Proc. of the 9th Intl. Conf. of Asian Society for Precision Engg. and Nanotechnology (ASPEN 2022)
15–18 November 2022, Singapore. Edited by Nai Mui Ling Sharon and A. Senthil Kumar
doi://10.3850/978-981-18-6021-8_OR-17-0226

Simulation of Planarization Model Considered with Temperature Function in Patterned Cu CMP

Yeongil Shin[1], **Haedo Jeong**[1,#], **Seonho Jeong**[1], **Youngwook Park**[1] **and Jongmin Jeong**[1]
1 Department of Mechanical Engineering, Pusan National University, Busan, South Korea
Corresponding Author / Email: hdjeong@pusan.ac.kr, TEL: +82-51-510-3210, FAX: +82-51-518-8442

KEYWORDS: Chemical mechanical planarization, Copper, Temperature, Dynamic etch, Removal amount, Modeling

In CMP, unlike blanket wafers, pattern wafers are affected by parameters such as line width and pattern density. In the previous research, a contact mechanism-based mathematical model considering the geometrical characteristics of oxide film pattern was derived, and it showed good consistency in predicting the step height reduction of oxide film pattern. However, the results of the copper pattern compared using the proposed model showed a relatively large error. Therefore, for copper CMP, not only geometrical properties, but also chemical factors are essential for deriving a model equation. Copper removal follows Preston's equation, which is proportional to the product of pressure and the relative velocity of the pad and wafer, and the chemical reactivity of the material follows Arrhenius' equation. In general, copper is more affected by temperature than oxide during CMP, and as the polishing temperature rises, the amount of material removal also increases. Due to these characteristics, in this study, a modified semi-empirical model considering the effect of temperature in the existing model equation was presented. The empirical formula obtained through the experiment can be expressed as a function of temperature, and is as follows. (1) Etching amount (2) total removal amount according to polishing temperature. First, the copper coupon was etched while controlling the slurry temperature to obtain copper etching rate according to the temperature. Through the experiment, it was confirmed that the etching rate of copper increased as the temperature increased, and it was found that the etching rate was proportional to the process time. Second, polishing was performed several times using polishing equipment to confirm the amount of copper removal according to the polishing temperature. As a result of the experiment, a polishing temperature profile was confirmed for each wafer, and the amount of copper removal also increased as the polishing average temperature increased. Finally, we present a modified MRR expression using the obtained semi-empirical models and contact mechanism theory.

NOMENCLATURE

$e_{Dynamic}$ = dynamic etch rate
A = frequency factor constant
E_a = activation energy
R = gas constant
T = temperature (K)
RA_{Cu} = copper removal amount
h = step height
σ = asperity height deviation
ξ = substitution coefficient
ξ^0 = planarization substitution coefficient
k_{eff} = effective asperity curvature
RA_{up} = material removal rate in up area of pattern
RA_{down} = material removal rate in down area of pattern

1. Introduction

Chemical mechanical planarization(CMP) is a planarization process that uses a combination of chemical and mechanical forces to smooth wafer surface. CMP is used as a technique to planarize patterned metal and ILD surface. However, there are still many problems to be solved such as dishing and erosion in order to achieve global planarization. The cause of this problem occurs during CMP of dissimilar materials with different material properties. These defects result in less current flowing due to material loss and lead to device failure.

In this study, polishing endpoint during copper bulk layer CMP is predicted by simulation. Model is a semi-empirical model that considers chemical factors in addition to the existing theoretical formulas.

2. Experimental Condition and Results

2.1 Dynamic Etching Rate

Copper removal occurs even when there are no contacts between pad and wafer surface. In this case, dynamic etch rates were measured to obtain copper etching rate as a function of temperature. The slurry used is a colloidal silica slurry in an acid-based solution. Oxidizer(H_2O_2) concentration was set to 1vol% of the total solution. Five pieces of wafers diced to a size of 20*20mm were prepared. Experiment within range of temperature from 25℃ to 55℃. Each specimen was etched for 3 min by the slurry.

In Fig. 1, fresh slurry flows continuously into the copper surface under a real CMP environment. Therefore, experimental conditions were stirred at a speed of 230 rpm considering CMP state. As shown in Fig. 2, dynamic etch rate also increased with increasing temperature. The increase in chemical reaction rate between material and slurry with increasing temperature follows the Arrhenius equation.

$$e_{Dynamic} = A \cdot \exp(-\frac{E_a}{RT}) \tag{1}$$

In this experiment, Equation 1 can be expressed as follows:

$$e_{Dynamic} = (4.82 \cdot 10^{11}) \cdot \exp(-\frac{6640.8}{T+273.15}) \tag{2}$$

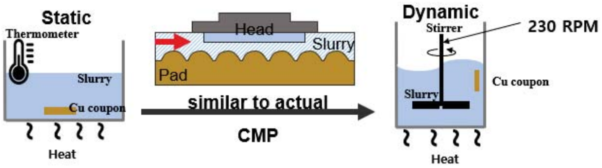


Fig. 1 Schematic diagram of dynamic etching experiment

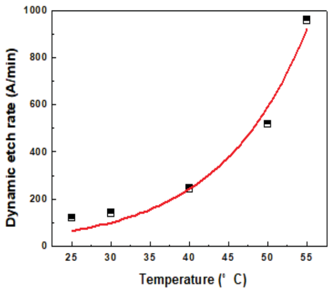


Fig. 2 Dynamic etch rate according to slurry temperature

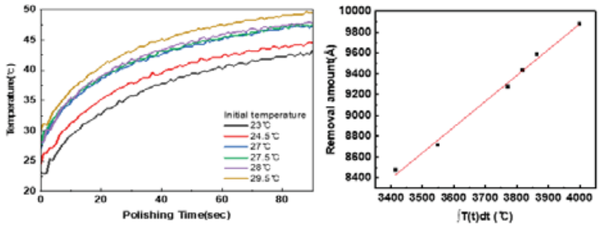
2.2 Removal Model of Copper Considering Temperature

How material removal rate changes as process temperature increases was compared through experiments. It was performed with a POLI-500 polishing equipment from G&P. Six electroplated 8" blanket copper wafers were prepared. Each wafer was polished at a different initial temperature for 90s. Polishing conditions were performed as shown in Table 1. As shown in Fig. 3(a) and (b), removal amount also increased as the total amount of temperature increased. Then, following equation was obtained by analyzing the relationship between temperature increase up to 't' second and removal amount.

$$RA_{Cu} = 2.47 * \int_0^t T(t)dt \tag{3}$$

where, T(t) is temperature function and the rate of increase in temperature is similar to each other as shown in Fig. 3(a). Using this data to find a function through a regression model, it is as follows.

$$T(t) = 22.0 - 8.463 \cdot \exp\left(-\frac{t}{14.031}\right) - 13.853 \cdot \exp\left(-\frac{t}{55.249}\right) + T_0 \tag{4}$$



(a) (b)

Fig. 3 (a)Temperature profiles according to polishing time and initial temperature and (b) removal amount according to the accumulation amount of temperature.

Table 1 Experimental condition

Pressure : Wafer/R-ring	2psi/3psi
Velocity : Head/Platen	87rpm/93rpm
Pad	KONI pad (stacked)
Slurry flow rate	150ml/min
Conditioning	In-situ

2.3 Planarization Model

In the previous study, deformation of pad asperity when the pad asperity and wafer were in contact was defined by dividing elastic section and plastic section. Therefore, difference in pressure distribution between top area and bottom area of pattern was explained. Through this, reduction of step height during polishing was predicted, and result was compared with oxide film wafer. Error was small in the oxide, but error was large in copper. So, in this study, a modified model is proposed and can be expressed as follows.

$$RA_{up} = \sqrt{k_{eff,up}} \cdot \frac{k_{eff,up} \cdot k_{eff,down}}{(k_{asp})^{\frac{3}{2}}} \cdot \frac{\xi^0}{\xi} \cdot \left(RA_{Cu} - e_{Dynamic}\right) + e_{Dynamic} \tag{5}$$

$$RA_{down} = e^{-\frac{h}{\sigma}} \cdot \sqrt{k_{eff,down}} \cdot \frac{k_{eff,up} \cdot k_{eff,down}}{(k_{asp})^{\frac{3}{2}}} \cdot \frac{\xi^0}{\xi} \cdot \left(RA_{Cu} - e_{Dynamic}\right) + e_{Dynamic} \tag{6}$$

Fig. 4 shows simulation result using the model equations (5),(6). Comparing with the actual measured value, it has an error of about 30nm to 40nm.

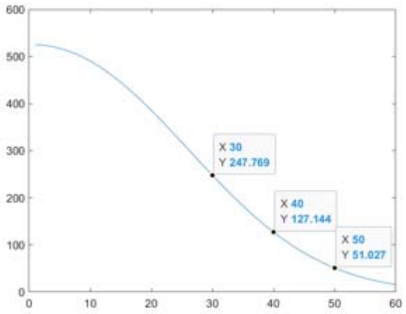


Fig. 4 Graph of simulated planarization model

3. Conclusions

Actual CMP is in a dynamic state, so the dynamic etch rate should be considered rather than the static etch rate. In addition, it can be seen that both etching and polishing test results are greatly affected by heat. That is, temperature affects both mechanical and chemical aspects.

Proportion of etch rate has a small proportion of around 5% of the total removal. However, the amount cannot be ignored from the perspective of nano-structures on the wafer.

The modified model consequently reduced the error significantly. However, it is necessary to further reduce error through additional research.

ACKNOWLEDGEMENT

This research was partially supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No.2021R1A2C1095017) and Ebara Corporation.

REFERENCES

1. H. Lee and H. Jeong, “A Wafer-Scale Material Removal Rate Profile Model for Copper Chemical Mechanical Planarization,” Int. J. Mach. Tools Manuf., Vol. 51, No. 5, pp. 395-403, 2011.
2. R. Chang and Costas J. Spanos, “Dishing-Radius Model of Copper CMP Dishing Effects,” IEEE, Vol. 18, No. 2, pp. 297-303, 2005.
3. H. Kim, H. Jeong, B. Park, S. Jeong and D. Lee, “Planarization Modeling Based on Contact Mode Between Pad Asperity and Oxide Pattern During CMP,” J. Korean Soc. Precis. Eng., Vol. 36, No. 4, pp. 363-372, 2019.