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A chemical kinetics model to explain the abrasive size effect on chemical mechanical polishing

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Abstract

A chemical kinetics model was proposed to describe the abrasive size effect on chemical mechanical polishing (CMP). The model is based on the consideration of a pad as a sort of catalyst and the re-adhering of abrasives due to the large size. Therefore, a general equation was deduced according the chemical kinetics methodology to give the meanings of the size effect. Finally, according a set of data related to the abrasive size effect on CMP, a possible form can be $PR=\alpha C_C C_T X_A C_{WA}^n/[\beta+\gamma X_A C_{WA}^n]$ where α, β, γ and n are the parameters in a CMP system.

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1. Introduction

Since copper was applied to the interconnect in semiconductor devices, the technology of CMP, which stands for "chemical mechanical polishing", has jumped to another generation [1,2]. Among many researches for describing CMP, the most famous mechanism was proposed by Cook in 1990. Cook [3] used the method of chemical kinetics to explain the polishing process. Recently, there have been some papers discussing CMP in the view of chemical reaction kinetics. Paul [4] considered the first step in CMP is to form a thin reaction film. Then, a thin reaction film is polished with the following two parallel reactions. One is the corrosion process for dissolution. The other is mechanical abrasion step, which is in terms of a chemical reaction. Thakurta et al. [5] combined slurry hydrodynamics, mass transport and reaction kinetics to predict the copper film polishing rate. The steps include: (i) mass transport of the oxidizer to the wafer surface, (ii) reaction of oxidizer with copper to form a reacted layer, (iii) subsequent removal of the reacted layer by mechanical abrasion. Gutmann et al. [6] have proposed a generic two-step model for the CMP process. Their model involves a balance between a chemical reaction of the slurry constituents with the surface being polished and mechanical removal of the reacted surface layer by the slurry abrasive particles.

However, as for the effect of particle sizes of slurry abrasives, the mechanical-based models dominate. Luo and Dornfeld [7] proposed an abrasive mechanism in solid–solid contact mode of the CMP. With the assumptions of periodic roughness of the pad surface, plastic deformation over wafer–particle and pad–particle interfaces, and normal distribution of abrasive particle size, they correlated the polishing rate with the average abrasive size and the standard deviation of the abrasive size distribution. Fu et al. [8] provided a plasticity-based model to explore the effects of various design parameters (e.g., abrasive shape, size and concentration, and pad stiffness). For spherical abrasives, the model predicted the decrease of the polishing rate with increasing abrasive size; however, for sharp abrasives, the polishing rate is independent of abrasive size in the stiff pad and high abrasive concentration regime, but

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the polishing rate increases with abrasive size in the soft pad and low abrasive concentration.

In this article, a chemical kinetics-based model is presented to describe the effect of the abrasive size on the polishing rate. For simplicity, oxide CMP is focused. The model is based on the concept of considering a pad as a catalyst.

2. Chemical kinetics model setup

Chen et al. [9] have proposed the catalytic-pad chemical kinetics (represented by CPCK) model based on the concept of Cook [3] who pointed out the role of chemistry in glass polishing. The advance of the CPCK model is to take the pad effect into consideration.

Jairath et al. [10] showed out the wafer-to-wafer polishing rate behavior with pad conditioning differs from that without pad conditioning. With no pad conditioning, the polishing rate will decay exponentially as the number of polished wafers increases. Hernandez et al. [11] studied the pad effects. They showed the scanning electron microscopy (SEM) pictures of three cases of (i) soaked in slurry only, (ii) soaked and polished, and (iii) soaked, polished and dressed. In the cases of (i) and (ii), slurry was adhered in some pad voids. Although, in the case of (iii), no slurry was shown; however, it is believed that pad aging happens during the CMP process. Thus, there should be a role of a pad in the CMP mechanism. We can treat a pad as some sort of catalyst. Then, the theories built in the field of catalyst chemical engineering can be used to explain the behaviors in the CMP process.

The basic mechanism of the CPCK model has seven steps: (a) abrasives move into pores at the top pad region and (b) they are grasped by surface active sites within the pores before reaching the polishing areas under a wafer; (c) meanwhile, some chemicals move onto the wafer surface and (d) they change the surface quality for polishing at the trench areas of the pad under the polished wafer; then (e) reactions happen between pad-grasped abrasives and active sites of wafer surface, and materials at the wafer surface are polished; (f) reacted abrasives within the pores of a pad will escape and (g) they move into the bulk slurry flow to leave a pad [9]. Some assumptions are made. First, the transportation of fresh or reacted abrasives is fast in a certain time scale such that the mass transfer resistance could be omitted. Second, this mechanism happens in a certain area and thus it is not necessary to take the non-uniformity into consideration. Third, abrasive size is the same in this basic mechanism. However, the effect of abrasive size will be concerned later in this article.

Fig. 1(a) shows the illustration of steps (a) and (b). If abrasives and pores are represented by the symbols A and P, respectively, a reversible reaction can be written as

$$A + P \leftrightarrow AP^* \quad (1)$$

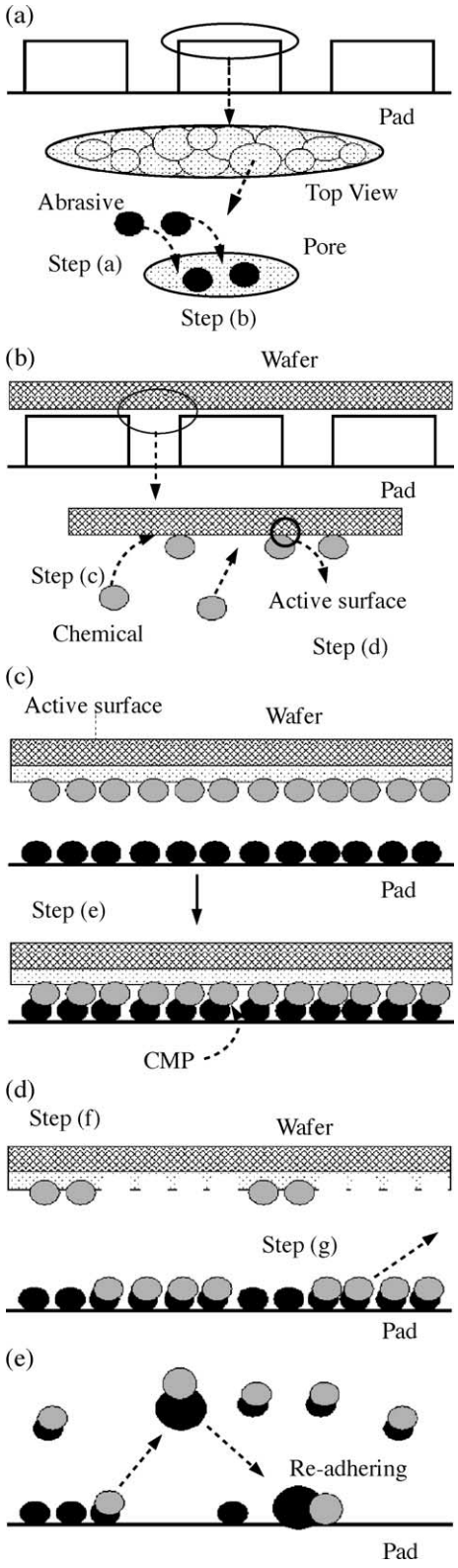

Fig. 1. Illustration of chemical kinetics mechanism for CMP.

In reaction (1), AP* means the pad-grasped abrasives that can participate in the CMP process. Fig. 1(b) shows steps (c) and (d). Let C stands for chemicals and M for