

Proposal # 4: The Mechanics of CMP and Post-CMP Cleaning

Sinan Muftu, Ahmed Busnaina and George Adams, Northeastern University

Goals and Objectives

The goal of our activities is to conduct a detailed analysis of the mechanics of particle, wafer and pad (or brush) interaction in CMP and post-CMP cleaning processes. We propose to study the real contact pressure at the interface between the pad and wafer, pad and particle or particle and wafer as a function of pad or wafer asperity distribution, deformation and height. The contact pressure variation can also be measured experimentally as a function of engagement height. Consequently, the relation between the real contact pressure and the apparent contact pressure, i.e., $p_r = g(p_a)$, can be established. The apparent contact pressure over the contact area results from the macro scale force equilibrium of the two contacting bodies. This analysis and model will have the capability to bridge the fluid and solid mechanics at the macro level with the forces required for the interaction of particles with the wafer and pad at the micro level.

Project Description

Contaminant particles adhere to the surface of a wafer due to van der Waals adhesion force and double layer forces. In post-CMP cleaning processes, external forces are applied to overcome the bonds between the contaminant particles and the wafer. The success of the cleaning operation i.e., removal of the particles depends on our ability to apply the necessary removal force on the particles. Particle removal involves the interactions of the forces in macro and micro length scales as depicted in Fig. 1. The CMP process is strikingly similar in that regard where a polymer (pad), particle and the wafer interact. Surfaces of the polymer (pad or brush) and wafer (before polishing) are typically rough with a seemingly random peaks and valleys¹. Surface topography can be characterized by using contact (stylus) or non-contact (optical) profiling instruments. Characteristics of the surface topography are related to the manufacturing methods used in obtaining the surface. In general, when two surfaces (or three if the particle is included) are brought together contact initially occurs on the tallest asperities of the surfaces. As the normal force on the surfaces is increased these asperities deform and shorter asperities start to contact each other. The real contact pressure, p_r , that occurs over the individual asperities during this process can be integrated over the overall contact area, also known as the apparent contact area, to yield the apparent contact pressure, p_a . This relation is symbolically represented as $p_a = f(p_r)$. This function depends on the material properties of the surfaces as well as the statistical distribution of surface topography parameters. Greenwood and Williamson² gave such a relation assuming that deformation of each asperity forms a Hertzian contact³:

$$p_a = \frac{4}{3} h E_c R_p \eta \left(\frac{\sigma_p}{R_p} \right) \int_d^{\infty} (s-d)^{3/2} f(s) ds$$

where $d (= h/\sigma_p)$ is the separation distance of the two surfaces, η is the asperity peak density, E_c , R_p and σ_p are composite elastic modulus, asperity tip radii, and standard deviation of asperity peak heights. Normalized probability density function for the two surfaces is $f(s)$. Non-dimensional variable s is equal to z/σ_p , where z is the measured surface height. Surfaces that display scale dependent surface height variation can be characterized by fractal analysis methods. Majumdar and Bhushan give a relation for predicting the contact pressure for fractal surfaces⁴. The contact pressure variation as a function of engagement height can also be measured experimentally. The relation between the real contact pressure and the apparent contact pressure, i.e., $p_r = g(p_a)$, can be similarly established. Then we can determine the amount of required

external force in order to apply specified local contact forces over the asperities. The apparent contact pressure over the contact area results from the macro scale force equilibrium of the two contacting bodies. Polishing pads and brush scrubbers used in CMP and post-CMP applications are made of highly deformable porous materials. In analyzing the equilibrium of such materials large deformation elasticity theory and poroelasticity should be employed ⁵. The cleaning process involves liquid which creates a lubrication layer in the interface and causes further deformation of the polishing pads or rollers, through a process known as elastohydrodynamic lubrication ⁶.

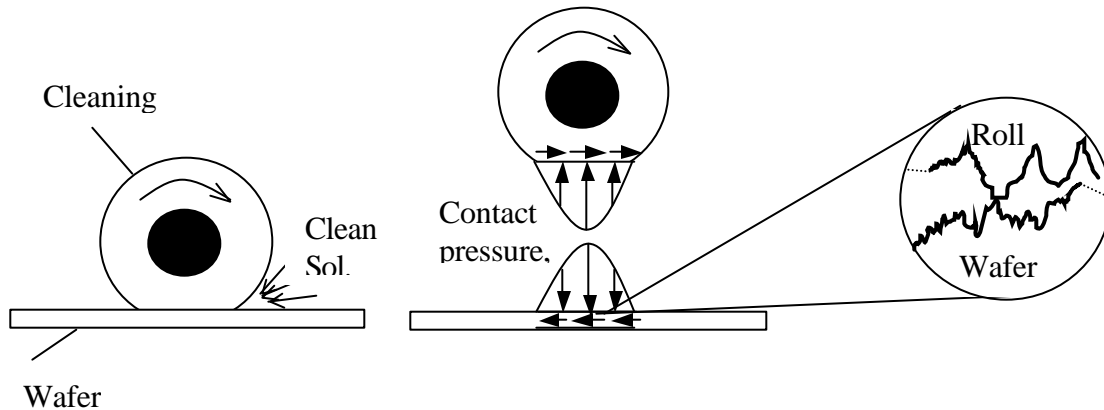


Figure 1. Different length scales are involved in a typical wafer polishing and cleaning operation.

1. Rabinowicz, E. (1995), Friction and Wear of Materials, John Wiley & Sons, NY.
2. Greenwood, J.A., Williamson, J.B.P., (1966), "Contact of Nominally Flat Surfaces," Proc. Royal Soc. of London Series A, Vol. 295, pp. 300-319.
3. Johnson, K.L., (1985), Contact Mechanics, Cambridge University Press, Cambridge, UK.
4. Bhushan, B., (1999) ed. Handbook of Micro/Nano Tribology, 2nd edition, CRC Press, Boca Raton, Florida.
5. Malvern, L.E. (1969), Introduction to the Mechanics of a Continuous Medium, Prentice-Hall, New Jersey.
6. Hamrock, B.J., (1994), Fundamentals of Fluid Film Lubrication, McGraw-Hill, New York.