REMOVAL RATE SIMULATION OF COPPER ELECTROCHEMICAL MECHANICAL PLANARIZATION

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ABSTRACT

An improved material removal rate method for simulating the Cu removal rate in electrochemical mechanical planarization (ECMP) based on the dissolution-type polishing mechanism was developed. The effects of the applied anodic potential, the Cu dissolution amount and the protective layer amount formed during ECMP process on the Cu removal rate are considered in this method. The protective layer amount and Cu dissolution amount were modeled using three simple equations, which were modeled on the basis of the dissolution-type polishing mechanism. This method is used to simulate the material removal rate in a rotary-type ECMP system. This understanding is beneficial for optimization of ECMP processes.

1. INTRODUCTION

The polishing mechanisms of ECMP can largely be categorized into two types: abrasion-type ECMP and dissolution-type ECMP [1-3]. The experiments developed in this study belong to the dissolution-type ECMP. The protective layer amount is a key element in the dissolution-type polishing mechanism and it depends on the dissolution amount, which obey to Faraday law. In this study, we developed a new simulation method based on the mechanisms of Cu ECMP obtained in this work to simulate the effects of the applied potential and the protective layer amount [4-6].

2. SIMULATION MODEL

The basic anodization model can be written as [7]:

$$\frac{dx}{dt} = \chi j_{ox}(t) \quad (1)$$

$$j_{ox}(t) = j_t [(1 + \gamma) + k_1 \exp(\lambda V(t))]^{-1} \quad (2)$$

where $\frac{dx}{dt}$ is the rate of increase of the oxide thickness, j_{ox} is the oxidation current density due to ionic transfer, j_t is the measured current density in experiment, V is the applied potential. χ and k are constant, respectively. In this work, λ and γ are considered as a constant, respectively. Substituting Eq. (2) into (1) can be expressed as:

$$\frac{dx}{dt} = \chi j_t [(1 + \gamma) + k_1 \exp(\lambda V(t))]^{-1} \quad (3)$$

The basic electrolyte composition in experiment consists of 6 wt.% HEDP, 0.3 wt.% BTA, 3 wt.% TAC at pH 8. According to experiments, it is found that the measured current density is proportional to the applied potential ranging from 1.6 V to 3.5 V (vs.SCE). The following equation can be got by fitting the experiment data as follows:

$$j_t = k_2 V \quad (4)$$

where k_2 is a proportional factor? Substituting Eq. (4) into (3):

$$\frac{dx}{dt} = \lambda k_2 V [(1 + \gamma) + k_1 \exp(\lambda V(t))]^{-1} \quad (5)$$

Eq. (5) can be simplified as:

$$\frac{dx}{dt} = \frac{k_3}{k_5} \frac{V}{k_4/k_5 + \exp(V)} \quad (6)$$

Where $k_3 = \lambda k_2$, $k_4 = 1 + \gamma$, $k_5 = k_1 \exp(\lambda)$. From Eq. (6), the relation between the rate of increase of the oxide thickness and the applied potential can be expressed as follows:

$$\frac{dx}{dt} \propto \frac{V}{k_6 + \exp(V)} \quad (7)$$

where $k_6 = k_4 / k_5$.

For the dissolution-type polishing mechanism, it is assumed that the Cu dissolution rate depends on the protective layer amount on the Cu surface [8]. The growth rate of the oxide layer was inversely proportional to the thickness when the potential was kept constant, being shown by the exponentially decreasing current density [9]. Therefore, the protective layer amount ξ is modeled as a dimensionless quantity using the following equation:

$$\xi = \int \alpha_0 (1 - \frac{\xi}{\xi^*}) dt - \int k_8 P dt_p \quad (8)$$

The protective layer formation rate reaches the maximum α_0 when the protective layer amount is 0; it becomes 0 when the protective layer amount saturates at ξ^* . From Eq. (7), we can have obtained as:

$$\alpha_0 = \frac{k_7 V}{k_6 + \exp(V)} \quad (9)$$

where k_7 is a factor, respectively?

Hence, the mechanical power can be calculated by Eq.(10):

$$P = VF = 2\pi wRF \quad (10)$$

For the protective layer amount ξ^* formed under different potential is different, the relationship between the protective layer amount and the applied potential is investigated as follows. The protective layer amount is proportional to the protective layer formation rate α_0 , that is $\xi^* \propto \frac{V}{k_6 + \exp(V)}$. Because

the change of the value of k_6 has little influence on the ration of ξ_i^* / ξ_{i-1}^* , we can have obtained as: $\frac{\xi_i^*}{\xi_{i-1}^*} \propto \frac{V_i}{V_{i-1}} \exp(V_i - V_{i-1})$. We assume that the protective

layer amount at 1.6V (vs.SCE) is ξ_1^* , the protective layer amount can be obtained as:

$$\xi^* = \frac{V}{1.6} \xi_1^* \exp(V - 1.6) \quad (11)$$

The relationship between the dissolution rate and the protective layer amount ranging from 1.6V to 3.5V (vs.SCE) can be expressed as:

$$R_E = \max[R_{E0}(1 - \frac{\xi}{\beta}), R_{Em}] \quad (12)$$

$$R_{E0} = R_0 + k_9(V - 1.6) \quad (13)$$

where R_E is the Cu dissolution rate in the aperture region (nm/min), R_{E0} is the maximum dissolution rate (nm/min), β is a coefficient determining the gradient of the dissolution rate, R_0 is the maximum dissolution rate at the applied potential of 1.6V (vs.SCE), and max is a function that returns the maximum value. The minimum dissolution rate (nm/min) R_{Em} can be obtained by fitting the experimental data and given by:

$$R_{Em} = -3.4864V^2 + 30.8303V - 39.1904 \quad (14)$$

The Cu dissolution amount EA (nm) can be calculated as:

$$EA = \int R_E dt_h + \delta \int R_E dt_p \quad (15)$$

t_h is the time required to pass through the apertures (min), and δ is the ratio of the dissolution rate in the non-aperture region to that in the aperture region? The value of δ depend on the applied potential and can be obtained by fitting the experimental data using the following equation:

$$\delta = 0.02943 + 5.3039 * 10^8 * \exp(-13.609V) \quad (16)$$

The Cu material removal rate (MRR) at different potentials can be calculated by the Faraday's law when the wafers contact with the pad in experiments [9]. The values of the other simulation parameters (k_6 , k_7 , k_8 , k_9 , R_0 , ξ_1^* , β) were determined by fitting the Cu material removal rate using the optimization method. Optimized simulation parameters were 32, 41, 15, 20, 80, 10, and 0.051, respectively.

3. SUMMARY

An improved material removal rate method for simulating the Cu removal rate in electrochemical mechanical planarization (ECMP) based on the dissolution-type polishing mechanism was developed. The effects of the applied anodic potential, the Cu dissolution amount and the protective layer amount formed during ECMP process on the Cu removal rate are considered in this method. This method is used to simulate the material removal rate in a rotary-type ECMP system.

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