Silicon/Pad Pressure Measurements During Chemical Mechanical Polishing

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Chemical mechanical polishing refers to a process by which silicon and partially-processed integrated circuits (IC's) built on silicon substrates are polished to produce planar surfaces for the continued manufacturing of IC's. Chemical mechanical polishing is done by pressing the silicon wafer, face down, onto a rotating platen that is covered by a rough polyurethane pad. During rotation, the pad is flooded with a slurry that contains nanoscale particles. The pad deforms and the roughness of the surface entrains the slurry into the interface. The asperities contact the wafer and the surface is polished in a three-body abrasion process.

The contact of the wafer with the "soft" pad produces a unique elastohydrodynamic situation in which a suction force is imposed at the interface. This added force is non-uniform and can be on the order of the applied pressure on the wafer. We have measured the magnitude and spatial distribution of this suction force. This force will be described within the context of a model of the sliding of hard surfaces on soft substrates.

Keywords: chemical mechanical polishing, interfacial pressure, silicon polishing, planarization

Introduction

Chemical mechanical polishing is extremely important in the manufacturing of integrated circuits. The polishing is done by pressing the silicon wafer into a rotating pad that is flooded with a slurry. Typically, the pad is roughened to have a $R_a \cong 5\mu m$ and the slurry pH is adjusted to oxidize the surface and the abrasive particles remove the surface oxide by a three-body abrasion process. There has been a suggestion in the literature that the polishing occurs by the hydrodynamic flow of the slurry at the interface [1]. Our research has shown that the process of polishing is consistent with asperity contact between the pad and the wafer [2]. The deformation of the pad, interfacial friction and edge effects of the wafer also leads to suction pressures at the interface. These suction pressures can be of the order of the applied loads.

Experimental Details

Figure 1 shows the experimental details of the apparatus that is used to measure the interfacial suction pressures. A fixture is manufactured with holes drilled through the thickness. A monometer or piezo- type gauge is used to measure pressure along an arc of constant velocity. Figure 2 shows a typical pressure versus location plot demonstrating a suction pressure over 2/3 of the fixture surface.

Model

A model that accounts for the suction pressure is shown in Fig. 3. The interfacial fluid pressure is generated by pressing the fixture into the polyurethane pad. This results in a pressure distribution as described by Johnson [3]. As the pad slides on the pad, the slurry is entrained in the interface and the fluid film thickness can be calculated as a function of the surface roughness using the Greenwood-Williamson equation. Next, the Reynolds' equation can be used to determine the interfacial pressure. The suction pressures eventually influence the load used in the Preston equation where the material removal rate is

$$MRR = k\frac{vP}{H}$$

where k is the wear coefficient, v is the velocity, P is the pressure and H is the hardness. In this case, P is modified to include an additional term so that

$$P = P_{applied} + P_{suction}$$

Acknowledgements

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References

[1] S. Runnels, 1994, "Tribology Analysis of Chemical-Mechanical Polishing," Journal of the Electrochemical Society, 141, 6, pp. 1698.

[2] Shan, L., Levert, J.L., Meade, L., Tichy, J., and Danyluk, S., Jul 2000, "Interfacial Fluid Mechanics and Pressure Prediction in Chemical Mechanical Polishing," Journal of Tribology, 122, 3, pp. 539–543.

[3] Johnson, K.L., 1985, "Contact Mechanics," Cambridge University Press, Cambridge, UK, pp. 41.

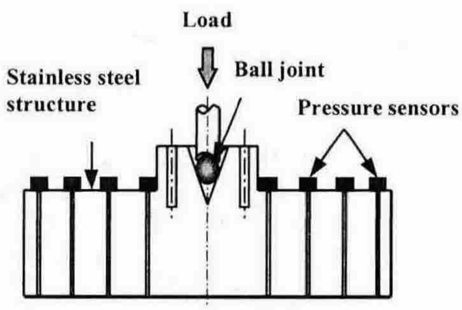

Figure 1: Schematic diagram of the pressure measurement apparatus.

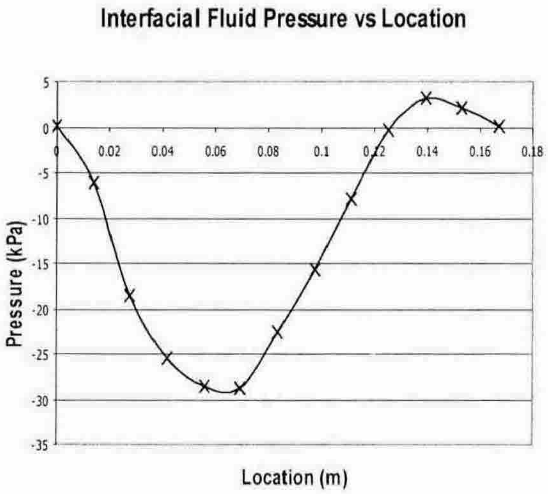

Figure 2: Typical pressure vs. location data for a fixture rotating at 200 rpm and a load of 14.15kPa (2.05psi) .

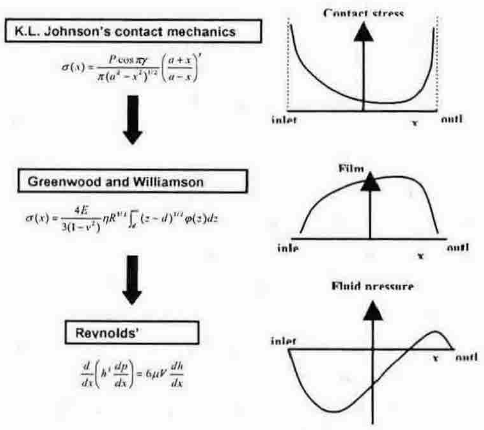

Figure 3: An abbreviated explanation of the analytical techniques used in obtaining the suction pressure.