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In-situ Measurement of Friction Force during Cu Chemical Mechanical Polishing

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1. Introduction

Low-dielectric-constant (low-k) materials have been developed for the demand of high-speed operation and low-power consumption of ultra-large-scale integrated circuits [1]. Not only low dielectric constant but also high mechanical strength, high chemical stability and high thermal stability are required for low-k materials [2]. One of the major issues is an adhesion failure of the film during the chemical mechanical polishing (CMP) process. Lin *et al*. [3] reported on the relationship between elastic modulus of the low-k material and the CMP tolerance.

When the wafer is forced to slide and press against the polishing pad, peeling off occurred because the friction force acts between the wafer and the polishing pad.

In this study, we established in-situ quantitative measurement technique of the friction force during CMP. We also proposed the modification of the Preston's equation.

2. Experimental

A friction force measurement setup is shown in Fig.1. A wafer is held at a holder which is fixed under weight A in the measurement system. The weights B to E are added on weight A one by one. The roller is attached at the periphery of a weight A. Weight A is 104 N and other weights are 110 N. The wire is put on around the roller, and the wire is connected with the load cell in the direction of X and Y. When the pad rotates, the friction force is generated between the polishing pad and the wafer. The moment around the wafer center is generated by this friction force. In order to obtain the magnitude of the friction force, by the use of the roller, the wafer and the weights are movable freely with rotation. F_f which is friction force and μ which is the coefficient of friction are calculated from the following equations:

$$F_f = \sqrt{F_x^2 + F_y^2} \quad , \qquad (1)$$

$$\mu = F_f / L \quad . \qquad (2)$$

Here, F_x and F_y are the force measured with the load cell in the direction of X and Y. And L is load of weight(s).

Table 1 shows the basic experimental conditions in this study. In order to investigate the influence of the process parameter, we operated under a low relative velocity condition that the hydroplane phenomenon does not occur [4].

We examined the relationship between the load torque of the motor and the friction force measured by the above mentioned technique. There is a relation of linear proportion between the load torque and the friction force as shown in Fig.2. As a result, the friction force F_f can be obtained quantitatively by measuring the load torque of the platen motor.

3. Modification of Preston's Equation

In general, the polishing rate in CMP is described by Preston's equation shown below [5]. However, the polishing rate does not follow this equation, and some modifications have been proposed about the Preston's equation up to now. These modifications have been brought together by Castillo-Mejia *et al*. [6] in detail. The modification of the Preston's equation which has been proposed is generally shown by the following equation:

$$RR = kP^{\alpha} V^{\beta} \quad . \qquad (3)$$

Here, RR is the average polishing rate on the wafer surface, P is the polishing pressure, V is the relative velocity between the polishing pad and the wafer, k is the constant, and α and β are fitting parameters decided by the process and the consumables. In Preston's equation, both α and β are equal to 1.

We examined the influence of polishing pressure on the polishing rate for two kinds of slurry A and B. Synchronously, the friction force was measured by the above mentioned technique. A relative velocity in our experiment is constant.

According to the Preston's equation, the relationship between the polishing pressure and the polishing rate is plotted as shown in Fig.3. Since the coefficient of determination (COD) about slurry A is extremely low, it shows that there is no linear correlation between the polishing pressure and the polishing rate. The coefficient of friction is greatly changed by the slurry A, depending on the dressing condition of the polishing pad. We propose the following equation in which the coefficient of friction is no longer constant:

$$RR = k' F_f V \quad . \qquad (4)$$

Here, k' is a constant. Based on equation (4), the data of Fig.3 is re-plotted in Fig.4. It is obvious that the polishing rate is linearly proportional to the friction force.

This is because the energy necessary for polishing is mainly given as a friction force.

4. Conclusions

We established the in-situ quantitative measurement technique of the friction force during the CMP process. It was confirmed that the friction force is linearly proportional to the torque of the platen motor. Also, we proposed the modification of Preston's equation so that the polishing rate is in proportion to the friction force.

Acknowledgements

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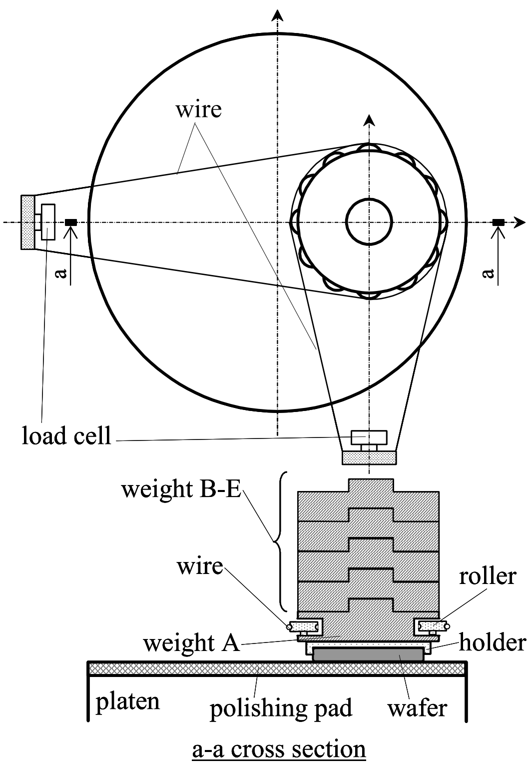

Fig. 1 A schematic diagram of the measurement system of the friction force.

Table 1 Experimental condition.

Parameter	Basic Condition	Experimental Range
Polishing Pressure	10.3 kPa	3.3 - 17.3 kPa
Slurry	-	A,B
Relative Velocity	0.4 m/s	constant
Polishing Time	120 s	constant
Sample Wafer	200mm Cu Plating	fixed

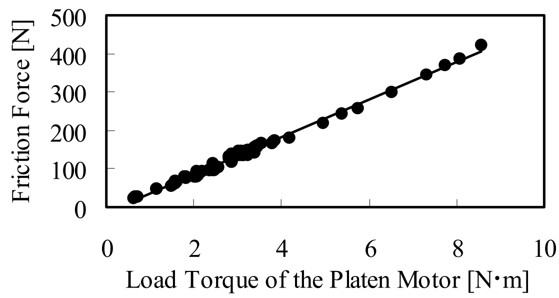

Fig. 2 Relation of linear proportion between the load torque of the platen motor and the friction force.

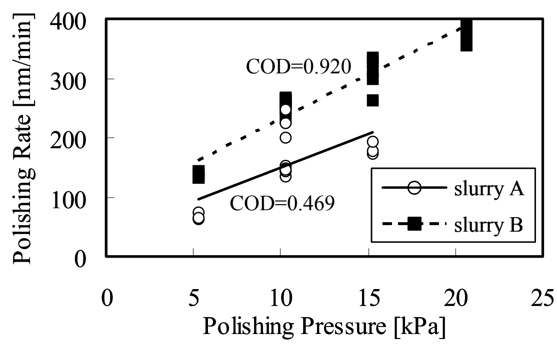

Fig. 3 Relationship between the polishing pressure and the polishing rate plotted according to Preston's equation.

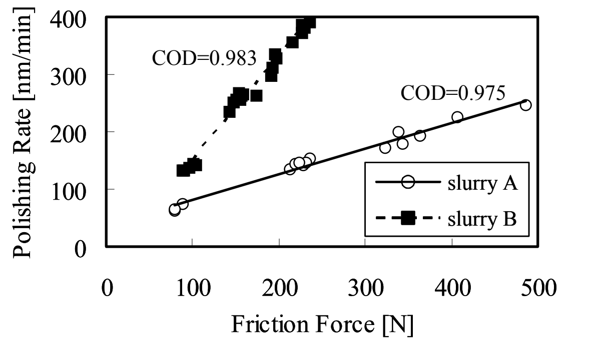

Fig. 4 Relationship between the friction force and the polishing rate plotted according to the proposed equation.