Electroplated Cu Pillar Feature Effects

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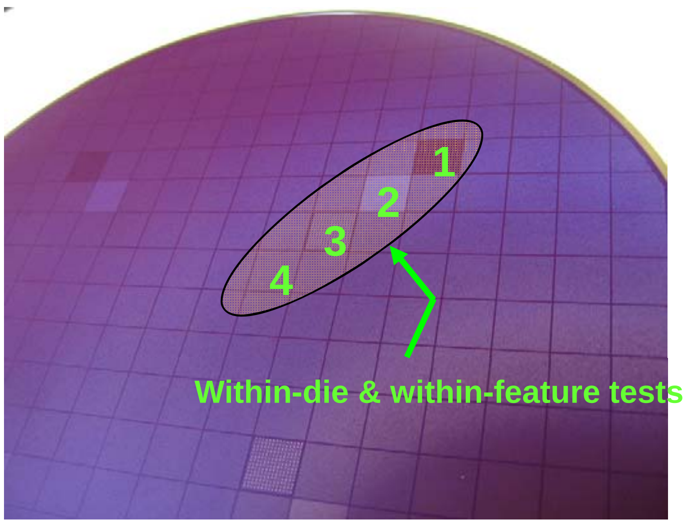
Cu pillar process & challenges

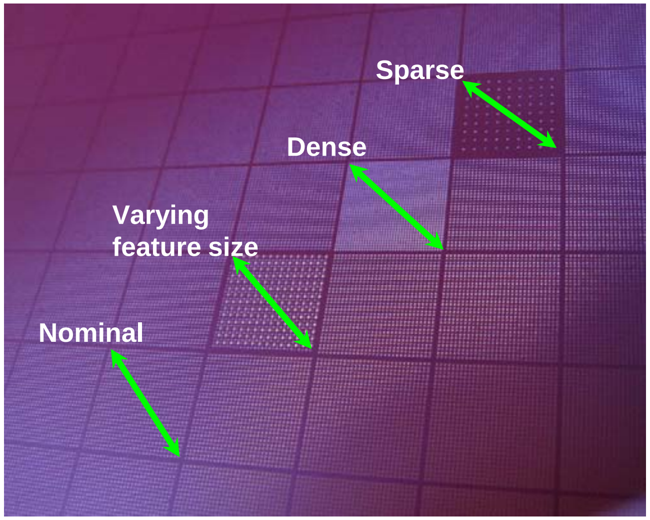
- *Electroplated Cu pillars attracting increasing interest for die attach*
  - *Needed for fine pitch*
  - *Better electrical and thermal conductivity than solder bump*
- *Primary challenge: coplanarity*
  - *Connections are made with smaller solder bumps: cannot use reflow to compensate for non-coplanarity*
- *Associated challenge: plating rate*
  - *Typically, coplanarity is improved by reducing plating rate*
  - *At pillar heights 50 – 100μm, maximum plating rate is required*
  - *At high rates, must also control surface quality: doming, roughness, etc*
- *Large aspect ratios*
  - *Need to extend boundary layer as far as possible into resist features*
- *Current effort: characterize available plating chemistries and processes against new requirements*

Experimental: Overview

- *Plating tool: Stratus S300*
  - *300mm capability, compatible with 200mm and other wafer diameters*
  - *Shear plate agitation provides thinner boundary layer for more effective plating at high deposition rates*
- *Test vehicle: Nexxsystems test pattern*
  - *200mm wafer*
  - *Cu plating to heights 45 – 90μm*
- *Metrology: Optical profilometry*
  - *Zygo series 6000*

Cu pillar test pattern





- *200mm wafer*
- *Test pattern imaged in 120μm thick dry film resist*
- *Wafer area filled with 10mm x 10mm dies*
- *Most dies: 100μm diam pillars on 333μm pitch*
- *3 special dies along each diagonal:*
  - *Sparse (1000μm pitch)*
  - *Dense (250μm pitch)*
  - *Varying diameter pillars (60μm, 80μm,100μm and 140μm)*

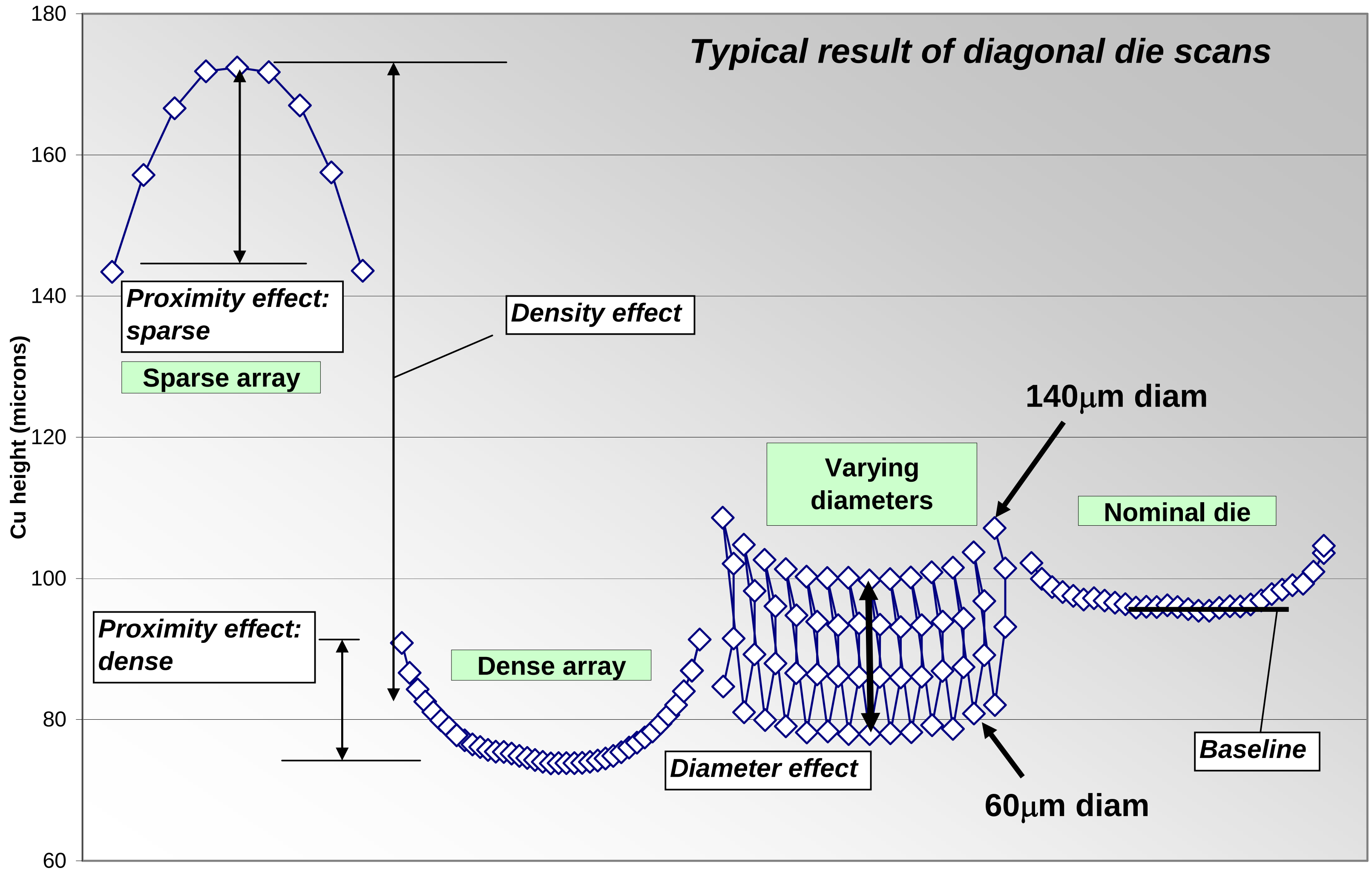
Chemistries and processes

Process	Cu g/L	H_2SO_4 g/L	Cl PPM	Temperature ºC
A	28	67	45	23
B	50	175	50	35
C	50	175	50	45
D	50	100	50	23
E	60	80	70	23
F	38	120	60	25

Metrology

- *Plated pillars measured using Zygo Series 6000 interferometric profilometer*
- *2-D surface height map for height averaging and morphology analysis*
- *Onboard analysis: levelling, roundness, roughness after correcting for pillar shape*
- *Combine results from 4 sets of test dies to eliminate any within-wafer bias*

Derived values based on pillar height

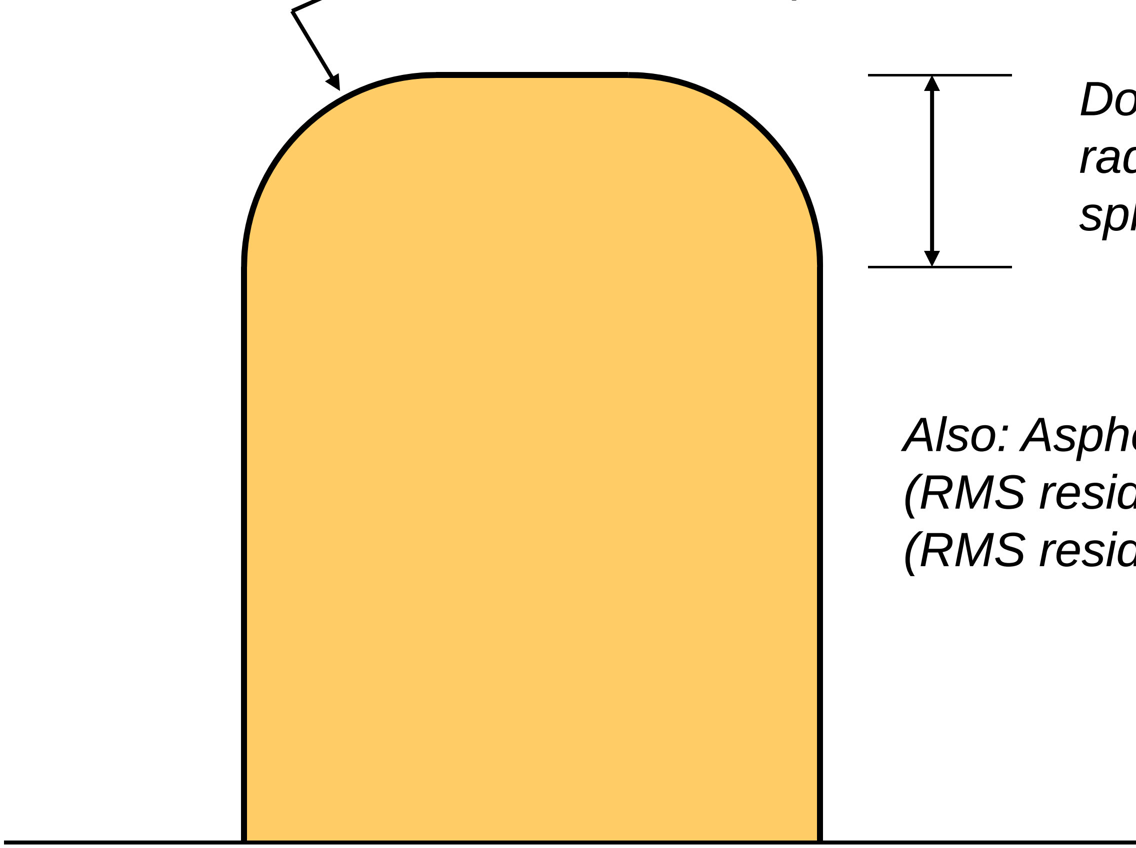


Derived values: definitions

- *Baseline height = center of nominal die*
  - *100μm diameter at 333μm pitch*
- *Simple density effect:* $$= \frac{(center\ height(sparse) - center\ height(dense))}{Baseline}$$
- *Proximity effect:* $$= \frac{|\,die\ corner\ height - die\ center\ height\,|}{Baseline}$$
- *Diameter effect:* $$= \frac{(height\ of\ 140\mu m\ diam\ pillar\ \text{-}\ height\ of\ 60\mu m\ diam\ pillar)}{Baseline}$$
- *Other quantities of potential interest:*
  - *Decay length for proximity effect*

Morphology measurements

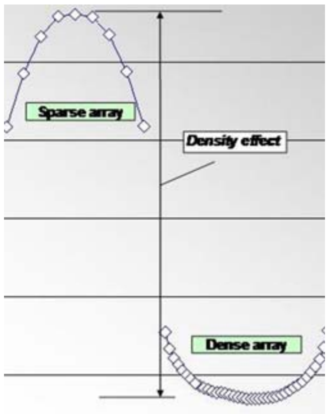
RMS roughness (residual after correcting for 4th order fit to surface)

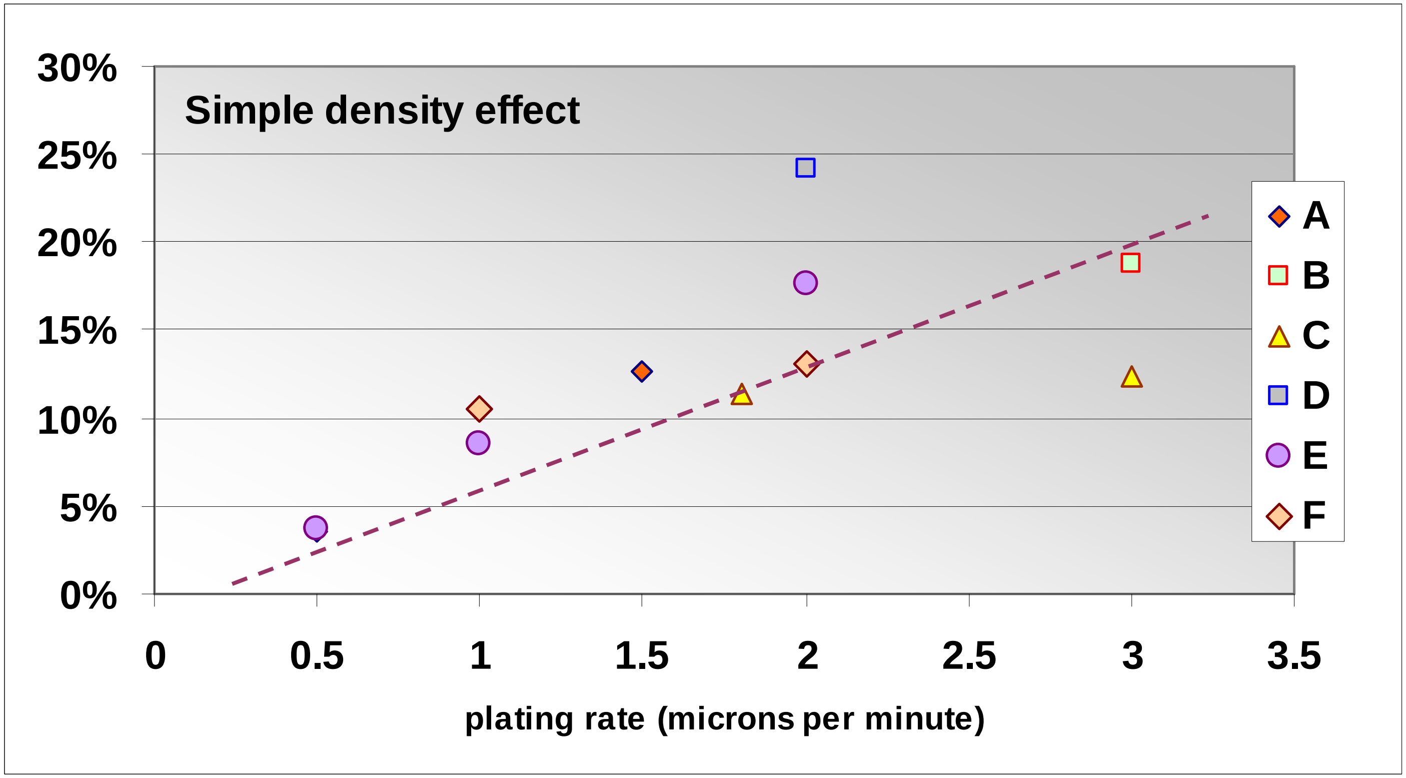


Doming (calculated from radius of curvature of spherical fit to surface)

Also: Asphericity (indirect measure): (RMS residual after spherical fit) – (RMS residual after 4th order fit)

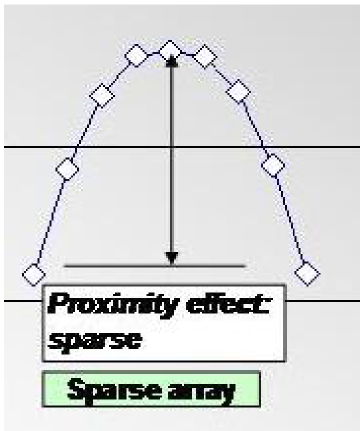
Results: coplanarity effects vs rate (1)

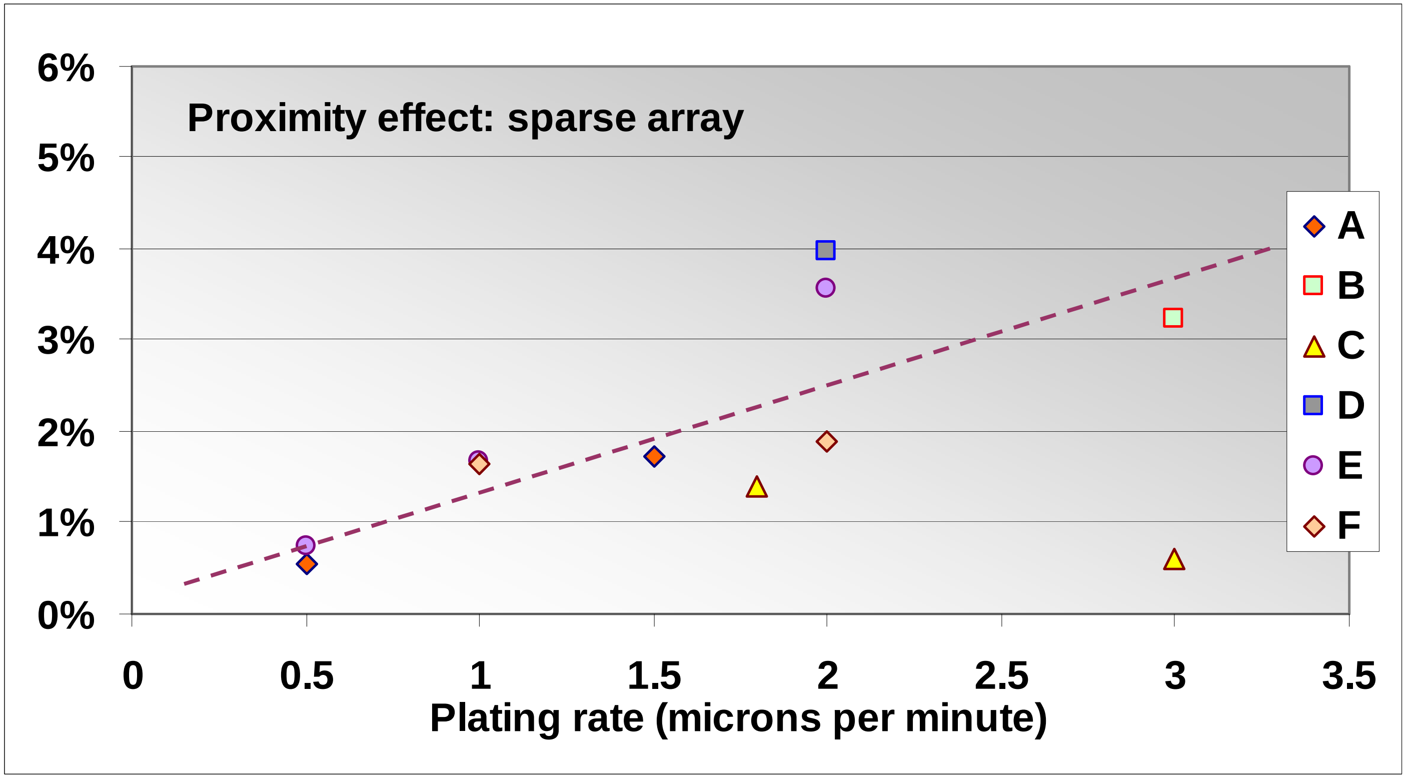




While primary current effect is a dominant influence, some chemistries are better optimized for use at high rates

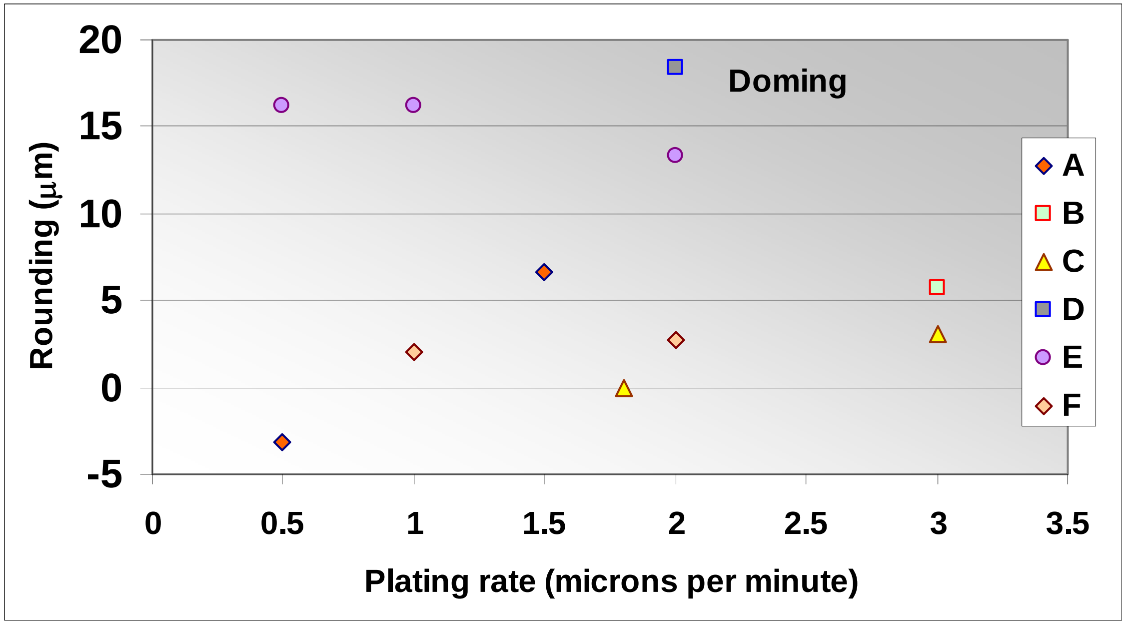
Results: coplanarity effects vs rate (2)





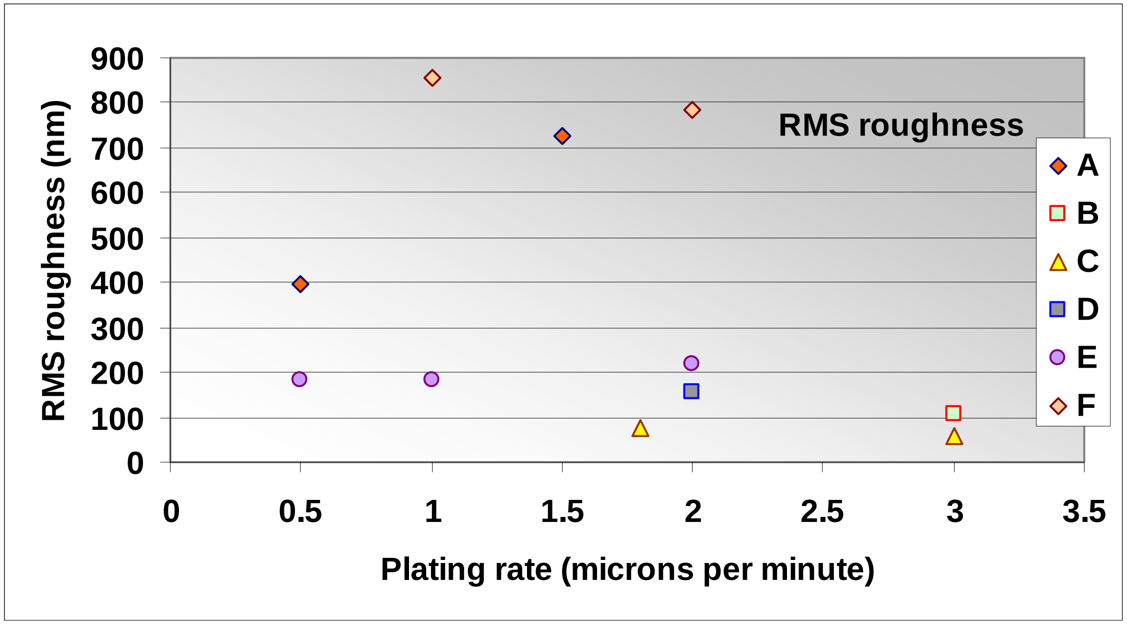
Some chemistries are particularly effective in countering the primary current effect at high plating rates

Results: within-feature effects vs rate (1)



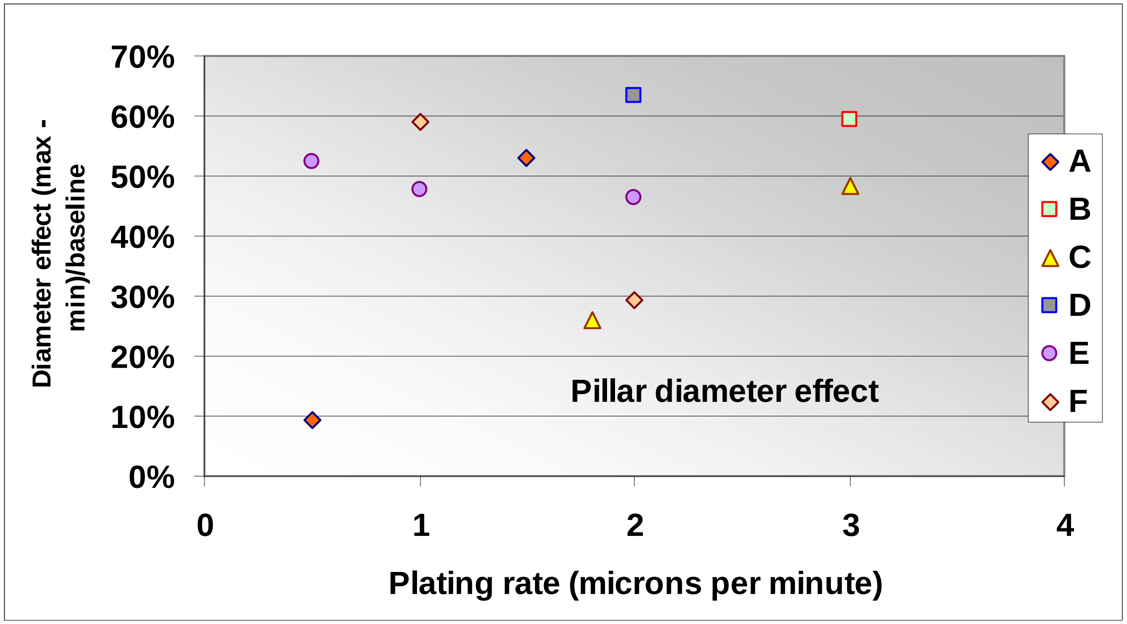
- *Overall effect is mainly dependent on base chemistry*
- *Rate dependence apparent only for some chemistries*

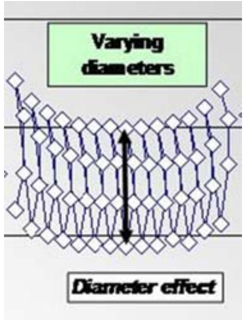
Results: within-feature effects vs rate (2)



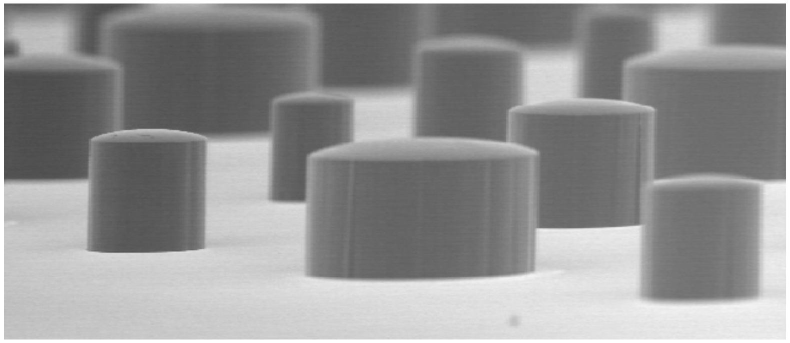
- *Dependent on base chemistry and additives*
- *Rate dependence is not typical*

Results: feature size effect vs rate



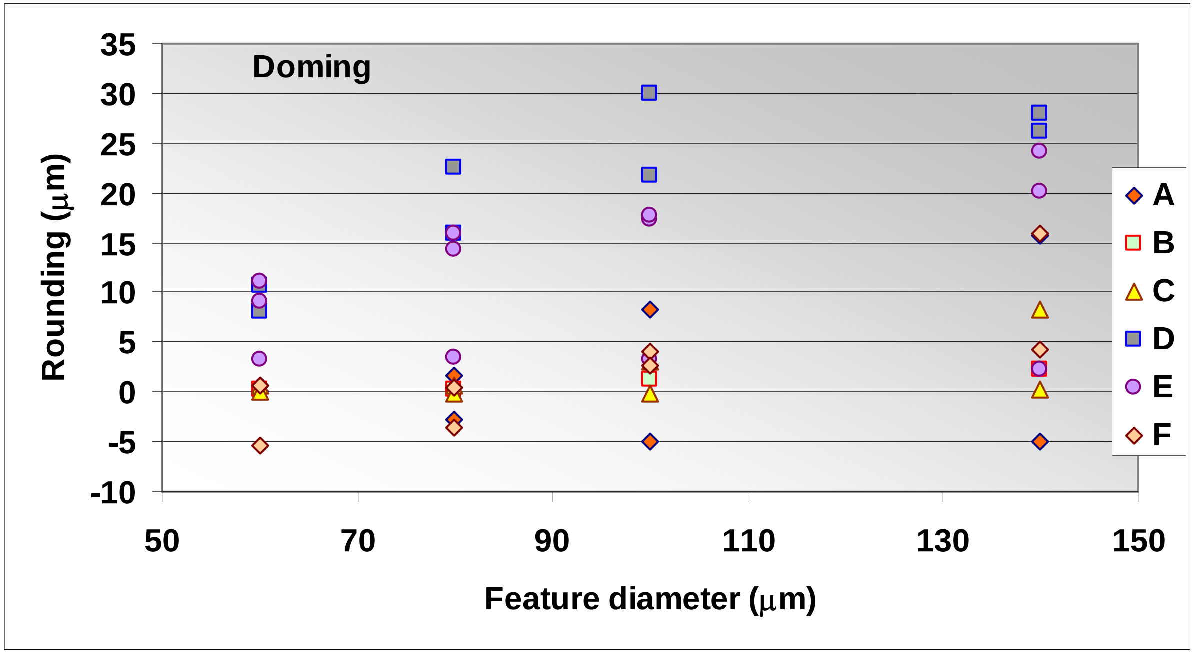


No "standard" behavior here: may be dependent on base chemistry, additive levels, temperature…



-This can be a significant component of coplanarity error if pillars of different sizes are present, or if any other features (alignment marks, etc) are used

Results: Dependence on feature diameter



- Where doming is significant, it is reduced for smaller pillar diameters
- For chemistries with low doming, little dependence on diameter

Summary and conclusions

- *Methodology has been developed to characterize performance of Cu plating chemistries and processes against Cu pillar process requirements*
- *Preliminary results show that some effects are field-driven, others are chemistry-driven*
- *Methodology is being used for in-house DOEs to develop pillar PORs, and in cooperation with chemistry suppliers to direct product improvements*
- *Optimum selection of chemistry may depend on pattern layout: variation of feature sizes and pattern densities*

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