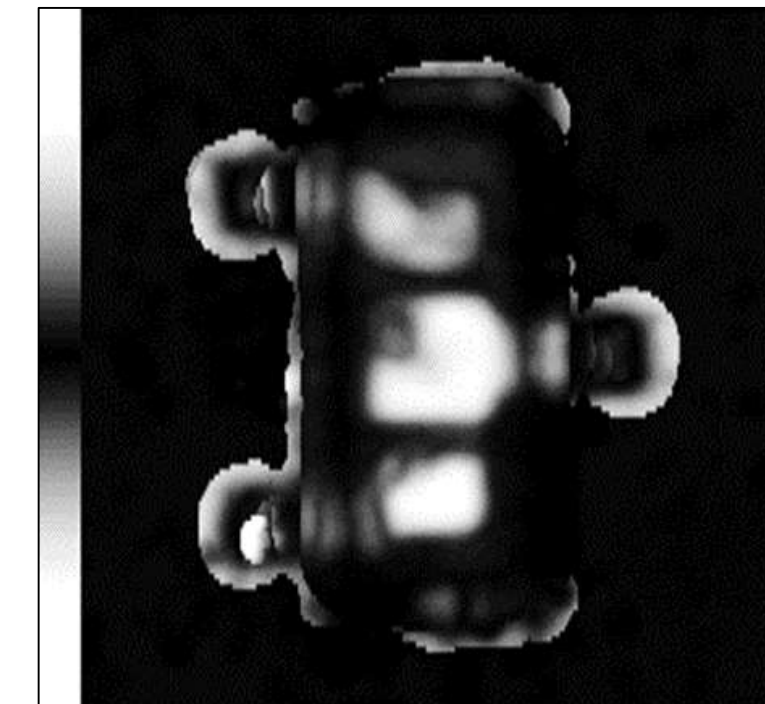
- Inspection technique for plastic-packaged components.
- High-frequency sound signal (15MHz – 180MHz).
- Detects layer delamination due to thermo-mechanical stress.
- No defects evident in op-amp or diode lots.



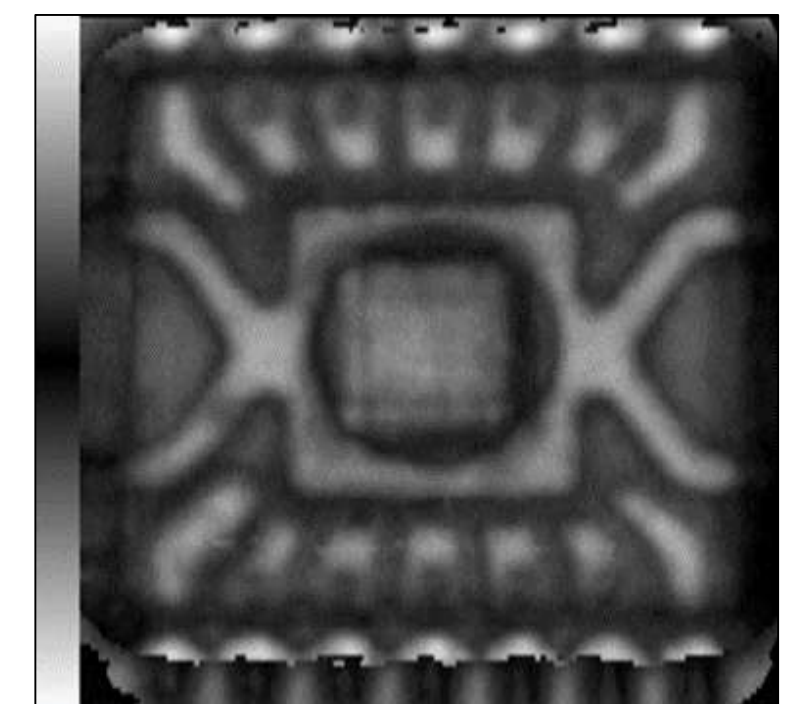
Infineon Diode (1536)



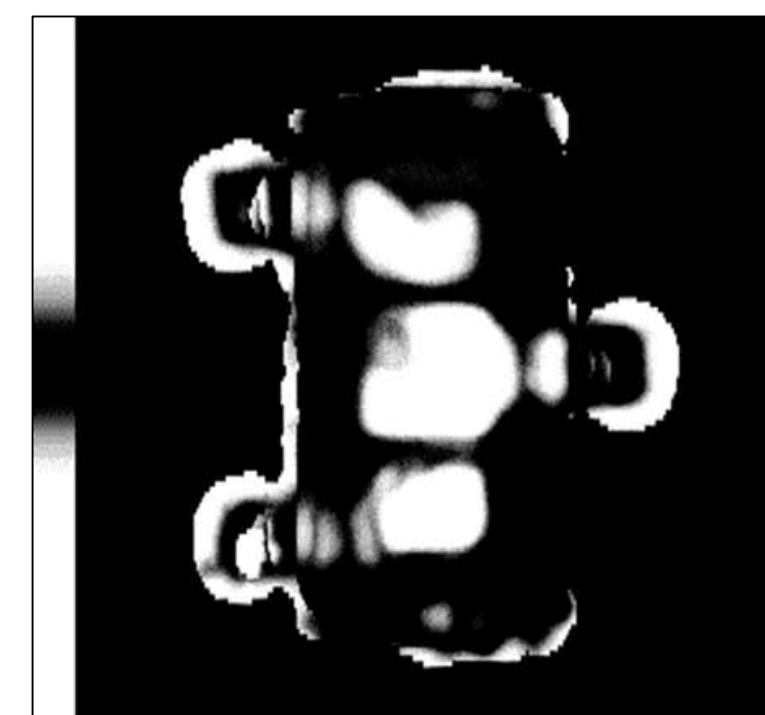
ST-Micro Op-Amp (1647)



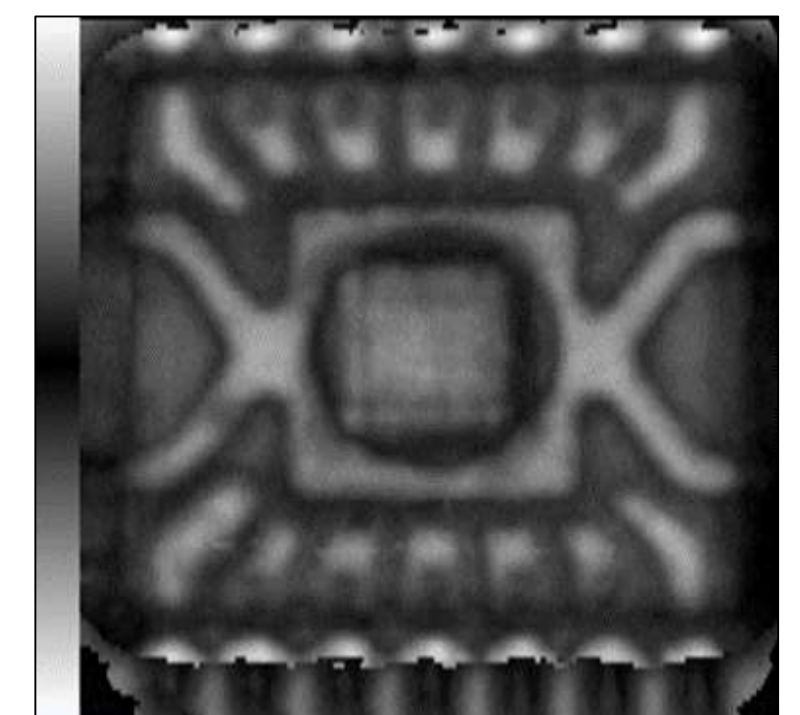
Infineon Diode (1829)



ST-Micro Op-Amp (1706)



Infineon Diode (1831)



ST-Micro Op-Amp (1816)



Sonoscan D-9000 System at Tyndall National Institute

Marking Permanence Test



Purpose: Evaluate the robustness of identification markings.

Method: ESCC24800

Solvents:

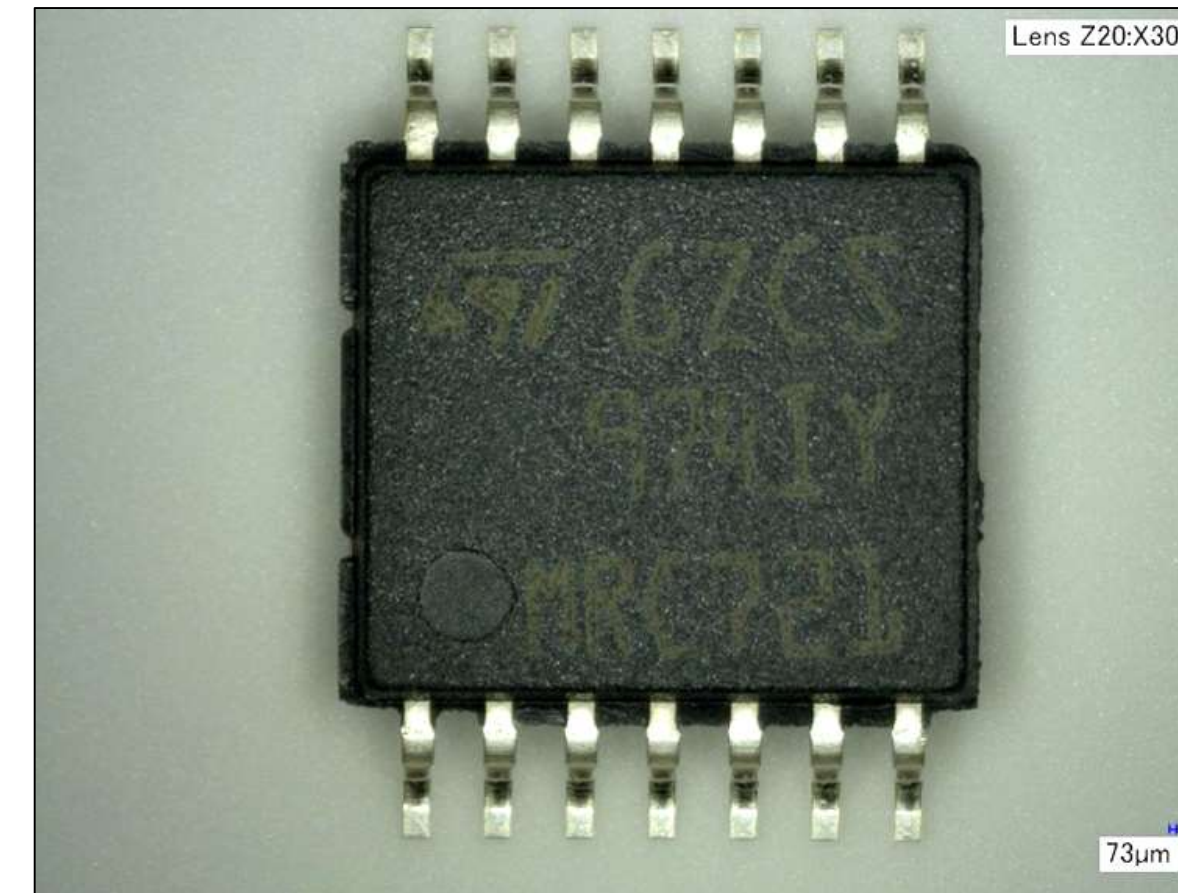
- Ethyl Alcohol (99.5%) or 95% pure by vol. at 25°C.
- Iso-Propyl Alcohol (99%) at 25°C.
- De-ionised water at 40°C.

Procedure:

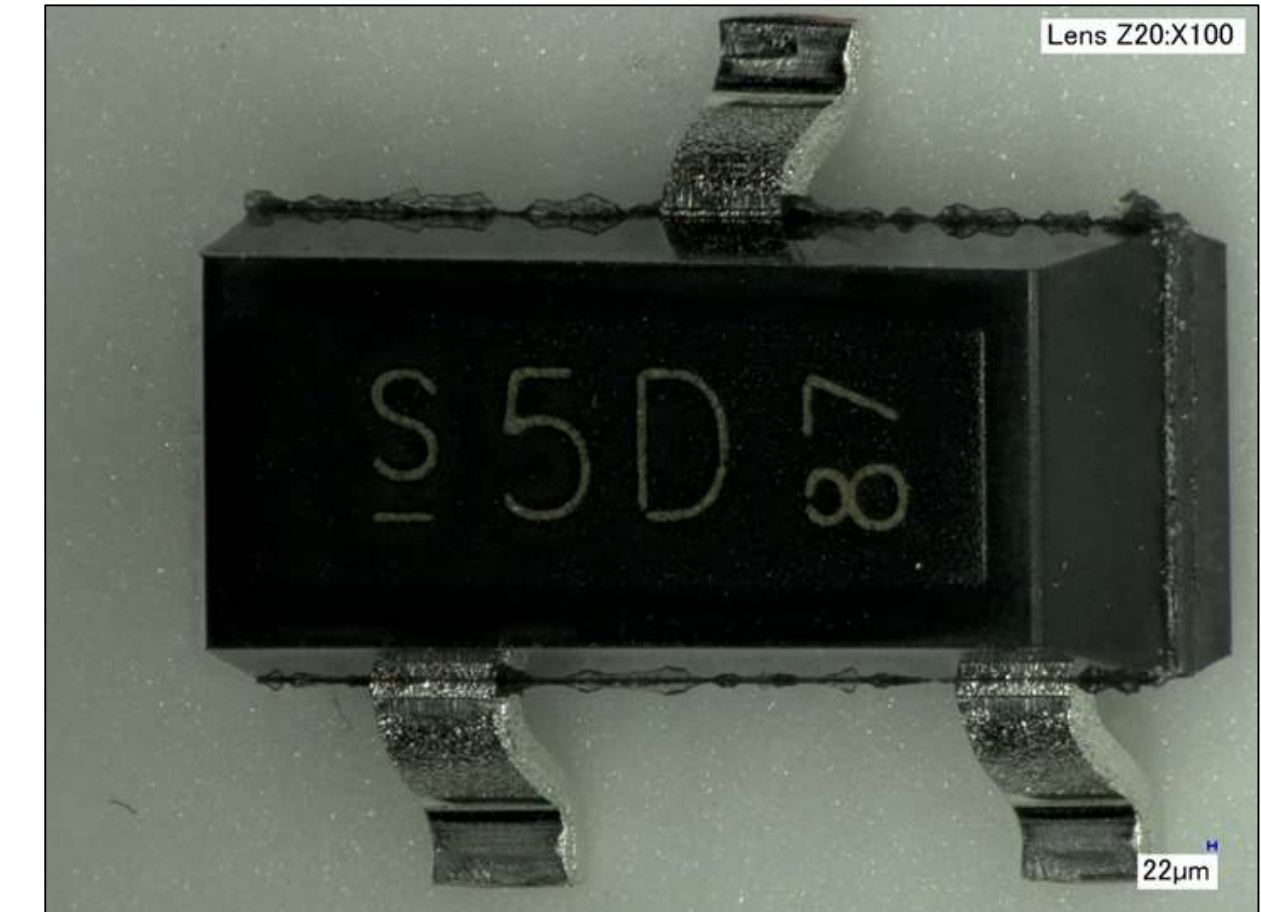
- Each sample exposed to each solvent in turn.
- Immersion for 60 sec.
- Brush (10 strokes).
- High Magnification Optical Inspection.

Result:

- ST-Micro Op-Amps (etched markings) – Pass
- Infineon Diodes (etched markings) - Pass



Examples of ST-Microelectronics Op-Amp Markings Following Solvent Tests (30X / 100X Mag)



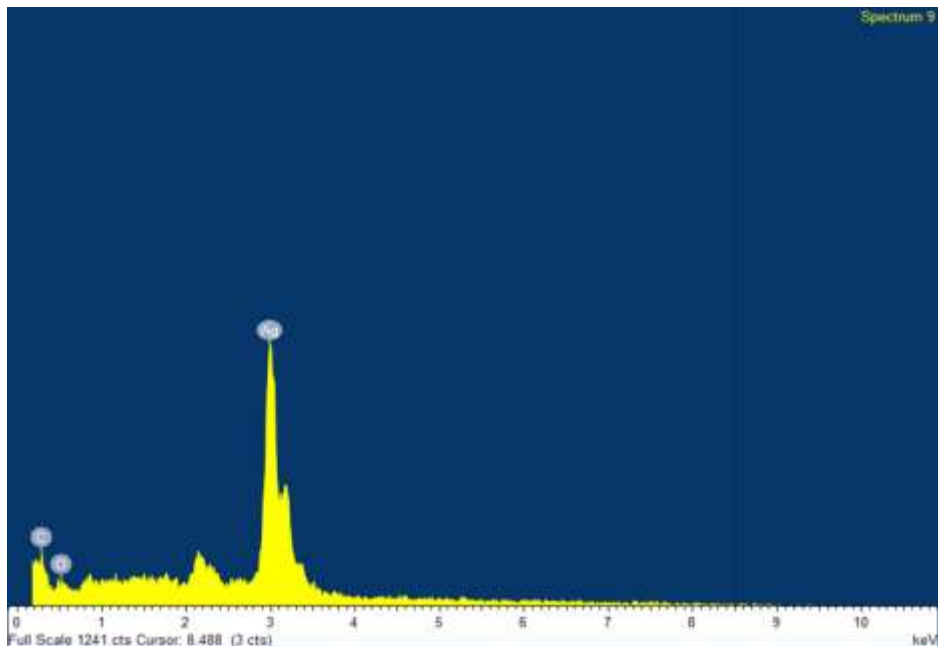
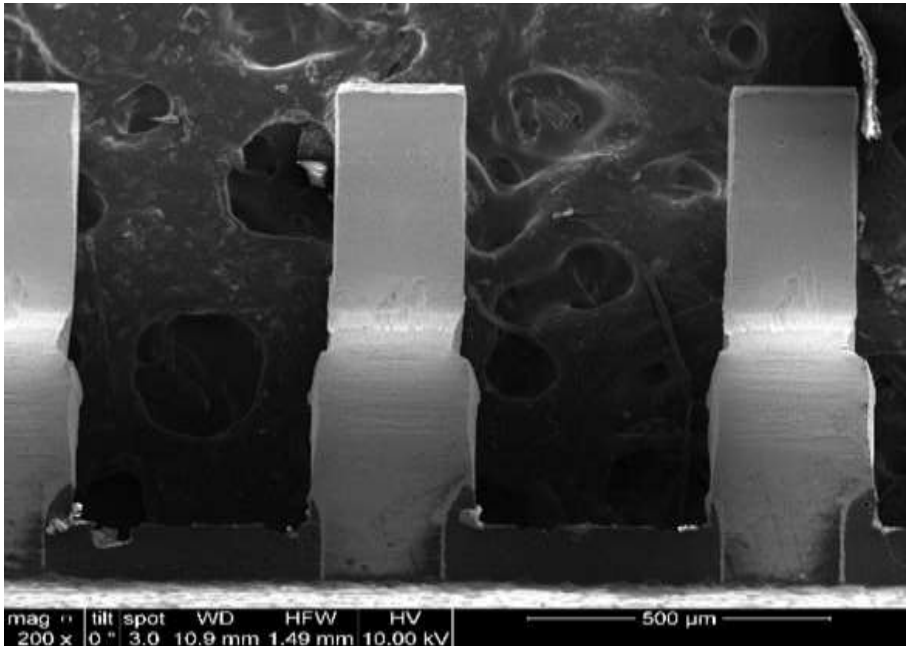
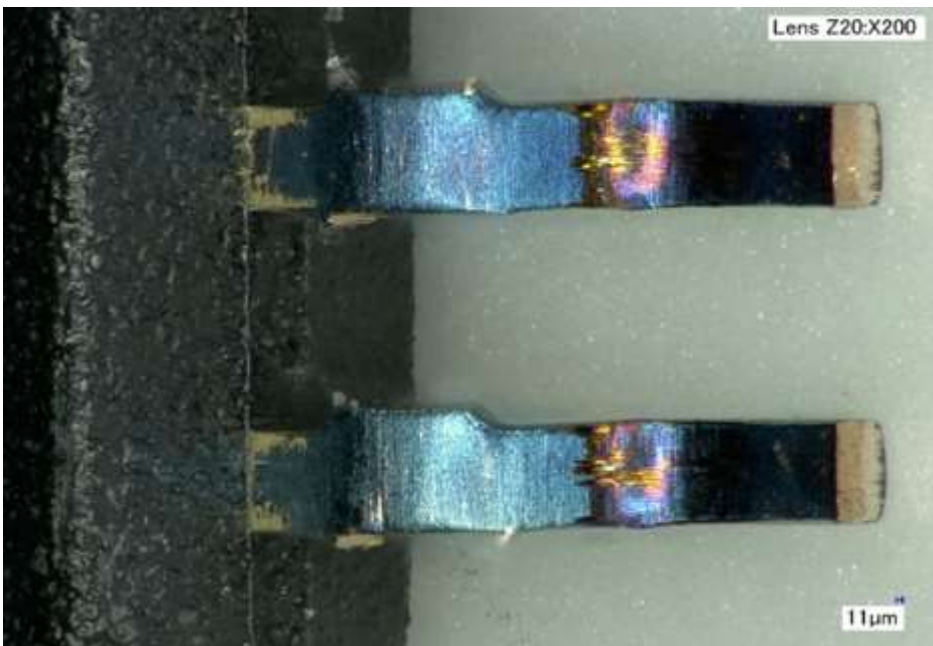
Examples of Infineon Diode Markings Following Solvent Tests (100X Magnification)

EDX Analysis of Termination Finish

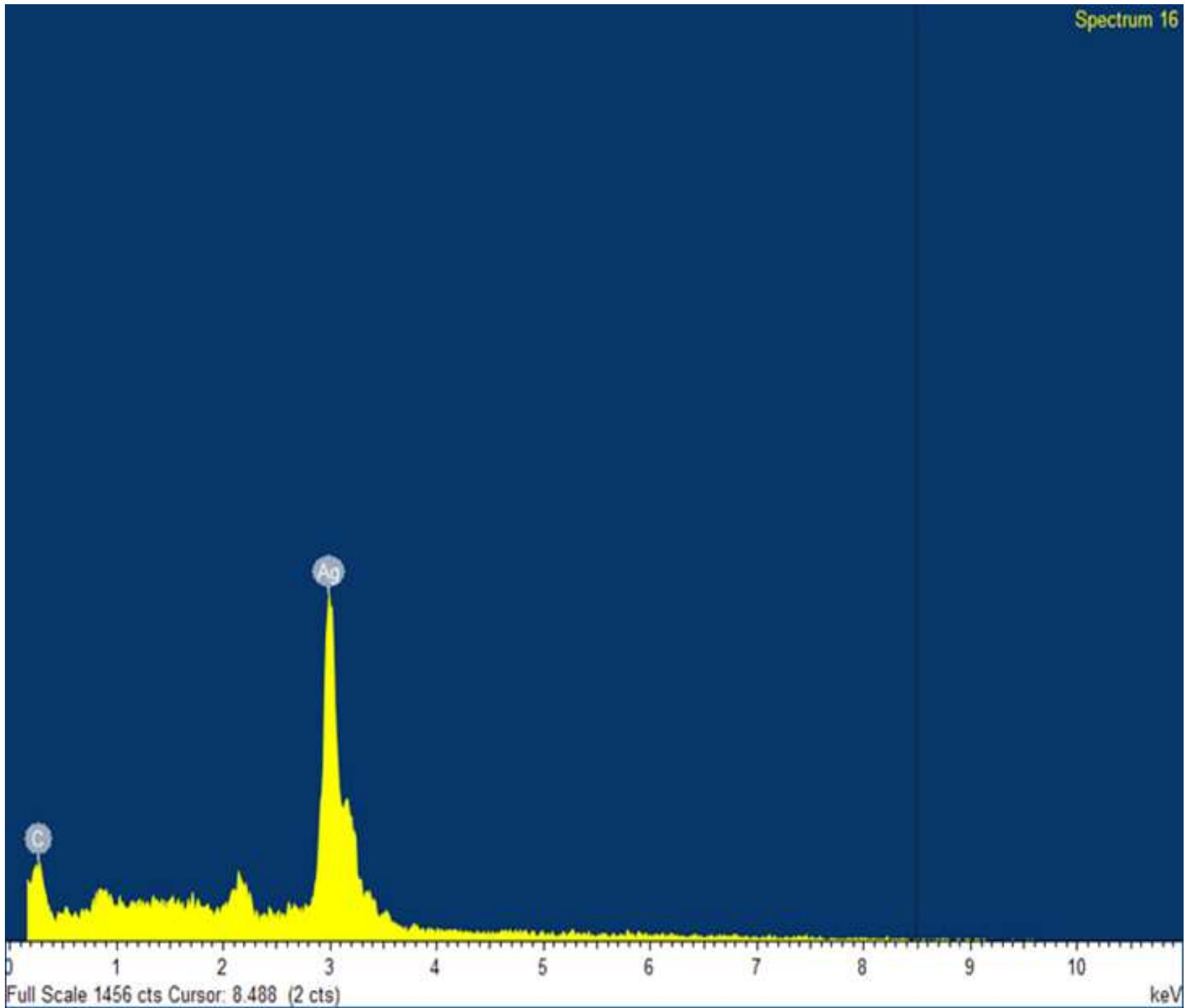


ST-Microelectronics Op-Amp

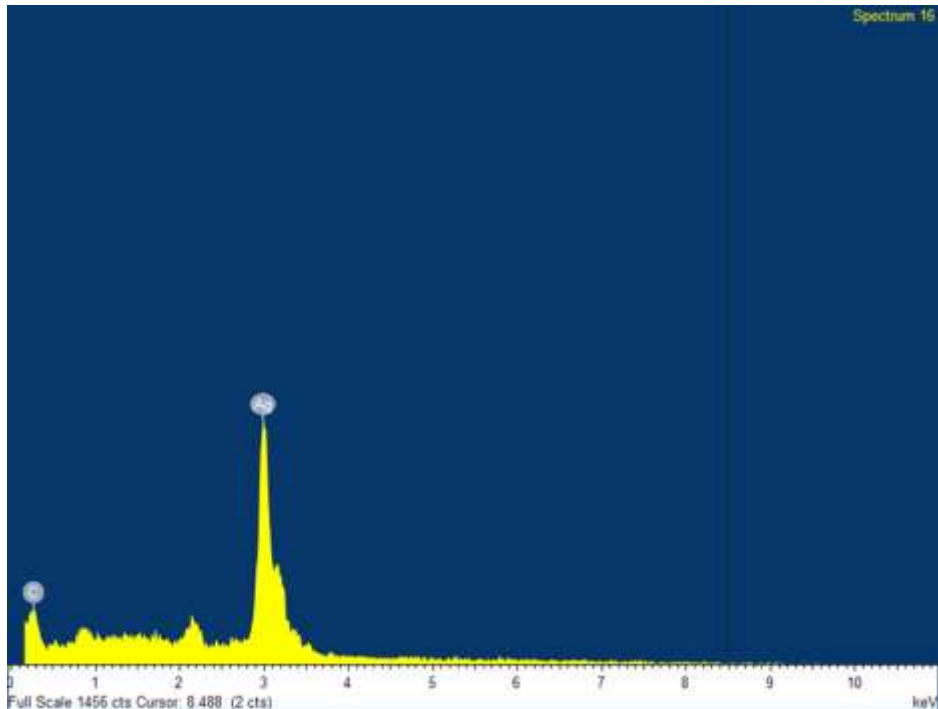
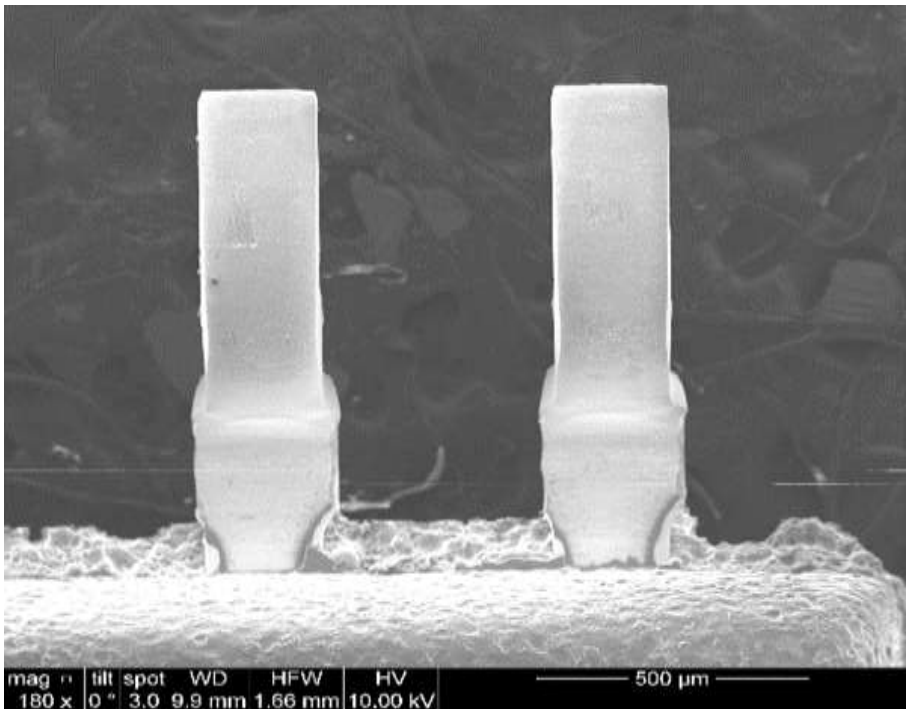
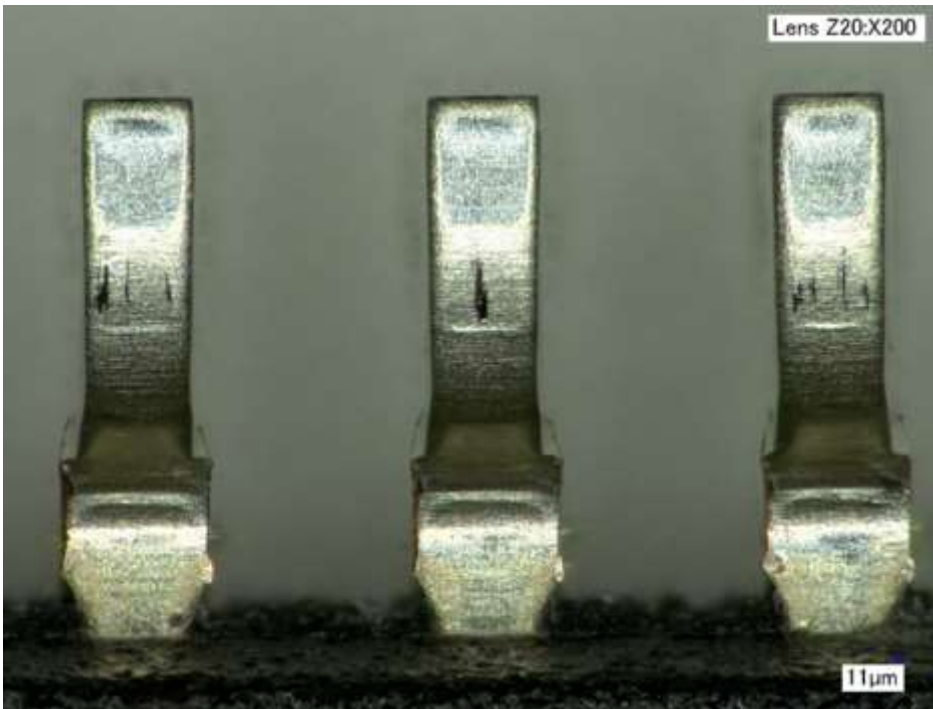
- Lot 1647 showed blue discolouration.
- Termination finish primarily Ag.
- Increased Oxygen in lot 1647



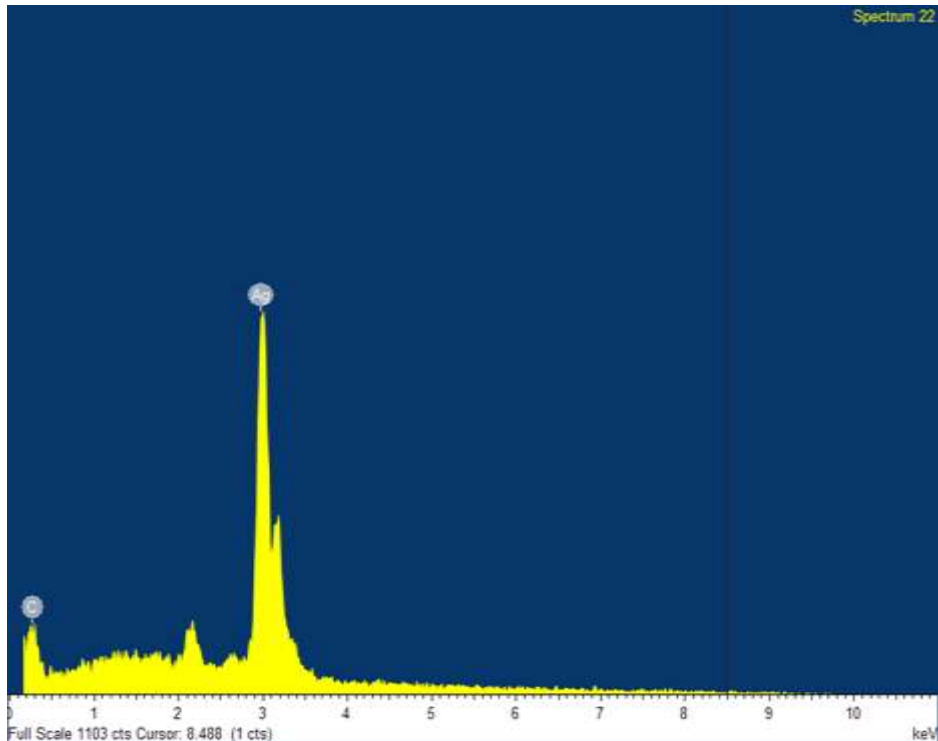
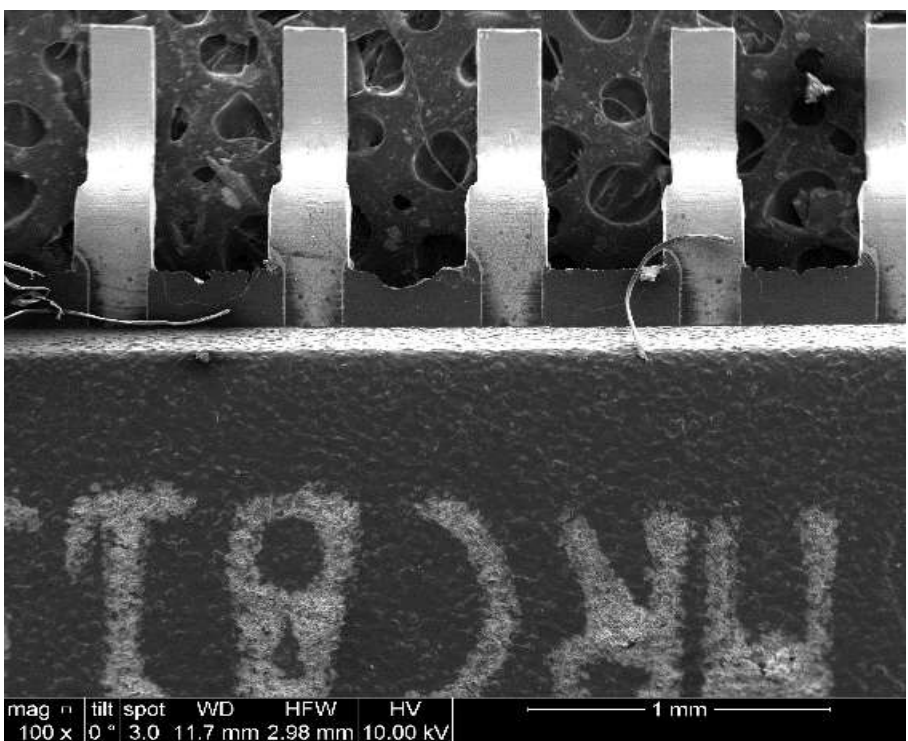
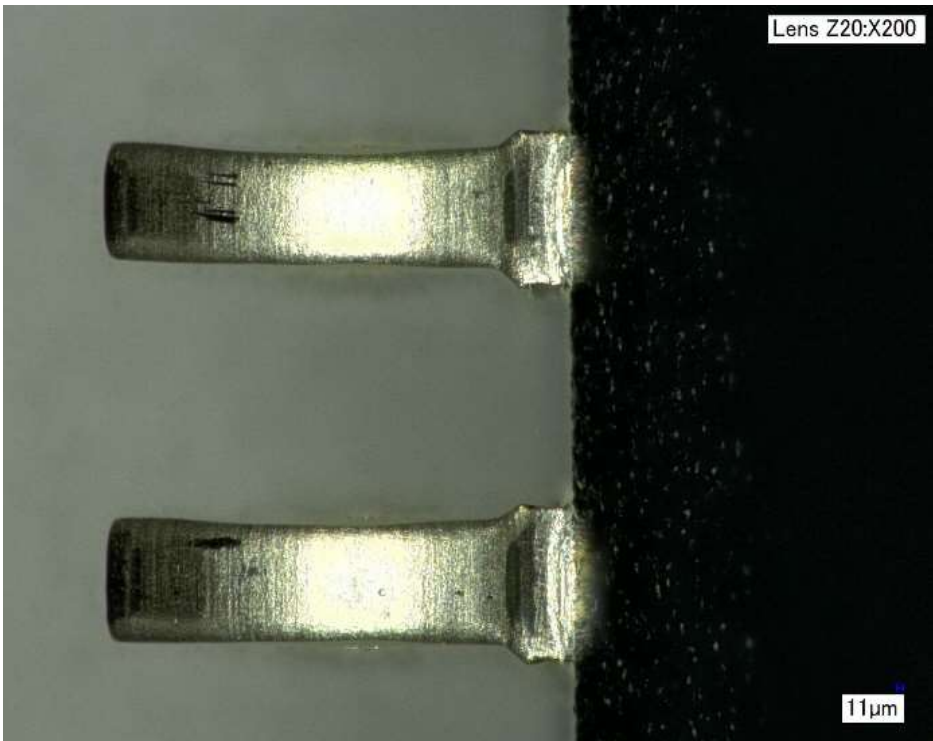
ST Microelectronics Op-Amp (Lot 1647)



Termination Finish – Primarily Silver (Ag)



ST Microelectronics Op-Amp (Lot 1706)



ST Microelectronics Op-Amp (Lot 1816)

EDX Analysis of Termination Finish

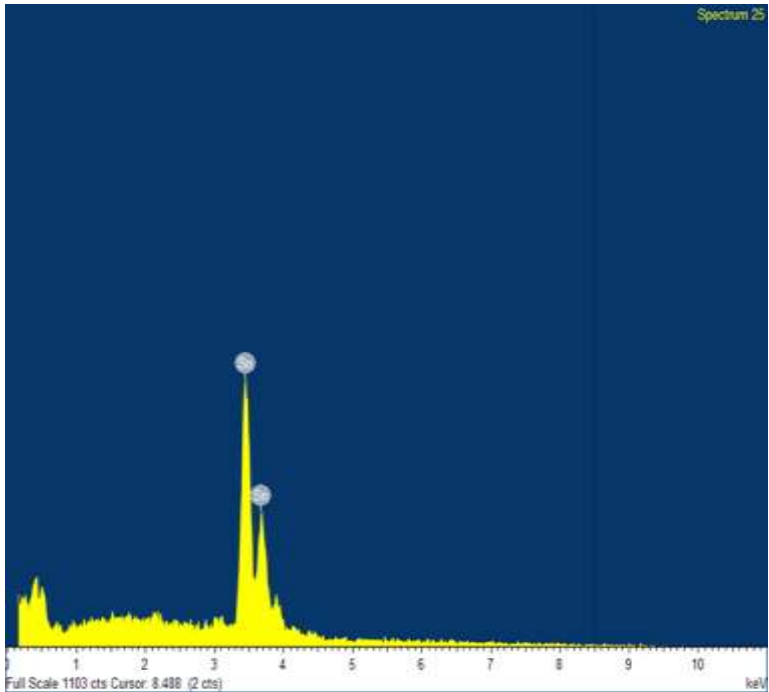
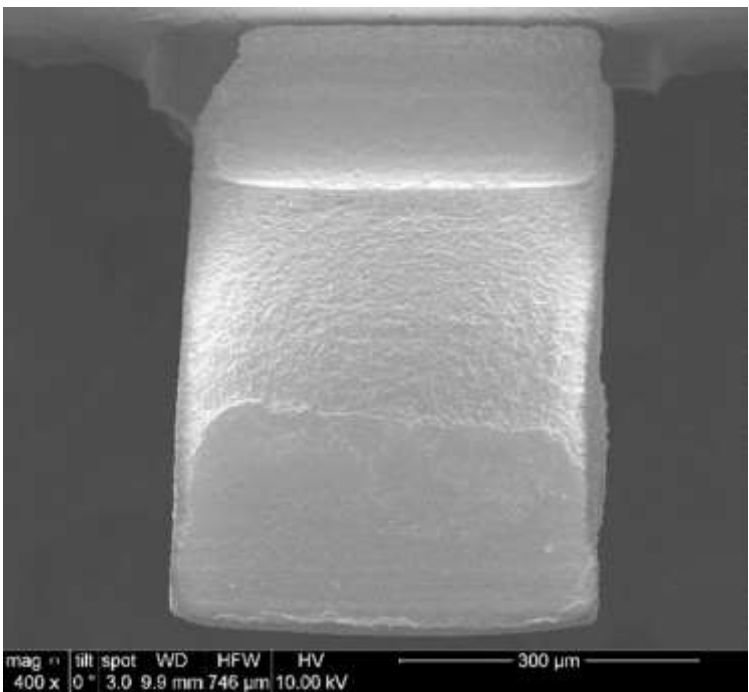


Infineon Diodes

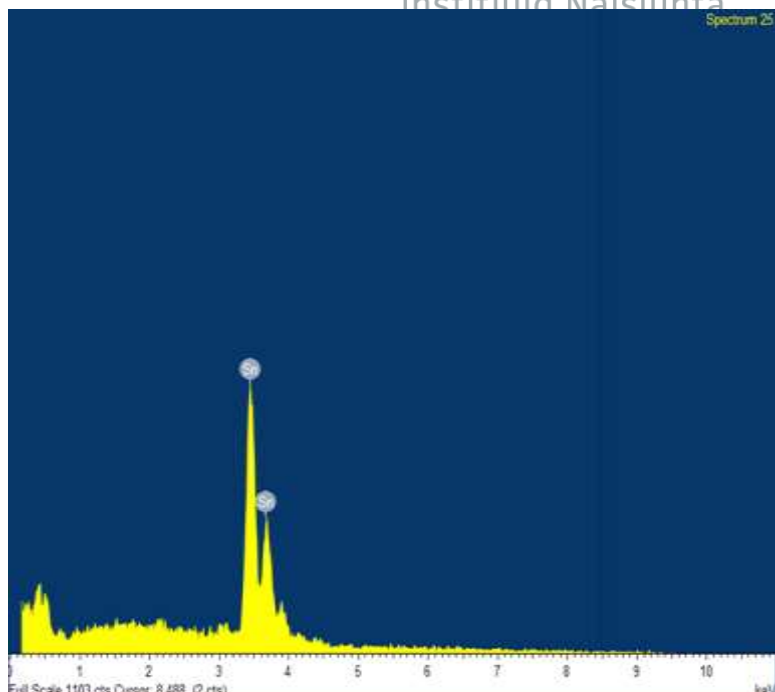
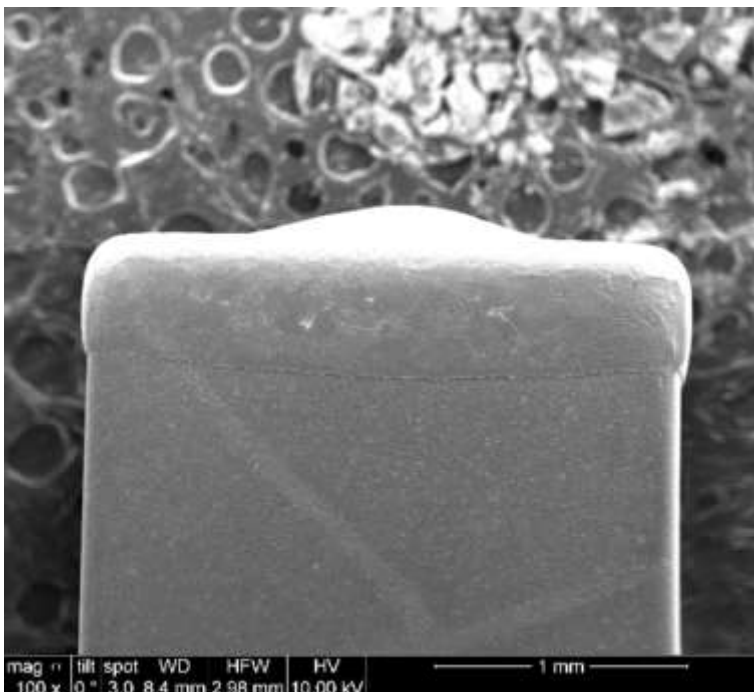
- Termination finish primarily Sn.
- No differences between lots.

AVX Capacitors

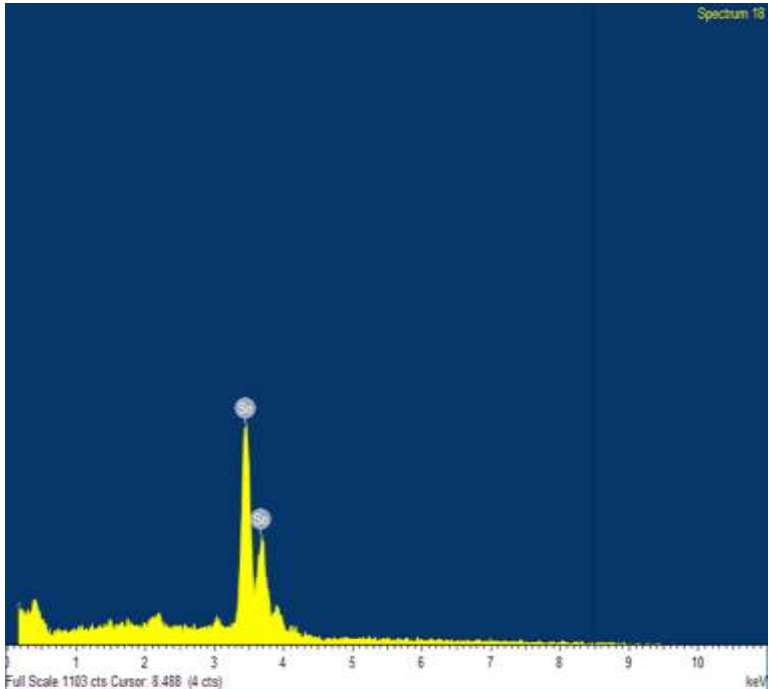
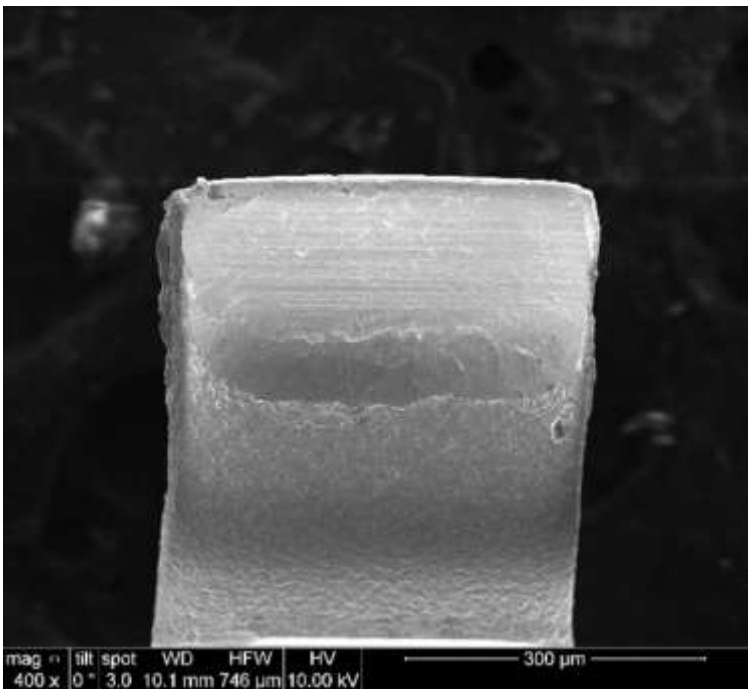
- Termination finish primarily Sn.
- No differences between lots.



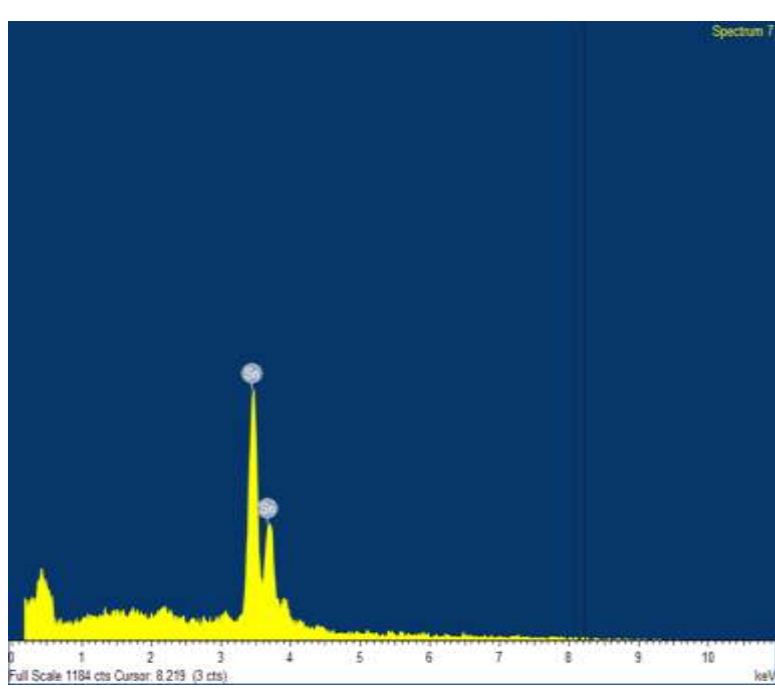
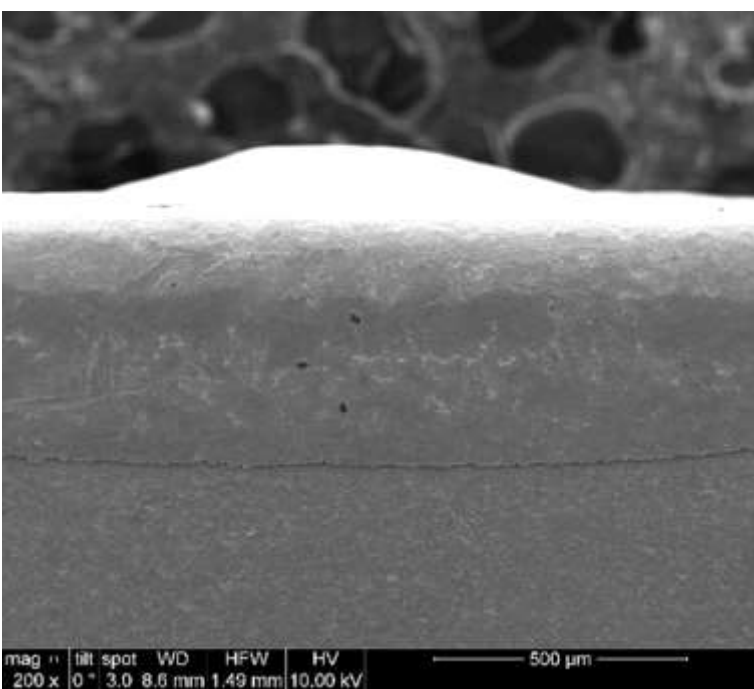
Infineon Diode (Lot 1536)



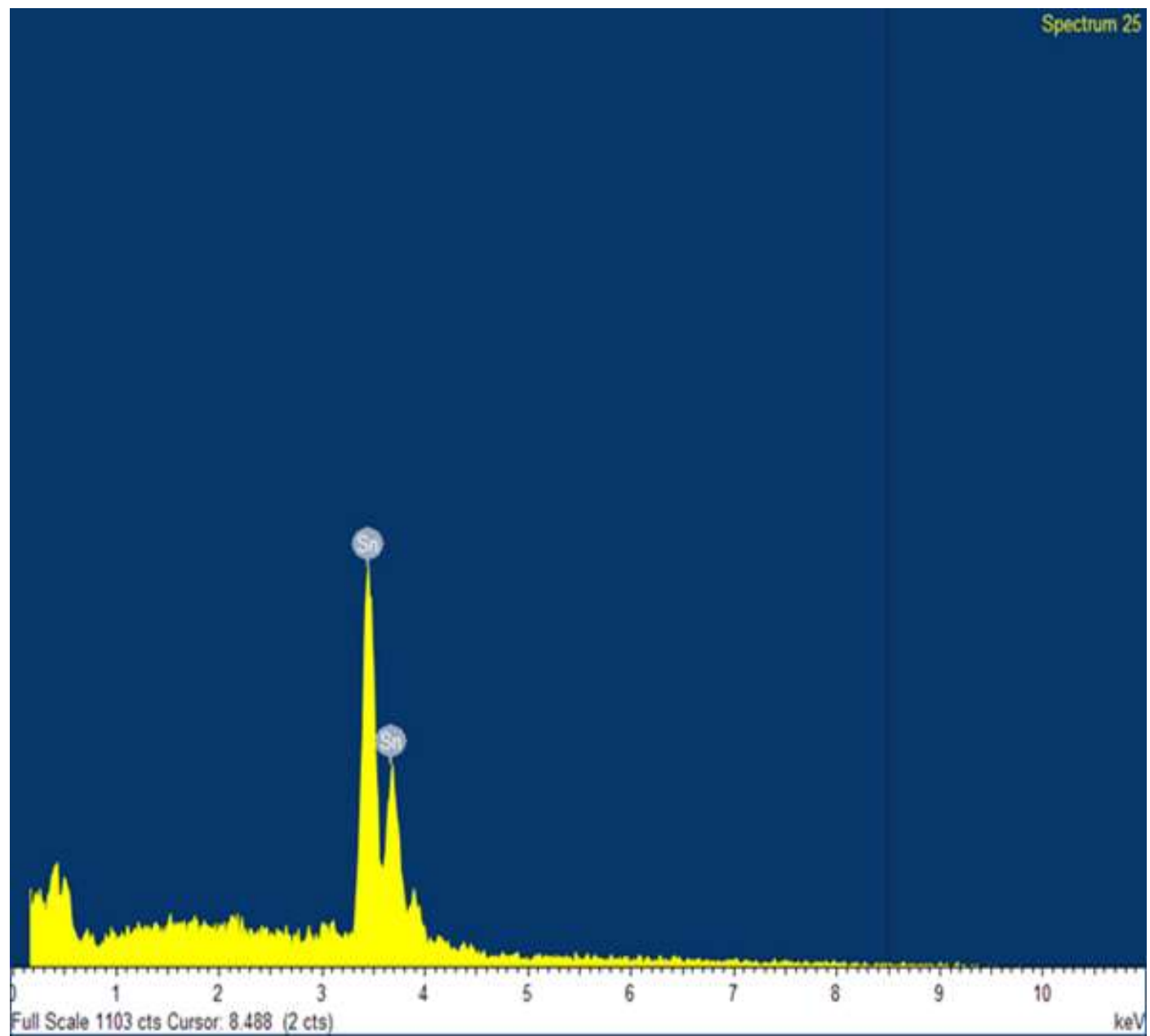
AVX Capacitor (Lot 1820)



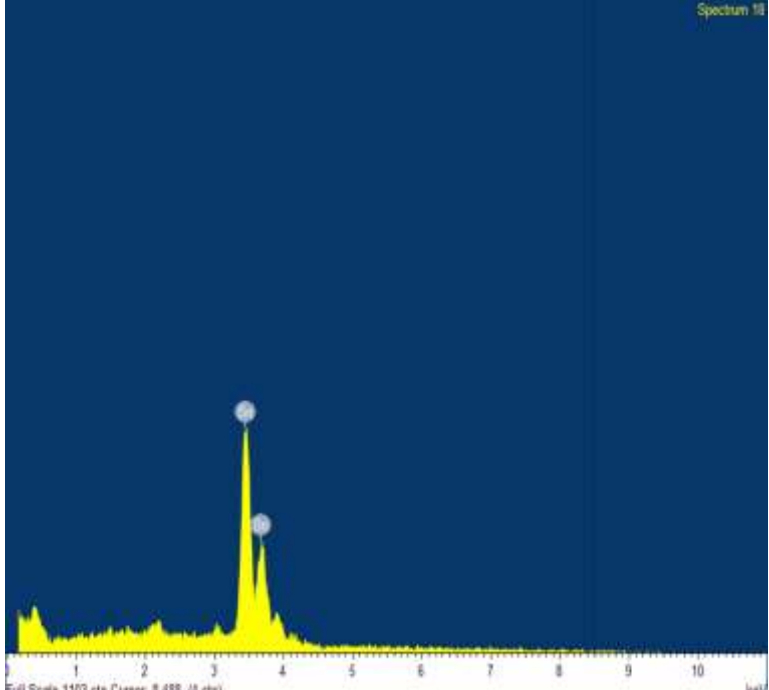
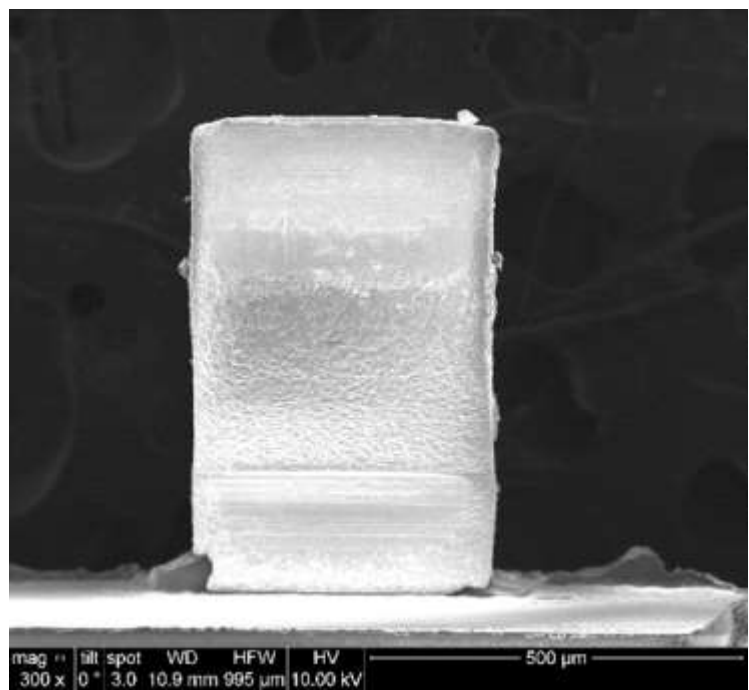
Infineon Diode (Lot 1829)



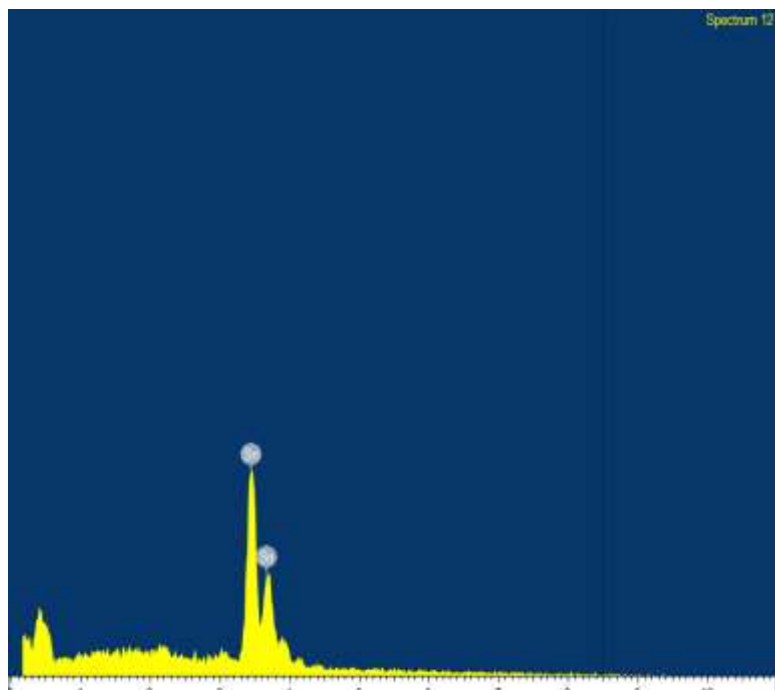
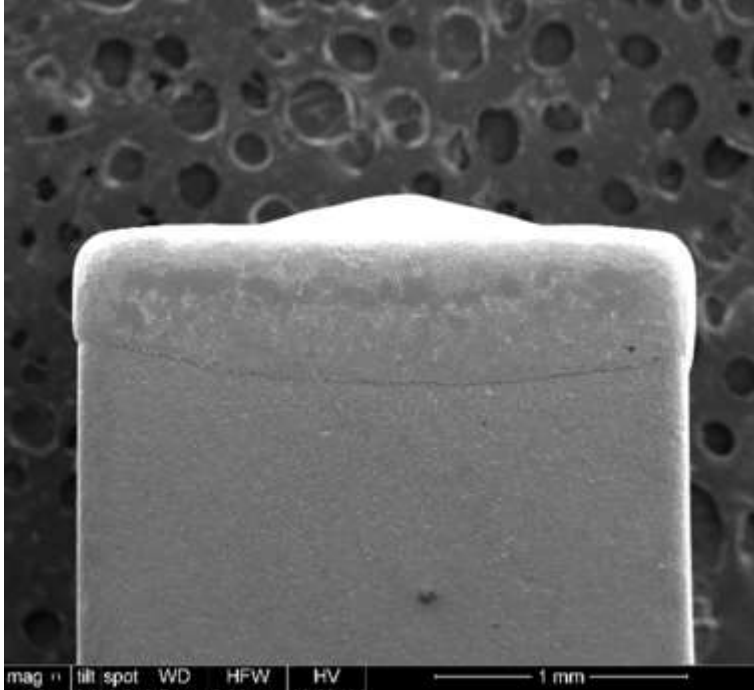
AVX Capacitor (Lot 1927)



Termination Finish – Primarily Tin (Sn)



Infineon Diode (Lot 1831)



AVX Capacitor (Lot 1937)

Solderability Test

Purpose: Assess solderability & compare lot-to-lot performance

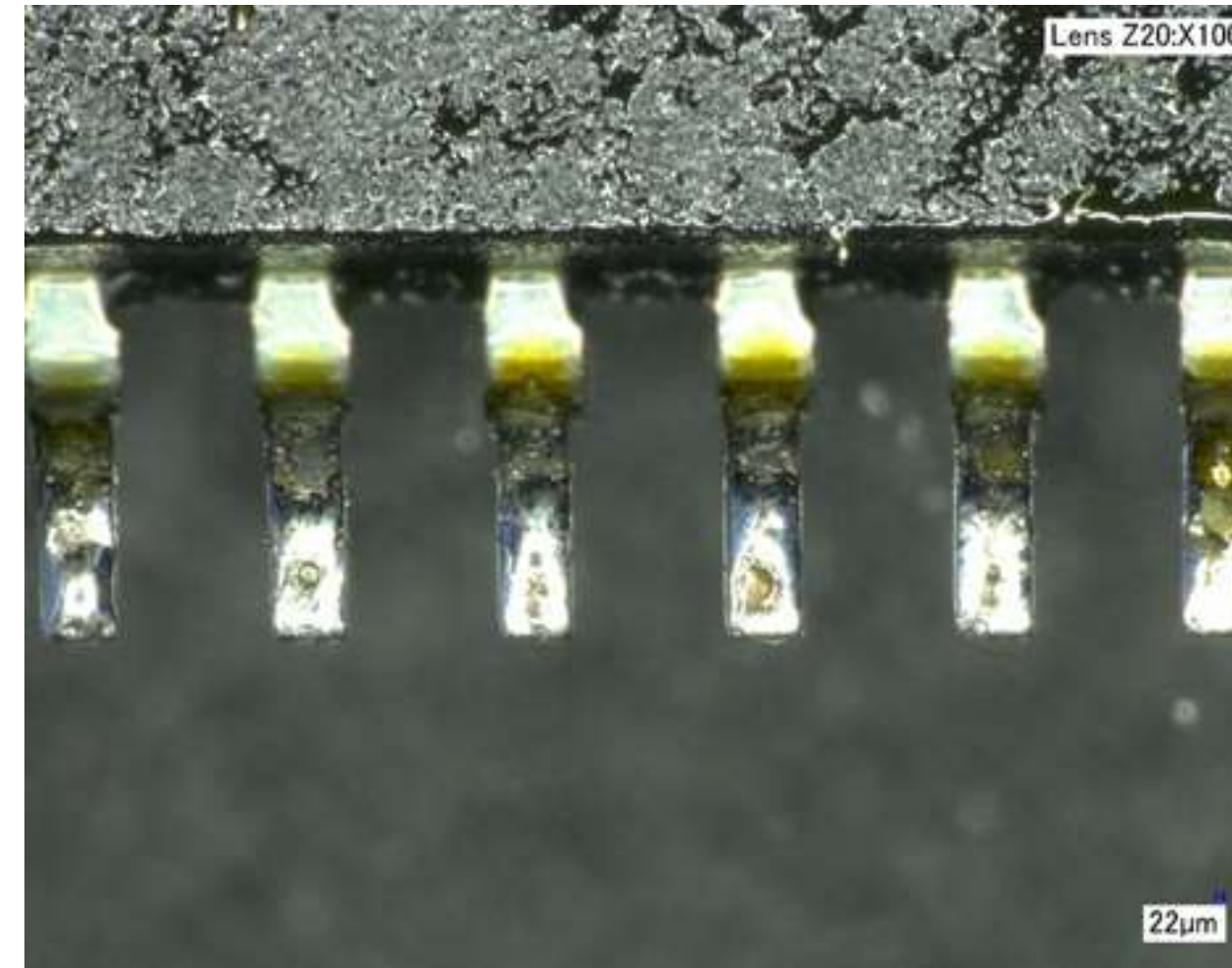
Method: Mil-Std-883, TM 2003 (Dip & Look Test)

Procedure:

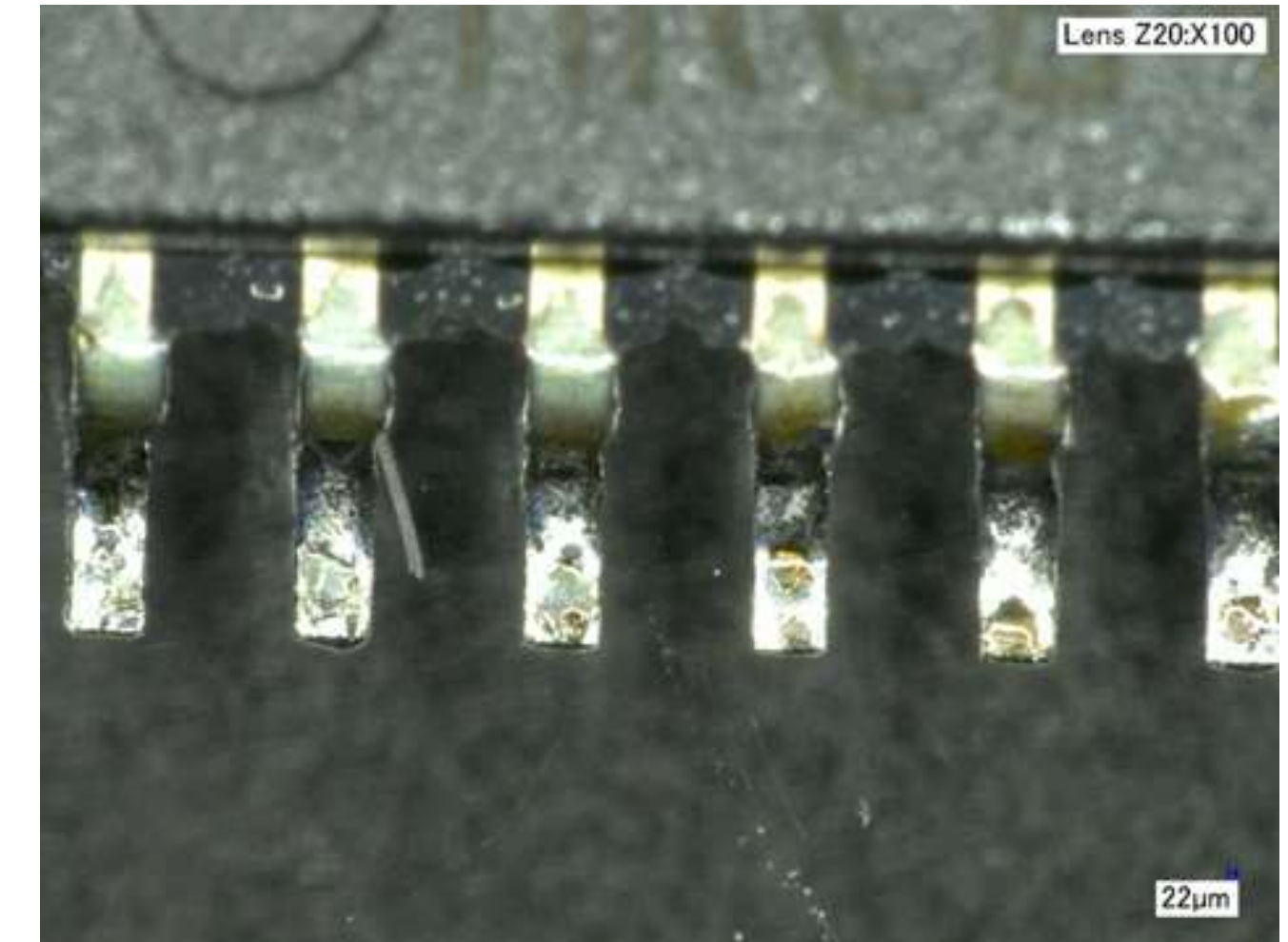
- 2 Samples selected from each lot
- Preconditioning (Steam ageing) 8 hours
- Air dry for 15mins
- Flux dip (10sec)
- One side SnPb dip at 245 °C
- One side SAC305 dip at 265 °C
- Inspect for 95% coverage.

Result

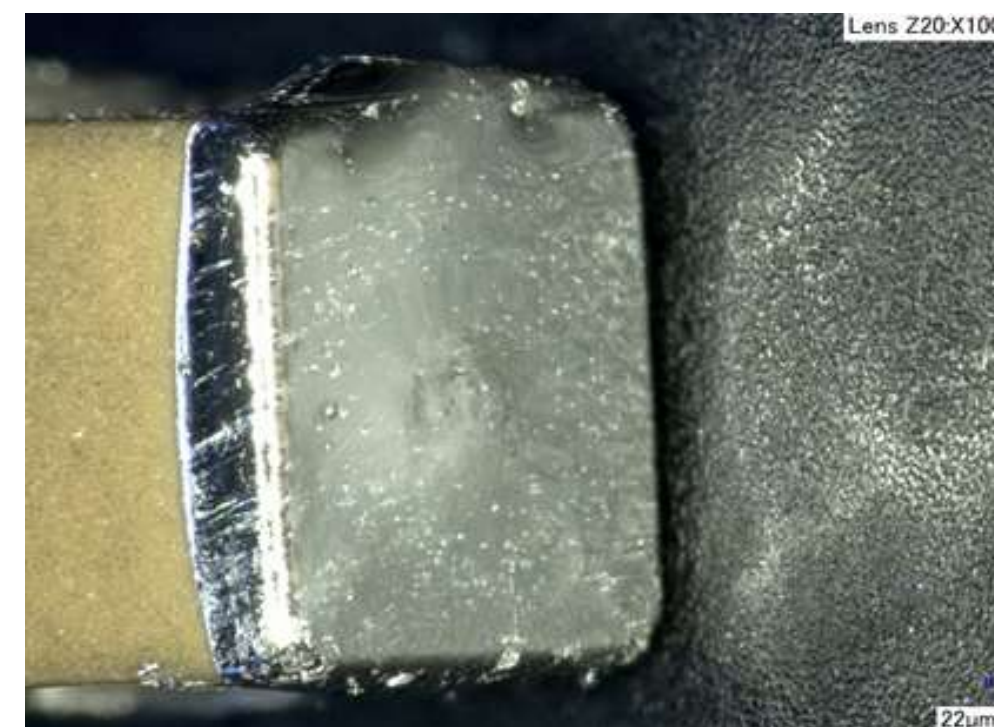
- All samples pass.
- Op-Amp Lot 1647 solders well.



ST-Micro Op-Amp (Lot 1647) SnPb



ST-Micro Op-Amp (Lot 1647) SAC305



AVX Capacitor (Lot 1820) SnPb



Infineon Diode SAC305 (Lot 1831) SAC305

Termination Strength Test

Purpose: Test Ability of Terminations to Withstand Load.

Method: Mil-Std-883, TM 2004, Condition A (Tension)

Procedure:

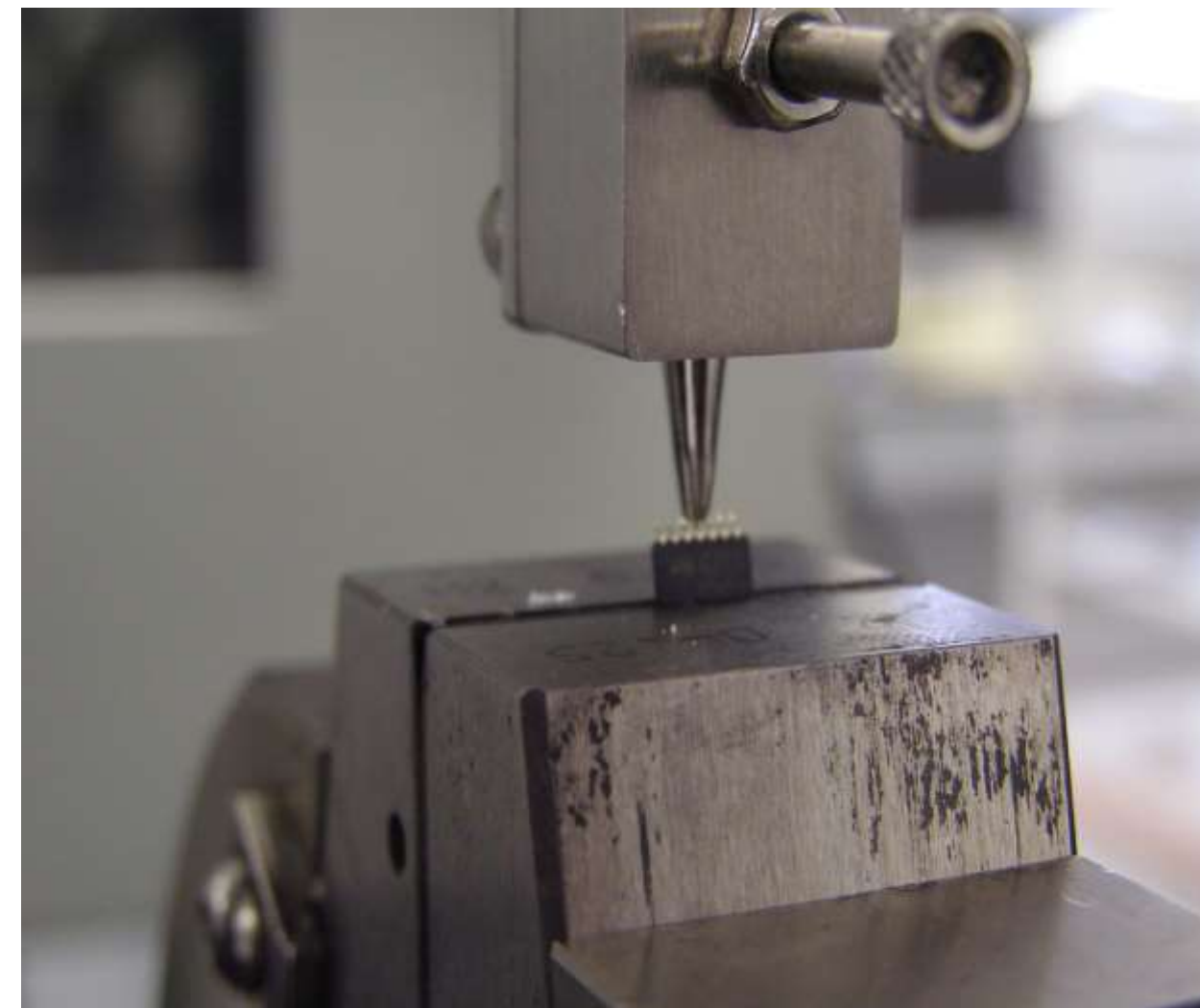
- *2 Samples selected from each lot*
- *Tensile load of 227gF applied*
- *Load maintained for 30sec.*
- *Inspect termination for damage.*

Result:

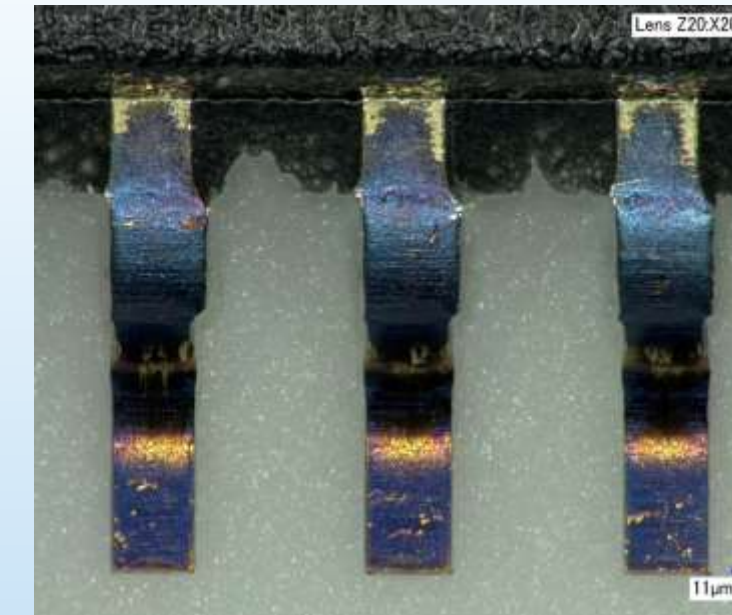
- *All Op-Amp & Diode Lots Pass.*



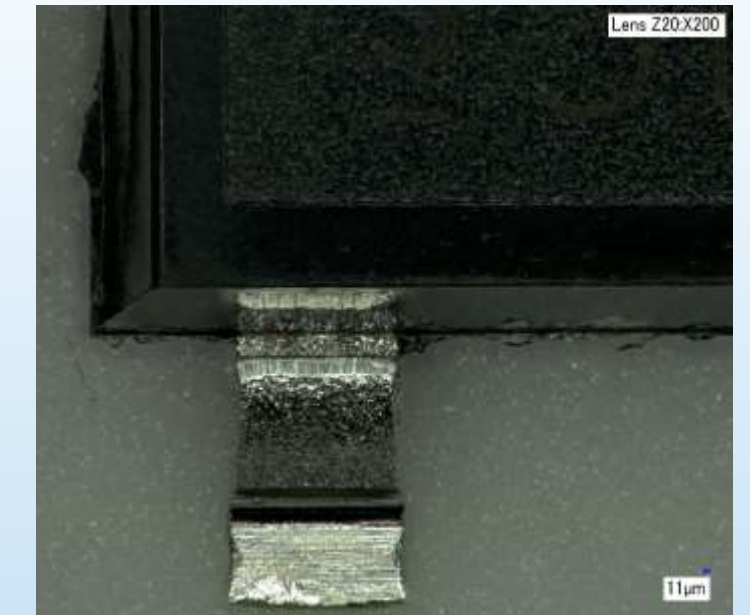
Instron 5565 Mechanical Tester



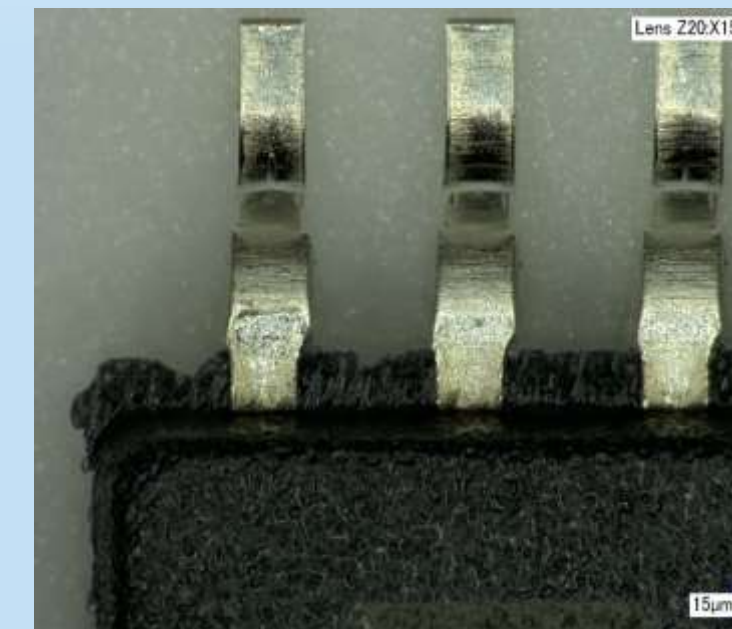
Test for Op-Amp Components



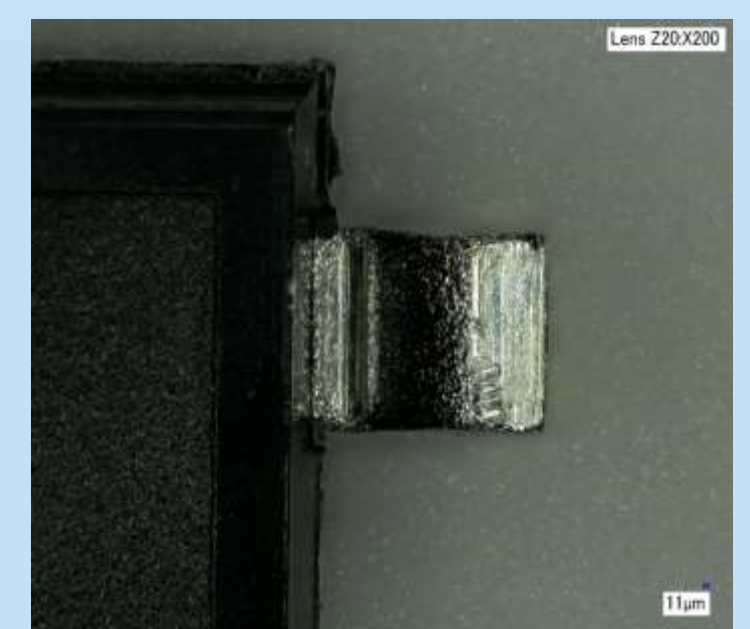
Op-Amp Lot 1647



Diode Lot 1536



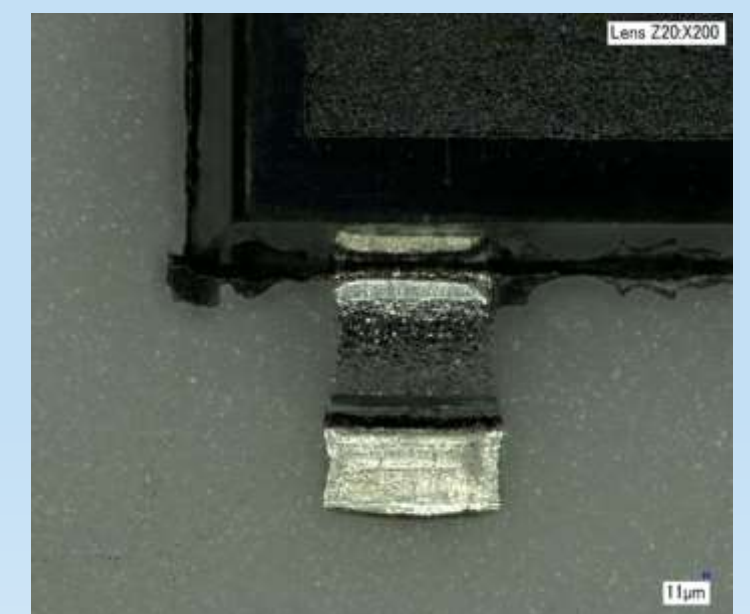
Op-Amp Lot 1706



Diode Lot 1829



Op-Amp Lot 1816



Diode Lot 1831

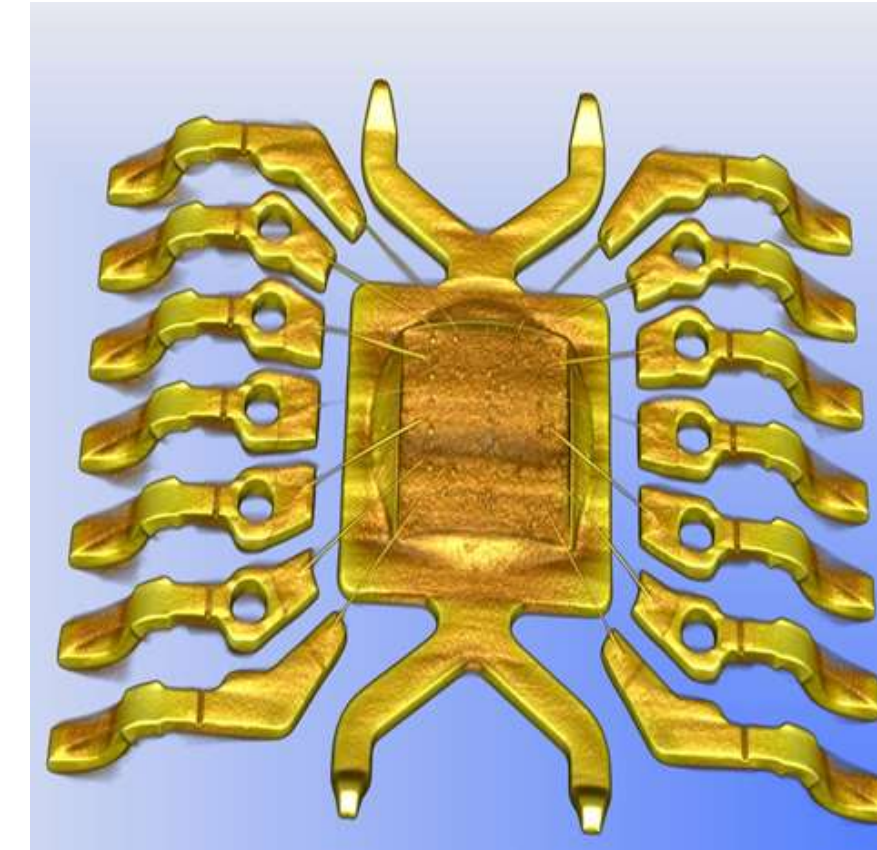
Chemical De-cap

Risks:

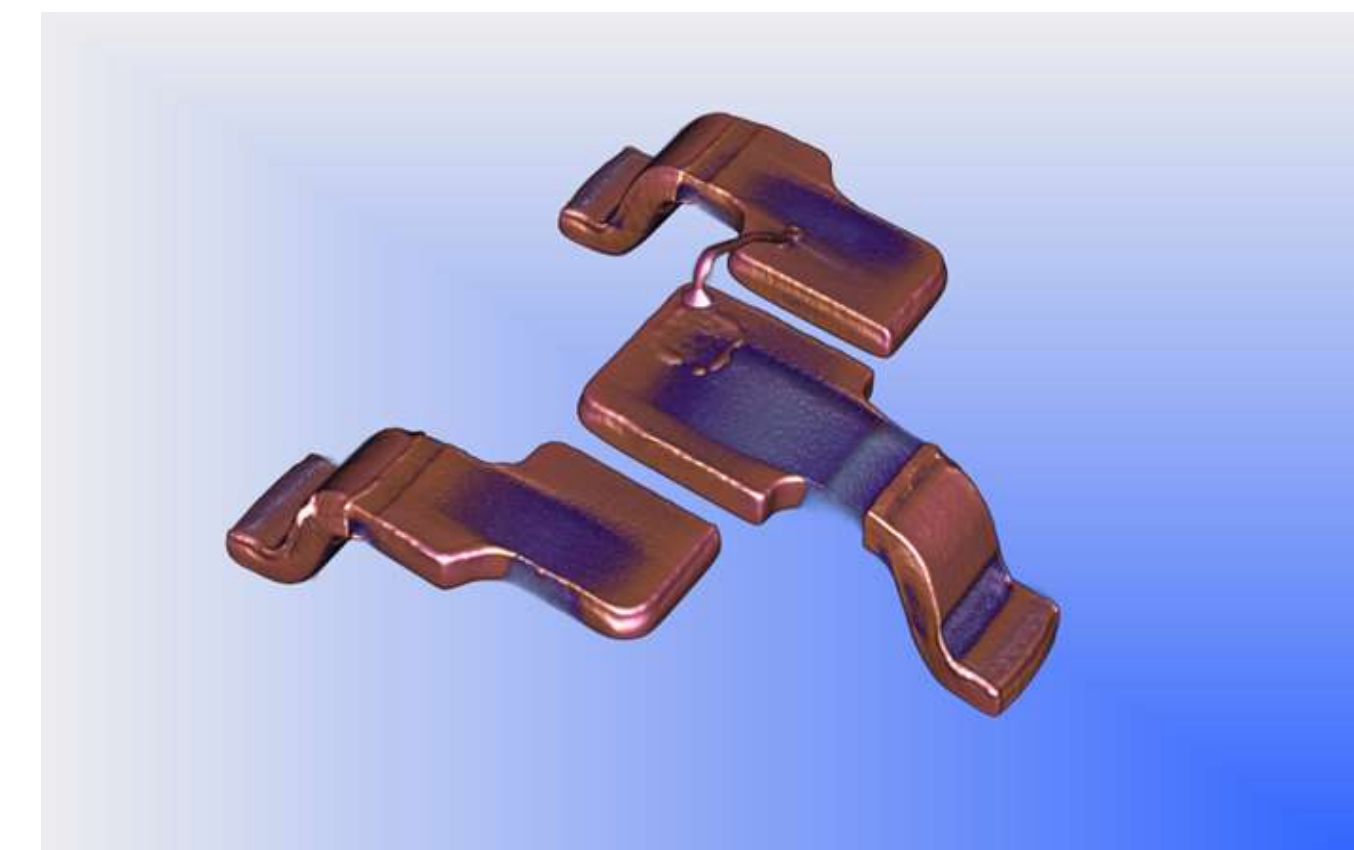
- Aggressive acid etch can damage internal metallisation.
- Cu wire bonds & lead frame vulnerable.
- Loss of structural integrity can damage bond wires.

Procedure:

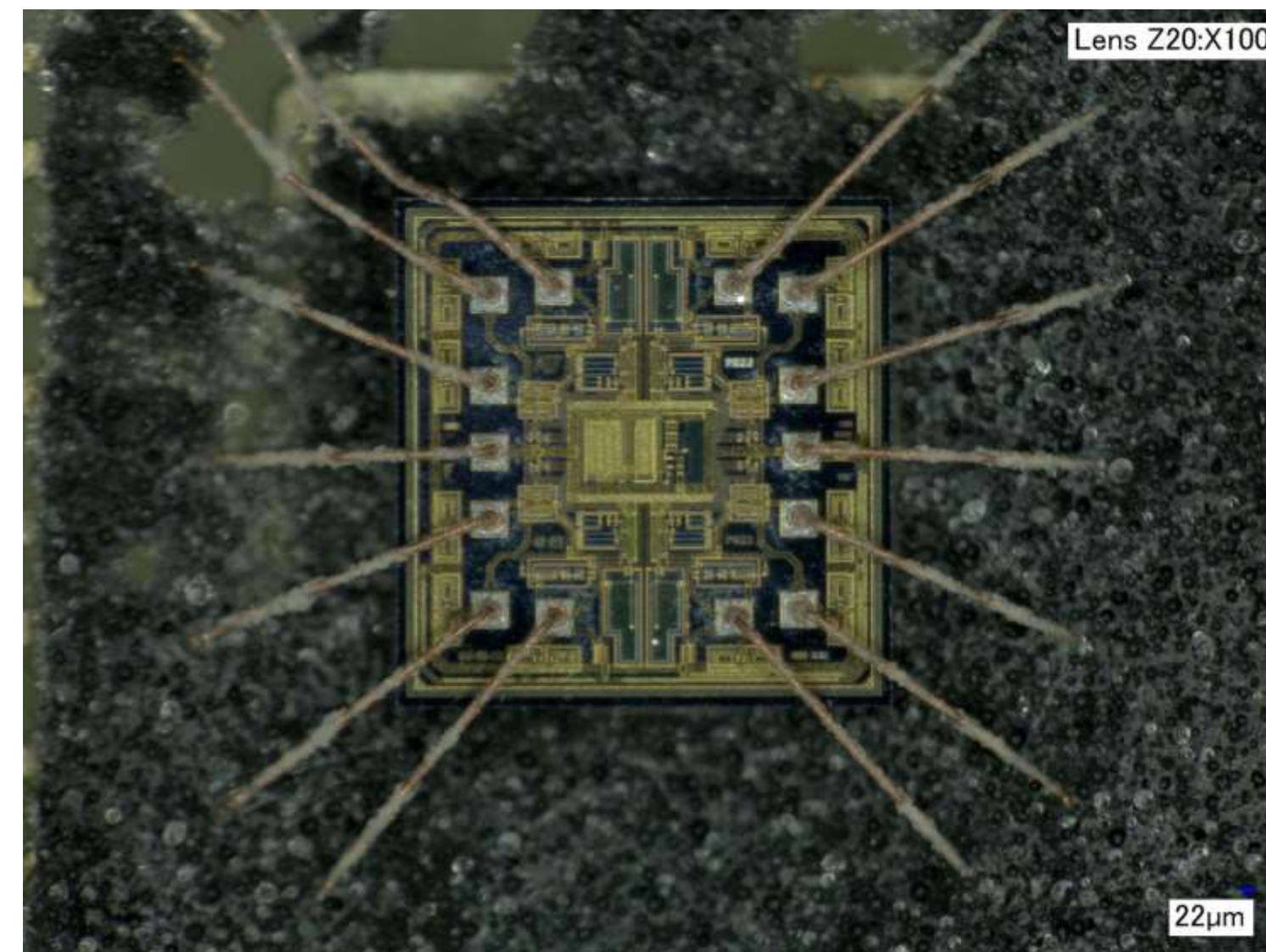
- 4 Samples selected from each lot.
- Mounted on glass slide using Ag-filled die-attach.
- Adhesive cured for 2 hours @ 125 °C
- Sample heated to 90 °C
- Boiling 90% HNO_3 (fuming nitric acid)
- Acid dropped on centre of sample.
- Reaction controlled with acetone rinse.



CT-Scan ST Micro Op-Amp



CT-Scan Infineon Diode



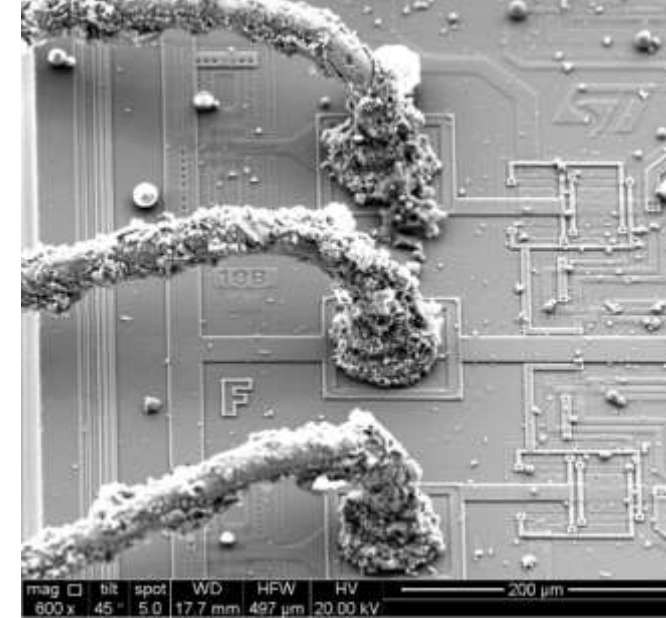
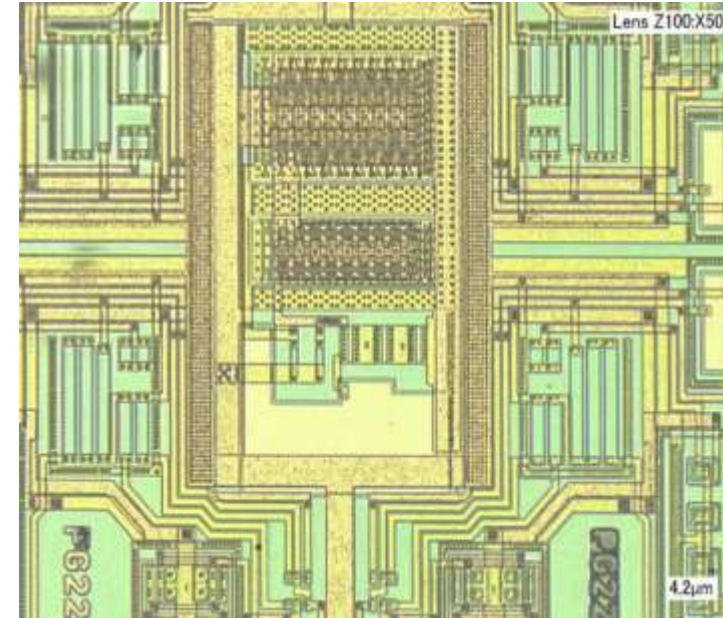
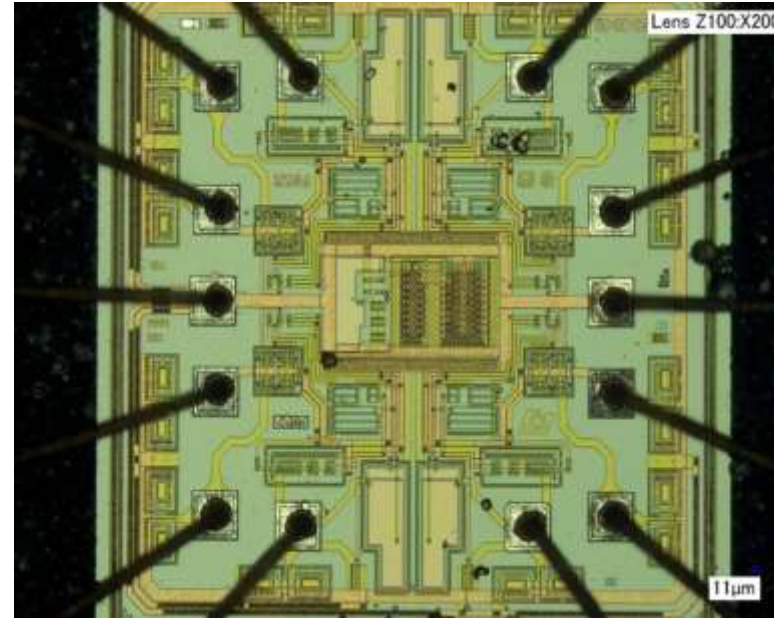
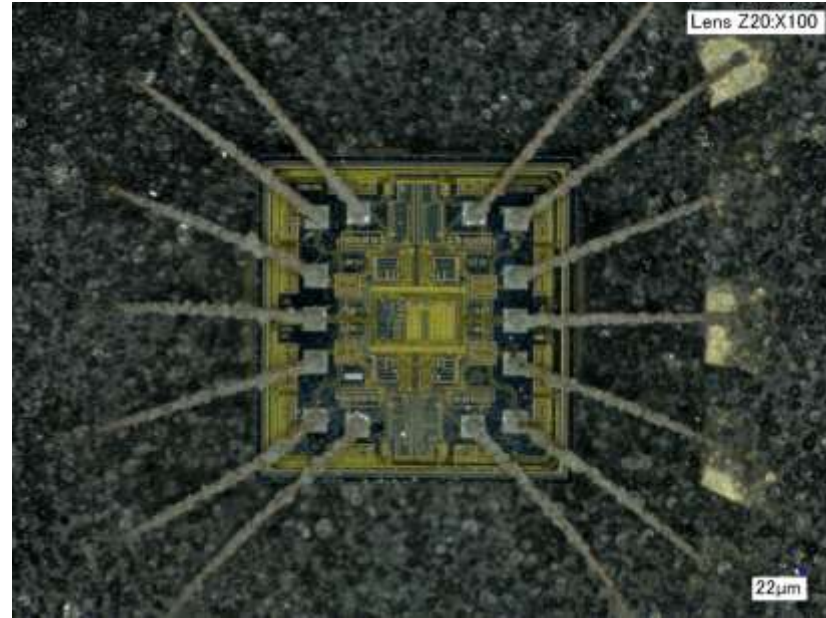
De-capped ST Microelectronics Op-Amp



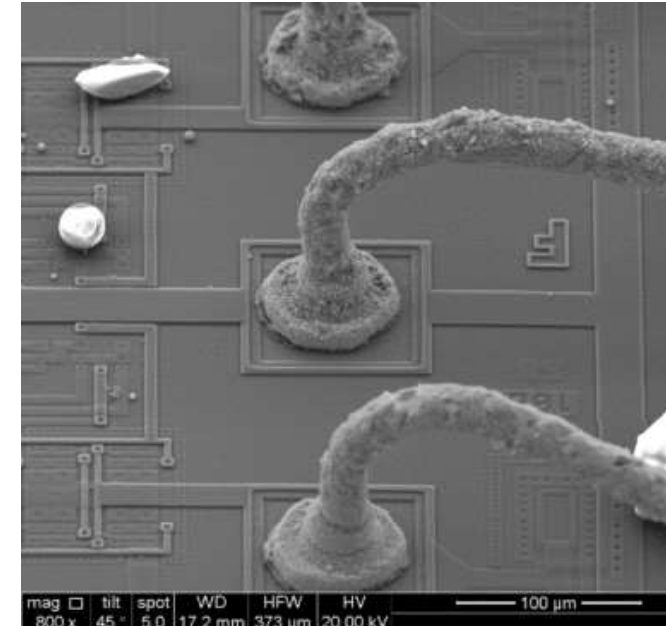
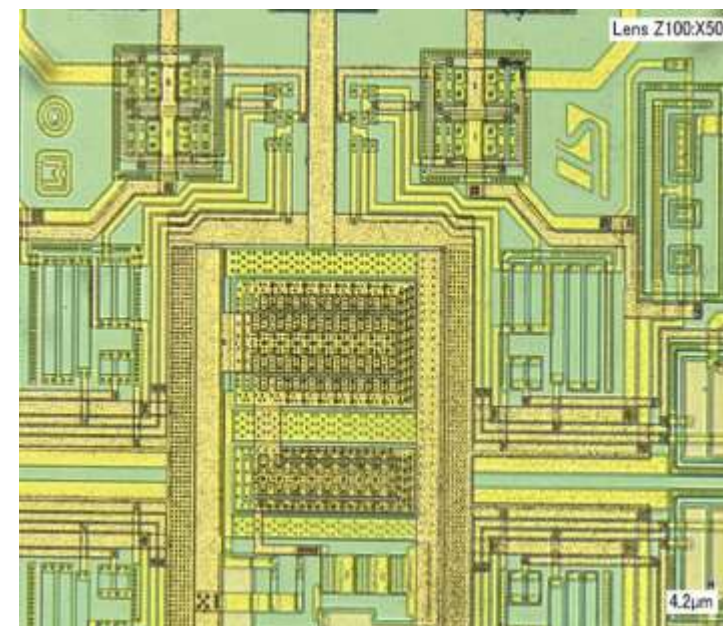
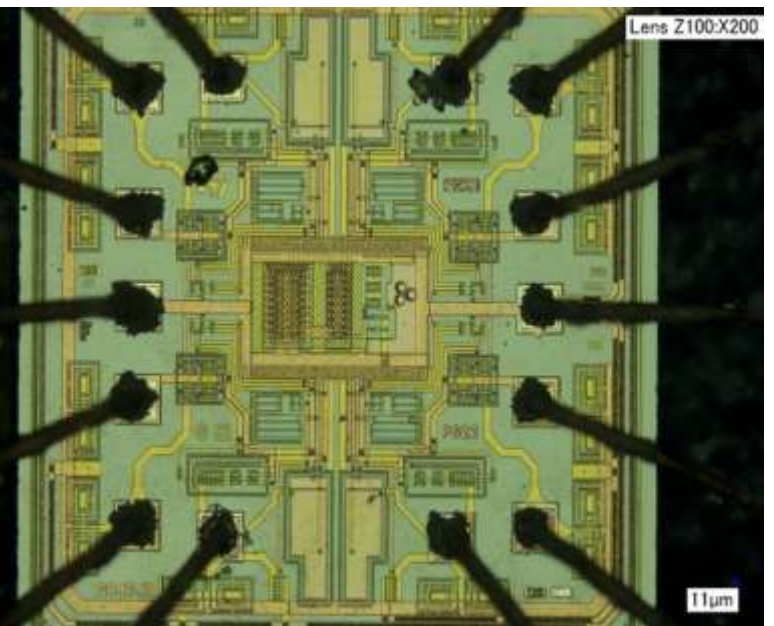
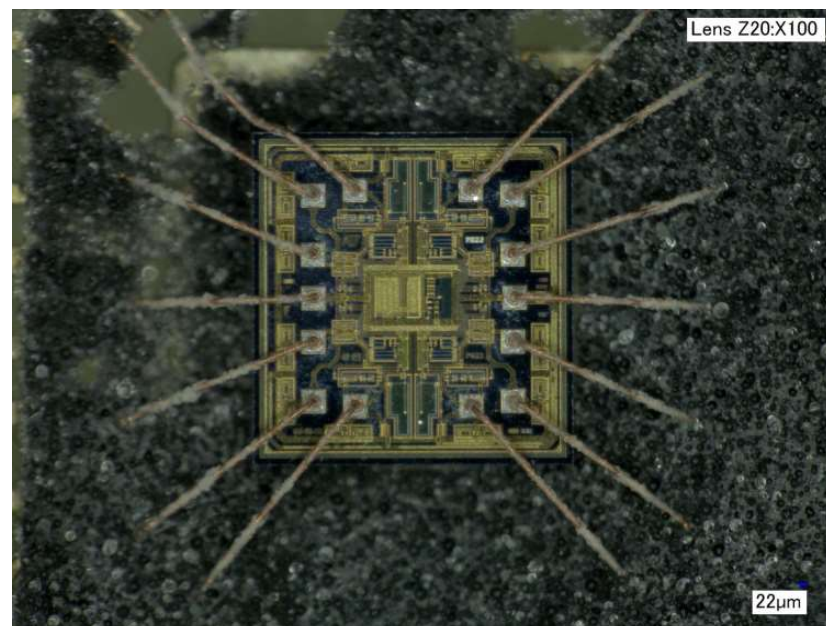
De-capped Infineon Diode

Internal Visual Inspection

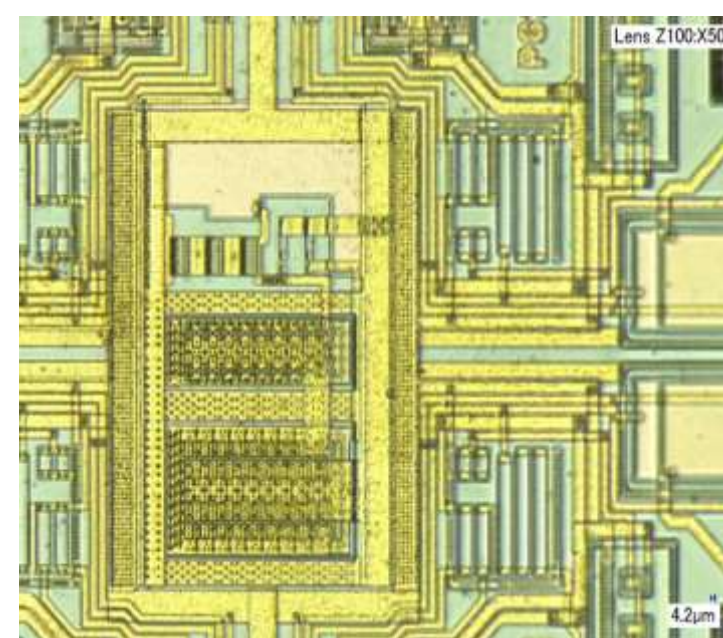
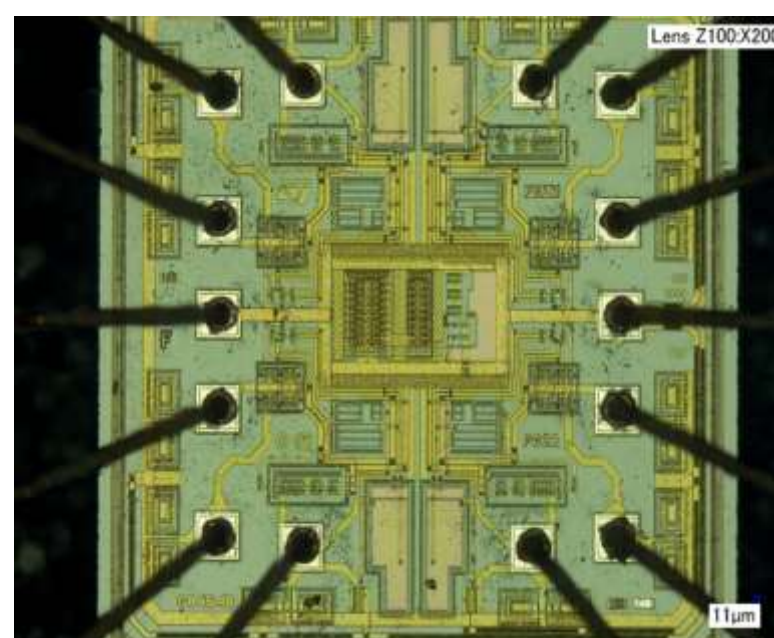
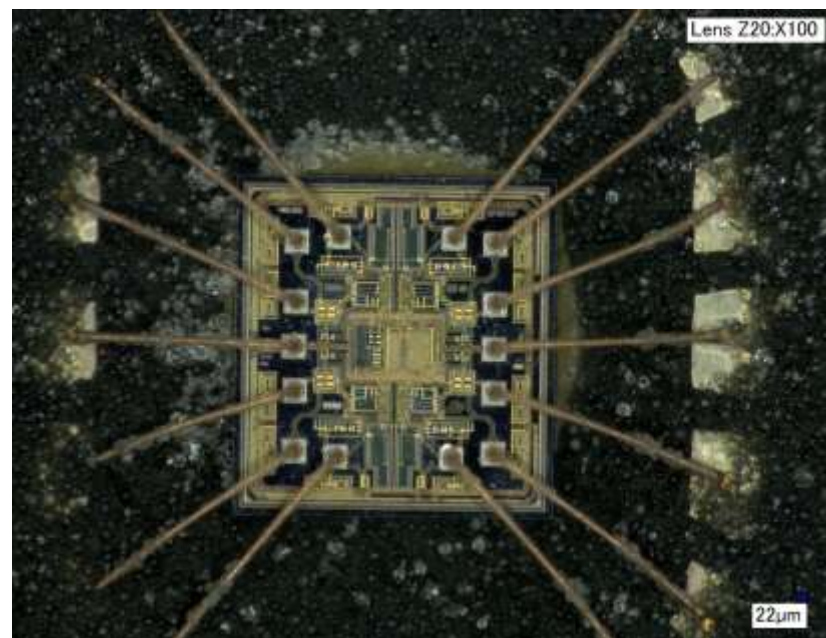
ST-Microelectronics Operational Amplifiers



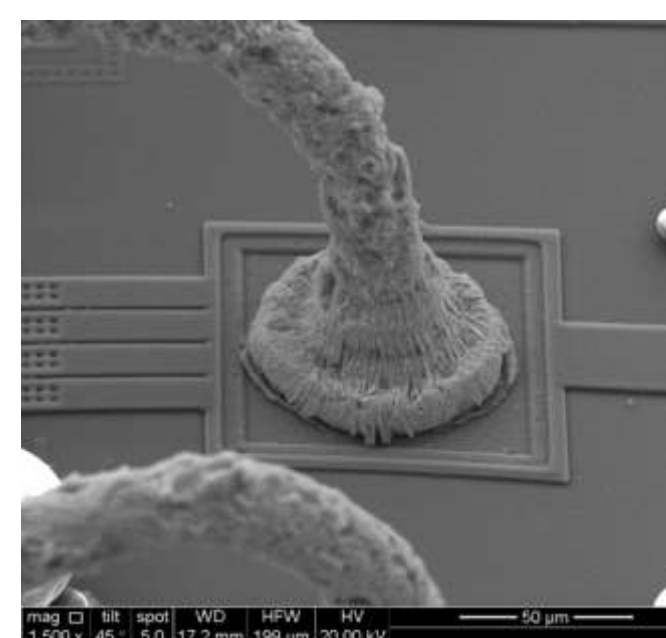
ST-Micro Op-Amp (Lot 1647)



ST-Micro Op-Amp (Lot 1706)



ST-Micro Op-Amp (Lot 1816)



Inspection Details:

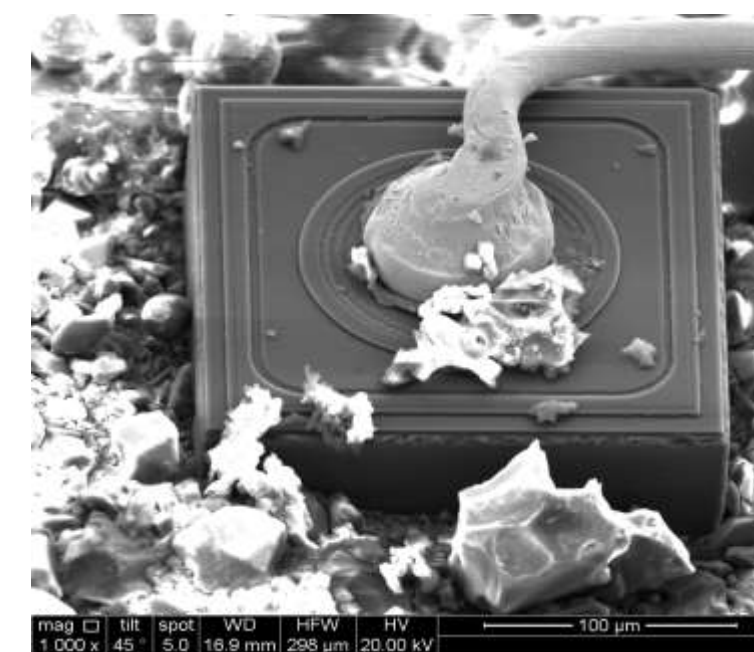
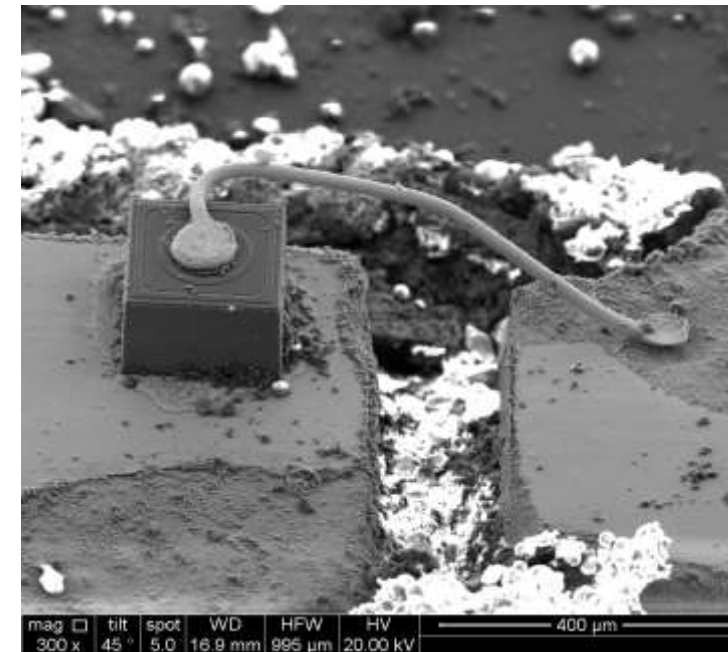
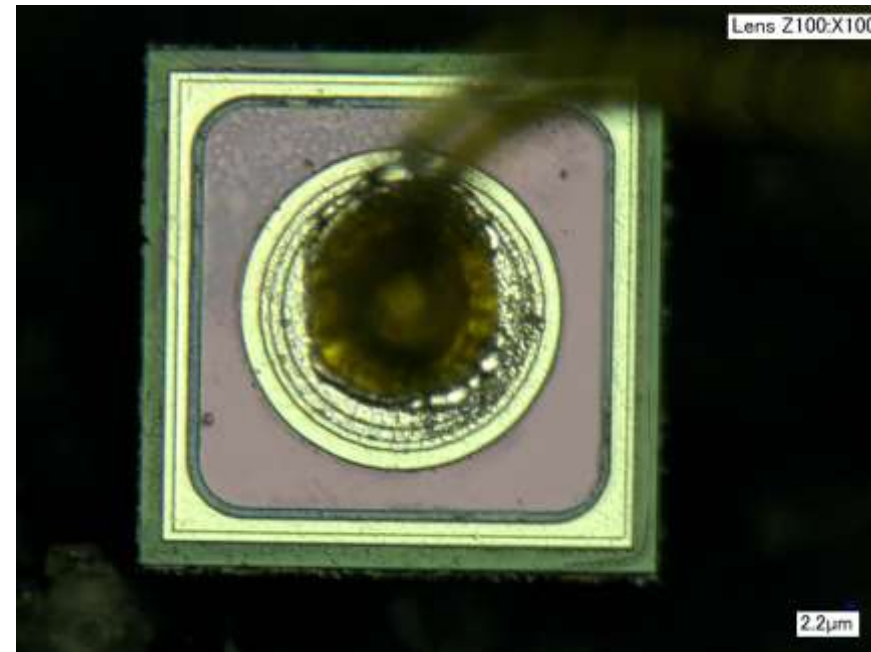
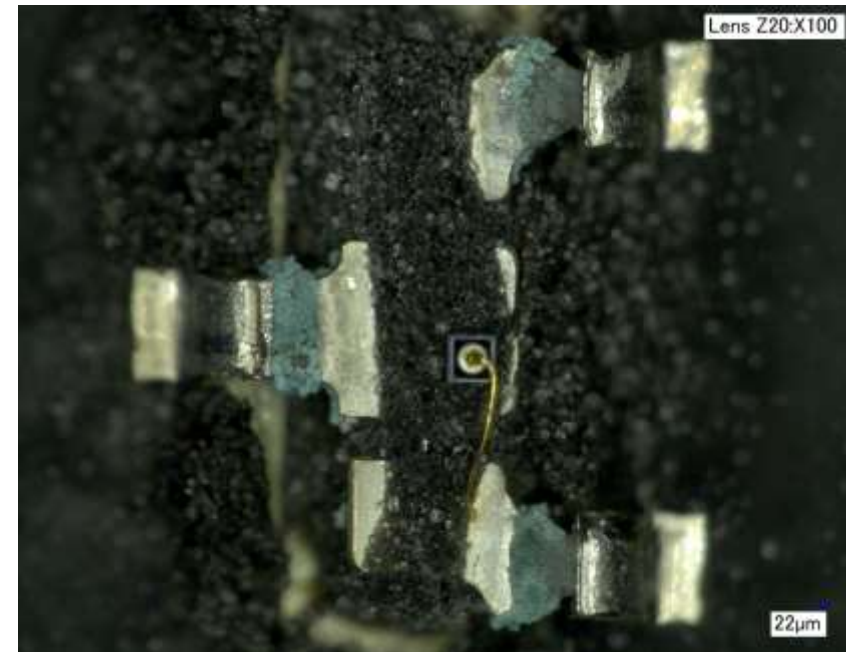
- Based on ESCC2045000, 2045010 & 2059000
- Optical Magnification up to 1000X.
- SEM inspection of die metal & bonds.
- Die Rev. No. & general condition.
- Die surface & metallisation condition.
- Die bond pad condition.
- Wire bond placement.
- Wire bond shape & loop height.
- Bond to lead frame.

Result:

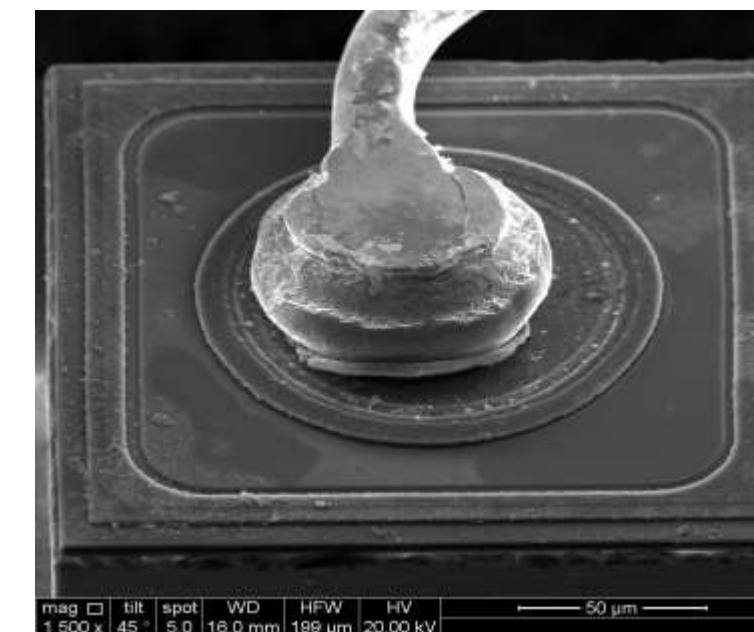
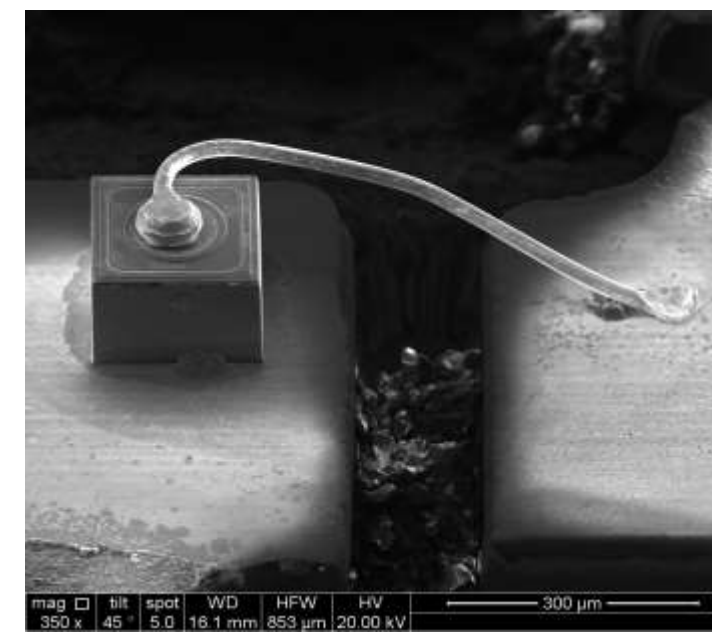
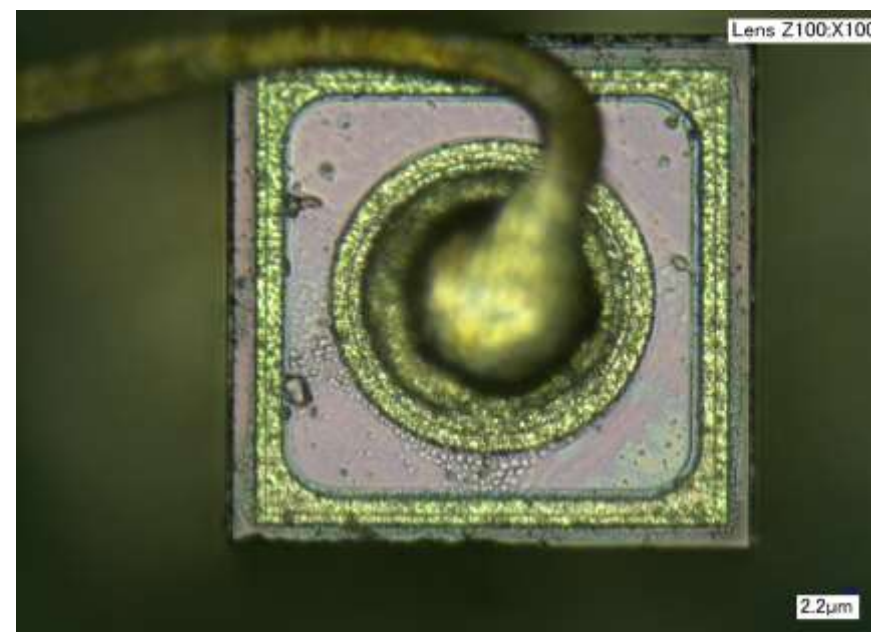
- All three ST-Micro Op-Amp lots internally identical.
- 30µm Cu bond wire.

Internal Visual Inspection

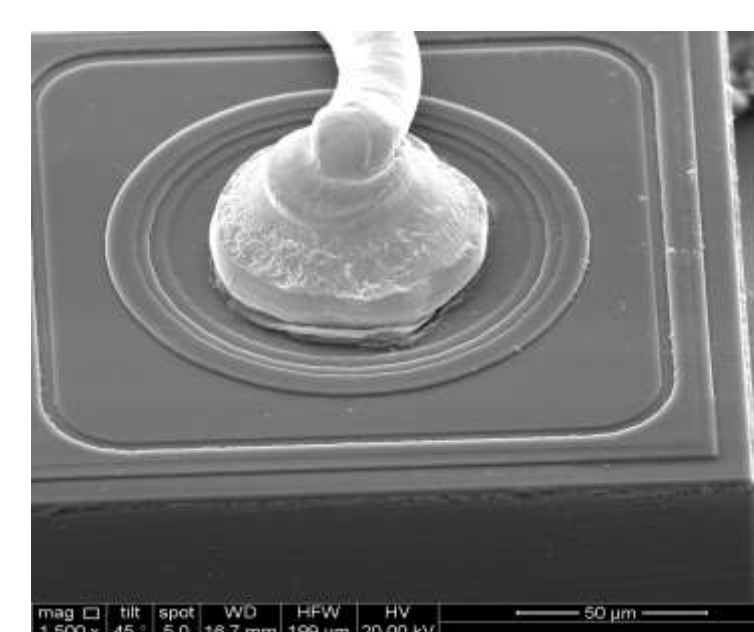
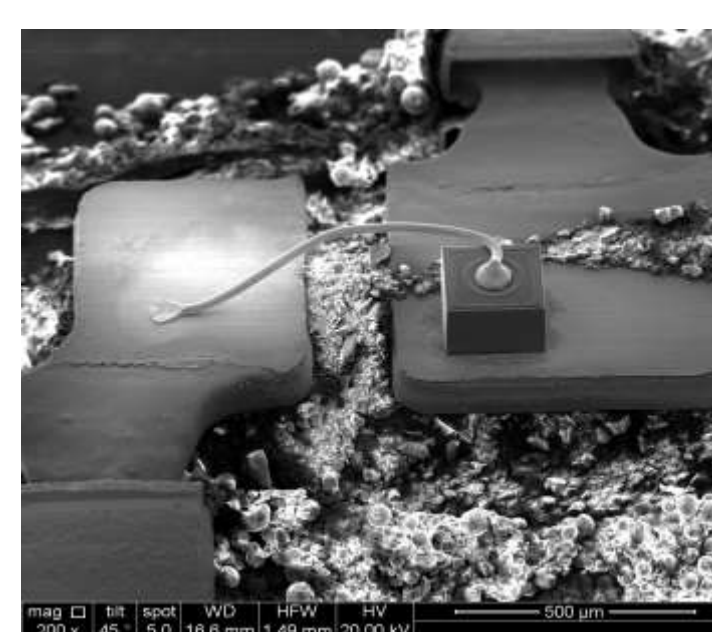
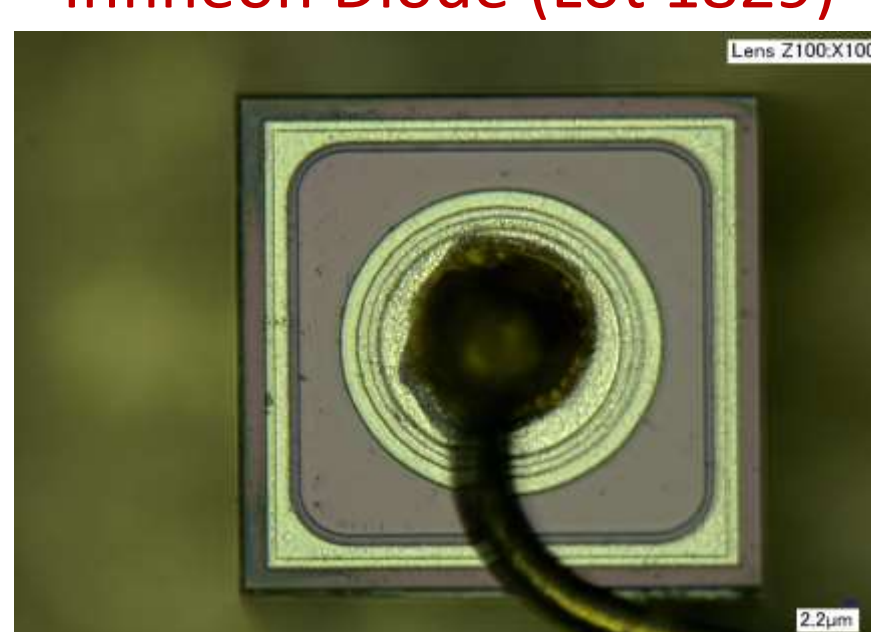
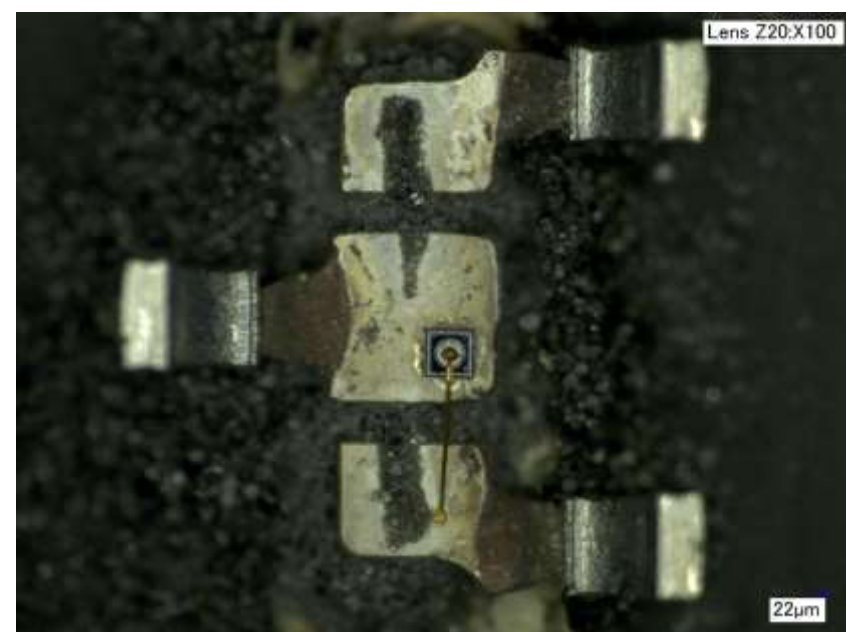
Infineon Diodes



Infineon Diode (Lot 1536)



Infineon Diode (Lot 1829)



Infineon Diode (Lot 1831)

Result:

- *All three ST-Micro Op-Amp lots internally identical.*
- *No. die ID or rev. nos.*
- *25µm Au bond wires.*
- *Compound bonding technique on die bond pad.*

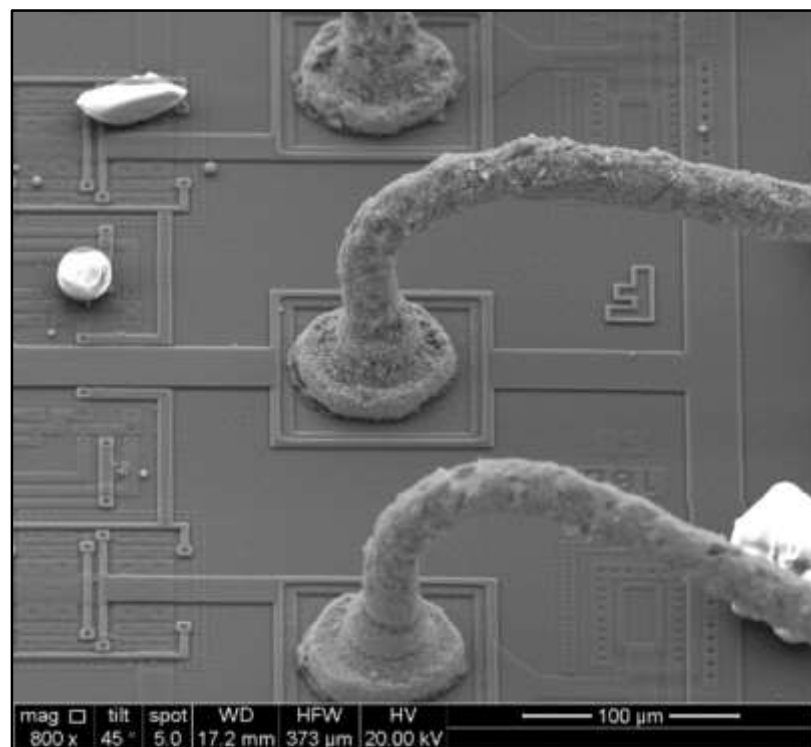
Ball Bond Shear Tests

Purpose: Evaluate bond strength & compare lot-to-lot performance

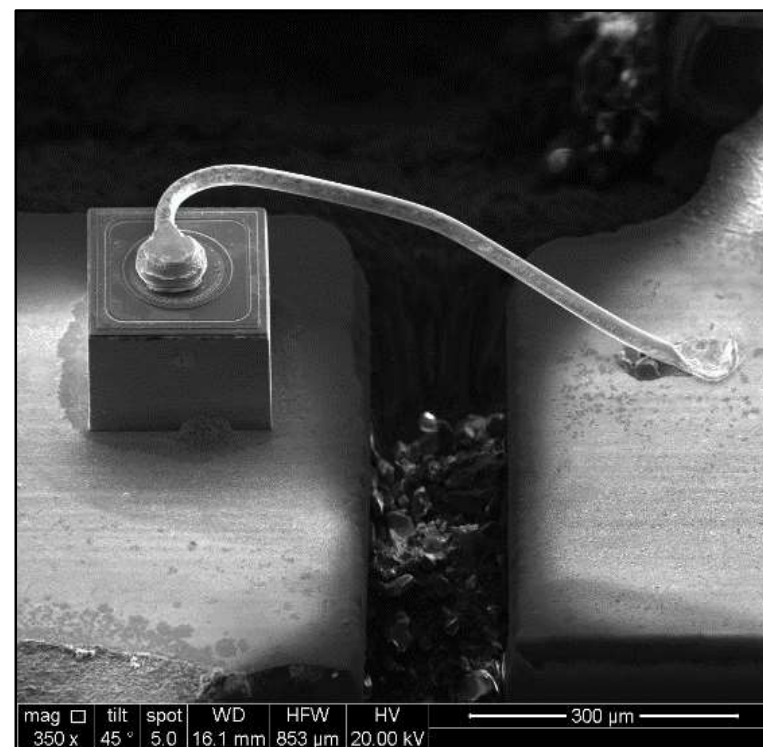
Method: JEDEC JASD22-B116

Procedure:

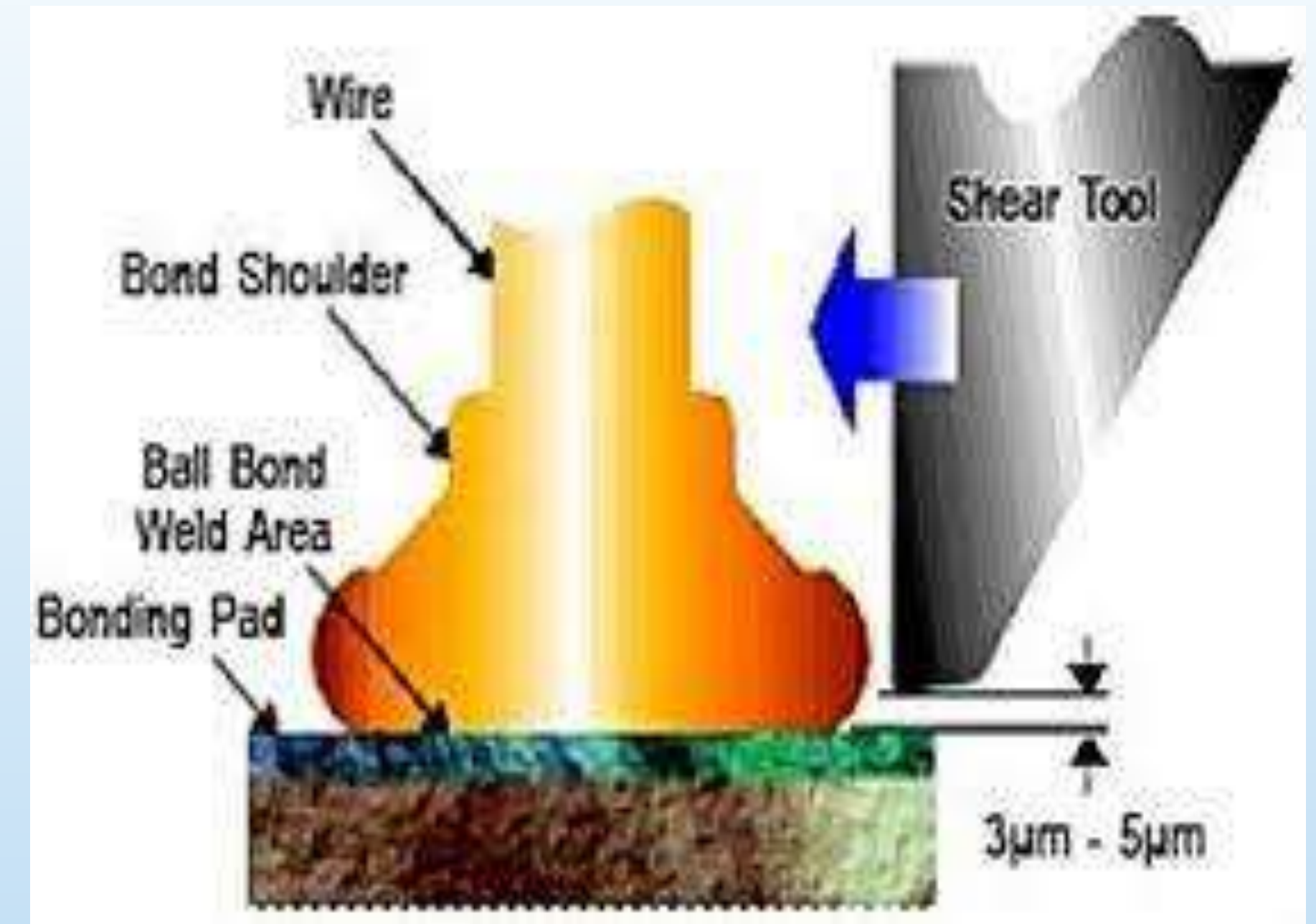
- *Performed on 4 samples per lot*
- *All bonds tested.*
- *ST-Micro Op-Amps (14 Cu wires each)*
- *Infineon Diode (1 Au wire per device)*
- *More suited to de-capped plastic device than pull test.*
- *Carried out with Royce 552 Microtester.*



ST-Micro Op-Amp Cu Bonds



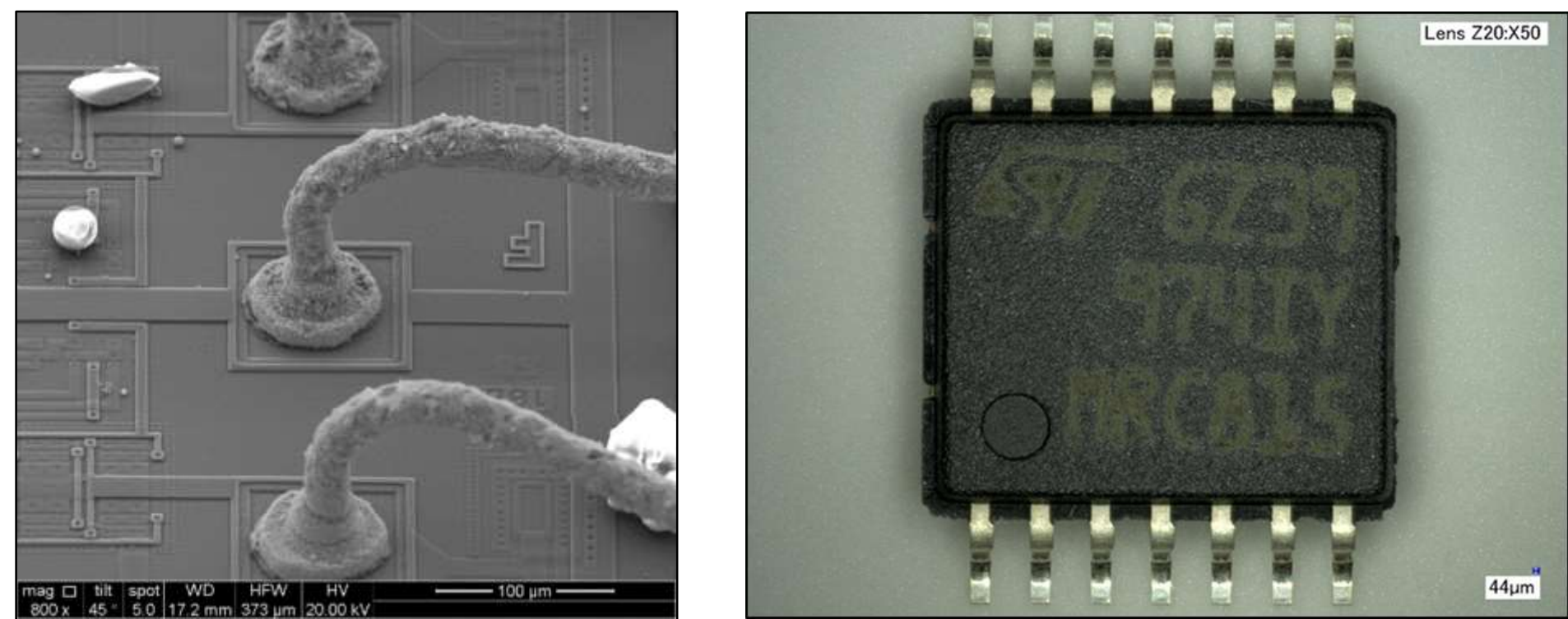
Infineon Diode Au Bond



Ball Bond Shear Test
Approach

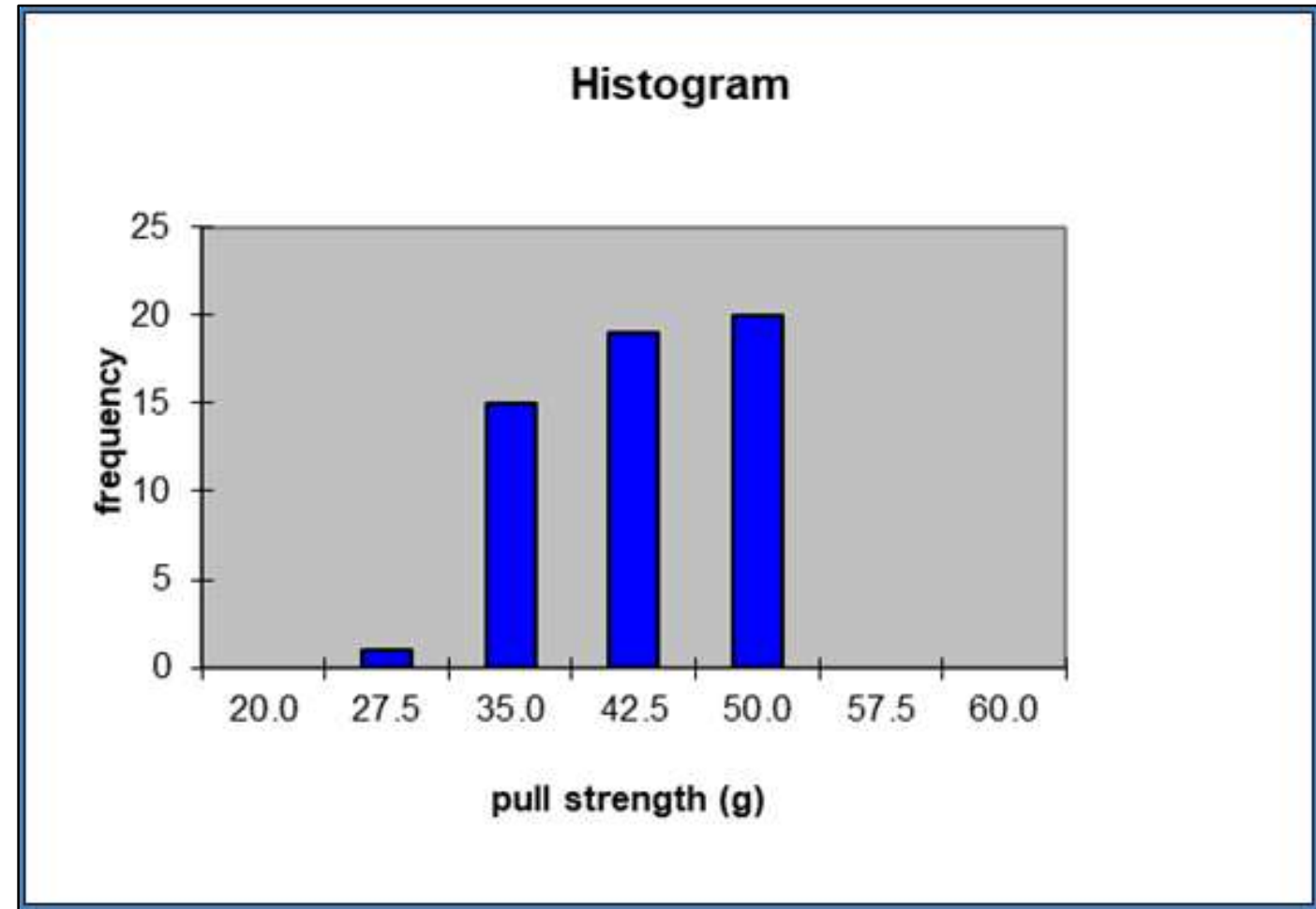
Ball Bond Shear Tests

ST-Microelectronics Operational Amplifiers

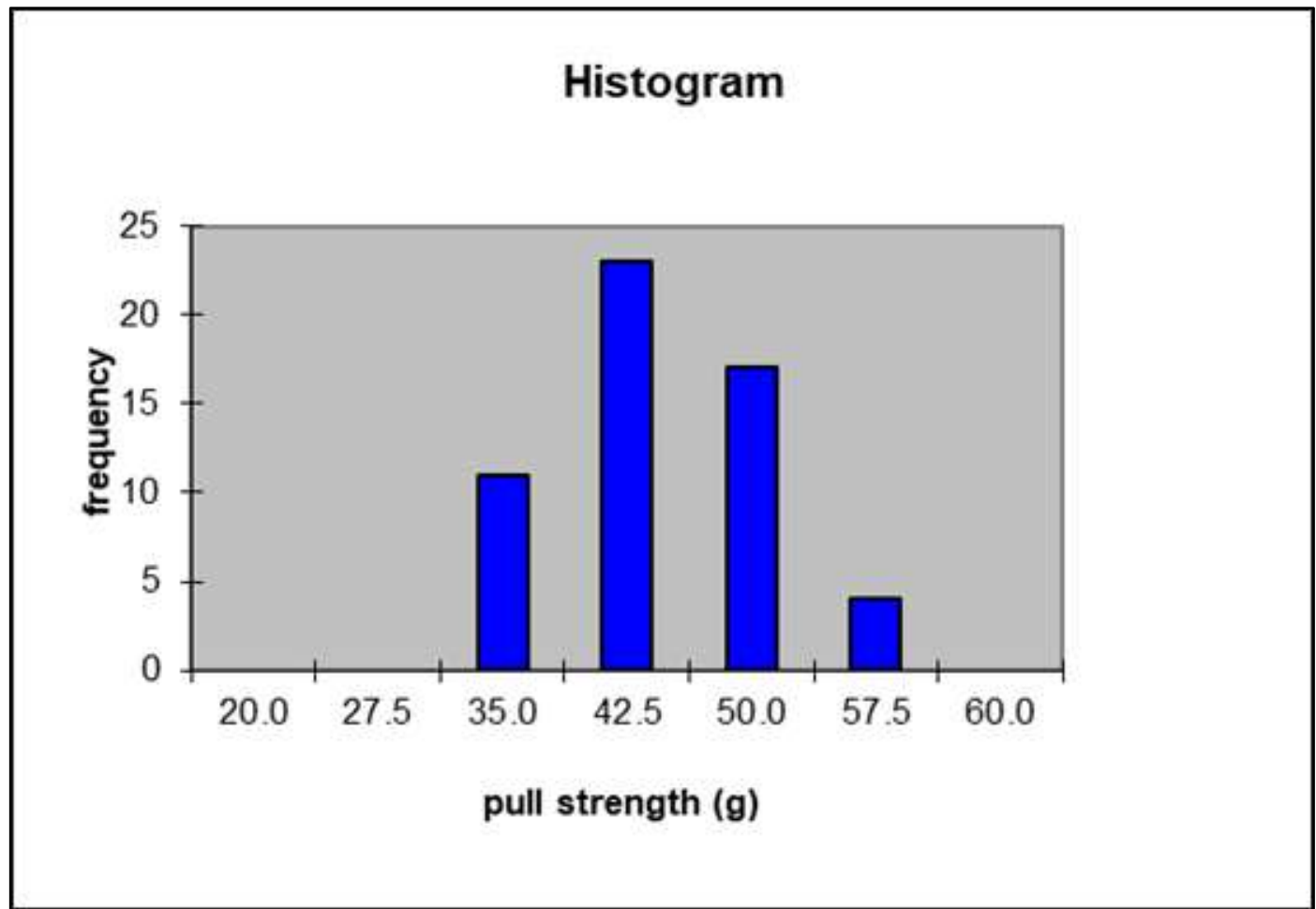


| ST Microelectronics TS974 Operational Amplifier Wire Bond Test (Ball Shear Strength) gF | | | |
|---|----------|----------|----------|
| | Lot 1647 | Lot 1706 | Lot 1816 |
| No. of wires tested | 56 | 56 | 56 |
| Mean pull strength (gF) | 39.89 | 41.25 | 40.12 |
| Std. Dev. (gF) | 6.50 | 6.76 | 6.01 |
| Minimum value (gF) | 26.50 | 28.50 | 27.00 |
| Maximum value (gF) | 50.00 | 56.00 | 56.50 |
| No. of bonds below Jedec. Std. limit (10.0gF) | 0 | 0 | 0 |

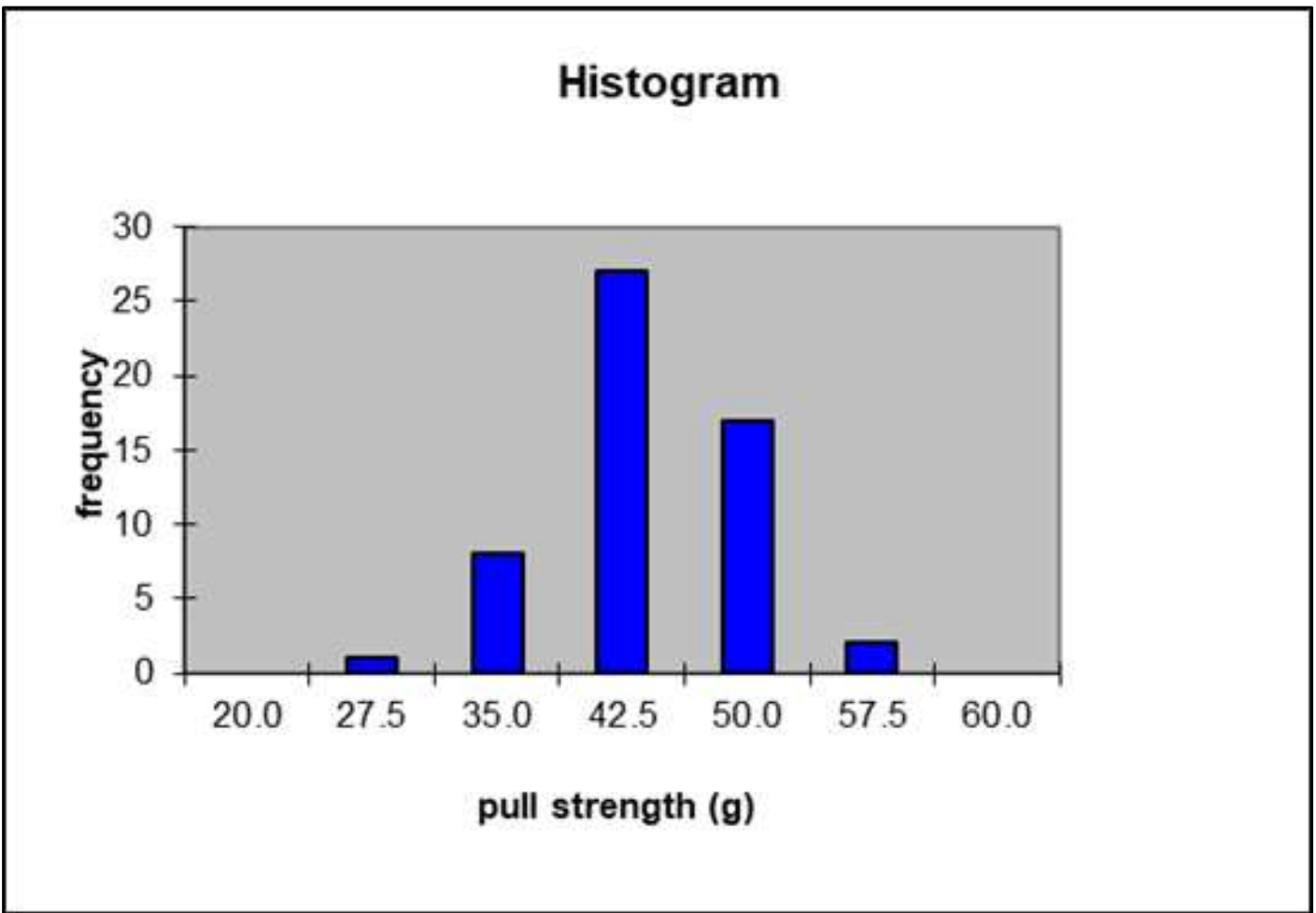
ST-Micro Op-Amp 30μm Cu Bond Shear Strength Test Results



ST-Micro Op-Amp (Lot 1647)



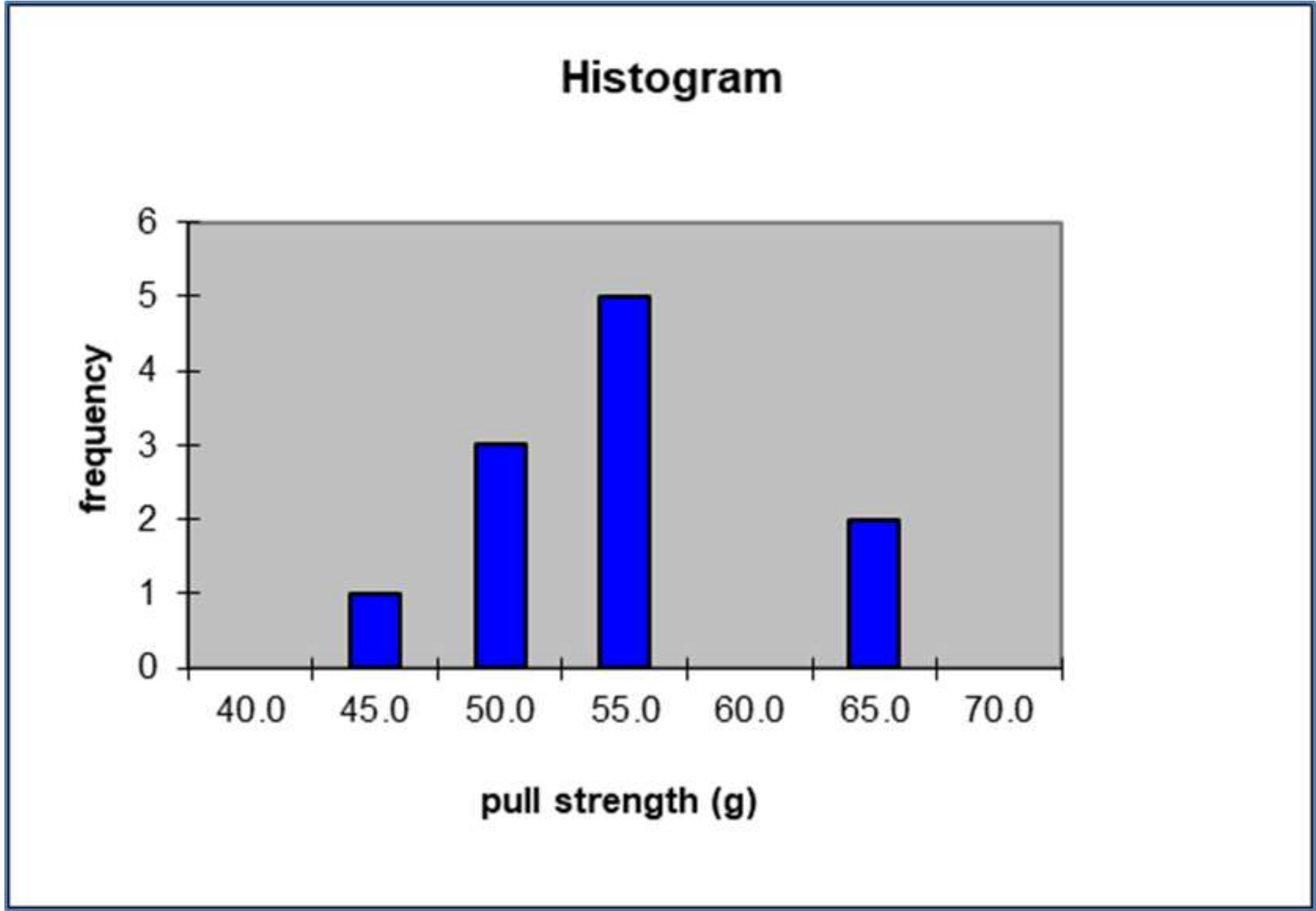
ST-Micro Op-Amp (Lot 1706)



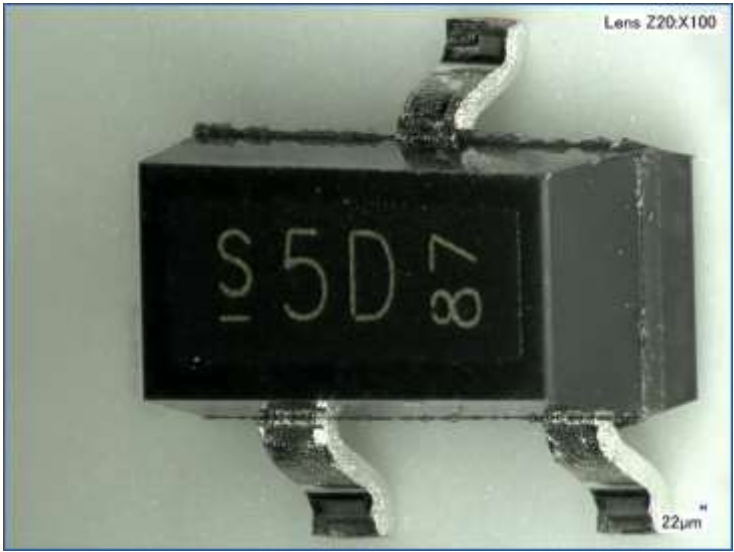
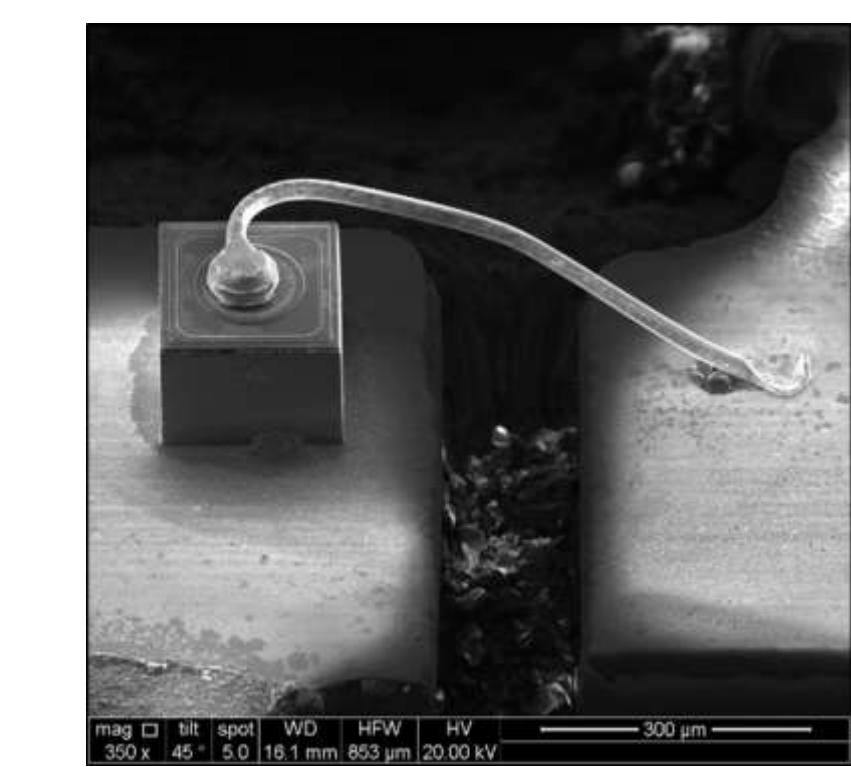
ST-Micro Op-Amp (Lot 1816)

Ball Bond Shear Tests

Infineon Diodes



All Infineon Diode Lots



| | Infineon SMBD914 High Speed Silicon Switching Diode | | |
|---|---|----------|----------|
| | gF | | |
| | Lot 1536 | Lot 1829 | Lot 1831 |
| No. of wires tested | 4 | 4 | 4 |
| Mean pull strength (gF) | 57.75 | 47.75 | 53.25 |
| Std. Dev. (gF) | 7.56 | 4.91 | 7.18 |
| Minimum value (gF) | 50.5 | 42.0 | 45.5 |
| Maximum value (gF) | 65.0 | 53.5 | 62.5 |
| No. of bonds below Jedec. limit (5.7gF) | 0 | 0 | 0 |

Infineon Diode 25μm Au Ball Shear Test Results

Glassivation Integrity Test

Purpose: Check for defects in protective passivation layer.

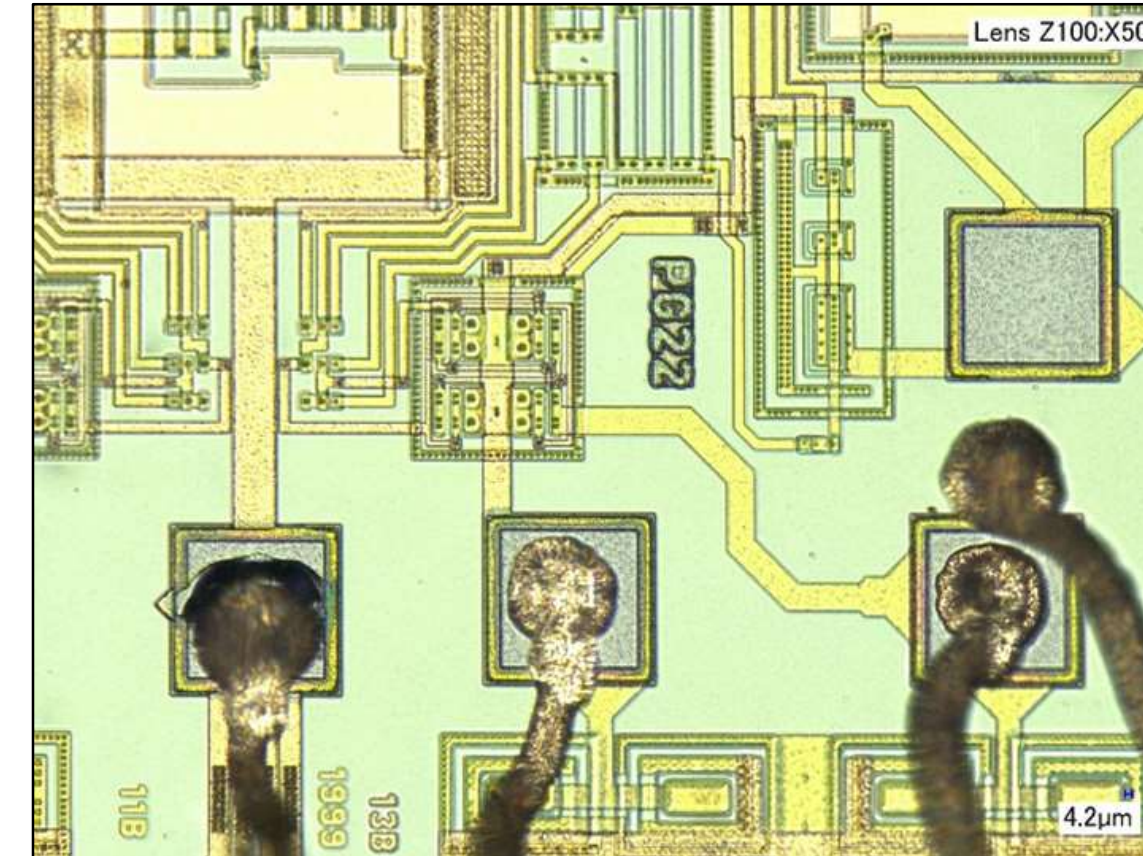
Method: Mil-Std-883, TM 2021

Procedure:

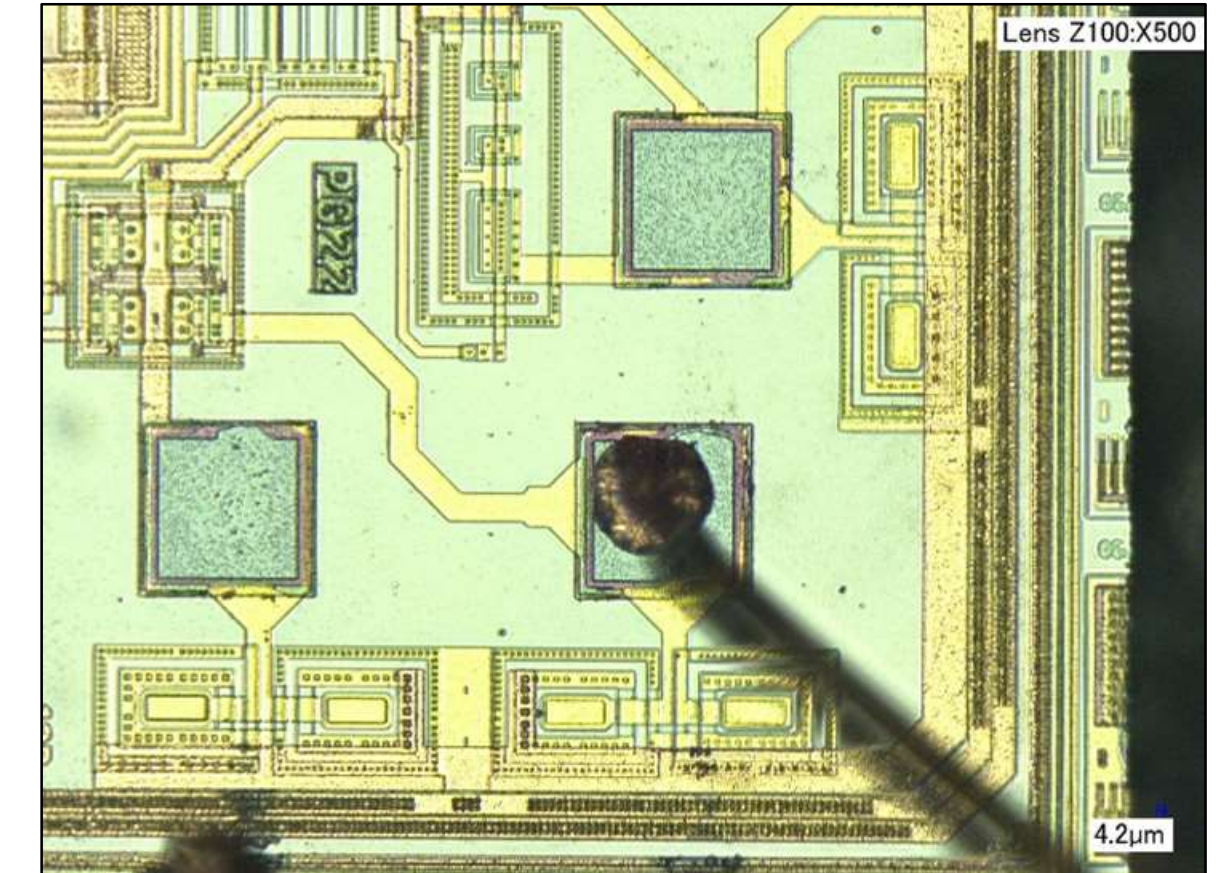
- Carried out on 3 de-capped samples per lot.
- Aluminium etch solution.
- Determine time to fully etch Al bond pad.
- Expose IC surface to etch for 2 x bond pad etch time.
- Inspect metallisation for defects.
- Only possible on ST-Microelectronics Op-Amp samples.
- Carried out after bond shear test.

Result

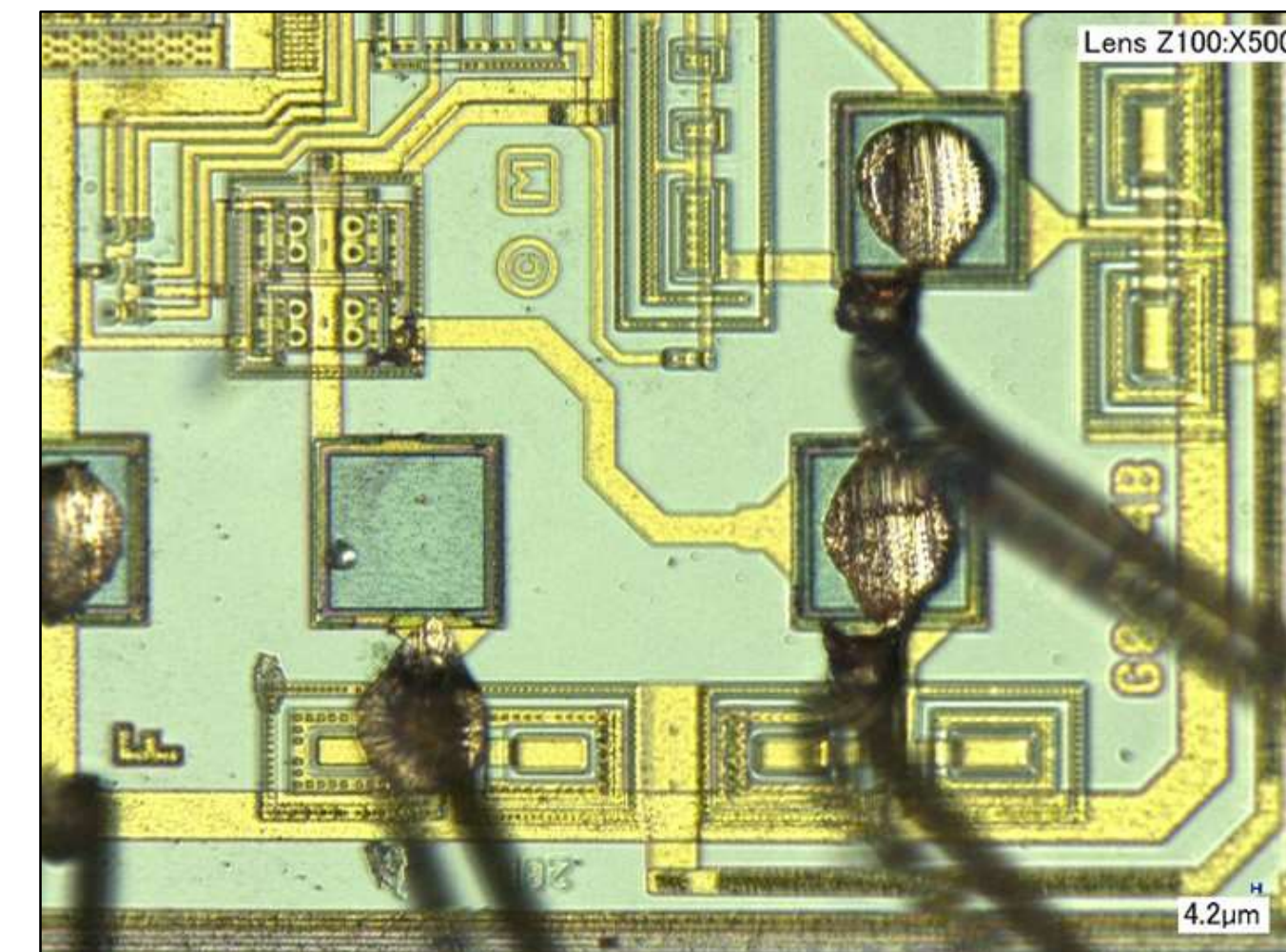
- No defects observed in any lot.



ST-Micro Op-Amp (1647)



ST-Micro Op-Amp (1706)

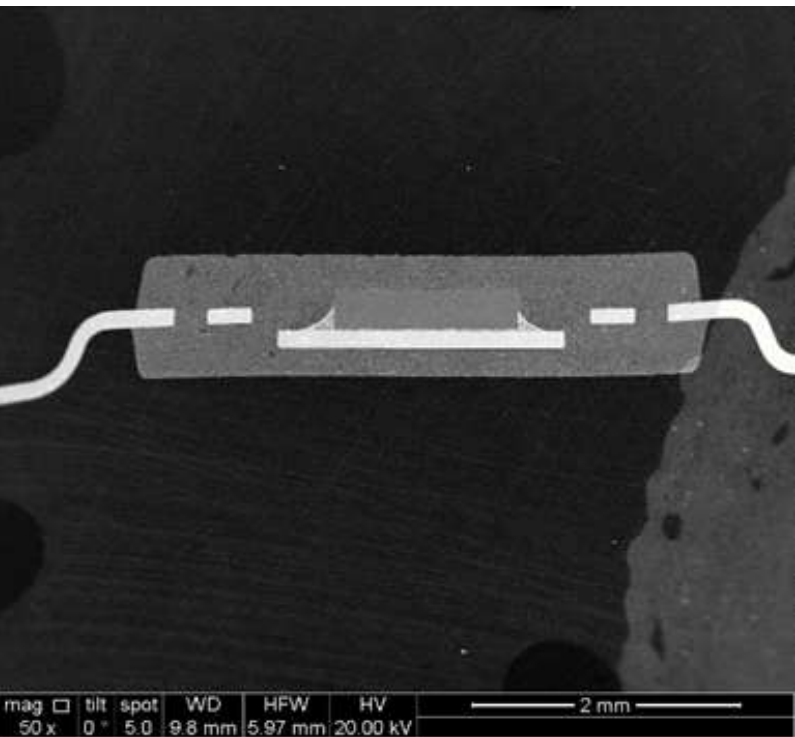


ST-Micro Op-Amp (1816)

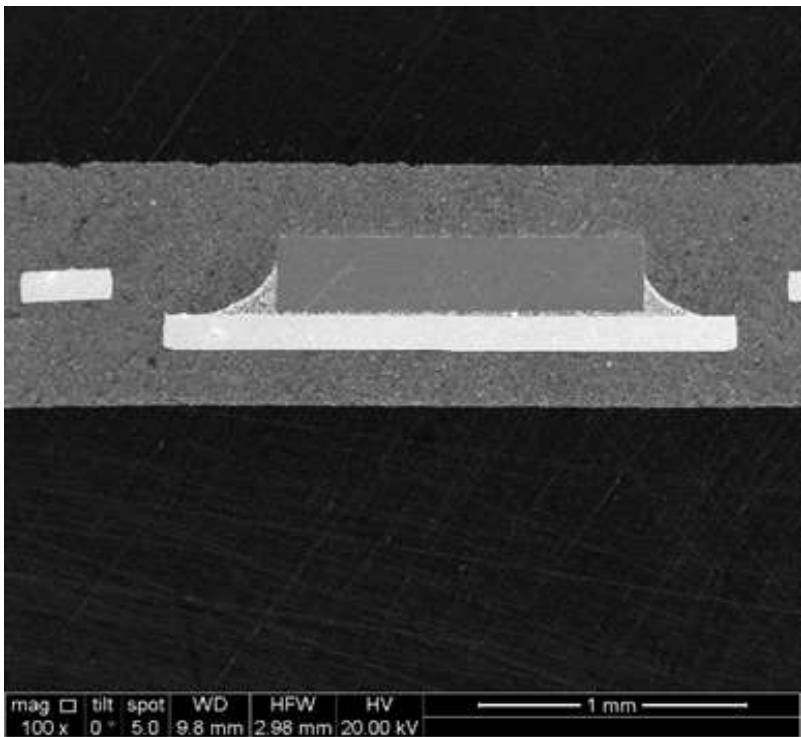
Cross-sectioning

ST-Microelectronics Operational Amplifiers

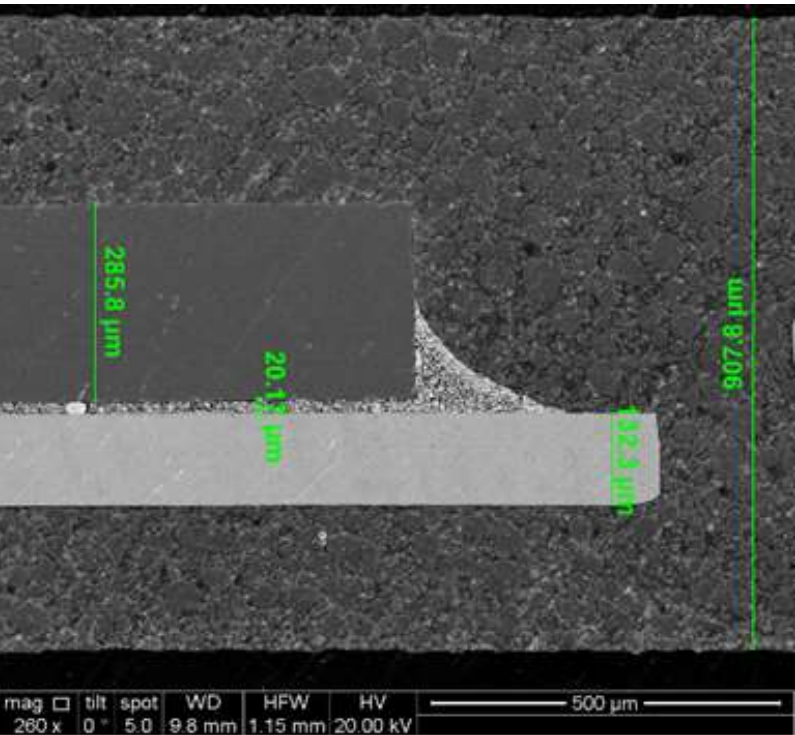
- SEM Inspection to measure & compare internal dimensions.
- EDX analysis to identify and compare all materials.
- No significant differences observed between lots.



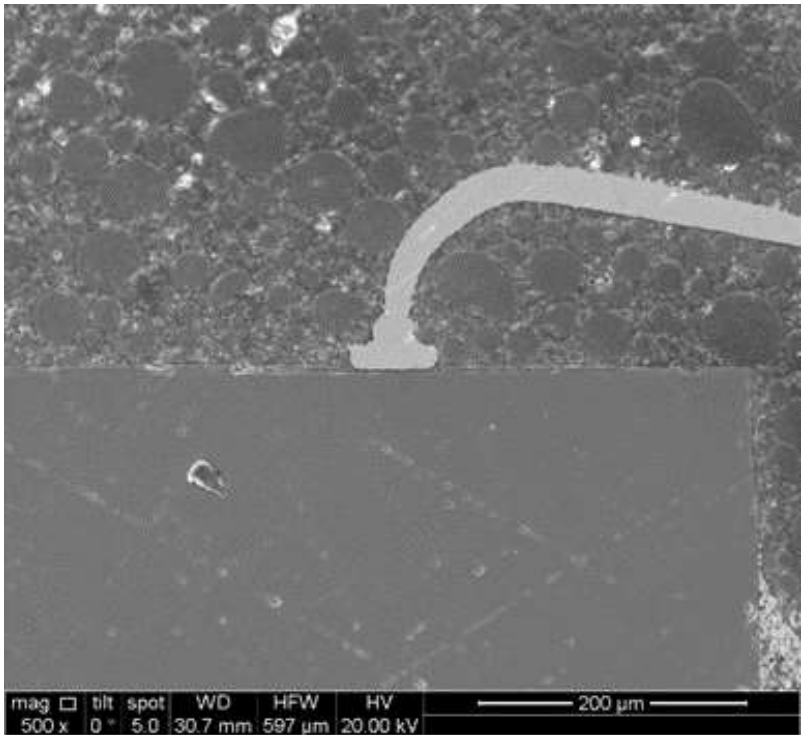
Cross-section overview



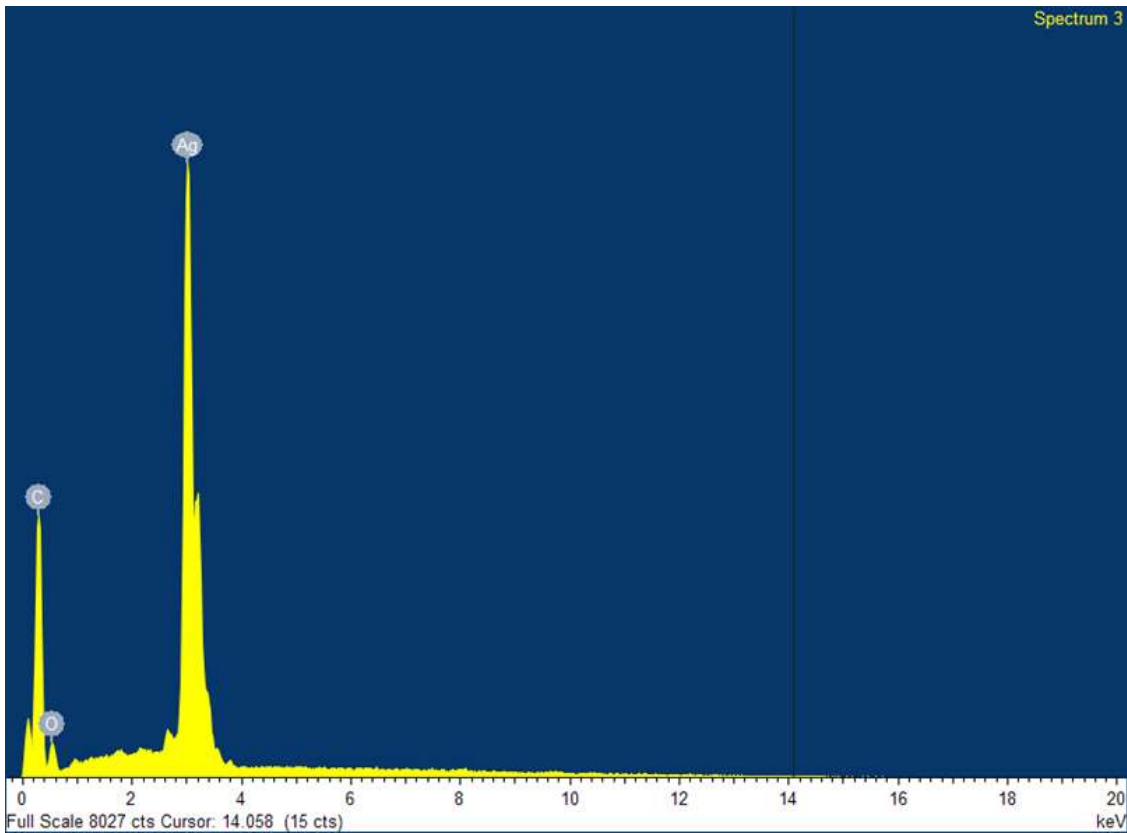
Die mounting



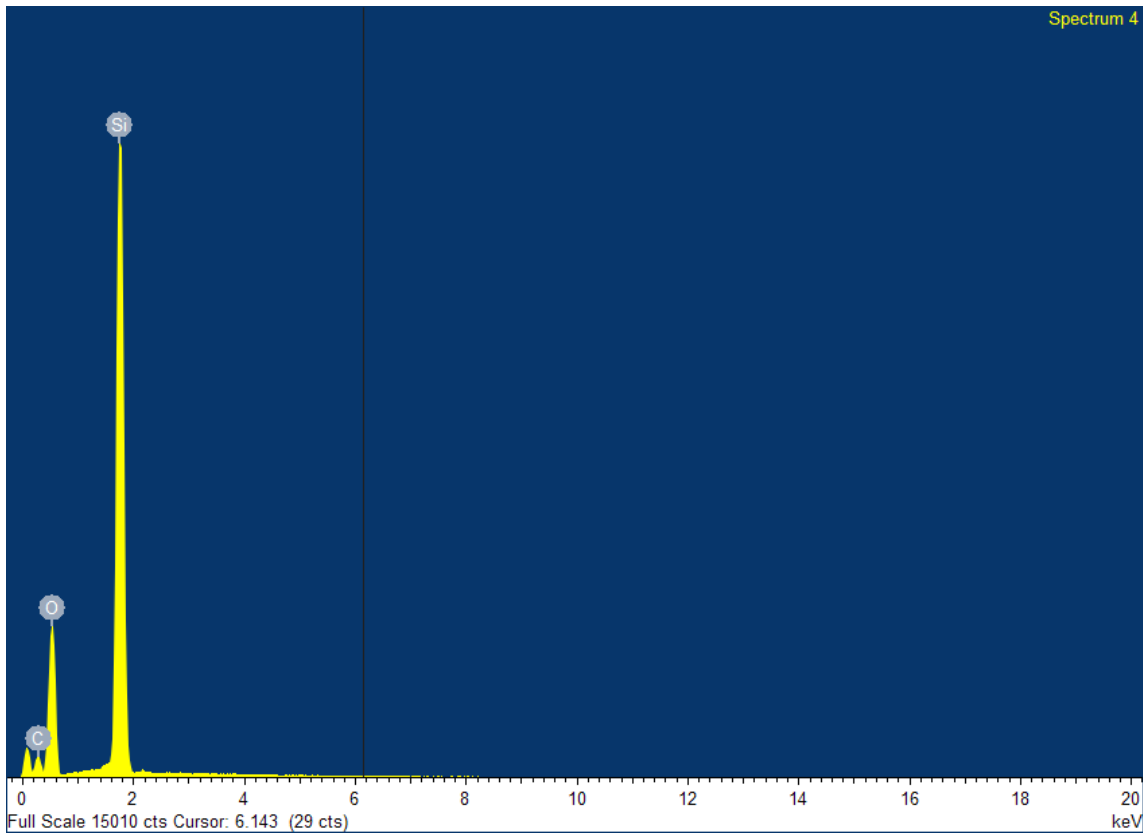
Dimensional measurement



Cu ball bond to die



EDX Spectrum – die paddle plating



EDX Spectrum – plastic filler particles

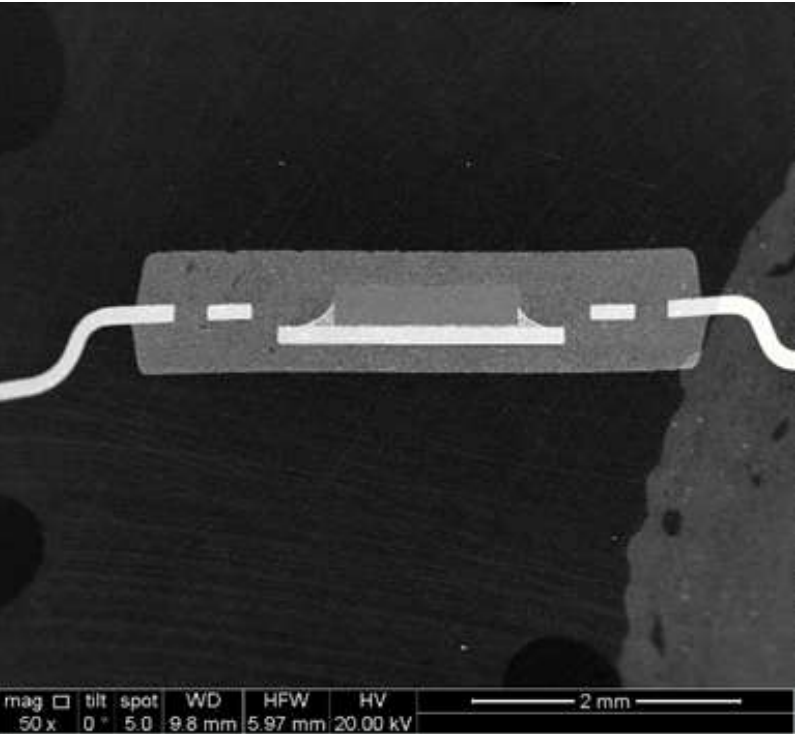
| Part Type | Principal Elements Detected | | |
|-------------------------|-----------------------------|------------|------------|
| | Lot 1647 | Lot 1706 | Lot 1816 |
| Die | Si | Si | Si |
| Die Paddle Bulk | Cu, Fe | Cu, Fe | Cu, Fe |
| Die Attach | Ag, C, O | Ag, C, O | Ag, C, O |
| Plastic | Si, C, O | Si, C, O | Si, C, O |
| Plastic Filler Particle | Si, O | Si, O | Si, O |
| Die Paddle Plating | Ag, Ni, Cu | Ag, Ni, Cu | Ag, Ni, Cu |
| Lead Plating | Ag Ni, Cu | Ag Ni, Cu | Ag Ni, Cu |
| Wire Bond | Cu | Cu | Cu |

Summary of materials analysis results – ST-Microelectronics Operational Amplifiers

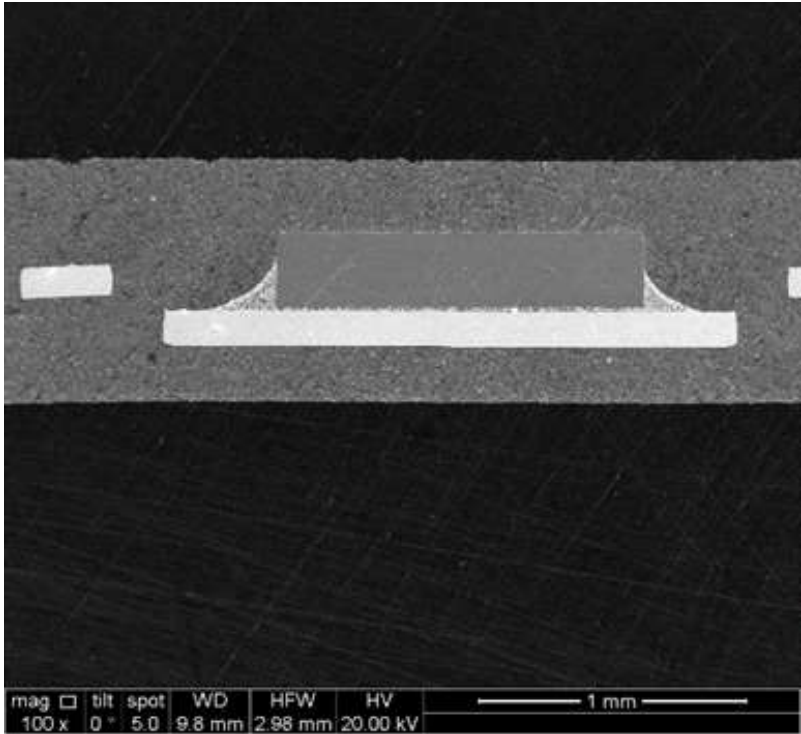
Cross-sectioning

ST-Microelectronics Operational Amplifiers

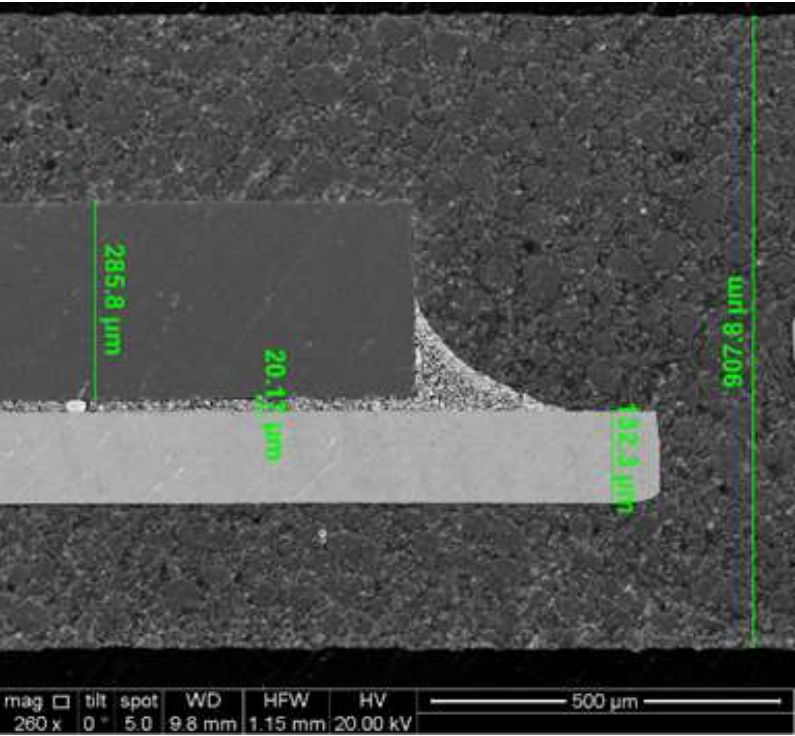
- SEM Inspection to measure & compare internal dimensions.
- EDX analysis to identify and compare all materials.
- No significant differences observed between lots.



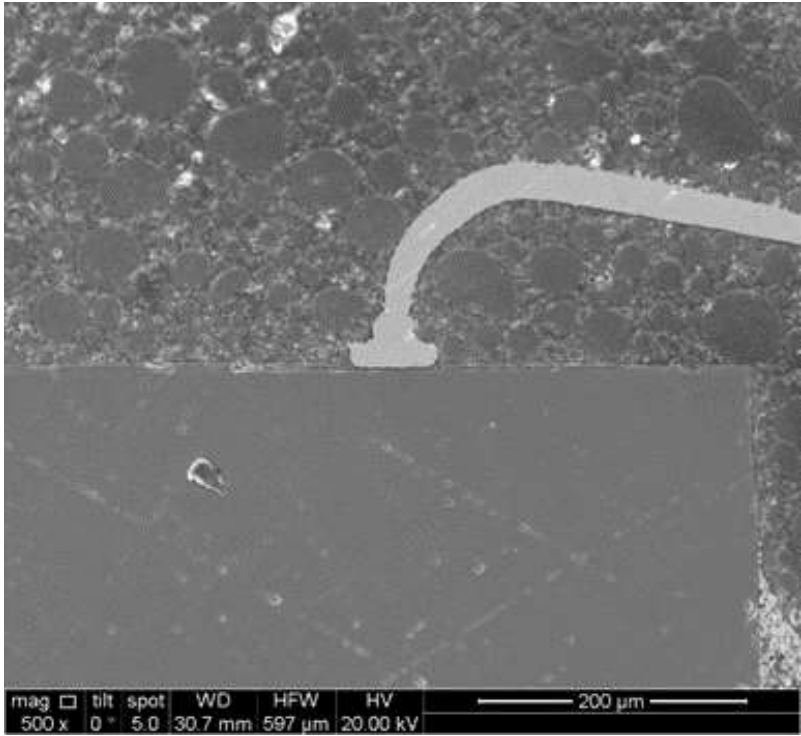
Cross-section overview



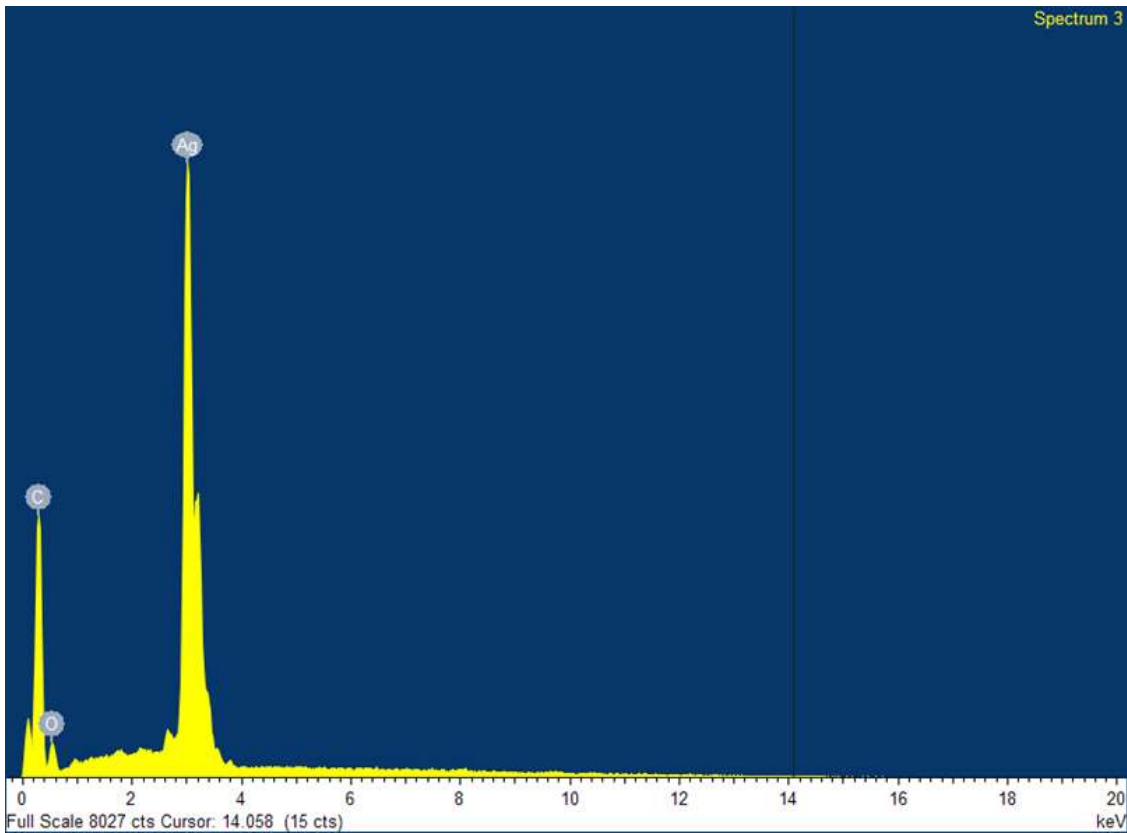
Die mounting



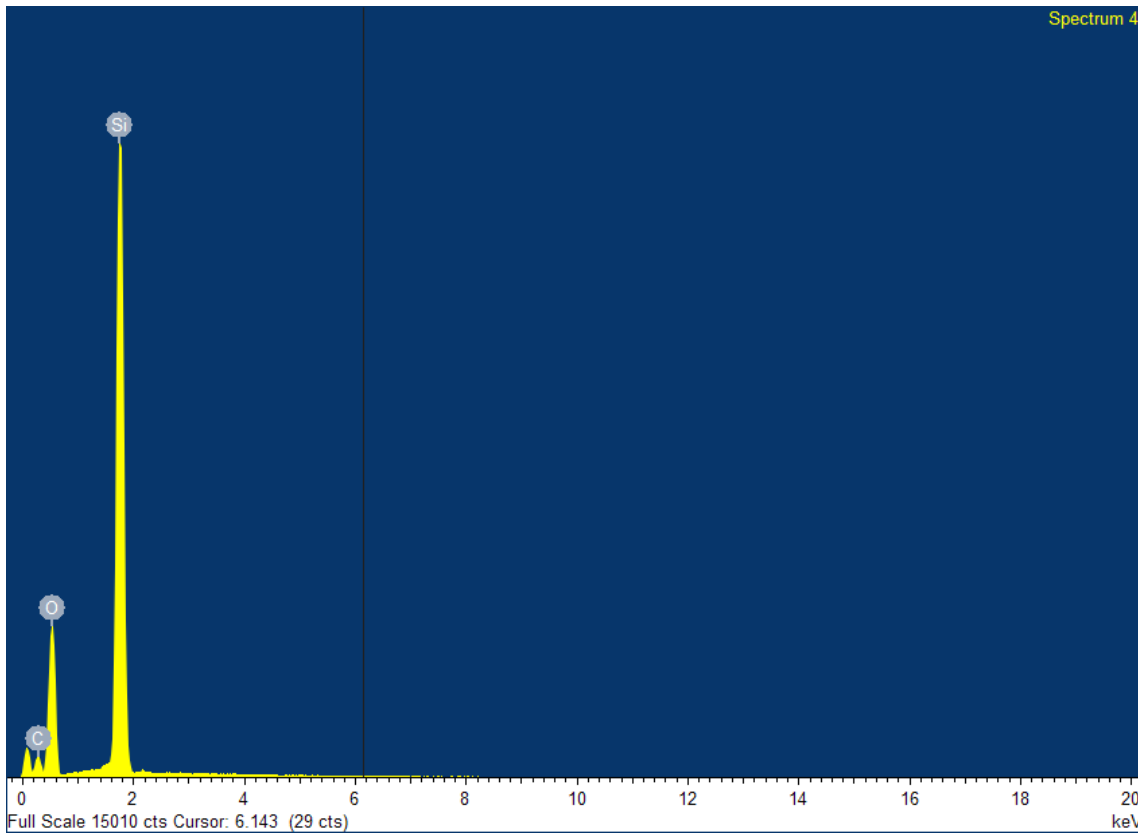
Dimensional measurement



Cu ball bond to die



EDX Spectrum – die paddle plating



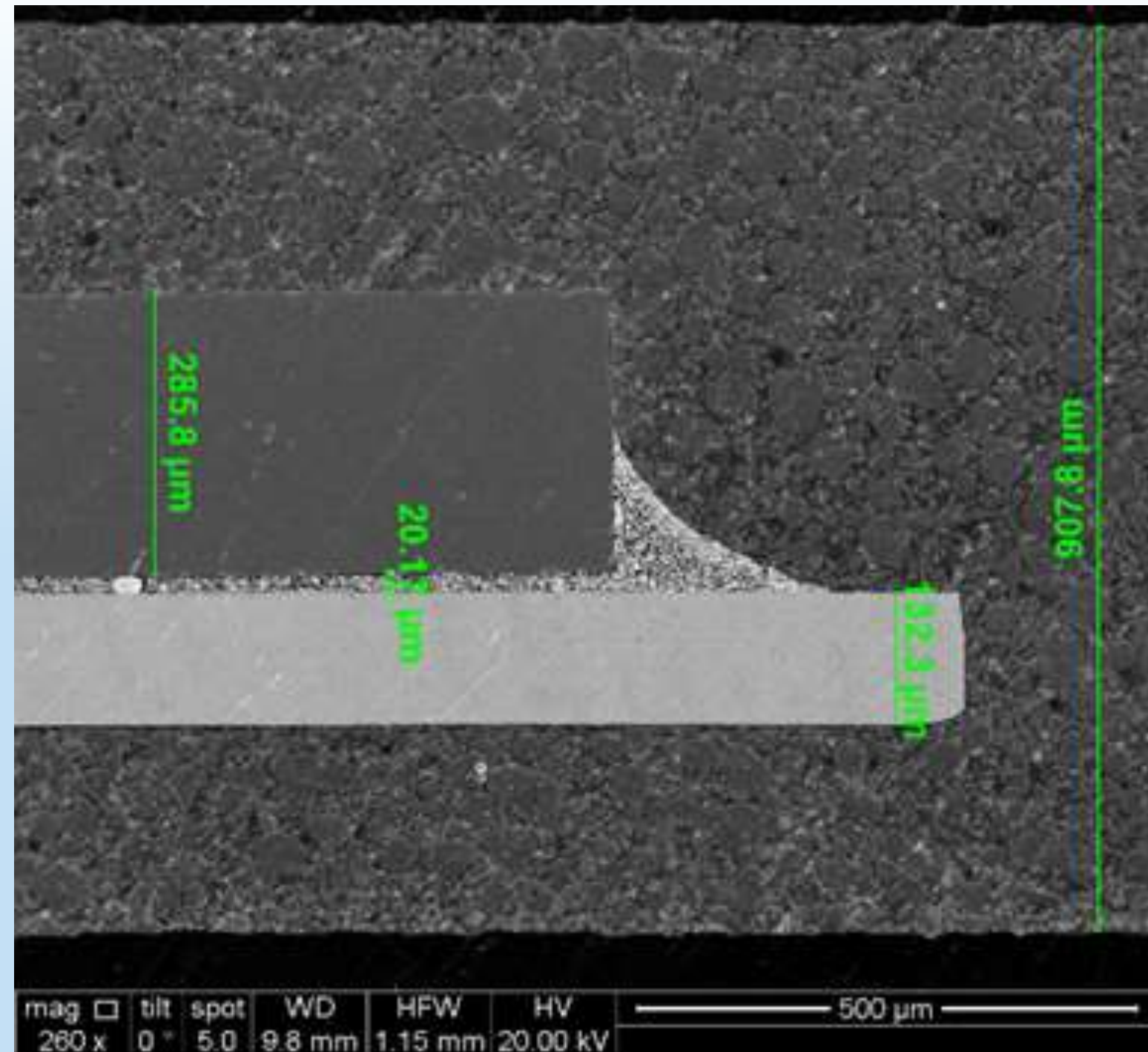
EDX Spectrum – plastic filler particles

| Part Type | Principal Elements Detected | | |
|-------------------------|-----------------------------|------------|------------|
| | Lot 1647 | Lot 1706 | Lot 1816 |
| Die | Si | Si | Si |
| Die Paddle Bulk | Cu, Fe | Cu, Fe | Cu, Fe |
| Die Attach | Ag, C, O | Ag, C, O | Ag, C, O |
| Plastic | Si, C, O | Si, C, O | Si, C, O |
| Plastic Filler Particle | Si, O | Si, O | Si, O |
| Die Paddle Plating | Ag, Ni, Cu | Ag, Ni, Cu | Ag, Ni, Cu |
| Lead Plating | Ag Ni, Cu | Ag Ni, Cu | Ag Ni, Cu |
| Wire Bond | Cu | Cu | Cu |

Summary of materials analysis results – ST-Microelectronics Operational Amplifiers

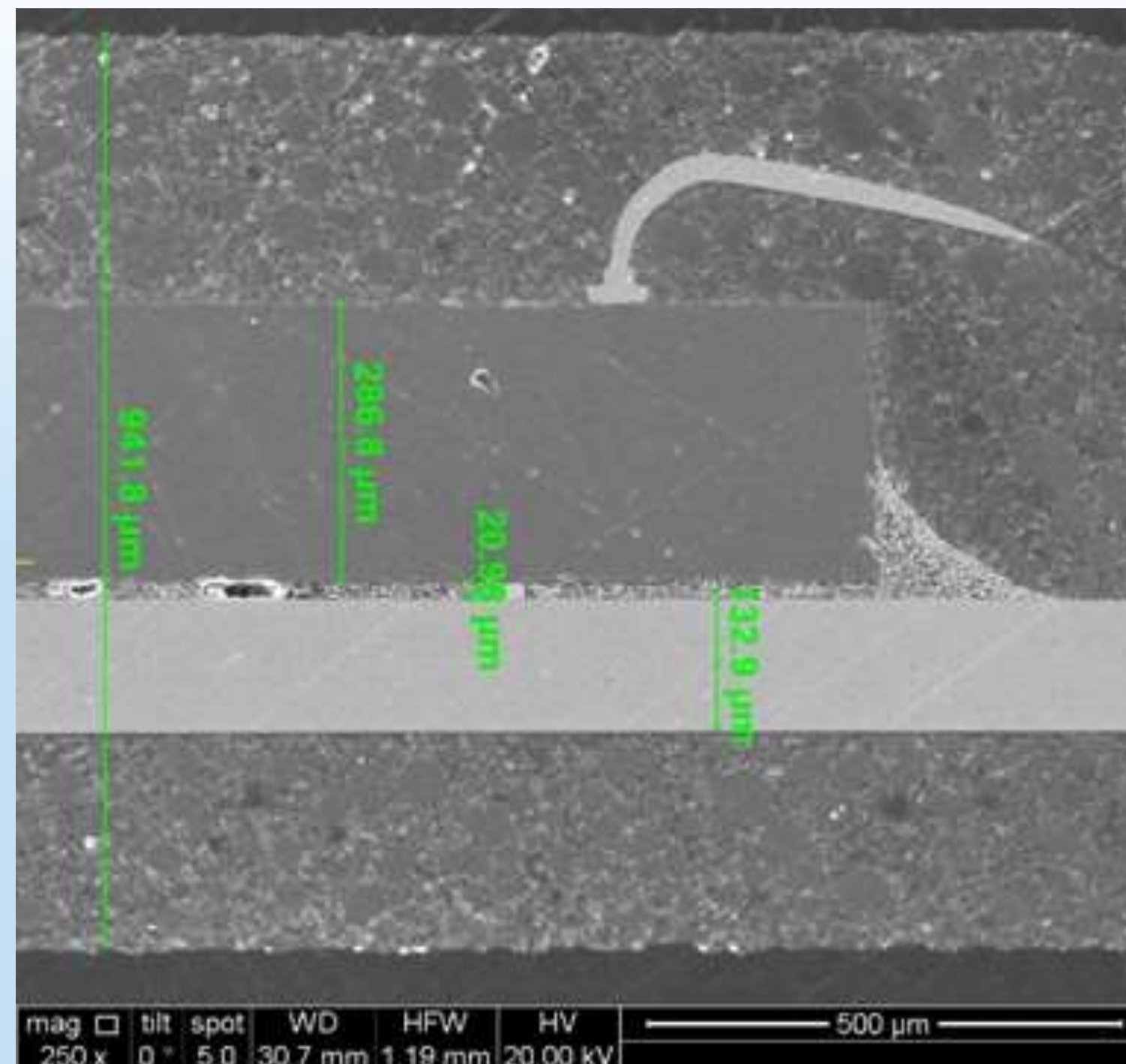
Cross-sectioning

ST-Microelectronics Operational Amplifiers



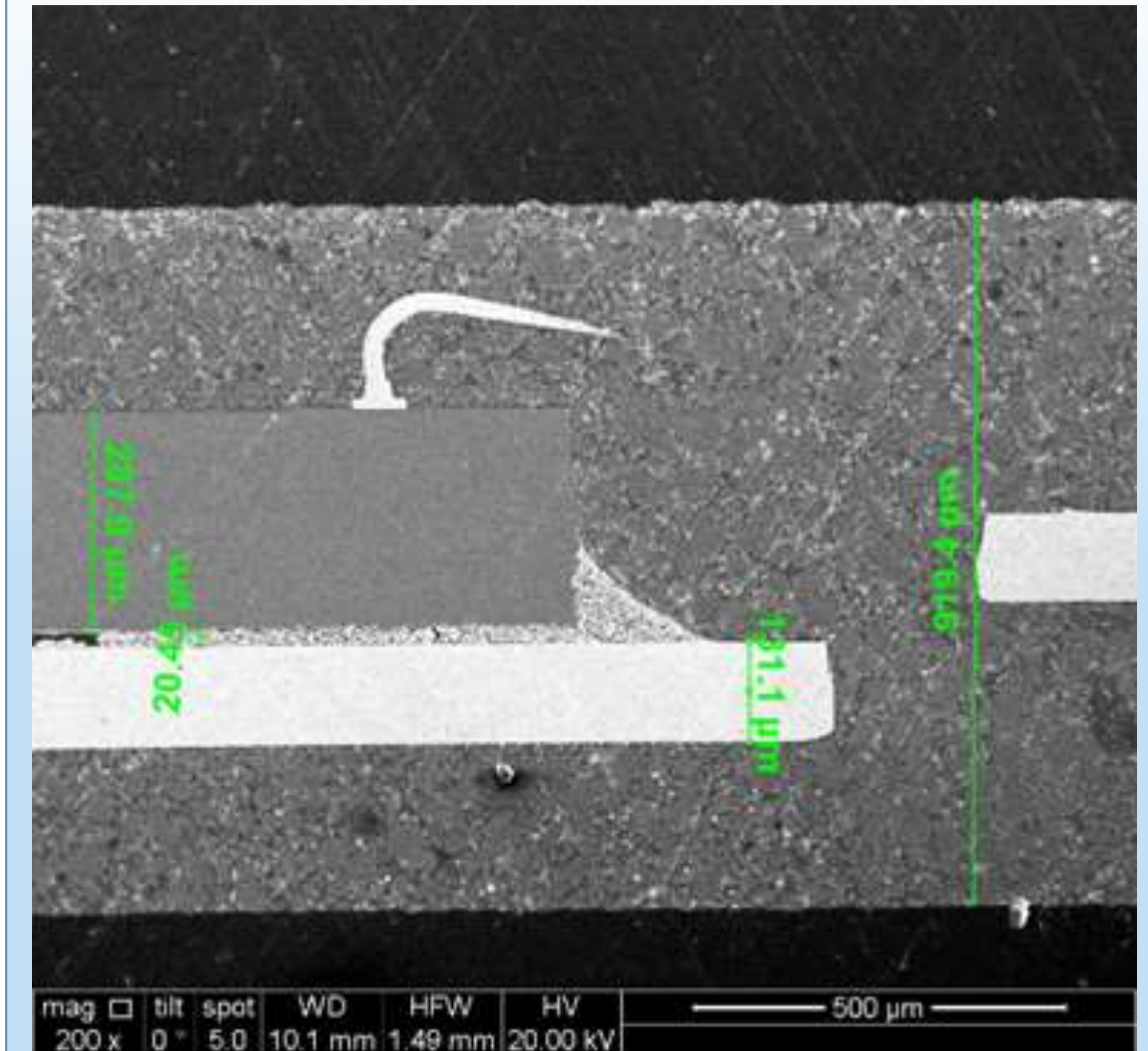
Lot 1647

- Die thickness = 285.8 μm
- Die-attach thickness = 20.17 μm
- Die paddle thickness = 132.3 μm
- Encapsulant overall = 907.8 μm



Lot 1706

- Die thickness = 286.8 μm
- Die-attach thickness = 20.92 μm
- Die paddle thickness = 132.9 μm
- Encapsulant overall = 941.8 μm



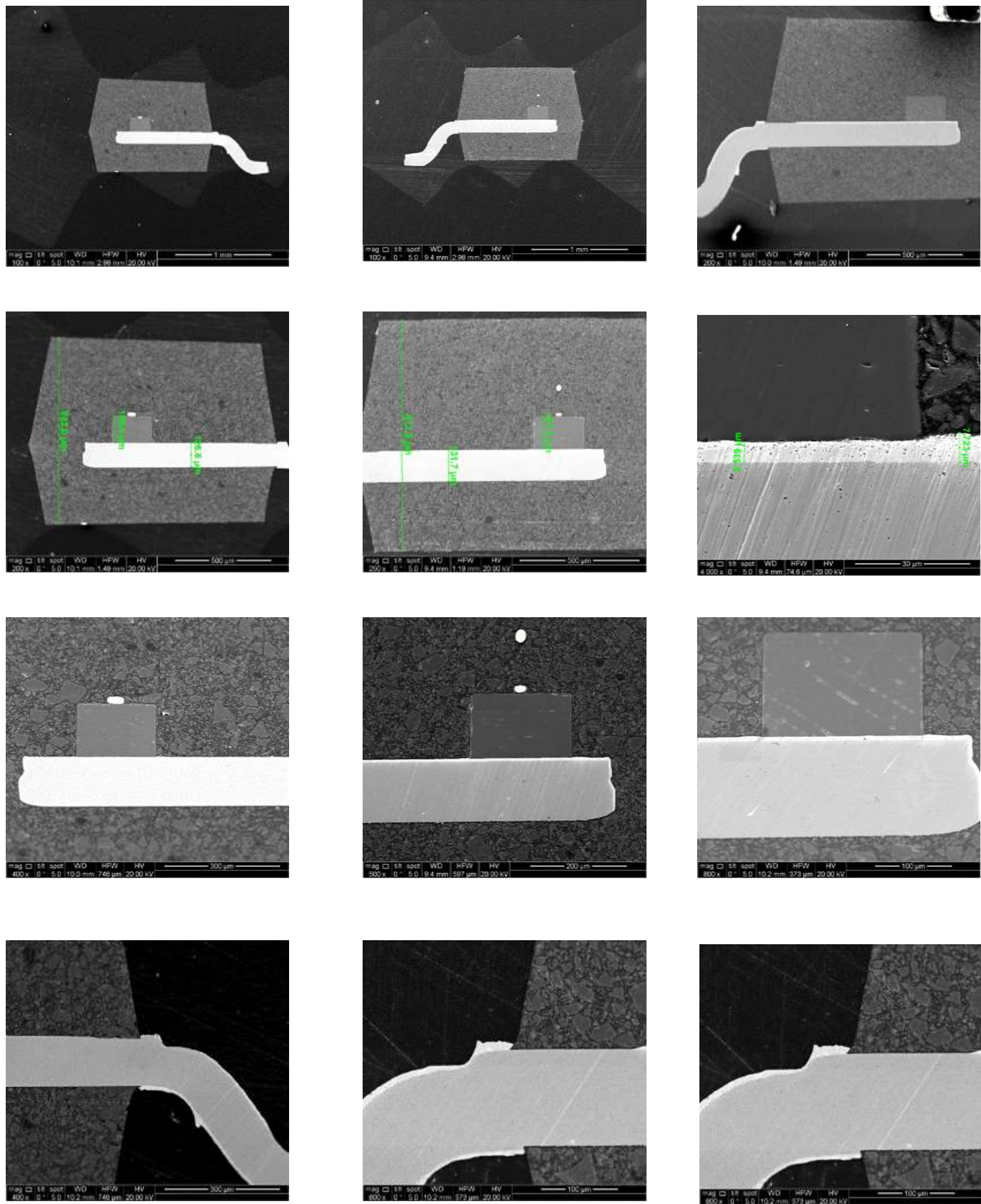
Lot 1816

- Die thickness = 287.0 μm
- Die-attach thickness = 20.45 μm
- Die paddle thickness = 131.1 μm
- Encapsulant overall = 919.4 μm

Cross-sectioning

Infineon Diodes

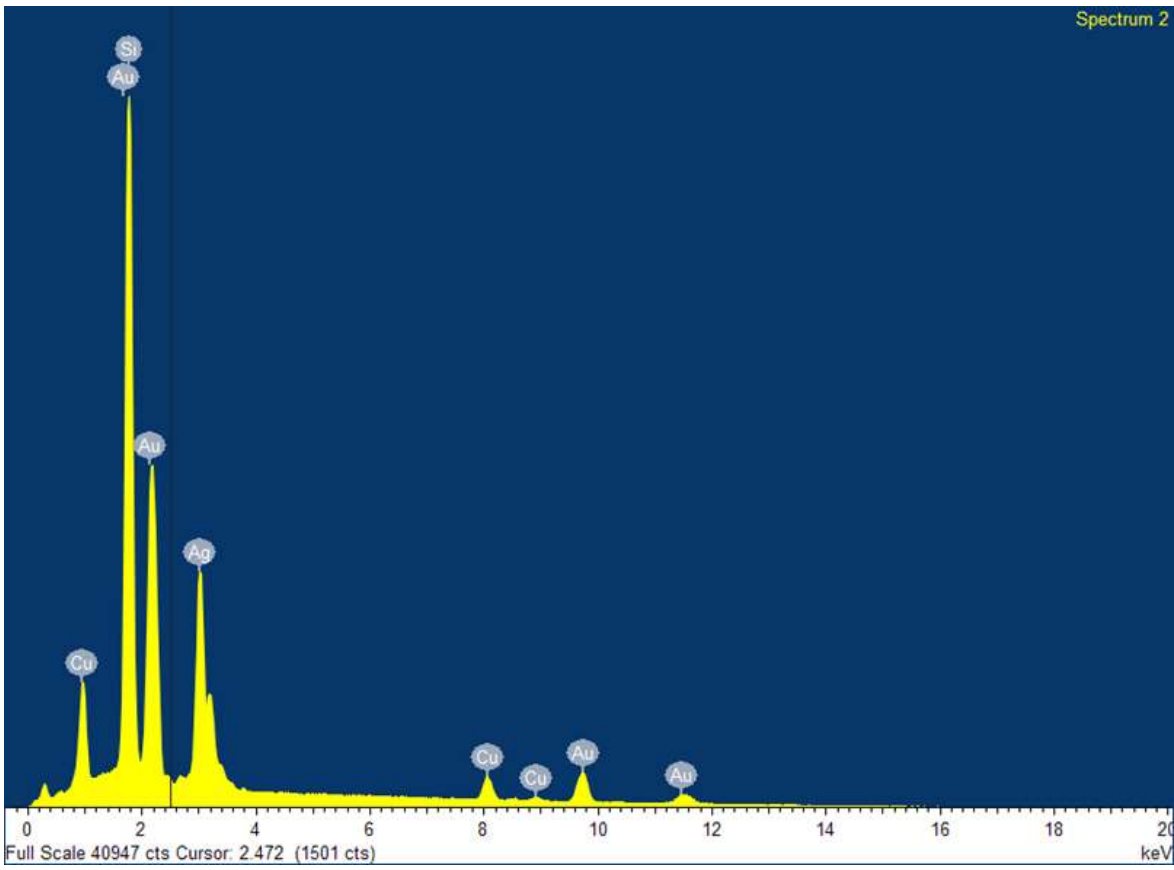
➤ No materials or dimensional differences between lots.



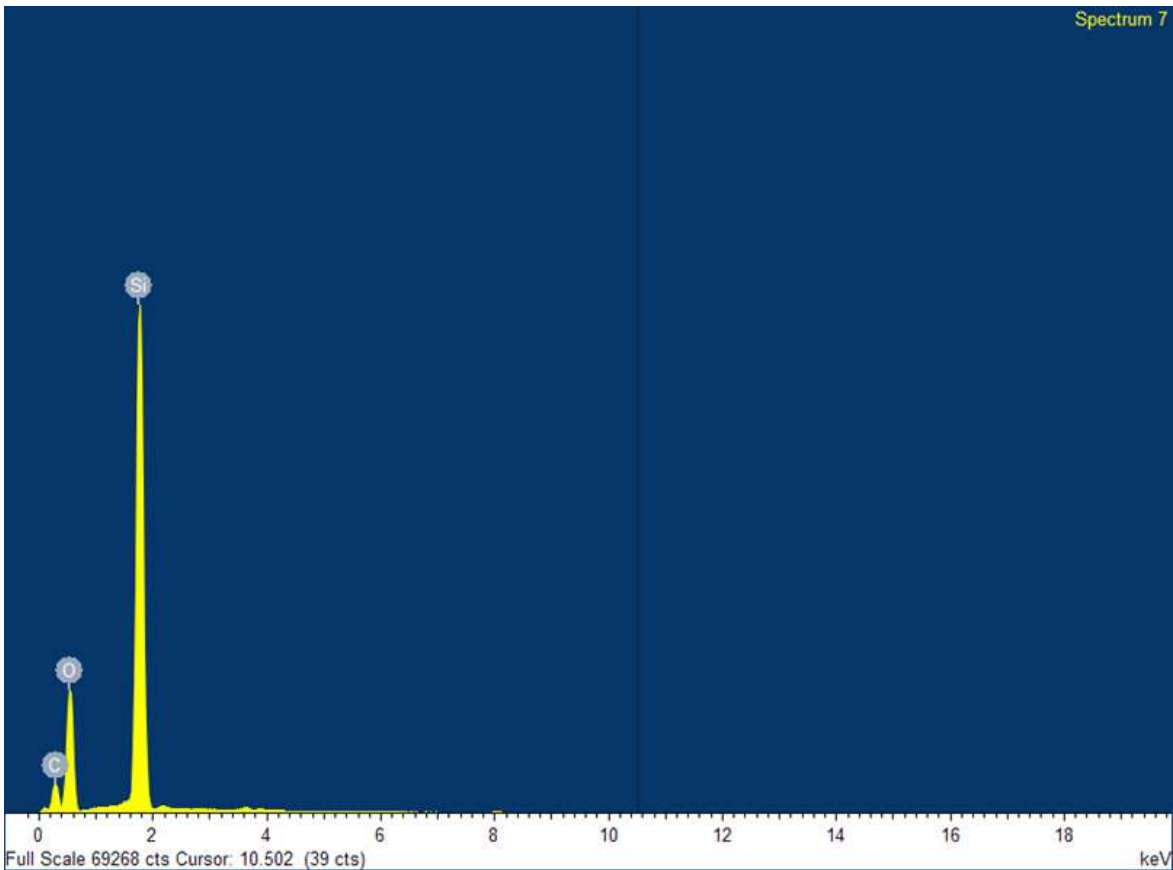
Lot 1536

Lot 1829

Lot 1831



EDX Spectrum – die back plating & attach



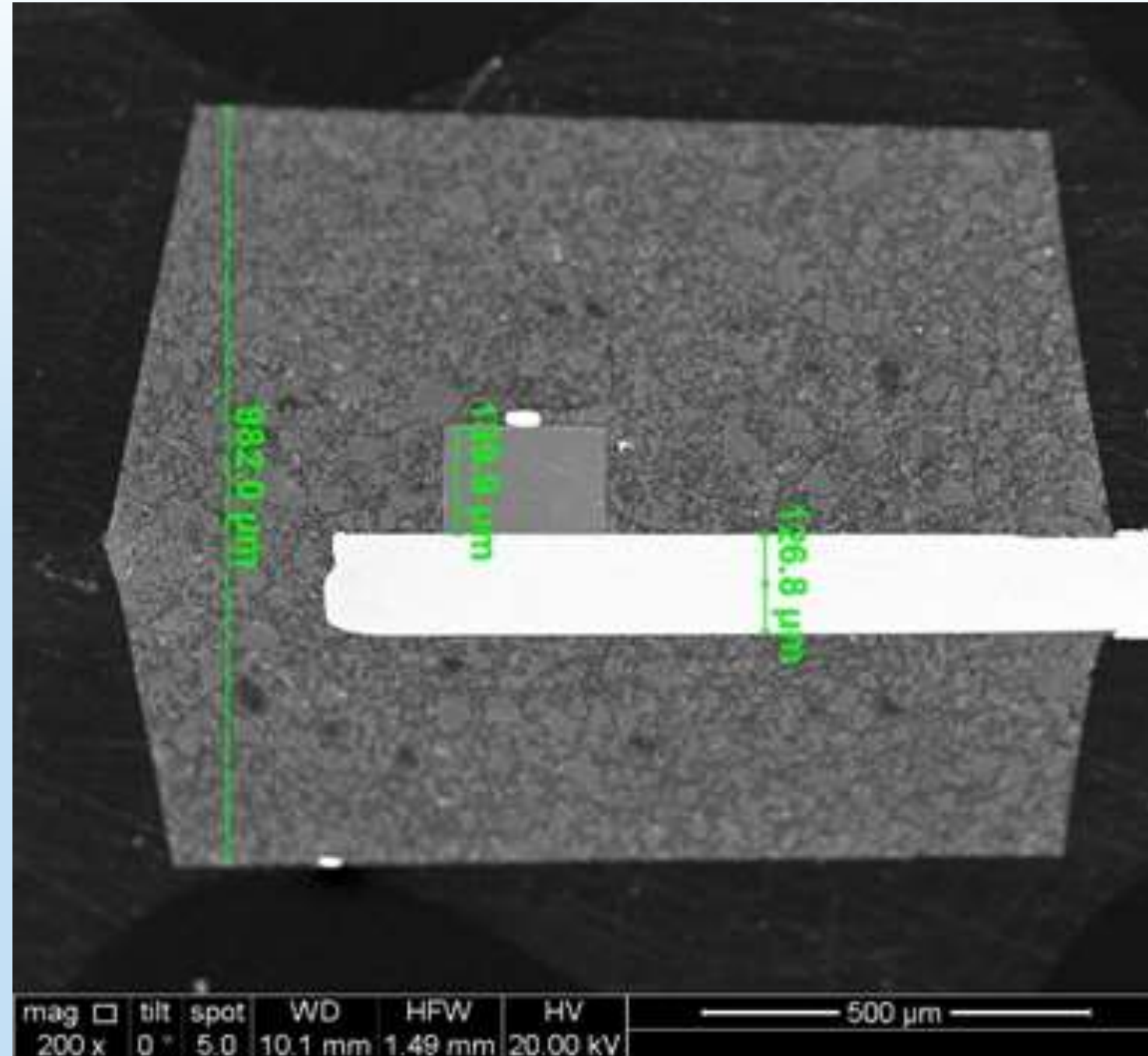
EDX Spectrum – plastic encapsulant

| Part Type | Principal Elements Detected | | |
|-------------------------|-----------------------------|----------|----------|
| | Lot 1536 | Lot 1829 | Lot 1831 |
| Die | Si | Si | Si |
| Die base plating | Au | Au | Au |
| Die Paddle Bulk | Cu | Cu | Cu |
| Plastic | Si, C, O | Si, C, O | Si, C, O |
| Plastic filler particle | Si, O | Si, O | Si, O |
| Die paddle Plating | Ag | Ag | Ag |
| Lead Plating | Sn | Sn | Sn |
| Wire Bond | Au | Au | Au |

Summary of materials analysis results – Infineon diodes

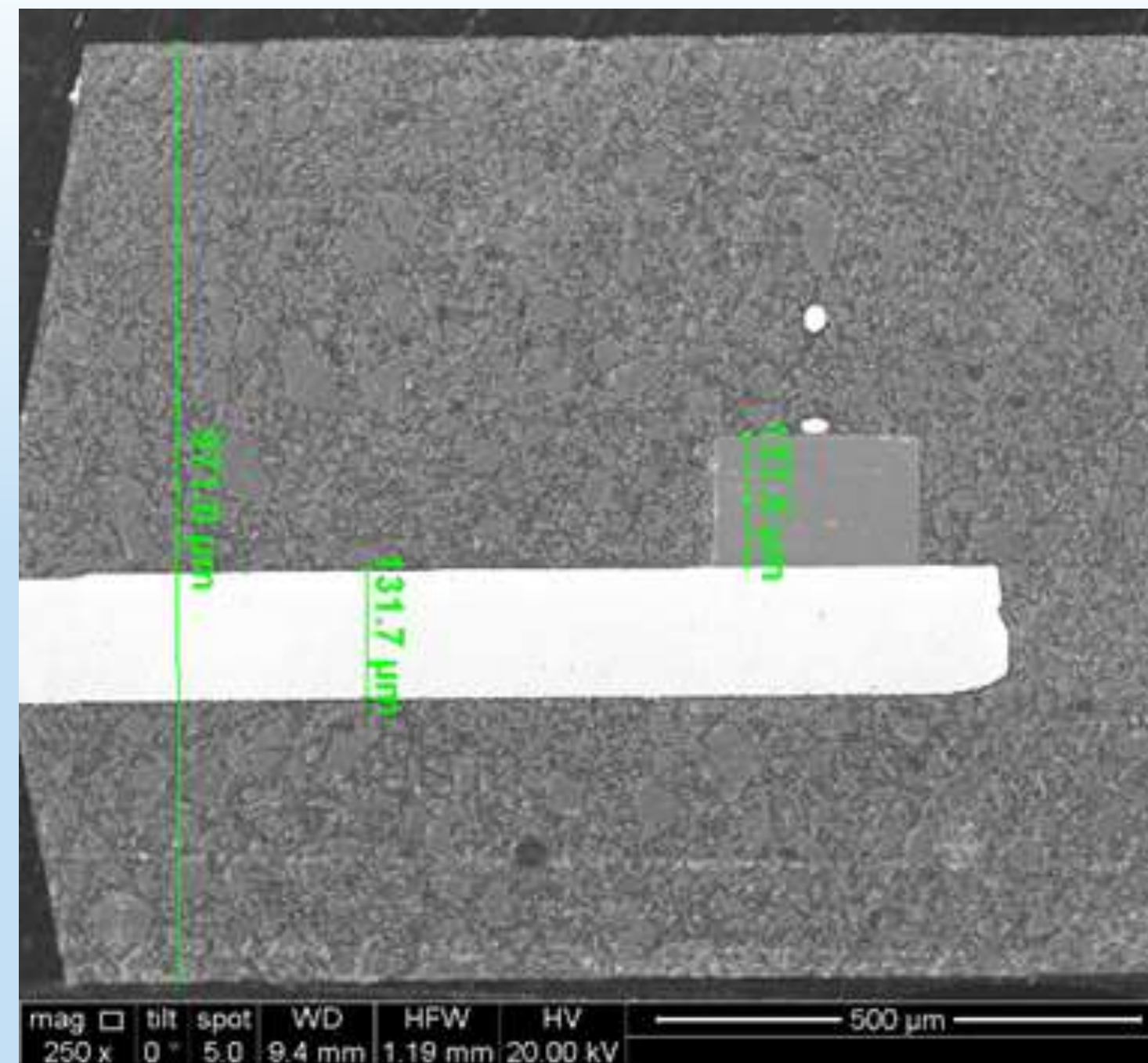
Cross-sectioning

Infineon Diodes



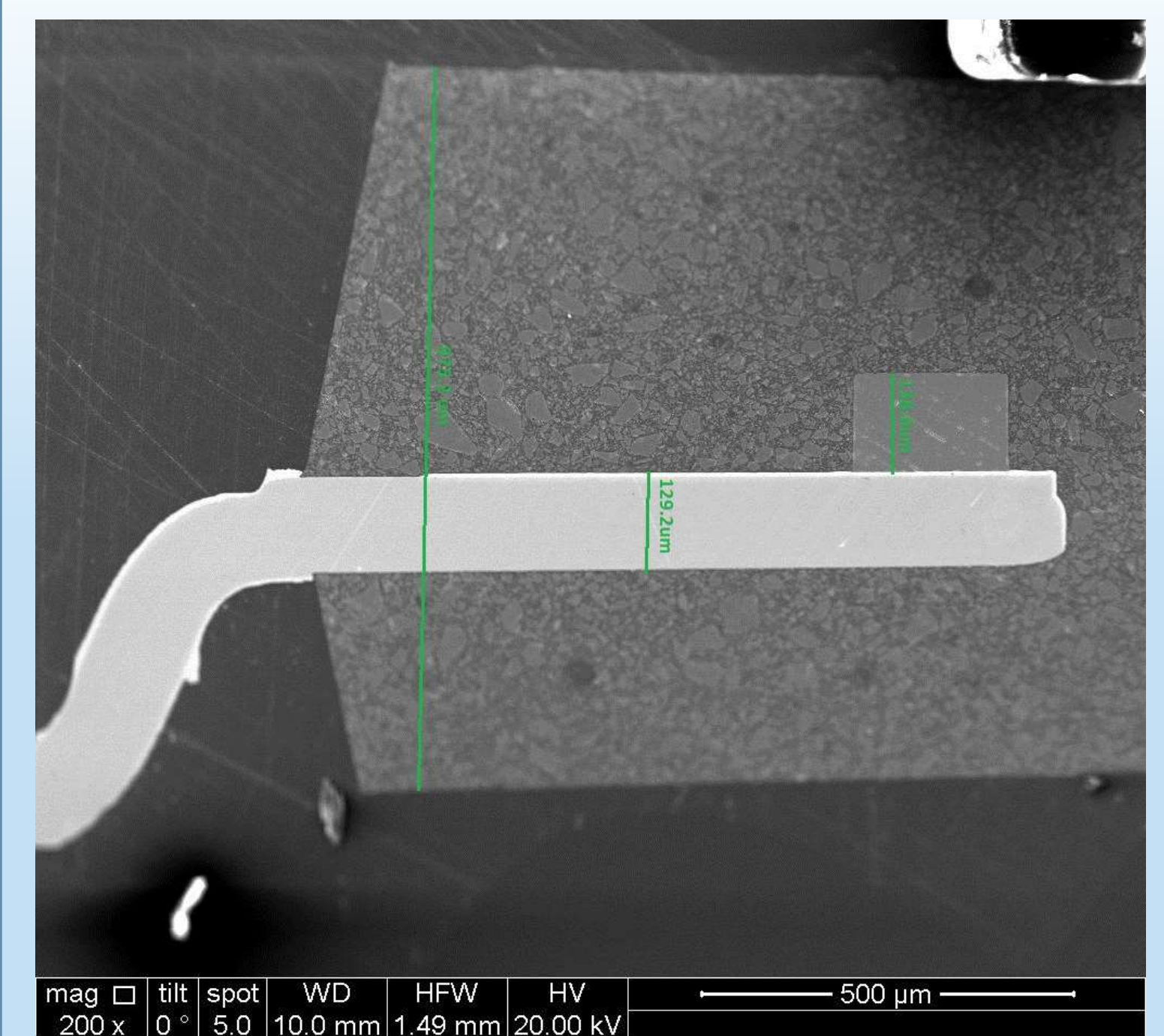
Lot 1536

- Die thickness = 139.9 μm
- Die paddle thickness = 126.8 μm
- Encapsulant overall = 982.0 μm



Lot 1829

- Die thickness = 137.5 μm
- Die paddle thickness = 131.7 μm
- Encapsulant overall = 971.0 μm



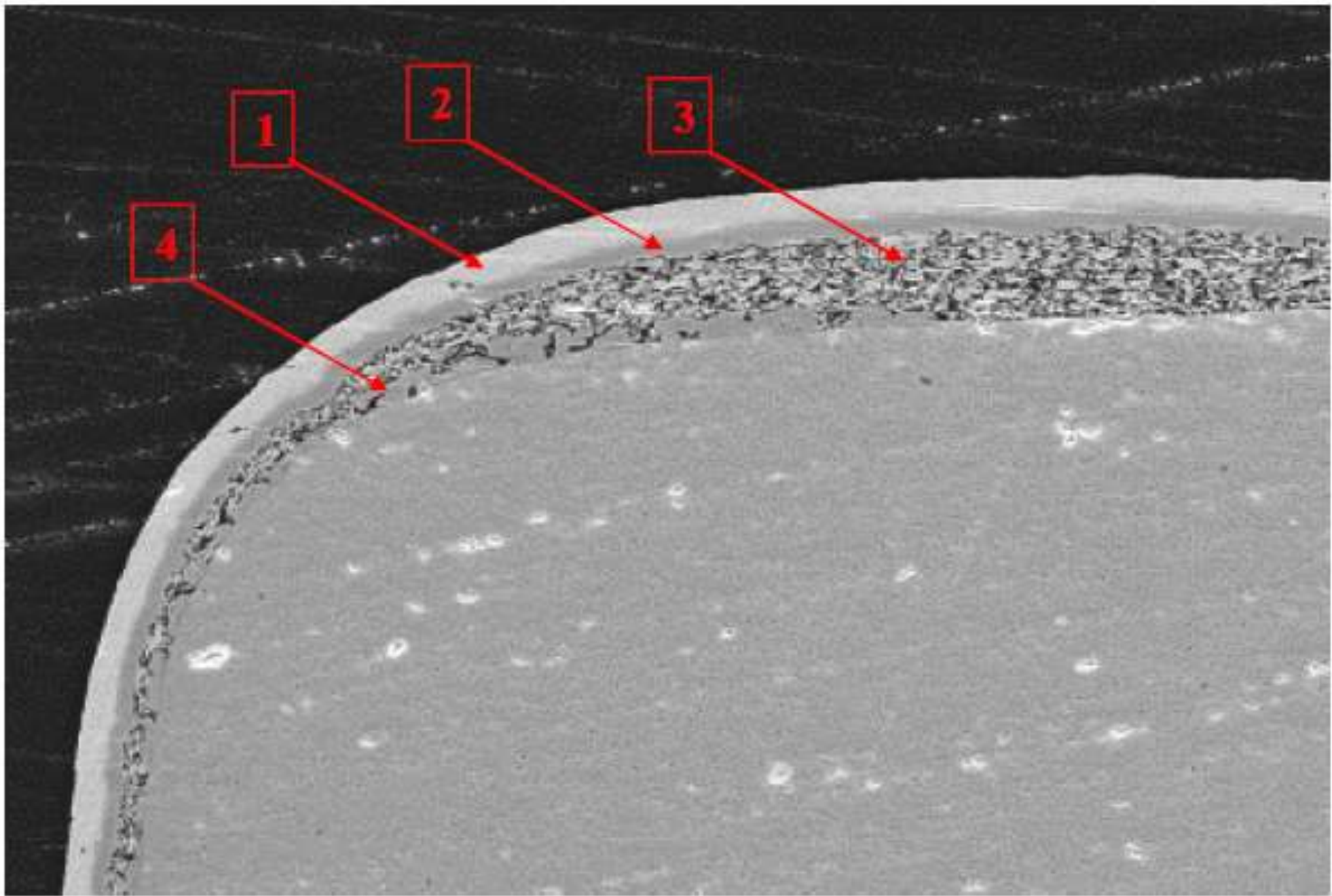
Lot 1831

- Die thickness = 138.6 μm
- Die paddle thickness = 129.2 μm
- Encapsulant overall = 975.2 μm

Cross-sectioning

AVX Capacitors

➤ No materials or dimensional differences between lots.



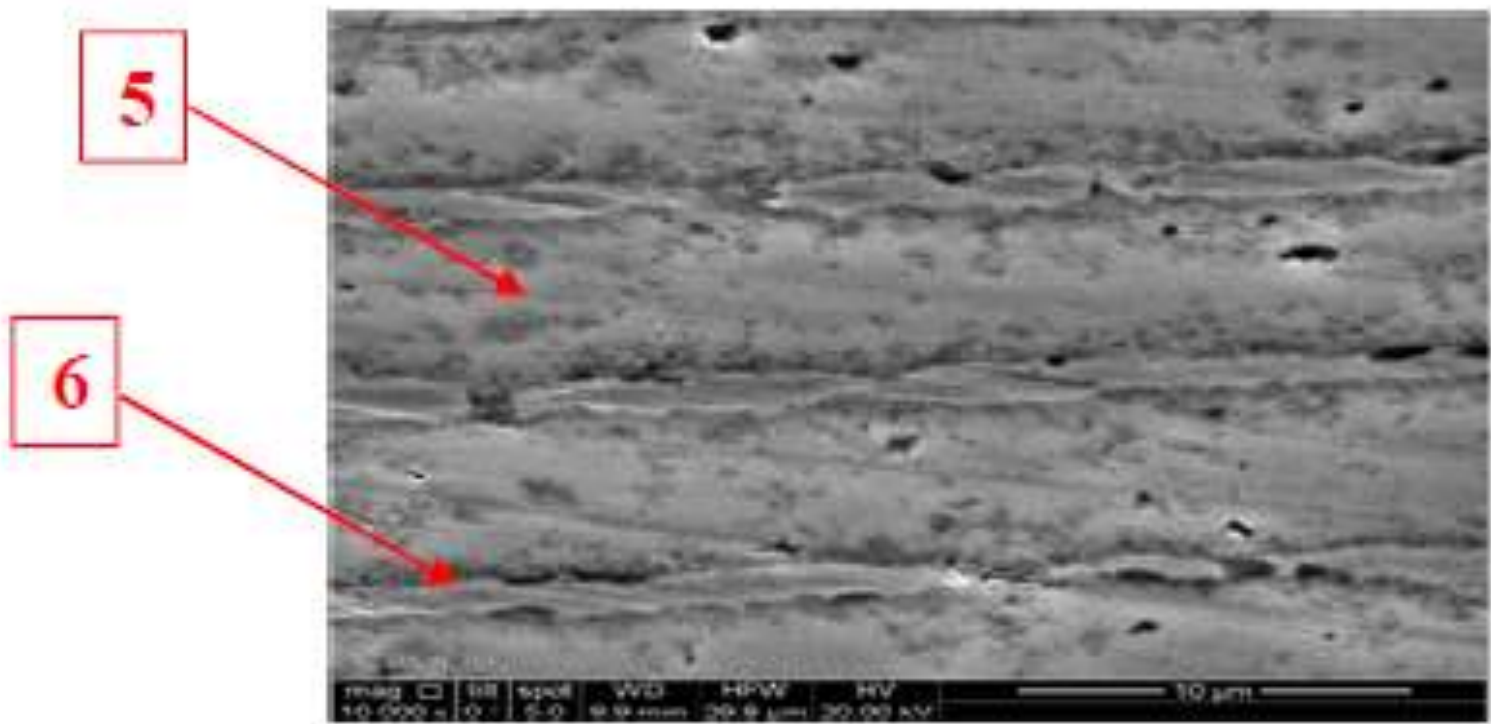
| Part Type | Principal Elements Detected AVX Capacitors | | |
|-------------------------------|---|--------------------|--------------------|
| | Lot 1820 | Lot 1927 | Lot 1937 |
| Outer Termination Plating (1) | Sn | Sn | Sn |
| Second Termination Layer (2) | Ni, Cu, Co | Ni, Cu, Co | Ni, Cu, Co |
| Third Termination Layer (3) | Ag | Ag | Ag |
| Inner Termination Layer (4) | Cu | Cu | Cu |
| Dielectric (5) | Ba, Ti, Co, Si, Zn | Ba, Ti, Co, Si, Zn | Ba, Ti, Co, Si, Zn |
| Capacitor Plate (6) | Ni, Co, Ti | Ni, Co, Ti | Ni, Co, Ti |

EDX Analysis Results – AVX Capacitors

Termination Structure: *Base metal = Cu, Plated with Ag, Barrier layer = Ni, Outer finish = Sn.*

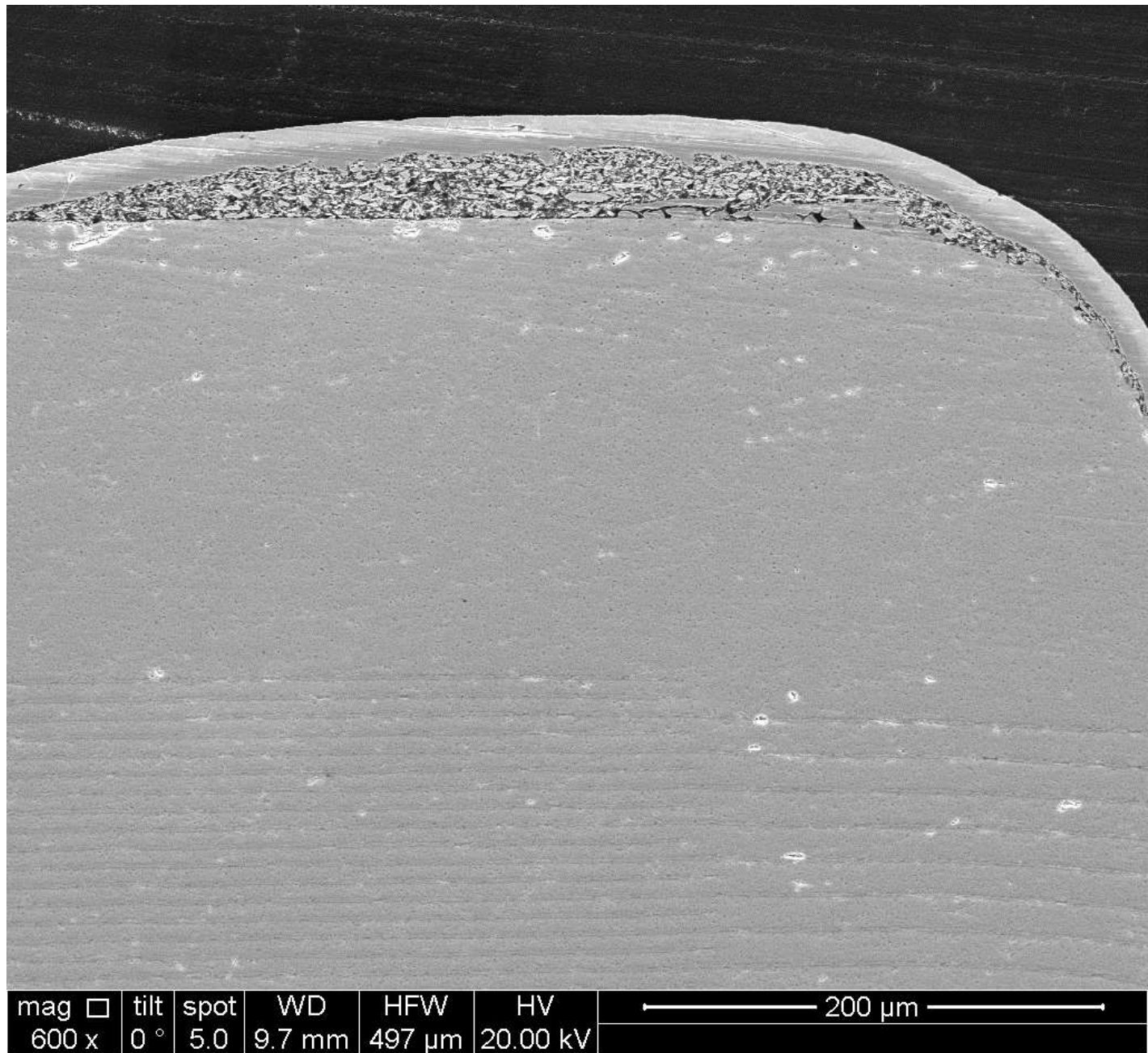
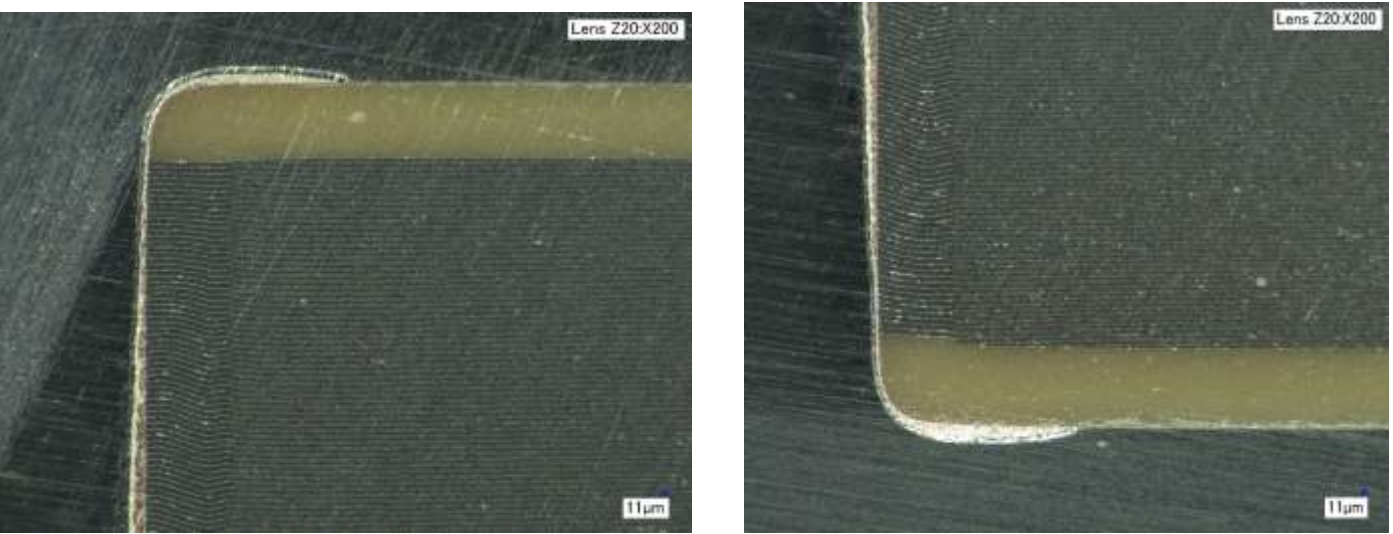
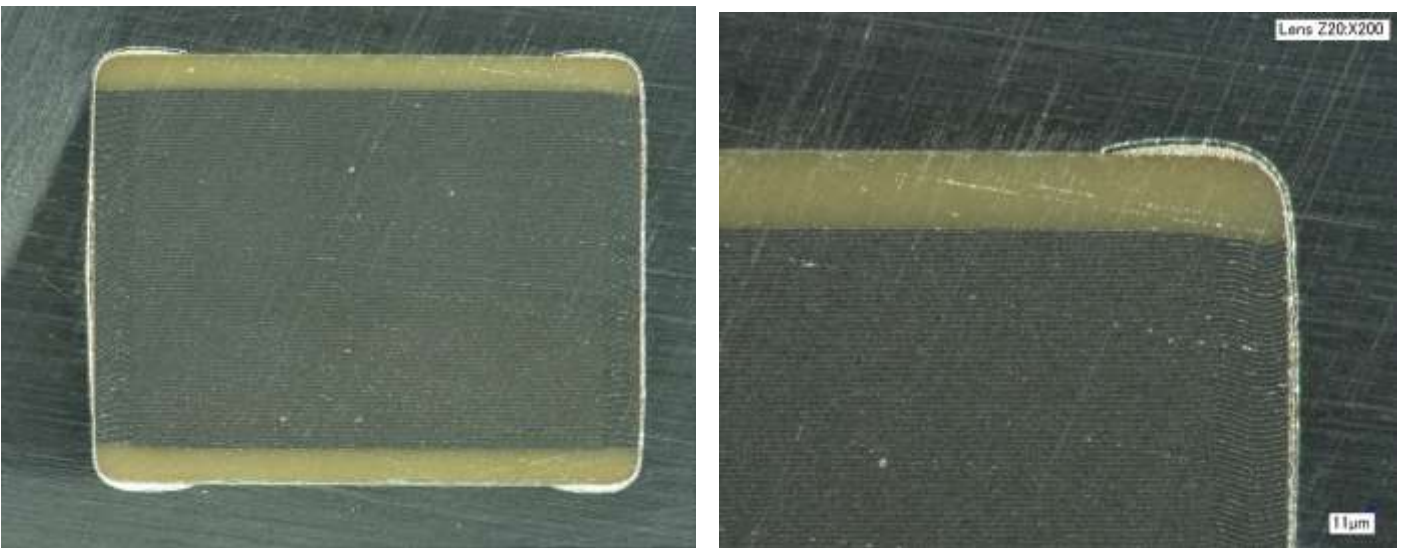
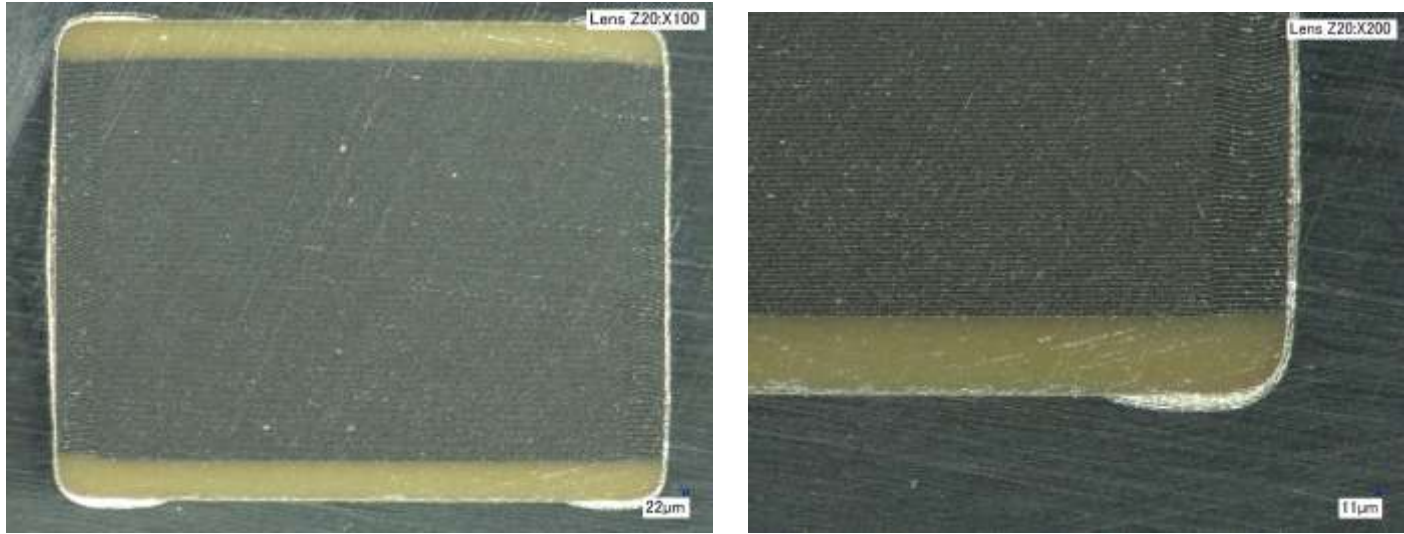
Capacitor Plates: *Primarily Ni.*

Dielectric Layers: *Primarily Ba & Ti (BaTiO₃)*

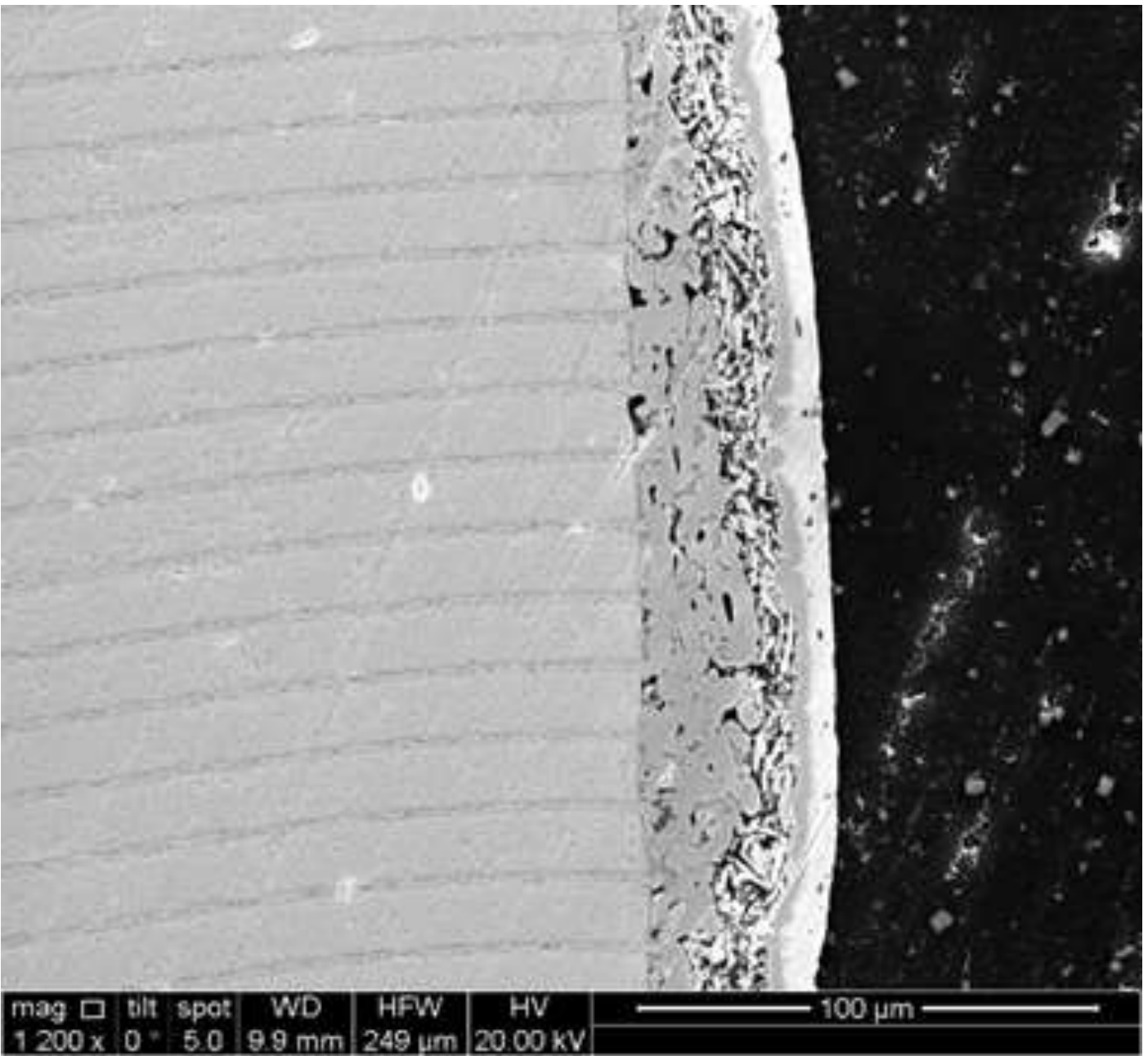


Cross-sectioning

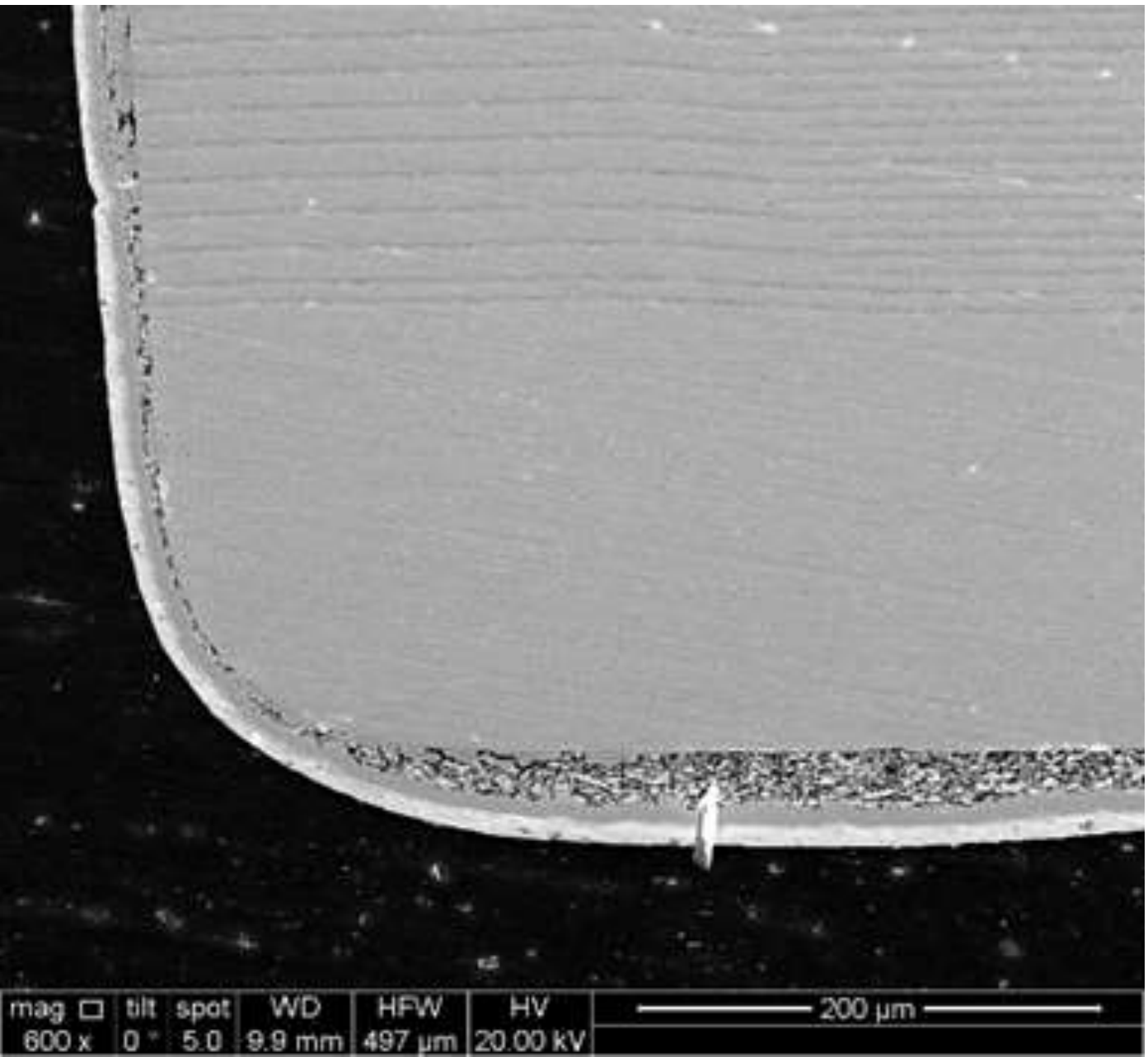
AVX Capacitors



AVX Lot 1820



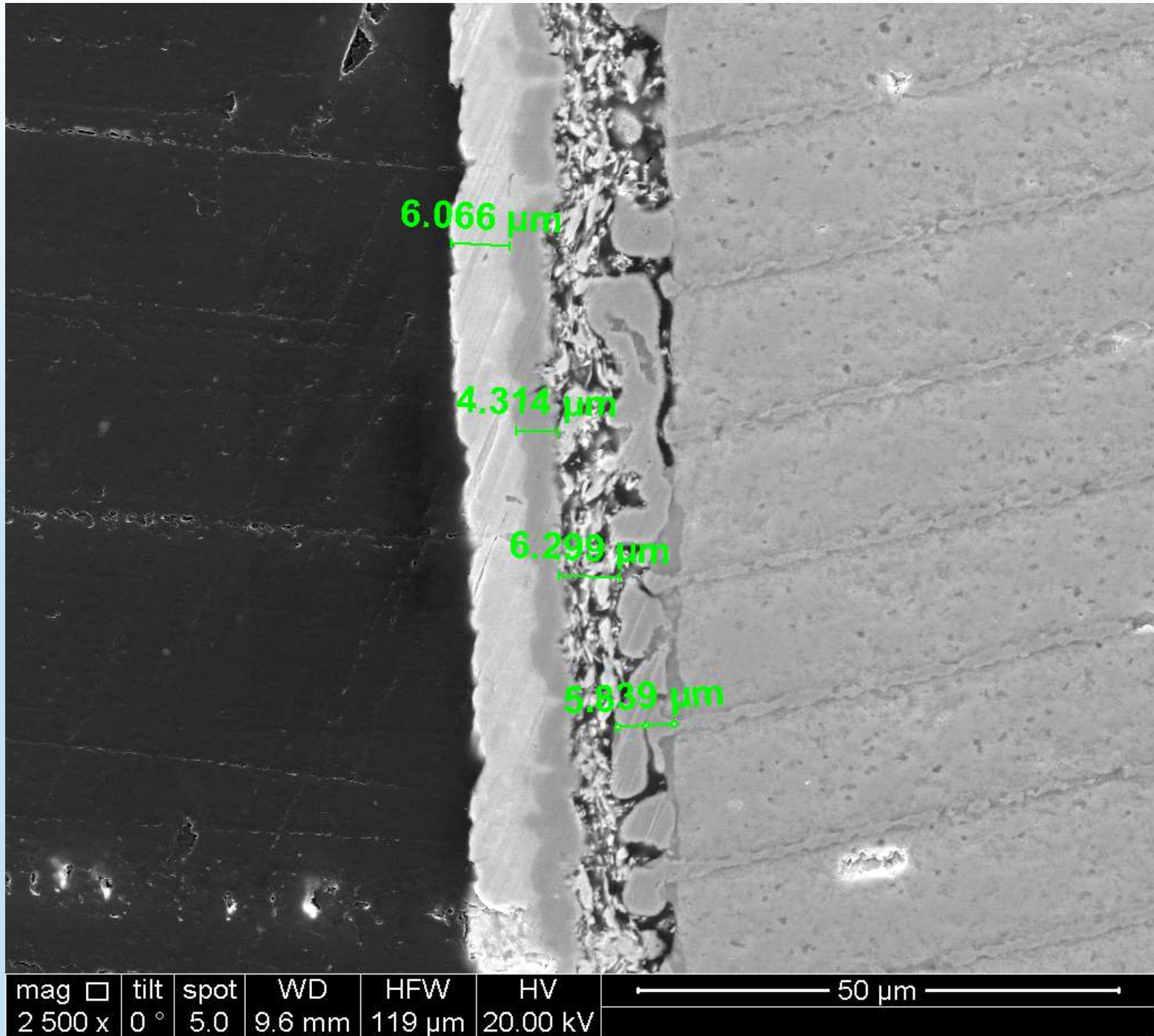
AVX Lot 1927



AVX Lot 1937

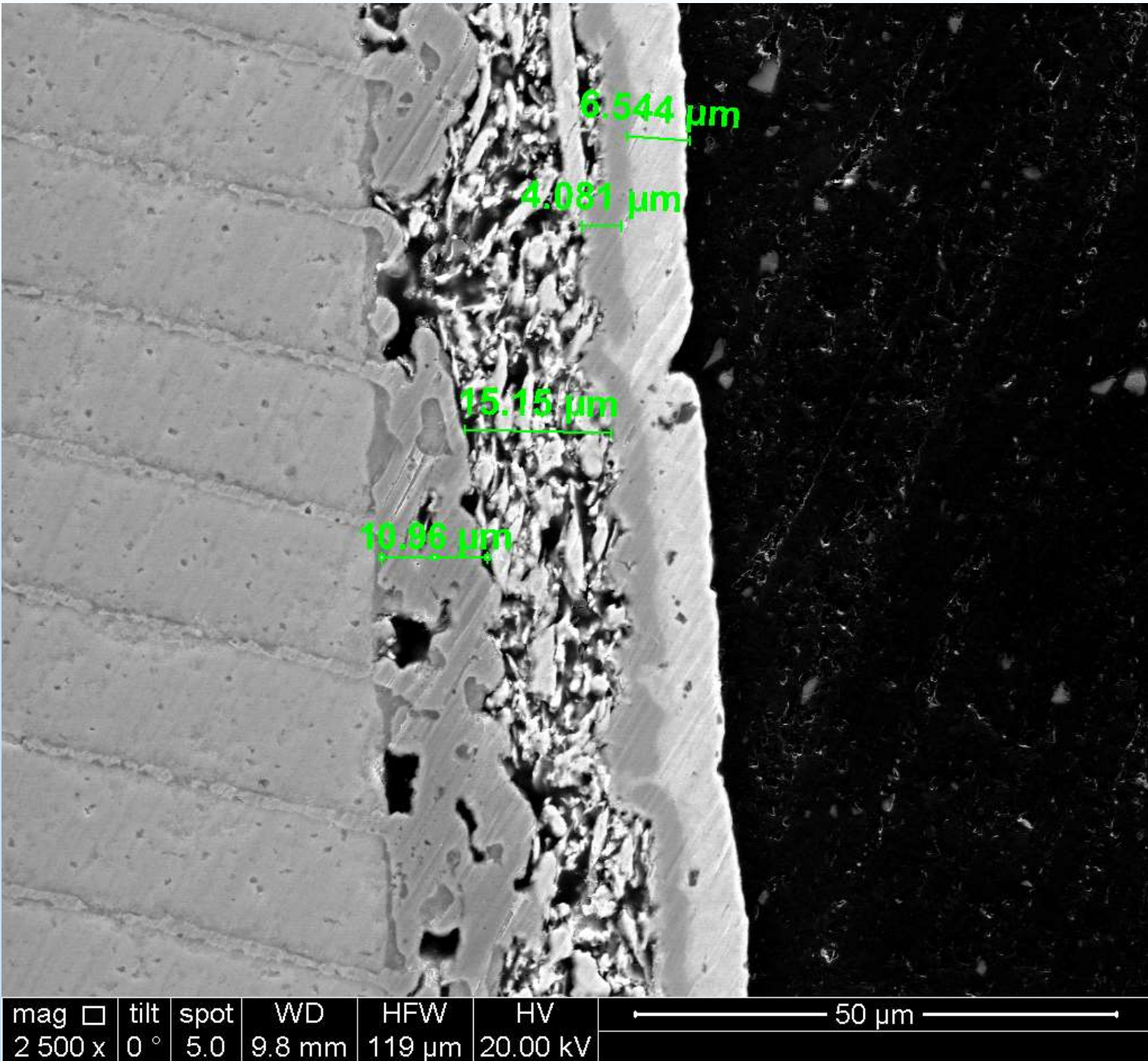
Cross-sectioning

AVX Capacitors



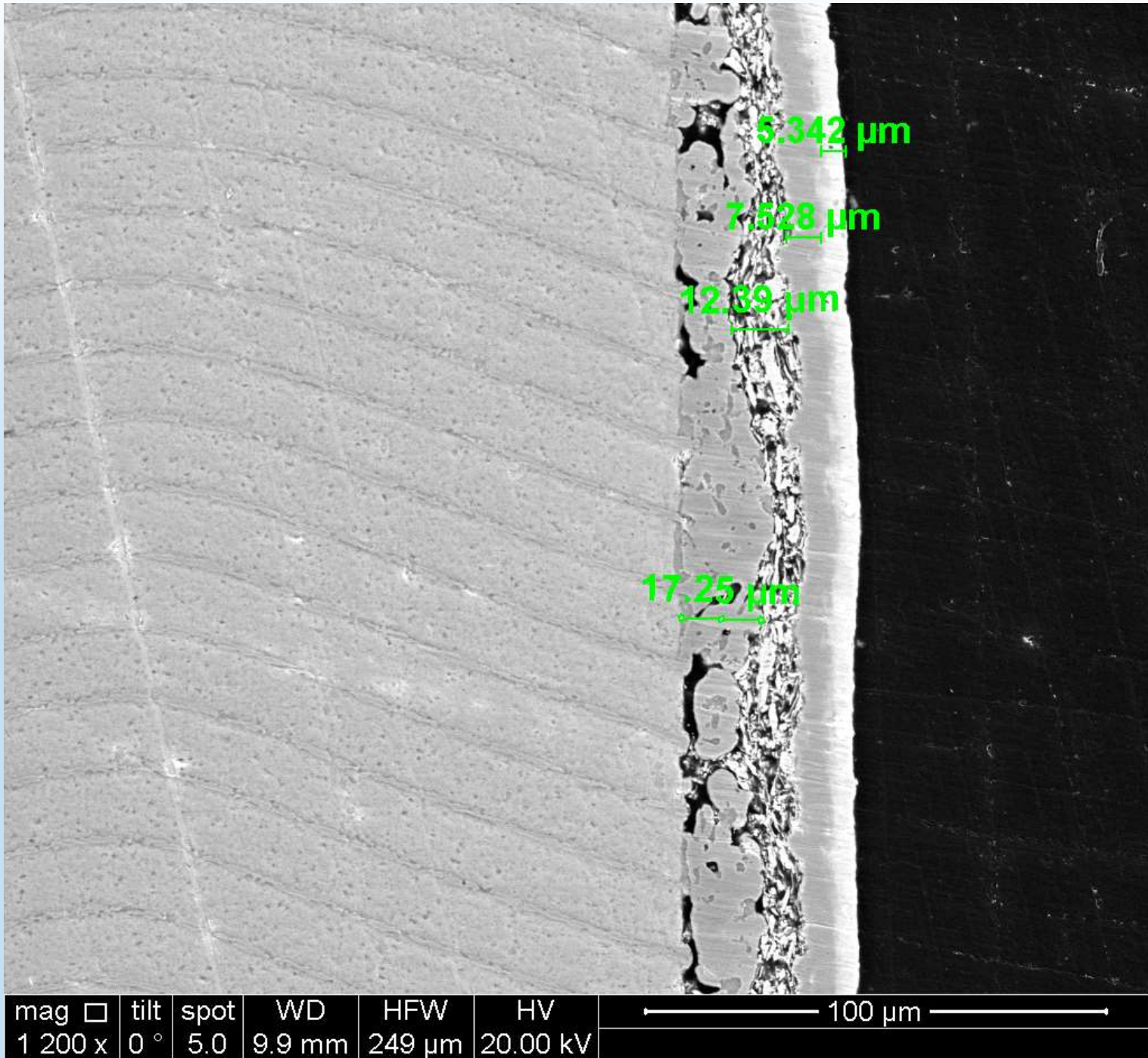
Lot 1820

- Outer Layer (Sn) = 6.066 μm
- Second Layer (Ni) = 4.314 μm
- Third Layer (Ag) = 6.299 μm
- Inner Layer (Cu) = 5.839 μm



Lot 1927

- Outer Layer (Sn) = 6.544 μm
- Second Layer (Ni) = 4.081 μm
- Third Layer (Ag) = 15.15 μm
- Inner Layer (Cu) = 10.86 μm

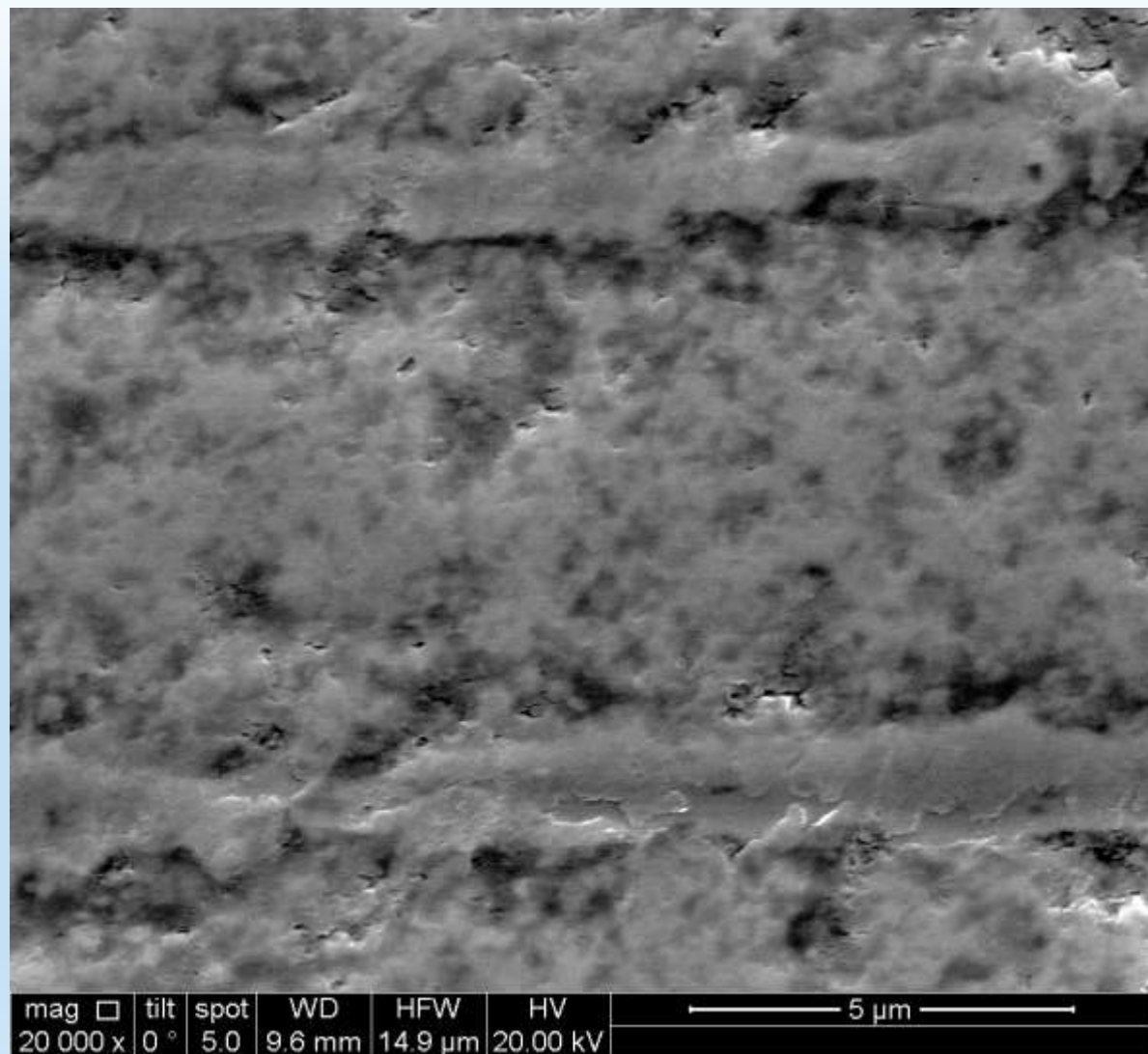


Lot 1937

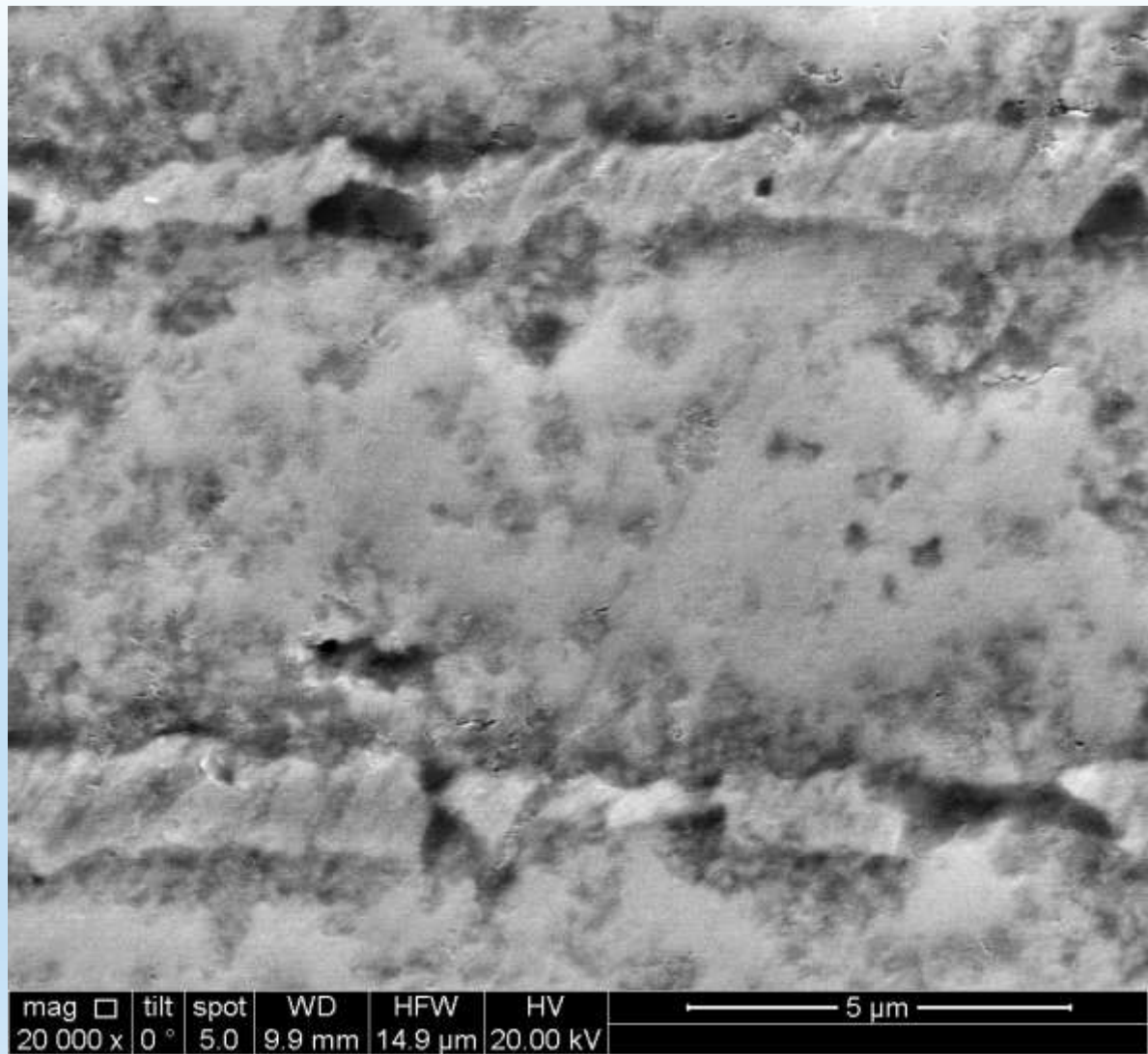
- Outer Layer (Sn) = 5.342 μm
- Second Layer (Ni) = 7.528 μm
- Third Layer (Ag) = 12.39 μm
- Inner Layer (Cu) = 17.25 μm

Cross-sectioning

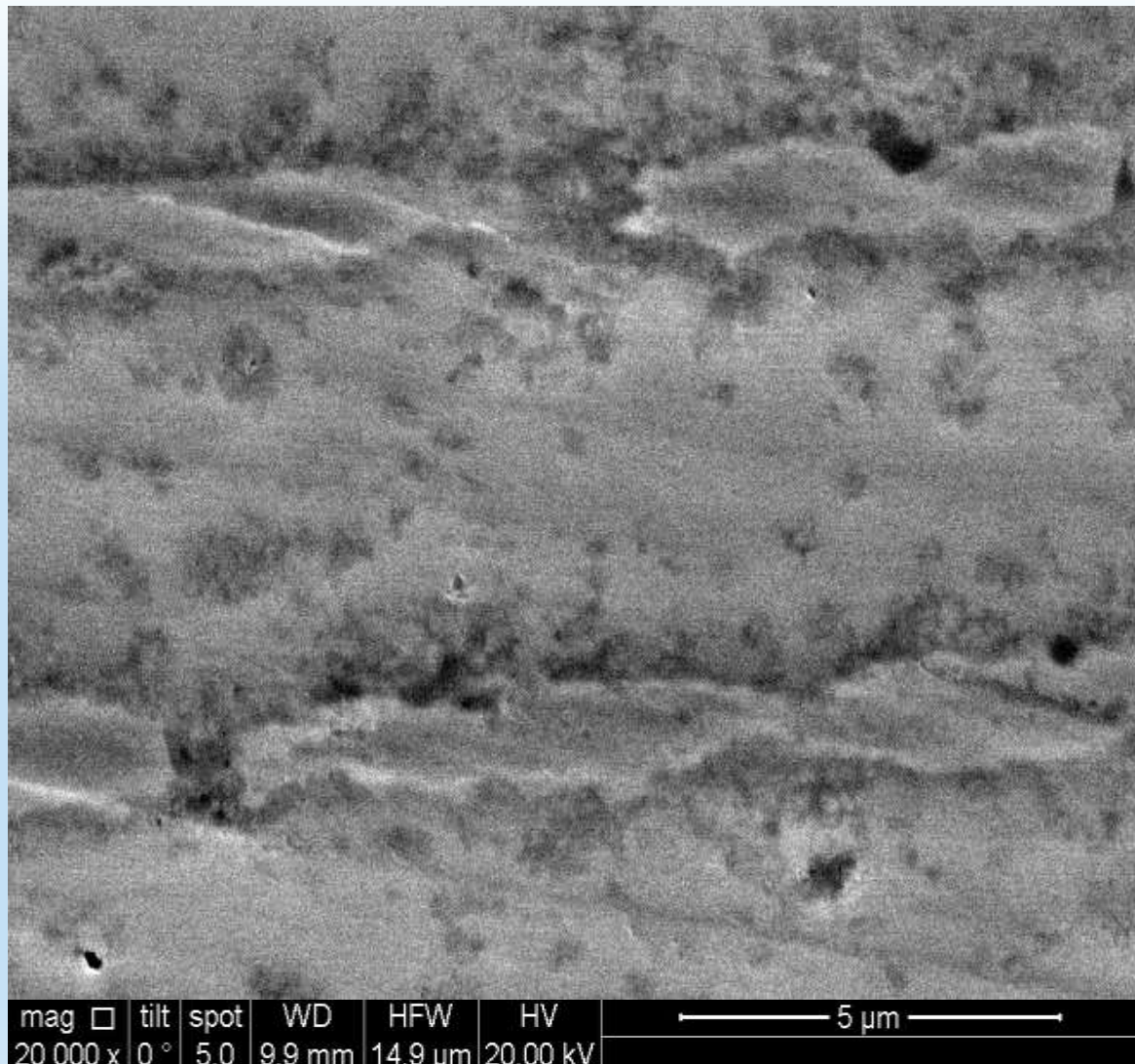
AVX Capacitors



AVX Lot 1820



AVX Lot 1927



AVX Lot 1937

| Layer | Mean Thickness Measurement (µm) | | |
|---------------------------|------------------------------------|----------|----------|
| | AVX 12105C475KAZ2A Capacitor | | |
| | Lot 1820 | Lot 1927 | Lot 1937 |
| Outer termination plating | 5.9 | 6.1 | 6.0 |
| Second termination layer | 4.9 | 4.9 | 5.1 |
| Third termination layer | 19.5 | 19.2 | 19.6 |
| Inner termination layer | 20.1 | 19.8 | 20.3 |
| Capacitor plates | 1.10 | 1.12 | 1.13 |
| Dielectric layers | 5.90 | 5.93 | 5.90 |

AVX Capacitors – Summary of Mean Internal Dimensions

Tg Measurement

- Characteristic property of a polymer.
- Tg marks transition from hard amorphous state to softer state.
- Measured by Differential Scanning Calorimetry
- Plastic Encapsulant (Op-Amps & Diodes)
- 0.25g sample of plastic required
 - 50 diodes
 - 10 Op-Amps
- Plastic harvested by cutting with Struers Minitom microsectioning saw.

| Sample No. | Glass Transition Temperature (T _g) °C | | |
|------------|--|----------|----------|
| | Lot 1647 | Lot 1706 | Lot 1816 |
| 1 | 156.8 | 155.4 | 157.9 |
| 2 | 157.5 | 156.7 | 156.0 |

ST-Microelectronics Operational Amplifiers

| Sample No. | Glass Transition Temperature (T _g) °C | | |
|------------|--|----------|----------|
| | Lot 1536 | Lot 1829 | Lot 1831 |
| 1 | 161.5 | 160.7 | 162.1 |
| 2 | 159.8 | 160.1 | 161.3 |

Infineon Diodes

- Results show close agreement between lots.
- Indicates same type of encapsulant used.

CTE Measurement

- CTE measured by TMA from ambient up to Tg
- Measured on full component in each case.
- 5 samples per lot.
- Matching values indicates same material structure

| Sample No. | Coefficient of Thermal Expansion (CTE) $\mu\text{m} / ^\circ\text{C}$ | | |
|------------|--|----------|----------|
| | Lot 1536 | Lot 1829 | Lot 1831 |
| 1 | 18.61 | 17.85 | 18.14 |
| 2 | 18.94 | 18.32 | 18.87 |
| 3 | 18.35 | 18.51 | 19.15 |
| 4 | 17.95 | 18.70 | 18.05 |
| 5 | 17.80 | 18.69 | 18.30 |
| Mean | 18.33 | 18.41 | 18.50 |

Summary of CTE Results – Infineon Diode Lots

| Sample No. | Coefficient of Thermal Expansion (CTE) $\mu\text{m} / ^\circ\text{C}$ | | |
|------------|--|----------|----------|
| | Lot 1647 | Lot 1706 | Lot 1816 |
| 1 | 16.89 | 17.41 | 16.87 |
| 2 | 17.25 | 17.22 | 16.98 |
| 3 | 17.15 | 16.91 | 17.47 |
| 4 | 16.70 | 17.37 | 17.55 |
| 5 | 17.37 | 17.68 | 17.19 |
| Mean | 17.07 | 17.32 | 17.21 |

Summary of CTE Results ST-Micro Operational Amplifier Lots

| Sample No. | Coefficient of Thermal Expansion (CTE) $\mu\text{m} / ^\circ\text{C}$ | | |
|------------|--|----------|----------|
| | Lot 1820 | Lot 1927 | Lot 1937 |
| 1 | 16.89 | 17.41 | 16.87 |
| 2 | 17.25 | 17.22 | 16.98 |
| 3 | 17.15 | 16.91 | 17.47 |
| 4 | 16.70 | 17.37 | 17.55 |
| 5 | 17.37 | 17.68 | 17.19 |
| Mean | 17.07 | 17.32 | 17.21 |

Summary of CTE Results – AVX Capacitor Lots

Outgassing Tests

Overview:

- TML (Total Mass Loss) Approach.
- Carried out on active (plastic) samples.
- 25 ST-Micro Op-Amp samples
- 50 Infineon Diode samples.

| Test Result | Lot 1647 | Lot 1706 | Lot 1816 |
|----------------------------------|----------|----------|----------|
| Initial Mass - 25 samples (g) | 1.3089 | 1.3105 | 1.3117 |
| Final Mass - 25 samples (g) | 1.2962 | 1.2987 | 1.2971 |
| Total Mass Loss - 25 samples (g) | 0.0127 | 0.0118 | 0.0146 |
| Total Mass loss (%) | 0.97 | 0.90 | 1.11 |

Summary of TML Results – ST-Micro Op-Amp Lots

Test Procedure:

- Pre-conditioning 21°C / 50% RH, 24 hours.
- Initial total mass measurements.
- Exposure to High Vacuum (10^{-5} Torr) at 125 °C.
- Final total mass measurement / mass loss.

| Test Result | Lot 1536 | Lot 1829 | Lot 1831 |
|----------------------------------|----------|----------|----------|
| Initial Mass - 50 samples (g) | 0.4108 | 0.4175 | 0.4151 |
| Final Mass - 50 samples (g) | 0.4079 | 0.4149 | 0.4117 |
| Total Mass Loss - 50 samples (g) | 0.0029 | 0.0026 | 0.0034 |
| Total Mass loss (%) | 0.71 | 0.62 | 0.82 |

Summary of TML Results – Infineon Diode Lots

Reliability Stress Test Programme

- Temperature Humidity Bias (THB) Test – 10 samples x 3 lots x 3 types (1,000 hours, 85°C / 85% RH).
- Temperature Cycling Test – 10 samples x 3 lots x 3 types:
 - Active Components mounted on FR4 PCB and tested to Mil-Std-883, TM1010, Condition B (+125 °C, -55 °C, 15min dwell, 10sec transfer, 500 cycles).
 - Capacitors mounted on polyimide & tested between 125 °C & -55 °C with change rate of 4 °C/min, 15min dwell, 500 cycles.
- High Temperature Operating Life (HTOL) – 10 samples x 3 lots x 3 types (1,000 hours at 125°C with bias).
- Pre & Post Stress Inspections:
 - External Visual Inspection.
 - SAM Inspection for plastic (active) samples.
 - Electrical test at ambient (~22 °C), low (-55 °C) & high (+125 °C) temperatures.
 - Failure Analysis (if required).

WP3 Delta Test Programme

Biasing & Electrical Parameter Measurement

■ Op-Amp Components:

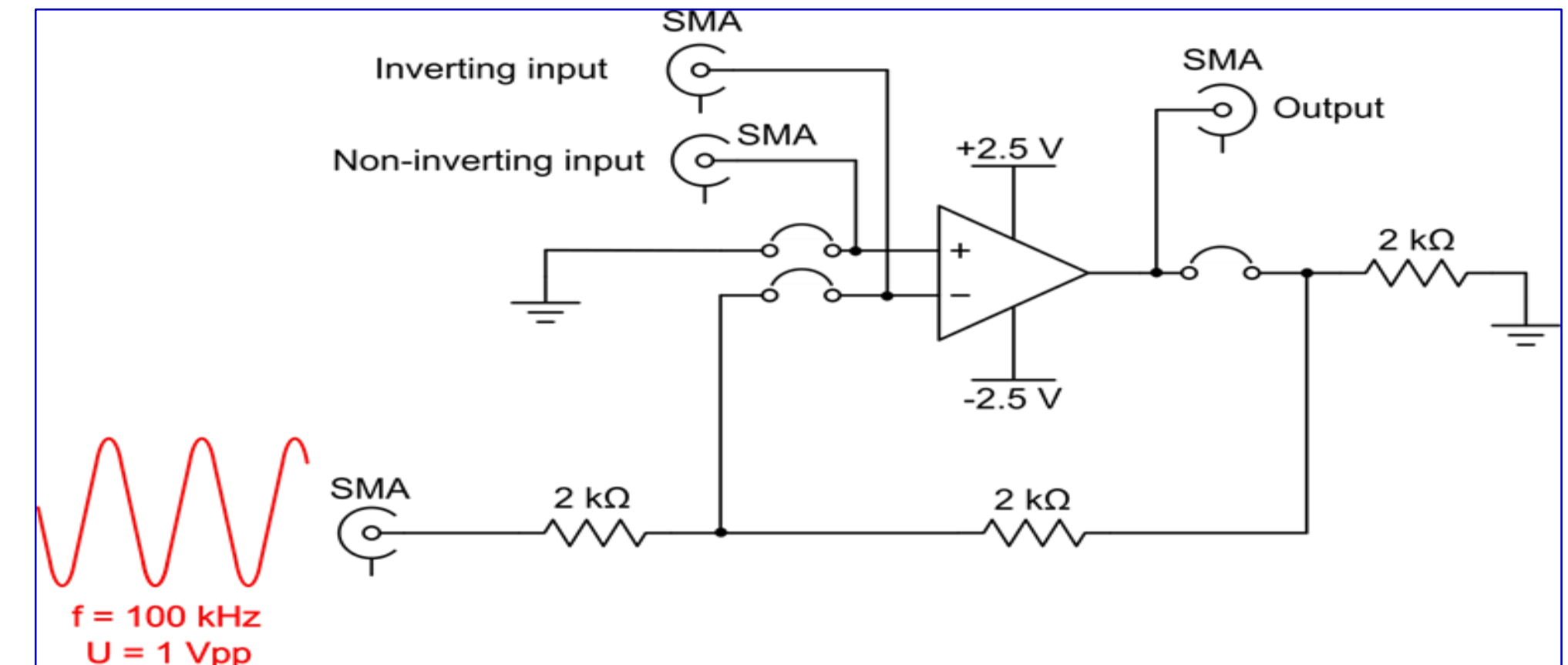
- Input Offset Voltage (V_{io})
- Input Offset Current (I_{io})
- Common Mode Rejection Ratio (CMRR)
- Supply Voltage Rejection Ratio (SVR)
- Source Current (I_{source})
- Sink Current (I_{sink})
- Gain Bandwidth Product (GBP)

■ High Speed Diode Components:

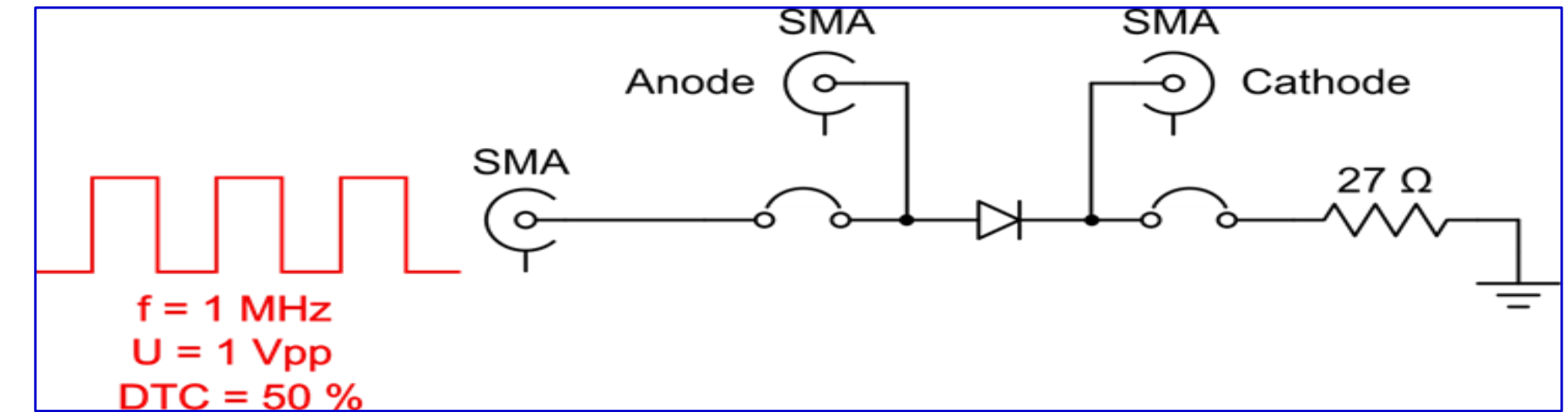
- Forward Voltage Drop (V_f) @ 1, 10, 50, 100, & 150mA.
- Forward Current (I_f)
- Reverse Breakdown Voltage (V_{br})
- Transition Capacitance (C_t)
- Reverse Recovery Time (T_{rr})

■ 1210, 4.7 μ F Ceramic Capacitors:

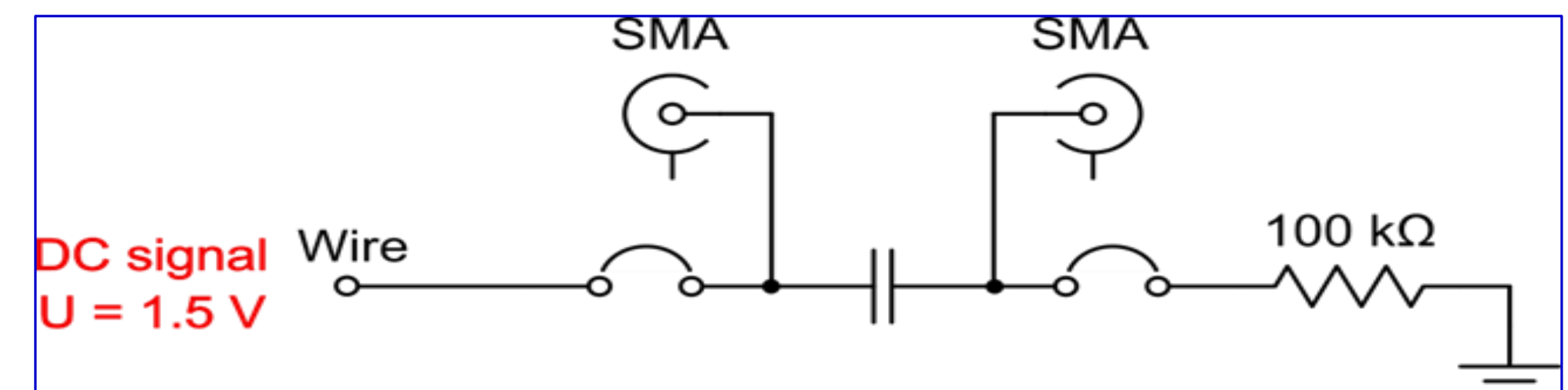
- Capacitance (C) @ 1MHz.



Op-Amp Biasing During Stress Tests



Diode Biasing During Stress Tests



Capacitor Biasing During Stress Tests

THB Test

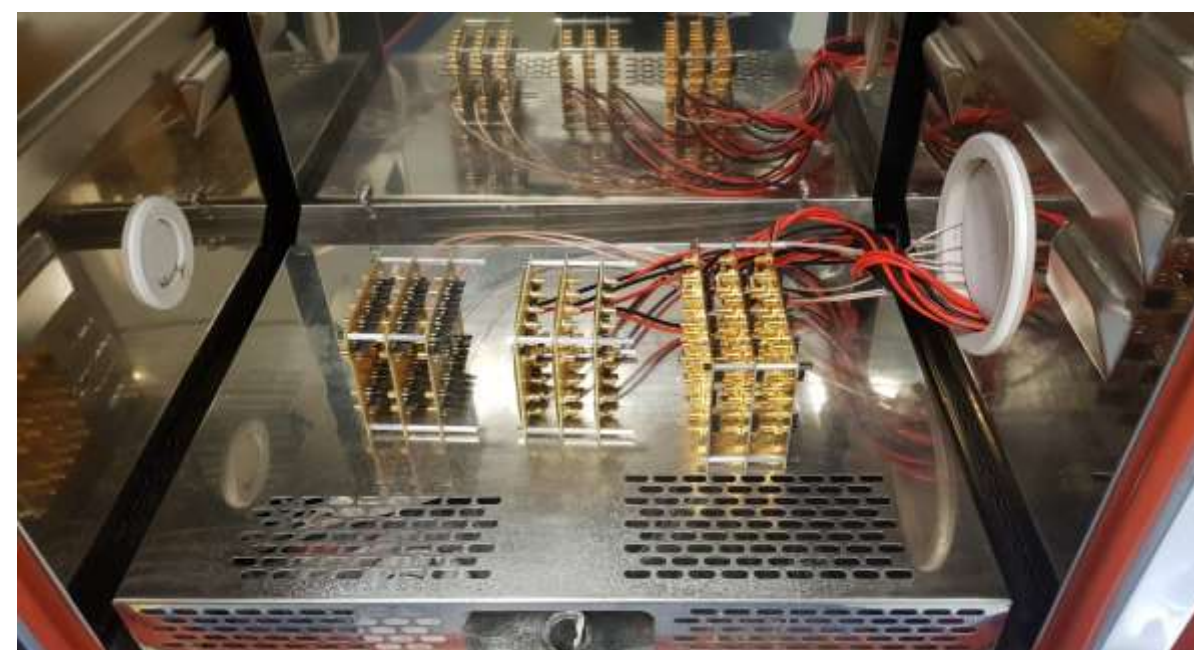
- 10 samples selected per lot.
- Initial Visual Inspection.
- PCB assembly / sample mounting.
- Second visual inspection.
- Initial electrical test (room temp)
- THB test, 1000hours at 85°C / 85% RH, biased
- Final visual inspection
- Final electrical test (ambient temp)



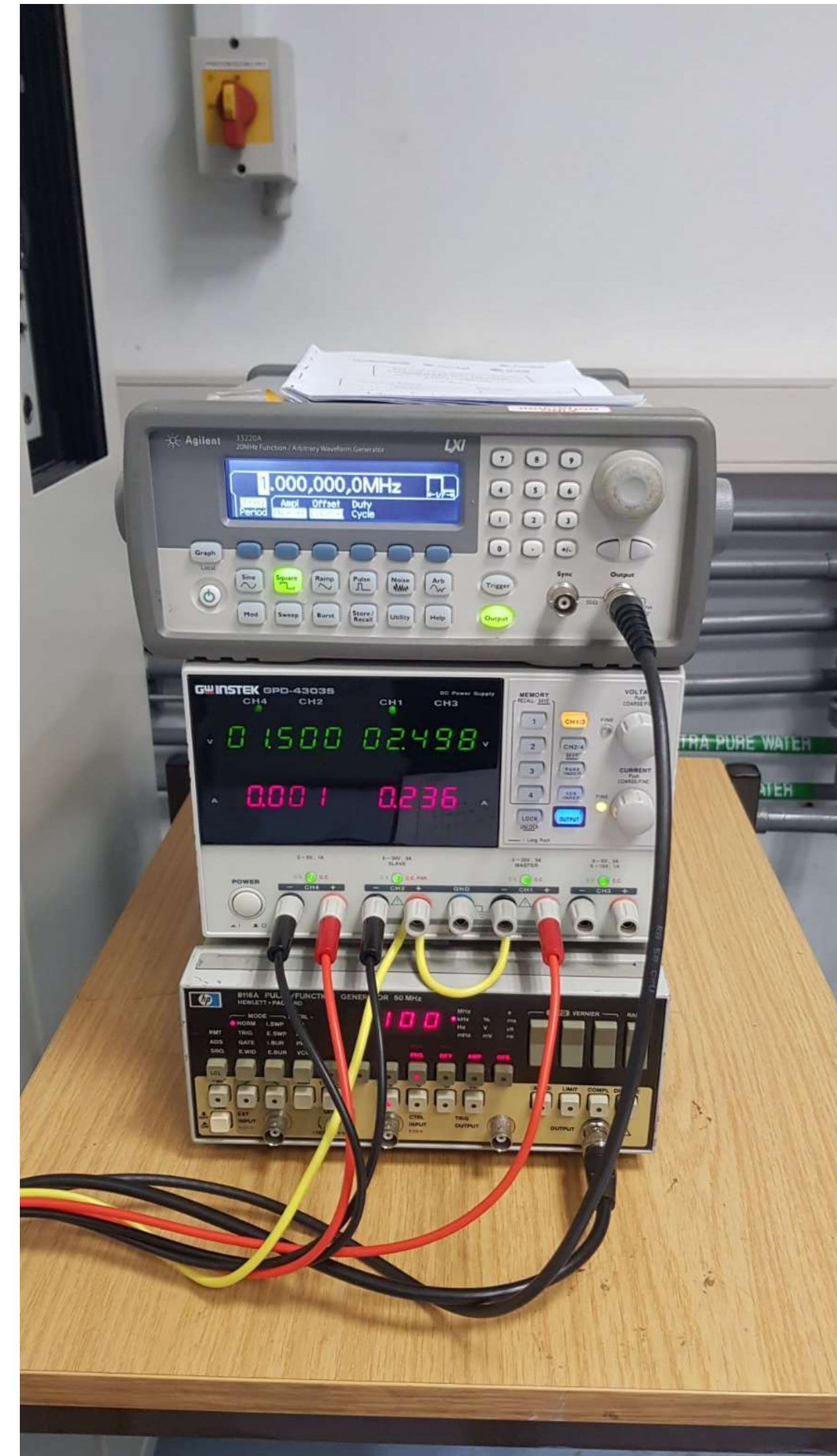
Test Chamber



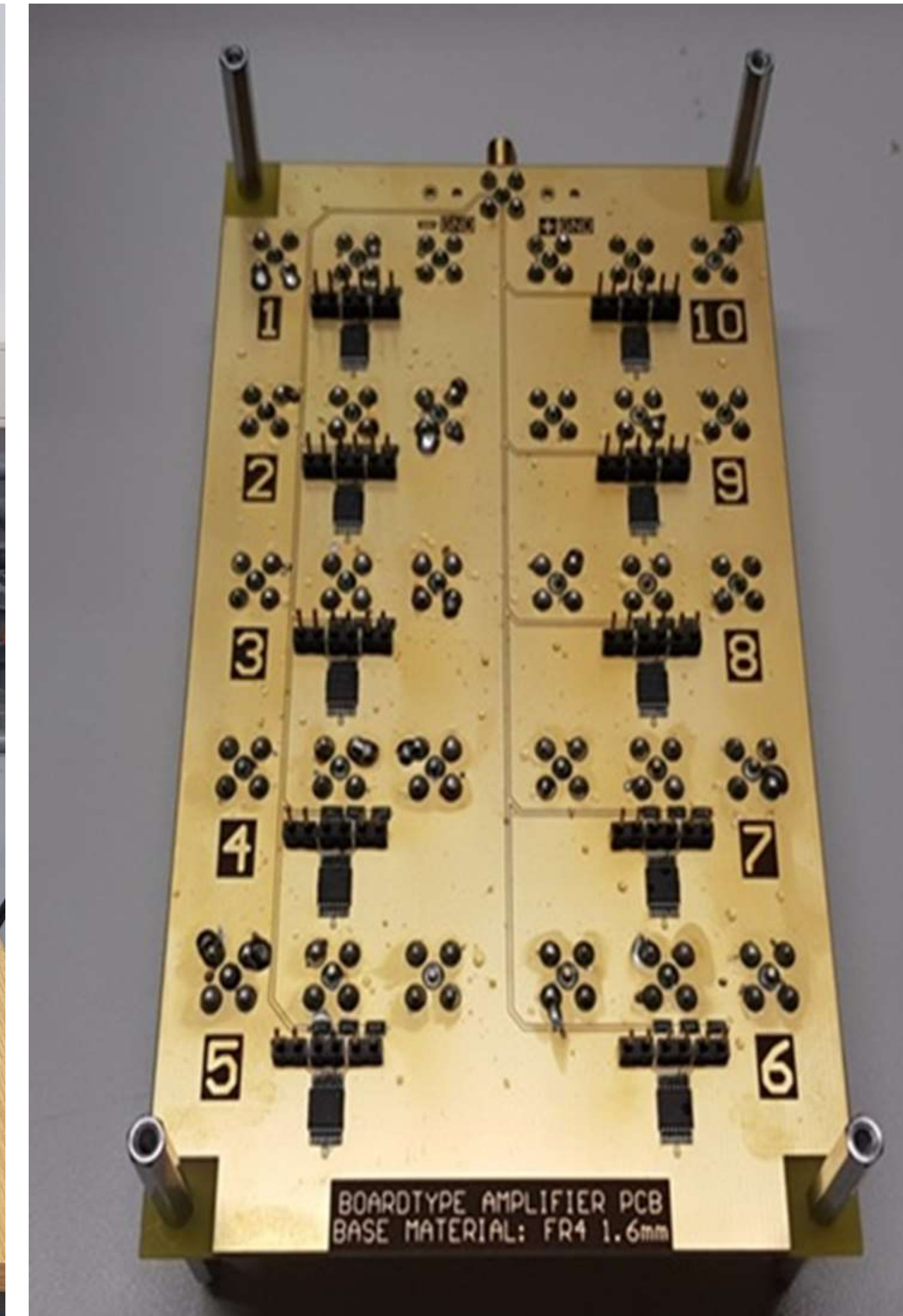
Test Chamber – Weiss Technik Wk 11/80



10 components per PCB



Bias set-up



Test Board ST-Micro Op-Amps

Thermal Cycling Test



Active Components (Op-Amps & Diodes)

- Based on Mil-Std-883, TM 1010.
- Samples mounted on FR4 PCBs
- Dual Chamber Thermal Shock System.
- 500 Cycles from -55°C to $+125^{\circ}\text{C}$.
- Dwell time 15min, 10 sec transfer, No bias.

Passive Components (Capacitors)

- Samples mounted on Polyimide PCBs
- Single Chamber Thermal Cycling System.
- Controlled ramp rate of $5^{\circ}\text{C} / \text{min}$.
- 500 Cycles from -55°C to $+125^{\circ}\text{C}$.
- Dwell time 15min, No bias.



Vötsch VT 7012 S2 Thermal Shock Test System



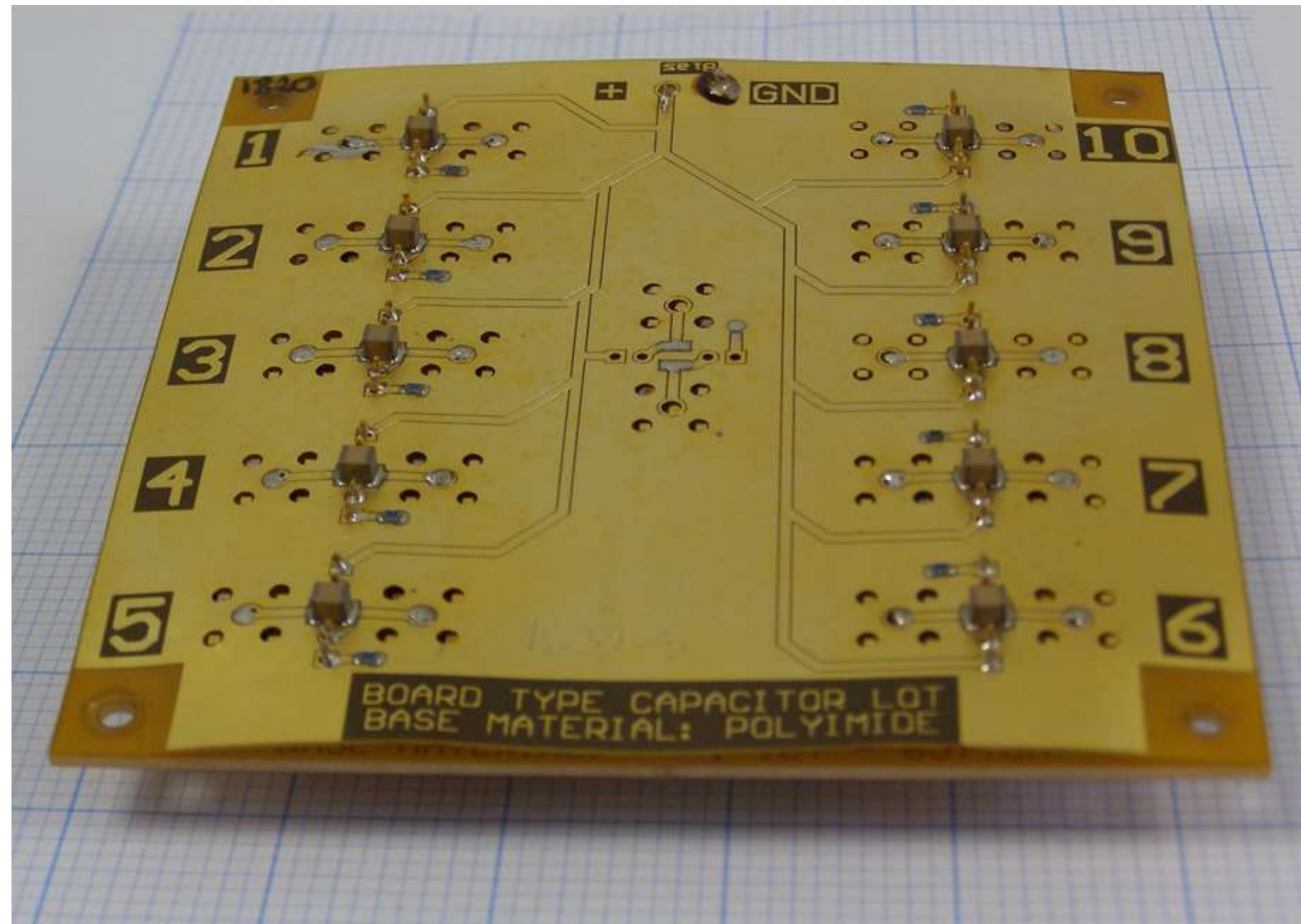
Vötschtechnik Labevent Thermal Cycling Chamber.



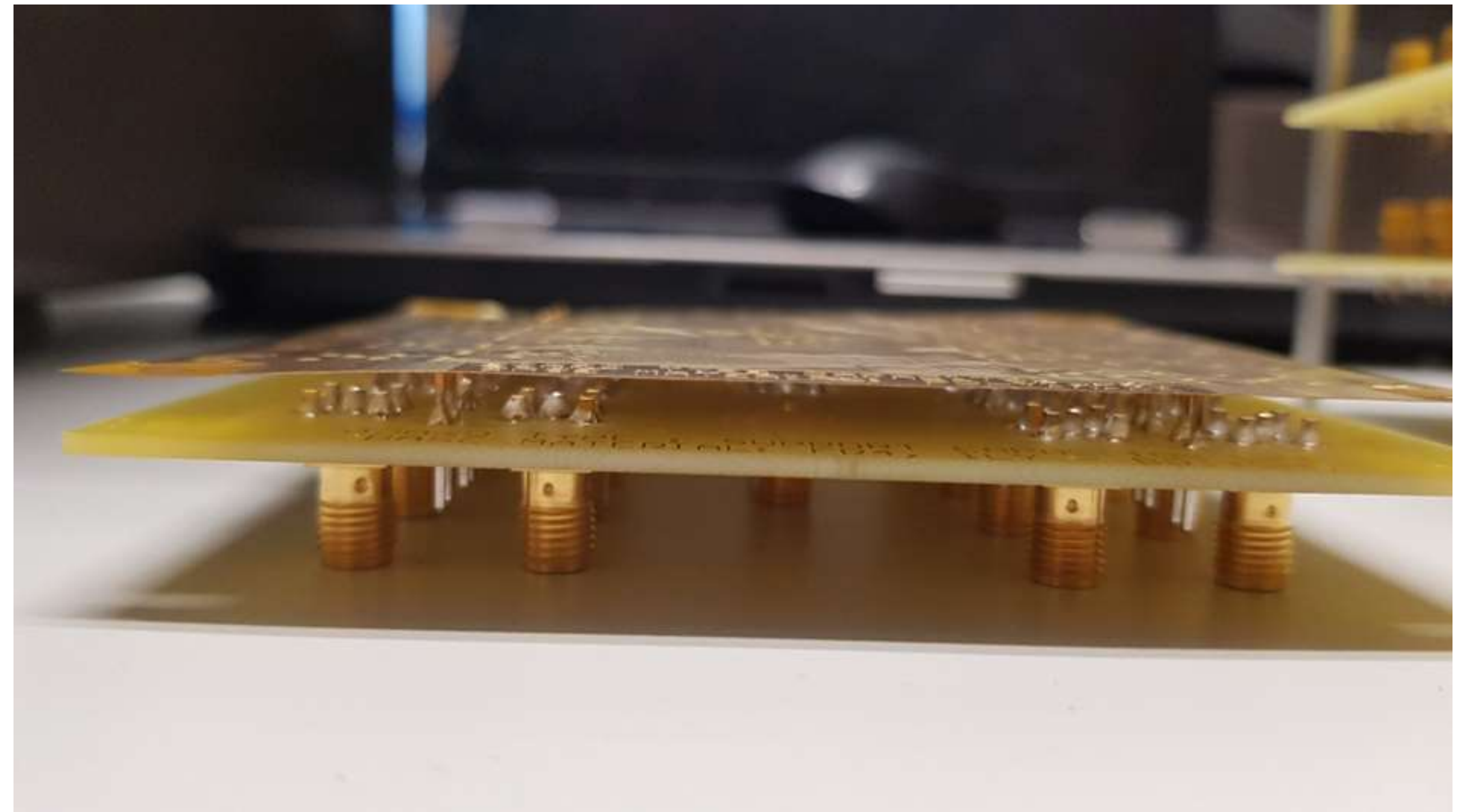
Thermal Cycling Test

Passive Components (Capacitors)

- Polyimide PCB chosen for low stress.
- Test on components, not on assembly.
- Rigid FR4 support PCB to interface test cables to samples.
- Samples mounted using SAC305 solder.



Populated Capacitor Test PCB (Polyimide)

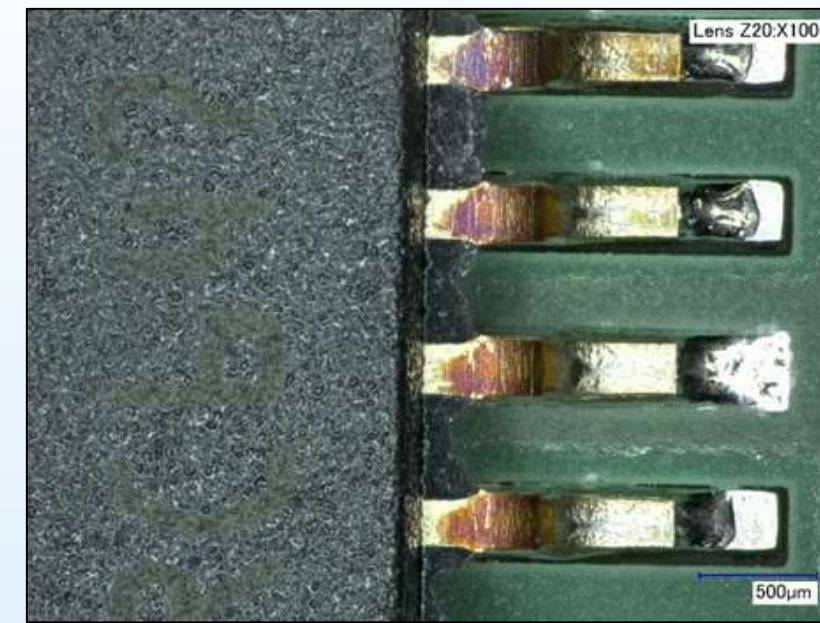


Polyimide Test PCB & Rigid Support PCB

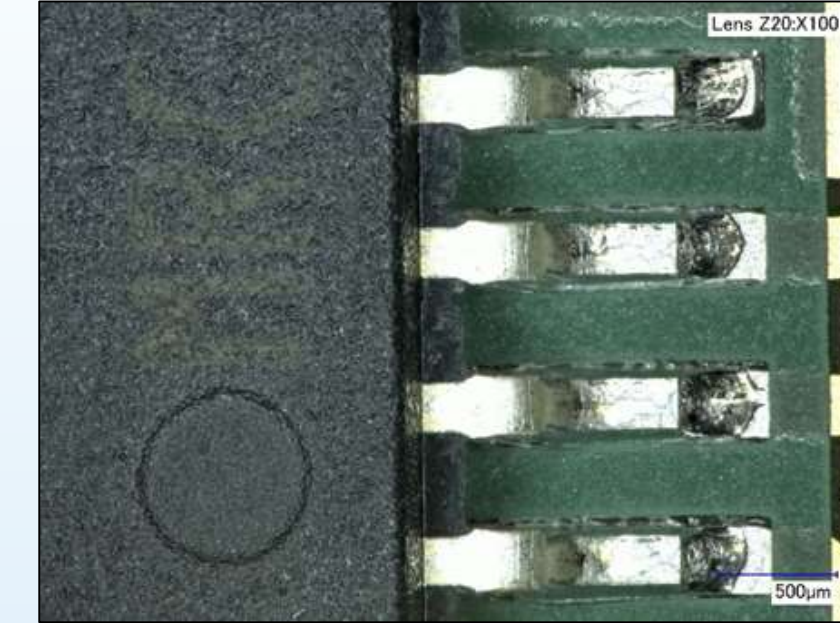
Thermal Cycling Test

Test Procedure

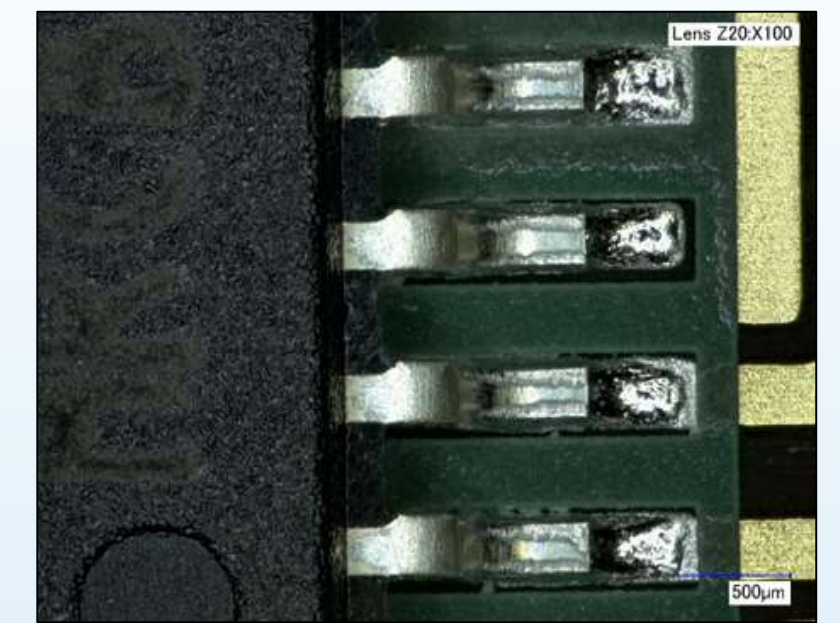
- Initial visual inspection / sample selection:
 - 10 Samples x 3 lots X 3 families
- Preconditioning:
 - 5 Temp cycles (-40 °C to +60 °C JESD22-A104E)
 - MSL1 moisture soak (168hr at 85°C/85% RH)
 - Bake out (24hrs at 125°C)
 - 3 IR Reflow cycles
- PCB assembly / sample mounting.
- Second visual inspection.
- Scanning Acoustic Microscopy.
- Initial electrical test (ambient temp)
- 500 Thermal cycles (-55°C / +125°C).
- Final visual inspection.
- Final Scanning Acoustic Microscopy.
- Final electrical test.



Op-Amp Lot 1647



Op-Amp Lot 1706



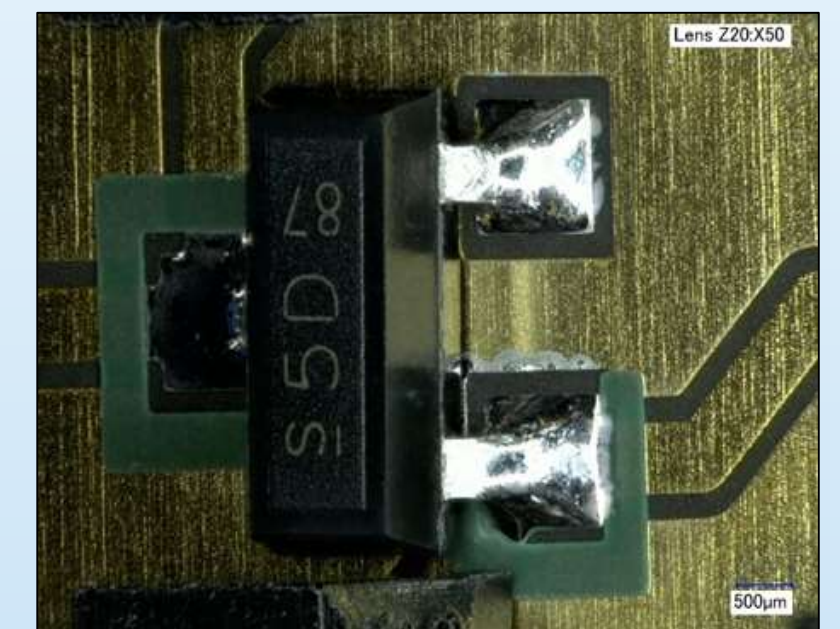
Op-Amp Lot 1816



Diode Lot 1536



Diode Lot 1829



Diode Lot 1831



Capacitor Lot 1820



Capacitor Lot 1927



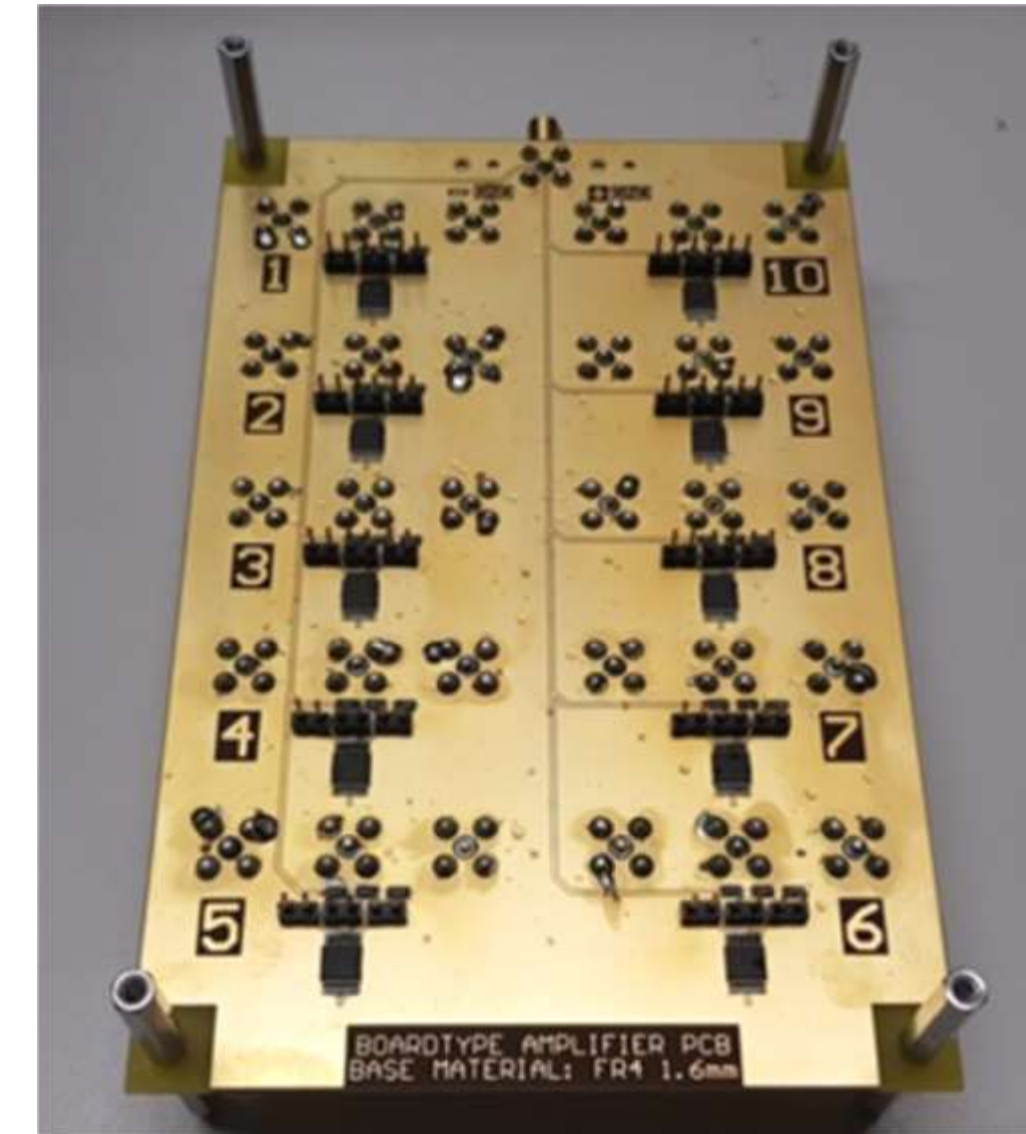
Capacitor Lot 1937

High Temp Operating Life Test



Test Procedure

- Initial visual inspection / sample selection:
 - *10 Samples x 3 lots X 3 families*
- PCB assembly / sample mounting.
- Second visual inspection.
- Initial electrical tests (-55°C / +21°C / +125°C)
- HTOL – 1,000 hours at +125°C with bias:
 - Op-Amp bias: Sine Wave Signal $1V_{pp}$, 100KHz.
 - Diode bias: Square Wave Signal $1V_{pp}$, 1MHz, 50% DTC
 - Capacitor bias: 1.5V DC
- Final visual inspection.
- Final electrical test (-55°C / +21°C / +125°C)



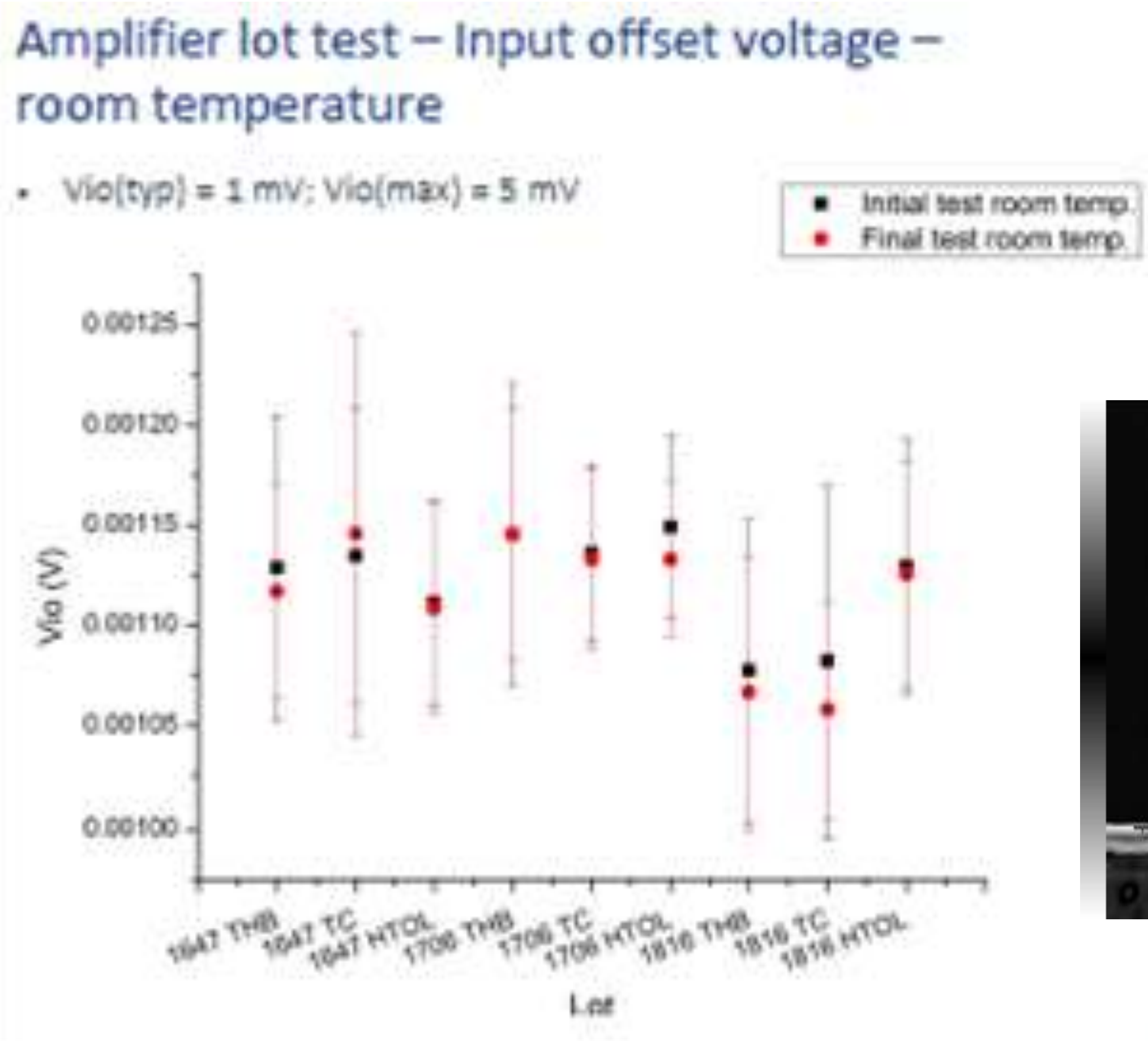
Op-Amp Test PCB



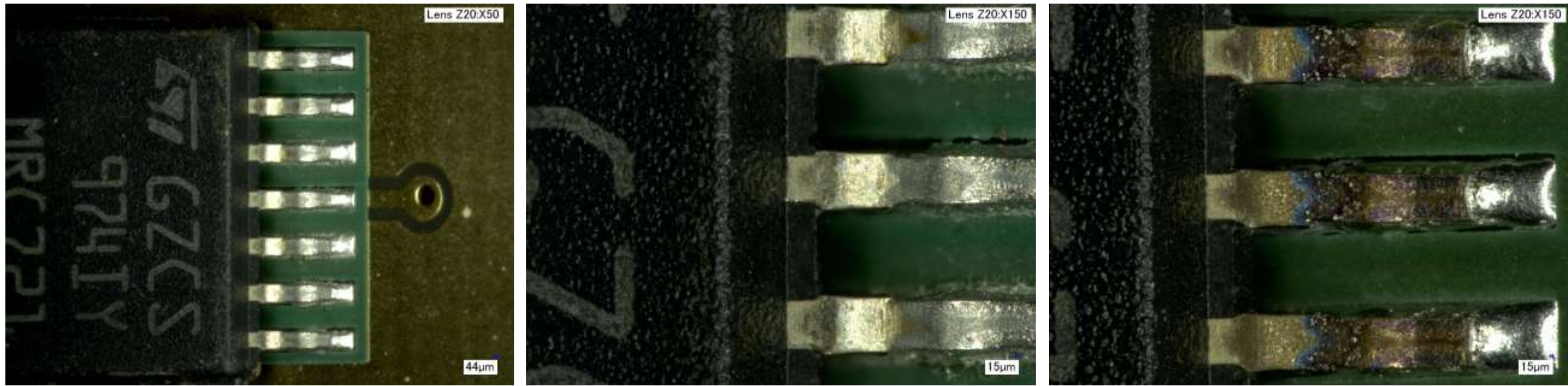
Diode Test PCB

WP3 Test Results (Reliability)

ST-Micro Operational Amplifiers



Example Electrical Test Results (V_{io}) pre & post stress.



Post Stress High Magnification Inspection – No Sn Whisker Growth Evident



1647

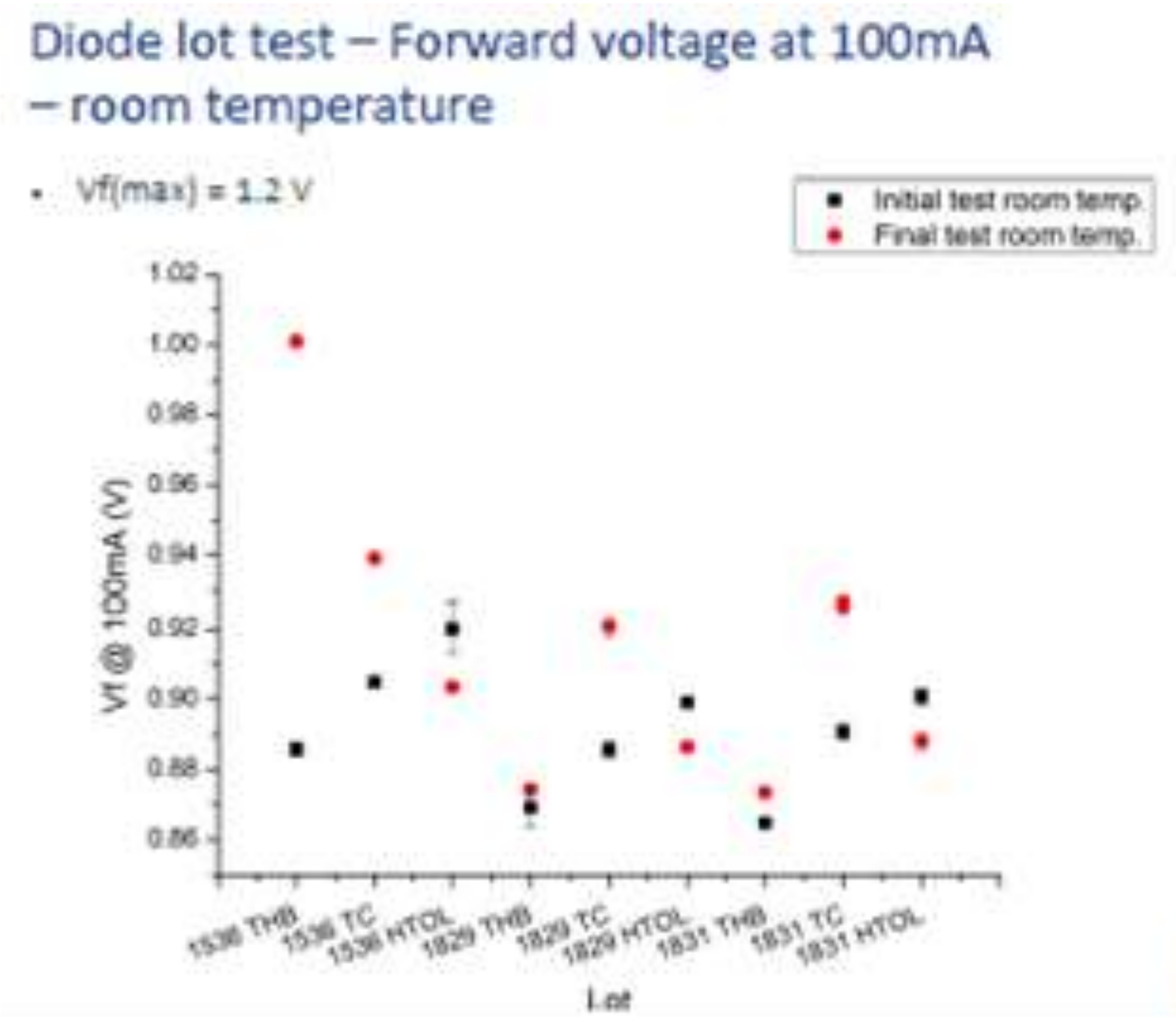
1716

1816

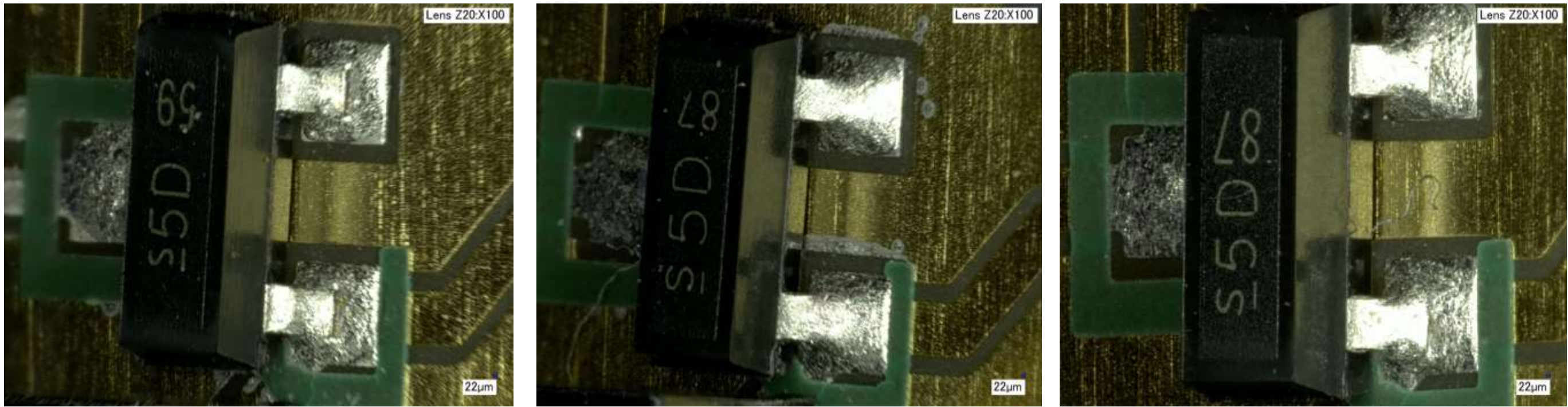
Post Stress (Thermal Cycling) SAM Imaging – No Delamination

WP3 Test Results (Reliability)

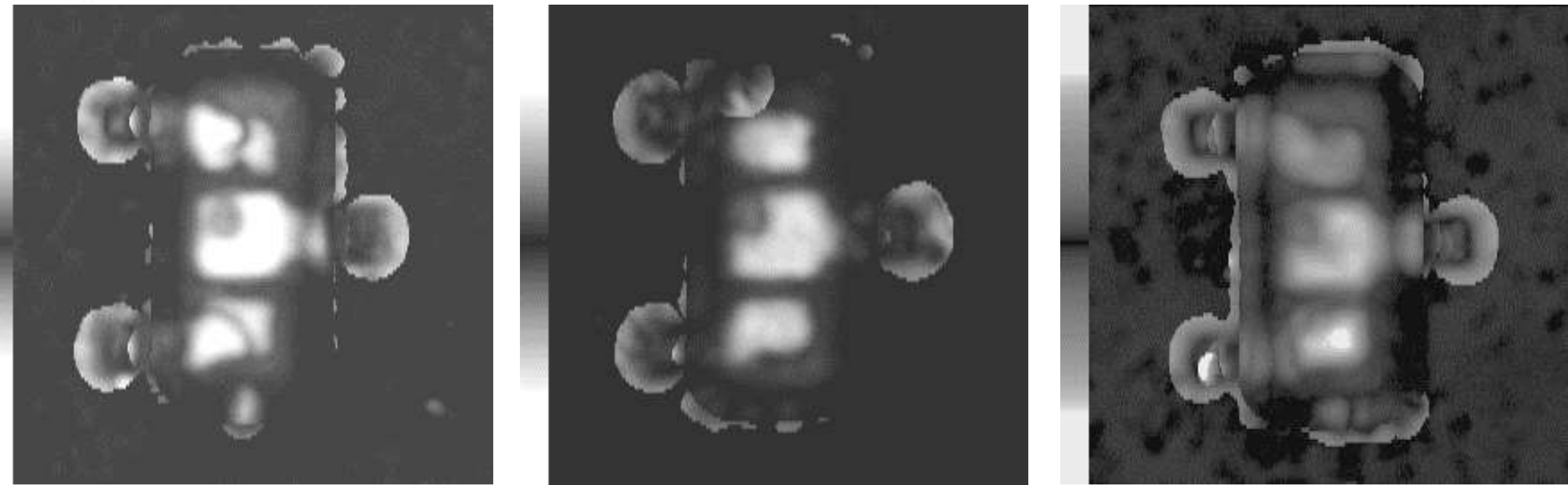
Infineon Diodes



Example Electrical Test Results (V_f @ 100mA) pre & post stress.



Post Stress High Magnification Inspection – No Sn Whisker Growth

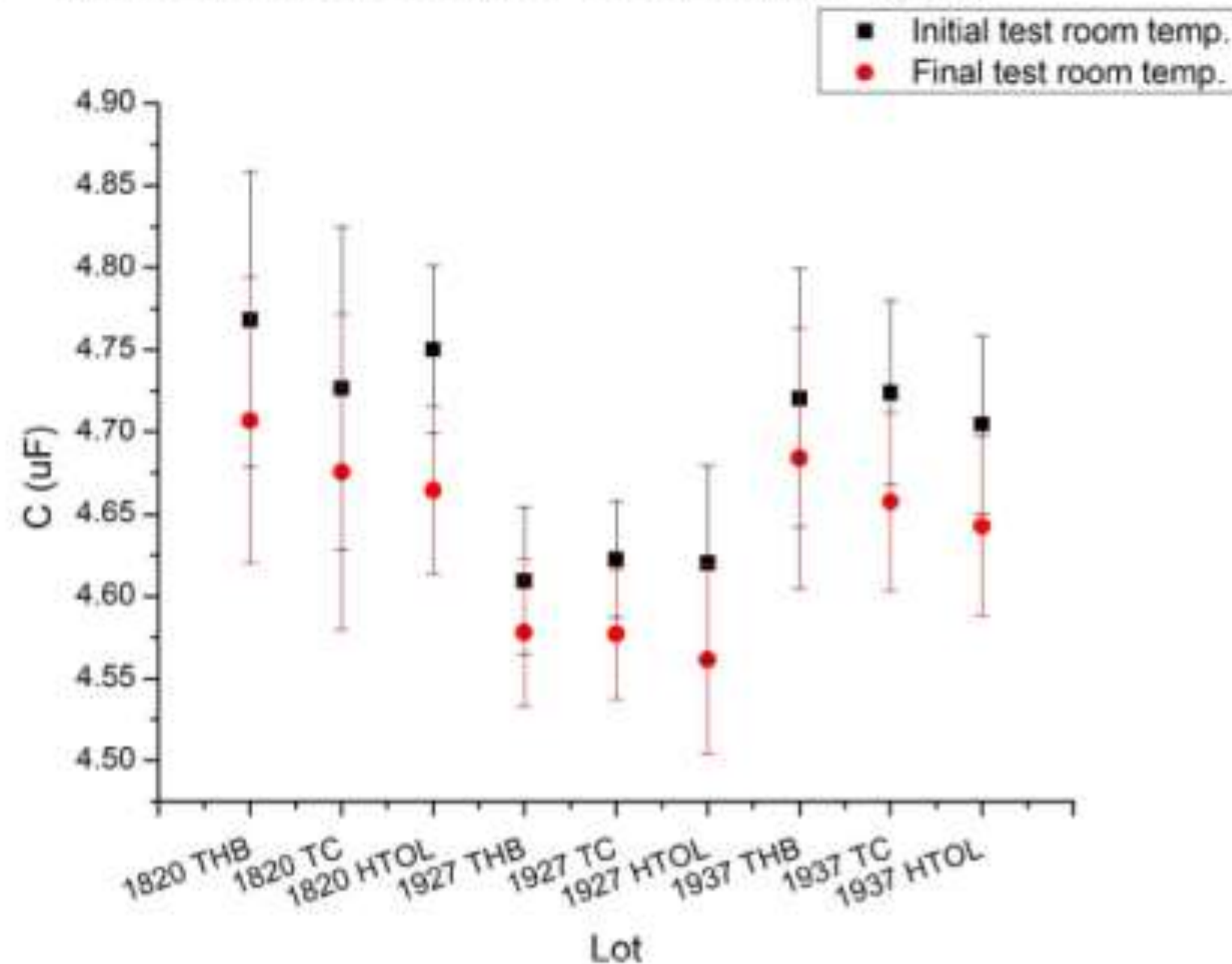


Post Stress (Thermal Cycling) SAM Imaging – No Delamination

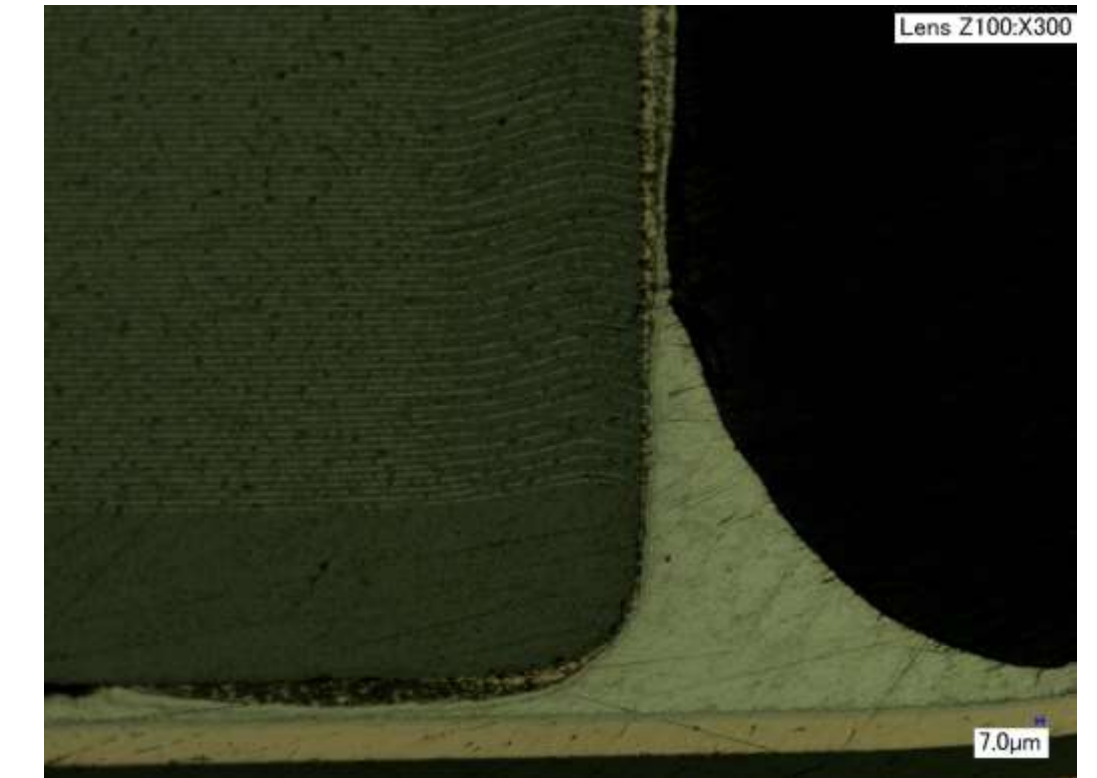
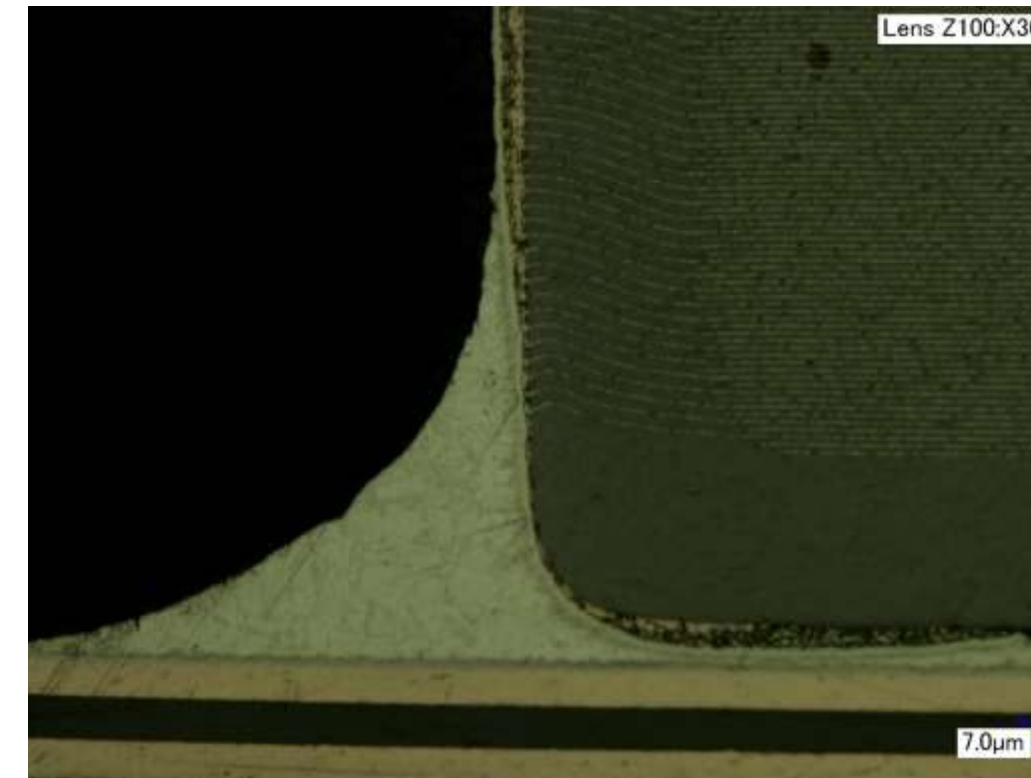
WP3 Test Results (Reliability)

AVX Capacitors

- $C = 4.7\mu\text{F} \pm 10\%$ allowed; $C_{\text{max}} = 5.17\mu\text{F}$, $C_{\text{min}} = 4.23\mu\text{F}$



Capacitance measurements pre & post stress test



Capacitor Cross-sections following Thermal Cycling



Inspection following HTOL & THB

Summary of Results



- Three lots of each of three components families (Low noise operational amplifier, high speed diode & ceramic capacitor) procured & tested.
- No lot-to-lot variation (materials, dimensions or quality of construction).
- Consistent lot-to-lot CTE, Tg & Outgassing results (confirms materials / process).
- Initial concern on discoloured lead finish in oldest lot of op-amps, however:
 - *Lot performed well in solderability tests (SAC305 & Sn63Pb37).*
 - *Soldered easily to test boards, no joint failures, no observable Sn-whisker growth.*
 - *Similar performance in electrical / reliability test to other lots.*
- No failures occurred in “delta test” reliability campaign (THB, Temp Cycling & HTOL).
- Only minor electrical parameter drift observed following reliability campaign:
 - *In some cases, improvements in performance observed following stress.*

Final Comments



- **Promising results indicate a potential for use of AEC parts in space, but:**
 - *Findings are specific to the 3 component families evaluated.*
 - *May not be representative of other EEE components families or manufacturers.*
 - *More complex component types (e.g. large-area plastic encapsulated ICs) may perform differently.*
- **AEC parts manufactured in high volumes & supplied through networks of distributors:**
 - *Very difficult to obtain detailed information on individual lots.*
 - *Storage, handling, shipping may be less well controlled than for space-grade components.*
- **AEC qualified parts not rad-hard:**
 - *Suited only to low radiation space applications (unless tested / verified).*
 - *Radiation test campaign outside scope of this project.*

Acknowledgements



- **Stephan Hernandez, ESTEC**
- **Tyndall National Institute:**
 - *Finbarr Waldron, Project Manager*
 - *Aleksandar Jaksic, Electrical Test & Characterisation*
 - *Nikola Vasovic, Electrical Test & Characterisation*
 - *Ken Rodgers, Construction Analysis*
 - *Tony Compagno, SAM & Reliability Stress Tests*
- **Thales Alenia Space, Espana:**
 - *Luis de Pablo Martinez*
 - *Gaizka Eiguren Arza*
 - *Fatima Garcia Donday*



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