Finite Element Analysis of a Physical Chemical Mechanical Planarization Model

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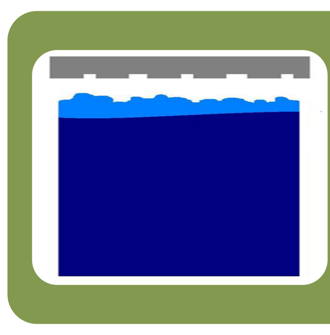
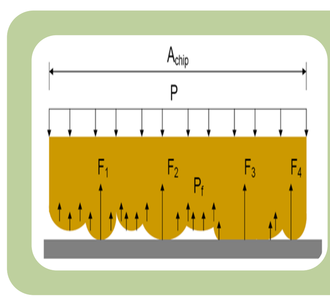
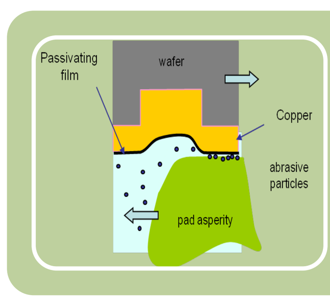
1 
Propose a **physical model** for the pad and the pad-wafer contact problem

2 

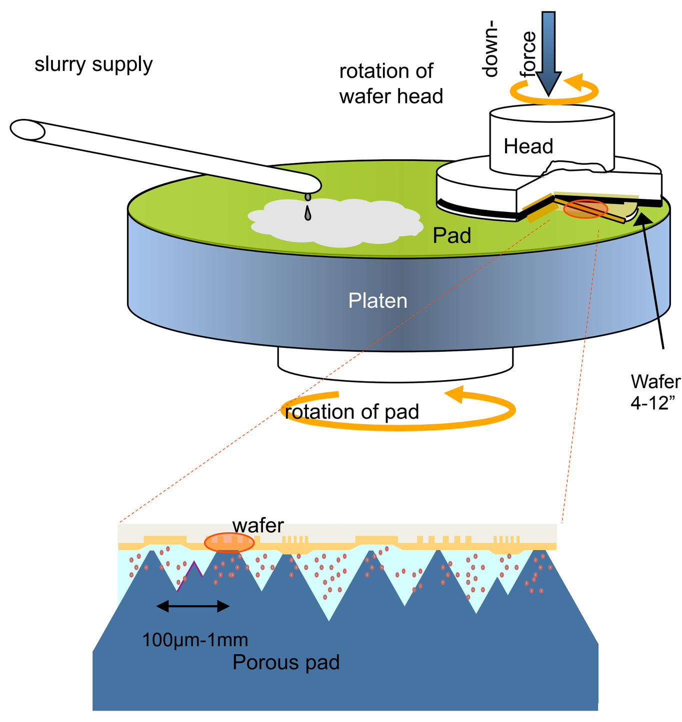
Include the model in a Finite Element Analysis to output **pressure distribution**

Refine the Finite Element by increasing the complexity of the model

3 

Include **relevant metrics** in the Copper CMP model

- Modeling of CMP process relies on the **understanding of the removal mechanism**. A model would allow a successful design for manufacturing and optimization.
- Pattern-dependency has been showed experimentally as one of the **most important factor influencing within-die non-uniformity**. With a pattern-dependency model, the local removal rate could be deduced from arbitrary layout.

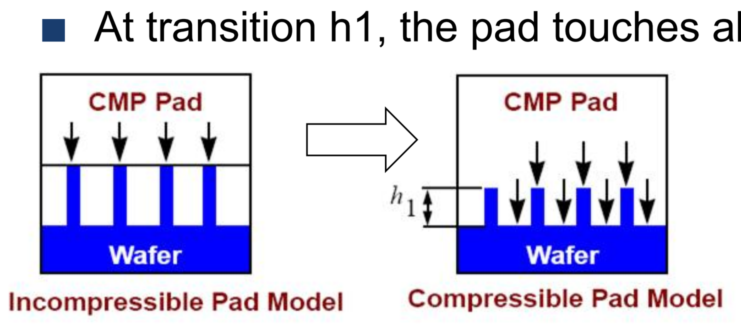


Previous Development

Effective local pattern density → Total up area in an evaluation window of radius R → Weight function modeling influence of nearby features

$$PD(x,y) = \rho(x,y,R) \otimes w(x,y,R)$$

- **Incompressible:** Removal rate scaled by pattern density which depends on weight function computed by contact wear model : step height reduction is linear.
- **Compressible:** Up area removal rate proportional to step height (Burke, Tseng) : step height reduction becomes exponential
  - Large step height: The pad touches only up area
  - At transition h1, the pad touches also down areas following:



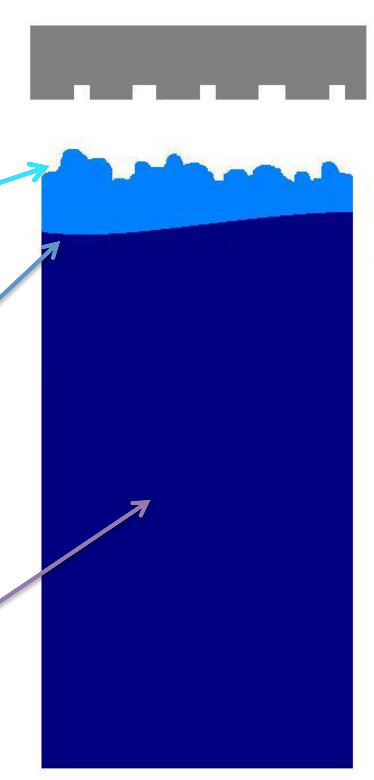
Smith: $h_1 = a_1 + a_2 \cdot e^{-PD(x,y)/a_3}$

Pad – Wafer Model

- New model: Include the **compressibility and deformation** of the multi-layered pad to output **pressures and stresses**
  - The asperities affects the **local planarization ability** of the pad: Asperities are **free-standing and deform in clusters.**
  - The exact position of the surface marking the separation between the bulk and asperities will be determined iteratively by considering the **deformation response of the asperities** to a point pressure

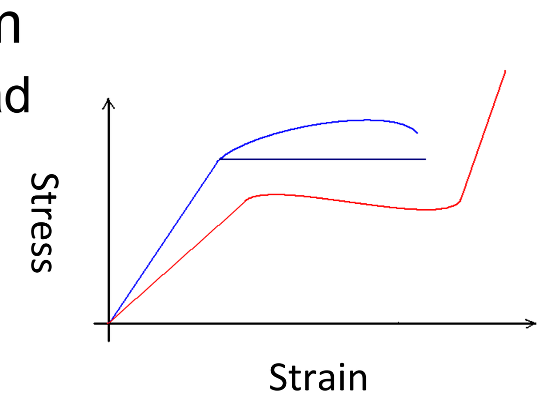
$$z(x,y) = F(x,y) \otimes P(x,y)$$

  - The bulk affects **global planarization ability** of the pad by bending over relatively long scale and following the long-range wafer surface topographical variation.



Constitutive Equations

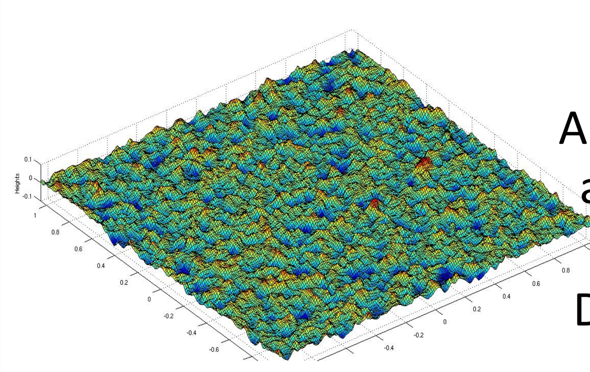
- IC1000: closed-cell elastomeric foam
  - The surface's pores makes it **rough**. Pad conditioning, wetting and grooving also makes this layer much softer.
  - The bulk is **porous** but largely impermeable.



Property	Asperities	Bulk
Measurement method	Properties tested in compression	Properties tested in tension
Elasticity / Hyper-elasticity	Low elastic modulus	High elastic modulus
Plasticity	Localized pad glazing – perfectly plastic	No plasticity
Visco-elasiticity	None as surface is regenerated by conditioning disk	Relaxation and/or creep over large period of time

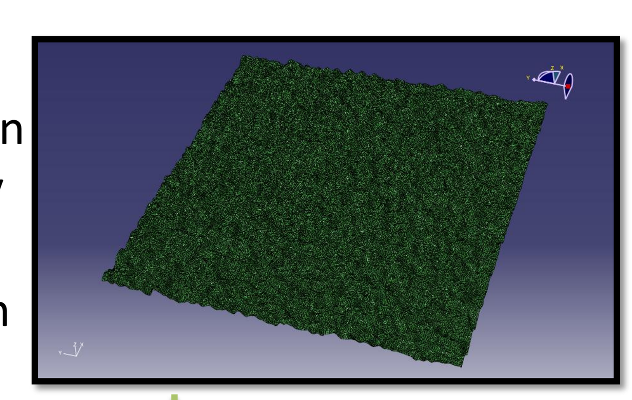
Geometry Generation

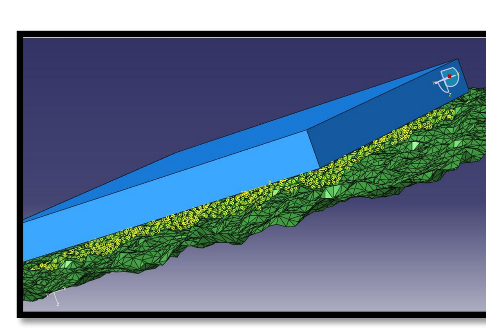
- **Generation of the rough surface:** A random distribution of points is generated. It is convoluted with a Gaussian white noise using Fast Fourier Transform . The surface approximates correctly a Gaussian probability density function and exponential autocorrelation function.



RMS = 15 µm, median asperity size: 30 µm

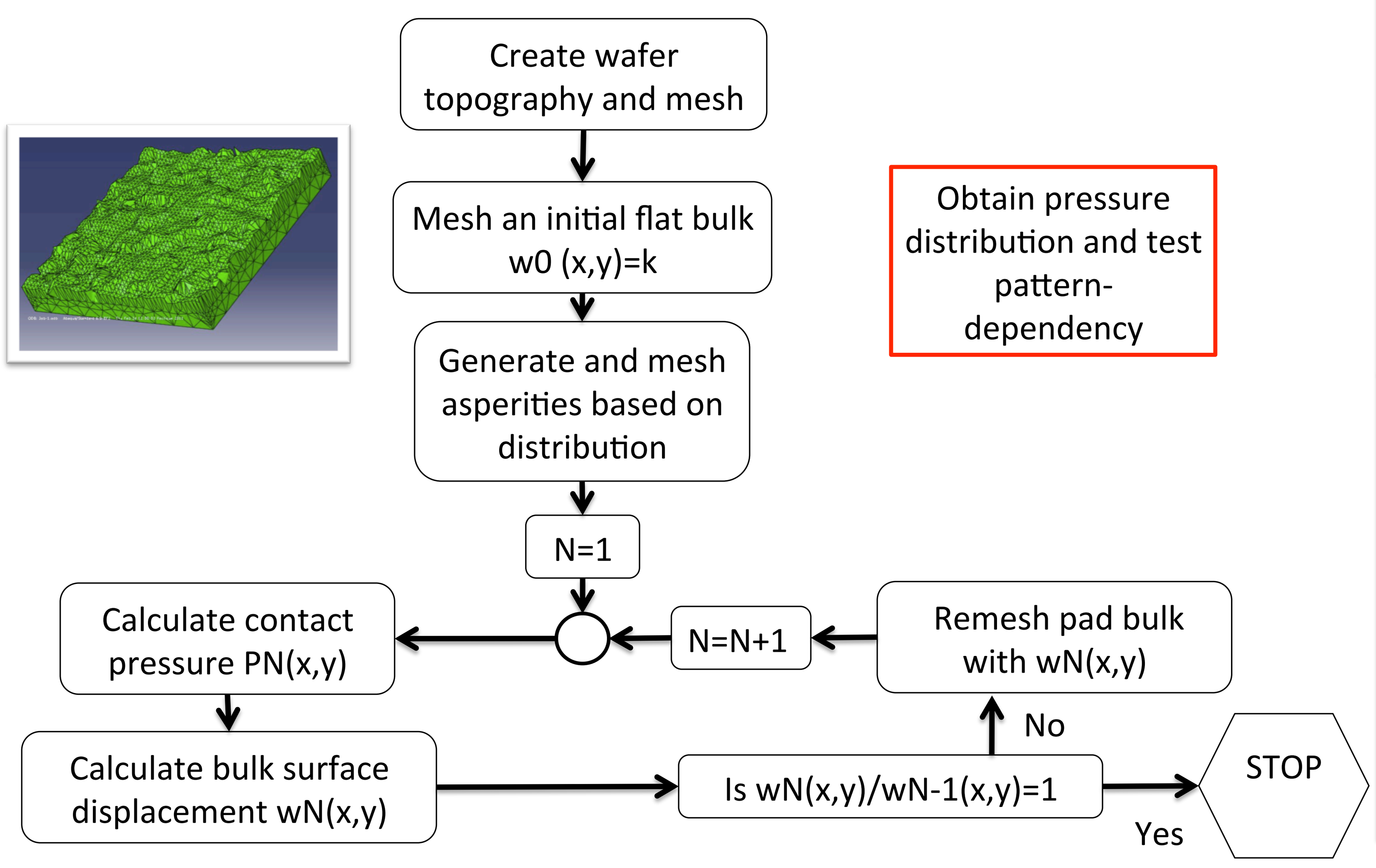
ABAQUS mesh based on a table of connectivity computed by a Delaunay triangulation





Steady-state contact mechanic

Finite Element Method for Contact Problem



- Include hyper-elastic et visco-elastic effects in constitutive equations
- Decompose the pad into several layers with their own mechanical properties
- Include all parameters: retaining rings, asperities, slurry, sub-pad, grooves…
- Obtain pressure distribution dynamically
- Relate the pressure distribution to the removal rate using the LMAS Copper CMP Material Removal Model

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