# ME461A: Manufacturing Technology

## Yield Improvement in Wafer Planarization: Modelling and Simulation

### A Literature Review


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# Introduction

- Chemical Mechanical Polishing (CMP) Process: A chemical and mechanical process being performed together to reduce height variation across a dielectric region.

- A key process steps during the fabrication of Ultra/Very Large Scale Integrated (ULSI/VLSI) chips in Integrated Circuit (IC) manufacturing.

- It has become the second-fastest growing area of semiconductor equipment manufacturing.

- It has emerged to be the most promising because of its capability to provide better local and global planarization of wafer surfaces.

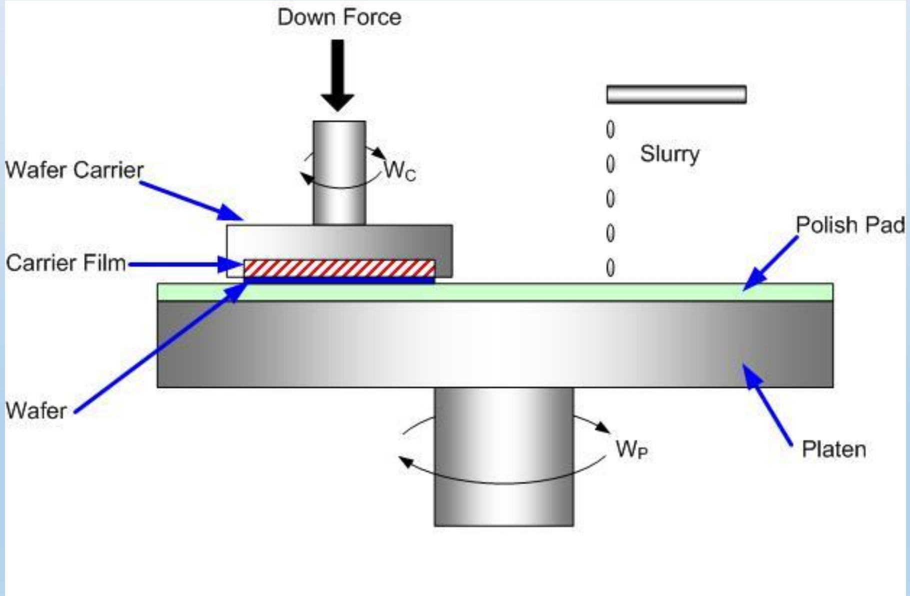


Figure 1: Schematic of CMP[1]

[1]Adapted from: http://www.ntu.edu.sg/home/mdlbutler/Research/Research_CMP.htm

# Motivation

- Wafer-scale uniformity has a significant impact on the yield from a wafer and is of critical importance to the IC manufacturing community.
- The polishing process adds value up to 3 to 4 times in the final product.
- The existing theories are not capable of predicting actual aftermaths efficiently.
- If one will succeed in producing a better theory, then it will make revolutionary impact on international chips market.
- A slight change in the quality or efficiency can make the product more cheaper and reliable.

# Timeline

- 1983 – Project launched at IBM Base Technology Lab in East Fishkill, NY
- 1986 – Oxide CMP development and pilot line (IBM)
- 1988 – Tungsten CMP development (East Fishkill and Yorktown Heights)
- 1988 – Sematech CMP project launched and first adopters outside of IBM
- 1992 – CMP first included in SIA roadmap
- 1995 – Industry embraces CMP. Ramping in numerous fabs.
- CMP is now accepted as a “mainstream” process in fabs worldwide

# Progress

- Preston in 1927 provides the MRR equation: $dH/dt = K_p PV$.

- Zhang et al. (1999) proposed $MRR = K_p\sqrt{PV}$, taking into account the normal and shear stress between abrasive particles and wafer surfaces.

- Zhao and Shi (1999) presented $MRR = K_p P^{2/3} V$ arguing that the number of abrasives between wafer and pad increase with the contact area.

- Luo and Dornfeld (2001) also introduced a nonlinear MRR model based on statistical distributions of abrasive particles.

- Fu et al.(2001) introduced another nonlinear MRR model based on the concept of incomplete and complete contact between the wafer and the pad.

# Wafer Scale Modelling: Assumptions

- Within wafer non-uniformity in MRR is primarily caused by the variation in contact pressure near the edge of wafer.
- Material removal occurs primarily due to solid-solid contact.
- Hydrodynamic effect is responsible for the slurry distribution.
- Pre-existing wafer curvature is modelled as quadratic equation $a_2r^2$.
- The wafer is initially subjected to a rigid body displacement of $a_0$ (in $nm$) due to the down load.
- Friction is considered only in hoop direction and neglected in the radial direction.

# Wafer Scale Modelling: Process

- An analytical expression is derived for the contact pressure distribution at the pad-wafer interface.
- The displacement field right under the wafer can be expressed as:

$$f(r) = a_0 + a_2 r^2$$

- This problem is decomposed into two cases with weak coupling between them and solved using superposition.

- Case I: The BC at $z = 0$ are as follows:
  - $\tau_{zr}^{(1)} = 0$ $(0 \leq r < \infty)$
  - $\tau_{z\theta}^{(1)} = 0$ $(0 \leq r < \infty)$
  - $\sigma_{zz}^{(1)} = 0$ $(r > a)$
  - $u_z^{(1)} = f(r)$ $(0 \leq r \leq a)$

- Case II: The BC at $z = 0$ are as follows:
  - $\tau_{zr}^{(2)} = 0$ $(0 \leq r < \infty)$
  - $\sigma_{zz}^{(2)} = 0$ $(0 \leq r < \infty)$
  - $\sigma_{z\theta}^{(2)} = 0$ $(r > a)$
  - $\tau_{z\theta}^{(2)} = \mu \sigma_{zz}^{(1)}$ $(0 \leq r \leq a)$

where $f(r)$ describes the position of the wafer, $\tau_{zr}$ and $\tau_{z\theta}$ are the shear stresses, $\sigma_{zz}$ is the normal stress (contact pressure) and $\mu$ is friction coefficient.

# Wafer Scale Modelling: Results

- By superposition of Case I and Case II the final solution is:

$$\sigma_{zz}\big|_{z=0} = \sigma_{zz}^{(1)}\big|_{z=0} =$$

$$-\frac{1}{2\sqrt{\pi}} \cdot \frac{E}{1-\nu^2} \sum_{k=0}^{n} a_k (1+k) \cdot a^{1+k} \cdot \frac{\Gamma\left(\frac{2+k}{2}\right)}{\Gamma\left(\frac{3+k}{2}\right)} \cdot \left\{ \frac{1}{r^2} \left[ \frac{1}{\sqrt{1-\frac{r^2}{a^2}}} {}_2F_1\left(\frac{1}{2}; -\frac{1+k}{2}; \frac{1-k}{2}; \frac{r^2}{a^2}\right) \right] \right\}$$

(Eamkajornsiri et al. 2003)

where k is the order of the polynomial which is 2, G is the hyperbolic function, and F1 is the hypergeometric function.

- The pressure distribution on the contact area can be expressed as follows:

$$P(r) = K \frac{4a_2 r^2 + (a_0 - 2a_2 a^2)}{(a_0 - 2a_2 a^2)\sqrt{1-\left(\frac{r}{a}\right)^2}}$$

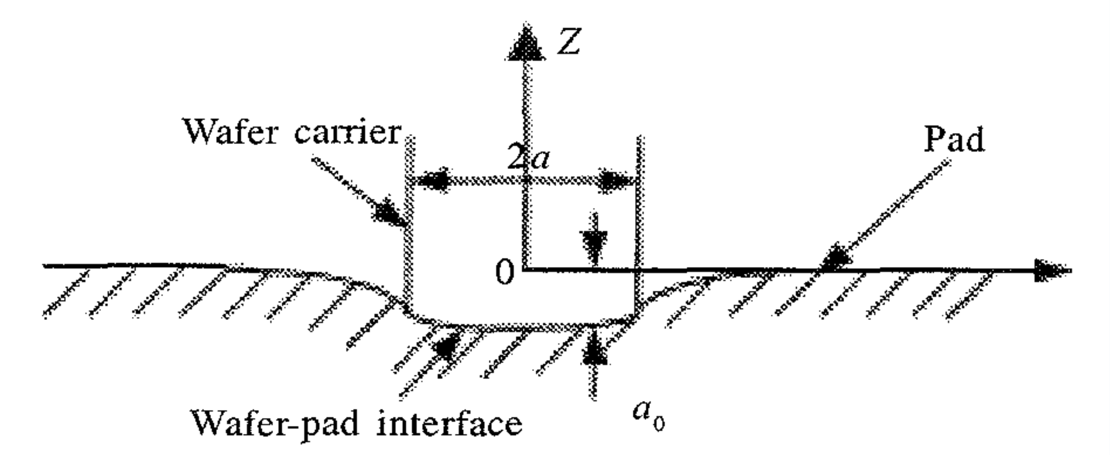


Figure 2: Model of Pad and Wafer Contact.
(Eamkajornsiri et al. 2003)

# Wafer Scale Modelling: Results

- For low load, the pressure profiles slope downwards.
- As the load increases, the pressure at the edge starts rising and at high loads, the increase in pressure is even higher.
- A uniform pressure profile would result in the best surface.

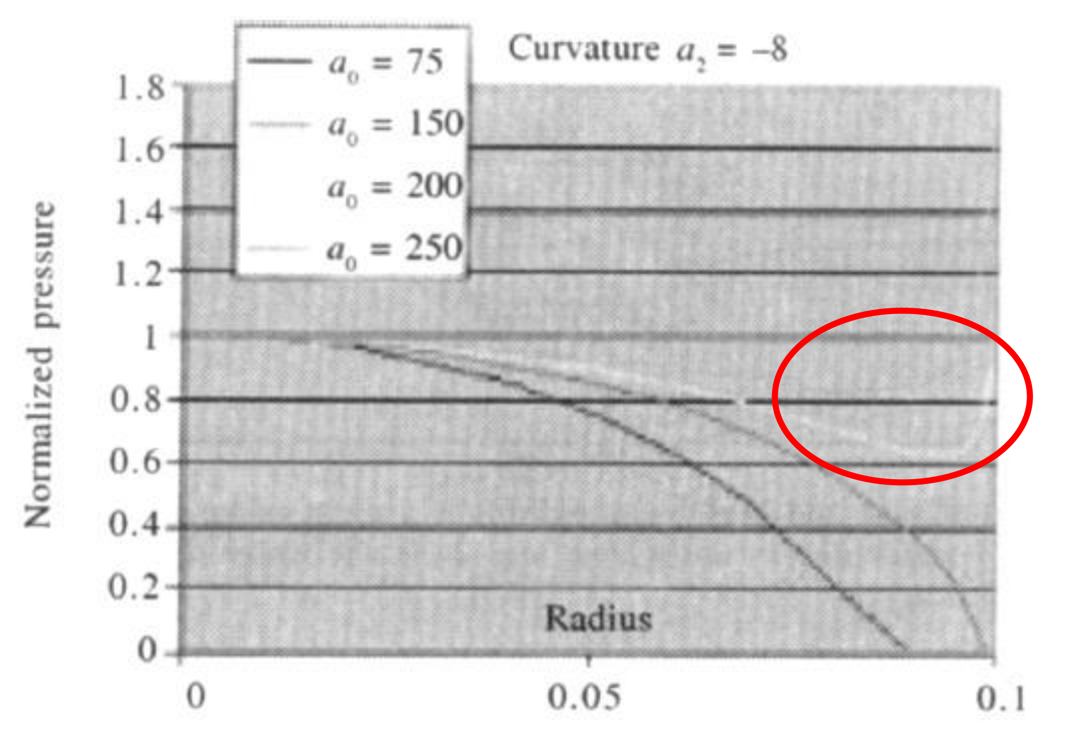


Figure 3: Normalized Pressure Profile Curves, $a_0$: indentation depth. (Eamkajornsiri et al. 2003)

- Note that the curvature is continuously changing as material is removed.
- Choose pressure profiles such that they compensating the upward-sloping pressure profiles with downward-sloping pressure profiles.

# Experimental Observations

- Experimental Conditions
  - Down Pressure: 6psi
  - Pad annular velocity is 35 rpm
  - Wafer annular velocity is 20 rpm
  - Wafer diameter is 200 mm
  - Offset distance between the axes of pad and wafer is 170 mm
  - Kp = 11.2 x 10-10 1/psi
  - Oxide thickness is 8000 Å
  - Desired final surface height is 1000 Å
  - Tolerance 200 Å
  - Carrier Film: R200T3 with modulus of elasticity of 10 psi.

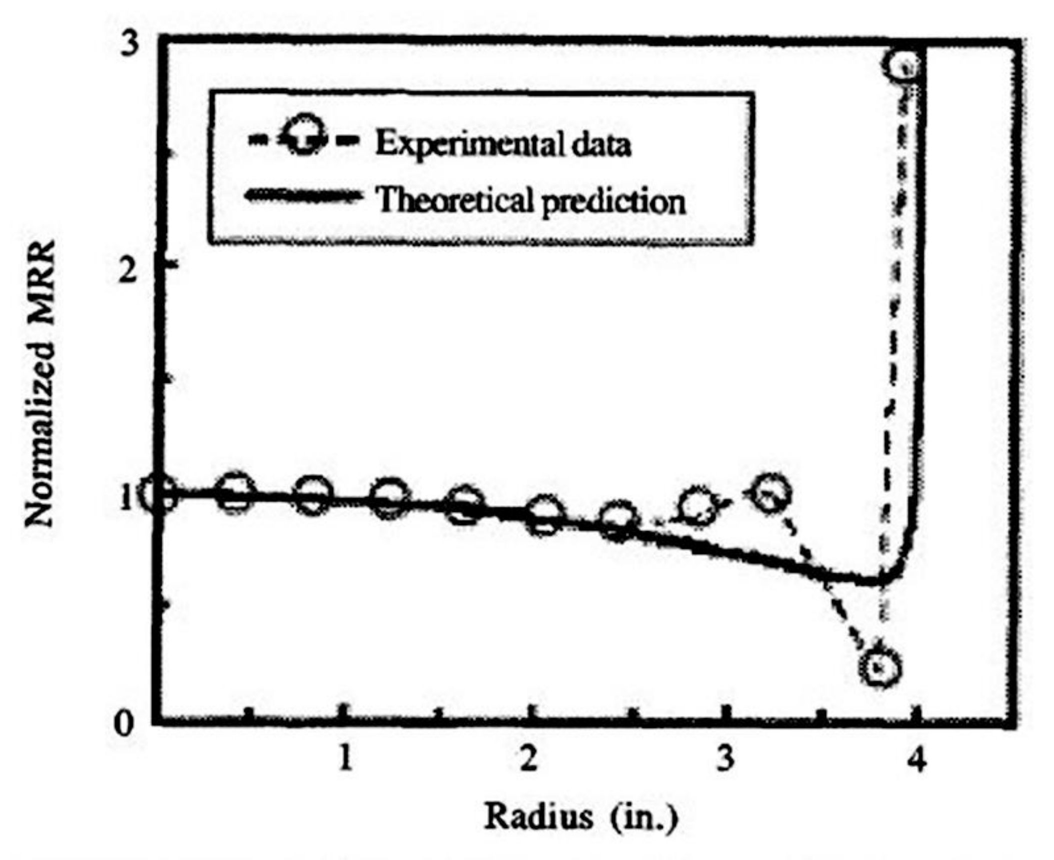


Figure 4: Model-Predicted MRR against Experimental Observations. (Srinivasa Murty et al. 1997)

# Present vs. Experimental Observation

- The MRR (material removal rate) is almost constant at the centre and is very high at the wafer edges.
- The theoretical and experimental data are consistent as long as radial distance does not exceed 3 in ( for a 4 in wafer radius).
- The extreme variation of model and experiment is also consistent.
- The rigid wafer model fails within an annular region of 1 in from wafer edge and does not capture the local peak and valley of MRR.

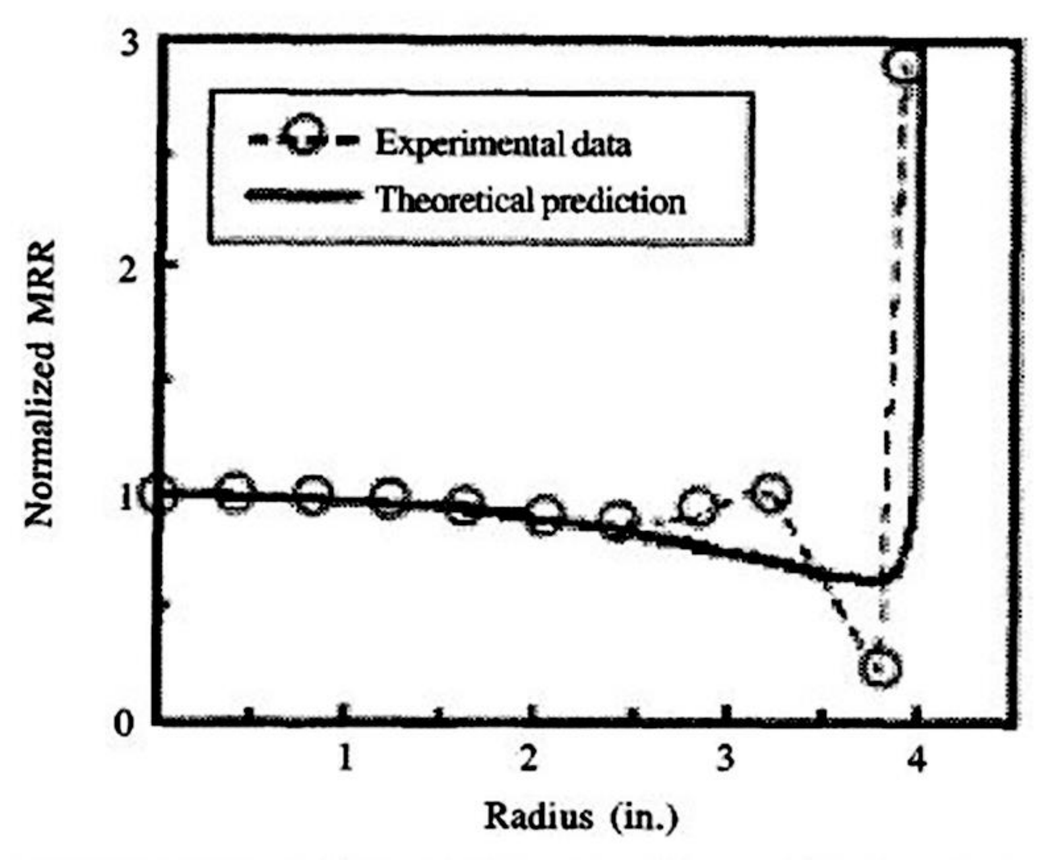


Figure 5: Model-Predicted MRR against Experimental Observations. (Srinivasa Murty et al. 1997)

# Conclusions

- Present model recognizes the following as important parameters in determining the quality of wafer planarized by CMP process:
    i. Within wafer non-uniformity (WIWNU), and
    ii. Wafer curvature

- Simulation results confirm that the CMP setup and process parameters causes the edge effect.

- The model can be used to observe the temporal and spatial variation of pressure which can be used to predict wafer yield and determine the stopping time.

- Varying the wafer curvature modify the spatial pressure distribution profile from a downward-sloping (edge slow) to an upward-sloping (edge fast). This can be used to make the entire surface of wafer uniform at the stopping time.

# Conclusions

- In CMP process, over polishing occurs at the periphery and diminishes yield.

- The model-based simulation is also capable of identifying optimum polishing time for maximization of wafer yield.

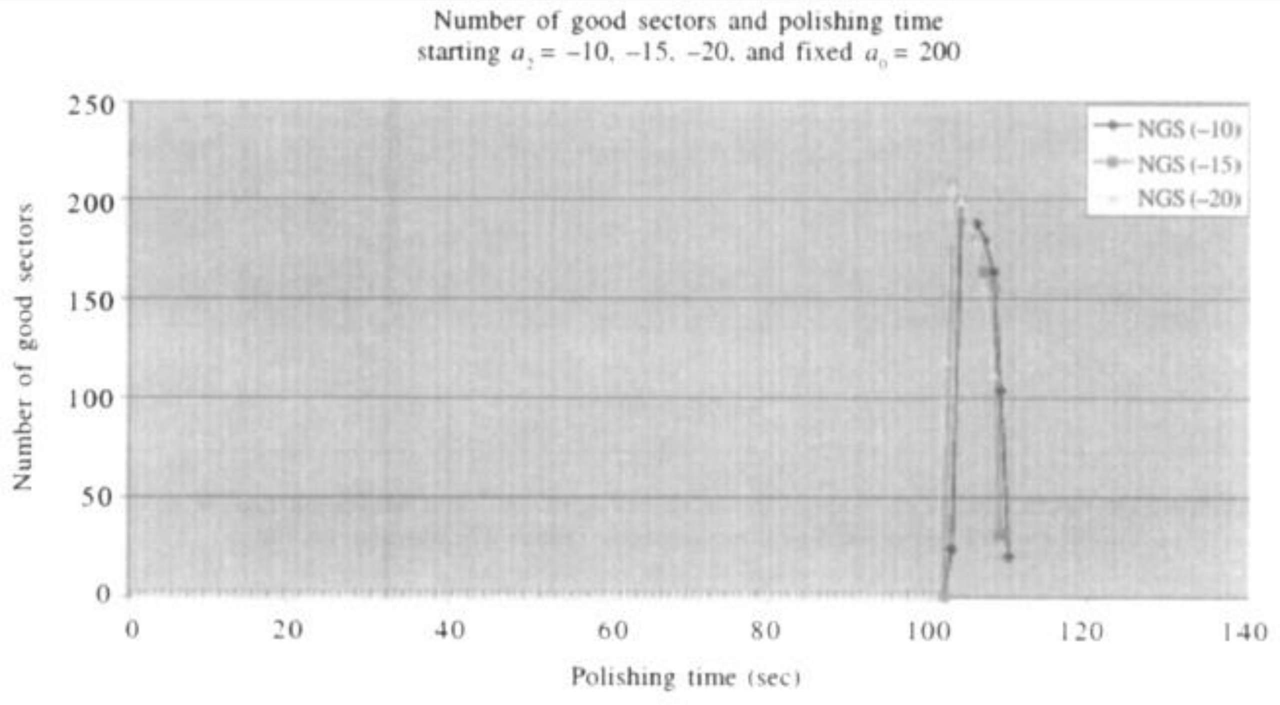


Figure 6: Variation of Wafer Yield with Polishing Time.
(Eamkajornsiri et al. 2003)

- As indicated by graph obtained from simulations, wafer yield is high only for a very short time period, making CMP stopping time estimation a very important parameter.

# Thank You