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Study on relationship between nano particle agglomeration action and polishing characteristics in CMP

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Abstract

The relationship between particle agglomeration and material removal rate, MRR, is the object of this work. There are two ways for tracking; theoretical estimation and experimental measurements.
For theoretical study, most of researchers qualitatively explained the reciprocal effect between MRR and shear force. We concerned the quantification of the shear force exerted by abrasive particles in the slurry.
MRR-aggregation model is proposed through the relation between MRR and shear force. To justify this model, the experiment is being performed. Majority of recent studies provided experimental results of aggregation and shear force; however, we want to extend them to real CMP. Consequently, a proper style could be achieved for surface finishing criterion.

1. Introduction

Particle is the name of the collection of correlating infinite bodies that differ in features from the constituent individuals
Relation between particle and removal mechanism:
We focus in this study on energy balance principal, where, the particle force needed to pull off the molecules on surface of the reacted layer is stipulated under the condition:

$$F\left(\frac{\pi R_p{}^2}{4}\right) R_m \geq 2\gamma\left(\frac{\pi R_m{}^2}{4}\right) N \qquad (1)$$

where F is the resultant particle force, R_p is particle diameter, R_m is molecule diameter, the surface energy γ, and N is the removed molecules from wafer surface.
How do aggregates affect the surface and MRR?
Yeon-Ah Jeong et al. [1] stated that the particle agglomerates massively bind the wafer surface molecules due to the large created drag forces generated from aggregates (Fig. 1).

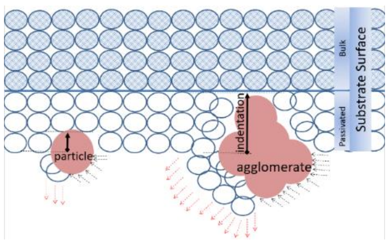

Fig.1 Particle force applied at removal mechanism.

In current study we investigate the relation between MRR and particle agglomeration through the effect of shear force which greatly dominates the wafer/pad interfacial region.

2. Modelling

Particle aggregation occurs due to particle collisions. Based on Smoluchowski theory, assume the primary particles e.g. n_i, n_j are the concentrations of particles of size $\{i, j\}$ respectively. After some period, aggregation is a second-order rate process, in which the rate of collision is proportional to the product of concentrations of two colliding species. Thus, the number of collisions between i and j particles in unit time in unit volume is given by

$$J_{ij} = k_{ij}n_in_j \qquad (2)$$

where k_{ij} is the rate constant. Assuming every collision is effective, the rate of change of concentration of k-fold aggregates (aggregate of size k where k=i+j) is:

$$dn_k/dt = (1/2)\sum_{i=1}^{i=k-1} k_{ij}n_in_j - n_k\sum_{k=1}^{\infty} k_{ik}n_i \qquad (3)$$

Define the total concentration as

$$n_T = n_1 + n_2 + \cdots \qquad (4)$$

where $[n_T]_{t=0} = n_0$, substituting (4) in (3), yields [2];

$$dn_T/dt = -(1/2)(k_{11}n_1^2 + k_{12}n_1n_2 + \cdots) \qquad (5)$$

Regarding all rate constants are equal, for any i,j; $k_{ij} = k$

$$dn_T/dt = -(1/2)kn_T^2 \qquad (6)$$

Integrating Eq. (6), yields:

$$n_T = \frac{n_0}{1 + \frac{k}{2}n_0t} \qquad (7)$$

n_T suffers from a decay due to particle collisions which have three types; (1) Brownian diffusion (perikinetic aggregation), (2) fluid motion (orthokinetic), (3) differential settling. Often, we focus on second mechanism because abrasives (colliding particles) are dispersed at non-Newtonian slurry or under turbulent flow [3]. It's implied that slurry stability increases as "k" decreases. The orthokinetic collision rate is given by:

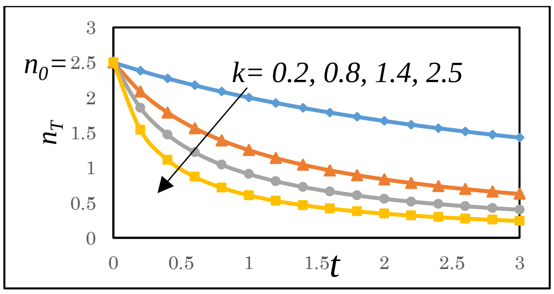

Fig.2 History of total particle concentration "n_T".

$$J_{ij} = \frac{4}{3} G R_{ij}^3 n_i n_j \quad (8)$$

Comparing Eq. (9) to Eq. (2):

$$k_{ij} = \frac{4}{3} G R_{ij}^3 \quad (9)$$

where $R_{ij}$the distance between the centers of two spherical particles and G is the shear of slurry. Invoke condition (6);

$$k = \frac{4}{3} G R_{avg}^3 \quad (10)$$

where R_{avg} the average over all R_{ij}'s. From (10) into (7):

$$n_T = \frac{n_0}{1+\frac{2}{3} G R_{avg}^3 n_0 t} \quad (11)$$

which reflexes the relation between particle concentration and the shear. Define the shear frequency f_τ [4] as:

$$f_\tau = \frac{V A_\tau}{A_n} (2R_p \sqrt{\frac{E_{sp}}{H_w}}) \left(\frac{6\rho_s \alpha}{\pi \rho_a R_p^3}\right)^{\frac{2}{3}} (1 - \phi(3\sigma_s - d)) (12)$$

where sliding velocity, V, equivalent particle pad modulus, E_{sp}, wafer hardness, H_w, slurry/particles densities, ρ_s/ρ_a respectively, particle concentration, α, and normal distribution [5] of pad asperities is ϕ. Regarding the condition (1), material removal rate model could be formulated as [6]:

$$MRR \propto removed\ volume \cdot f_\tau \cdot N \quad (13)$$

$$MRR = \frac{1}{3}\frac{F}{\gamma} R_m^2 f_\tau \quad (14)$$

In general, the resultant particle force needed to pull off molecules/atoms at reacted layer is given by combination of the shear force from (slurry/pad). In case of very large sliding velocity, F_{pad} could be included inside F_{slurry}, meaning: turbulent, non-Newtonian slurry, and wafer is underlying hydroplaning motion [7]. Hence: $F = F_{slurry}$,

From Eq. (11), shear is given by:

$$G = \frac{3}{2} \frac{1}{R_{avg}^3 n_0 t} \left(\frac{n_0}{n_T} - 1\right) (15)$$

Using viscosity (ν) the shear force is defined as:

$$F_{slurry} = \frac{3}{2} \frac{\nu}{R_{avg}^3 n_0 t} \left(\frac{n_0}{n_T} - 1\right) \quad (16)$$

Substituting Eq. (16) into Eq. (14), yields:

$$MRR = \frac{1}{2\gamma} \frac{\nu}{R_{avg}^3} \frac{1}{t} \left(\frac{1}{n_T} - \frac{1}{n_0}\right) {R_m}^2 f_\tau \quad (17)$$

If we consider $\frac{\nu R_m^2 f_\tau}{2\gamma R_{avg}^3}$ is a constant "c", then $MRR = MRR(t, n_T)$. Fig. 2 shows that removal mechanism dramatically descends at the beginning period as well as for small particle concentrations, therefore it tends to settle near zero as $\{t, n_T\} \to \infty$. The Sharp drop of MRR could be mitigate through increasing of parameter "c".

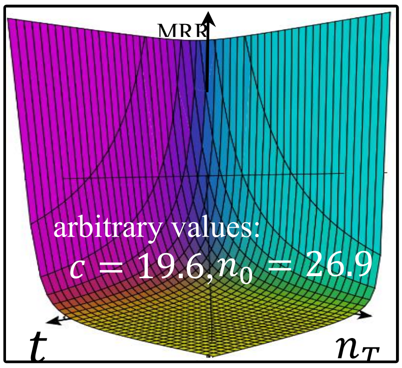

Fig. 3 MRR as a function of time and particle concentration.

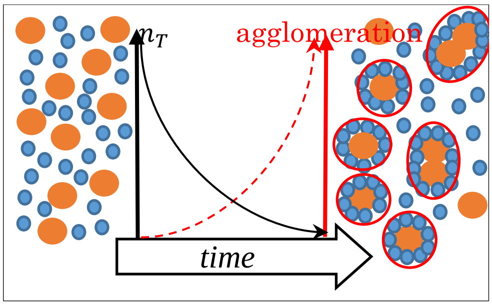

Fig. 4 Relation between particle concentration and aggregation.

MRR undergoes from general decay (Fig. 2). On other hand, the collisions among different particles enhance the aggregates growth (Fig. 3). Accordingly, MRR could be stabilized as n_T is maintained through controlling the particle aggregation process.

3. Conclusions

A study of material removal with particle agglomeration effect has been discussed during CMP to understand stabilization ability for material removal mechanism.

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