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Effects of Temperature on Removal Rate in Cu CMP

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Cu CMP에서 온도가 재료 제거율에 미치는 영향

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ABSTRACT

Chemical mechanical polishing(CMP) realizes a surface planarity through combined mechanical and chemical means. In CMP process, Preston equation is known as one of the most general approximation of the removal rate. Effects of pressure and relative speed on the mechanical property of Cu CMP has been investigated. On the other hand, The amount of abrasion also increased with changes in pressure and speed, resulting in a proportional increase of temperature during CMP. Especially this temperature is an important factor to change chemical reaction in a Cu CMP. However, when the slurry temperature became higher than 70°C, the removal rate went lower due to abrasives aggregation and scratching occurred on the Cu film. Therefore, it was found that the slurry temperature should not exceed 70°C during Cu CMP. Finally, authors could increase the pressure, speed and slurry temperature up to a ceratin level to improve the removal rate without surface defects.

Key Words : CMP(화학기계적 연마), Slurry Temperature(슬러리 온도), Size of Particles(입자 크기)

1. Introduction

As the semiconductor industry has advanced, the eight semiconductor processes have also been steadily studied and evolved ceaselessly. That is, significant changes in the processes have occurred, including the introduction of extreme ultraviolet lithography (EUVL) as the minimum line-width has become smaller than 10 nm. More recently, copper, which is less expensive and more conductive than existing materials, has been commercialized in state-of-the-art memories and central processing units (CPUs). As the wiring size inside the wafer has decreased, chemical vapor deposition (CVD) or physical vapor deposition (PVD), which is a gap filling process in the Damascene process, has reached an impasse. As a result, electrochemical deposition (ECD) in the wire filling process has been highlighted as the most important technique. However, flattening in the plating layer has been more strictly required due to the occurrence of defects due to chemical mechanical polishing (CMP), which is a follow-up process of the wire-filling process.

The CMP is a process conducted after one

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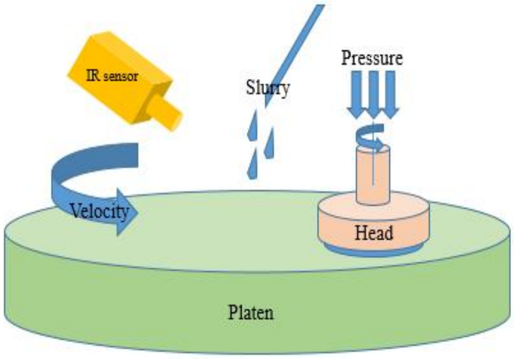

Fig. 1 Schematics of CMP process

substance is deposited when laying various chemical substances and metals. It is a process of polishing and flattening a rough surface by applying mechanical and chemical force on the semiconductor wafer surface by combination of CMP slurry and CMP pad[1] (Fig. 1).

CMP is a process that removes the target material by mechanical and chemical actions. It is divided into oxide CMP and metal CMP according to the target material for removal. Oxide CMP removes an oxide film by mechanical action through pressure and relative motion after a hydration layer is formed on the surfaces of wafer and particle, thereby making a chemical bond via the chemical reaction.

However, Cu CMP removes the reaction layer through mechanical action via pressure and relative motion as well as chemical action that removes the material after the reaction layer is formed on the wafer surface by oxidant and complexing agent, and Cu ions are created at the same time. When comparing the two mechanisms, chemical action plays an important role in the case of the metal CMP. Thus, since the role of oxidant and complexing agent contained in slurries used in the process plays an important role in the Cu CMP, it is important for slurries to be applied evenly to the CMP pad[2].

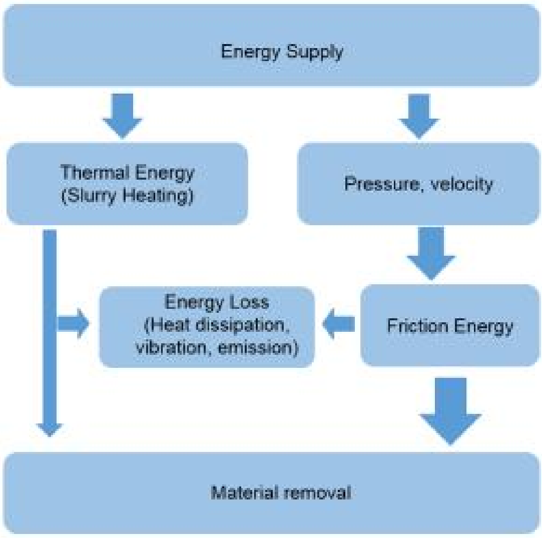

Fig. 2 Energy flow in CMP Process

Fig. 2 shows the energy flow that affects the material removal during CMP. The energy flowing back into the machine during CMP is converted into pressure, speed, and thermal energy, and then converted into frictional energy while the thermal energy experiences energy loss. The frictional energy is also lost by conversion to vibration energy or thermal energy during CMP, and such loss of energy plays a role in degrading removal rate.

This study aims to investigate the CMP conditions such as slurry temperature (thermal) and pressure and speed (mechanical) conditions on polishing temperature rise, and to identify the effect of polishing temperature on removal rate and surface defect.

2. Study method and contents

2.1 Temperature generated during process

In the CMP mechanism, polishing temperature has a proportional relationship with the frictional energy between wafer and CMP pad. Thus, the Preston equation should be modified to consider polishing

Table 1 Experimental conditions

Parameter	Conditions
Tool	POLI-500(GnP Tech Corp.,)
Material	Cu (4 inch)
Wafer Pressure	200, 300, 400 g/cm²
Rotating velocity (Head, Platen)	60, 90, 120 rpm
Process time	1 min
Slurry flow rate	100 ml/min
Polishing pad	Stacked pad(SUBA400/IC1000)
Slurry	Cu target slurry
Slurry Temperature	50, 60, 70, 80 °C

efficiency, and chemical reactivity of the slurry should also be considered for clear understanding of the CMP mechanism. Fig. 2 shows the rising polishing temperature by pressure, relative speed, frictional heat generation, and slurry heating.

This study aims to verify the correlation between removal rate and slurry temperature supplied during CMP with the measurement of polishing temperature. The temperature change that occurs in the CMP process is a factor that influences the polishing result. The CMP process requires mechanical and chemical energy to remove the materials on the wafer surface.

2.2 Energy flow during CMP

This study verifies the removal rate see the effect according to change in slurry temperature. In order to evaluate the CMP characteristics of the Cu wafer, polishing temperatures was measured during polishing of 4-inch Cu wafer with different polishing speeds and slurry temperatures under the conditions presented in Table 1. The removal amount of the processing target material depends on the chemical and mechanical properties of the material contacted. At the same time, polishing particles and scratches differ according to the slurry temperature. This change also affects the polishing rate.

The removal rate has been studied from the energy viewpoint. The energy spent during polishing is converted into frictional energy, by which polishing takes place. Then, the frictional energy is lost by conversion to vibration energy or thermal energy during polishing, and such loss of energy plays a role in degrading removal rate[3]. The energy used during material removal and frictional energy, and energy loss due to heat and vibration can be expressed by a relationship as presented in Eq. (1).

$$E_M = E_f - E_{th} - E_{vid} \quad (1)$$

where E_M refers to the total energy used during polishing, E_f refers to the frictional energy between wafer and pad during polishing, E_{th} is the energy which is lost via frictional heat during polishing and slurry temperature, and E_{vid} refers to the energy lost due to vibration occurrence of the device itself during polishing.

However, since a slurry temperature is added, the energy flow can be expressed by Eq. (2)[4].

$$E_{RR} = E_M + E_T \quad (2)$$

The removal amount is expected to increase if the slurry temperature is raised since the thermal energy (E_T) is obtained through the slurry temperature change from the total energy used during polishing.

2.3 Experimental conditions

The polishing condition of pressure and relative speed was chosen as follows: 200g/cm² and 40rpm (low), 300g/cm² and 80rpm (medium), and 400g/cm² and 120rpm (high). Generally, polishing slurry is used at room temperature (20°C), but the temperature was raised to 50°C, 60°C, 70°C, and 80°C to identify the slurry effect.

3. Results and discussion

3.1 Polishing characteristics according to changes in speed and pressure

As shown in Fig. 3, temperature during polishing is proportionally increased with the increase in pressure and relative speed. The trend of the removal rate can be identified through the measurement of temperature when the process condition changes. However, the error factor is also included to some extent during the precise prediction of removal rate. The CMP can not show whether chips occur visually, in contrast with cutting machining, and judging the removal mechanism via the thickness reduction. The removal rate is expressed by the unit of Å/min. The processing condition widely used is 200g/cm² and 80rpm of speed, at which removal rate would be 4,300Å/min.

A difference in removal rate was 2000Å/min under 400g/cm² and 80rpm, and the removal rate was increased by 500Å/min when the speed was raised to 120rpm.

These results show that increasing the pressure was more effective than raising the speed for removal rate increase. They also implied that the correlation with removal rate could be evaluated through the measurement of mechanical energy supplied to the inside or temperature rise, which was the output factor that occurred due to the mechanical energy.

3.2 Polishing characteristics according to changes in slurry temperature

Fig. 4 shows an experimental setup for temperature measurement on the pad and slurry simultaneously using an infrared camera and thermometer.

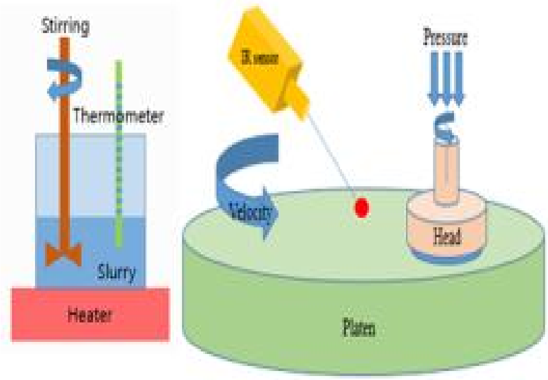

Fig. 4 Experimental setup for the measurement of the temperature of the slurry and pad

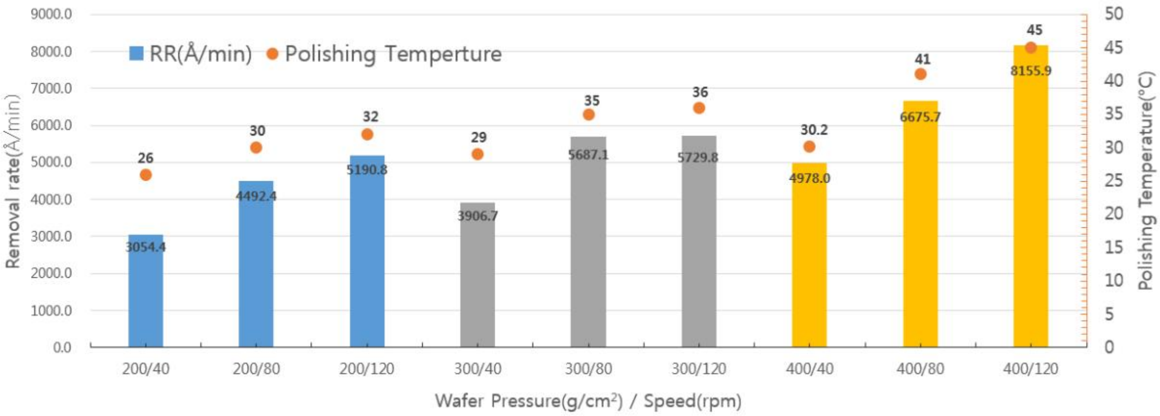

Fig. 3 Removal rate and polishing temperature according to polishing conditions

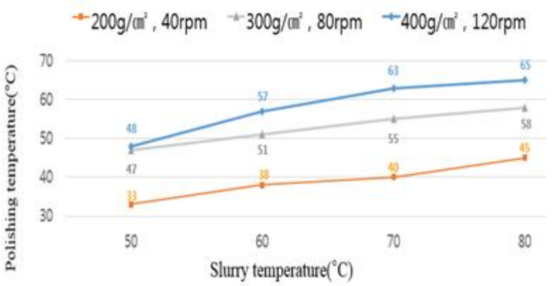

Fig. 5 Removal rate according to slurry temperature change

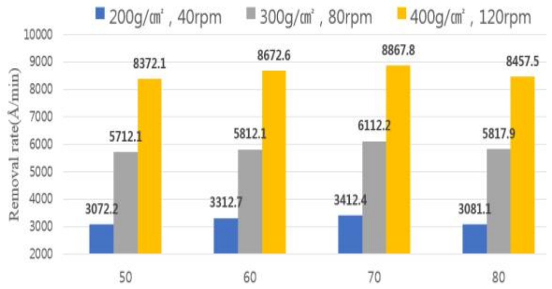

Fig. 6 Removal rate according to slurry temperature change

Fig. 5 shows that the temperature rises during polishing as the slurry temperature increased at each condition. The difference in removal rate while raising the slurry temperature arbitrarily was approximately 200Å/min per 10°C as the pressure and relative speed increased. A lower difference in removal rate was revealed than by controlling the speed or pressure.

In Fig. 6, when the pressure and relative speed increased at the 60°C condition, the removal rate was significantly improved to 3312.7Å/min, 5812.1Å/min, and 8672.6Å/min, but the removal rate was degraded with the difference of around 400Å/min if the slurry temperature exceeded 70°C when the pressure and speed were the same. Thus, increasing the speed or pressure, rather than raising the slurry temperature, was more effective for removal rate increase.

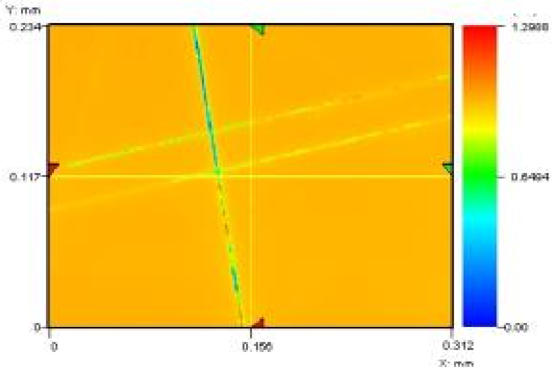

Fig. 7 Scratch through 3D measurement system

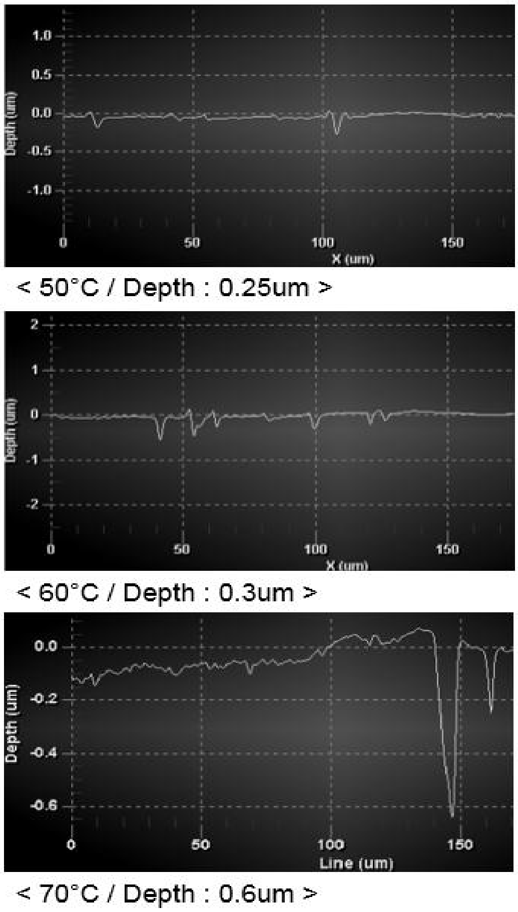

Fig. 8 Scratch depth according to abrasive size resulting from slurry temperature change.

3.3 Surface and abrasives characteristics according to temperature change

A slurry is composed of various wet chemicals and mixtures of abrasives. Thus, it can induce abrasives agglomeration due to the excessive change in polishing temperature in terms of polishing abrasives, thereby inducing changes in removal rate and scratches.

Fig. 8 shows that the scratches are generated deeply due to the abrasive agglomeration when polishing is done at 70°C slurry temperature, and abrasive size and scratch depth increase when the slurry temperature increases.

Fig. 7 shows that scratches occur at the wafer surface along with the removal rate decline at some specific temperature due to the abrasive agglomeration observed by the confocal microscope.

The scratch depths were 250nm, 300nm, and up to 616.9nm when slurry temperatures went up to 50°C, 60°C, and 70°C, respectively. Although the scratches were fine, the scratch depth was very deep because of the slurry agglomeration at 70°C of slurry temperature.

4. Conclusions

There were many factors involved in increase in polishing temperature during the CMP process. The direct factors were frictional heat between the pad and wafer, pressure applied to the wafer, and a relative speed of head and platen. The indirect factors were slurry temperature control and surface plate temperature control.

This study achieved an improvement of removal rate by increasing the pressure, relative speed, and slurry temperature. When the pressure and relative speed increased, the removal rate increased up to 2,000Å/min by the increase of pressure, and more 500Å/min by the increase of speed.

Raising the polishing speed and pressure was more effective in removal rate than raising the slurry temperature. Scratches were generated more deeply due to the abrasives agglomeration as the slurry temperature exceeds 70°C, which means that polishing by increasing slurry temperature was inefficient.

The goodness-of-fit test proved that a removal rate could be improved by increasing the polishing speed and pressure under the slurry temperature below 70°C.

This study verified the suitable mechanical factors and slurry temperature effects during Cu CMP. However, since Cu is more vulnerable to scratches than other metals, it is necessary to minimize the scratches in future study. A study on scratch control should also be undertaken using the slurry temperature and mechanical conditions proposed in the present study.

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