CMC
INTERCONNECT TECHNOLOGIES

Electroplating for Electronic Packaging Applications Tutorial

September 2006

CMC Laboratories, Inc.

Outsource Your Problems to CMC Interconnect Technologies

Basic Principles of Electroplating

Outsource Your Problems to CMC Interconnect Technologies

Types of Plating

1. Electrolytic Plating (Electroplating)
    - Uses electrical current to reduce metal ions (drive chemical reaction)
    - All features need to be electrically connected
    - Allows control of the plating process
2. Electroless Plating (Autocatalytic)
    - Chemical reaction induces metal atom reduction
    - Non-conductive substrates
    - Features do not need to be electrically connected
    - Difficult to control plating parameters
    - Limited bath lifetime

Types of Plating

3. Immersion Plating (Displacement reaction)
    - Metal ion is reduced from solution by exchange with a metal atom from the substrate
    - Type of metal deposited must be more noble- higher Electromotive Force (EMF, E_o) than the metal dissolved
    - Deposition stops after 10-20 micro inches of deposition

$$\text{Zn (solid)} + \text{Cu}^{2+}\text{(aqueous)} \rightarrow \text{Zn}^{2+}\text{ (aqueous)} + \text{Cu (solid)}$$

$\text{Zn (solid)} \rightarrow \text{Zn}^{2+} + 2e^-$ or the oxidation of Zn^o (electrons released)

$\text{Cu}^{2+} + 2e^- \rightarrow \text{Cu (solid)}$ or the reduction of Cu^{2+} (electrons consumed)

Core Plating Principle: Electroless, Electrolytic, Immersion

Metal Ion Electrons Deposited Metal

$$M^{z+} + Ze^{-} \rightarrow M^{0}$$

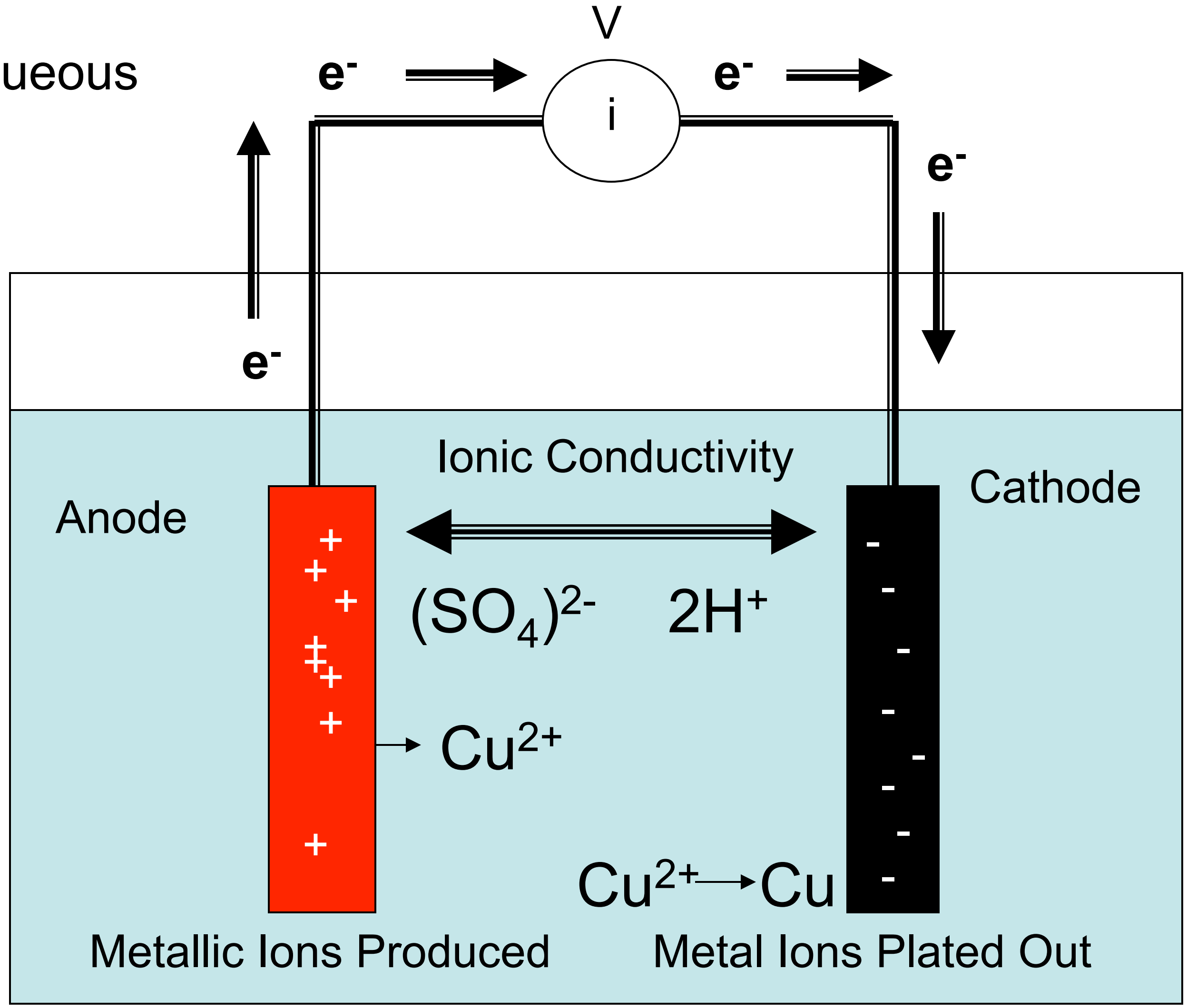
Plating Process: Reduction of metal ions from solution

Source for this reduction:

- Electrolytic plating- Applied current
- Electroless plating- chemical reaction in solution
- Displacement plating- dissolution of electrode metal

Electroplating- Electrically Driven REDOX Reactions

H_2SO_4 in an aqueous electrolyte



V

i

e^-

e^-

e^-

e^-

Ionic Conductivity

Anode

Cathode

$(SO_4)^{2-}$ $2H^+$

$\rightarrow Cu^{2+}$

$Cu^{2+} \rightarrow Cu$

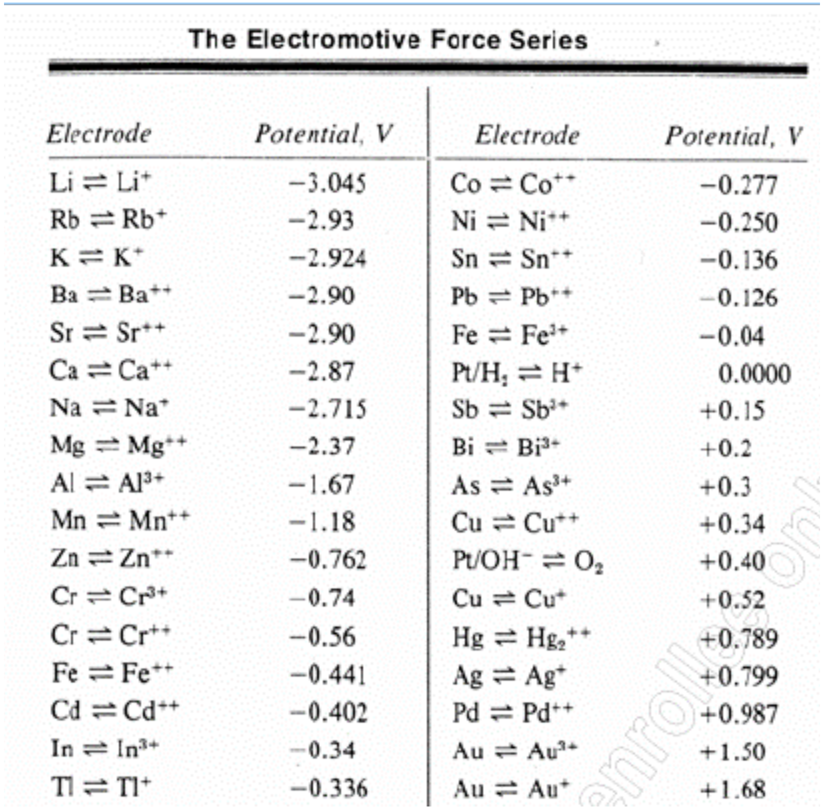
Metallic Ions Produced

Metal Ions Plated Out

Electrochemical Potential E_o

- Reduction voltage of metals under a standard set of conditions
- Voltages are relative to a standard reaction: $2H^+ (aqueous) + 2e^- \rightarrow H_2(gas)$
- More positive E_o, stronger oxidation agent (electron acceptor)
- More positive E_o, more noble metal
- More negative E_o, stronger reducing agent (electron donor)

Electromotive Force E_o



The Electromotive Force Series

Electrode	Potential, V	Electrode	Potential, V
$\mathrm{Li} \rightleftharpoons \mathrm{Li}^{+}$	−3.045	$\mathrm{Co} \rightleftharpoons \mathrm{Co}^{++}$	−0.277
$\mathrm{Rb} \rightleftharpoons \mathrm{Rb}^{+}$	−2.93	$\mathrm{Ni} \rightleftharpoons \mathrm{Ni}^{++}$	−0.250
$\mathrm{K} \rightleftharpoons \mathrm{K}^{+}$	−2.924	$\mathrm{Sn} \rightleftharpoons \mathrm{Sn}^{++}$	−0.136
$\mathrm{Ba} \rightleftharpoons \mathrm{Ba}^{++}$	−2.90	$\mathrm{Pb} \rightleftharpoons \mathrm{Pb}^{++}$	−0.126
$\mathrm{Sr} \rightleftharpoons \mathrm{Sr}^{++}$	−2.90	$\mathrm{Fe} \rightleftharpoons \mathrm{Fe}^{3+}$	−0.04
$\mathrm{Ca} \rightleftharpoons \mathrm{Ca}^{++}$	−2.87	$\mathrm{Pt/H_2} \rightleftharpoons \mathrm{H}^{+}$	0.0000
$\mathrm{Na} \rightleftharpoons \mathrm{Na}^{+}$	−2.715	$\mathrm{Sb} \rightleftharpoons \mathrm{Sb}^{3+}$	+0.15
$\mathrm{Mg} \rightleftharpoons \mathrm{Mg}^{++}$	−2.37	$\mathrm{Bi} \rightleftharpoons \mathrm{Bi}^{3+}$	+0.2
$\mathrm{Al} \rightleftharpoons \mathrm{Al}^{3+}$	−1.67	$\mathrm{As} \rightleftharpoons \mathrm{As}^{3+}$	+0.3
$\mathrm{Mn} \rightleftharpoons \mathrm{Mn}^{++}$	−1.18	$\mathrm{Cu} \rightleftharpoons \mathrm{Cu}^{++}$	+0.34
$\mathrm{Zn} \rightleftharpoons \mathrm{Zn}^{++}$	−0.762	$\mathrm{Pt/OH^{-}} \rightleftharpoons \mathrm{O_2}$	+0.40
$\mathrm{Cr} \rightleftharpoons \mathrm{Cr}^{3+}$	−0.74	$\mathrm{Cu} \rightleftharpoons \mathrm{Cu}^{+}$	+0.52
$\mathrm{Cr} \rightleftharpoons \mathrm{Cr}^{++}$	−0.56	$\mathrm{Hg} \rightleftharpoons \mathrm{Hg_2}^{++}$	+0.789
$\mathrm{Fe} \rightleftharpoons \mathrm{Fe}^{++}$	−0.441	$\mathrm{Ag} \rightleftharpoons \mathrm{Ag}^{+}$	+0.799
$\mathrm{Cd} \rightleftharpoons \mathrm{Cd}^{++}$	−0.402	$\mathrm{Pd} \rightleftharpoons \mathrm{Pd}^{++}$	+0.987
$\mathrm{In} \rightleftharpoons \mathrm{In}^{3+}$	−0.34	$\mathrm{Au} \rightleftharpoons \mathrm{Au}^{3+}$	+1.50
$\mathrm{Tl} \rightleftharpoons \mathrm{Tl}^{+}$	−0.336	$\mathrm{Au} \rightleftharpoons \mathrm{Au}^{+}$	+1.68

Electromotive Force E_o

$Cu^{2+} + 2e^- \rightarrow Cu \quad E_o = +0.337\ V$

$Ag^+ + e^- \rightarrow Ag \quad E_o = 0.779\ V$

- Silver ion is easier to reduce than cupric ion
- If both are present in an electrolyte, the silver will plate out first (lower E_o)
- It will take twice the number of electrons to reduce the same number of copper ions as silver (Faraday's First Law)

Faraday’s Second Law

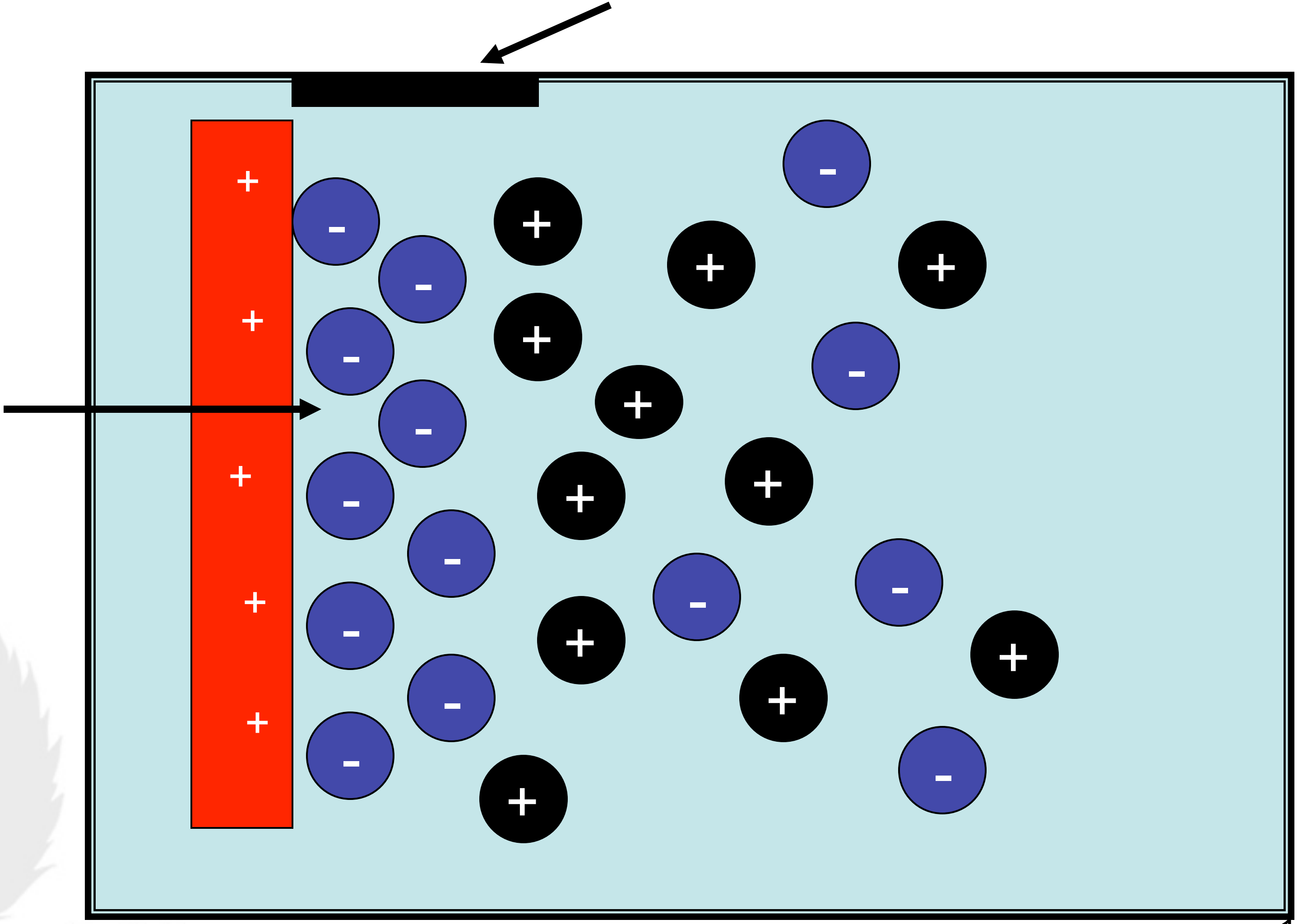
- Used to determine a relationship between plating conditions and amount of metal deposited
- Valid as long as no side reactions are occurring

$$\text{Weight (grams)} = \{\underbrace{I}_{\text{Applied current}} \text{ (amps)} * \underbrace{t}_{\text{Plating time}} \text{ (seconds)} * \underbrace{E}_{\text{Chemical Equivalent Weight}}\} / 96{,}500 \text{ Coulombs}$$

What Actually Happens during the Plating Process?

What Actually Happens During the Plating Process? Electrolyte Dynamics, Charged Electrode

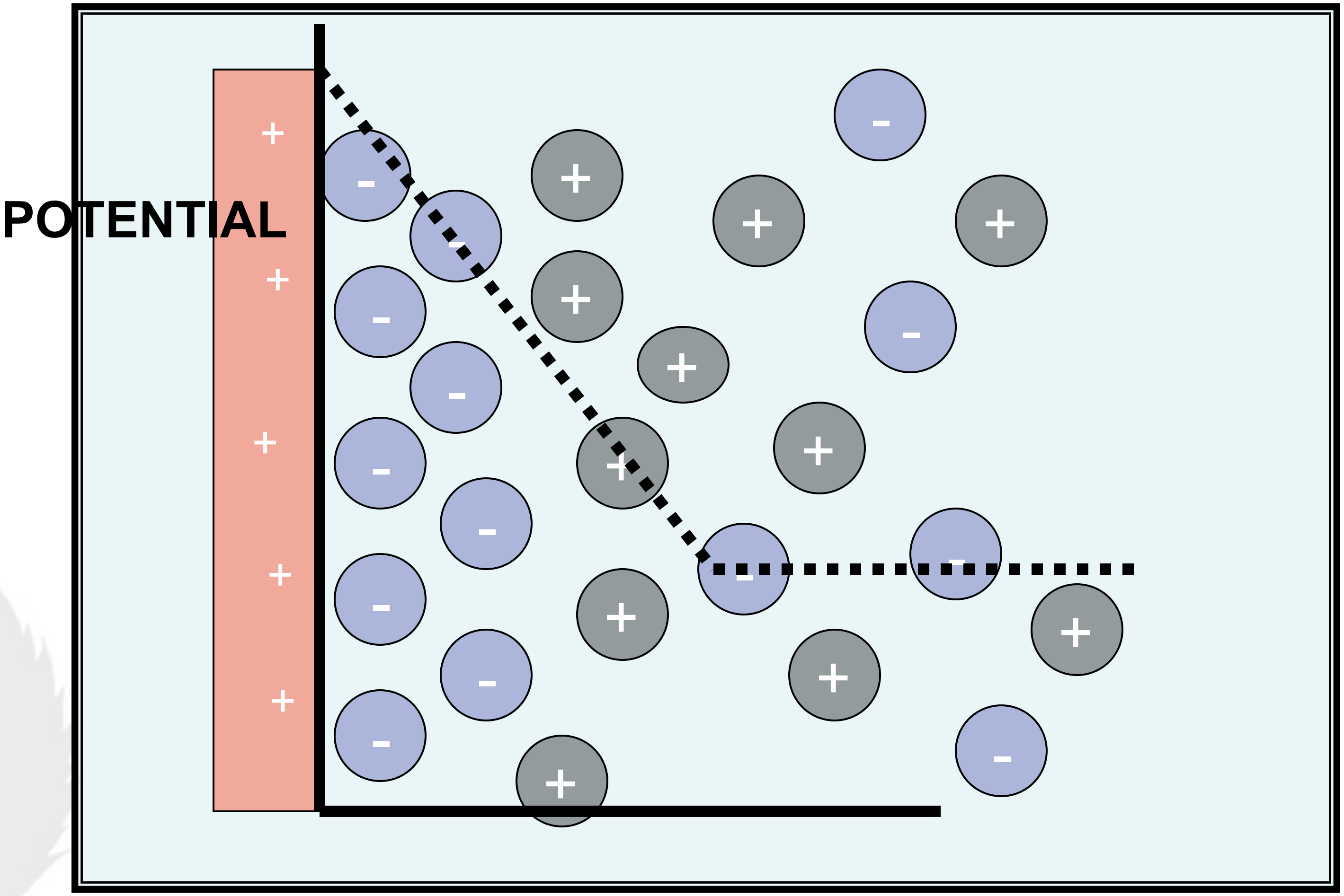
An Electrical Double Layer Forms (Capacitor)



Ions align in solution to screen the applied potential

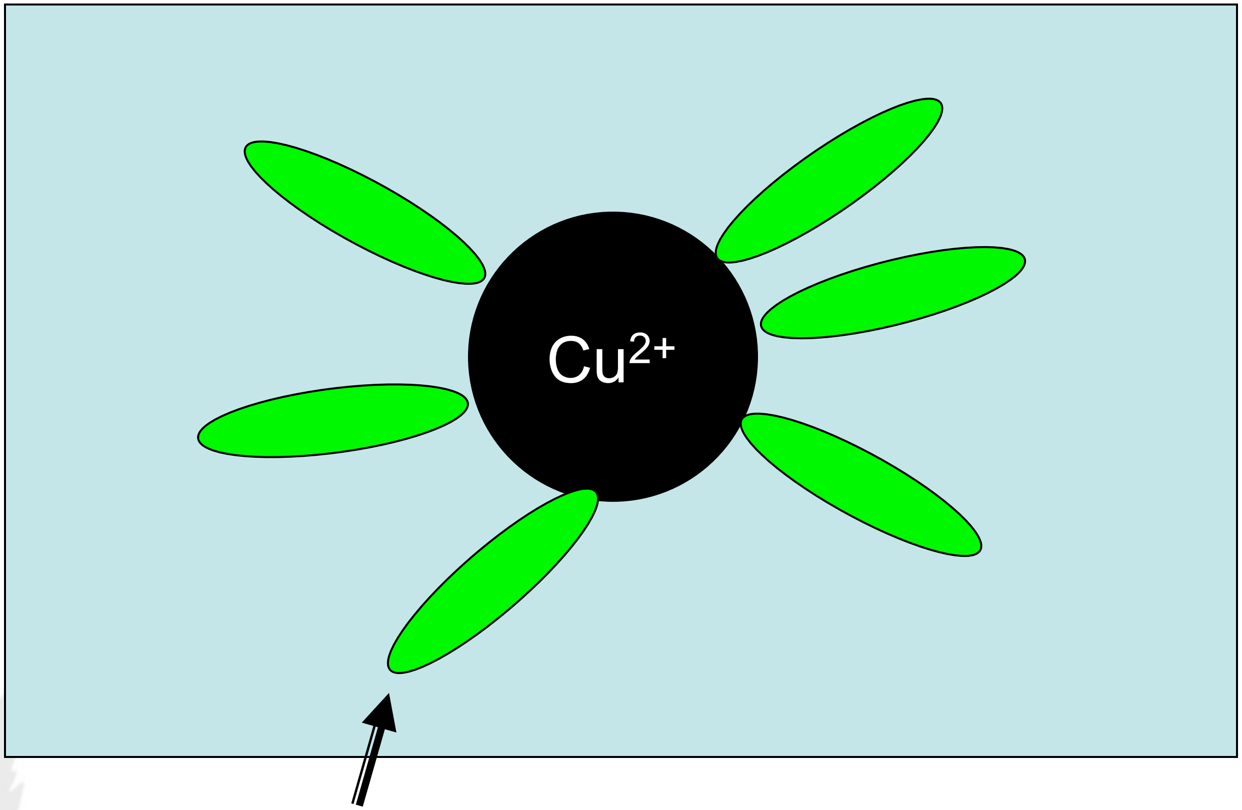
What Actually Happens During the Plating Process?
Electrolyte Dynamics, Charged Electrode

Diffusing Ions must move through the double layer potential to reach the electrode



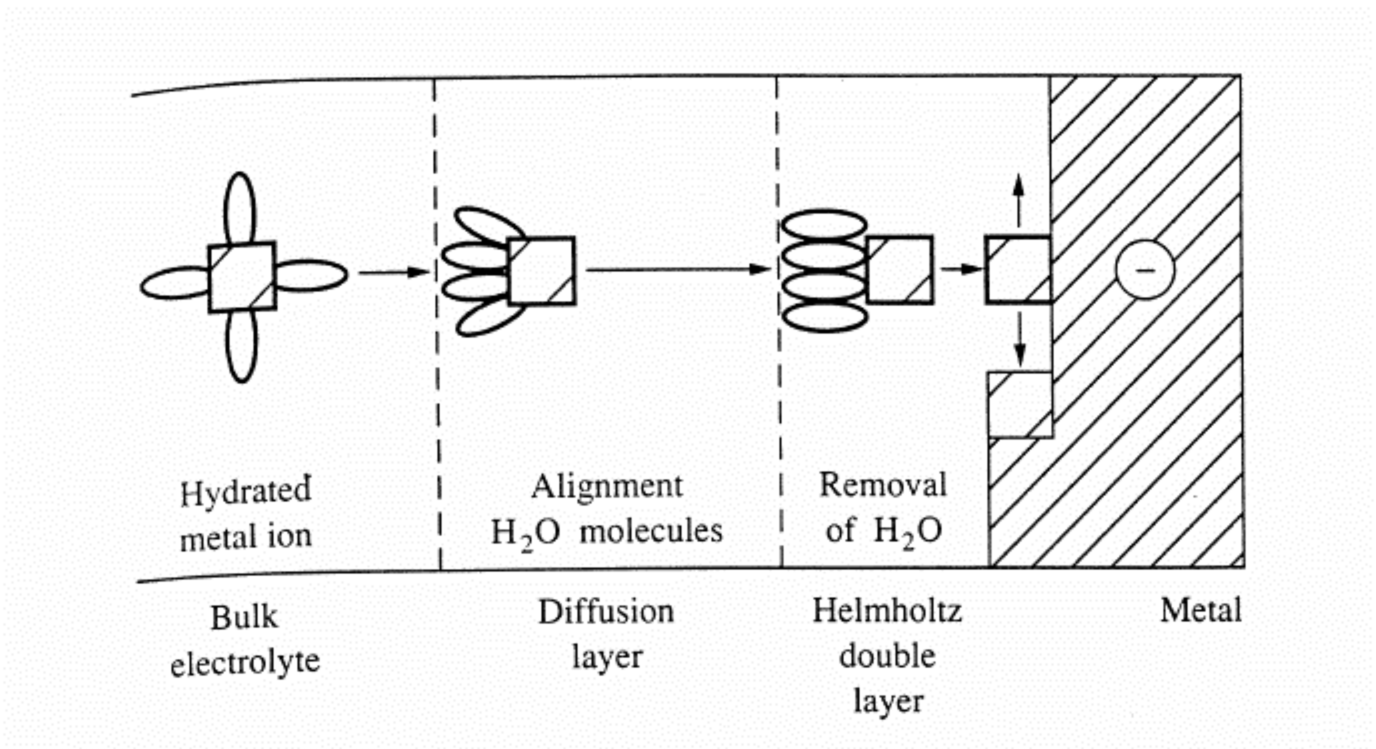
What Actually Happens During the Plating Process? Ions in Solution

$Cu(H_2O)_6^{2+}$



Oriented (polar) water molecules- ligands

What Actually Happens During the Plating Process? Diffusion to the Electrode



From Roy Magnusun, Endicott Interconnect (IBM)

What Actually Happens During the Plating Process- Summary and Discussion

- Applied voltage to an electrode results in alignment of ions in solution (to screen out the applied field)
- This produces an electrochemical potential near the electrode surface
- Ions in solution form complexes with polar species (water) or other ligands
- These complexes (ion and ligands) must diffuse through the double layer to react at the electrode surface

What Actually Happens During the Plating Process- Summary and Discussion

- Ligands slow the diffusion of ions through solution
- Removing ligands slows diffusion through the double layer
- The more strongly complexed an ion, the harder it is to reduce the ion
- **pH control is critical to reduce the level of ligands attachment to ions- this is why pH is critical in effecting plating rates**
- **Temperature and agitation will also improve ion diffusion rates**

What Actually Happens During the Plating Process: Metal Deposition Steps- Summary (Cu Example)

1. Transport of hydrated Cu ions in the electrolyte toward the cathode surface
2. Diffusion of the hydrated ions through the double layer- dehydration process
3. Attachment on the cathode surface with charge exchange to become adatoms
4. Migration through surface diffusion of adatoms to nucleation sites
5. Incorporation of adatoms into the lattice to form the copper film

Components of a Plating Bath

Components of a Plating Bath

Component	***Role***	***Example***
Metal Salt	Source of plating metal	Copper sulfate
Acid, Base additive	Provides ionic conductivity in the bath	Sulphuric Acid
Carriers	Help increase throwing power into holes and other surface features	Polyethers or polyoxyethers
Levelers	Improve plating thickness uniformity	Organic nitrogen compounds, amines, amide surfactants
Brighteners	Control deposit brightness and hardness	Sulphur containing compounds
Wetters	Decrease surface tension in solution	Surfactants

Components of a Plating Bath- Mechanism for Additives to Control Properties

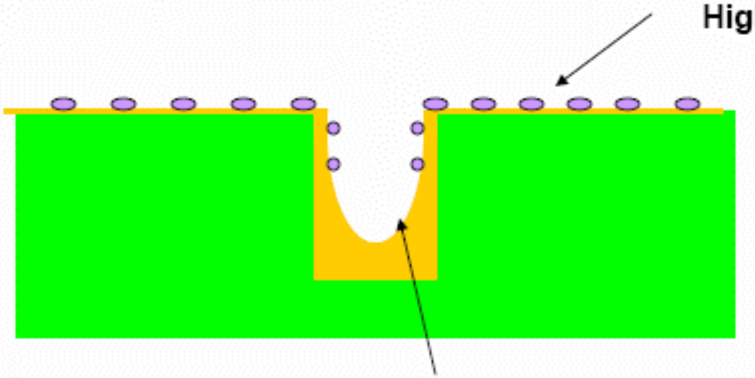
Additive	***Mechanism (How it Works)***
Carriers	Adsorbs on the cathode surface during plating to form a monolayer film. Forms a barrier to diffusion of Cu^{2+} to the surface and suppresses plating rate. Replaced by accelerators (brighteners) in vias and other features.
Levelers	Adsorb strongly to the surface at high current density regions. This lowers the plating rate at corners and protrusions and levels the plated layer.
Brighteners	Attach to the copper metal ions during plating and facilitate charge transfer at the electrode. Brighteners accelerate plating rates and also control grain structure and deposit characteristics.
Wetters	Surfactants with lower the surface tension of the plating solution allowing better wetting of the electrolyte at the electrode. Reduces the incidence of bubbles and allows the plating bath to penetrate features such as vias.

Components of a Plating Bath- Mechanism for Additives to Control Properties

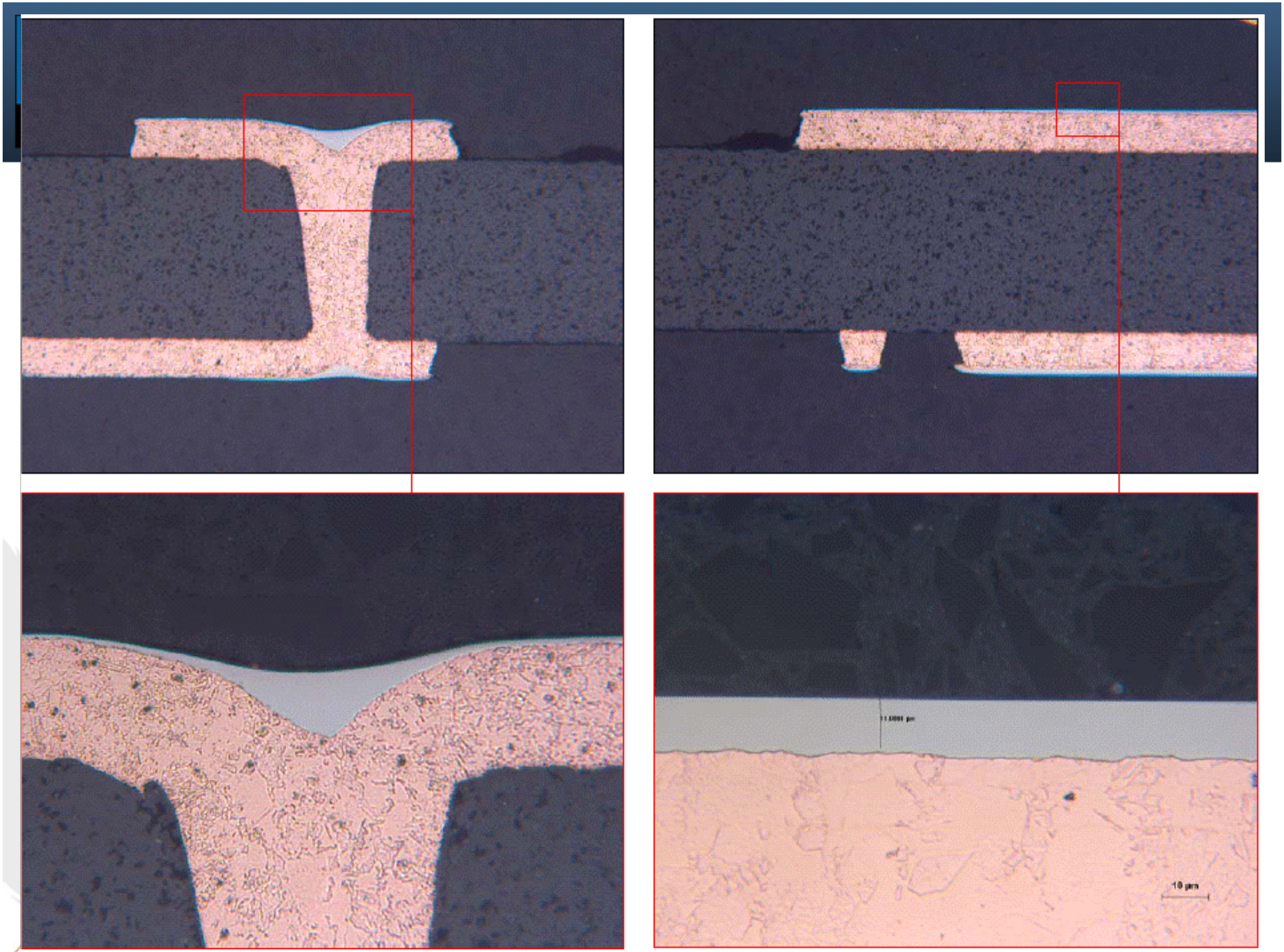
- Goals for the inorganic additives
  - Acid, base concentration optimized for good solution conductivity
  - Metal ion concentration sufficient to support plating current requirements
- Goals for the organic additives
  - Levelers attached to high current density surface features
  - Carrier attached to exposed surface regions
  - High concentration of brighteners in occluded features such as vias
  - Result is higher plating rates in vias, lower plating rates on high current density features, moderate plating rate on exposed surfaces

Components of a Plating Bath- Leveler Mechanism Schematic

Strongly adsorbing leveller, suppressing rate at surface



P. M. Vereecken, R. Binstead, H. Deligianni, P. Andricacos, IBM J. Res. & Dev., *49*, 2005, pp3-18.


10 µm

Rectifier Cycle Effects

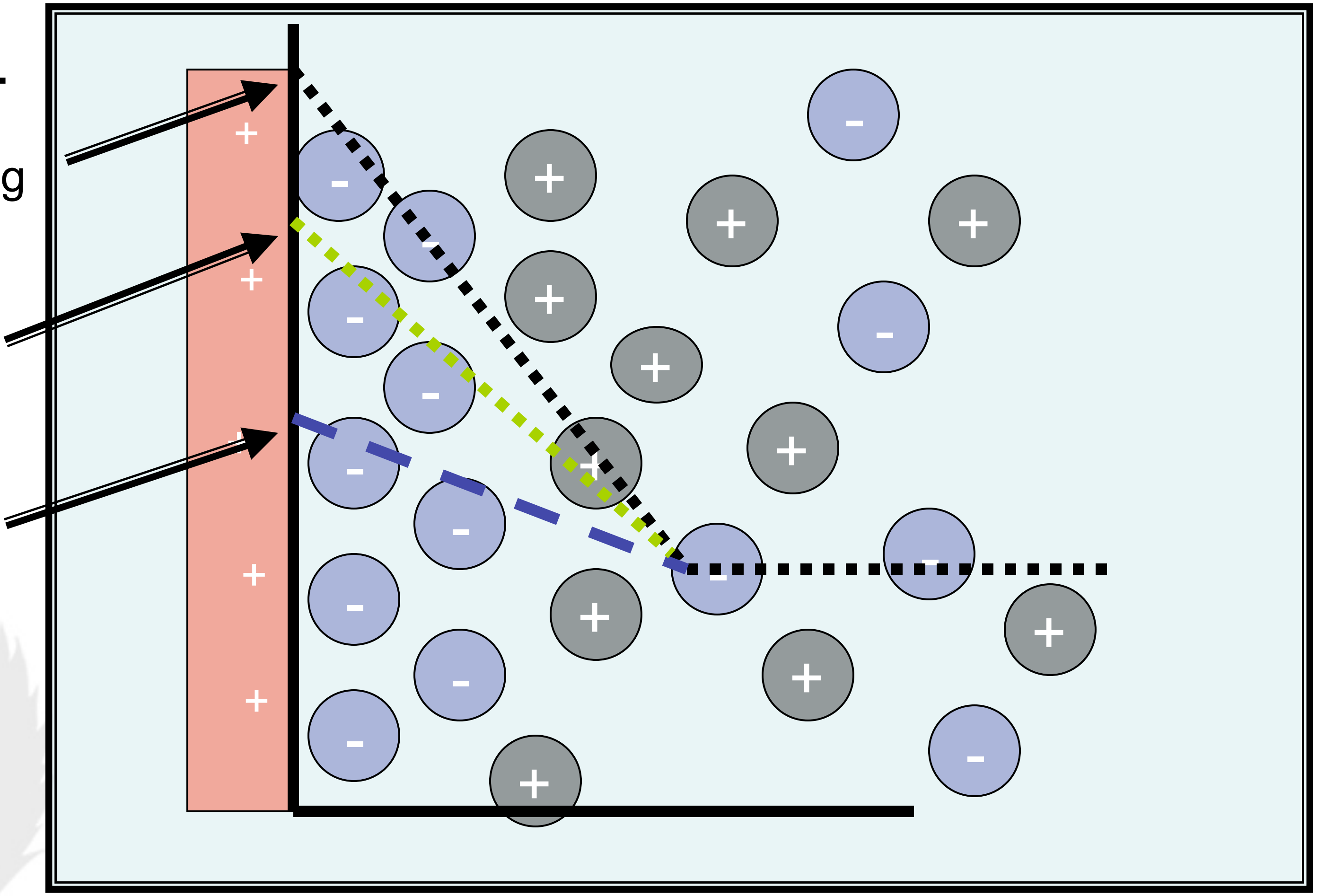
- Pulse plating- Grain Size Control
- PPRP in combination with bath additives- Via Fill Review

Voltage Cycle Effect on the Plating Process and Plated Deposit

- Goals for the plating cycle
  - For complex surfaces (vias, dense metal), facilitate the optimum organic distributions
    - Brighteners in vias
    - Carriers on the surface
    - Levelers on high current density feature
  - Control the deposit grain structure (with grain refining additives)
  - Optimize the plating rate
- DC Plating
- Pulse Plating
- Pulse Reverse Plating

Pulse Plating: Electrolyte Response

Diffusing Ions must move through the double layer potential to reach the electrode



POTENTIAL

DC Plating

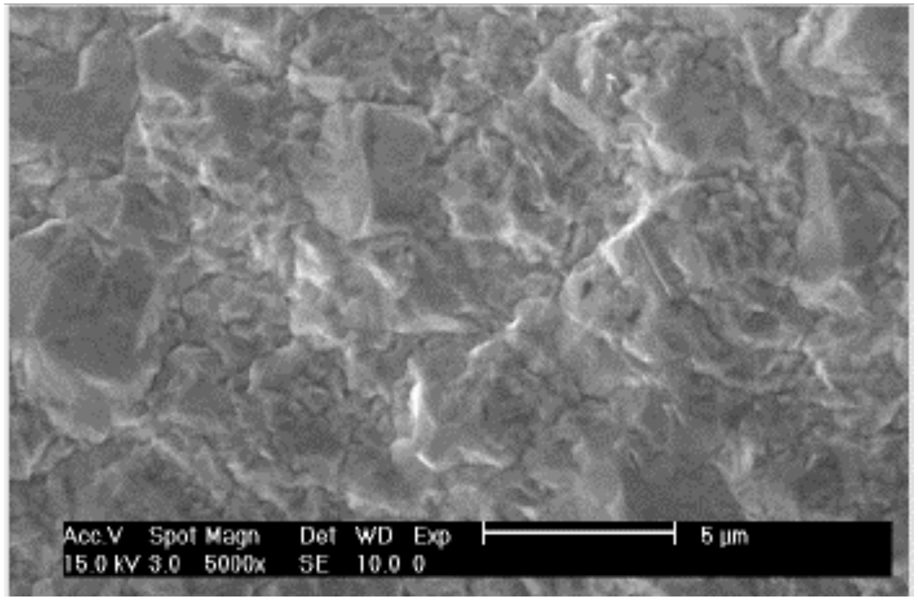
Pulse Plating
Pulse ON

Pulse Plating
Pulse OFF

Pulse Plating

Parameter	Plating Impact
Relaxation after pulse lowers ionic potential at electrode surface- allows more effective diffusion of plating species to electrode surface.	Increased plating rate in diffusion controlled situations and increased plating thickness uniformity.
During each pulse, deposition and film nucleation is initiated.	Controlling the pulse frequency allows control of the nucleation rate and thus controls the grain growth dynamics, size and orientation.

Pulse Plating: Au Grain Structure Example

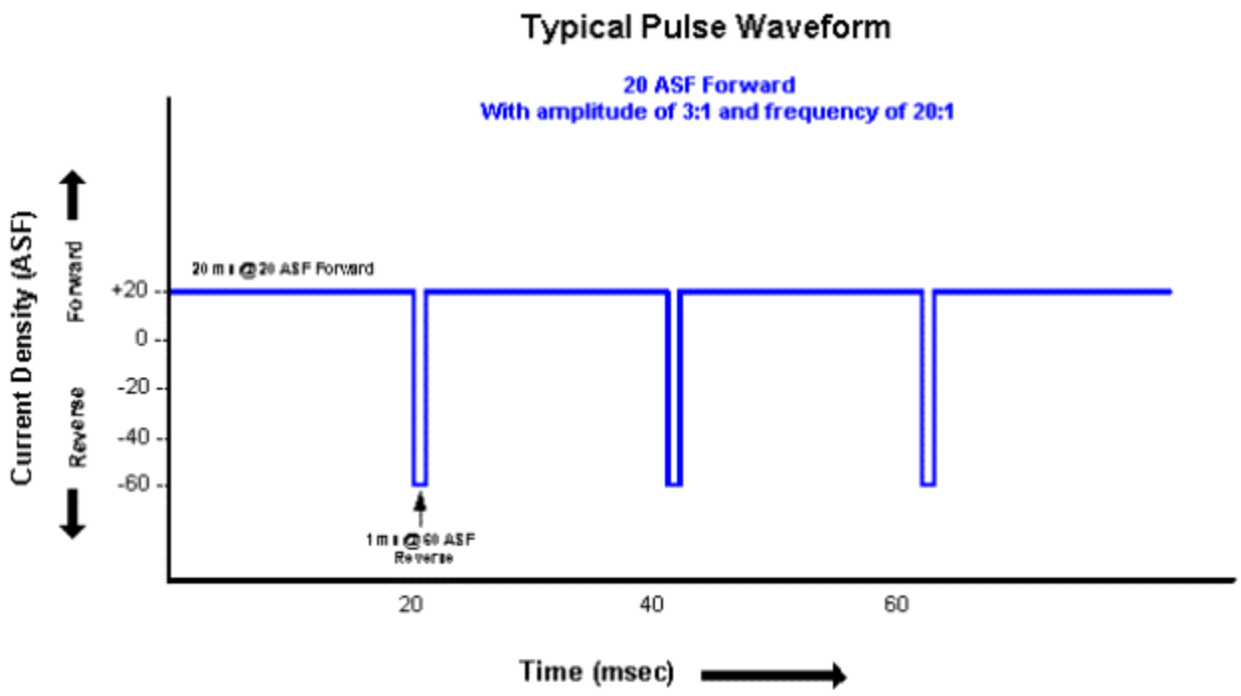


Pulse plating is used to create large grained gold (to inhibit Ni diffusion during die attach

Periodic Pulse Reverse Plating for Enhanced Via Fill (PPR)

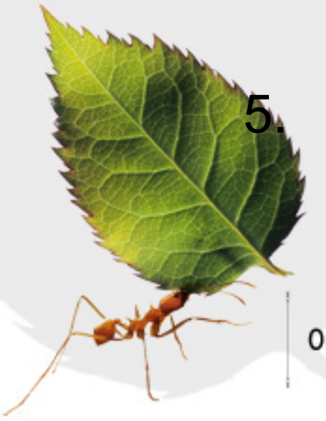
- Long duration forward current (substrate is the cathode) followed by short duration reverse current (substrate is the anode)
- Typical 20ms forward/ 1ms reverse (20:1)
- Reverse current is typically 3 times higher magnitude than the forward current (1:3)

Periodic Pulse Reverse Plating for Enhanced Via Fill



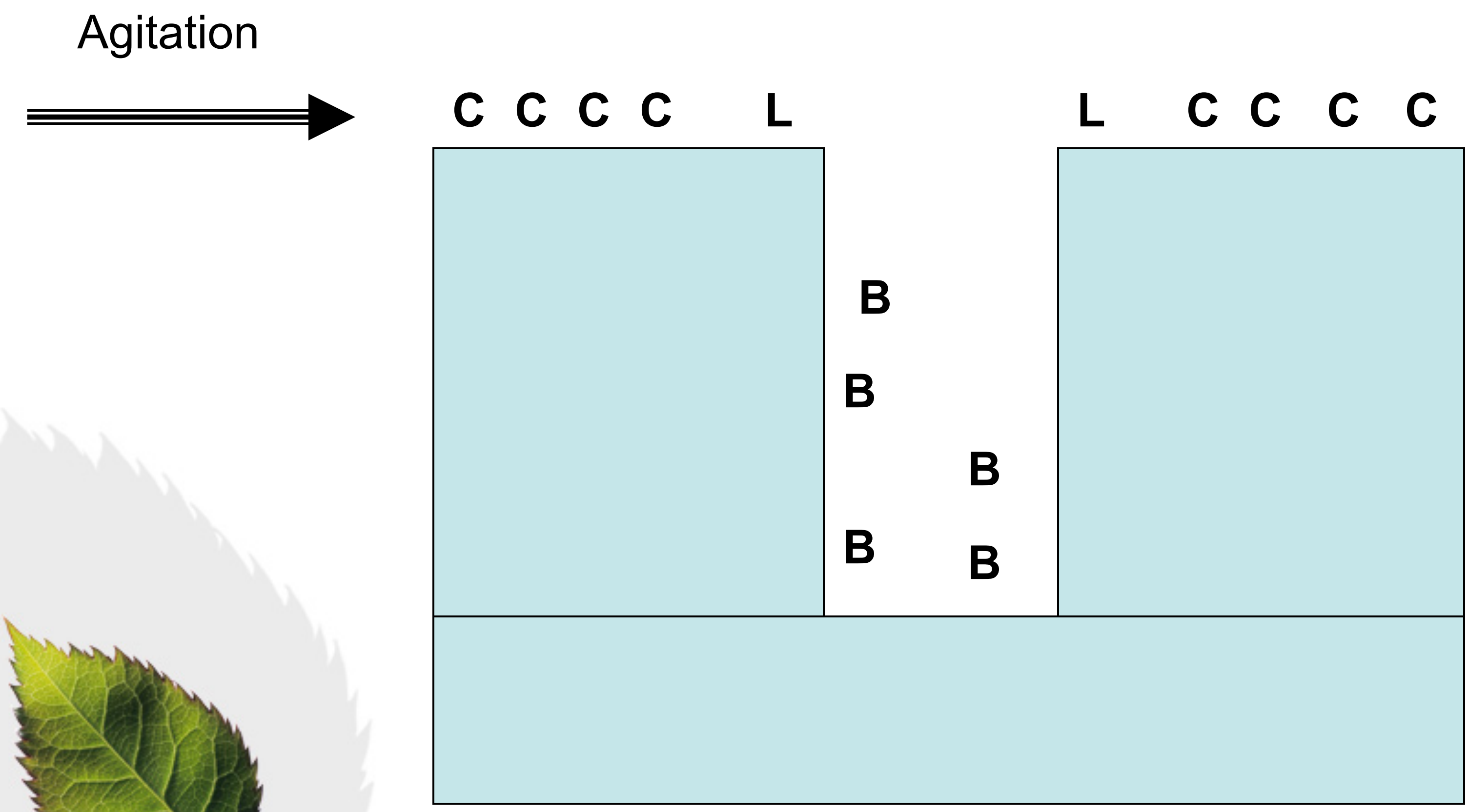
PPR Plating- How it Works to Fill Vias

1. Initially the Carrier (plating suppressor) is uniformly absorbed on the surface of the substrate
2. During I_f Brightener is absorbed on the surface of the substrate and in the through holes with the concentration proportional to the (local) current density
3. During I_R Brightener desorbs from both the surface and the via holes with the amount of desorption proportional to current density→ More desorption from the surface than in the vias
4. Due to high mass transport at the surface- the desorbed brightener is easily washed from the surface region but remains concentrated in the (more stagnant) via holes
5. Result: Higher brightener concentration in the via holes which enhances the via hole plating rate



PPR Plating for Via Fill Organic Distribution

Schematic Showing the Dominant Organic species in each location



PPR- Different Plating Environment in Different Parts of the Substrate!!

PPR Plating and Via Fill- Summary Points

- Very effective in filling high aspect ratio open or blind vias
- Creates different plating environments in different regions of the substrate by manipulating the surface concentration of organic additives
- Agitation is critical to remove Brightener from surface regions
- In-Via agitation can disrupt the required Brightener concentration in via holes
- The plating bath MUST be designed for PPR Plating

Other Critical Factors for Effective Cu Via Fill

- Ohmic resistance through the length of a high aspect ratio Via is a major obstacle to uniform plating
- Ohmic resistance is minimized by *increasing* the ratio of H_2SO_4 /Cu or increasing temperature

(1) High throw Cu bath for electronic applications
(2) Bath designed for filling high aspect ratio vias

Property	***Cu Bath M (1)***	***Electro-deposit 1000(2)***
CuSO4 (g/L)	68	25
Cu (g/L)	17	6
H2SO4 (g/L)	173	225
H2SO4:Cu	10:1	38:1
Current ASF	20-40	10-20

Other Critical Factors for Effective Cu Via Fill

- IR drop through via structure leads to poor via fill
  - Thickness of seed layer along the via walls
  - Thickness of substrate
  - Plating current density
- Via size must be wide enough to sputter minimum of 1000 angstroms of seed metal along the wall
- Low current density cycle followed by higher current density (once the wall is plated) can also help with this issue

Other Critical Properties of the Plated Layer and Plating Factors Which Effect These Properties

1. Plating Thickness Uniformity
2. Surface Morphology and Texture
3. Mechanical Properties

Other Critical Properties: Plating Thickness Uniformity

Plating Thickness Uniformity-Fundamentals

- Differences in plating potential change the plating rate (and resultant plating thickness)
- $\Delta E_t = \Delta \eta_{ct} + \Delta \eta_{mt} + E_{IR}$
  - $\Delta \eta_{ct}$ represents differences in charge transfer rates (kinetics)
  - $\Delta \eta_{mt}$ represents differences in mass transfer (solution flow and diffusion)
  - E_{IR} represents IR drop differences

Plating Thickness Uniformity-Fundamentals

- Key Goal: Minimize ΔE_t
  - Within a substrate
  - From substrate to substrate on a rack
  - From rack to rack within a shift
  - From week to week
- Each of these areas requires control of different parameters

Critical Factors for Thickness Control

Factor	*Influence*	*Comments*
Electrolyte conductivity/ metal concentration	E_{IR}	The higher electrolyte conductivity/ metal concentration ratio decreases ohmic resistance in the electrolyte
Lateral Flow	$\Delta\eta_{ct}\ \Delta\eta_{mt}$	Controls reacting species concentration across the substrate. Effects charge transfer by controlling additive distributions.
Cell Configuration and Rack Design	$\Delta\eta_{mt}\ E_{IR}$	Key attributes: anode cathode ratio, shielding and thieves
Plating Current Density	$\Delta\eta_{mt}\ E_{IR}$	Lower current density enhances uniformity
Waveform		

Critical Factors for Thickness Control

Factor	***Influence***	***Comments***
Plating bath additives	$\Delta\eta_{ct}\ \Delta\eta_{mt}$	Minimize differences in plating rate vs. current density
Substrate Resistance	E_{IR}	
Metal Pattern	$E_{IR}\ \Delta\eta_{ct}$	

Critical Factors for Thickness Control-Electrolyte Conductivity

- $E_{IR} = E_{IR}$ (electrolyte) + E_{IR} (substrate resistance)
- Higher Electrolyte conductivity κ lowers E_{IR} (electrolyte)
- E_{IR} (electrolyte) = $C\ i(A/cm^2)/\ \kappa$
- Less position dependence than substrate resistance term

Critical Factors for Thickness Control: Electrolyte Flow

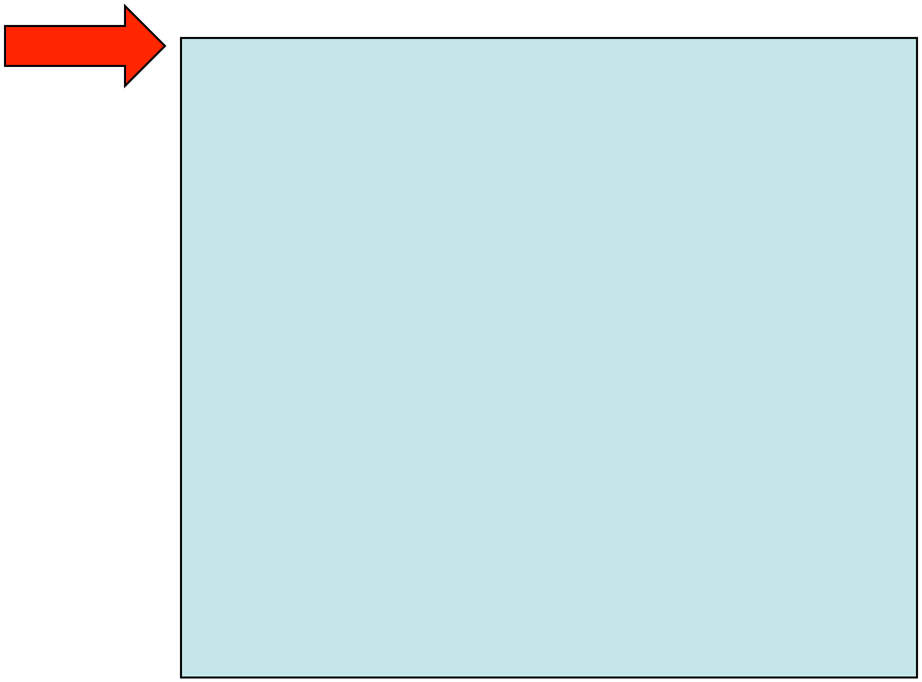
- Lateral flow across substrates is critical to decrease $\Delta\eta_{mt}$
- Solution flow normal to substrates may disrupt effective via
- Solution flow vs. substrate movement is required

Critical Factor for Thickness Control- Cell Configuration

- Thieves and shielding
  - Electric potential distribution
    - Rack construction materials are critical
    - High conductivity metals (Cu)
    - Stainless steel structures are high resistivity (problem)
  - Electrochemical screening
- Anode to Cathode Ratio

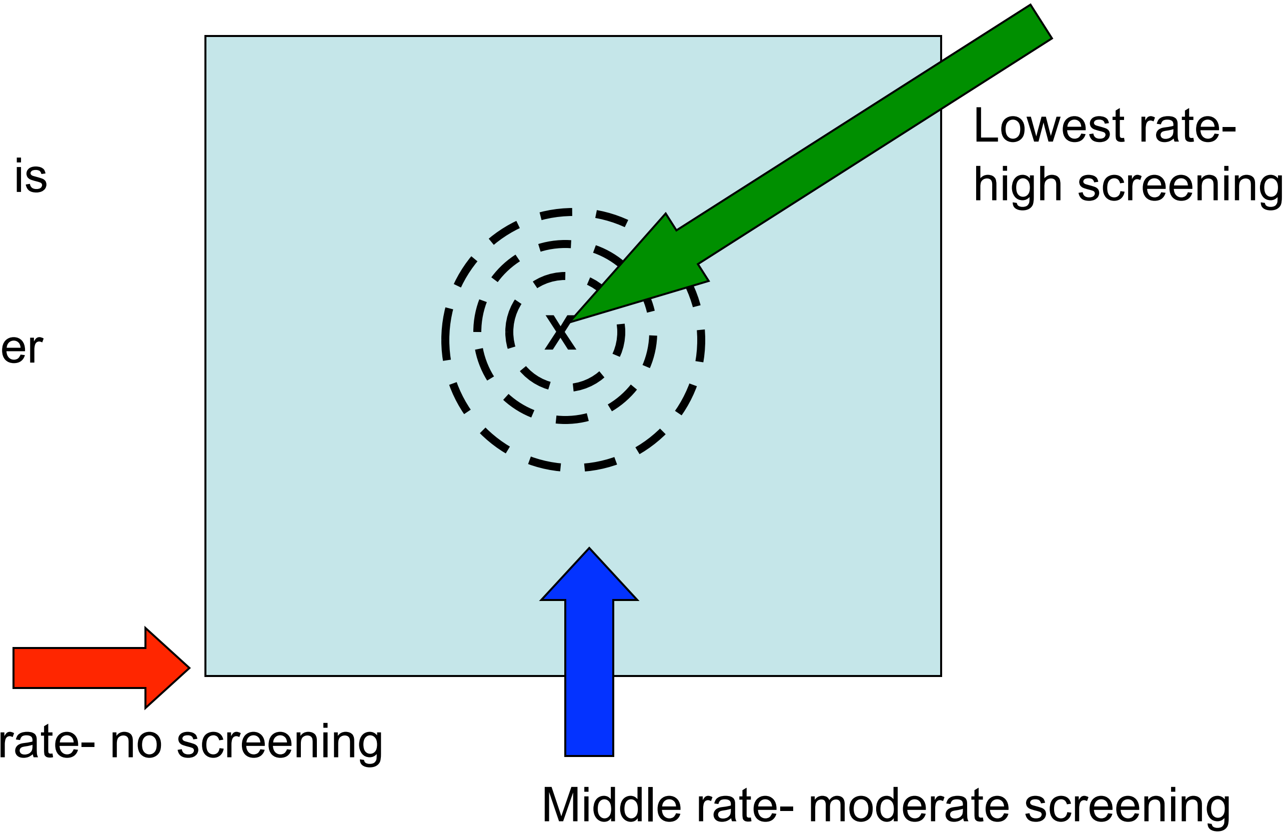
Critical Factor for Thickness Control: Role of Shielding

1. Edge and corner, higher electric fields → Higher potential means higher plating rate



Critical Factor for Thickness Control: Role of Shielding

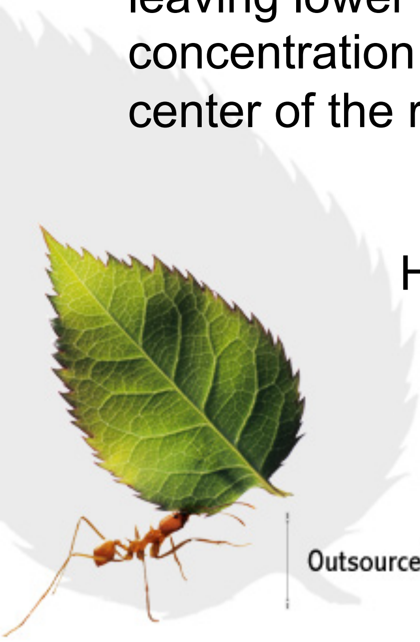
2. The plating rate at the center of the rack is reduced because concentric reaction rings around the center consume metal ions leaving lower ion concentration for the center of the rack



Lowest rate- high screening

Highest rate- no screening

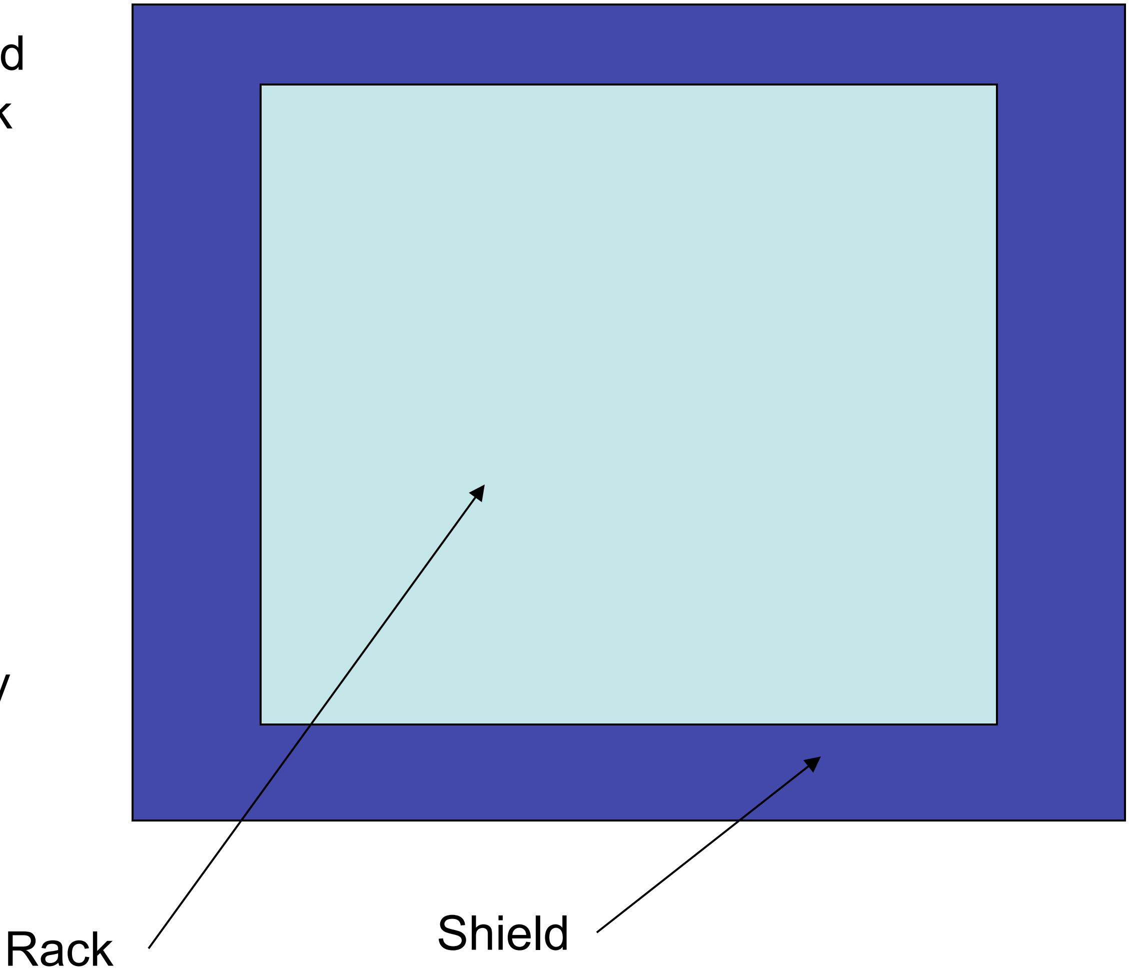
Middle rate- moderate screening

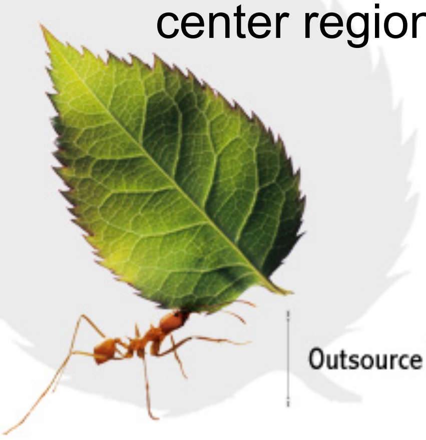


Critical Factor for Thickness Control: Role of Shielding

Metal screen around the edge of the rack

1. Shifts the high electric field concentration to the edge of the shield from the edge of the rack
2. Moderates the screening effects except at the very center region



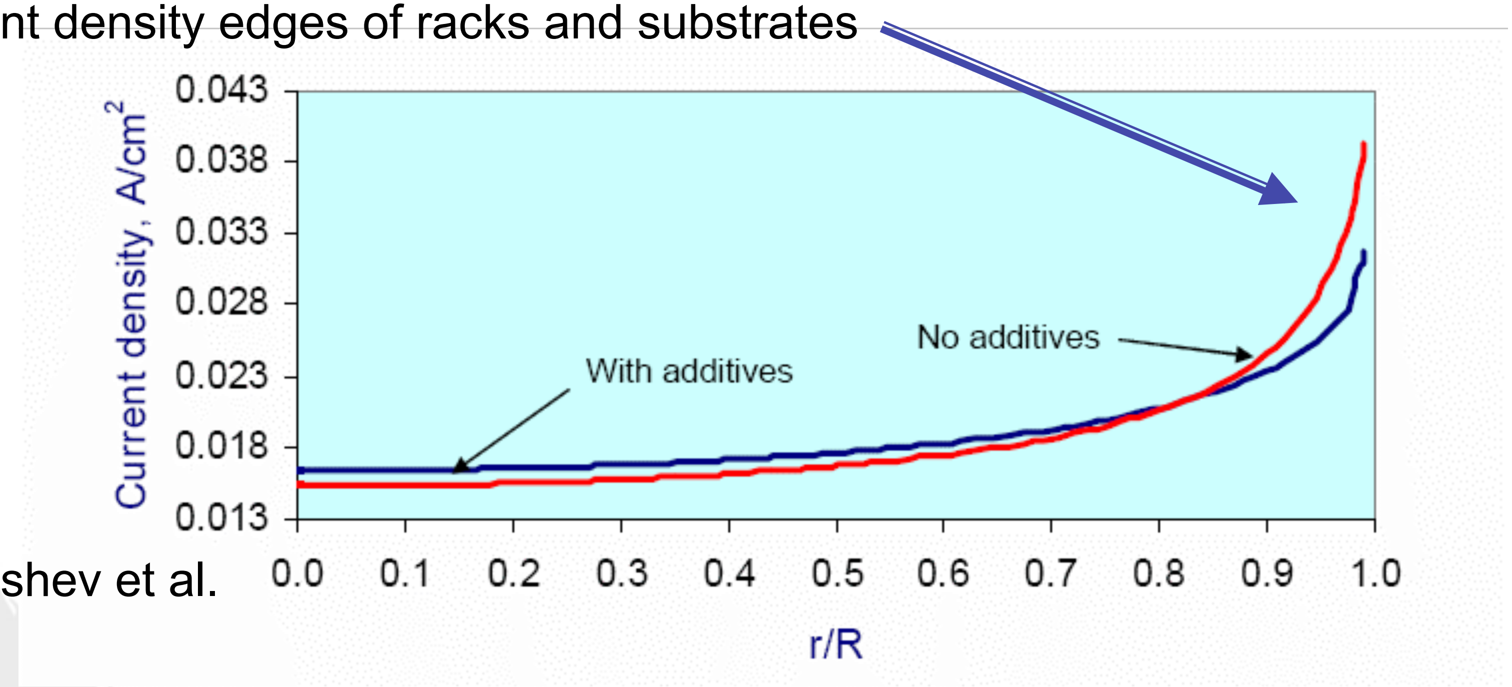


Critical Factors for Thickness Control-Plating Bath Additives

- Key role played by organic additives (levelers)
- Attach to high current density regions
  - edges
  - sharp features
- Inhibit charge transfer at high current density regions and thus lower $\Delta\eta_{ct}$

Critical Factors for Thickness Control- Plating Bath Additives

Key role of additives (levelers) at lowering the plating thickness at the (high current density edges of racks and substrates



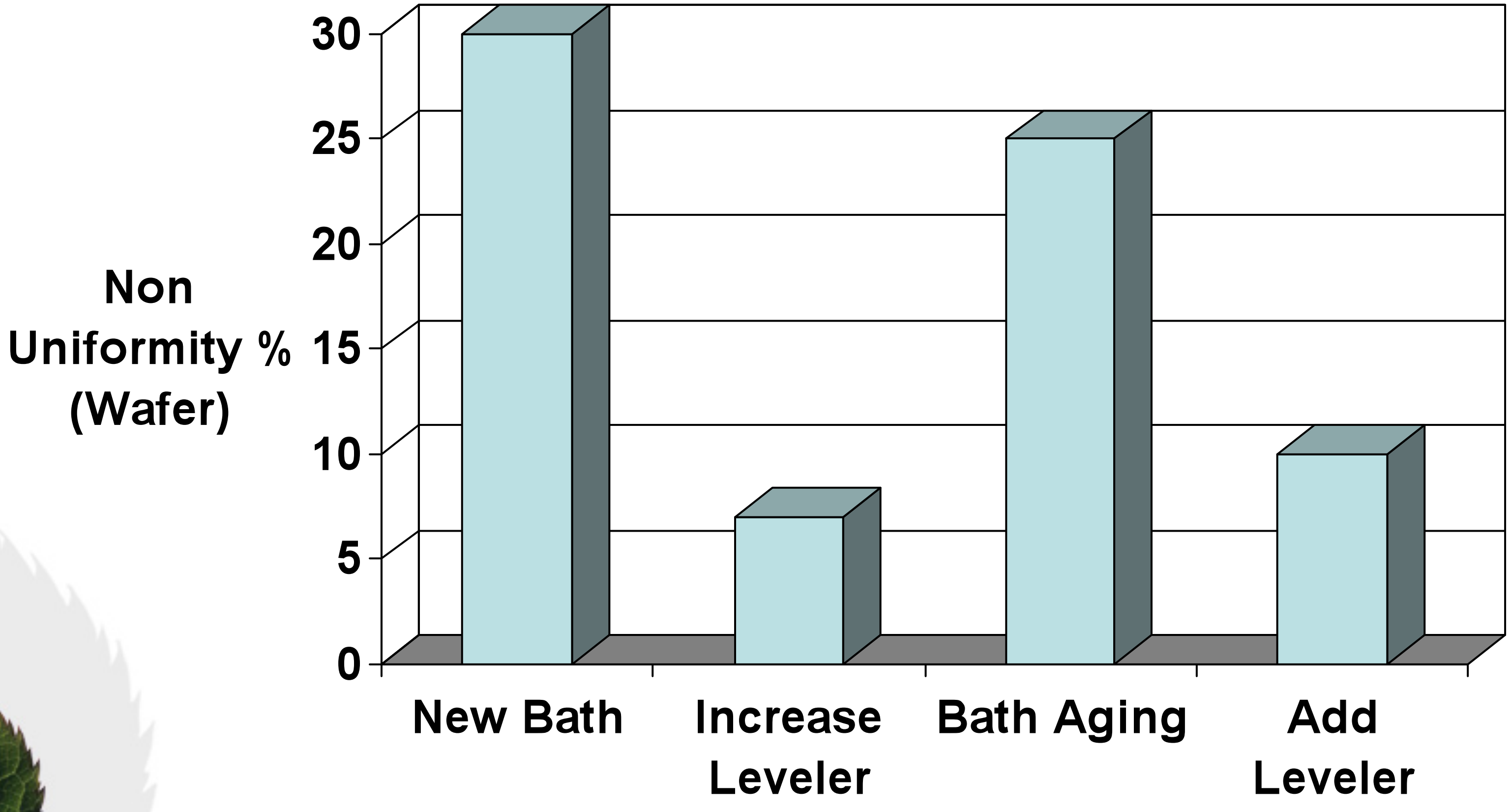
Mayshev et al.

Red line is pure copper sulphate (o.5M, pH=2), blue line is the same electrolyte with 70 ppm Cl, 50 ppm SPS and 200 ppm Polyethylene Glycol

Levelers- bond to high current density regions and lower the plating rate (inhibit charge transfer)

Critical Factors for Thickness Control- Plating Bath Additives

Dumas et al.

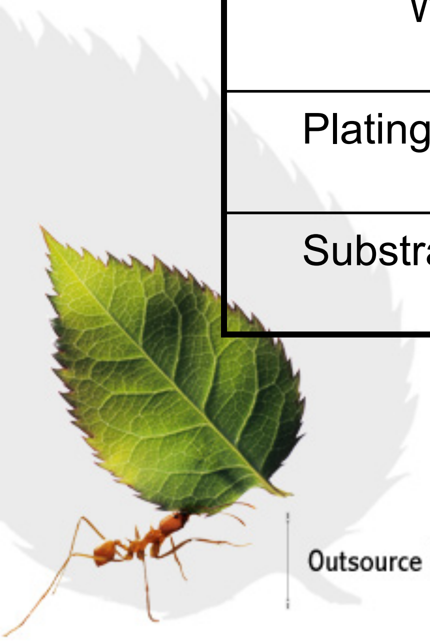


Critical Factors for Thickness Control- Current Density

- Lowering current density lowers E_{IR} which strongly depends on position along the substrate
- Plating rate limited by charge transfer kinetics η_{ct} which is independent of location ($\Delta\eta_{ct}$ is very small)

Critical Factors for Thickness Control-Trade-offs

Factor	***Trade-off***
Metal Concentration	Lower current densities/ lower plating throughput
Cell Configuration and Rack Design	Plating bath loading is lowered by utilization of shielding (thieves)
Plating Current Density	Lower current densities will decrease plating through-put
Waveform	Optimizing uniformity may impact other key properties such as via fill effectiveness
Plating bath additives	Increased bath maintenance (organics additives and carbon treatment of by-products)
Substrate Resistance	Sputter cost if a thicker seed layer is required. More undercut possible during etching



Maximize Via Fill and Thickness Uniformity (Cu Example)

- Organic package designed for optimum via fill
- PPR Plating Cycle
- High H2SO4/Cu ratio
- High H2SO4
- Good lateral flow across substrate
- Minimum flow into substrates
- Lowest practical current density
- Thick seed layer- especially in-via metallization

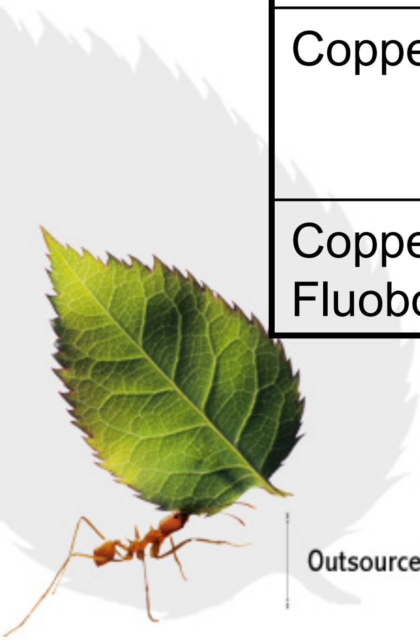
Copper Plating

Copper Plating

- Role of Copper plated layer or plated via
  - Electrical conductor
  - Thermal conductor
  - Ductile layer (mediate TCE mismatch)
- Typical Key Properties
  - Thick deposit
  - Dense via fill to avoid trapping plating impurities

Standard Copper Plating Baths

Bath	***Properties***	***Main Applications***
Copper Cyanide	High adhesion strike, very rapid plating	Wire plating, thick copper
Copper Pyrophosphate	Ductile, high throwing power	Electroforming, plating on plastic, PCB
Copper Sulphate	High throwing power, economical, few waste treatment issues	PCB, Electronics, semiconductors
Copper Fluoborate	High plating speed	PCB, electronics, plating on plastic, electroforming



Copper Sulphate- Typical Constituents

- Copper sulfate, sulfuric acid, chloride, organic additives
- Anode/cathode efficiencies 100%
- Current densities 15-30 ASF (typical)
- For high throw applications:
  - Copper sulfate 60-75 g/liter
  - Sulfuric acid 187-225 g/liter
  - Chloride 50-100 ppm
  - Organic additives (per bath vendor)
  - Metal/Acid ratio 1:30
  - PPRP Cycle

Copper Sulfate Contamination

- Organics from decomposition of brighteners, resist
  - Green colored bath
  - Decrease in deposit ductility
  - Non-uniform surface morphology and grain structure
  - Nodules
- Anode bag contamination (incomplete leaching)
- Drag-in of previous chemistries
- Tank liner degradation

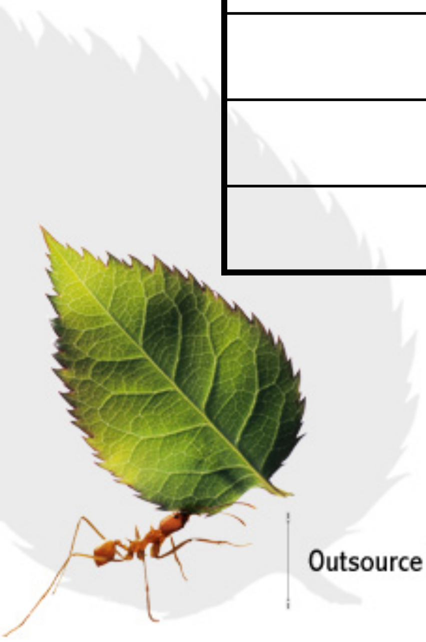
Carbon treatment to remove organic contamination is critical

Copper Sulfate Troubleshooting

Issue	*Cause*	*Corrective Action*
Burning of Deposit	Low Cu, High Acid	Analyze and correct
	Low temperature	Adjust temperature
	Insufficient agitation	Lower current or increase agitation
	Organic contamination	Carbon treat
	Low Chloride	Analyze and correct
Rough Deposit	Particles in solution	Increase filtering
	Torn anode bags	Replace
	Improper anodes	Phospherized copper
	Low chloride	Analyze and correct

Copper Sulfate Troubleshooting

Issue	***Cause***	***Corrective Action***
Pitting	Low chloride	Analyze and correct
	Organic contamination	Carbon treatment
Poor Distribution	Low or non-uniform agitation	Improve agitation
	Excessive anode area	Decrease anode area
	Improper anode film	Dummy plate
	Current supply AC ripple	Adjust to <<5%
	Organic contamination	Carbon Treatment

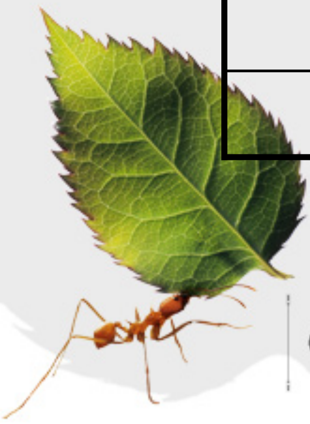


Copper Nodules

- Substrate cleaning- residue from resist developer (source of bath contamination)
- Filter bath with 1 micron filter, 5 turnovers/hr
- Minimize all sources of particulates
  - corrosion
  - dust
  - anode bag
  - Rack contacts
- Excessive current density
- Excessive brightener concentration
- Leach tanks (when a new bath is installed)
- Batch carbon treatment with activated carbon (every 3 months)

Copper Sulfate Troubleshooting

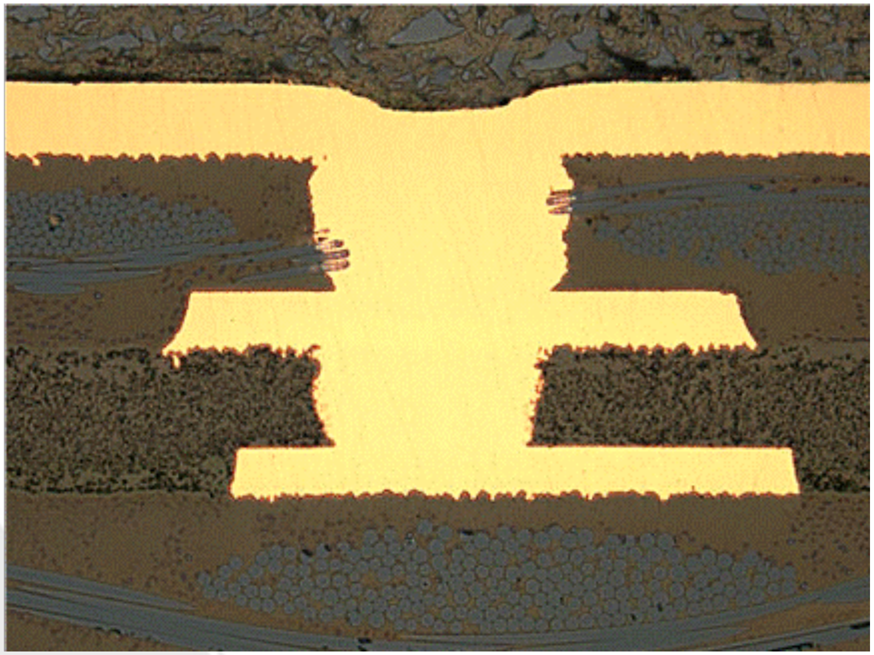
Issue	***Cause***	***Corrective Action***
Anode Polarization	Tin or gold contamination	Dummy plate
	Low temperature	Adjust temperature
	Improper anodes	Phospherized anodes
	High Chloride	Clean anode film, dummy to reformulate, precipitate out Cl with Ag sulphate and carbon filter
	High Sulfuric acid	Dilute bath
	Low Copper sulfate	Analyze and adjust
	Organic Contamination	Carbon treatment



State of the Art Cu Plating Bath Suppliers

Supplier	*Bath*	*Characteristics*
Rohm and Haas Electronic Materials	InterVia Cu 8530	Excellent filling characteristics for micro via holes, high throwing power
Cookson Electronics	Enthone Cuprostar CVF1	Very high throwing power, optimized for DC plating, through holes and blind vias
Uyemura	Thru Cup EPL	High throwing power, optimized for DC, suppresses nodule growth.
Technics	Cu 2300	DC or PPRP compatible.
Atotech	Cupracid HLF	State of the art. Commonly used in Taiwan (good support). See next slide

State of the Art Cu Plating Bath Suppliers- Atotech

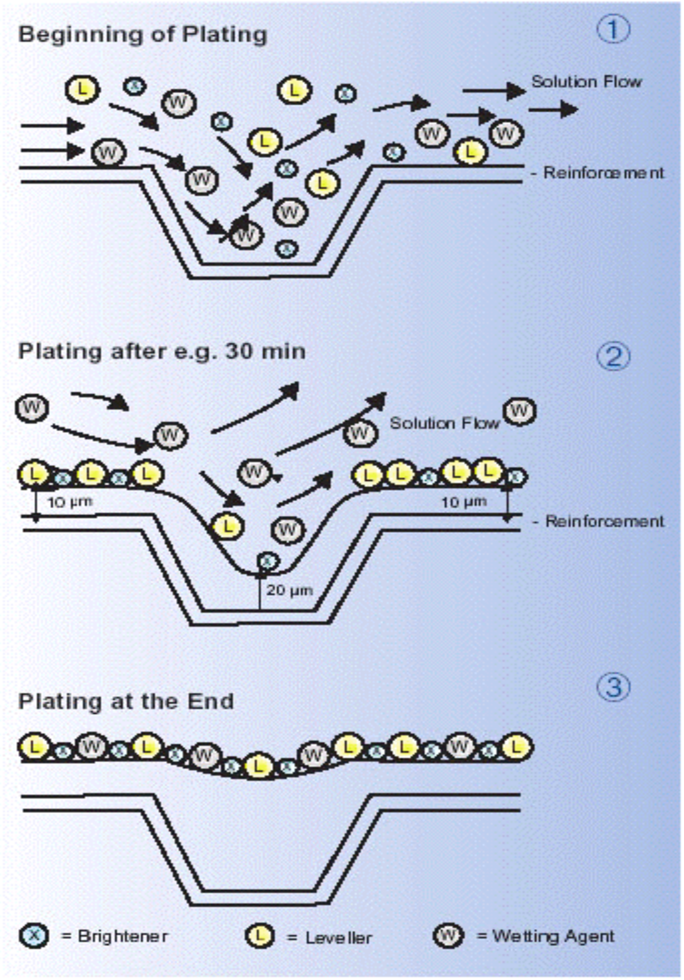


Via fill copper baths are designed to fill blind micro-vias- these baths and plating conditions may need to be optimized for open vias

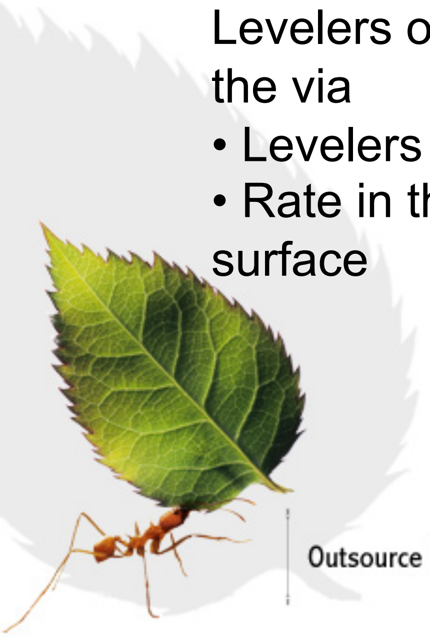
State of the Art Cu Plating Bath Suppliers- Atotech

AtoTech Cupracid Via Fill Mechanism

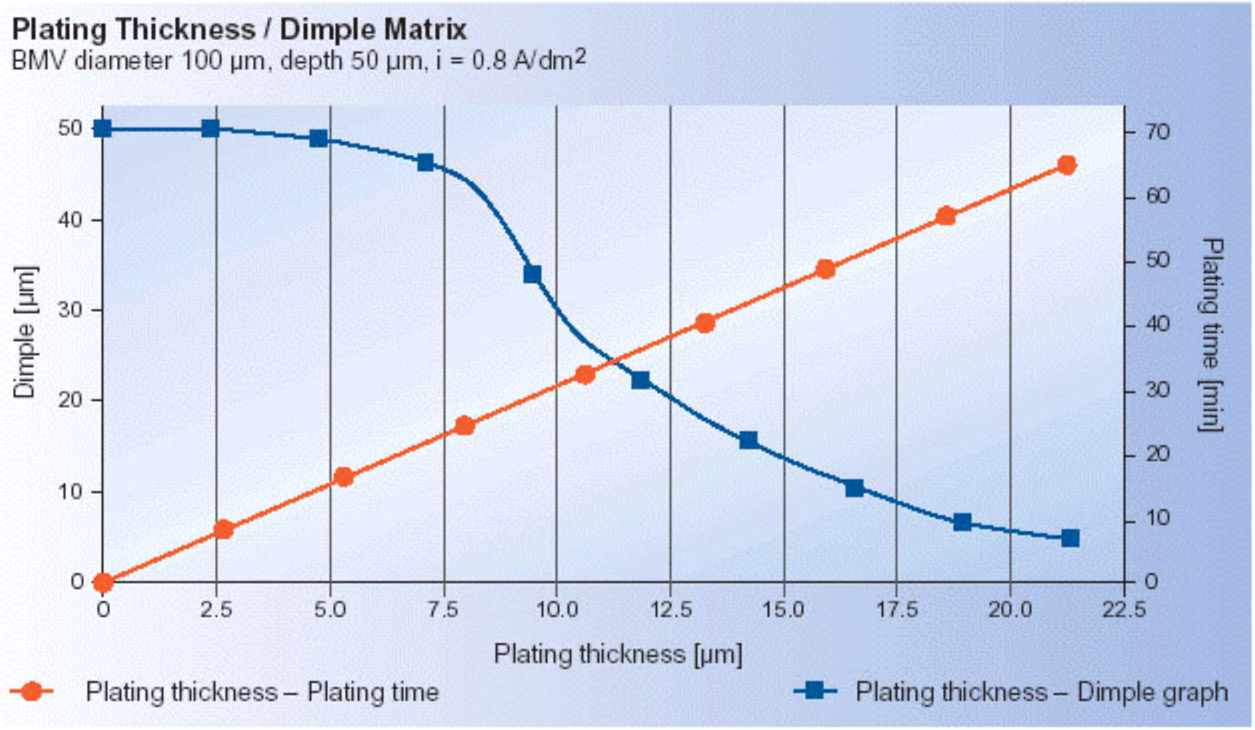
- Similar to the process outlined in the “Bath Components” Section
- Levelers are strongly attached to the plating surface
- Levelers are depleted in the via, but are refreshed due to solution flow on the surface → Higher concentration of Levelers on the surface versus inside the via
- Levelers inhibit plating rate
- Rate in the via is higher than the surface



Via Filling Mechanism



State of the Art Cu Plating Bath Suppliers- Atotech

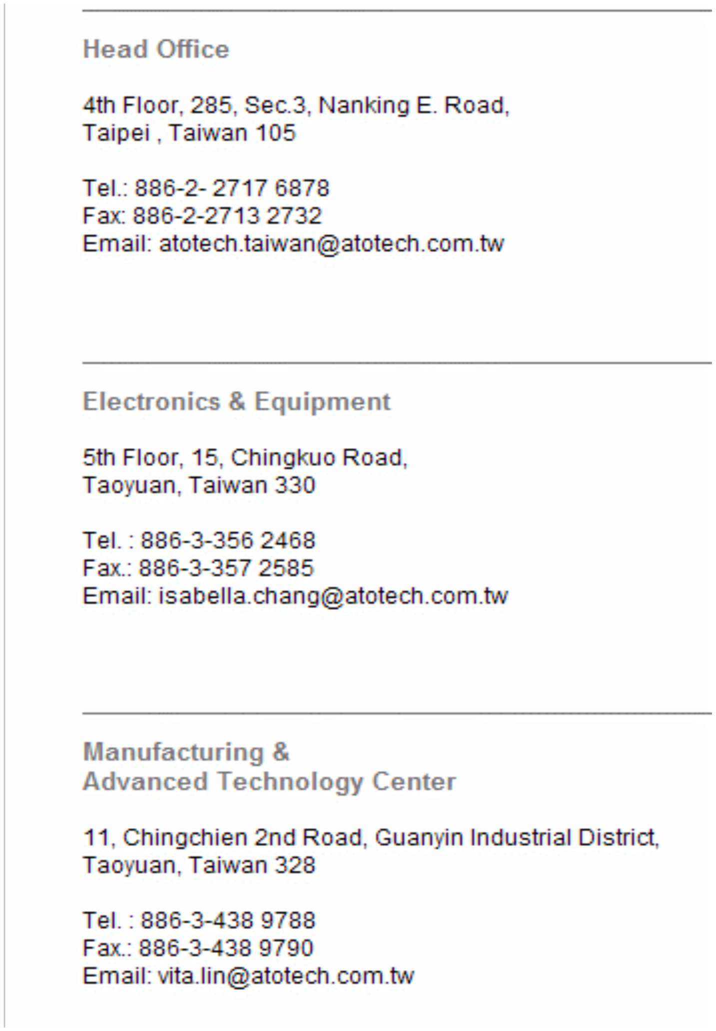


Plating Thickness / Dimple Matrix

BMV diameter 100 µm, depth 50 µm, i = 0.8 A/dm^2

The via filling process, represented by a declining dimple, is not linear – speed increases at the beginning and slows down towards the end.

AtoTech in Taiwan



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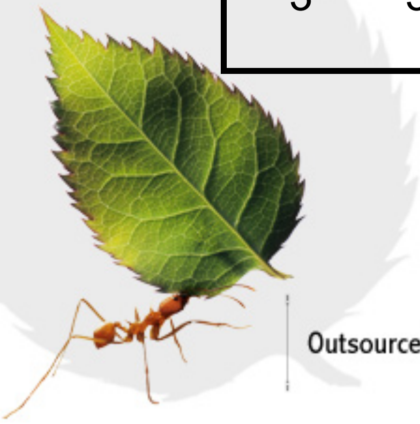
Nickel Plating

Nickel Plating

- Role of Nickel Layers
  - Surface for wirebond and die attach
  - Diffusion barrier for underlying metal layers (Cu, Ti)
- Typical Key Requirements
  - Nickel is not oxidized
  - Nickel layer is less than 400 micro-inches
    - Thermal barrier
    - Stress in thick nickel layers
- Ultra Smooth Reflective Leveling Nickel
  - CMC developed at Lumileds Request
  - In a separate presentation

Ni Plating Baths- Typical Compositions

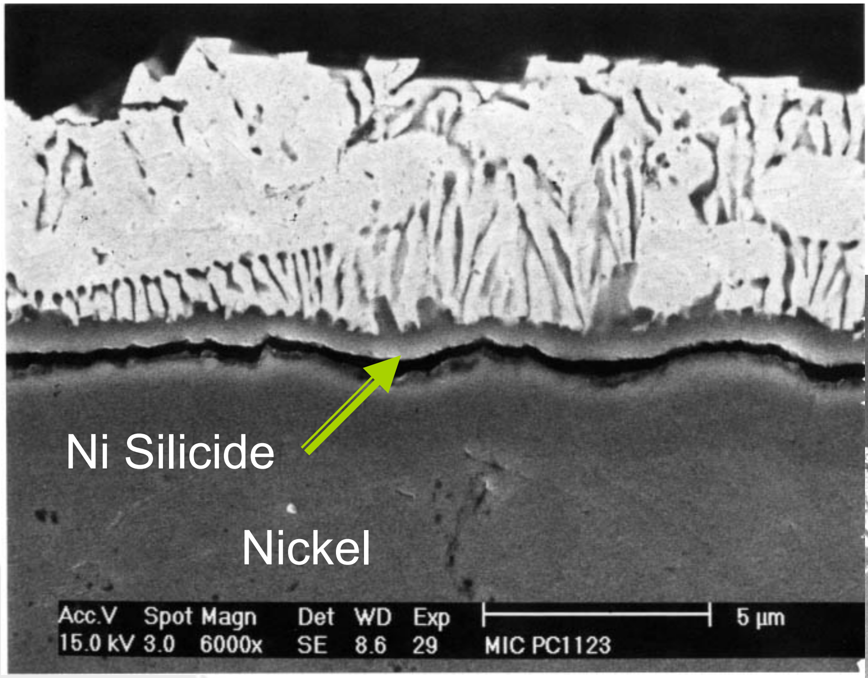
Additive	*Watts Nickel Bath (g/L)*	*Nickel Sulfamate Bath (g/L)*
$NiSO_4$	225-300	
$Ni\ (SO_3NH_2)_2$		315-450
$NiCl_2$	37-53	0-22
H_3BO_3	30-45	30-45

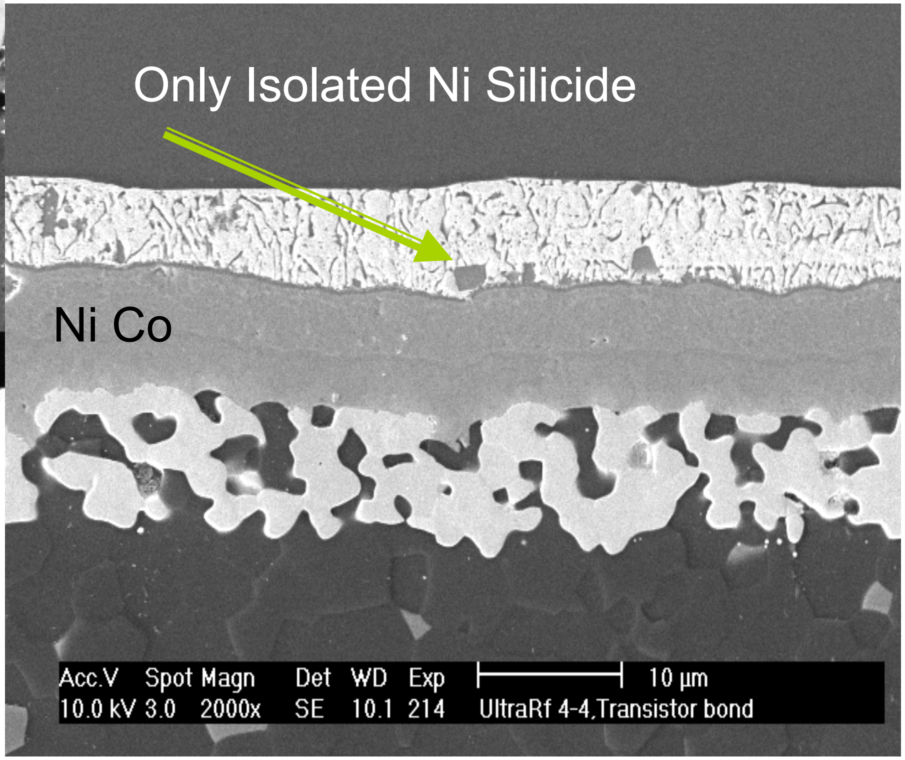


Nickel-Cobalt

- Ni plated layers are very susceptible to intermetallic compound formation during solder or die attach
  - Nickel Silicide
  - Ni_3Sn_4
- IMC layers cause reliability issues
- Doping the Ni plating bath with Co frustrates Ni based IMC formation
- 10-40% Co in the deposit

Nickel Plating- IMC Issues





Gold Plating

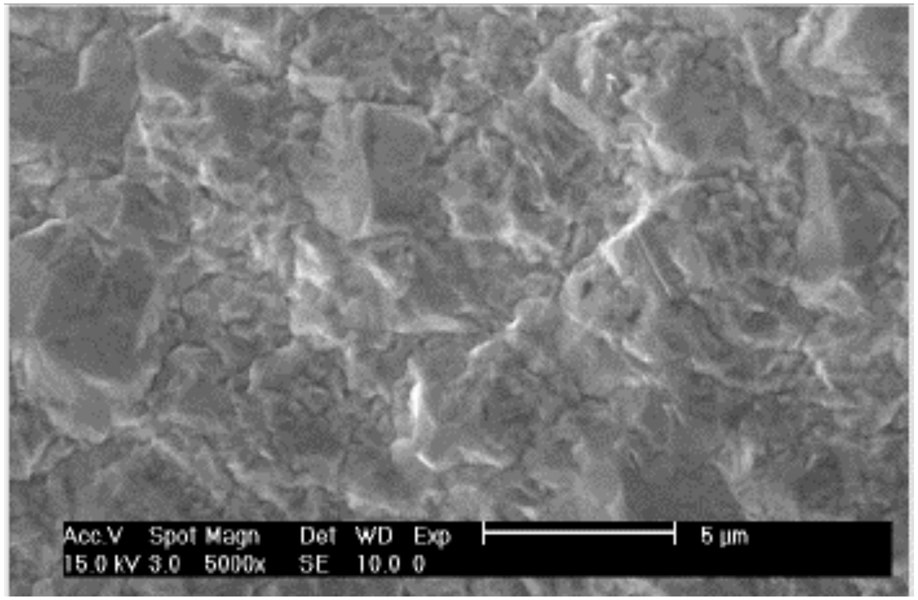
Gold Plating

- Role of Gold Layer
  - Protect underlying nickel layer from oxidation
  - Facilitate die attach and wirebonding
- Typical Key Requirements
  - Gold layer is as thin as possible to reduce cost
    - 80-100 micro inches for AuSi die attach
    - 40 micro inches for AuSn die attach
    - 40 micro inches or less for wirebonding
  - Gold layer is 99.9% pure (free of both inorganic impurities and organics)

Au Plating- Die Attach and Wirebond Applications

- Au Cyanide bath (4.4-5.5)
- Potassium gold cyanide
- Proprietary grain refiners (Pb, Tl)
- Deposit 99.9% pure
- High sensitivity to organics
  - Cyanide breakdown
  - Resist breakdown
  - Drag in
- PPM sensitivity to metal contamination
  - Nickel
  - Iron
- Pulse plating cycle to control grain size

Au Grain- Large Grain Size



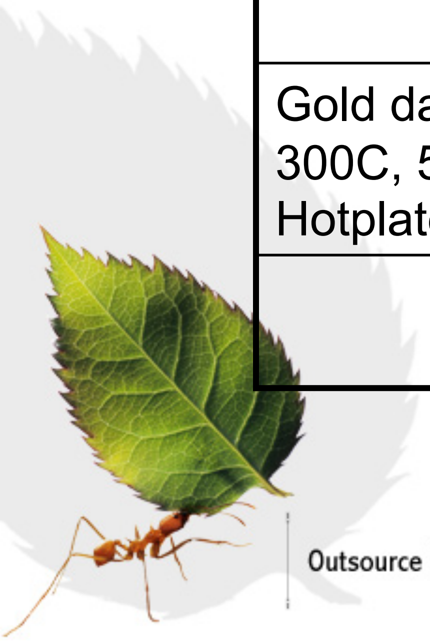
- Gold concentration and pulse cycle are optimized to produce large “amorphous” grain structure
- Ni migration along Au grain boundaries are minimized
- Enhances GGI and wirebond characteristics
- 40 micro-inches or less for optimum grain structure

Au Plating- Bath Maintenance

- Organic removal through periodic carbon treatment is critical
- Gold hardness measurements to determine Ni contamination level (Coupon)
- Maintenance of the Au Strike to keep Au plating bath clean
- Monitor Pulse Plate rectifier noise profile

Au Plating Troubleshooting

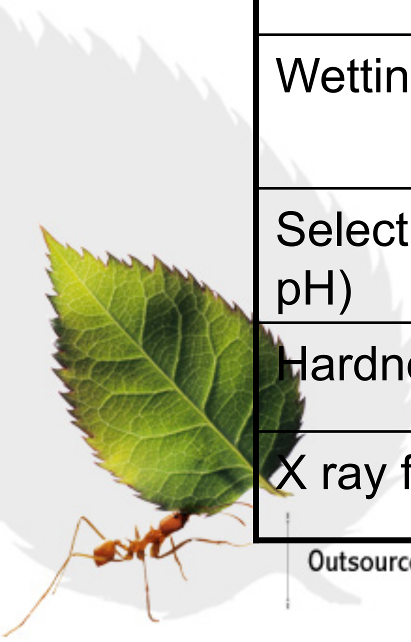
Issue	*Cause*	*Corrective Action*
Orange color gold deposit	Organic contamination, low gold concentration	Carbon treatment, add gold
Low GGI ball shear or wirebond failure	Organic contamination	Carbon treatment
	Nickel contamination	
Gold darkens after 300C, 5 minute Hotplate test	Au layer is too thin	Re-plate for longer period
	Nickel contamination	



Measurements and Techniques to Control Plating

Plating Bath Control

Technique	*What is Measured*	*Example*
Titration	Concentration of a reactant in solution	Cu concentration in a Cu Sulfate bath
Atomic Absorption	Dissolved metals in a plating solution	Identifying and quantifying metallic impurities
Hull Cell	Deposit quality versus current density	Monitoring organic brightener
CVS	Active organic components in a bath	Brighteners or carriers in a copper plating bath
Wetting Angle	Wetting characteristics of the bath.	Measures surfactant levels. Key to via fill and bubble elimination.
Selective ion (Cl, pH)	Activity of an active ion such as H+, OH- or Cl	Monitor Cl concentration in a copper sulfate bath
Hardness Testing	Hardness of a plated layer	Excellent for detecting small levels of impurities in gold
X ray fluorescence	Major bath constituents or plated layer thickness	Gold or nickel concentration



Hull Cell Measurements- Process Control Tool

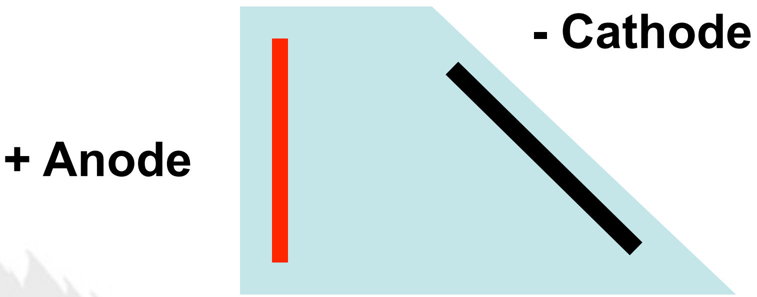
- Optimization for current density range
  - Optimum deposit characteristics at chosen current density
  - Bath optimization for widest current density range (improves thickness uniformity, via fill, feature fill)
- Optimization of additive concentration
- Recognition of impurity effects
  - Organic
  - In-organic
- Indication of throwing power capability

Hull Cell Measurements: Process Development and Control Tool

- Utilize Hull Cell measurements to optimize bath additive composition (organics) during process development
  - Maximize current density range
  - Maximize leveling
  - Maximize brightness/ reflectivity
- Use routine Hull Cell Measurement to monitor changes in bath chemistry
  - Impurities
  - Organic additive depletion
  - Mechanical properties of the deposit (stress)

Hull Cell Basic Set-Up

2A through cell translates to a current density range .25 to 10 A/dm^2



Top View

Cell Volume= 267 ml
2 g addition → 2 oz/ gallon in plating bath

Hull Cell Measurement Procedure: Metallic Impurities

1. Insure that plating bath parameters such as pH, metal concentration, acid concentration are within specified limits
2. Take a sample of the plating bath chemistry and transfer to the Hull Cell and plate
3. Look for a dark deposit at low current density regions indicating metallic contamination
4. If a contaminant is present, analyze with AA to identify the source (note that the concentration in the deposit can be much higher than in the bath)
5. Remove the contaminant with ion exchange and/or dummy plating
6. Repeat Hull Cell measurement to insure dark deposit is no longer present

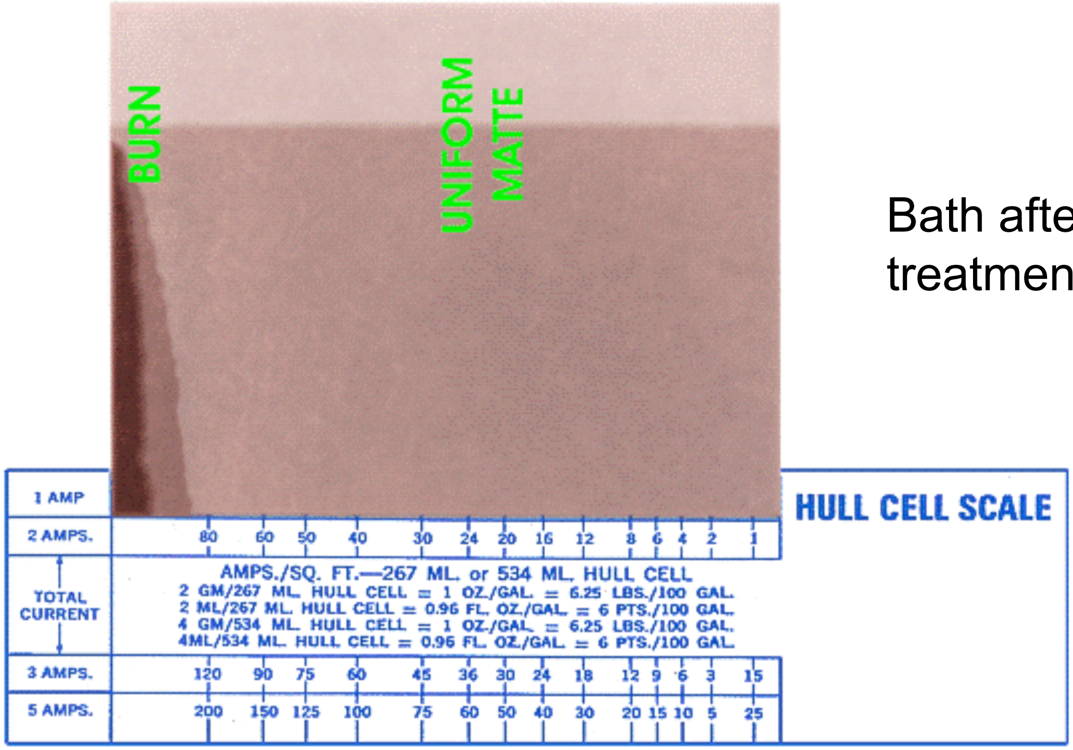
Hull Cell Measurement Procedure: Organic Impurities

1. Take a sample of the plating bath chemistry and transfer to the Hull Cell and plate
2. A dark or black deposit near the solution level interface indicates organic or metallic contamination
3. If this is seen, carbon treat the Hull Cell solution
4. Repeat the test on a new Hull Cell panel
5. Replenish the Brightener if necessary (noting how much was added)
6. Plate another panel
7. Once the desired deposit quality is reached, perform the same carbon treatment and Brightener adds to the plating bath

Hull Cell Measurement Procedure: Leveling Power

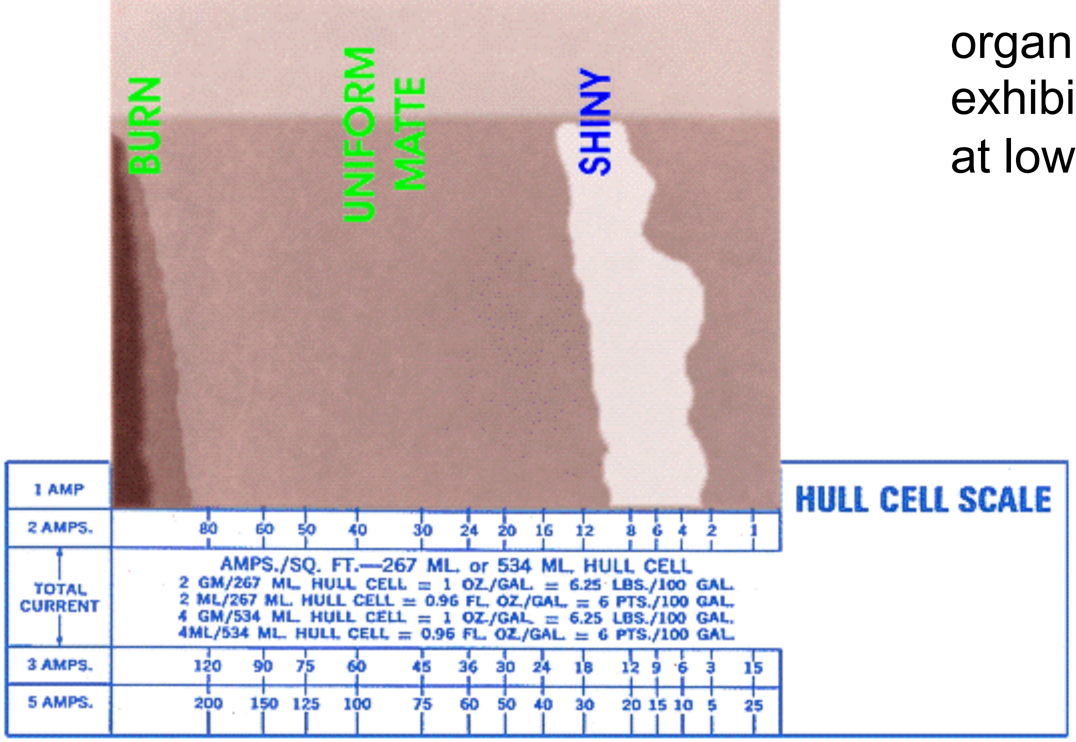
1. Take a representative sample of the bath and transfer into the Hull Cell
2. Plate onto a brass panel with a scratched surface
3. Inspect the deposit for smoothness
4. Adjust Leveler concentration until desired current density region on the Hull cell panel exhibits a smooth finish (no evidence of scratches)
5. Reproduce these adds in the plating bath

Hull Cell Panel Examples: Acid Cu Bath



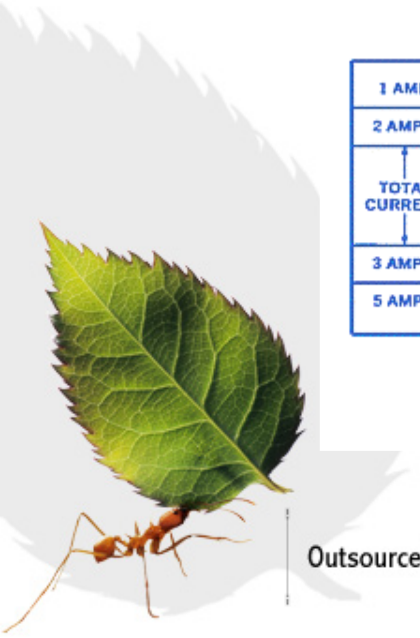
Bath after carbon treatment, no brightener

Hull Cell Panel Examples: Acid Cu Bath

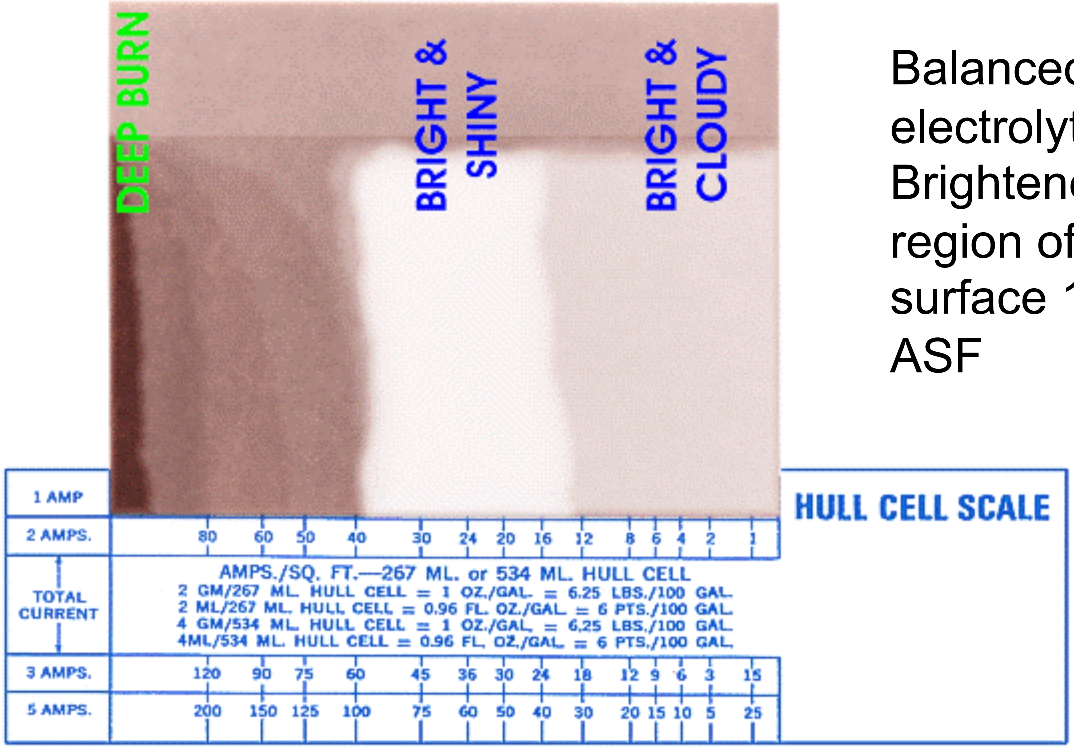


AMPS./SQ. FT.—267 ML. or 534 ML. HULL CELL
2 GM/267 ML. HULL CELL = 1 OZ./GAL. = 6.25 LBS./100 GAL.
2 ML/267 ML. HULL CELL = 0.96 FL. OZ./GAL. = 6 PTS./100 GAL.
4 GM/534 ML. HULL CELL = 1 OZ./GAL. = 6.25 LBS./100 GAL.
4ML/534 ML. HULL CELL = 0.96 FL. OZ./GAL. = 6 PTS./100 GAL.

Bath with residual organic contamination exhibiting a shiny region at low current densities

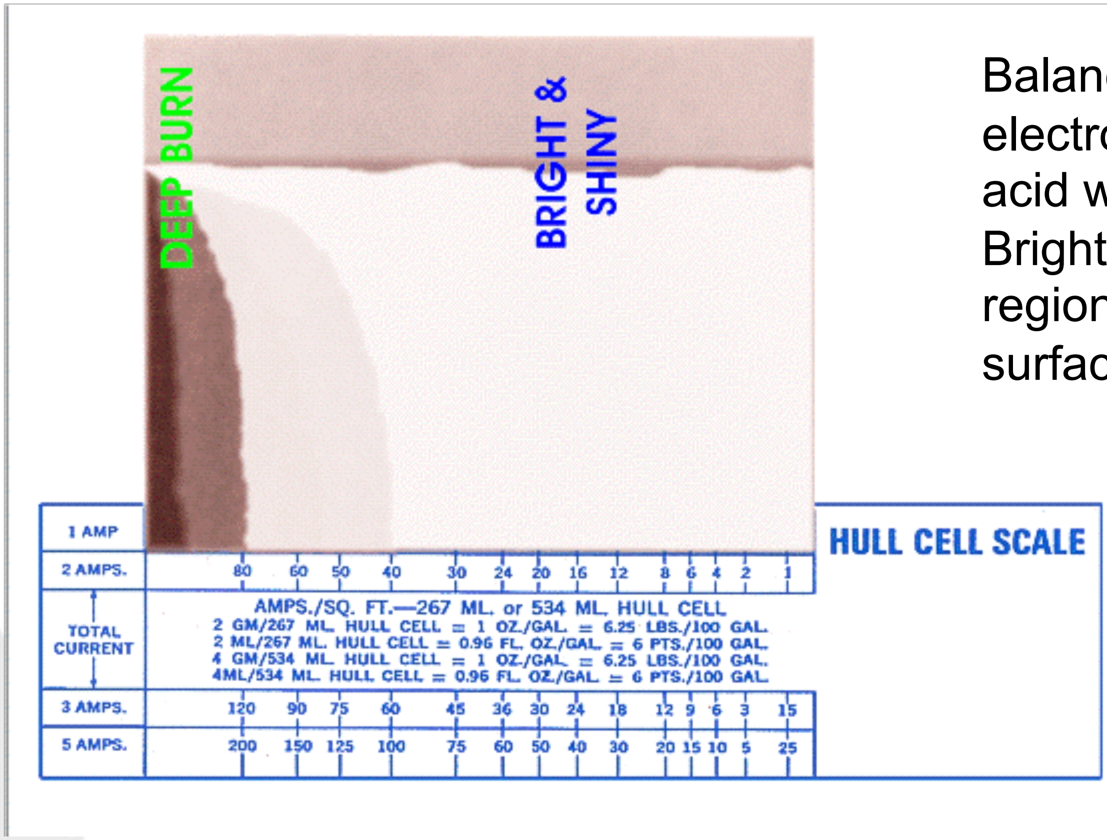


Hull Cell Panel Examples: Acid Cu Bath



Balanced electrolyte with Brightener- broad region of shiny surface 12-40 ASF

Hull Cell Panel Examples: Acid Cu Bath



1 AMP														
2 AMPS.	80	60	50	40	30	24	20	16	12	8	6	4	2	1
3 AMPS.	120	90	75	60	45	36	30	24	18	12	9	6	3	15
5 AMPS.	200	150	125	100	75	60	50	40	30	20	15	10	5	25

TOTAL CURRENT

AMPS./SQ. FT.—267 ML. or 534 ML. HULL CELL
2 GM/267 ML. HULL CELL = 1 OZ./GAL. = 6.25 LBS./100 GAL.
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Balanced electrolyte high acid with Brightener- broad region of shiny surface 1-40 ASF

Plating Process **Window** Characterization

CMC Experience in Plating Process Development

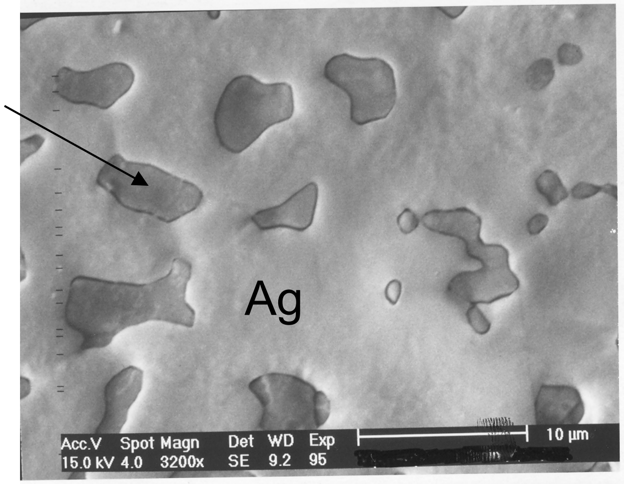
- Critical to determine processing windows for all key plating steps using the *physical and chemical signature on the plated part*
- Establish a library of process characterization data
- Troubleshooting approach: use this library to identify problem plating steps and to develop solid leads into root-cause
- Up-front time investment in process characterization saves significant time in more directed problem solving
- Key tool in yield improvement and process optimization
- Most important for cleaning/etching/pretreatment steps.

Outsource Your Problems to CMC Interconnect Technologies

Process Window Example: CuAg Etch Prior to Plating

- CuAg is a high temperature braze material
- Ag is very difficult to activate and plate without blisters (due to AgCl formation)
- Goal of the CuAg etch is to produce a copper-rich surface prior to plating
- An etch mixture containing H_2O_2 (peroxide) is used
- The time in the etch is varied and the surface microstructure is established
- The goal is to determine etch time for a consistent surface chemistry

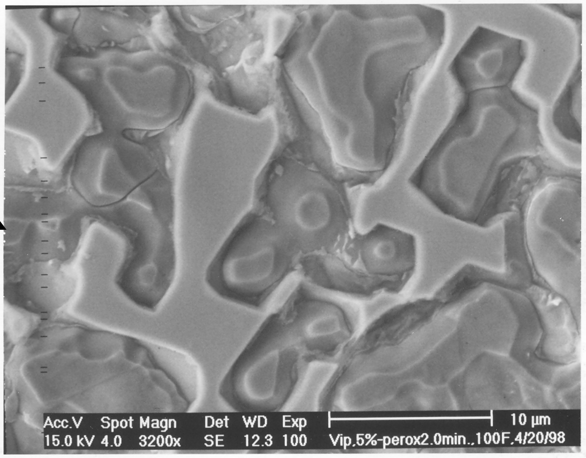
Process Window Example: CuAg Etch Prior to Plating



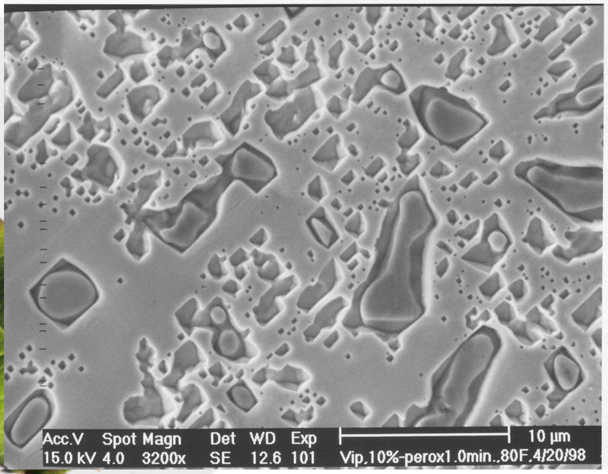
As received

VIPER CAVITY SURFACE - AS BRAZED

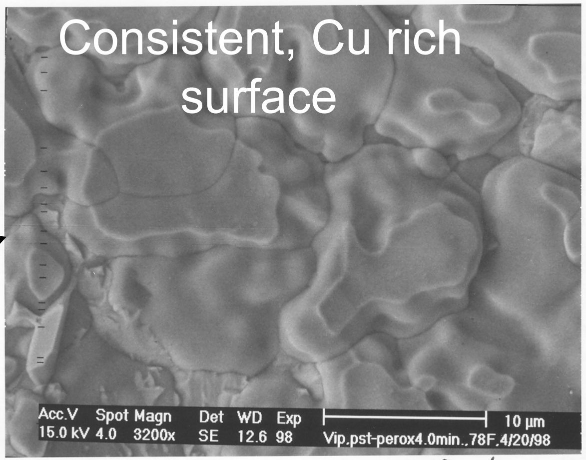
2 minutes



1 minute



4 minutes



Consistent, Cu rich surface

10% H_2O_2