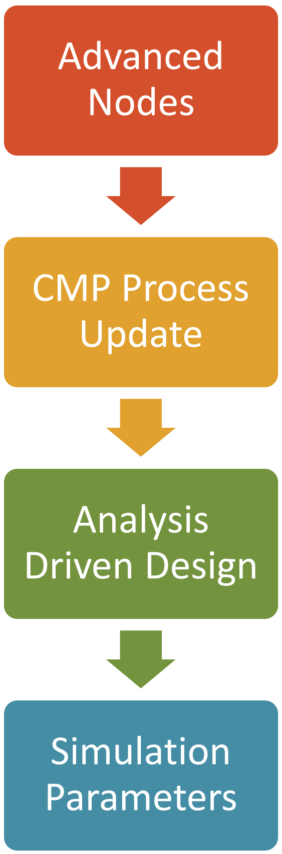
MODEL VERIFICATION TECHNIQUES FOR ANALYSIS OF EDGE ROLL OFF EFFECTS DURING THE CMP PROCESS

Justin Isaacs, Engineering Manager

2024-12-05

INTRODUCTION



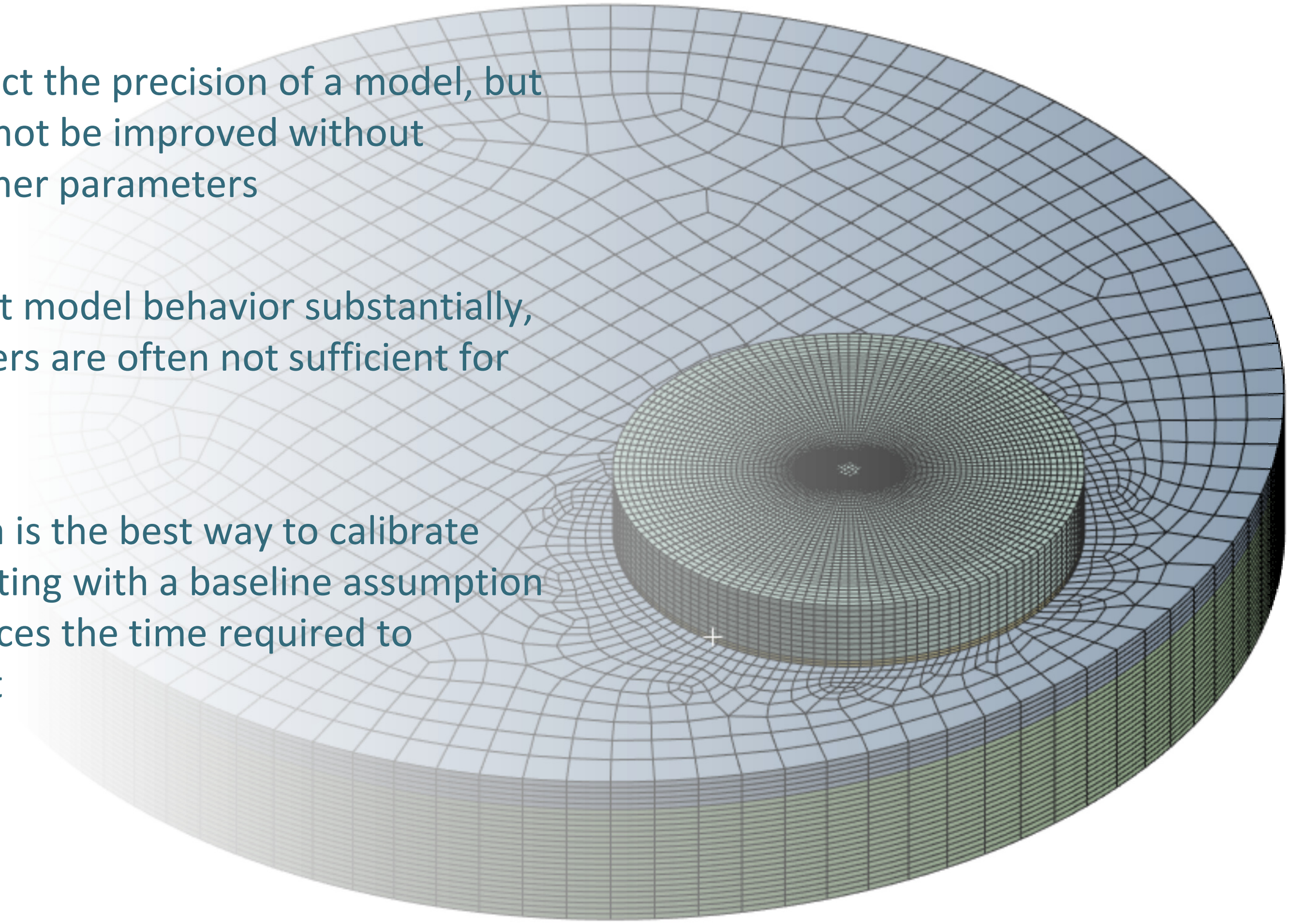
- As advanced nodes continue to drive challenges in the CMP process, accurate finite element models (FEMs) are necessary to meet the needs of the industry

- For any analysis of the CMP process, well-defined contact parameters are critical for accurately modeling the load distribution between the wafer and retaining ring, as well as evaluating pressure uniformity
  - Software-defined parameters often need tuning to drive reliable and accurate results

- Design optimization studies which aim to address minimizing edge roll-off effects during the CMP process require specialized modeling techniques to properly simulate pad/wafer edge contact

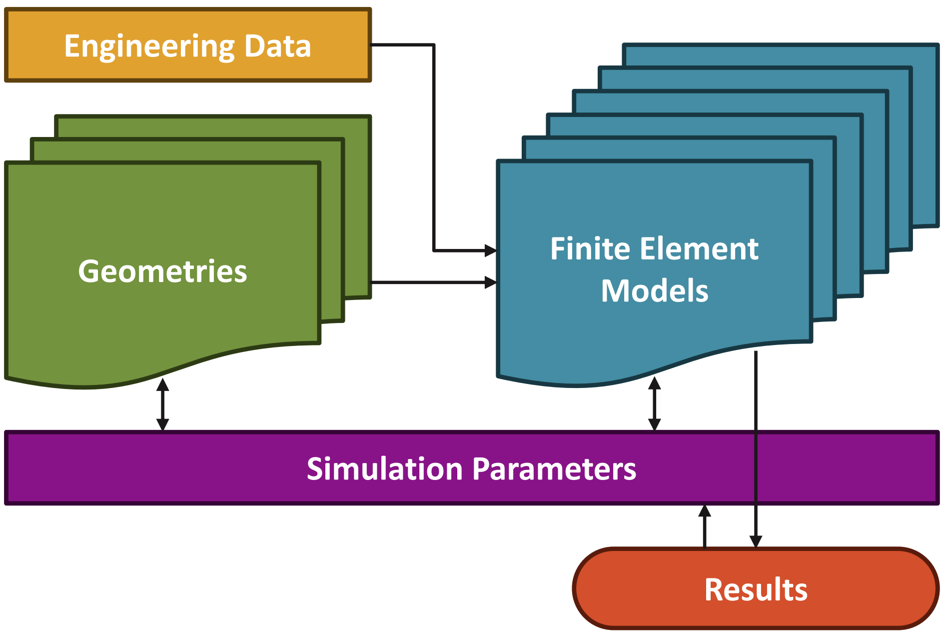
- An idealized FEM of a CMP assembly was developed to explore model parameters that ensure meaningful results
  - A sensitivity study was performed to demonstrate the importance of understanding software-defined parameters in a non-linear contact model

BACKGROUND



- Mesh density studies can impact the precision of a model, but the accuracy of the model cannot be improved without understanding the effect of other parameters
- Contact parameters can impact model behavior substantially, and default software parameters are often not sufficient for generating an accurate model
- Anchoring a model to test data is the best way to calibrate unknown parameters, but starting with a baseline assumption that closer mimics reality reduces the time required to converge on an accurate result

EXPERIMENTAL PROCEDURE



- Reference model generated from paper [1]
- Engineering Data
  - Material properties
- Geometries
  - 2D Axisymmetric and 3D
  - Double sided and single sided configurations
  - Wafer/retainer offsets
- Simulation Parameters
  - Contact stiffness
  - Friction
  - Nodal alignment
- Results
  - Contact pressure distribution
  - Computation time

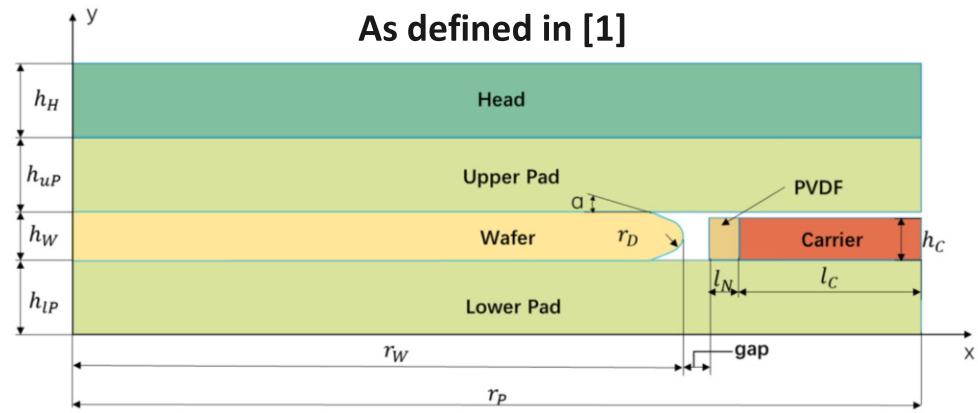
[1] J. Chen, Y. Liu, D. Wang, W. Yu, and L. Zhu, "Numerical Analysis in Double-Sided Polishing: Mechanism Exploration of Edge Roll-Off," Materials, vol. 17, no. 19, p. 4761, Sep. 2024, doi: https://doi.org/10.3390/ma17194761.

Geometry, Material Properties

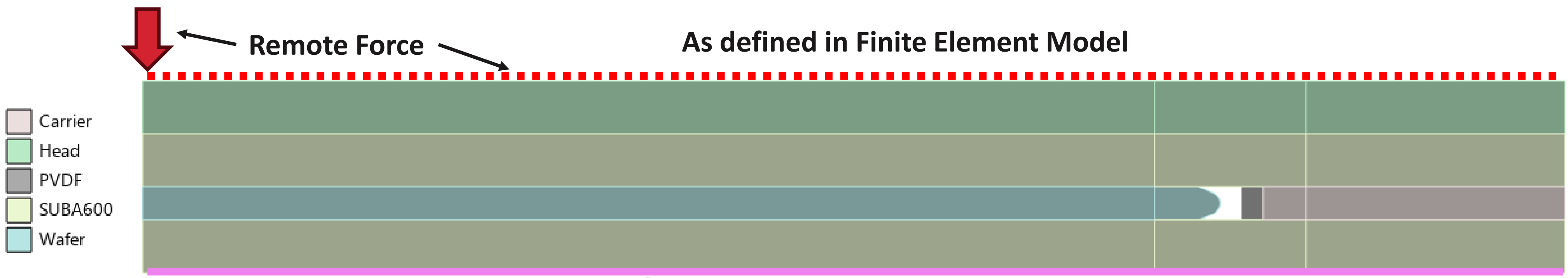
- Reference geometry and material properties from [1]

Part	Young's Modulus (MPa)	Poisson's Ratio
Head	5000	0.3
SUBA800M2	205.8	0.2599
SUBA600	34.14	0.2448
SL12	243.25	0.3229
Carrier	193,000	0.31
Wafer	190,000	0.27
PVDF	840	0.3

As defined in [1]



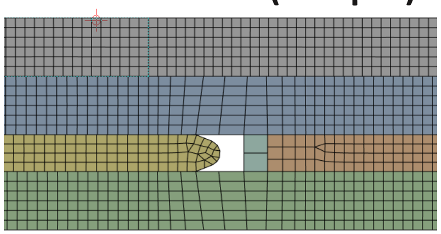
As defined in Finite Element Model

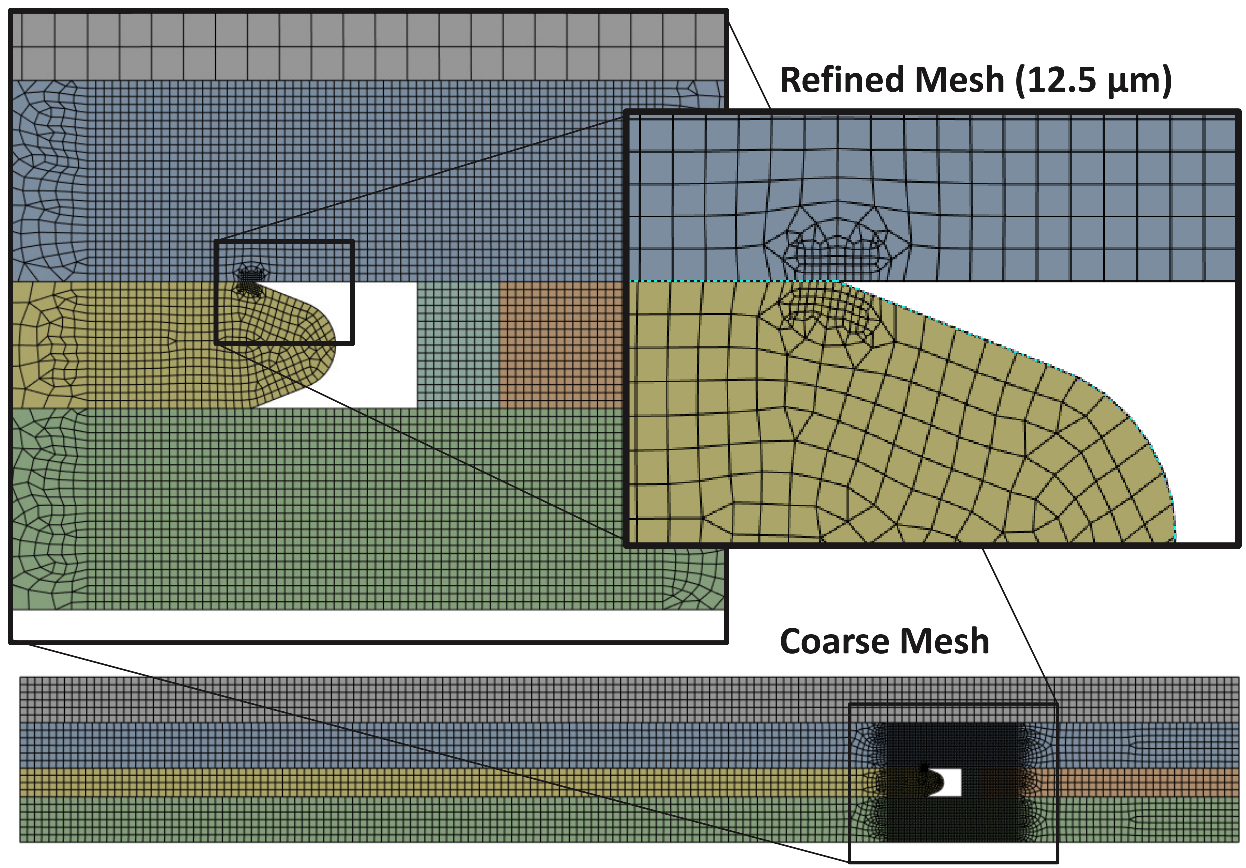


Mesh Definition

- Coarse mesh used for stiffness representation remote from area of interest
- Fine mesh used around edge roll off locations
- Refined mesh used at corner contact location
- Grid size was not specifically studied or converged upon
- Grid sizes tested: 500 – 12.5 µm

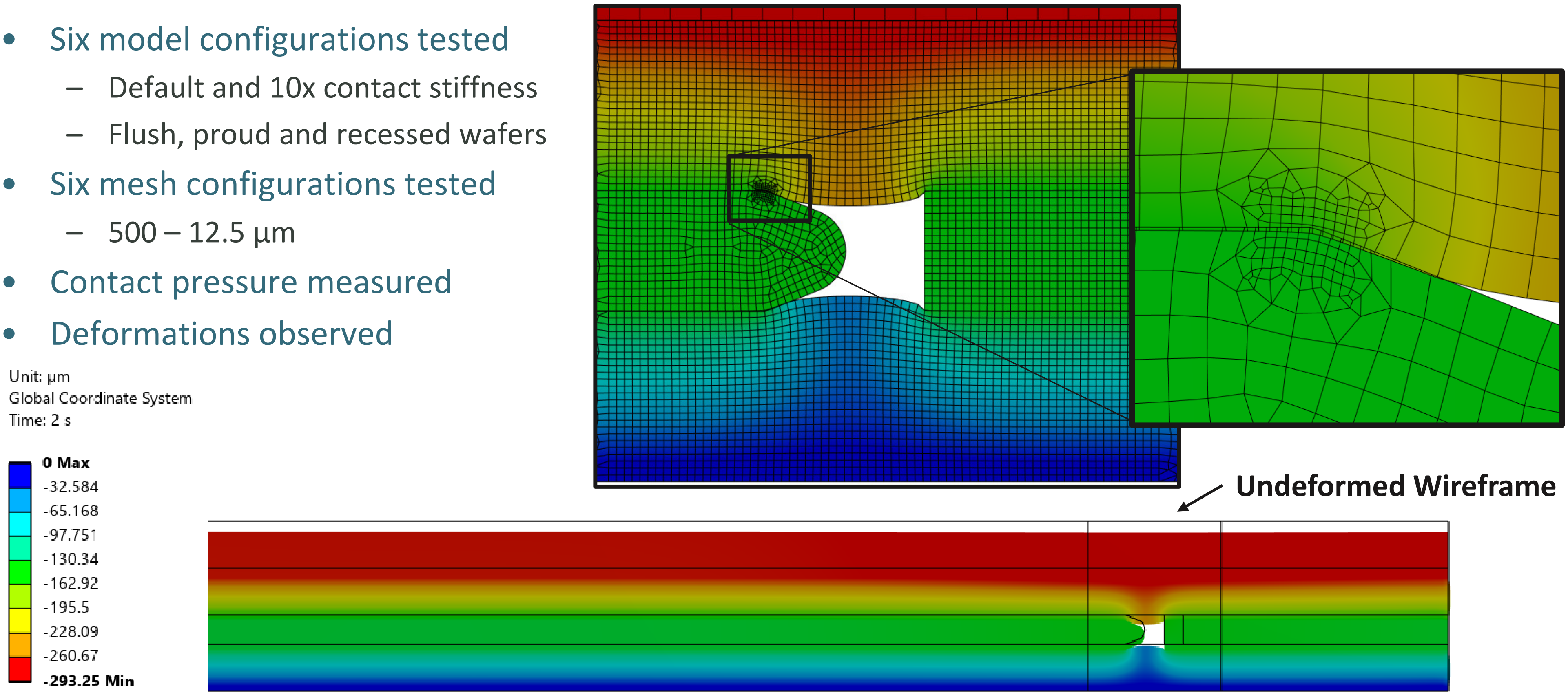
Coarsest Mesh (500 µm)





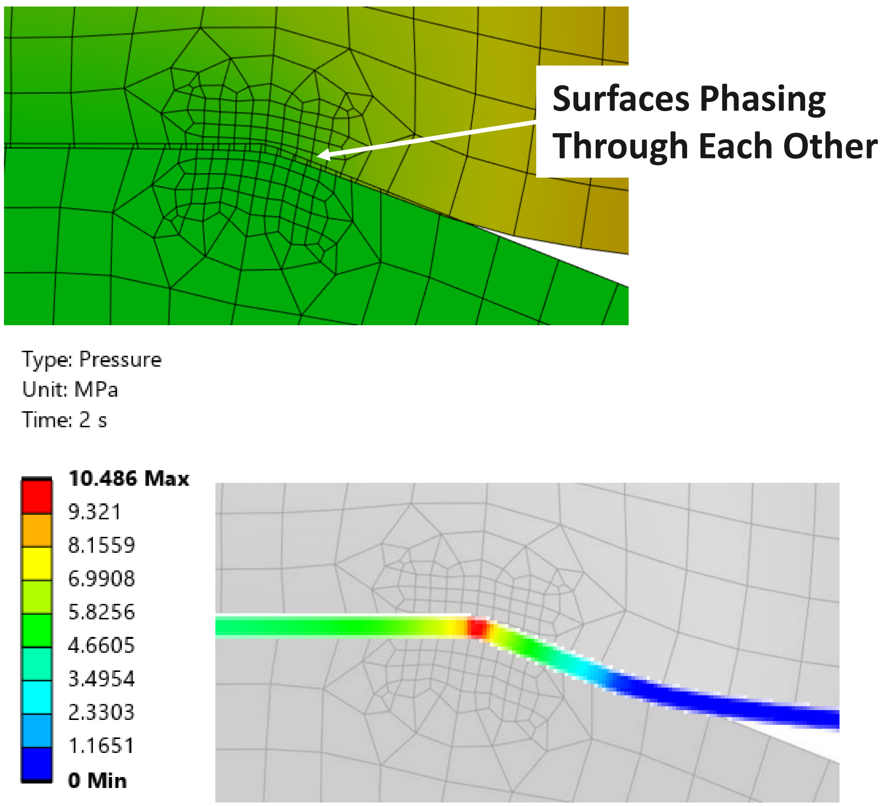
Results | 2D FEM Contact Stiffness

- Six model configurations tested
  - Default and 10x contact stiffness
  - Flush, proud and recessed wafers
- Six mesh configurations tested
  - 500 – 12.5 µm
- Contact pressure measured
- Deformations observed

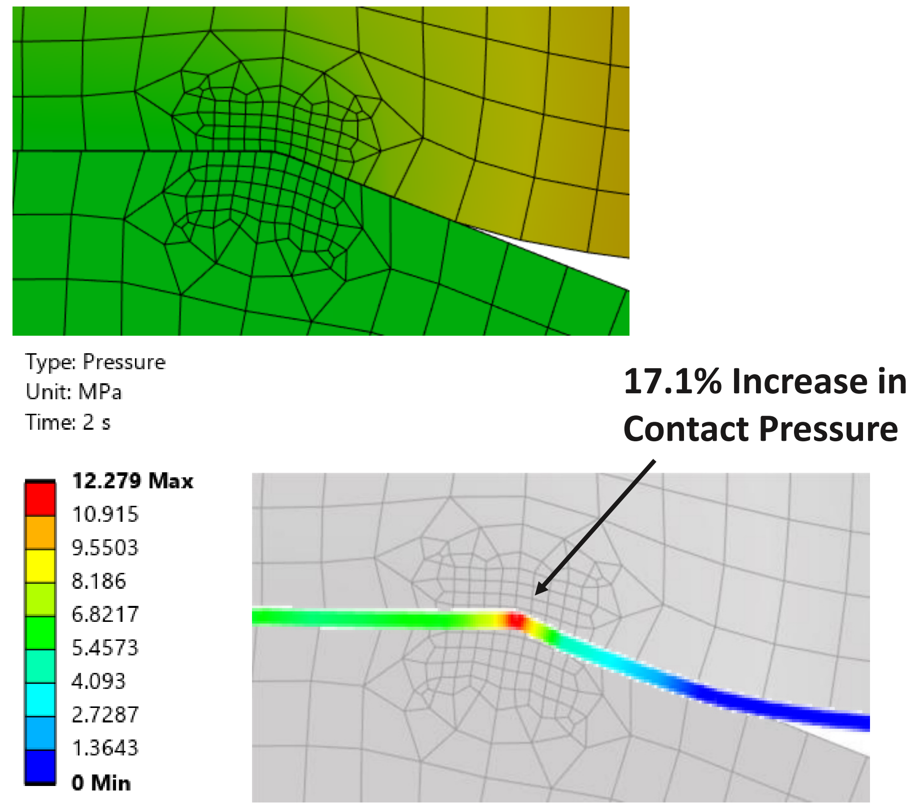


RESULTS | 2D FEM CONTACT STIFFNESS

Default Contact Stiffness

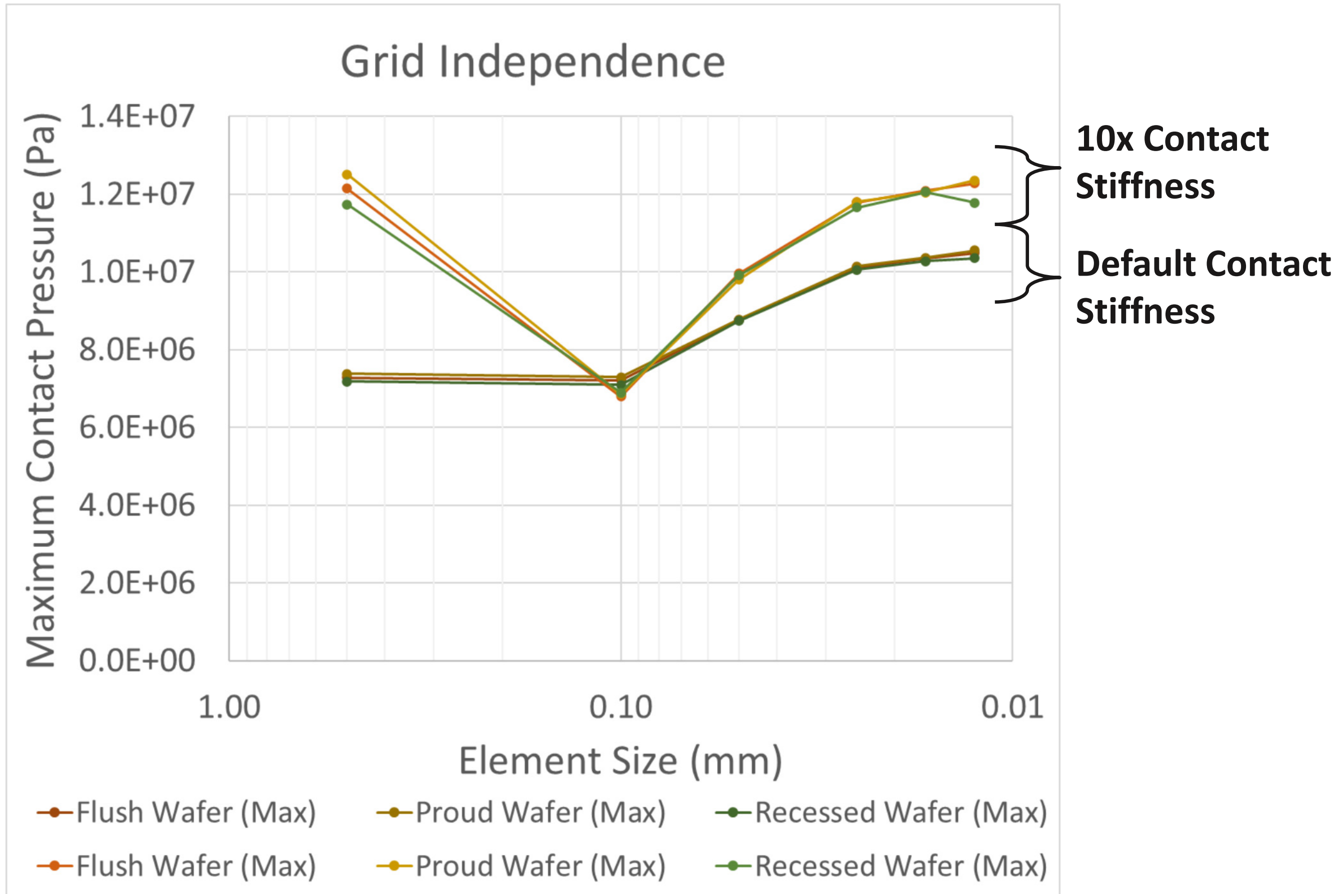


10x Contact Stiffness



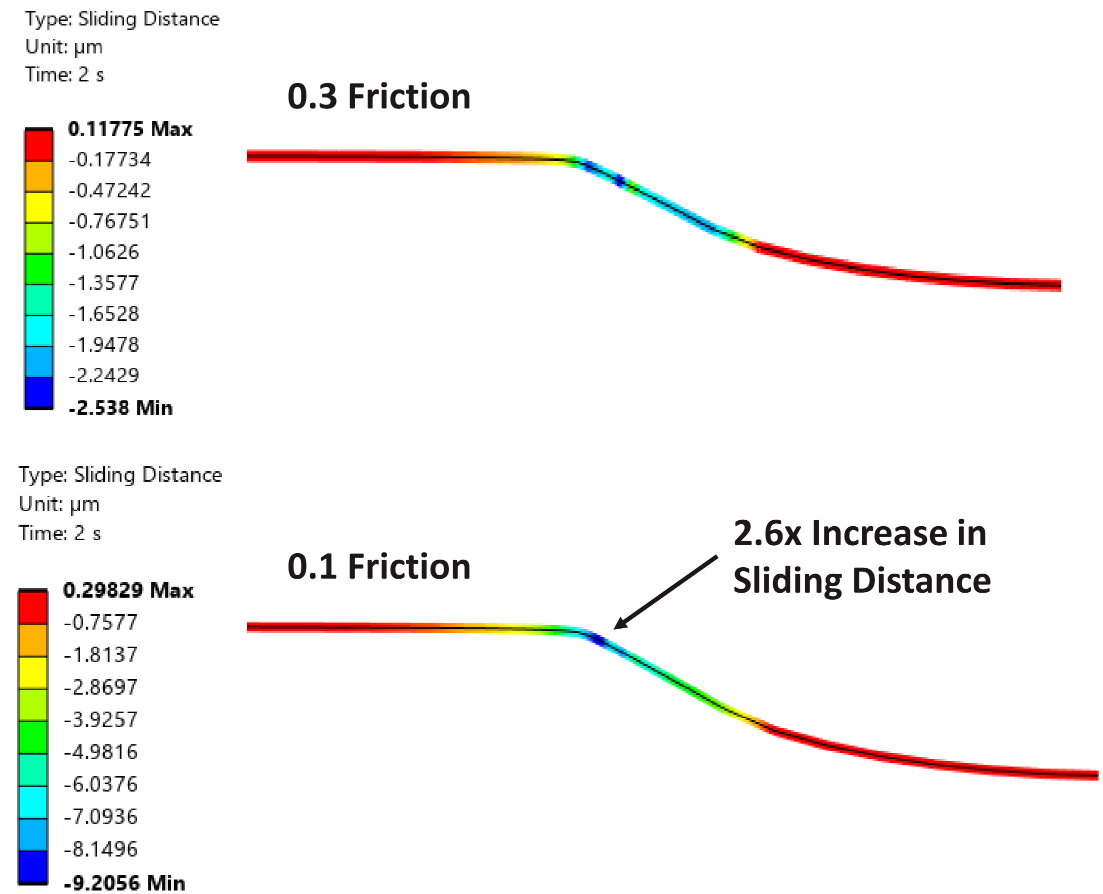
RESULTS | 2D FEM CONTACT STIFFNESS

- Contact pressure is sensitive to contact stiffness
  - Peak contact stiffness on corner of wafer
  - Contact spread influence
- Contact behavior related to contact stiffness
  - Contact surface phasing
- 0.1x contact stiffness results were too soft
  - Did not reach grid independence (not shown)
  - Excessive surface phasing



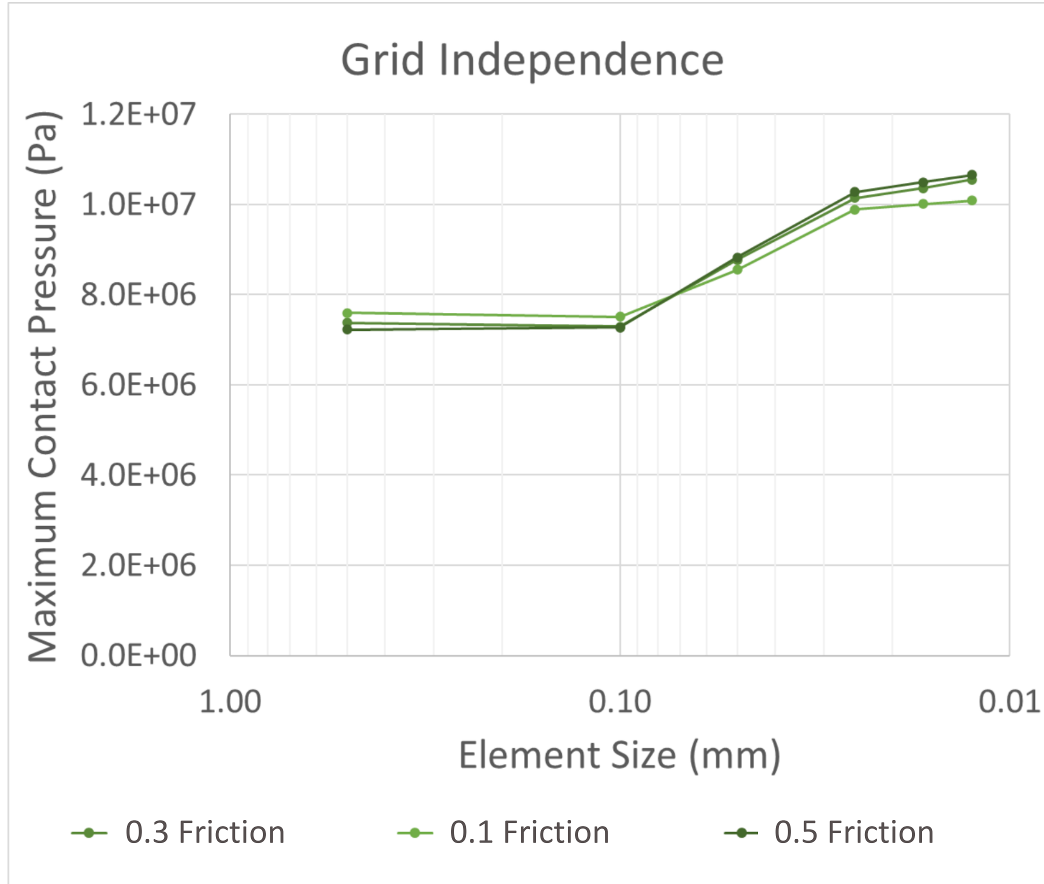
RESULTS | 2D FEM FRICTION

- Default contact stiffness used
- Nine model configurations tested
  - Friction: 0.1, 0.3, 0.5
  - Flush, proud and recessed wafers
- Six mesh configurations tested
  - 500 – 12.5 µm
- Contact pressure measured
- Sliding distance measured
- Deformations observed



RESULTS | 2D FEM FRICTION

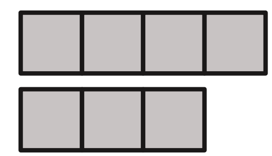
- Contact pressure in axisymmetric models not sensitive to friction
  - Vertical loads only
    - No rotation simulated
  - Frictionless and low friction (0.1) tend to underpredict contact pressure
- Similar results for all geometry configurations
- A true wear model with rotations against pad simulated will increase the sensitivity of contact pressure to friction



Results | Other Considerations

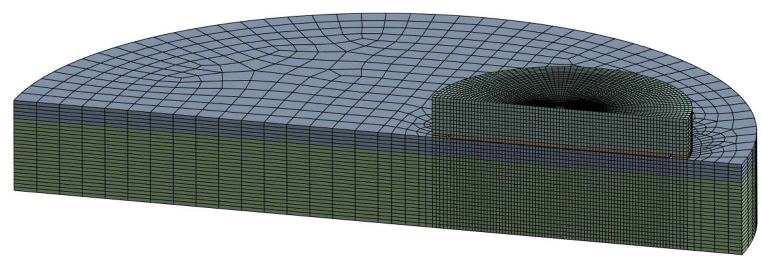
- Nodal Alignment
  - The alignment of nodes from the contact surface to the target surface requires careful consideration. Best practices vary by software and contact detection methods. Refer to the software's technical manual for advice
- Moving from 2D to 3D
  - 2D models are great for rapid iterations (optimization) and tuning model parameters (sensitivity studies)
  - 3D elements recommended for confirmation of final results
    - Axisymmetric and 2D plane models have reduced degrees of freedom and different element shape functions
  - A 3D model with equivalent mesh resolution will have a significant increase in computational requirements
    - Axisymmetric models in this study: a few minutes of solve time on local hardware
      - 4 cores of Intel(R) Core(TM) i9-10885H CPU @ 2.40GHz
      - 64 GB RAM
    - 3D models used in this study: several hours on solver rack
      - 12 cores of Intel(R) Core(TM) i9-7920X CPU @ 2.9GHz
      - 128 GB RAM

Aligned Elements



Offset Elements

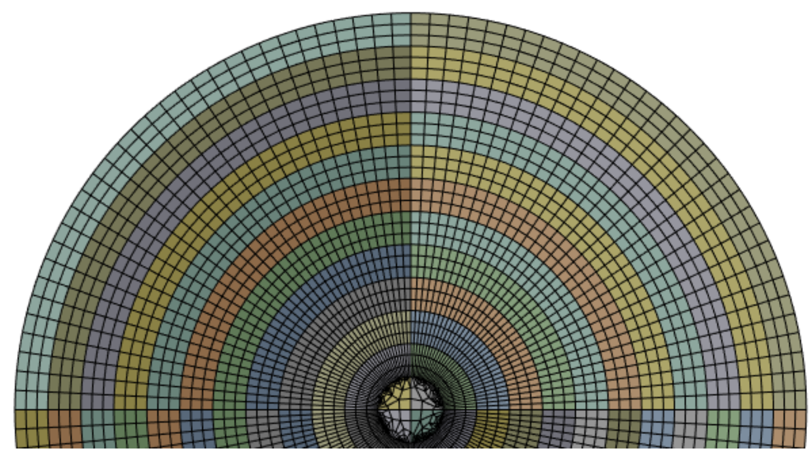
3D FEM of Single-Sided CMP Assembly



Conclusions and Future Work

- Contact pressure, the performance-driving output of CMP simulations, is sensitive to the methodology and parameters used to define the contact between the wafer and the polishing pads
  - Contact stiffness is the leading driver of sensitivity to results
    - Contact stiffness should be tuned to avoid contact surface phasing
      - while still maintaining reasonable convergence times
  - It is important to consult the software's technical manual to ensure compliance with best practices
- During design and sensitivity studies, use model reducing strategies (2D, axisymmetric, symmetry)
  - Maintain reasonable grid independence (mesh size convergence)
- Future work to be performed
  - Optimization routines recommendation
  - Tuning wafer/retainer heights
  - Multi-zone secondary pressure carrier designs

Multizone FEM



For additional information, please contact:

Justin Isaacs
Engineering Manager
Justin.isaacs@quartus.com

CITATIONS

[1] J. Chen, Y. Liu, D. Wang, W. Yu, and L. Zhu, “Numerical Analysis in Double-Sided Polishing: Mechanism Exploration of Edge Roll-Off,” Materials, vol. 17, no. 19, p. 4761, Sep. 2024, doi: https://doi.org/10.3390/ma17194761.