Process Modeling of Chemical Mechanical Polishing (CMP)

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Abstract--- In this report, the modeling process of CMP process based on prediction of material removal rate (MRR) and pressure and velocity distribution over wafer-pad interface is discussed. Software to predict MRR and with-in wafer non-uniformity (WIWNU) is being developed.

1. *CMP and CMP Model*

The chemical mechanical polishing (CMP) has been widely accepted in the semiconductor industry for oxide dielectric and metal layer planarization. It is used to insure that the interconnects between multi-layer chips are achieved reliably and that the thickness of dielectric materials is uniform and sufficient. The most important CMP process outputs of interest to the semiconductor manufacturer include the material removal rate (*MRR*), within-wafer non-uniformity (*WIWNU*), within-die non-uniformity (*WIDNU*), wafer-wafer non-uniformity (*WWNU*) and surface quality such as roughness, particles and corrosion resistance. A significant number of input variables have influence on the outputs, such as the slurry chemical, slurry viscosity, down pressure, back-pressure, abrasive size, abrasive geometry, velocity, frictional forces, pattern geometry, pattern layout, pattern density, wafer geometry, pad geometry, pad material, temperature distribution over wafer-pad interface, wafer size and wafer cleaning. The optimization of CMP outputs and better control of CMP process require considering the effects of more than one input value mentioned above. For example, while effective head design and choice of an optimum consumable set are critical to achieving good within-wafer non-uniformity, it is found that down force, wafer protrusion and back-pressure also have significant effects.

1.1) Model Describing Material Removal Mechanism

Because of the large number of inputs and the high cost incurred in experiments, modeling has become an important ingredient in the furtherance of CMP technology. In recent years, a lot of models for CMP have been developed. The most important one is Preston's equation (Preston, 1927) $MRR = CPV$ where C is a coefficient resembling the chemical effect, P down pressure and V the relative velocity of wafer to pad. This abrasion/wear-based equation has described the material removal mechanism roughly and related the average material removal rate with the down pressure and the relative velocity of wafer.

A more fundamental insights into CMP by Zhao and Shi (Zhao and Shi, 1999), however, shows that a sub-linear pressure dependence of MRR exists and a revised Preston's equation ($MRR = CVP$^(2/3) was introduced. Neither the Preston's equation nor the revised Preston's equation demonstrates influences of other input values on the *MRR* except the down pressure and the velocity. Experimental results have shown that the material removal rate is also the results of input values including the abrasive numbers, abrasive size, wafer materials and pad hardness. Especially, the pad hardness has significant influences on *MRR* and *WIWNU*. Therefore, a more detailed and accurate model describing the material removal mechanism should consider the effect of all of these important input values.

Recently, a model with the pad hardness, wafer hardness, abrasive geometry and abrasive size considered has been developed to fully understand the material removal mechanism in solid-solid contact CMP (Luo, 1999 A). This model is based on the assumption of fully plastic contact at abrasive-wafer and abrasive-pad interfaces and normal distribution of abrasive size. In this model, the so-called *active* abrasive number plays an important role. Experimental results vs. predicted results shows that the model is promising in better understanding the material removal mechanism in CMP.

1.2) Dynamic and Mechanics Models to Consider the Velocity and Pressure Distribution over Wafer-Pad Interface

Pressure and velocity are the two most important input parameters in CMP. Dynamic models to predict the velocity distribution and mechanistic models to predict the pressure distribution over wafer-pad interface have been developed. The importance of the pressure and velocity distribution lies on their influence on the *WIWNU*, the non-uniform material removal rate along the diameter of wafer. The motion of the wafer relative to the pad can be separated into two parts, one part a translation and the other part a rotation. The calculation of the relative velocity at any place on the wafer surface has be discussed in details by Hansen et al. (Hansen et al., 1996). It is shown that the distribution is an output of the geometry parameters of wafer and pad. The pressure distribution comes from the elastic deformation of the wafer, pad, carrier film and carrier. Numerical methods including finite element method (FEM) and boundary element method (BEM) have been used by investigators (Wang et al., 1997) to predict the stress and pressure distributions over wafer-pad interface. The details about a 2-D FEM model to predict the pressure can be found in (Wang et al., 1998). Once the velocity and pressure distribution is known, the WIWNU can be predicted based on the material removal models listed in section 1.1.

2. CAD Software for CMP

Based on the success of the above models, a computer aided design (CAD) environment to predict the output values such as *MRR* and *WIWNU* considering all the related input values has become possible. CAD software for the prediction and optimization of *MRR* and *WIWNU* based on the material removal model and the prediction of pressure and velocity distribution is being developed. Such software will be helpful for the optimization and control of the CMP process. It should include at least two parts, the user interface and the modeling or prediction module. Figure 1 shows the structure of the software schematically. Figure 2 shows the user interface of the software. The pressure distribution computation module is the most important part of the software. The software is still in development.

Reference:

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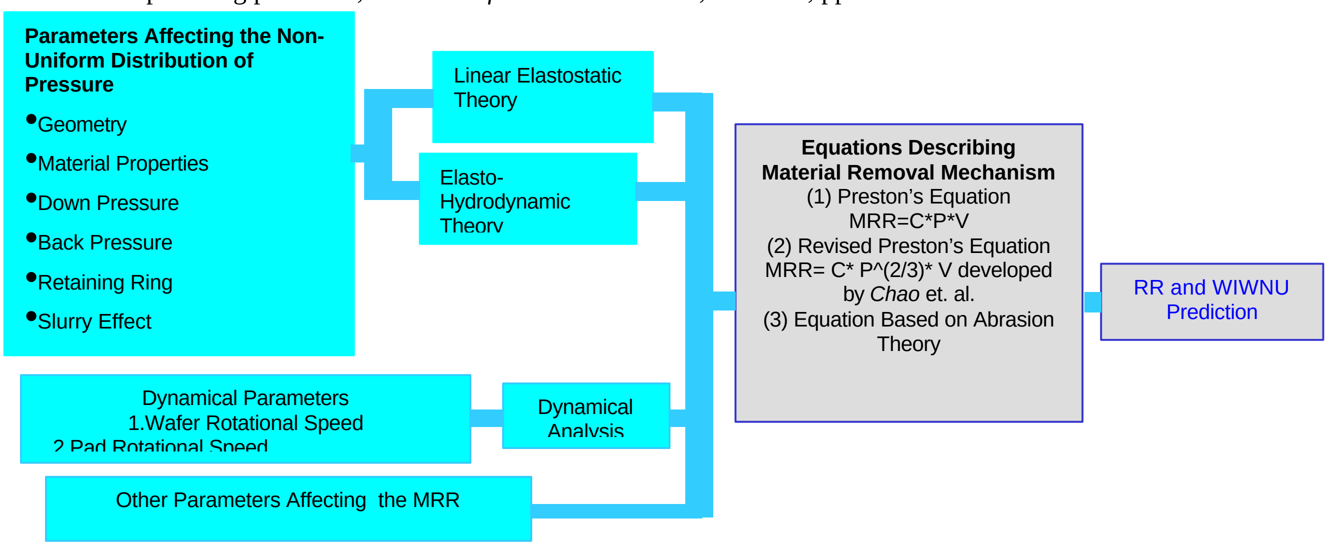

Figure 1. Structure of the software

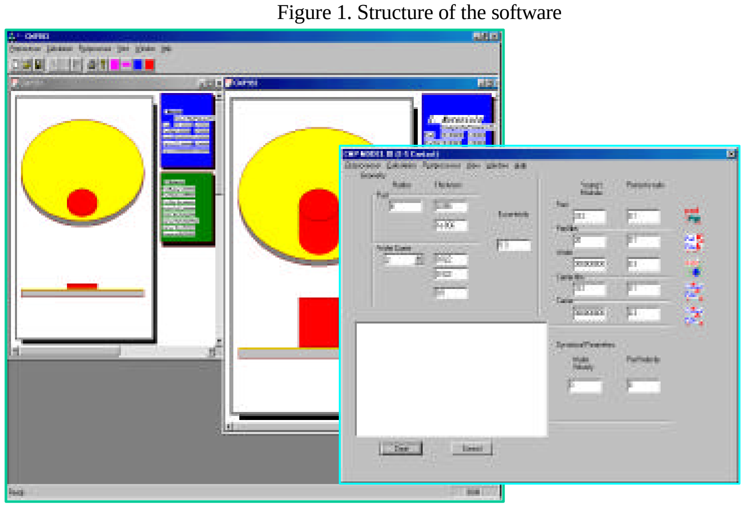

Figure 2. User interface of the software