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Feature-Scale Simulations of Particulate Slurry Flows in Chemical Mechanical Polishing by Smoothed Particle Hydrodynamics

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Abstract. In this paper, the mechanisms of material removal in chemical mechanical polishing (CMP) processes are investigated in detail by the smoothed particle hydrodynamics (SPH) method. The feature-scale behaviours of slurry flow, rough pad, wafer defects, moving solid boundaries, slurry-abrasive interactions, and abrasive collisions are modelled and simulated. Compared with previous work on CMP simulations, our simulations incorporate more realistic physical aspects of the CMP process, especially the effect of abrasive concentration in the slurry flows. The preliminary results on slurry flow in CMP provide microscopic insights on the experimental data of the relation between the removal rate and abrasive concentration and demonstrate that SPH is a suitable method for the research of CMP processes.

AMS subject classifications: 76M28, 74F10, 70E18, 35Q30

Key words: Chemical mechanical polishing, smoothed particle hydrodynamics, particulate flow, rough pad, wafer defects, abrasive concentration.

1 Introduction

Chemical mechanical polishing (CMP) is a key process widely used in semiconductor manufacturing industry to provide local and global planarity of silicon wafers [1]. As

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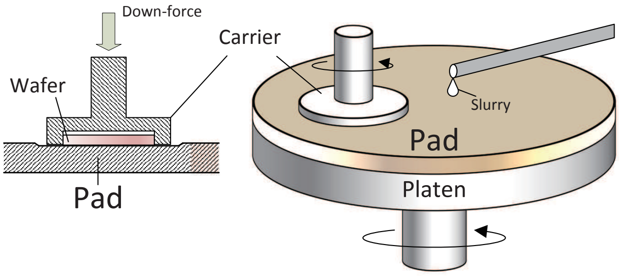

Figure 1: A sketch of the functional principle of chemical mechanical polishing (CMP). A wafer is mounted on the carrier and pressed upside-down against a polishing pad (the left plot). A chemical slurry with solid abrasives is deposited on the pad by the slurry delivery system. The rotation of both wafer and pad together with the chemical and mechanical effects of slurry leads to the planarization of wafer surface (the right plot).

illustrated in Fig. 1, during a CMP process, a wafer is mounted on a carrier and pressed upside-down against a polishing pad. A chemical slurry with solid abrasives sized from dozens of nanometres to several microns [1–5] is deposited on the pad by the slurry delivery system. The rotation of both wafer and pad together with the chemical and mechanical effects of slurry leads to the planarization of wafer surface. Although CMP has been extensively utilized in industry, the polishing mechanisms are still not well understood. This is due to the complex chemical and mechanical interactions at wafer-pad interface and the difficulties of in-situ observations at feature scales.

In CMP, the most important measurement is the material removal rate (MRR), which is determined by many factors, including chemical characteristics of the slurry, hydrodynamics of the slurry flow, the wafer-back pressure, the roughness and hardness of polishing pad, the rotation of wafer and pad etc. The commonly accepted description for MRR is based on Preston's theory [6] on glass polishing

$$\mathrm{MRR}=kPV, \tag{1.1}$$

where k is the coefficient of wafer-pad friction, P is the pressure applied on the wafer, V is the relative velocity between the wafer and the pad. A number of studies concerning various physical and chemical properties of the pad, the wafer and the slurry have been conducted to investigate the factors that influence the coefficient k. Among these chemical-mechanical factors, the hydrodynamics of the slurry flow attracts much attention. In recent years, numerous investigations with respect to the slurry hydrodynamics from wafer scale to feature scale have been carried out, including mathematical modellings [7–9], numerical simulations [10–12] and experimental studies [13–15]. The results of all these studies have indicated that the slurry plays an important role in material removals. For a comprehensive review of the research on slurry hydrodynamics, one can refer to [16] and references therein.

However, due to the complexity of the nano-structure and the topography at the pad-wafer interface, as shown in Fig. 2, it is difficult to directly probe the hydrodynamic phe-