Evaluation of the Efficiency of a CMP Pad and Abrasives in Removing BTA Layer on Copper during CMP

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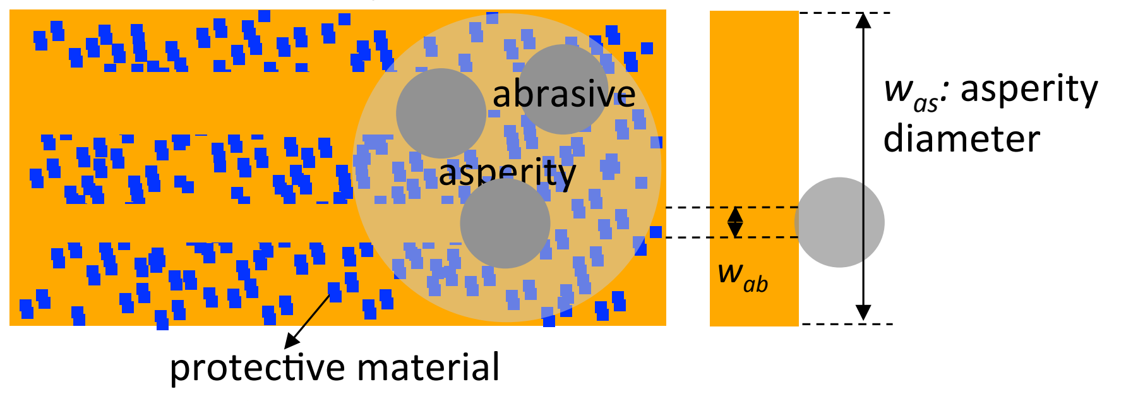
Definition of Removal Efficiency

- Less than a monolayer of adsorbed BTA
  - Interval between consecutive interactions by asperities is of the order of 1 ms

$$\eta = \frac{\theta_{before\ abrasion} - \theta_{after\ abrasion}}{\theta_{before\ abrasion}}$$

θ: areal ratio occupied by protective material

Schematic of removal of protective materials

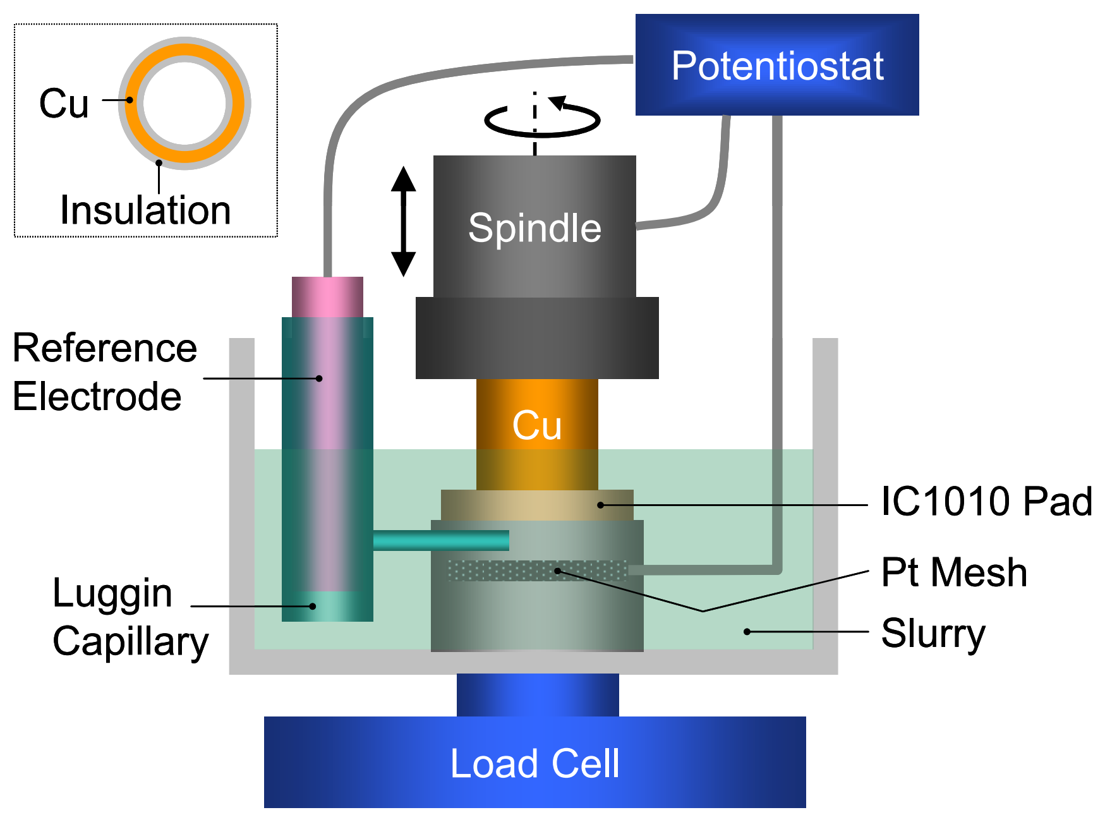


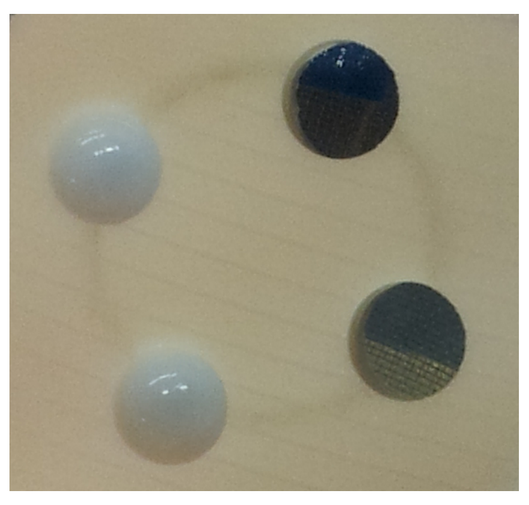
θ=0.3 → θ=0.21 Removal efficiency, η=0.3

- *Want to quantify*
  - Removal efficiency vs. Down pressure or Sliding velocity
  - Removal efficiency vs. Concentration of the abrasives

Experimental Detail

- In situ electrochemical measurement during polishing
  - Potential of copper was externally adjusted to 0.6 V (vs. SCE) instead of using oxidizing agents
  - Current densities were measured for various down pressures and sliding velocities
- Slurry contains 0.01M BTA, 0.01M glycine and 5wt% alumina abrasives at pH 4

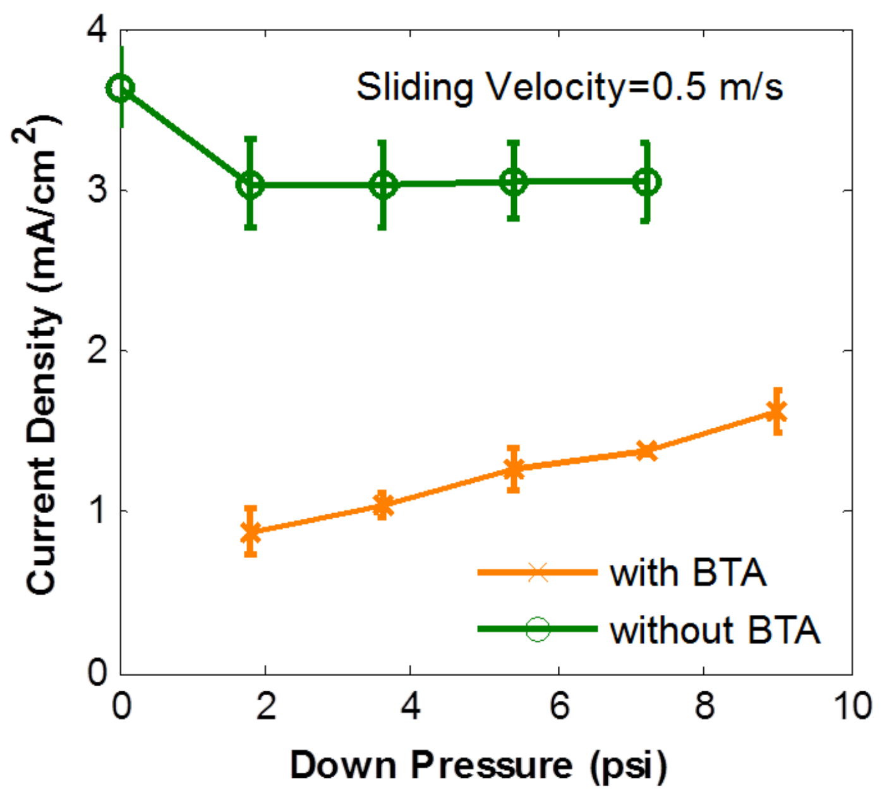


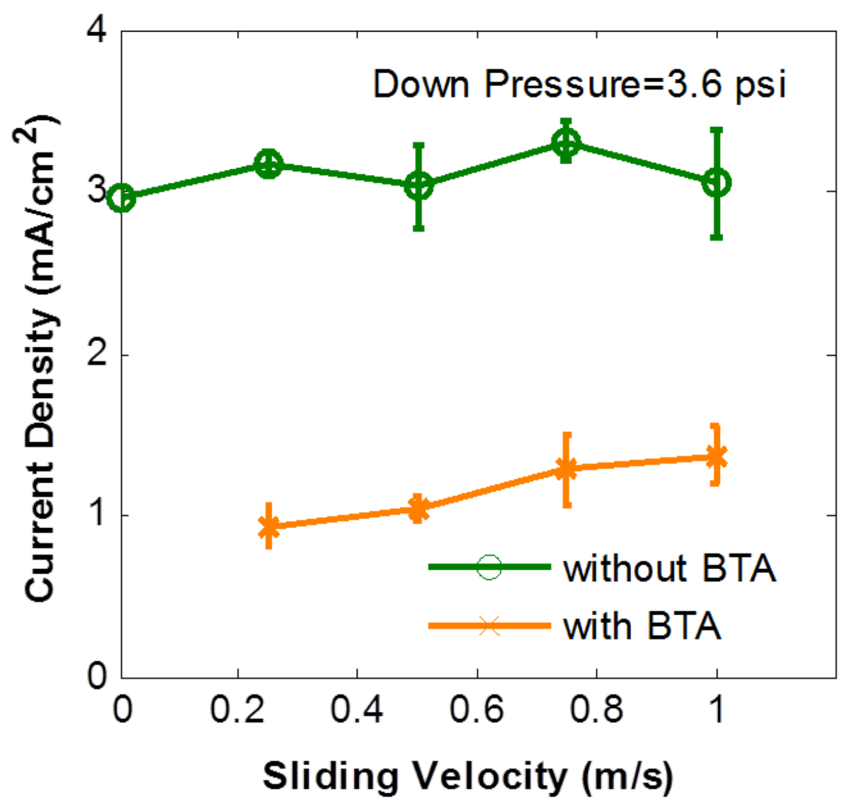


IC1010™ CMP pad with four machined holes after CMP of copper. Oxidized copper remained on the surface of the pad leaving an annular trajectory of the electrode

Measured Current Densities

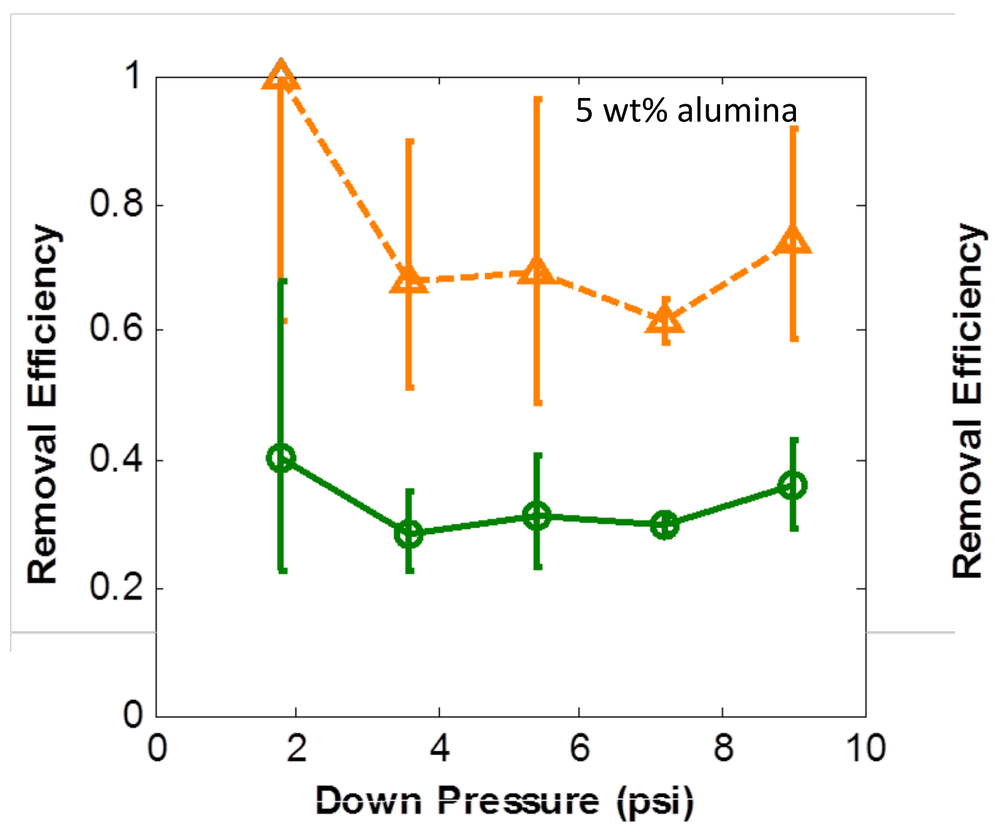
- Current densities in the absence of BTA were nearly constant
- Current densities in the presence of BTA increased with the down pressure and the sliding velocity
  - Suggesting lower coverage by the adsorbed BTA layer

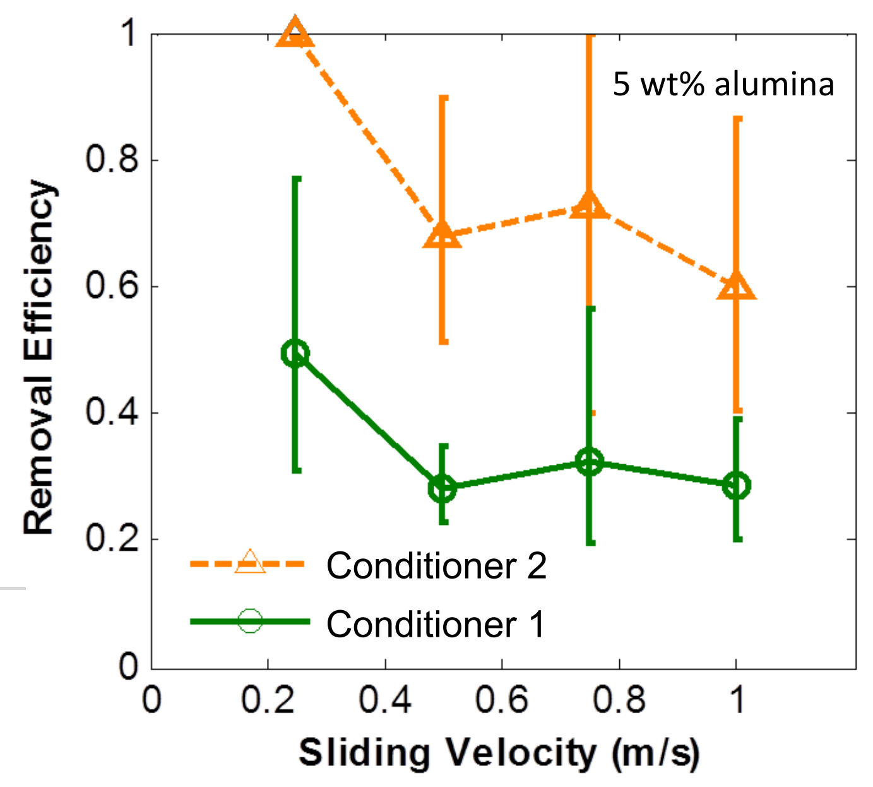




Evaluated Removal Efficiencies from Experiments

- $t_{as\text{-}as}$ was estimated from the literature for the same pad
  - Dependent on the conditioning specifications
- Nearly insensitive to the down pressures or the sliding velocities
  - Increase in the measured current densities is due to reduced $t_{as\text{-}as}$



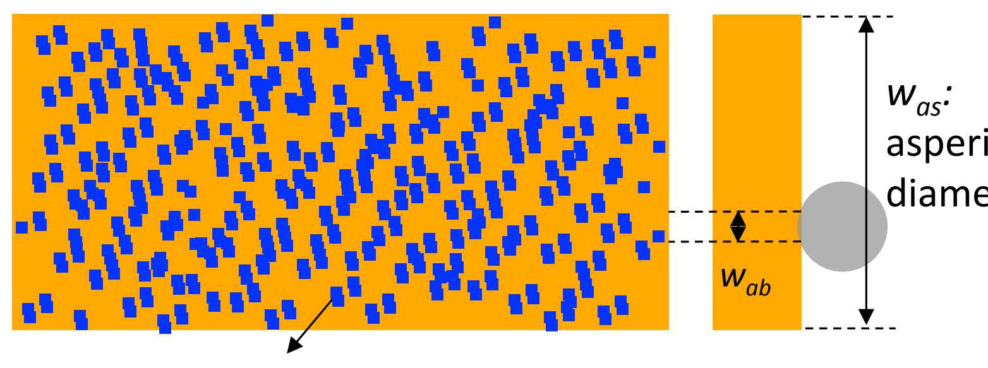


*Error bars correspond to the standard deviation of the experimental data

Analytical Prediction of the Removal Efficiency

- Assumptions
  - Sliding of abrasives
  - No removal by asperities
  - No additional removal on overlapped paths
  - No redeposit of the removed materials
  - No interaction between tangential and normal forces
  - Agglomerated abrasives broken into individual particles
  - An asperity and abrasives slide in the same direction by the same distance

Schematic of removal of protective material



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- Hertz contact theory was used when copper is elastically deformed
- Nanohardness of copper ~15GPa [Ziegenhain (2009), Saraev (2005)] was used when copper is plastically deformed

$$\eta = \frac{w_{abs}}{w_{as}}$$

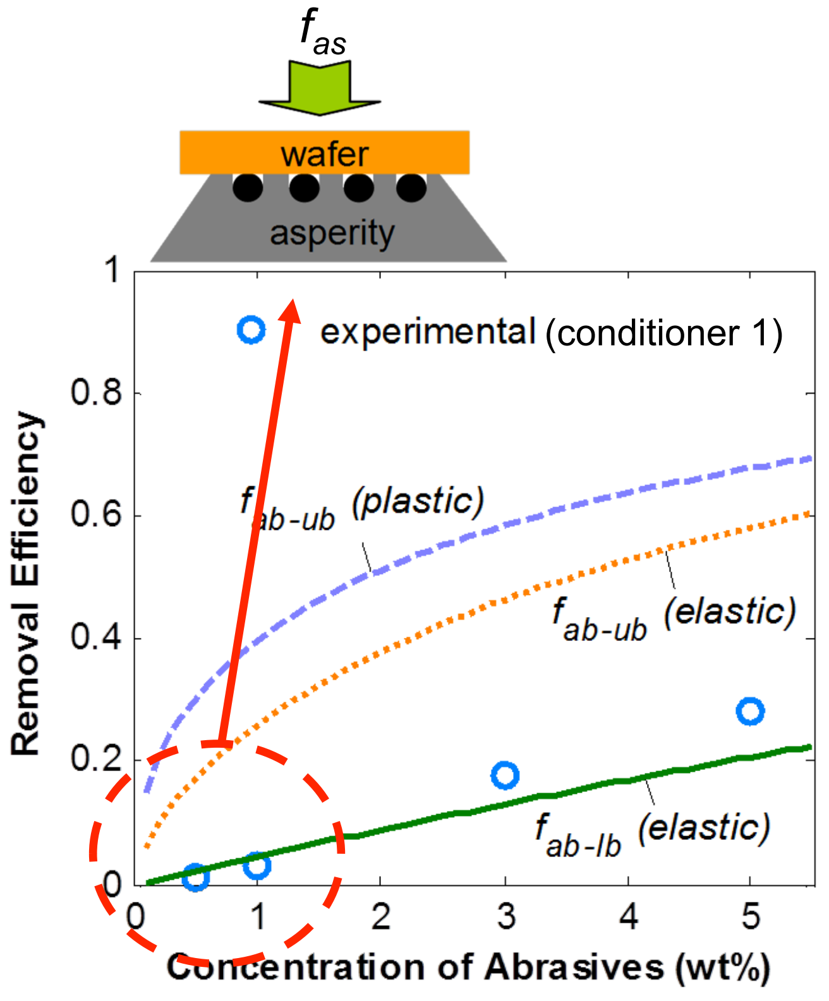
$$w_{abs} = (w_{ab})_1 + (w_{ab})_2 + (w_{ab})_3 + \ldots + (w_{ab})_{n_{ab}}$$

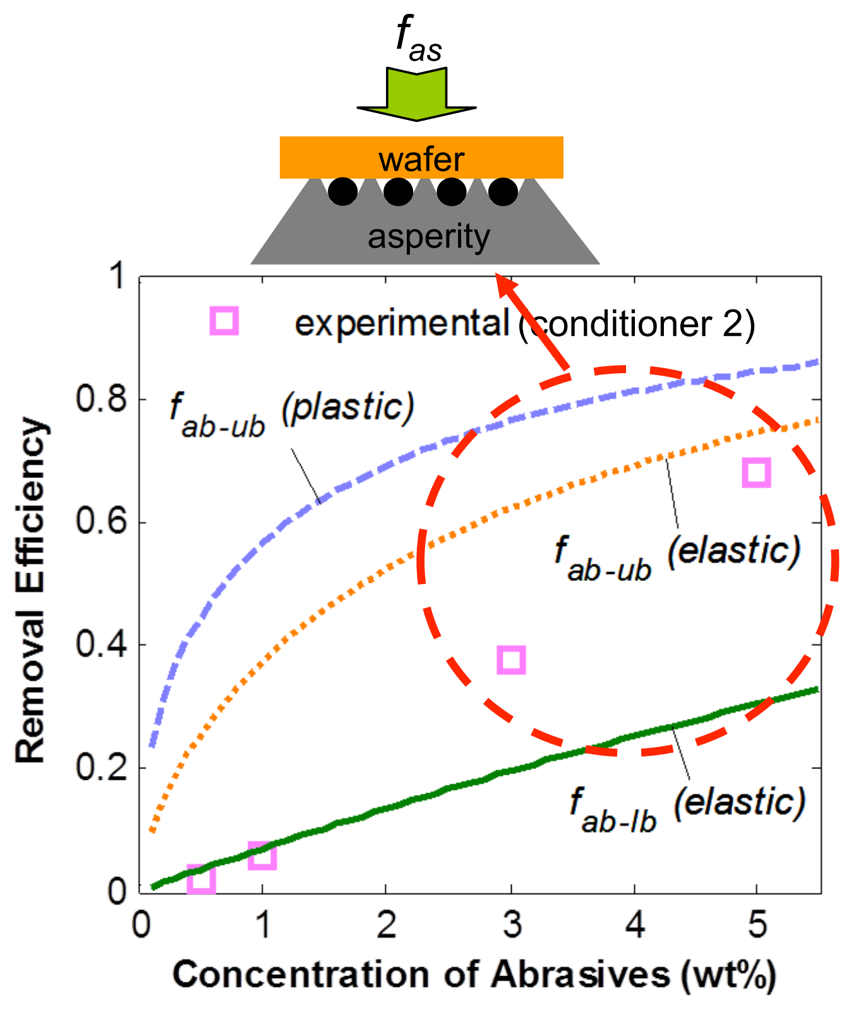
$$= (w_{ab})_1 \left[1 + (1 - \frac{(w_{ab})_1}{w_{as}}) + (1 - \frac{(w_{ab})_1 + (w_{ab})_2}{w_{as}}) + \ldots + (1 - \frac{(w_{ab})_1 + (w_{ab})_2 + \ldots + (w_{ab})_{n_{ab}-1}}{w_{as}}) \right]$$

Expected width of the 2nd sliding trajectory is reduced by the overlapped amount

Predicted Removal Efficiency

- For lower concentrations of the abrasives the experimentally resolved values approximated the prediction with elastic deformation of copper for the lower bound of the estimated forces
- For higher concentrations the experimentally resolved values were intermediate between the predictions with the upper and lower bounds





Deformation of Copper by Abrasives

- Theoretical shear strength of copper (t_{th}) was from literature
  - The maximum shear stress in the copper at the onset of plasticity during nanoindentation approximated the theoretical shear strength of the material [Ziegenhain (2009), Saraev (2005), Suresh (1999) and Chen (2003)]
  - t_{th} ~8.5 Gpa
- Assuming friction between the abrasives and copper is present (m=0.6), the threshold maximum shear stress in the copper for the copper to be plastically deformed is 3.8 GPa
- Copper was elastically deformed for most cases even when a very high friction coefficient was assumed
  - Agreed well with the figures in the previous slides confirming the validity of the analysis

c_{wt} (wt%)	τ_{max} Conditioner 1 (GPa)	τ_{max} Conditioner 2 (GPa)
0.5	1.5	1.5
1	1.5	1.5
3	2.2	3.7
5	2.4	5.0

Maximum shear stress in copper

$$\tau_{\max} = 0.30 p_0 \qquad p_0 = \left(\frac{6 f_{ab} E^{*2}}{\pi^3 r_{ab}{}^2} \right)^{1/3}$$

p_0: maximum Hertz contact stress

Conclusion and Future Work

- Removal efficiencies were independent on the down pressure and the sliding velocity
- Experimentally resolved removal efficiencies agreed well with the predictions by an analytical method
- The contact mode between the pad, abrasives and wafer determines the force applied on an abrasive, resulting in varied amount of removal of the protective material
- In the future, a model that predicts the material removal rates during copper CMP will be proposed based on these findings

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