‘Pad-in-a-Bottle’: Planarization with Slurries Containing Suspended Polyurethane Beads

(*Task 425.039)*

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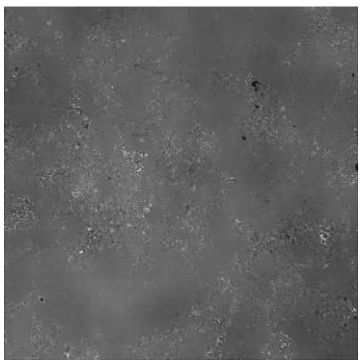
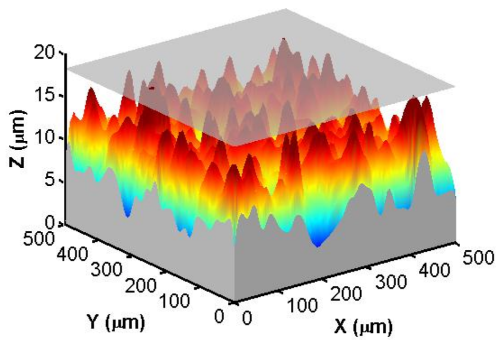
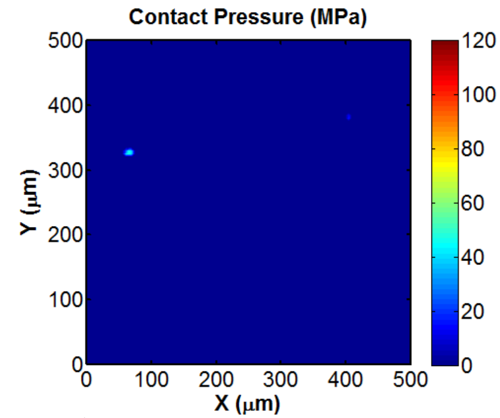
CMP is via Random Pad-Particle-Wafer Events

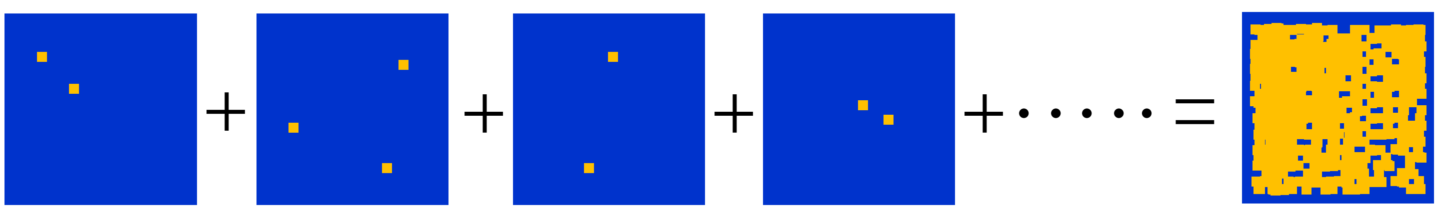
- **Current understanding of CMP:**
  - **Contact area between pad and wafer is extremely small (0.01 percent).**
  - **Polishing is driven by microscopic contact events.**
  - **Polishing is achieved by accumulation of single removal events with random pad asperity heights, and random asperity contacts.**







P_0 = 5 PSI (35,000 Pa)



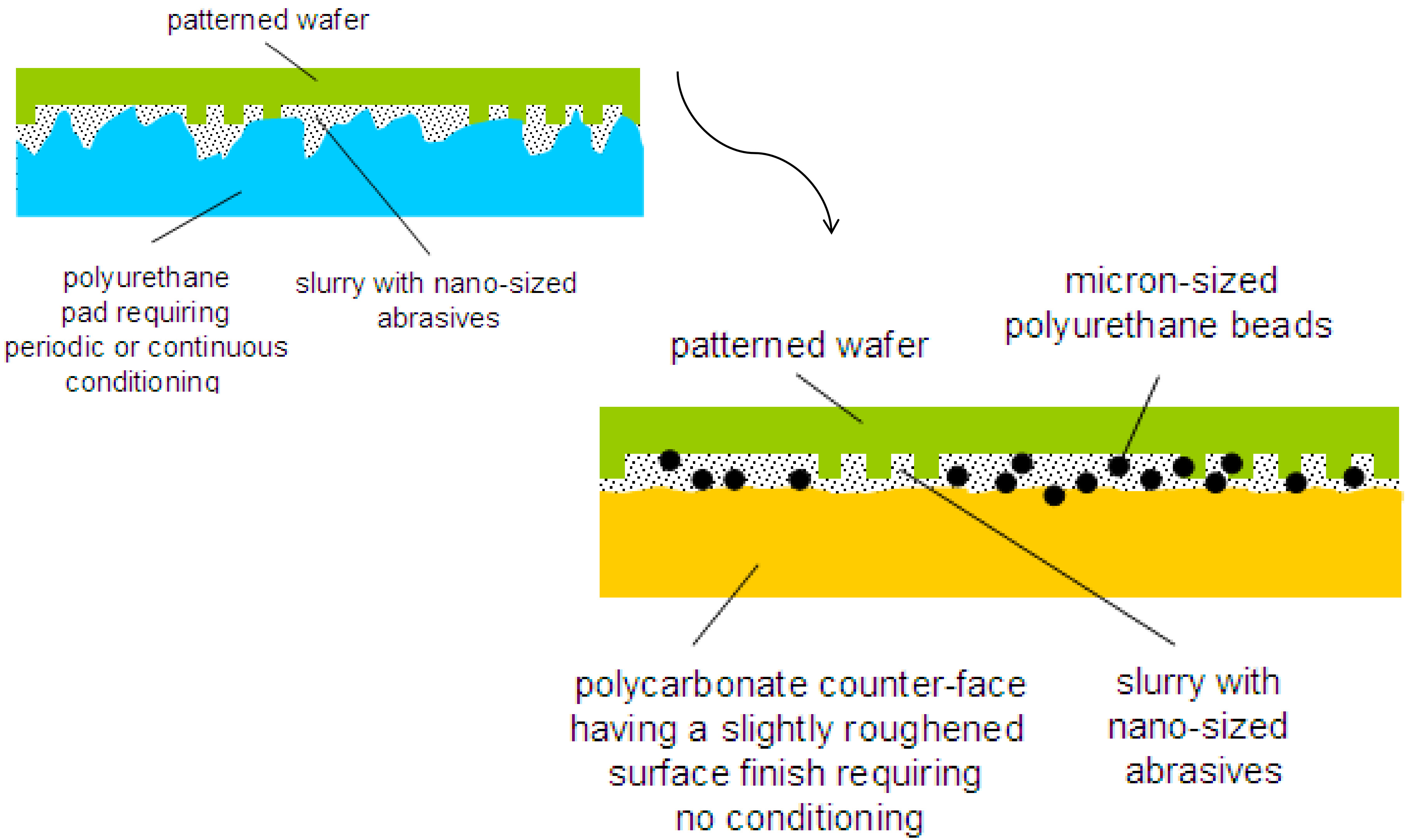
Polishing

Alternative Approach: ‘Pad-in-a-Bottle’ (PIB)

- **Idea: Replace random pad surface asperities with ‘controlled’ pad particles.**

- **Result: Disruptive technology for planarization with slurries containing suspended polymeric (polyurethane) beads.**
  - ✓ **Eliminates need for pads and conditioners.**
  - ✓ **Pad asperities are replaced with micron-sized polymeric beads suspended in off-the-shelf slurries (with some simple additives).**
  - ✓ **The pad is replaced with a low-cost counter-face material made of polycarbonate.**
  - ✓ **PIB will have significant technological, cost and EHS impact if properly developed and commercialized**
  - ✓ **Early ILD CMP polishing results have shown comparable removal rates to that of conventional polishing**

PIB


patterned wafer
polyurethane pad requiring periodic or continuous conditioning
slurry with nano-sized abrasives
micron-sized polyurethane beads
patterned wafer
polycarbonate counter-face having a slightly roughened surface finish requiring no conditioning
slurry with nano-sized abrasives

Technological and Scientific Benefits

- **Intrinsic to conventional CMP:**
  - ✓ **Pad asperities with irregular and uncontrollable shapes and wear properties which cause variations in CMP performance.**
  - ✓ **Pad asperities that will trap unwanted products (such as silica particles) and by-products such as (metal oxides) which contribute to defect levels.**

- **PIB offers predictable and controllable pad asperities.**
- **PIB will give us the unique capability to study the fundamentals of CMP since it offers a platform with controlled asperity size and wafer contact area.**

Environmental Benefits

- **Commercial polishers use 3 to 4 polyurethane pads and diamond conditioners simultaneously.**
- **EOL for each pad and conditioner is ~ 3 days in HVM.**
- **Each polishers uses 100s of pads and conditioners per year (10s of 1000s of pads and conditioners per HVM factory).**
- **This is a huge waste:**
  - ✓ **For pads, only about one-third of the thickness is used.**
  - ✓ **For diamond discs, only a few hundred diamonds (out of tens of thousands) are used.**
  - ✓ **Pads and diamonds are never re-used or re-cycled.**
- **PIB is estimated to reduce polymer usage by 3X (by weight).**
- **Beads can be recycled or removed from the waste stream.**
- **Diamonds will be replaced by soft brushes.**

PIB Design Considerations

- **Selection of polymer particles**
  - ✓ Superior chemical and heat resistance
  - ✓ Stable mechanical properties
  - ✓ Tight, engineered size distribution
  - ✓ Good spherical shape and consistent surface texture

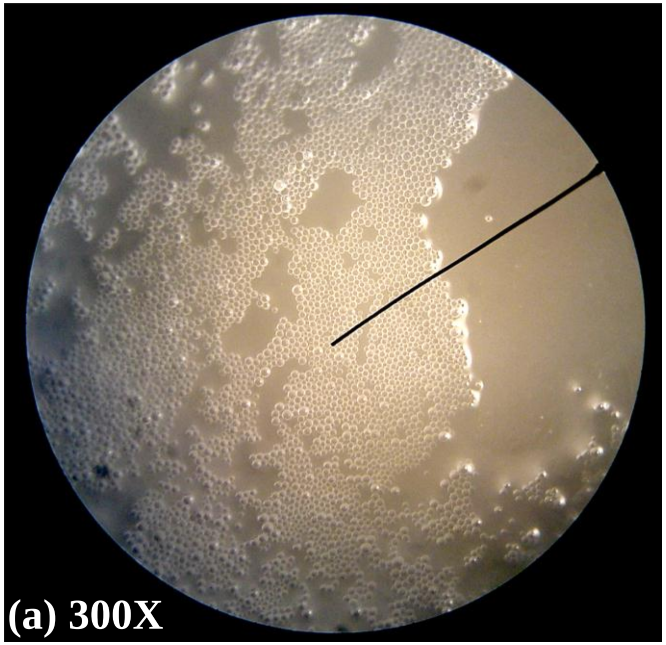
- **Selection of counter-face**
  - ✓ Sufficient hardness
  - ✓ High wear resistance
  - ✓ Sufficient hydrophilicity
  - ✓ Some texture to prevent rolling of particles, but smooth enough to prevent direct contact with the wafer

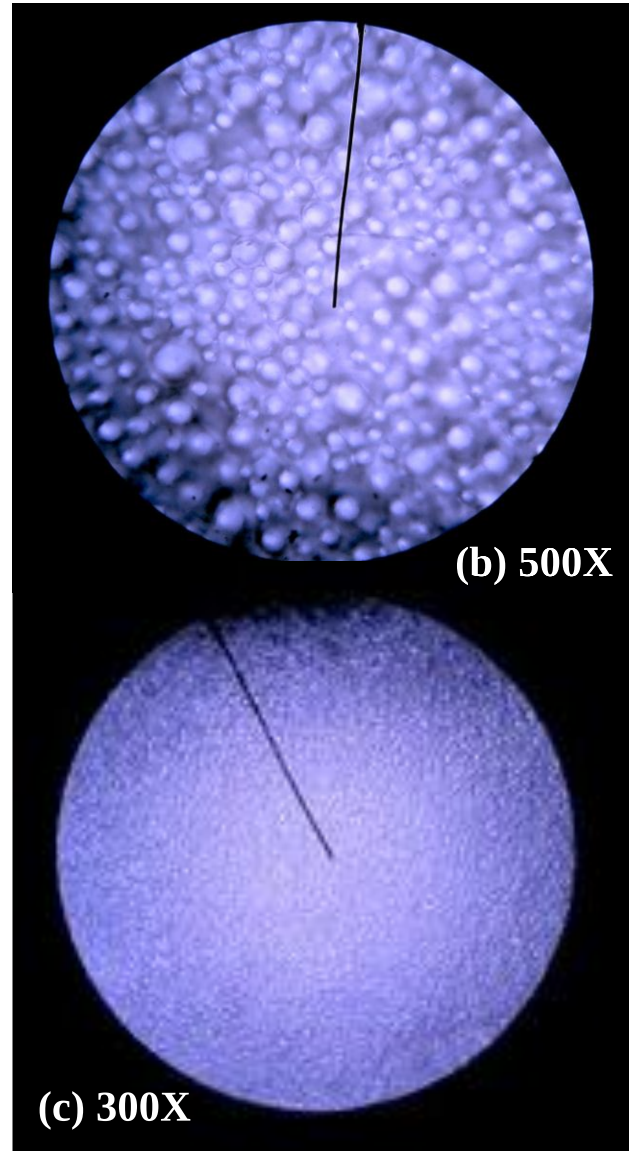
PIB Design Considerations

- **Slurry design**

  - ✓ **Polymer particles and abrasives can both be charged in the background chemical environment.**
  - ✓ **Abrasives can be adsorbed onto the surface of polymer particles and entrained between them**
  - ✓ **Abrasive concentration must be high enough to coat polymer particle surface, but low enough to prevent agglomeration**
  - ✓ **Polymer particles can associate strongly with the counter-face to maximize removal rate and minimize defects**

Directed-Assembly of PU Beads



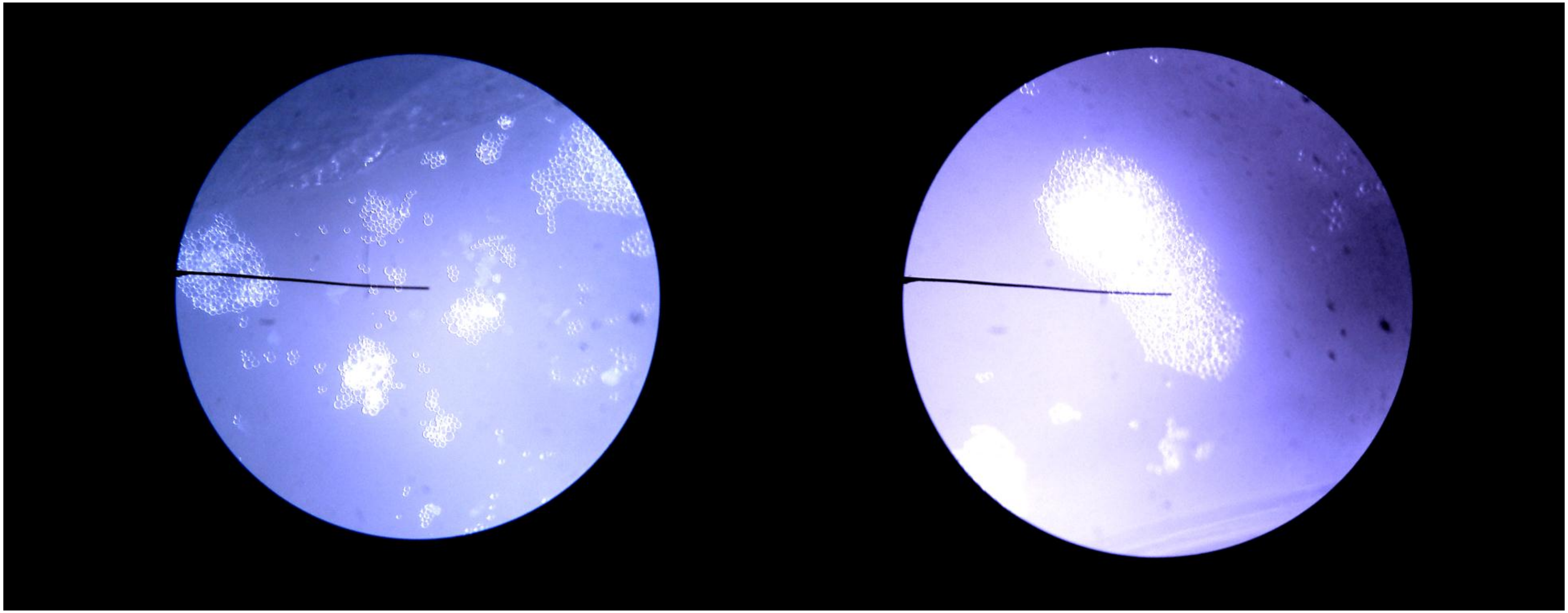


Assembly of 15 micron polyurethane beads on PC counter-face at pH 7 (post UPW rinse)

(a) monolayer rafts

(b) & (c) continuous bilayers

Second Generation PIB Prototype



Multi-layer rafts of 15 micron PU on PC counter-face from CMC SS25-based formula at pH 12 (post UPW rinse)

Indications of silica interstitial space fill and coating (bright regions)

Year 1 Plans

- **Subtask 1 – ILD CMP Experiments under Prof. Philipossian**
  - ✓ **Test different types and amounts of surfactants and additives that allow beads (with different sizes and concentrations) to be suspended in slurries. Select a few candidate formulations.**
  - ✓ **Screen and select a proper counter-face. Potential candidates include PC, quartz and PEEK with different values of roughness and stiffness.**
  - ✓ **Polish blanket oxide wafers at fixed pressure and velocity with different PIB slurries and counter-face materials.**
  - ✓ **Measure process temperature and frictional forces in real-time during polishing.**
  - ✓ **Determine RR and wafer-level defects at various test conditions.**
  - ✓ **Determine extent of counter-face surface wear.**
  - ✓ **Identify proper counter-face and proper ranges of bead sizes and concentrations.**

Year 2 and Year 3 Plans

- **Subtask 1 – ILD CMP Experiments under Prof. Philipossian**

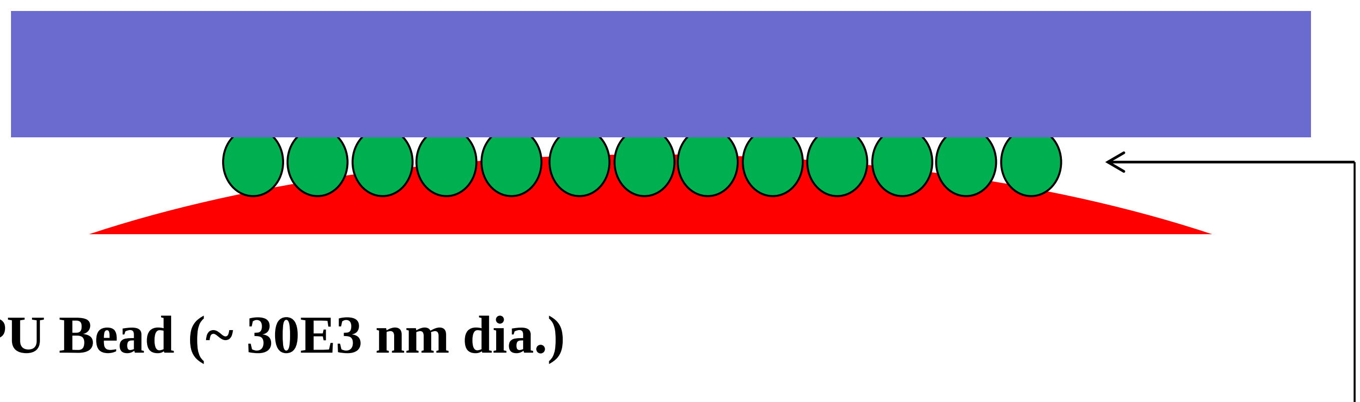
  - ✓ **Slurries containing beads with different sizes and concentrations will be used to polish blanket oxide wafers at different pressures and velocities.**
  - ✓ **Results will be compared with wafers directly polished on the counter-face with the unaltered slurry, as well as wafers polished on conventional pads with the unaltered slurry to illustrate how beads affect the tribological, thermal, kinetic and defect attributes of CMP processes.**
  - ✓ **Slurries containing beads with different sizes and concentrations will be used to polish patterned oxide and copper wafers to investigate the effect of polyurethane bead size and concentration on dishing, erosion, and planarization efficiency.**

Year 1 Plans

- **Subtask 2 – Simulations under Prof. Boning**
  - ✓ **Develop new wafer-level models of pad beads and slurry characteristics to understand and encapsulate the physical interactions between these new consumable components and polishing performance.**
  - ✓ **Integrate with slurry particle agglomeration models for bead, slurry and surface interactions.**
  - ✓ **Collaborate on experiments to determine which model case applies (or drive toward desired case) – See next page**

Model Approaches for PIB

Wafer (30E7 nm dia.)



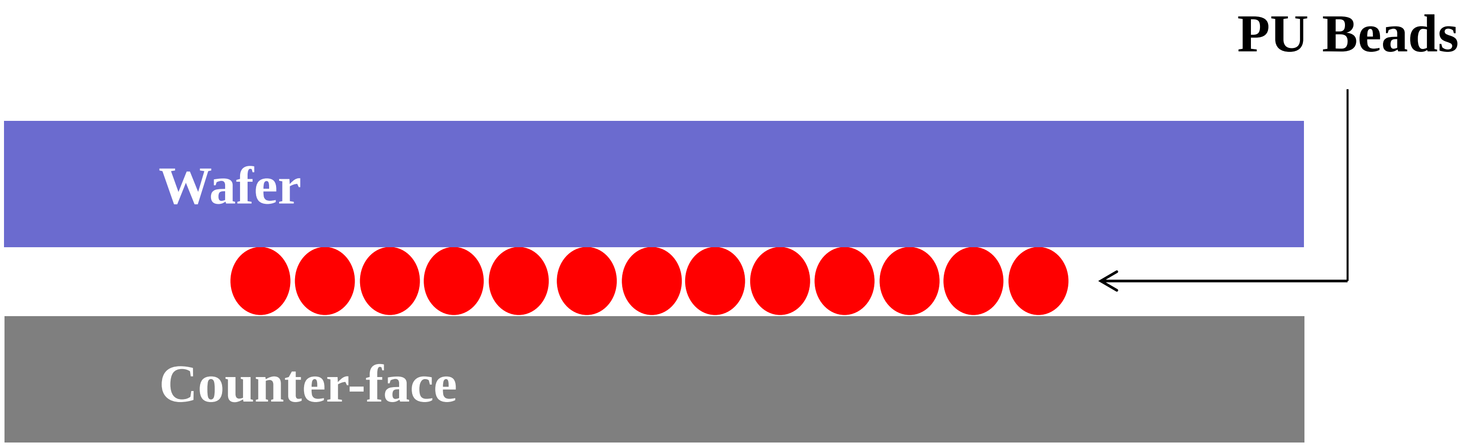
PU Bead (~ 30E3 nm dia.)

Slurry abrasive particle (~ 30 nm dia.)

Model Approaches for PIB

- **Bead Packing**

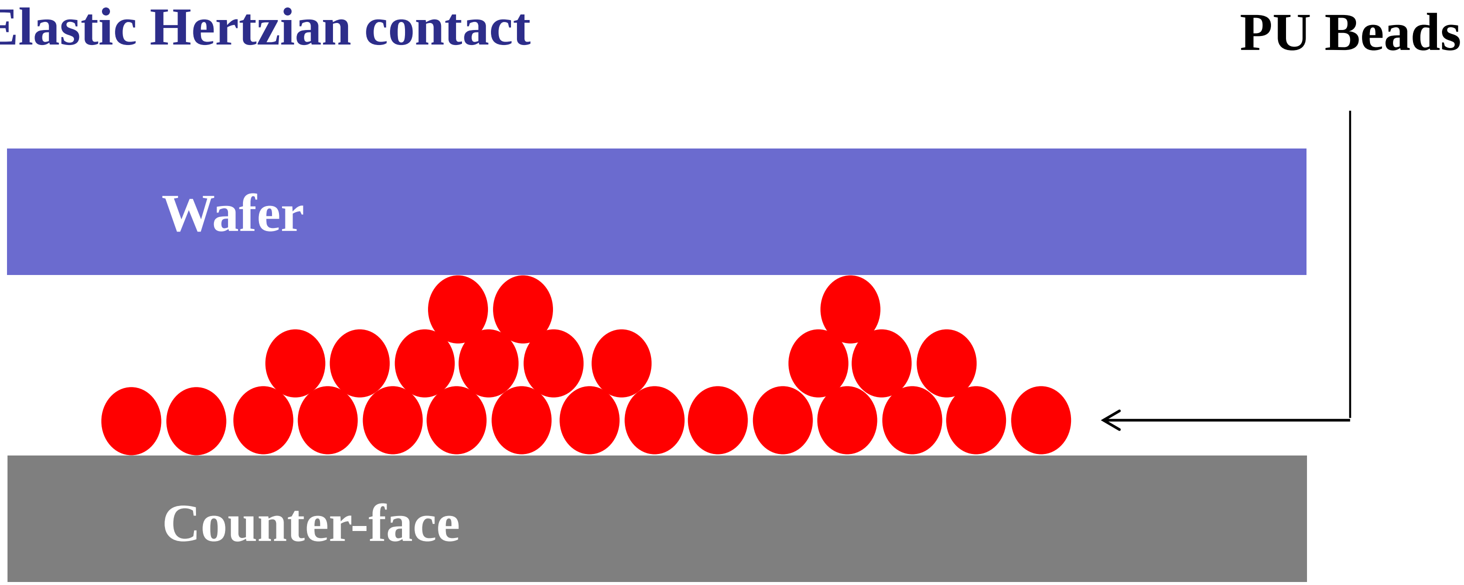
  - ✓ Single size PU beads that are much bigger than abrasive particles
  - ✓ Pure translational motion
  - ✓ Particles are densely packed (and multiple packing layers are possible)
  - ✓ Elastic Hertzian contact



Model Approaches for PIB

- **Bead Stacking**

  - ✓ Single size PU beads that are much bigger than abrasive particles
  - ✓ Pure translational motion
  - ✓ Particles are randomly stacked
  - ✓ Stacking height distribution can be determined
  - ✓ Elastic Hertzian contact



Year 2 and Year 3 Plans

- **Subtask 2 – Simulations under Prof. Boning**

  - ✓ **In Year 2, models to predict chip-scale planarization performance using the new consumables will be developed.**
  - ✓ **Die-level models will be extended, enabling prediction of chip topography evolution including dishing and erosion effects.**

  - ✓ **In Year 3, comparisons to patterned wafer experiments will be used to guide required improvements in the model.**
  - ✓ **Optimization studies will be conducted using the models to identify process consumable minimization, dishing and erosion limits, alternative design rule formulations, and dummy fill strategies.**