MULTISCALE MECHANICAL MODELING OF CMP

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In recent years, chemical mechanical polishing (CMP) has become the leading technique for planarization of wafer surface in integrated circuit (IC) fabrication. The most important role of CMP is to minimize the variations of wafer surface topography caused by the deposition of interlevel dielectric (ILD) and/or metal interconnection and the etching process for shallow trench isolation (STI). The rapid technological development of the integration of this process requires tighter topographical margins for polished wafer surfaces, from the viewpoints of both local and global planarization.

While the necessity of CMP is now broadly understood in industry, the understanding of underlying removal mechanisms has not yet reached a sufficient level to be utilized in an actual process. This has resulted in most CMP research involving expensive experiments performed in an ad-hoc way. The main reason is that the process involves complicated solid-solid and solid-fluid interactions which induce boundary lubrication accompanied with various wear mechanisms between the wafer and the rough pad, albeit the deformation of the wafer is merely ignored. A further complication arises when the compliant wafer and backing plate in an actual CMP tool is taken into consideration. The wafer deforms due to the contact pressures on the wafer exerted by asperities on the pad and fluid hydrodynamic pressures that also change the geometry of the fluid film channel. These changes affect the contact mechanics in the region of concern. It is now accepted that the existence of the asperities on the bulk pad provides a thin channel for fluid flow (up to several tens of microns), that can induce subambient fluid pressures between the wafer and the pad in certain circumstances [1]. In recent work [2] it was analytically proved that the occurrence of the subambient pressure is the consequence of the involved interactions of the pad, asperities and slurry flows.

Even though reverse engineering based on empirical data sometimes provides good means to predict CMP performance, computer simulations based on mathematical modeling can elucidate the CMP mechanism in a cost-effective way. To meet such challenging and aggressive requirements for future CMP, the analysis of microscopic material removal mechanism typically happening between the tips of asperities and the to-be-polished surface of multichip modules (MCM) and thorough understanding of macroscopic phenomena are now inevitable.

Two possible explanations of material removal mechanism have been proposed in CMP: (1) erosion model, and (2) abrasion model. The erosion model is based on the assumption that the workpiece is separated from the polishing pad by a hydrodynamic film of slurry and polishing is done by collision of the slurry particles with the surface. The abrasion model has its root in the assumption that the hydrodynamic effect is not strong enough to separate the workpiece from the pad and the asperities of the pad rub against the wafer with entrained slurry particles. The existence of subambient pressures clearly supports the validity of the latter model.

The present study focuses on the contact interactions of the elastohydrodynamic system consisting of the compliant wafer on a backing plate with the rough pad and with the interfacial fluid flow channel filled with moving slurries. Since the velocities of propagating waves are quite large compared to that of the CMP tool, dynamic influences are ignored in the treatment. Although the actual mechanism of CMP cannot be explained solely by either mechanical or chemical aspects, most analyses for a CMP process handles the two effects separately. In this paper, we treat only the mechanical effects; especially the solid-solid contact mechanism and solid-fluid interaction.

The analysis in this study can be classified into four categories: 1) contact stress and deformation of the bulk pad, 2) wafer deformation on an elastic foundation, 3) asperity contact stresses, and 4) hydrodynamics of slurry between the wafer and the pad. The proposed simulation model integrates the four groups of analyses to explain their combined effects on CMP performance.

Due to the finite thickness and the effects of the additional compliant wafer and the backing plate, the existing analytical treatments using a half-space assumption for CMP modeling do not hold. The contact analysis for a layer with finite thichness performed by Sneddon using Fourier transforms [3] guides the analysis of the wafer on the thin pad in this work.

The random roughness of the polishing pad in contact mechanics was first characterized through a statistical asperity model by Greenwood and Williamson [5], which is also employed in the study for the connection of contact stresses at different scales. The random roughness of the pad surface makes it difficult to explain the actual slurry flow in the interfacial region. Suitable compensation factors [4] have to be incoporated to predict the correct hydrodynamic behavior in a global sense.

The characteristics of large deformations of the polymer material used for the pad, however, prevent the direct use of linear elastic theory. A reasonable extension of the theory to highly deformed asperities is successfully implemented by adopting a hyperelastic constitutive law [6].

In this paper, numerical results are presented as well, and the results provide a good quantitative prediction of CMP performance to identify the complicated characteristics of the CMP mechanism.

REFERENCES

1. J. A. Levert, S. Danyluk, and J. Tichy, *ASME J. of Tribol*., **122**, p. 450 (2001).
2. J. Tichy, J. A. Levert, L. Shan, and S. Danyluk, *J. Electrochem. Soc*., **146**(4), p. 1523 (2001).
3. I. N. Sneddon, *Fourier Transforms*, McGraw-Hill, (1951).
4. N. Patir and H. S. Cheng, *ASME J. of Lubrication Technol*., **100**, p. 12 (1978).
5. J. A. Greenwood and J. B. P.Williamson, *Proc Roy Soc London*, A295, p. 300 (1966).
6. A. T. Kim, J. Seok, J. A. Tichy and T. S. Cale, *Proceedings 18th VMIC*, T. Wade (ed.), IMIC, p. 129 (2001).