# Advanced Electroplating Process for IC Substrates

Sam Dharmarathna
Line of Business R&D – IC Substrates

MacDermid Alpha ELECTRONICS SOLUTIONS



## MacDermid Alpha Electronics Solutions

**$1.4 B**
2023 NET SALES

**>30 COUNTRIES**
WITH FACILITY OPERATIONS

**>6,800**
CUSTOMERS WORLDWIDE

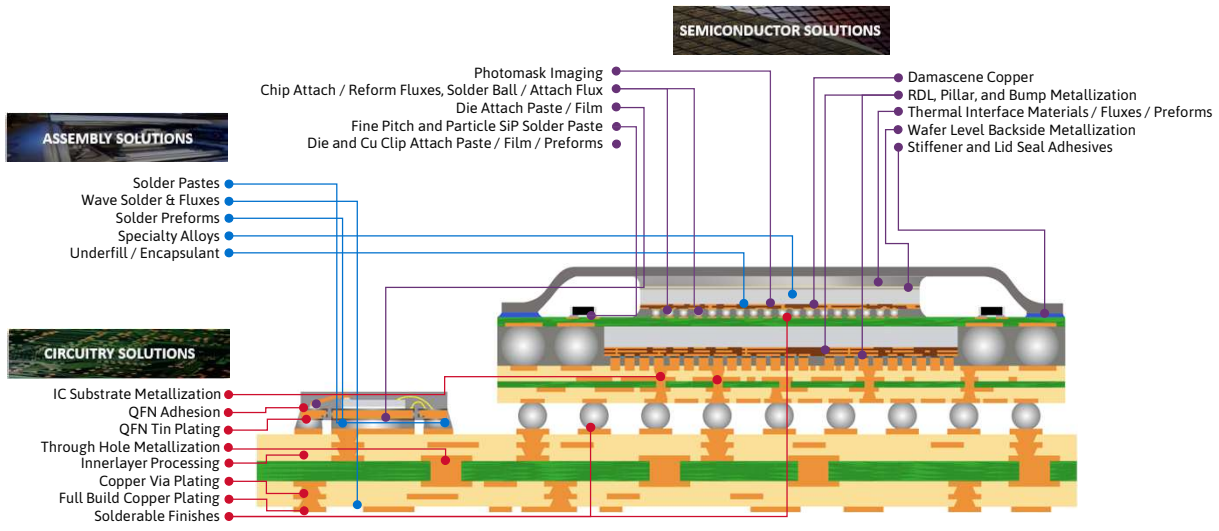
**>2,200**
EMPLOYEES

MacDermid Alpha ELECTRONICS SOLUTIONS



Circuitry Solutions
**Semiconductor & Assembly Solutions**
Film & Smart Surface Solutions

## We are INTEGRAL to Electronics Manufacturing

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## Our Product Offerings

A Full Portfolio to Support the Electronics Manufacturing Industry

**Primary Metallization**
- Direct Metallization
  - Wet Etch Graphite DM
  - Dry Etch Carbon and Graphite DM
- Electroless Copper
  - Stress-free Electroless Copper and SAP Copper

**Electrolytic Metallization**
- Electrolytic Coppers
- High Throw DC
- Periodic Pulse Reverse
- Via Fill / Through Hole Fill
- RDL 2-in-1

**Circuit Formation**
- Copper Adhesion Promotion
- Leadframe Adhesion Promotion
- Component Termination Solderability
- Molded Interconnect Devices
- Light Emitting Diodes
- Solar Cell Metallization

**Final Finishes**
- Organic Solderability Preservative
- Immersion Tin
- Immersion Silver
- Electroless Nickel Immersion Gold (ENIG)
- Electroless Nickel Electroless Palladium Immersion Gold (ENEPIG)

**Connector Finishes**
- Electroplate
  - NiAu, NiPd
  - Ag/SnAg
  - Rd, Ru
  - NiW
  - Cu
- Indium
- NiP

**Memory Disk**
- Preclean and Zincate Solutions for Al substrate
- High Quality EN
- High Corrosion Resistance
- Low Particle Inclusion (PDI)
- Low Pit Count

**Inks & Pastes**
- MicroCat Conductive Ink
- ActiveCopper Paste
  - Copper Coin
  - Through Hole Fill for Power

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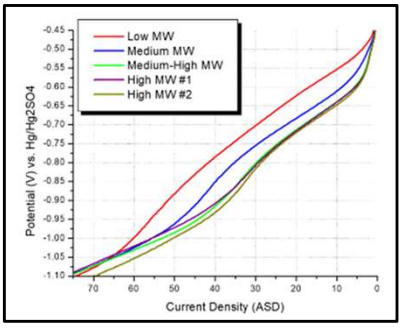
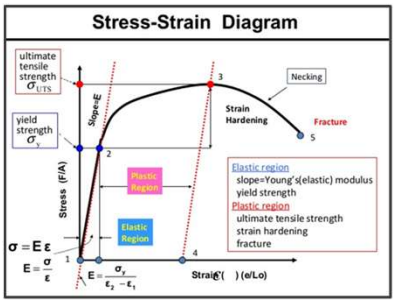
# Additives Tailored to Customer Needs

- **In-House synthesis - Libraries of Additive Molecules**
  - Develop and maintain comprehensive collections of additive **Reduce the time from conception to market.**
- **Novel Molecules – IP Protection**
  - Create **innovative molecules** with the potential for intellectual property protection.
- **Fine Tune Performance – Fine L/S**
  - Ability to modify the **electro-chemical** properties of **additives** and **physical/mechanical properties** of **deposit** leading to robust plating formulations.

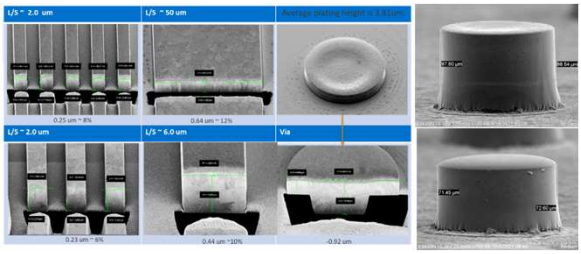


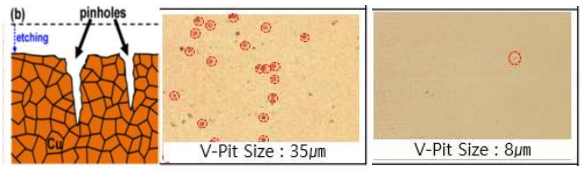






# Tailored Formulations To Enable Specific Technologies

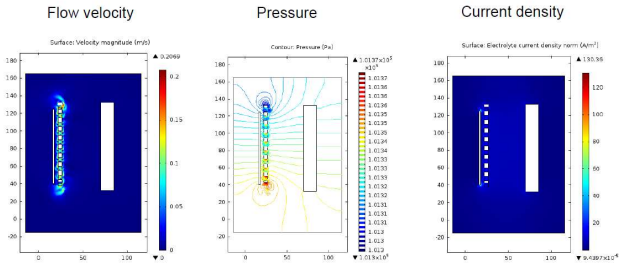
- **Ability to Modulate – Flat vs. Domed**
  - Develop molecules that **enable the modulation** of surface **profiles**.
- **Mitigate Defects - Reliability**
  - **Proprietary blend of functional groups** in the molecules to control grain refinement and final grain structure
- **Deposit Properties - Mechanical, Physical & Purity**

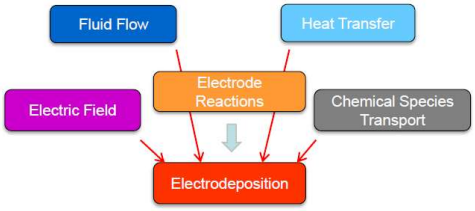


# Plating Tools for Advanced Packaging

- **Electrodeposition** for **advanced L/S** requires precise **coordination and cadence** between **equipment and additives** to achieve optimal performance.
- Modern tools **utilize unique mass transfer** methods as opposed to conventional VCP systems



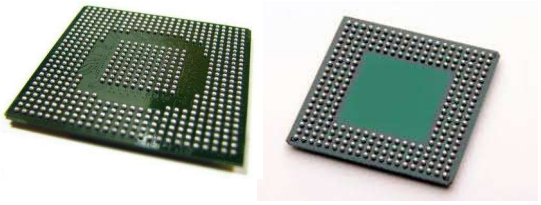



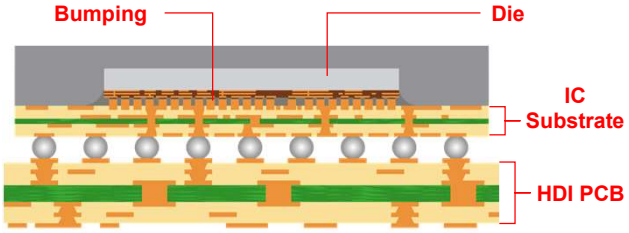

- Better **understanding of tools and additives** leads to more **robust formulations**



# IC Substrate Technology

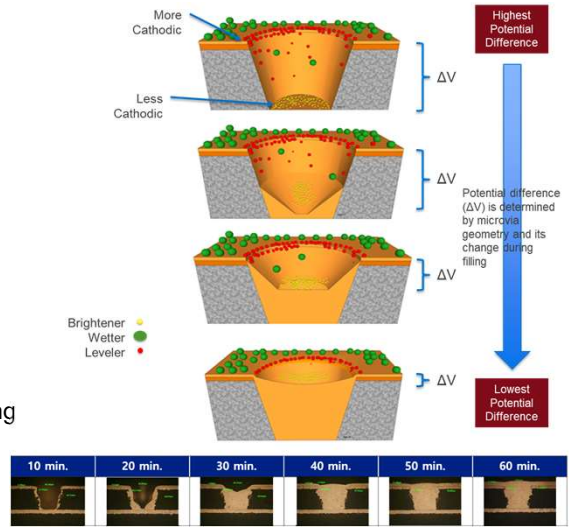
- Higher functionality with more components in a “package”
  - Sensors, memory, logic, CPU
  - PoP, SiP, etc.
- Transition from **wire bonding to flip chip** designs
  - Reduced chip area
  - Increased I/O count
  - Reduced inductance
  - Higher signal speeds
  - Improved heat management
- Still need to route signals out of the die to the component substrate for connection to the PCB





# Deposition Mechanism

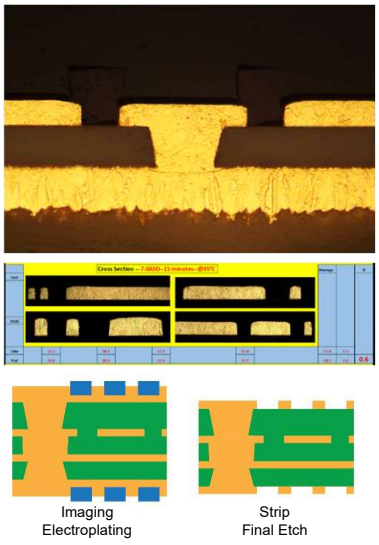
- **Bath composition**
  - Lower **$H_2SO_4$** to reduce solution **conductivity** and promote larger difference in potentials
  - Higher **$CuSO_4$** to increase **filling** speed
  - **Chloride** ions provide adsorption **sites**
- **Additives**
  - **Suppressor preferentially** adsorbed on the surface
  - **Brightener diffuses** to the bottom of the microvia
  - **Leveler selectively** adsorbs on the high current areas
- **Fill progression**
  - Plating at via bottom is fastest at the beginning
  - As plating proceeds, the potential differences and plating rate difference of surface and microvia lessen
  - Once filled, all plating rates are similar






# Systek UVF 200 Process Overview

- DC Acid Copper plating process specifically designed for **2-in-1 RDL applications for FCBGA**
  - **Pattern plate process**
  - **High coplanarity of traces and pads**
    - Typically, <2 µm R-Value
  - **Highly controlled trace profile**
    - Typically, <15%
  - **Via Fill**
    - Up to 60 µmØ x 30-35 µm deep
    - Dimple: <5 µm, Overfill <3 µm
    - Surface Copper: 10-15 µm
- **Compatible with High-Speed Plating Tools**
  - ASM-NEXX Stratus P500
  - Semsysco



## Process Cycle and Operating Parameters

Acid Cleaner → Water Rinse → Acid Dip → UVF 200

| Cleaner | Chemistry | Concentration |
|---|---|---|
| Additive | Acid Cleaner | 10% |
| | $H_2SO_4$ | 5% |
| Parameter | Dwell time | 1-5 min |
| | Temp | 20-35°C |

| Acid Dip | Chemistry | Concentration |
|---|---|---|
| Additive | $H_2SO_4$ | 5-10% |
| Parameter | Dwell time | 1 min |
| | Temp | 20-25°C |

**Bath Make-up**

| UVF | Chemistry | Concentration |
|---|---|---|
| VMS | $CuSO_4$ | 230 g/L |
| | $H_2SO_4$ | 120 g/L |
| | $Cl^-$ | 50 ppm |
| Additives | Leveler | 5 ml/L |
| | Brightener | 2 ml/L |
| | Wetter | 10 ml/L |
| Parameter | CD | 1.0-7.0 ASD |
| | Temp | 30-35°C |

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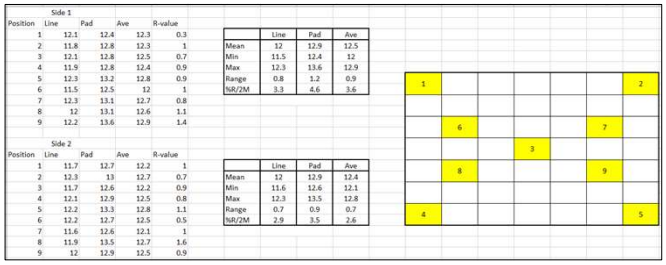
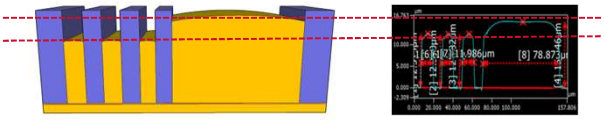
## Capabilities

- Panels with different designs, feature sizes, and copper thickness specifications were plated during the evaluation

| Features/Spec | Design 1 | Design 2 |
|---|---|---|
| Line/Space | 9/12 µm | 15/20 µm |
| BMV Diameter | 40 µm | 49 µm |
| BMV Depth | 15 µm | 20 µm |
| Plating Thickness | 12 µm | 17 µm |
| Plating Time | 15 minutes | 15 minutes |
| Current Density | 4-5 ASD | 5-6 ASD |
| Dimple | ± 2 µm<br>± 2 µm (POR) | ± 2 µm<br>+ 2 µm (POR) |
| Uniformity (WIU) | 2 µm<br>4 µm (POR) | <5 µm<br>8 µm (POR) |
| Uniformity (WIP) | <15%<br>20% (POR) | <15%<br>20% (POR) |
| Anode | Insoluble | Insoluble |



- 9 areas were measured on each side of the panel
- The best result was with 200/120/50 VMS

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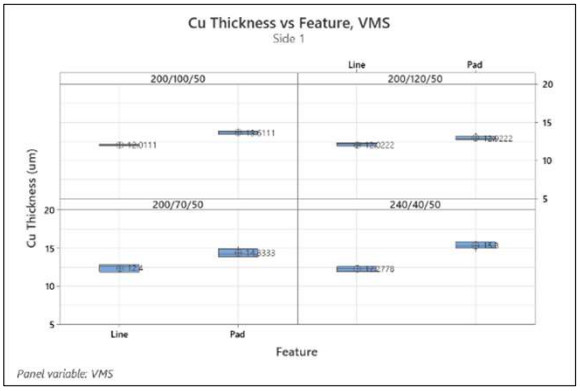
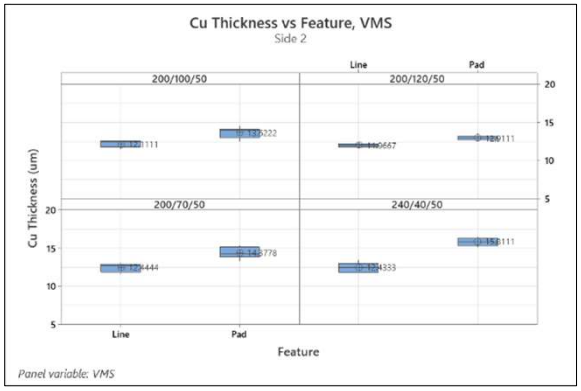
# Substrate Design 1 Results

Copper Thickness vs Feature, VMS

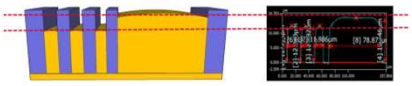


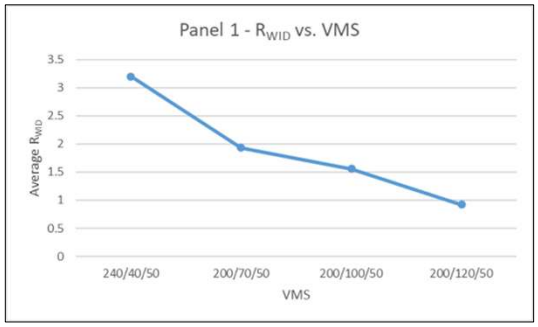



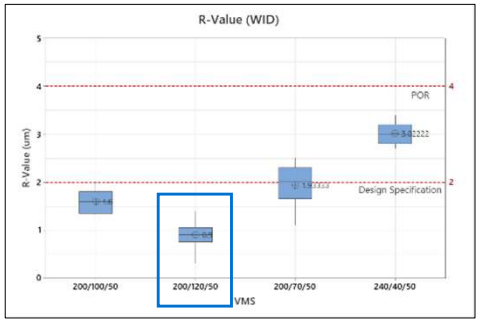



# Substrate Design 1

Uniformity






- The average $R_{WID}$ was calculated via the difference on the plated height between fine line and pad/filled via
- **R-value improved** with **lower copper** sulfate and higher sulfuric acid
- WID **uniformity was < 2** um with copper sulfate concentration **< 200 g/L**
- **WID** uniformity was further **improved with additional sulfuric acid**

# Capabilities

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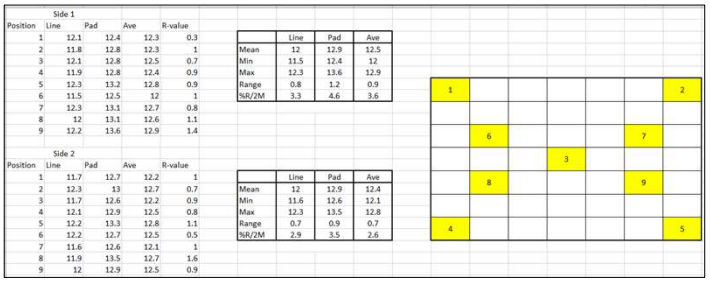


Side 1

| Position | Line | Pad | Ave | R-value |
|---|---|---|---|---|
| 1 | 12.1 | 12.4 | 12.3 | 0.3 |
| 2 | 11.8 | 12.8 | 12.3 | 1 |
| 3 | 12.1 | 12.8 | 12.5 | 0.7 |
| 4 | 11.9 | 12.8 | 12.4 | 0.9 |
| 5 | 12.3 | 13.2 | 12.8 | 0.9 |
| 6 | 11.5 | 12.5 | 12 | 1 |
| 7 | 12.3 | 13.1 | 12.7 | 0.8 |
| 8 | 12 | 13.1 | 12.6 | 1.1 |
| 9 | 12.2 | 13.6 | 12.9 | 1.4 |

| | Line | Pad | Ave |
|---|---|---|---|
| Mean | 12 | 12.9 | 12.5 |
| Min | 11.5 | 12.4 | 12 |
| Max | 12.3 | 13.6 | 12.9 |
| Range | 0.8 | 1.2 | 0.9 |
| %R/2M | 3.3 | 4.6 | 3.6 |

Side 2

| Position | Line | Pad | Ave | R-value |
|---|---|---|---|---|
| 1 | 11.7 | 12.7 | 12.2 | 1 |
| 2 | 12.3 | 13 | 12.7 | 0.7 |
| 3 | 11.7 | 12.6 | 12.2 | 0.9 |
| 4 | 12.1 | 12.9 | 12.5 | 0.8 |
| 5 | 12.2 | 13.3 | 12.8 | 1.1 |
| 6 | 12.2 | 12.7 | 12.5 | 0.5 |
| 7 | 11.6 | 12.6 | 12.1 | 1 |
| 8 | 11.9 | 13.5 | 12.7 | 1.6 |
| 9 | 12 | 12.9 | 12.5 | 0.9 |

| | Line | Pad | Ave |
|---|---|---|---|
| Mean | 12 | 12.9 | 12.4 |
| Min | 11.6 | 12.6 | 12.1 |
| Max | 12.3 | 13.5 | 12.8 |
| Range | 0.7 | 0.9 | 0.7 |
| %R/2M | 2.9 | 3.5 | 2.6 |

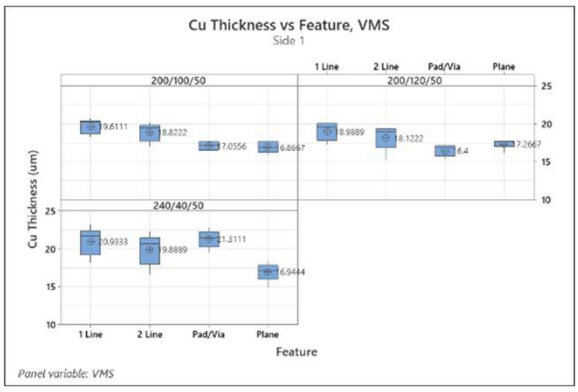


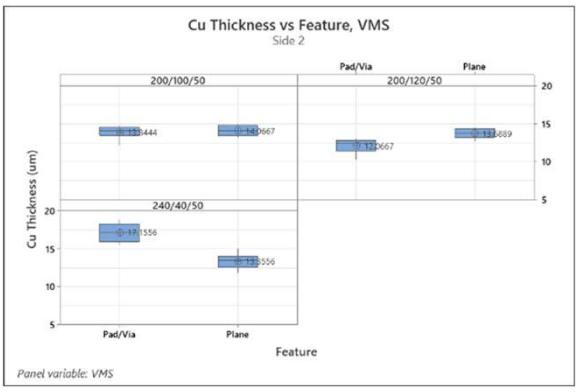
- 9 areas were measured on each side of the panel by ZYGO profiler
- The best result was with 200/120/50 VMS



# Substrate Design 2 Results

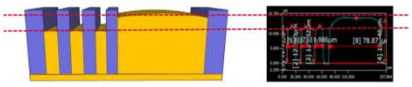
Copper Thickness vs Feature, VMS

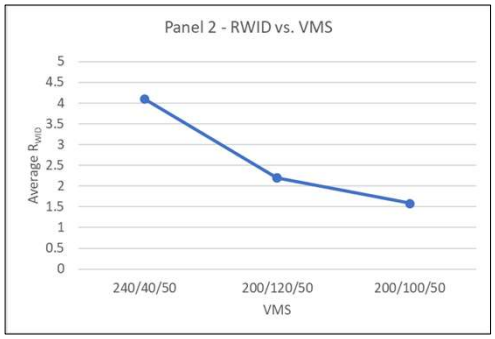


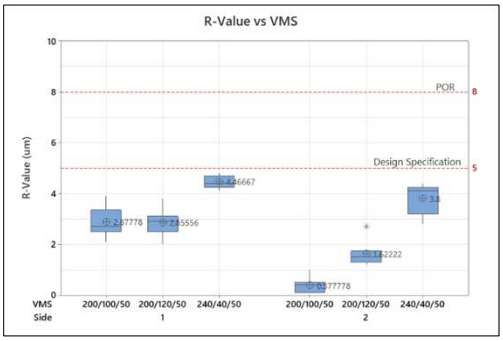



# Substrate Design 2 Results

Uniformity





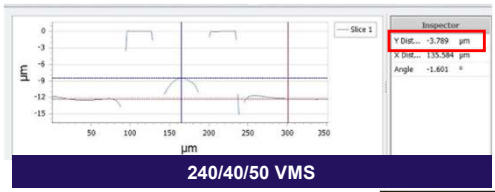

- The average $R_{WID}$ was calculated via the difference on the plated height between fine line and pad/filled via
- **R-value improved** with **lower copper** sulfate and higher sulfuric acid
- WID **uniformity was < 5** um with copper sulfate concentration **< 240 g/L**



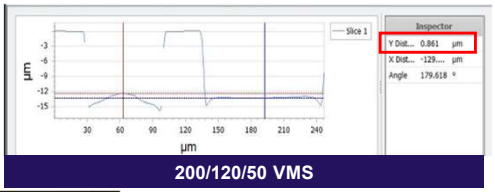
# Via Fill Results

- Via size: 40x15 µm
- Plated thickness: 12 µm
- All conditions resulted in a bump on the filled vias
- As Cu was reduced and acid was increased, the domes on the filled vias decreased and the uniformity improved (reduced R values)

| VMS | Bump (um) |
|---|---|
| 240/40/50 | 3.8 |
| 200/120/50 | 0.9 |

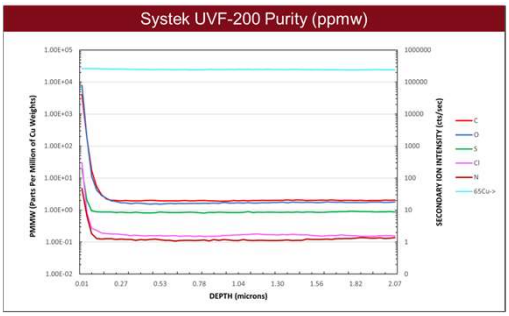



240/40/50 VMS

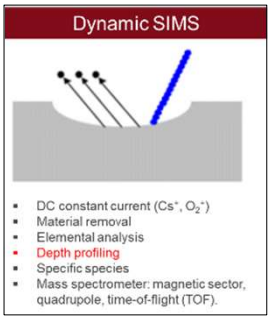



200/120/50 VMS

## SIMS Analysis




| Element | Concentration (ppmw) |
|---|---|
| Sulfur | 0.848 |
| Carbon | 1.98 |
| Oxygen | 1.66 |
| Chlorine | 0.163 |
| Nitrogen | 0.114 |



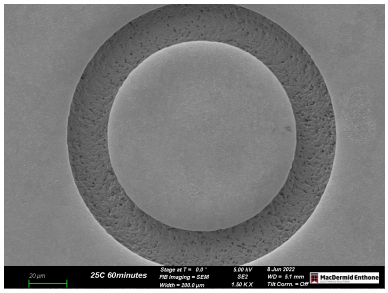

- Low impurities co deposit with Cu
  - Electrical conductivity, grain structure, Cu reduction during SAP / mSAP, physical properties

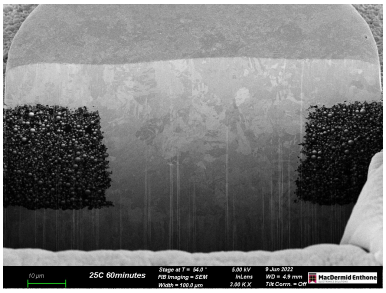


## Properties of Deposit

- Physical properties exceeded IPC class III specifications
- Deposit had equiaxial grain structure

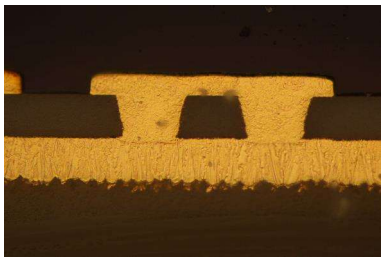
| Plating Condition | 2.0 ASD, 25°C | 4.5 ASD, 35°C |
|---|---|---|
| Elongation (%) | 22.0 | 20.1 |
| Tensile Strength (kPSI) | 40.4 | 40.4 |
| Internal Tensile Stress ($kg/mm^2$) | 0.87 | 0.85 |




# UVF 200 Summary

- Systek **UVF 200** is a **versatile** plating process for the **2-in-1 RDL plating** of fine lines and filling of microvias in build up layer applications
  - Filling of microvias **up to 60 µmØ x 30 µmD**
  - Plating **thickness of 15-18 µm** within **15–20 min** plating time
  - **Low R**-values between various features
  - **Good within device (WID) and within panel (WIP) uniformity**
- Process is very stable and tunable
  - **Wide VMS operating** range
  - **Wide** operating **current density range**
  - Compatible with **Nafion** membranes
  - All additives are **CVS analyzable** and controllable

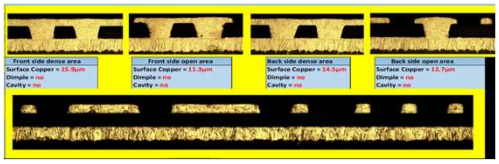


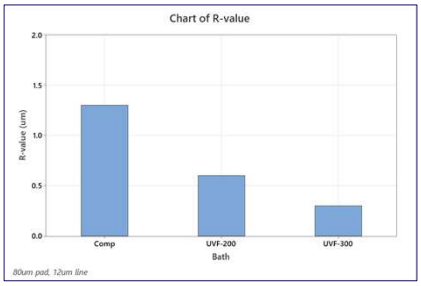


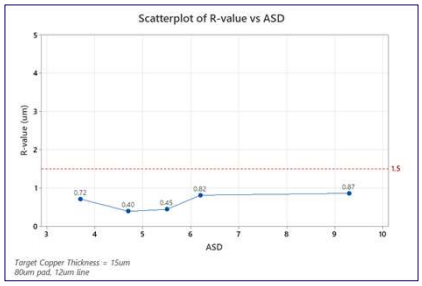
# Next Gen RDL Plating

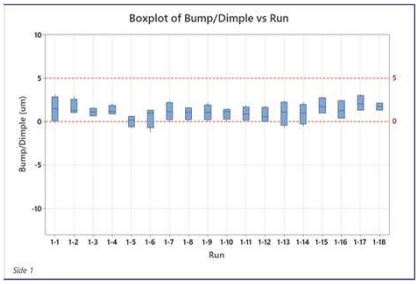
**Systek UVF 300**

- Reduced variation in copper thickness
- High coplanarity across a wide range of current density
- Consistent via fill



## Contact Us

**Sam Dharmarathna**

*Line of Business Partner – IC substrate R&D*

saminda.dharmarathna@macdermidalpha.com

macdermidalpha.com

https://www.linkedin.com/in/dasaminda/

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