A MULTISCALE MECHANICAL CMP MODEL FOR PATTERNED WAFERS

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Chemical mechanical planarization (CMP) is widely used to planarize metals and dielectrics in multi-level-metal (MLM) interconnection processes. It has expanded into an integral component of the design, development, and integration of process modules necessary to manufacture and yield cost-effective leading-edge products. Fundamental studies still need to be performed to understand the basic mechanisms involved in CMP and hence help in process development.

The conventional CMP setup comprises a wafer, resting on a carrier film, which is pressed against the polishing pad, while an aqueous solution containing nanometer sized abrasive particles is continuously fed into the system [1]. Generally, the pad is made of a relatively soft impermeable polyurethane material and a conditioning process generates a rough surface. The asperities obtained are assumed to have no pores and grooves and to be in a considerable amount.

Material removal mechanisms during CMP involve complex mechanical and chemical actions. In this analysis, it is assumed that the slurry softens the wafer surface and transports the abrasive particles as well as the abraded material. This paper describes a physics-based multiscale mechanical material removal model for conventional CMP processes. The objective is to develop a model (that uses experimental results [2] for calibration) to predict removal rates on representative features.

From recent experimental [3] and theoretical [4,5] research results supporting a direct pad-wafer contact mechanism with abrasive particles, it is considered in this paper that abrasive wear is the main material removal mechanism in CMP. It is assumed in the abrasive particle scale model that abrasives in the slurry are a few tens of nanometers in size [6], are spherical in shape, and are made of a very hard material. The material removal by a single abrasive with the assumption of plastic deformation of the wafer surface is evaluated.

Pad asperities are assumed to be approximately spherical, at least near their tips, and an exponential distribution characterizes the random variations in asperity heights. The bulk pad and asperities undergoes a linear elastic deformation and both are modeled using the Hertz theory of elastic contacts [7]. The fluid pressure distribution is expressed using Reynolds equation [8] with the pressure and shear flow factors included to account for the roughness effects of the pad surface [9].

To obtain the material removal at the wafer scale, the results from the analyses of the abrasive particle and asperity scales are integrated using an extended Greenwood-Williamson [10] statistical homogenization approach. The results obtained are then employed to predict the material removal on representative patterned wafers, along with the time evolution of the features' surface though the use of a semi-numerical model.

We present simulation results for CMP of Cu films, which might result from electrochemical deposition [11]. EVOLVE [12], a feature scale simulator that incorporates the level set method [13], is employed for surface evolution. The model parameters are adjusted to match material removal rates measured experimentally. Numerical results are presented in the paper and some implications are discussed.

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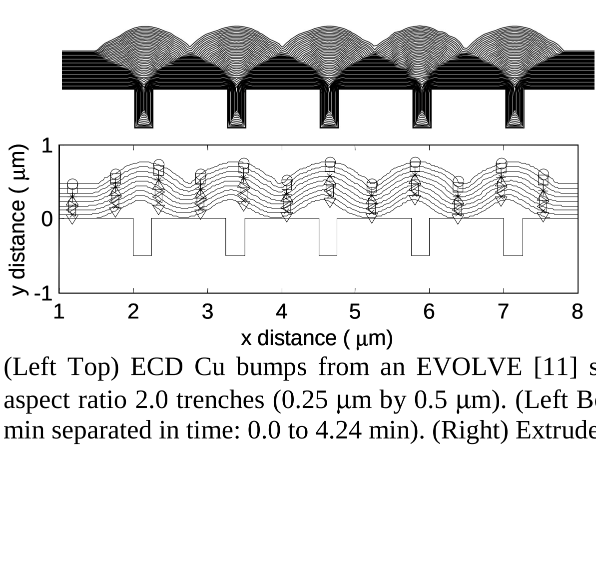

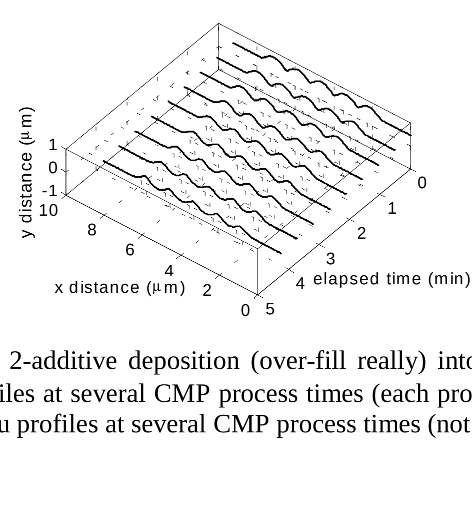

(Left Top) ECD Cu bumps from an EVOLVE [11] simulation of a 2-additive deposition (over-fill really) into identical, aspect ratio 2.0 trenches (0.25 µm by 0.5 µm). (Left Bottom) Cu profiles at several CMP process times (each profile is 0.53 min separated in time: 0.0 to 4.24 min). (Right) Extruded Plot of the Cu profiles at several CMP process times (not scaled).