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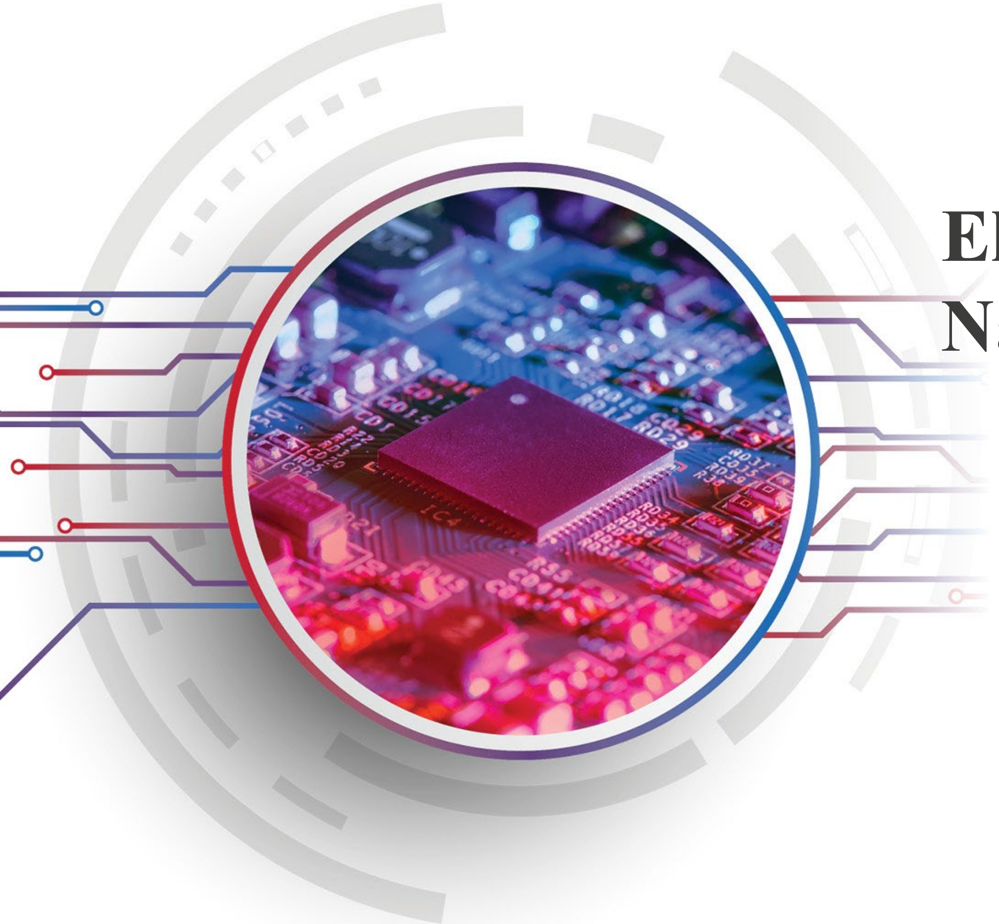

Electrochemical Plating System Development of Nanotwinned Cu for Multiple WLP Features

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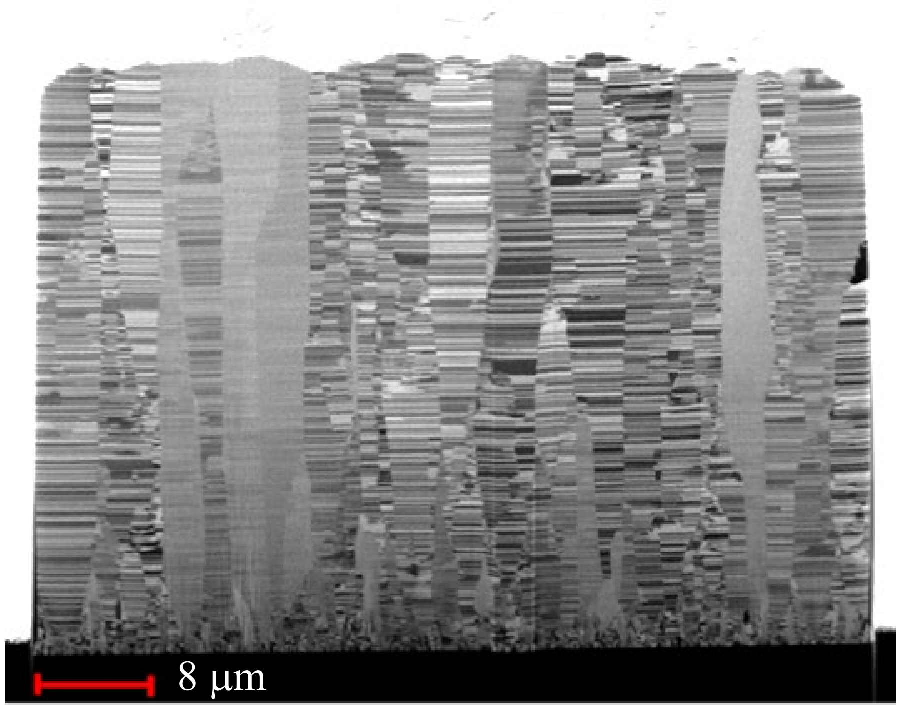
New ECP processes to generate high density nt-Cu

- ➢ High density nt-Cu (close to 100%)
- ➢ Controllable grain size (0.10 to 1.0 micron)
- ➢ Vertical columnar structure
- ➢ Minimal transition layer between Cu seed and nt-Cu initial position
- ➢ Different WLP features can be filled with a flat surface & high density nt-Cu
  - Pads, Lines, Pillars and Vias
- ➢ Wide process window for generating nt-Cu
- ➢ No strong substrate-dependency for nt-Cu formation:
  - High-density nt-Cu films on copper and stainless-steel substrates

Why Nanotwinned Copper?

- Nanotwinned Cu demonstrates both superior mechanical and electrical properties
  - ➢ Cu-Cu direct-bonding / hybrid-bonding
    - ➢ Low temperature bonding
  - ➢ Electromigration resistance
  - ➢ RDL anti-cracking

- Evaluation of nt-Cu performance
  - ➢ Amount of nt-Cu
  - ➢ Columnar Structure
  - ➢ Transition layer
    - Between Cu seed and nt-Cu initial position
  - ➢ Grain Size
    - Correlation with surface roughness



- Pillar (40 μm height)

ECP Process for Nanotwinned Copper

- Bath:
  - Makeup: $CuSO_4$, H_2SO_4, Cl^-
  - Additive(s)

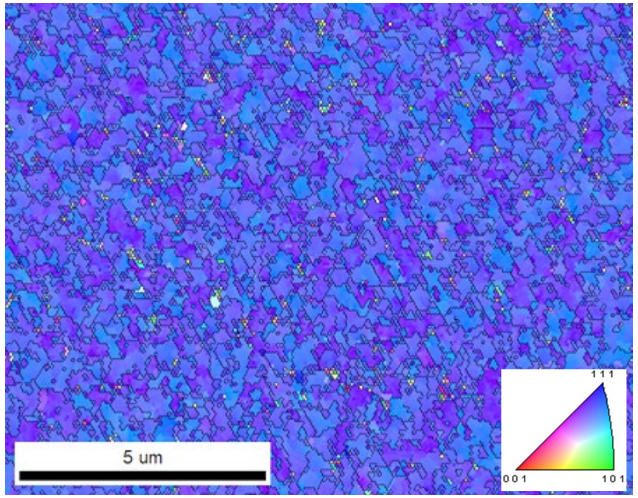
- ECP Waveform:
  - Direct Current
  - Step / ramping Current
  - Pulsed Current

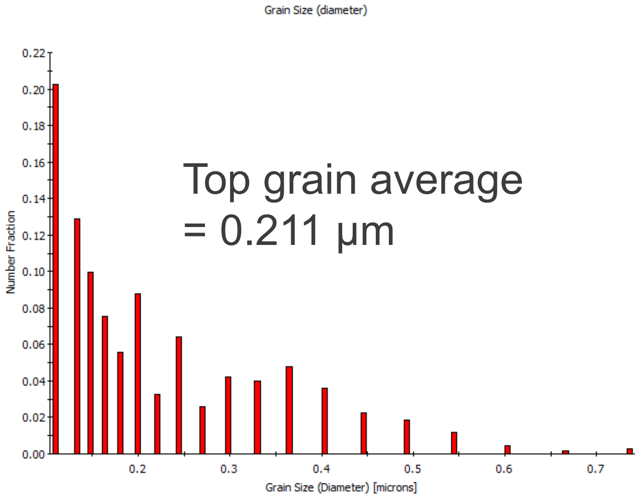
- Bath agitation:
  - 50 ~ 450 RPM

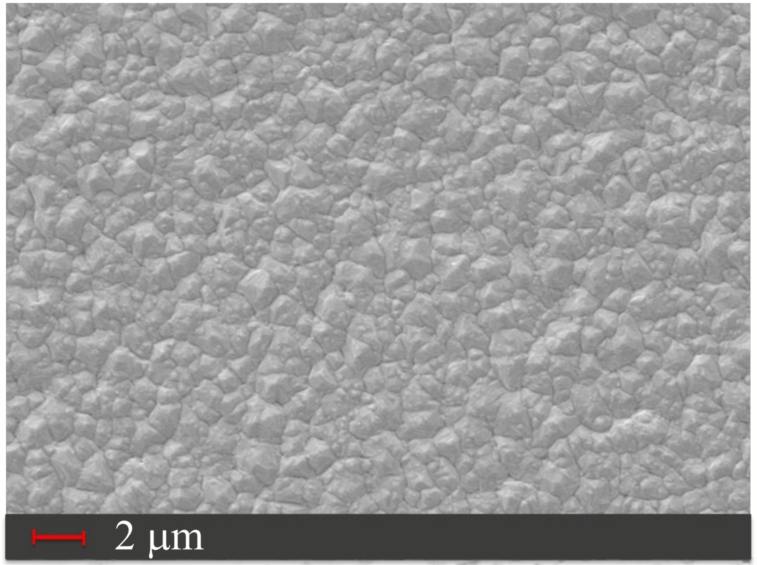
- Bath Temperature:
  - 15 ~ 35 °C

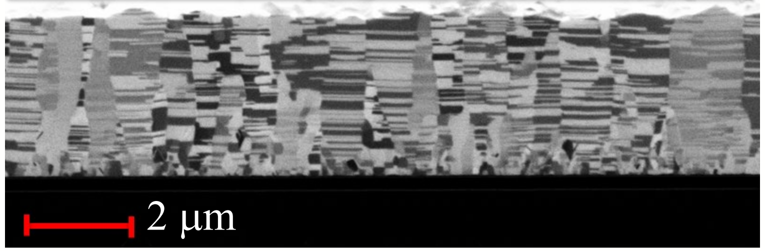
Nanotwinned Cu on blanket PVD Cu substrate

- Blanket Substrate
  - Top View
  - Cross Section
  - EBSD (Electron backscatter Diffraction)







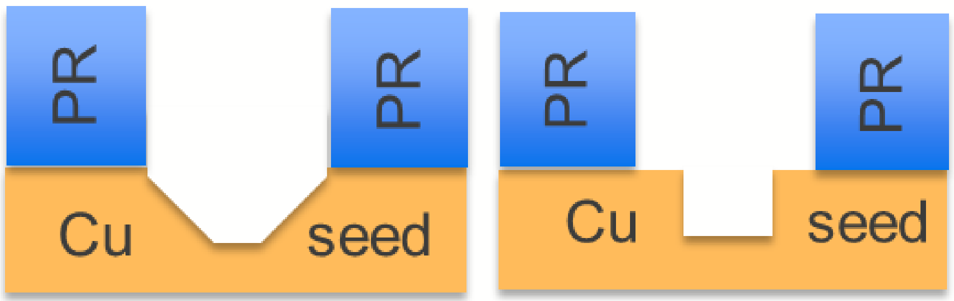


- Typical ECP nt-Cu on PVD Cu shows high density nt-Cu (close to 100%), small grain size, vertical columnar structure, and minimal transition layer between Cu seed and nt-Cu initial position (a few nanometers).
- Dominating nt-Cu orientation is Cu (111)

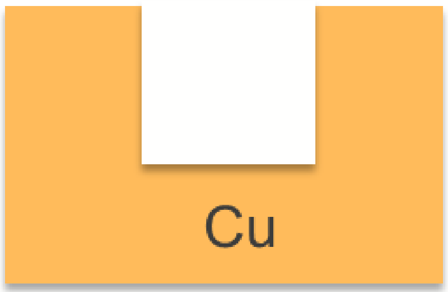
Nanotwinned Cu on WLP features

- WLP Features
  - ➢ Pad
  - ➢ Line
  - ➢ Via
  - ➢ Pillar

A: Without recess
- Makeup + additive(s)
- Conformal ECP

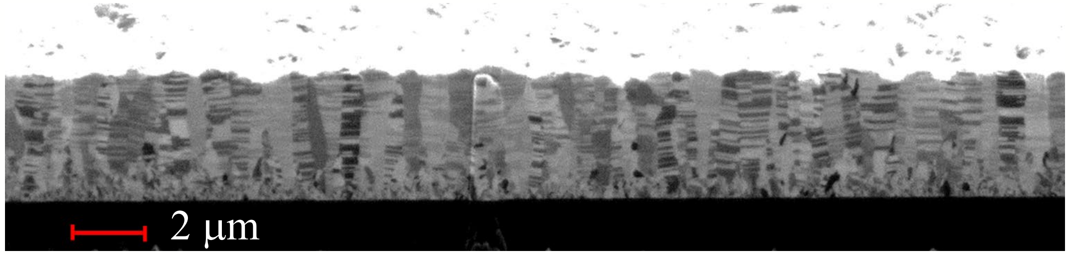


B: With recess
- Makeup + additive(s)
- Conformal ECP + Bottom-up ECP

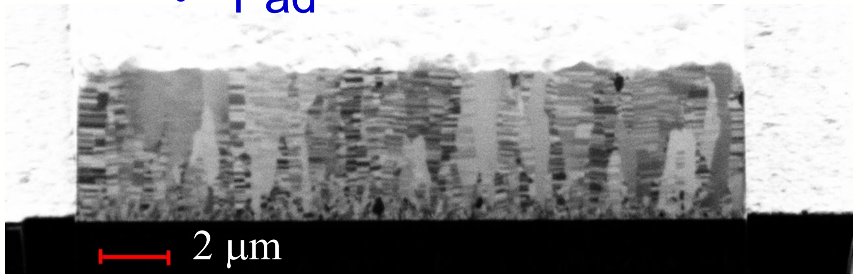


C: Without PR
- Makeup + additive(s)
- Bottom-up ECP

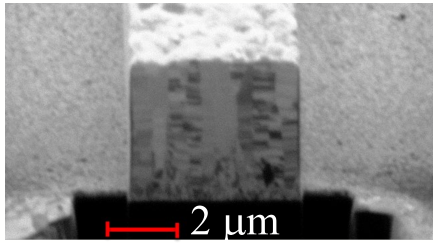
Nanotwinned Cu on WLP features – Pad, Line, Via



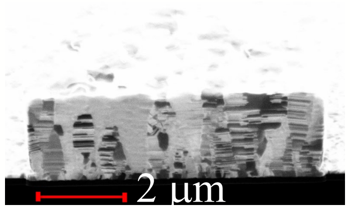
- Pad



- Line – low A/R



- Line – high A/R



- Via

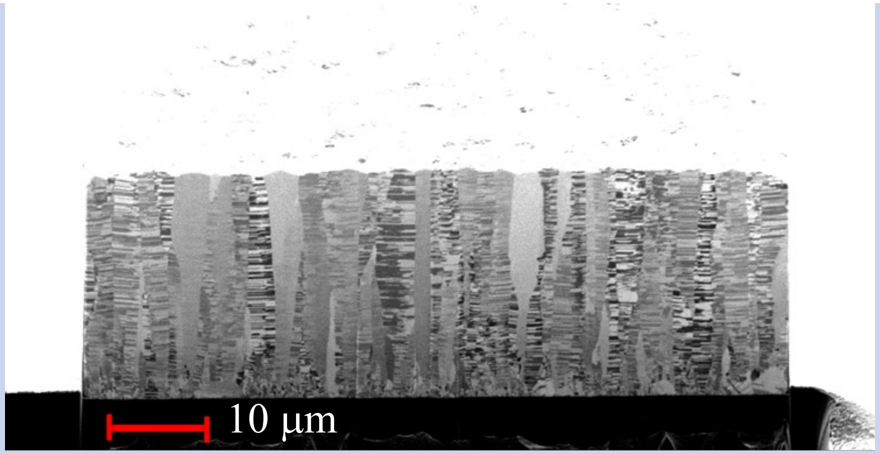
- ECP nt-Cu on the wafer die with Pad, Lines (different A/R) & Via shows great uniformity:

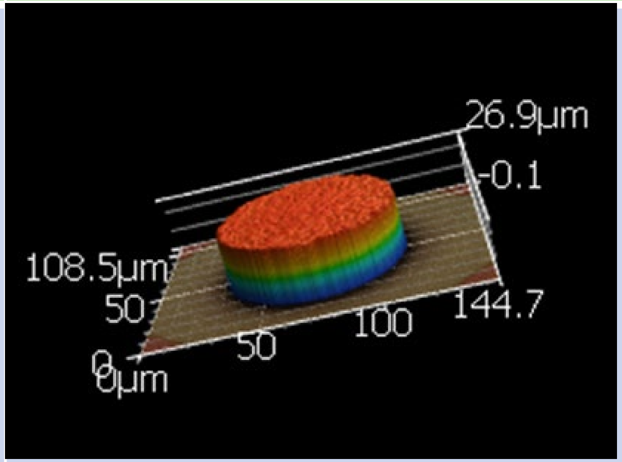
nt-Cu ECP	WID (%)
Recipe #1	5.0%
Recipe #2	3.9%

Nanotwinned Cu on WLP features – Pillar

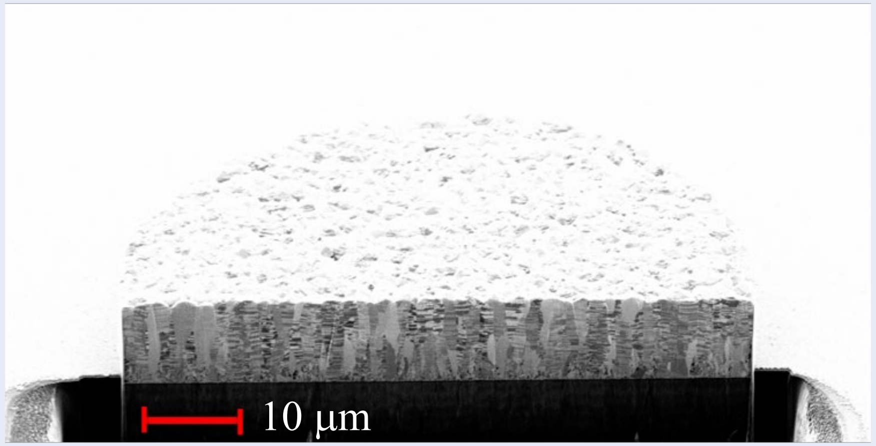
FIB / Cross section | **Profilometer**

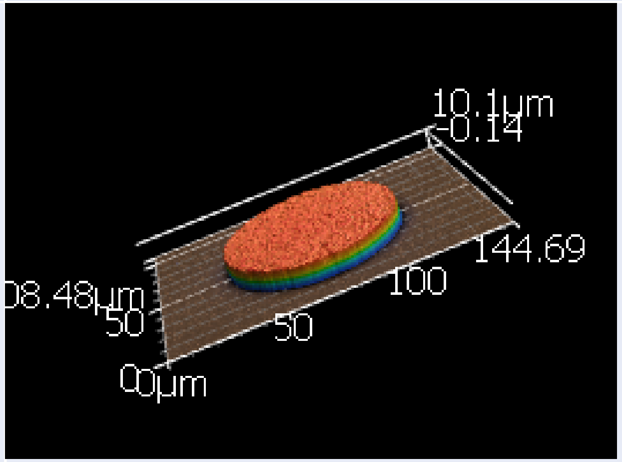
26 um





10 um



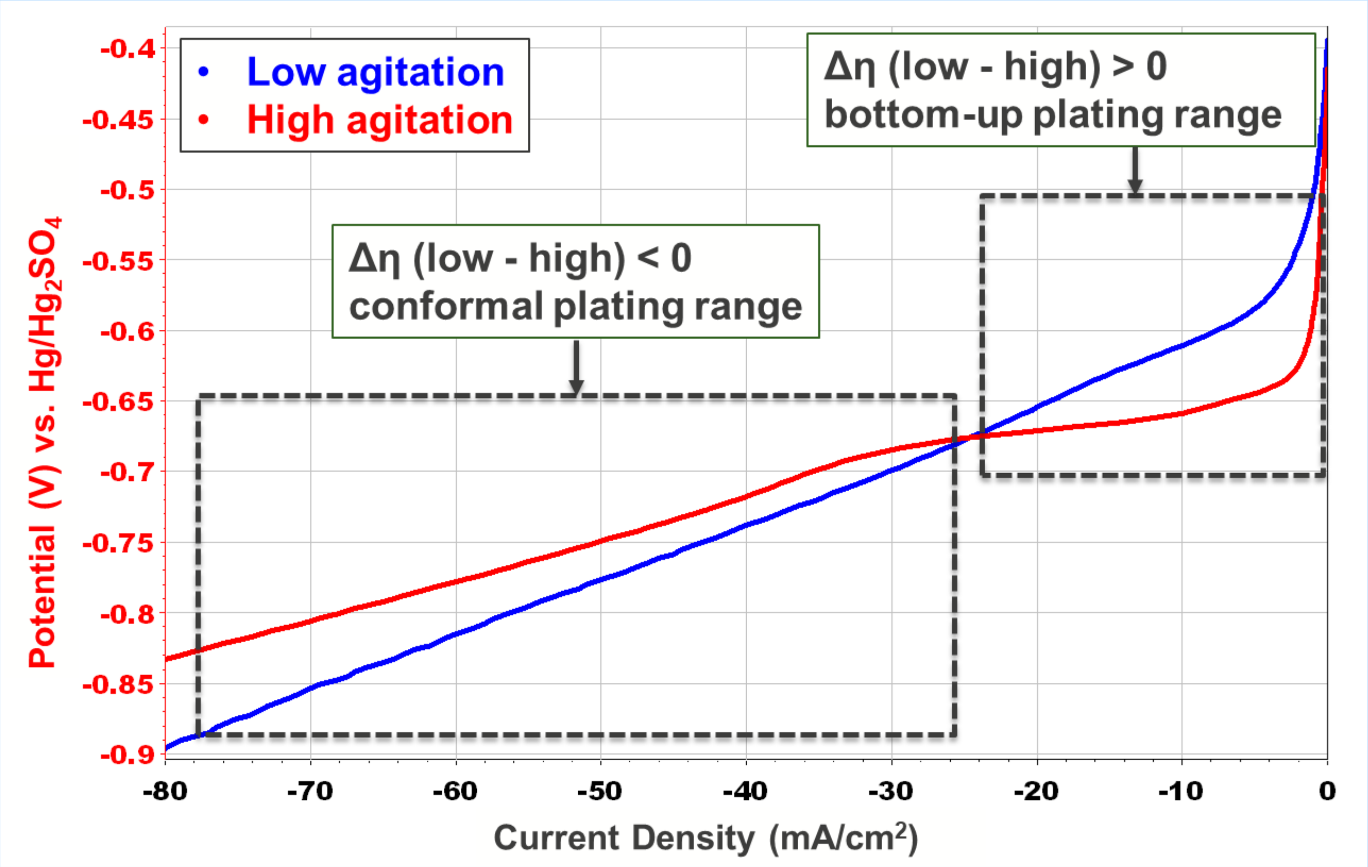


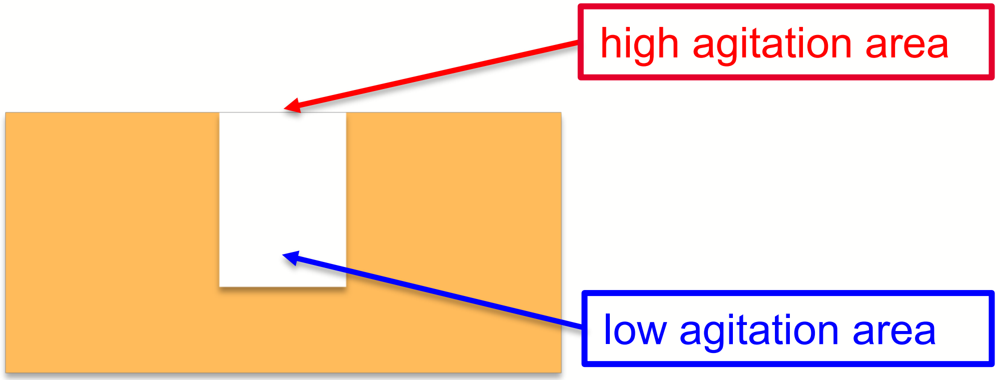
- ECP nt-Cu on the wafer die with Pillar shows great uniformity:

Nt-Cu ECP	WID (%)
26 µm	3.6%
10 µm	4.0%

CDA (Convection Dependent Adsorption) – Bath Screening

- Linear Sweep Voltammetry (LSV)

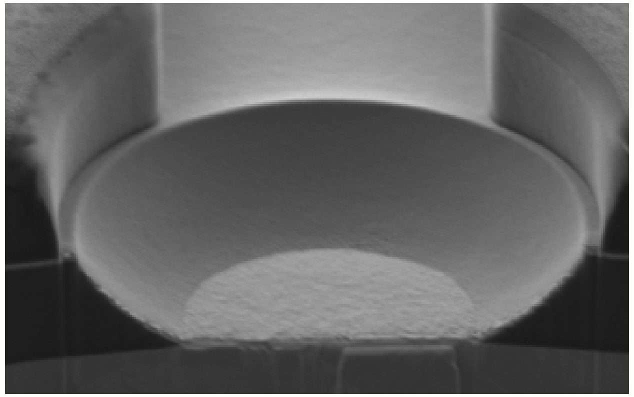




Conformal Plating vs. bottom-up fill

- Conformal Plating:
  - The electrolyte at lower agitation is more polarized than (or similar as) that at higher agitation
- Bottom-up fill
  - The electrolyte at higher agitation is more polarized than that at lower agitation
- CDA behavior is mainly controlled by additives and current density rather than by the electrolyte

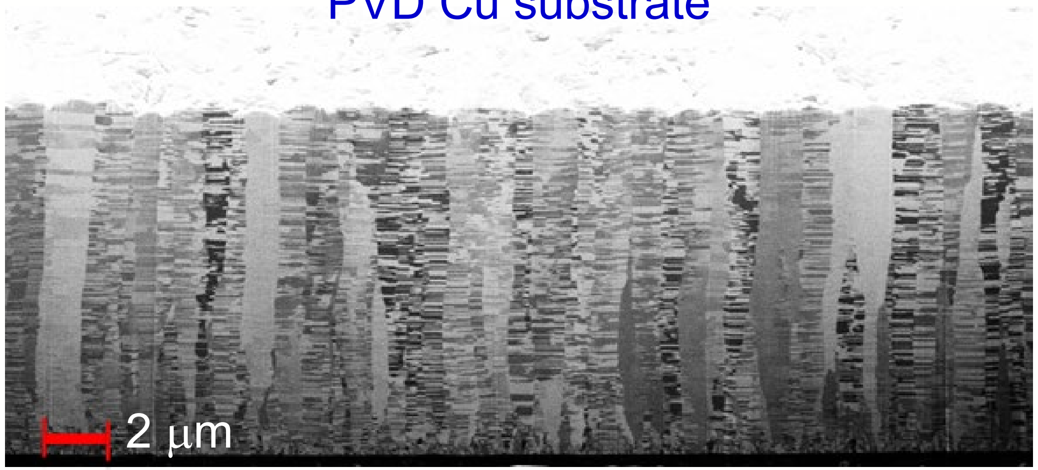
Nanotwinned Cu on WLP features – Via with recess



- ECP nt-Cu on the wafer die with recessed via show flat surface and high density nt-Cu.
  - Diameter 15µm
  - Total depth 4µm
  - Recess 2µm
- Diagonal nt-Cu growth from corner of the recess
  - One of the challenges to be solved.

Effect of substrate on nt-Cu formation

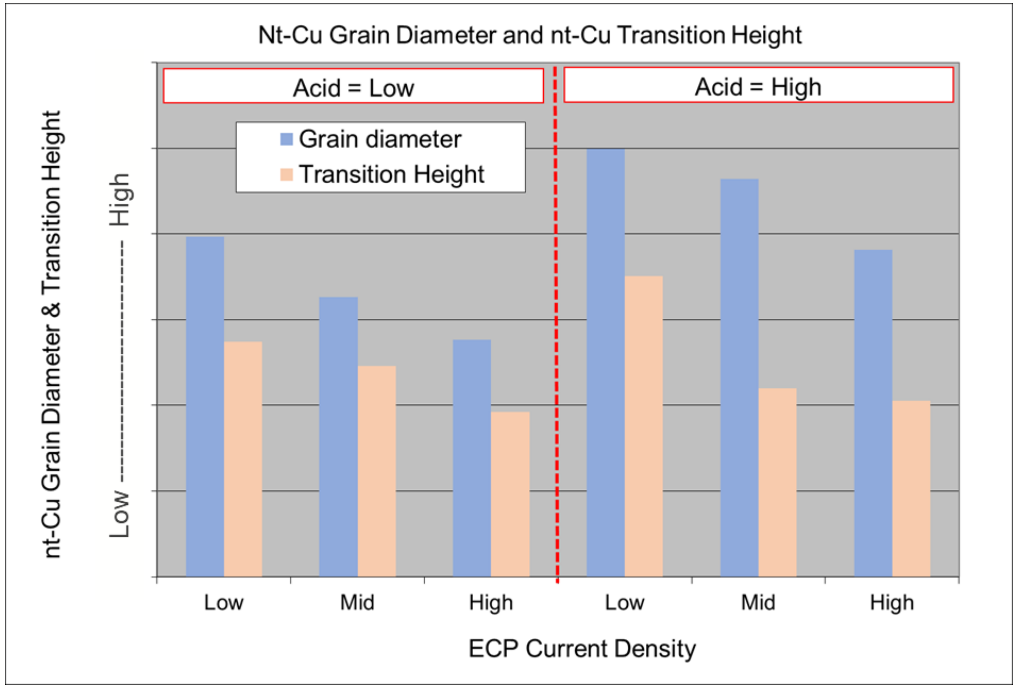
PVD Cu substrate



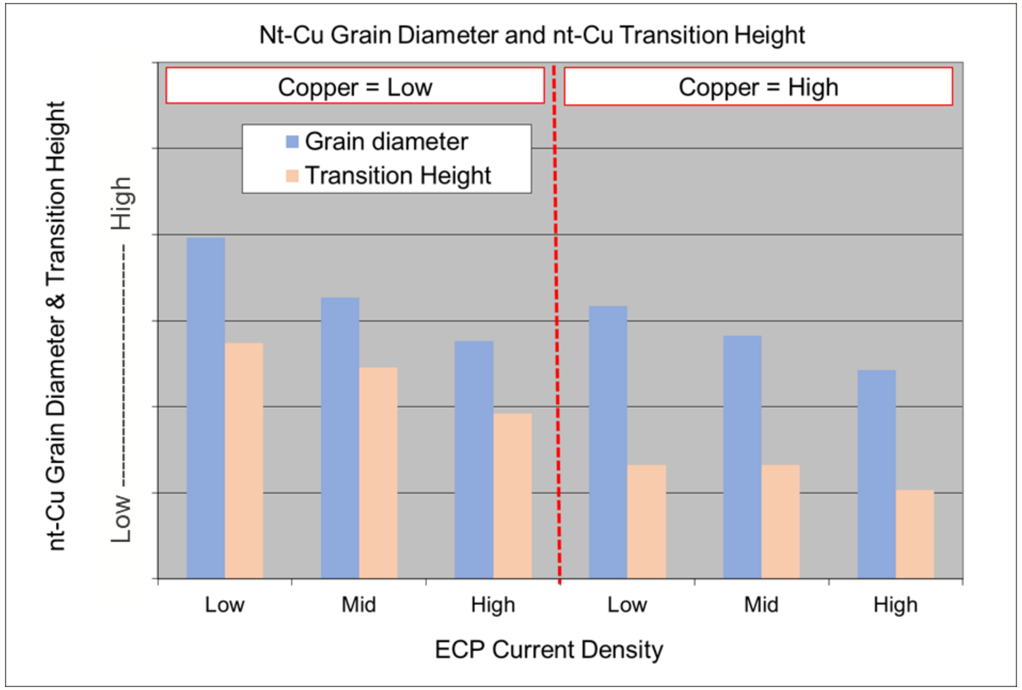
Stainless Steel substrate

- Both substrate show high density of nt-Cu, with PVD Cu substrate showing more columnar structure
- In general, the ECP process does not exhibit strong substrate-dependency for nt-Cu formation

Effect of Makeup and ECP Current Density on nt-Cu grain size/transition layer



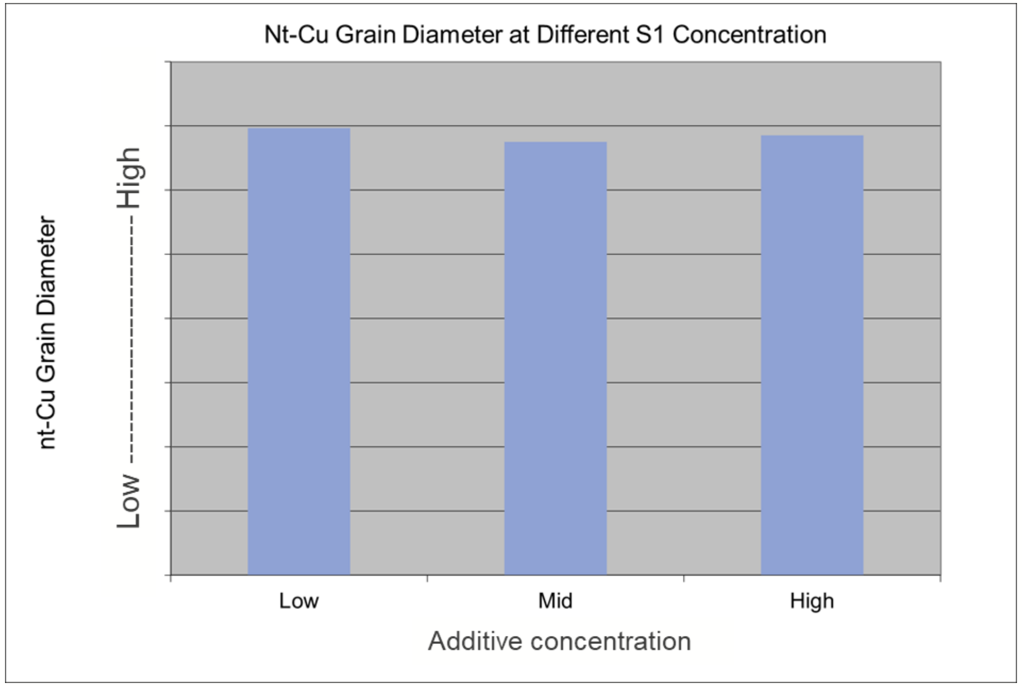
Acid effect at different current density



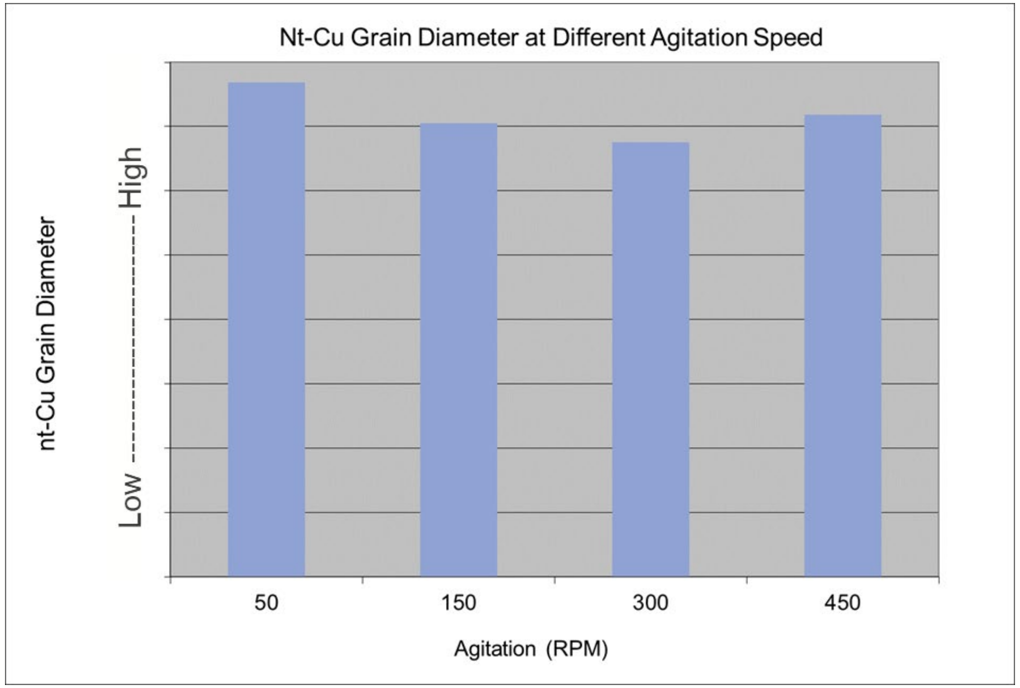
Cu effect at different current density

- The transition layer thickness is proportional to the nt-Cu grain size
- Lower acid, higher Cu, higher current show relatively smaller grain size / lower transition layer

Effect of additive concentration and agitation on nt-Cu grain size/transition layer



Additive concentration effect



Agitation speed effect

- Additive(s) show a wide concentration process window with insignificant change in nt-Cu grain size
- Agitation speed slightly affects nt-Cu grain size, with 300 RPM showing a relatively smaller grain size

Conclusions

- A new nanotwinned copper ECP system has been developed to generate a high density nt-Cu film, with a columnar structure and a limited transition layer
- With or without recess, different WLP features such as Pads, Lines, Pillars and Vias can be ECP filled with a flat surface and high density nt-Cu structure with minimal transition layer
- Low acid, high Cu & high current density show better nt-Cu performance with relatively smaller grain size and lower transition layer, with all the tested splits show close to 100% nt-Cu
- In tested range, additive concentration and ECP bath agitation speed show minor impact on nt-Cu
- Overall, the ECP process shows a wide process window to achieve high density nt-Cu
- The new process does not exhibit strong substrate-dependency

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