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16th International Conference on Device Packaging

Improving WID & WIW Non-Uniformity in ECD Applications

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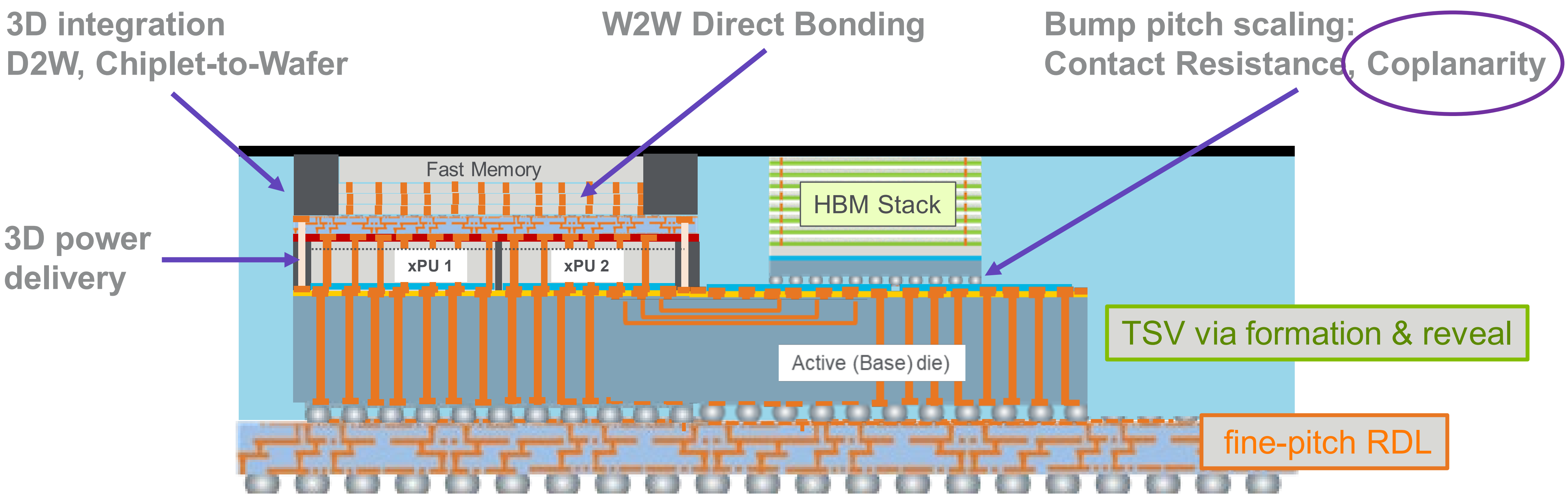
Applied Materials | Advanced Packaging Group
March 3, 2020

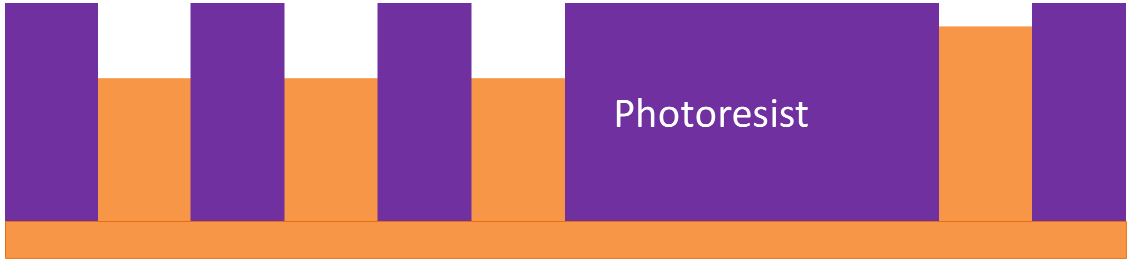
Increasing Challenges for Future High-Performance SiP



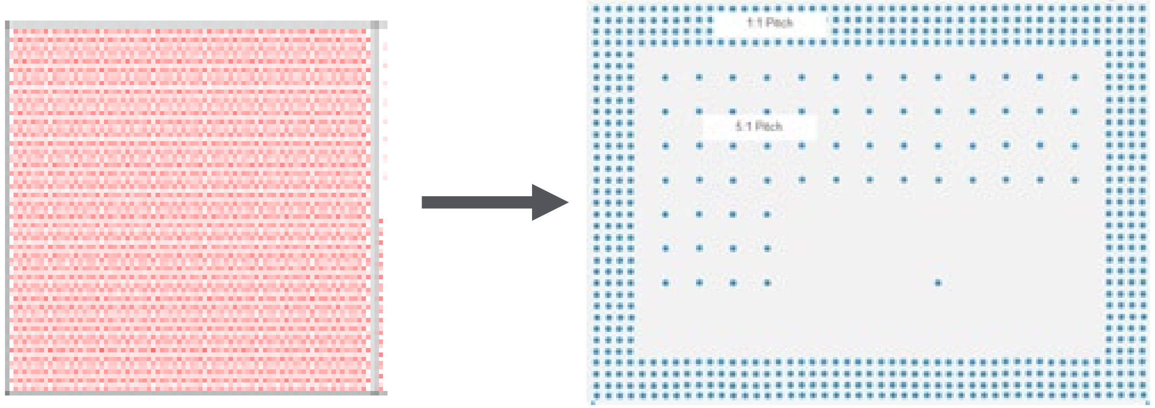
New challenges require innovation in process technology + Materials + system integration + new design elements

Bump/Pillar | Increasing Challenge of Coplanarity

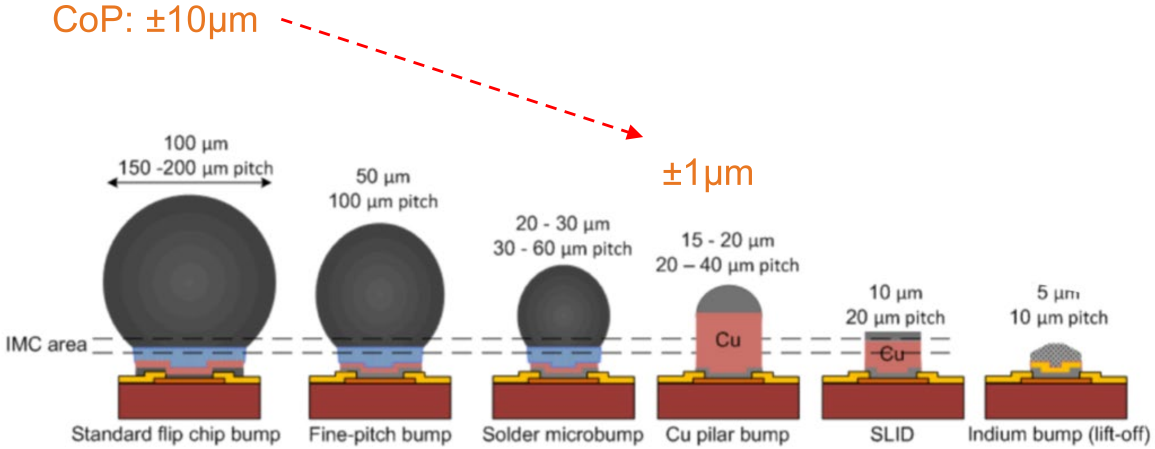
Electroplating Photoresist Masks



Pattern Complexity Challenges Coplanarity

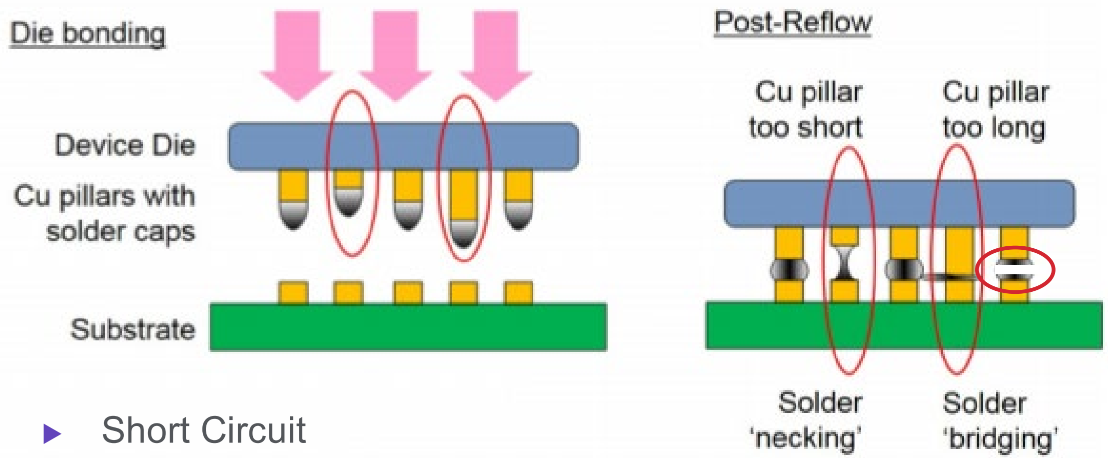


Node & feature shrink drives bump pitch shrink



Source: Introduction to High-density interconnection technologies on silicon wafers. 2010. S. Vahanen CERN

Impact During Assembly



- Short Circuit
- Reliability Fails

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Within-Die Coplanarity (CoP) Modeling | Industry Pioneers

Expert Models

Input Parameters
- Process & HW Factors
- Chemistry Factors
- Wafer Layout / Die Layout

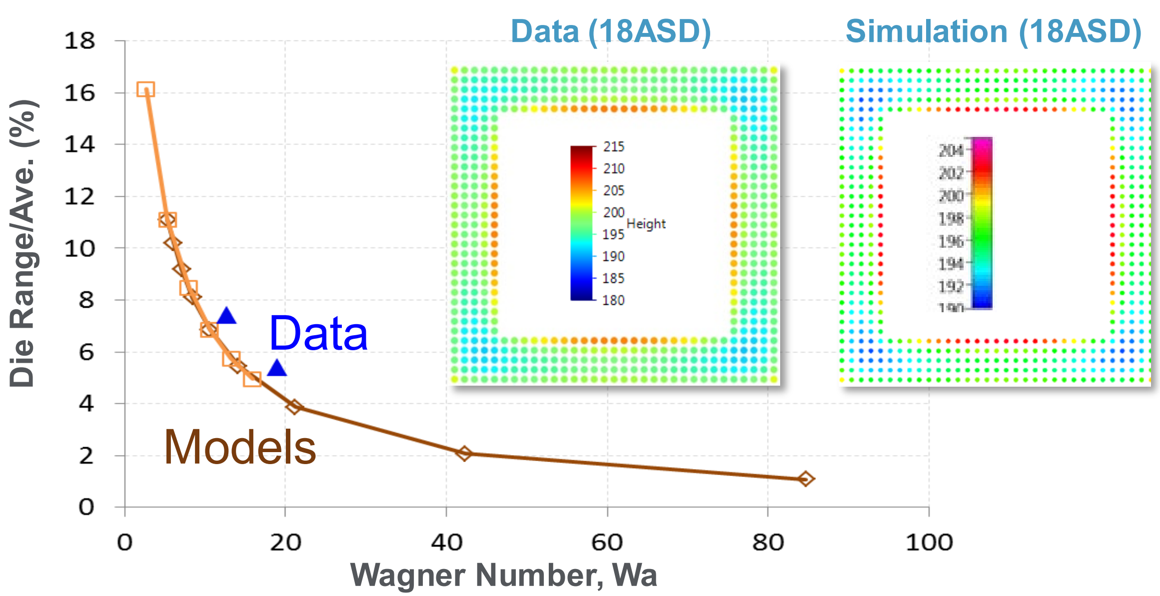
Die Layout Modeling
- Analytical resistance models
- 2D – 3D macro scale models
- Wafer Level / die level / feature level

Optimized Output
- Current Density
- Exchange Current (Additives)
- Bath Conductivity
- Pattern Density Variation & Spacing

Guide CoP Reductions

Experienced Modelers

- SECAP / EMC3D
  - Applied (Semitool) Founding Members
- Over 20 years modeling experience:
  - **May 2-6, 1999** *P.R. McHugh, G.J. Wilson, L. Chen, "Numerical Simulations of Fluid Flow and Mass Transfer with an Electrochemical Copper Deposition Chamber," Proceedings of the 195th Meeting of the ECS, Symposium G1, Electrochemical Processing in ULSI Fabrication and Semiconductor/Metal Deposition II, Seattle, WA*



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Wagner Number | Definition

$$Wa = \frac{Interface\ Resistance}{Bath\ Resistance} = \frac{RT/(\alpha_c+\alpha_a)Fj_oA}{L_{pattern}/\kappa A}$$

κ = bath conductivity
R = gas constant
T = temperature
α_a = anodic transfer coefficient
j_0=Exchange current density
α_c = cathodic transfer coefficient
F = Faraday's constant
$L_{pattern}$ = Effective Pattern length scale
A = Effective area for resistance estimate

Wagner Number draws a direct analytical relationship between process & hardware factors to on-pattern density variation & die layout

Key Factors:

- Bath Conductivity
- Current Density
- Exchange Current (Additives)
- Pattern Density Variation and Spacing
- (Bath) Temperature

Potential Indirect Factor:

- Mass Transport (Additives and LCD)

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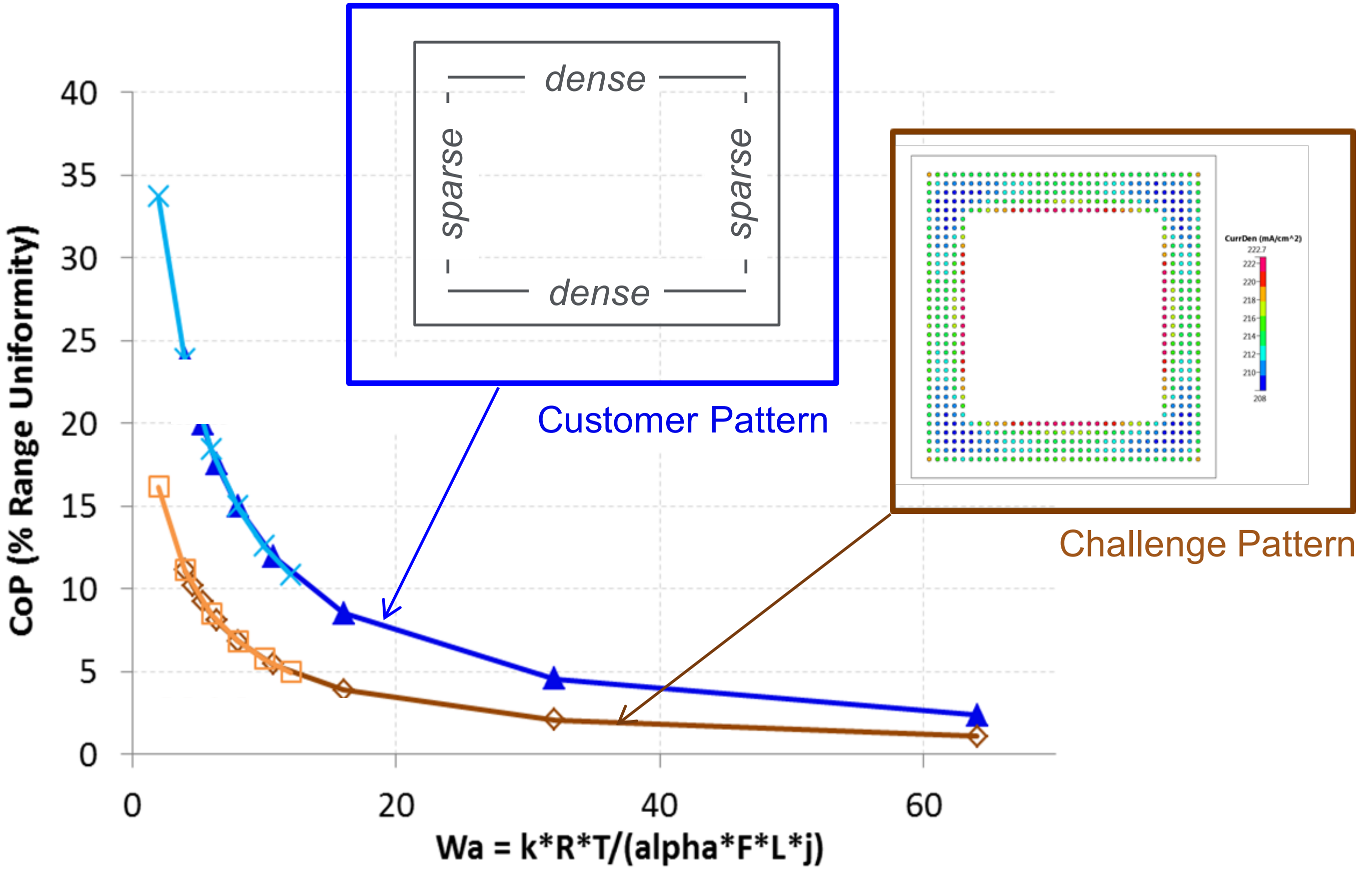
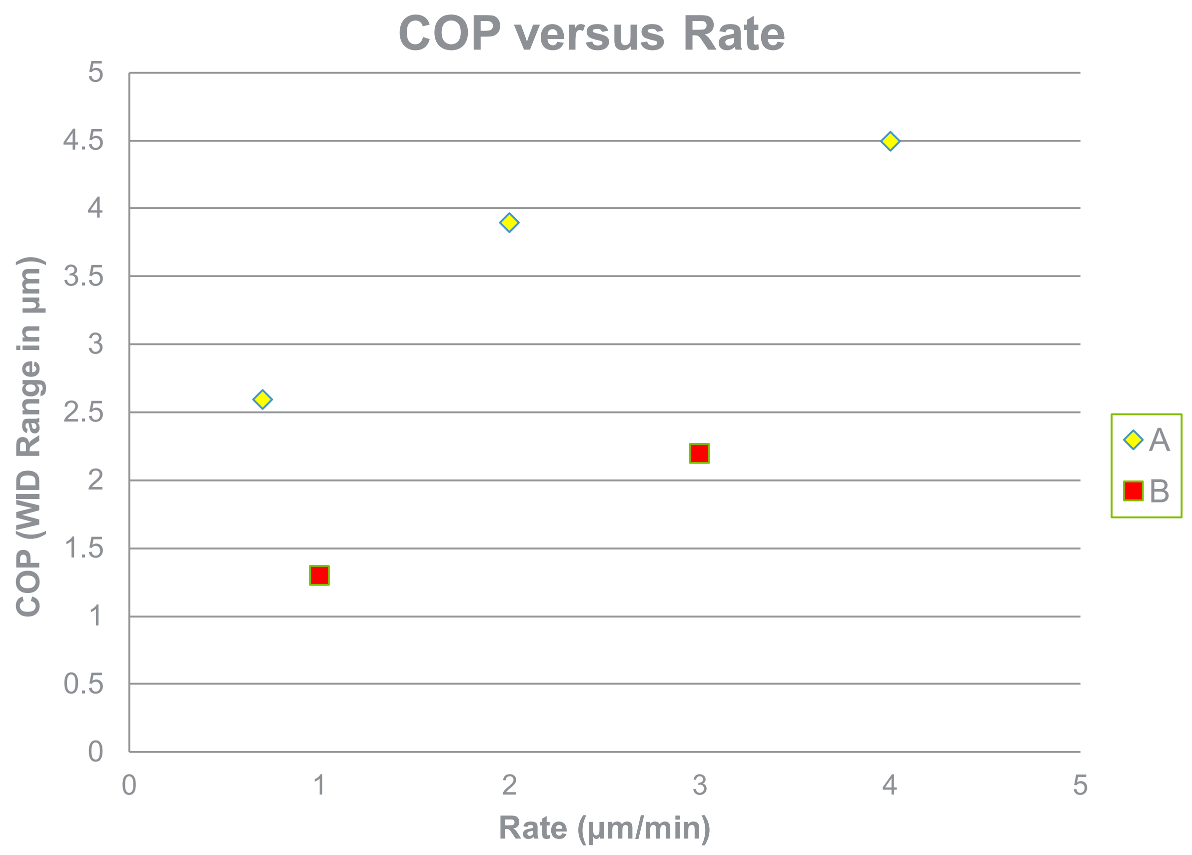
Modeling Examples | Pattern Dependence of ECD CoP

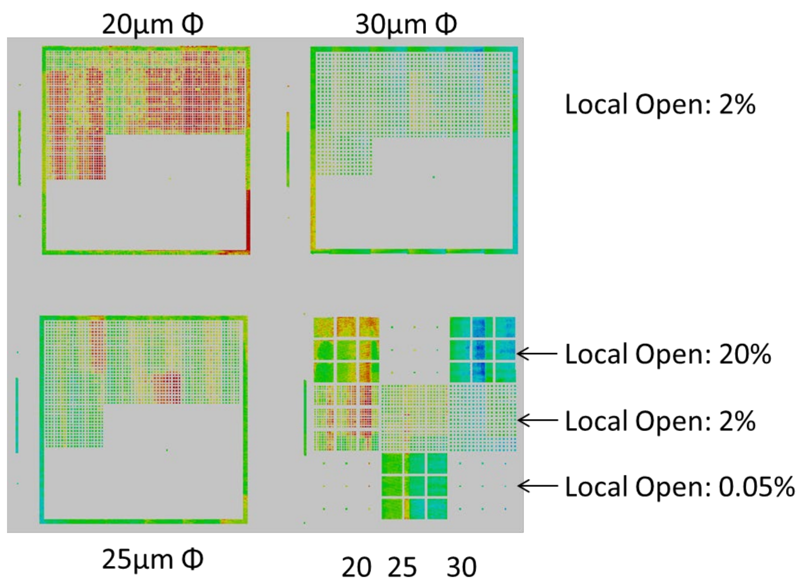
Modeling experience with dozens of patterns / die layouts including major Taiwan foundries & fabless customers



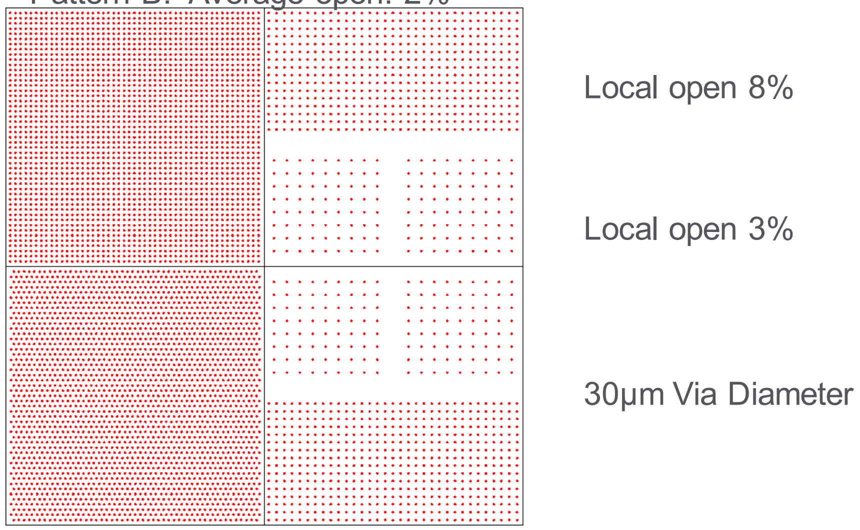
Coplanarity(CoP) | By Dep Rate and Pattern



Pattern A , Average Open: 4



Pattern B: Average open: 2%



As deposition rate increases
As pattern complexity increases

COP Increases

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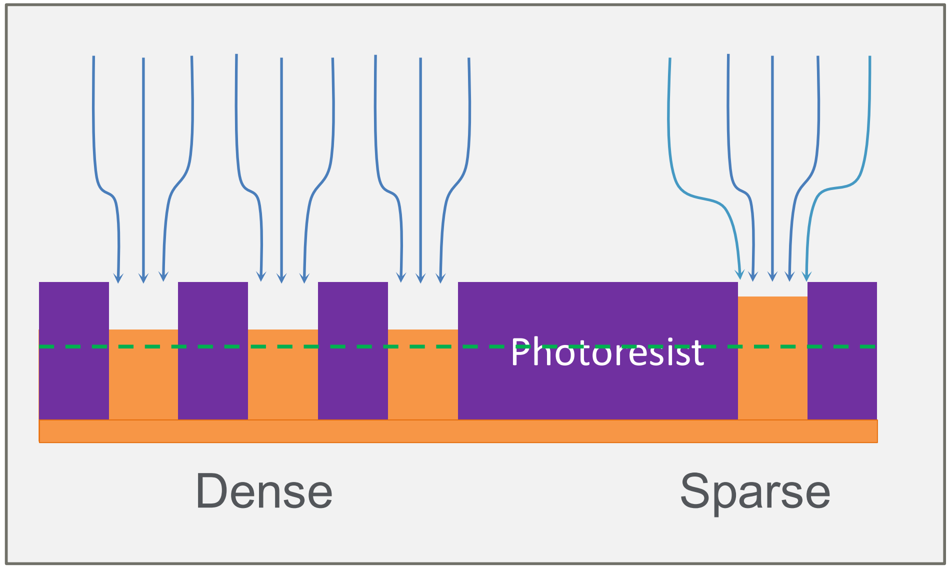
Nokota Process | 2 Step Plate & Deplate Process

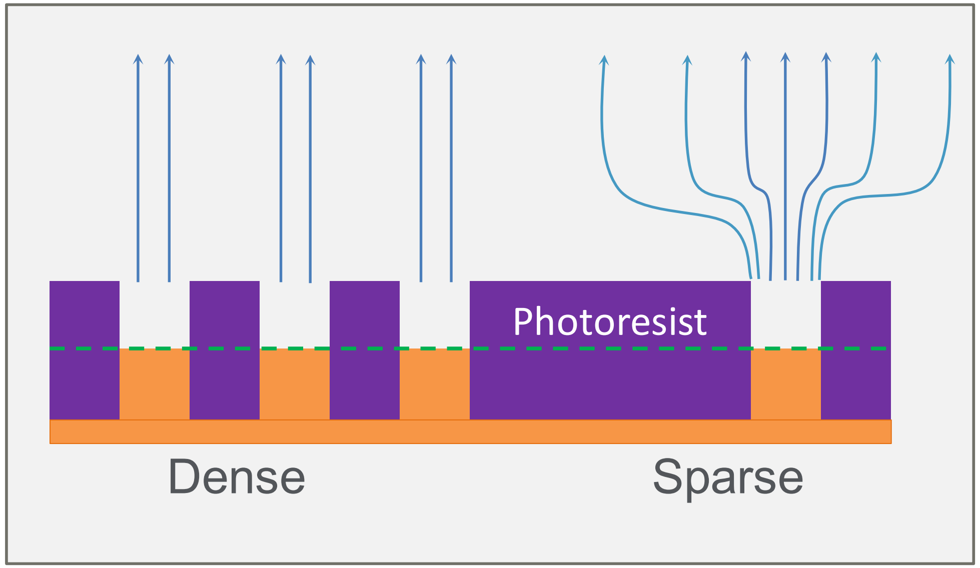
ECD Portion



Electric Field Lines

Target Thickness

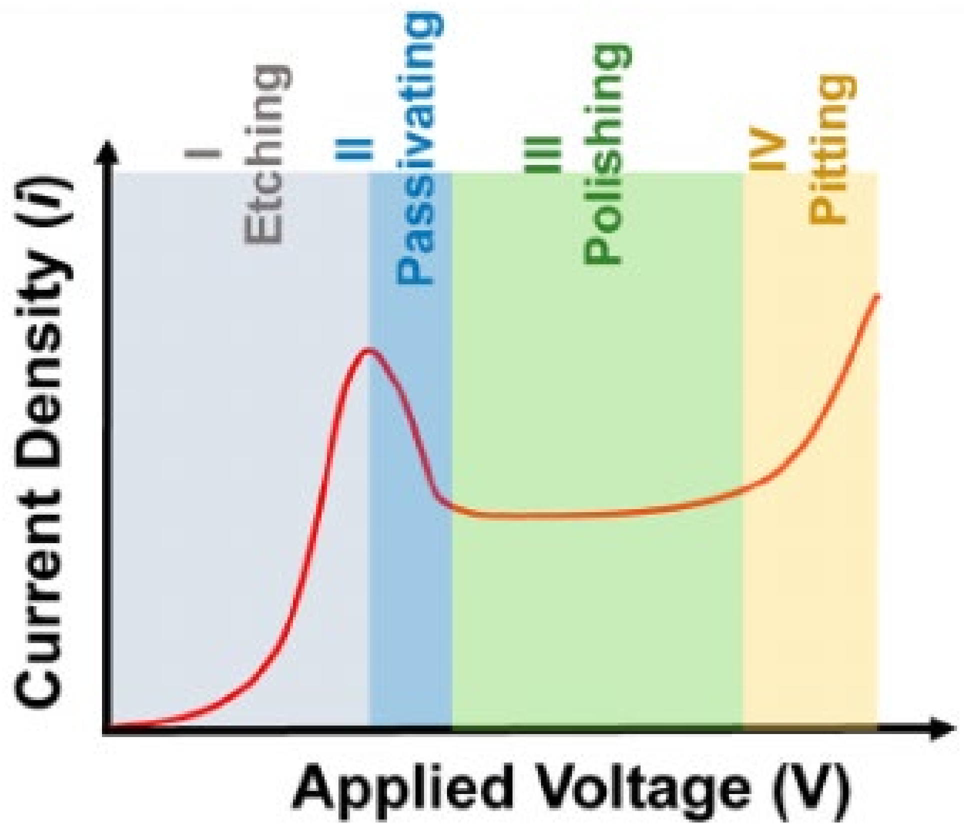
Deplate Portion



- Industry standard ECD bath/process
- High Wa number bath/process
- Deposition higher than target thickness
- Deposit at higher rates

- Specifically formulated low Wa number bath and process conditions
- Selectivity cu removal in sparse vs dense region to achieve target thickness in dense and sparse regions

Deplate Conditions



Factors

- Bath Formulation
  - (Conductivity / Viscosity)
- Current Density
- Mass Transport
- Temperature
- Pattern Layout

Wagner Number | Correlation to Coplanarity Revisited

$$Wa = \frac{Interface\ Resistance}{Bath\ Resistance} = \frac{RT/(\alpha_c+\alpha_a)Fj_oA}{L_{pattern}/\kappa A}$$

κ = bath conductivity
R = gas constant
T = temperature
α_a = anodic transfer coefficient
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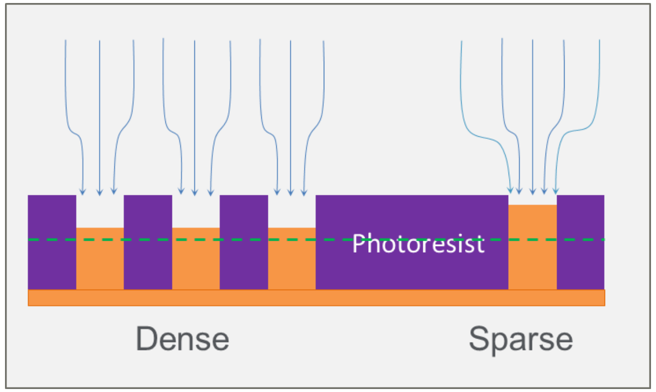
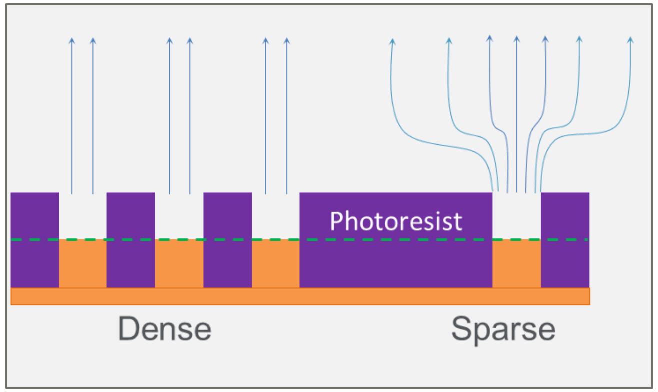
F = Faraday's constant
$L_{pattern}$ = Effective Pattern length scale
A = Effective area for resistance estimate

ECD larger Wagner Number
Deplate smaller Wagner Number

ECD



Deplate



Trends:

Wa scales inversely with current density
- As current density increases, Wa decreases
- As Wa decreases, selectivity in removal increases

Wa scales proportionally with bath conductivity, κ
- As bath conductivity decreases so does Wa
- As Wa decreases, selectivity in removal increases

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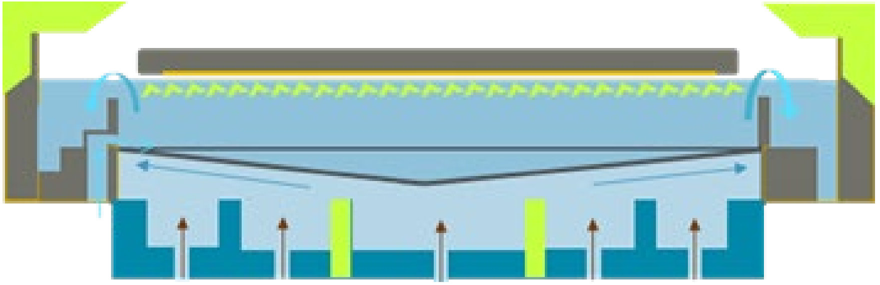
Standard Hardware And Tool Sequence Utilized



Standard Nokota Reactor

Wafer Side Or Cathode

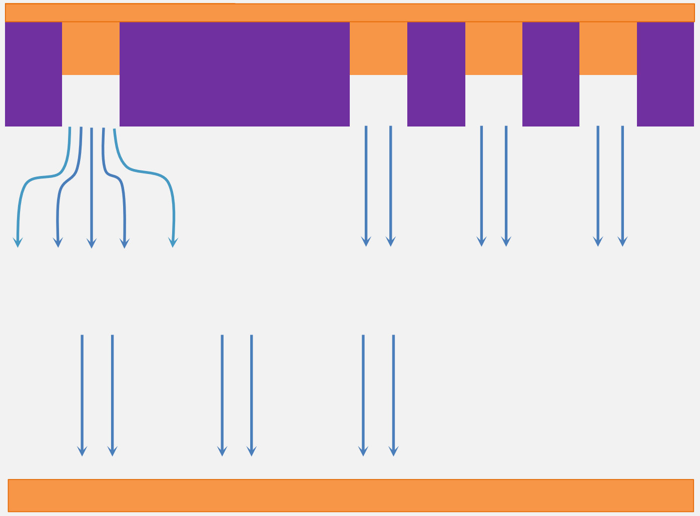
$Cu^{(0)} \rightarrow Cu^{+2} + 2e^-$

Deplate or oxidation reaction

Anode Side

$Cu^{+2} + 2e^- \rightarrow Cu^{(0)}$

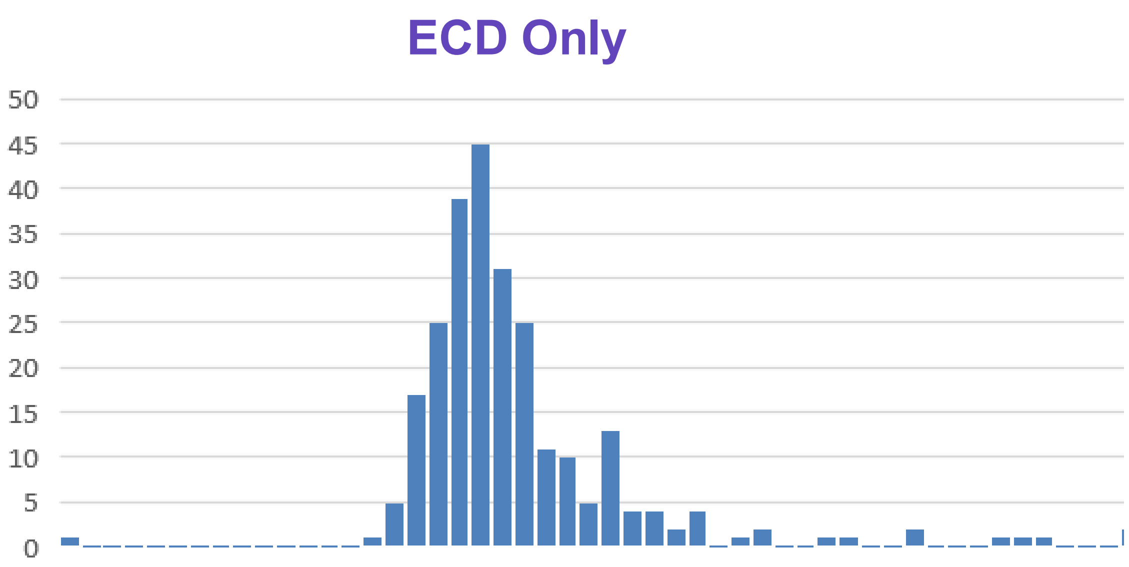
Reduction of Cu

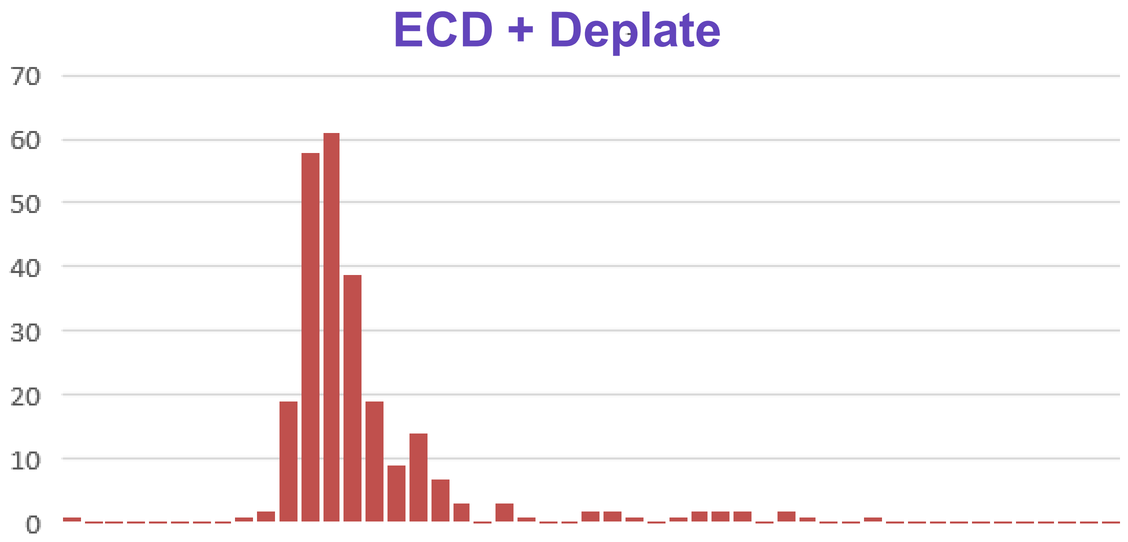


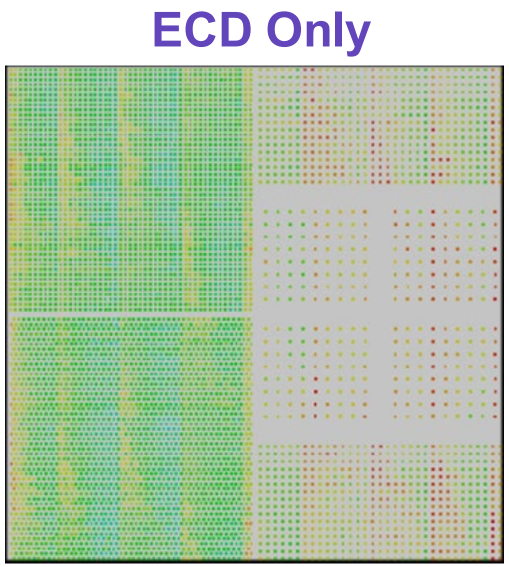
Tool Sequence Cu Pillar/Leadfree Stack

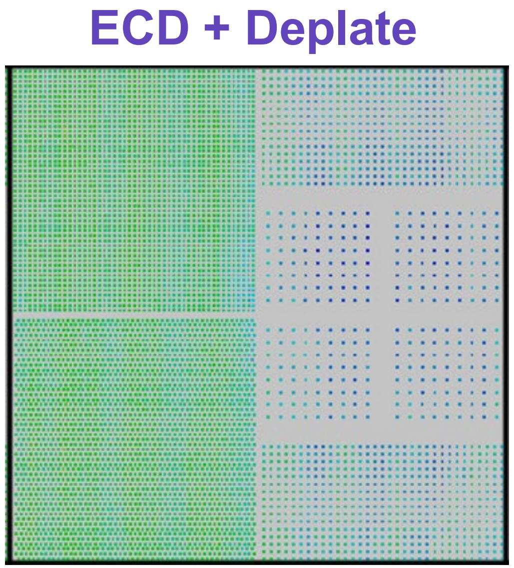
Prewet → **ECD Cu Deposition** → **Deplate** → **Leadfree Deposition** → **Rinse | Dry**

ECD + Deplate | 40% Reduction In Avg COP









- 300 mm wafer
- Cu Pillar 30x50 μm Features Target 30 μm
- Avg 3.0 μm/min both processes
- Calculations
  - COP or WID (max-min)
  - Avg COP based on all die across wafer

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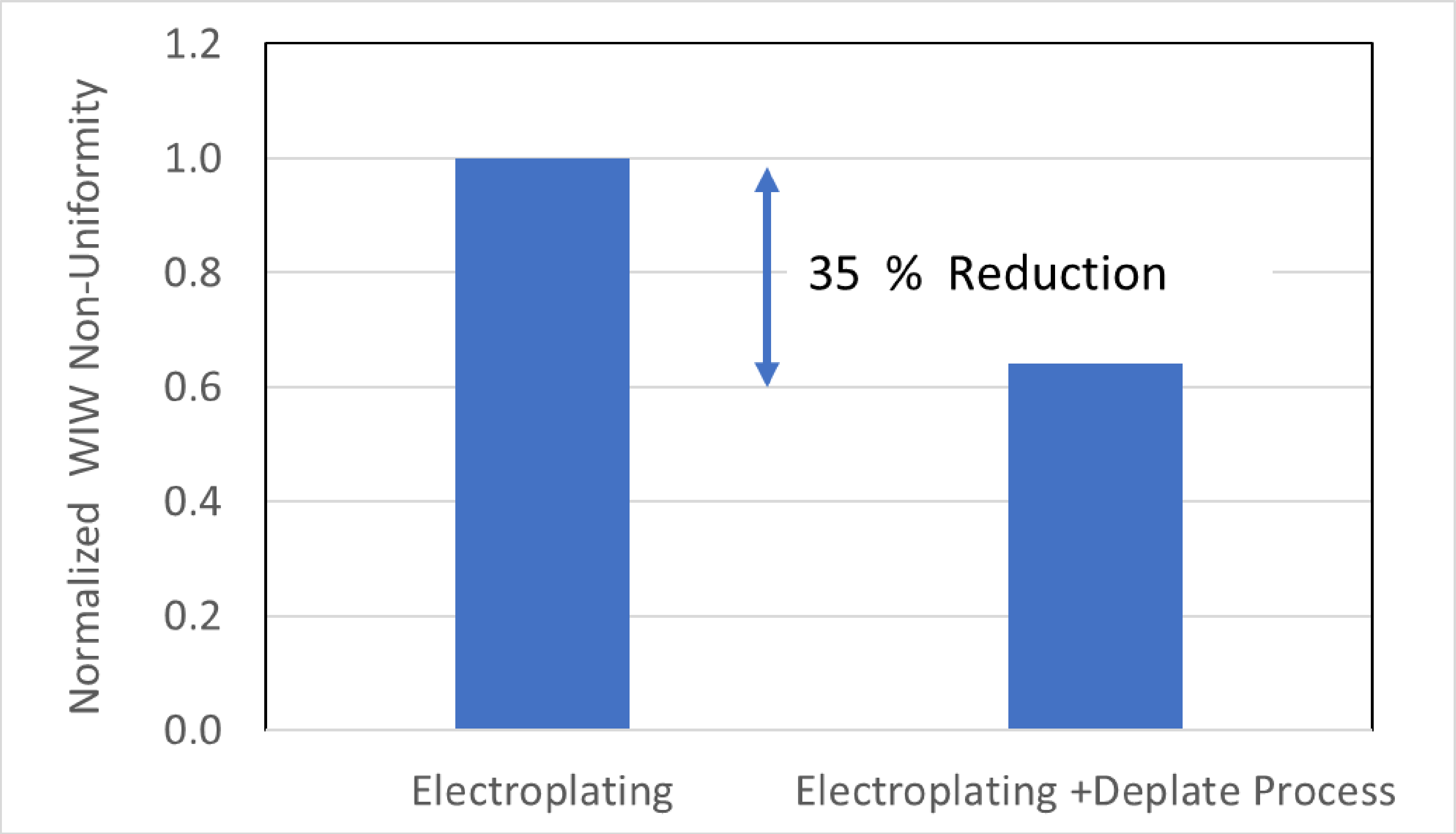
Device Packaging 2020 - Fountain Hills, AZ USA - March 2-5, 2020
Visit www.imapsource.org for more IMAPS papers

ECD + Deplate | WIW Improvement



Improving WID Performance → Yield Improvement in WIW performance

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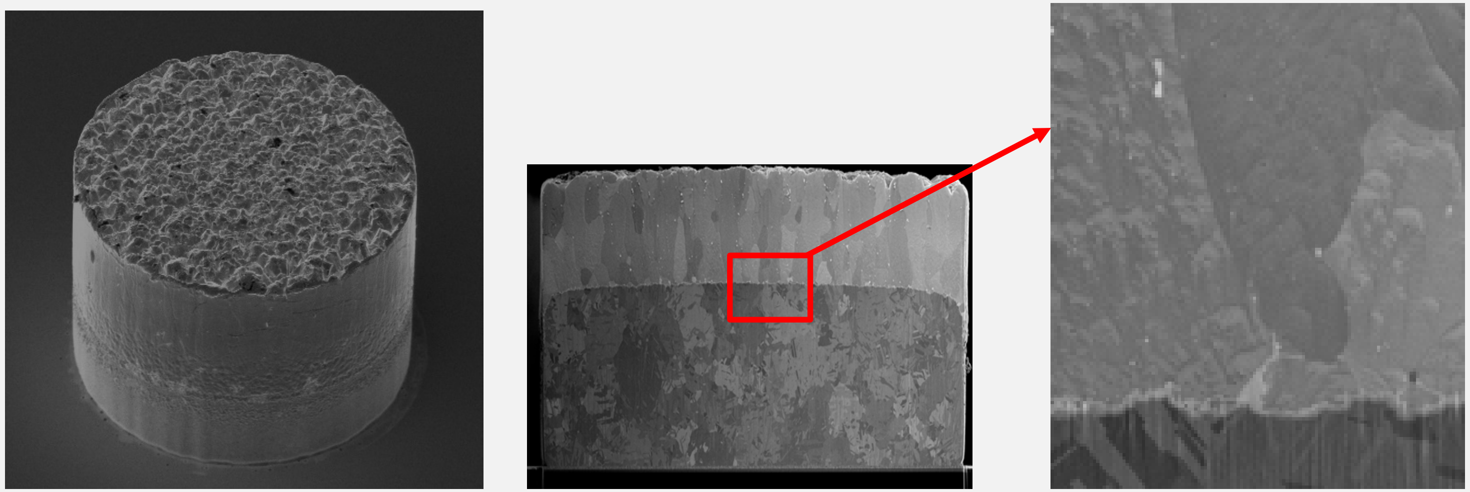
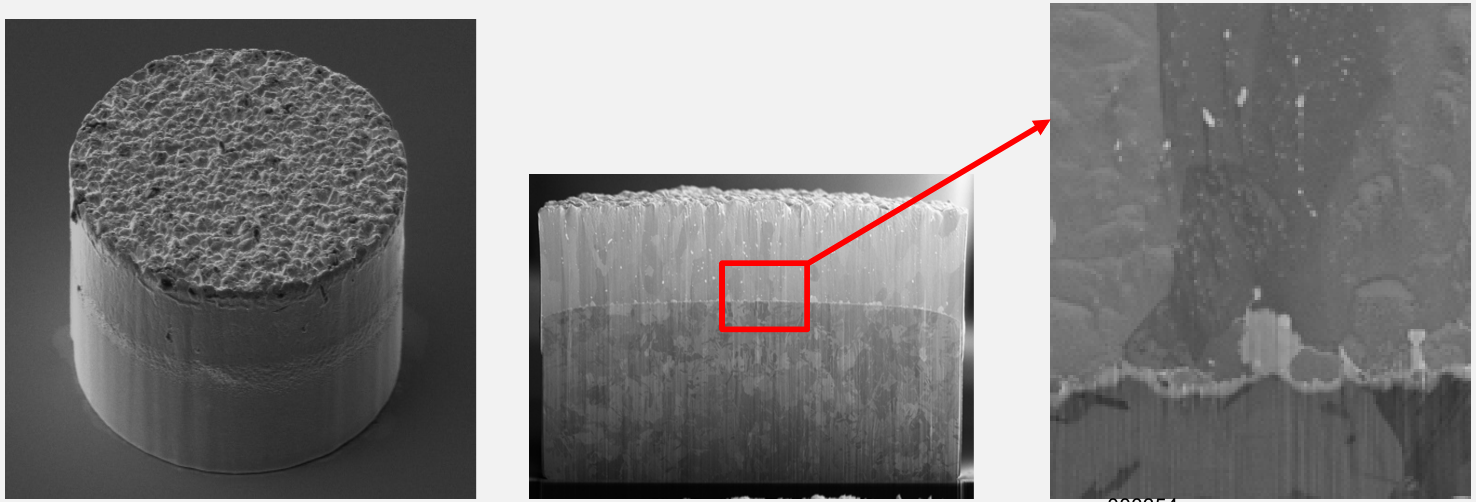
Integration Process Flow | Cu/Leadfree

ECD Cu + *Deplate* + Leadfree



ECD Cu + Leadfree



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No voids or grain size differences between with and without deplate process

Integrates into typical process flow

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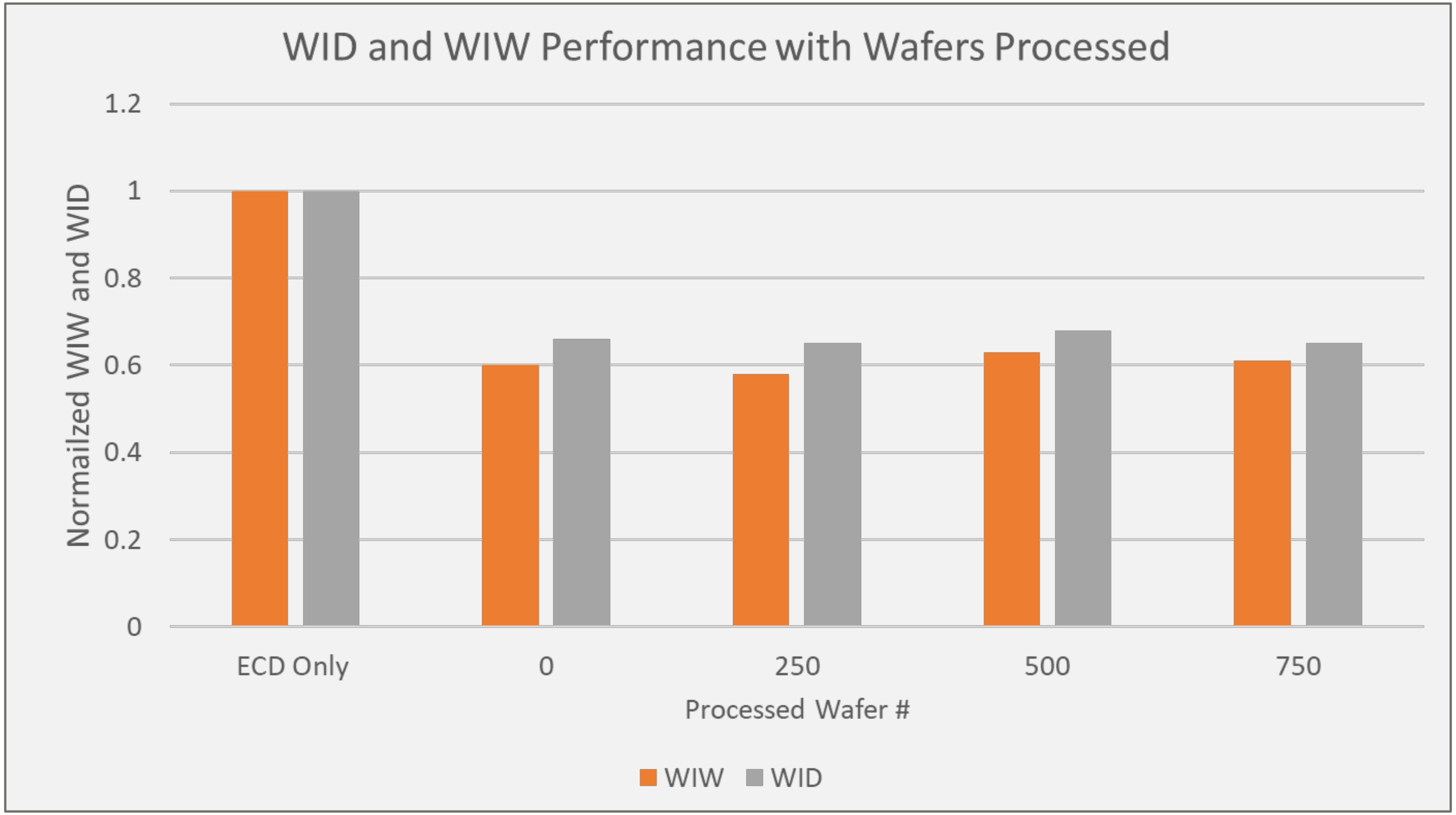
Process Stability / Repeatability



Stable WID and WIW performance with bath aging

Summary

- Modeling proven to be valuable tool in improving COP
- Plate/Deplate process breaks the link between coplanarity and deposition rate
- Plate/Deplate process improves COP for applications that need it
- Stable and patented process demonstrated
- Enabling for advanced packaging applications

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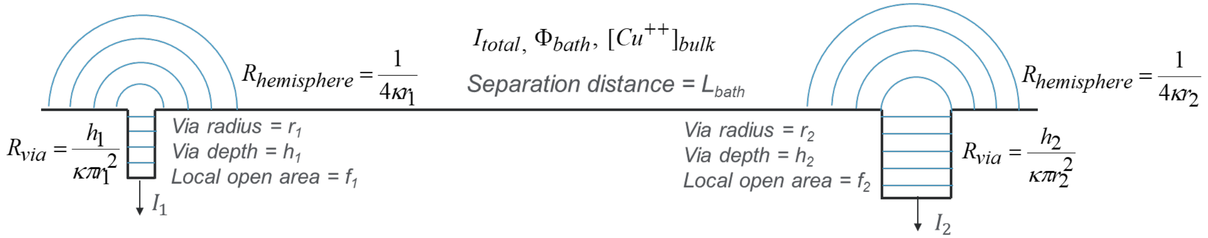
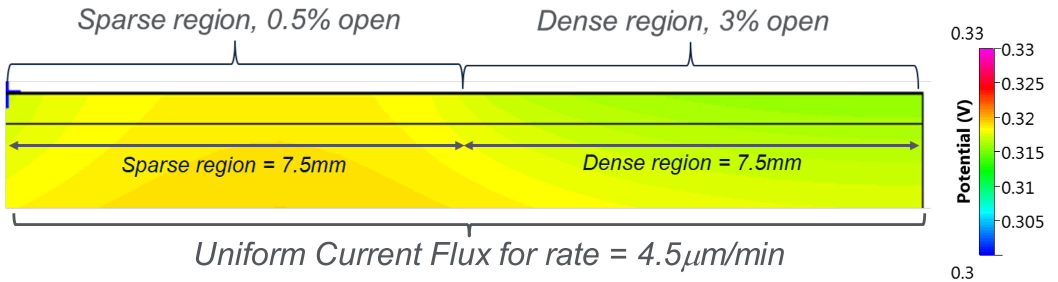
Within-Die Co-Planarity Modeling Capabilities

Model Complexity and Accuracy

- Analytical resistance network model
  - Ohmic resistance
  - Mass-transfer resistance

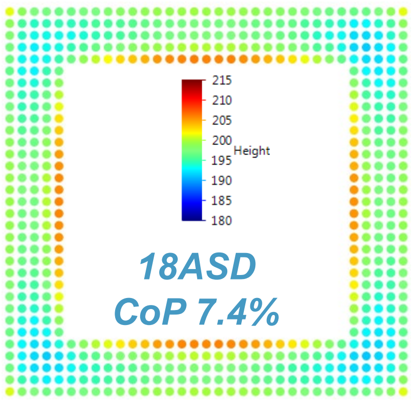


- 2-D and 3-D macro-scale models using active area density functions to mimic pattern

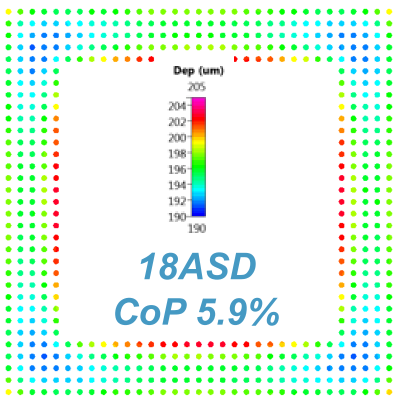


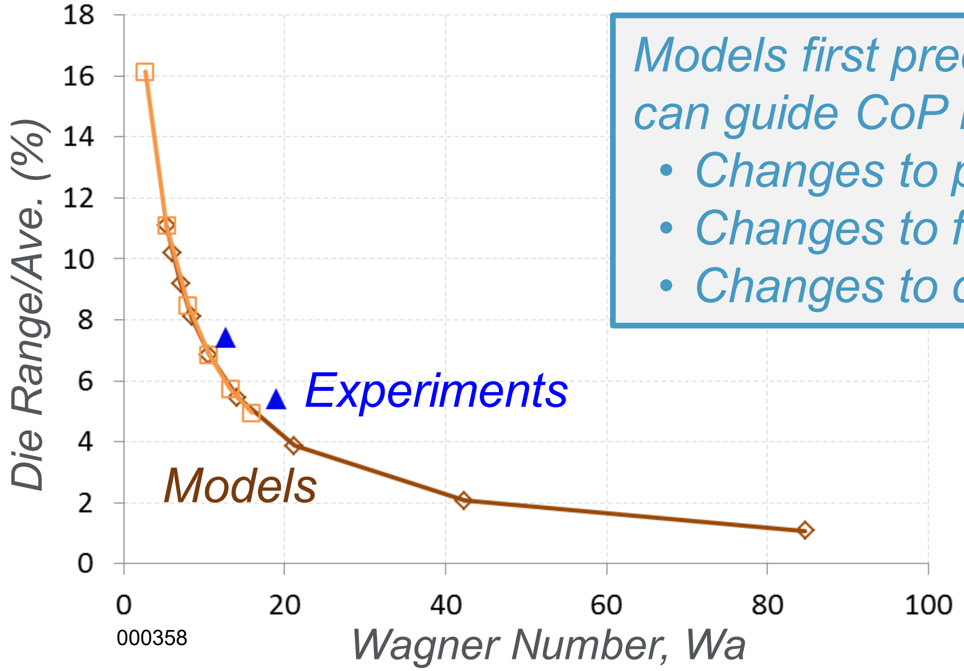
- 3-D models that include individual features and complete die pattern

Data (Camtek)



Simulation





Models first predict CoP and then can guide CoP reductions:
- *Changes to process conditions*
- *Changes to feature dimensions*
- *Changes to die pattern*

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