THE MECHANICAL EFFECT OF SOFT PAD ON COPPER CHEMICAL MECHANICAL PLANARIZATION

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ABSTRACT

Smaller transistor sizes challenge the traditional chemical mechanical polishing (CMP) in semiconductor manufacturing. New consumables and deep mechanism studies can alter the cliff of defect mitigation. Commercial pad suppliers offer the hard pad model IC 1000 but multiple soft pads. Basic research on soft pads was needed to support design and manufacturing process optimization.

INTRODUCTION

Copper replaced aluminum with interconnected conductors to reduce resistance and produce faster, smaller, and cheaper microprocessors [1]. Multi-stage CMP including bulk copper removal, barrier removal, and over polishing has been used in copper wiring [2]. The target depends on the polishing step. The over plated copper is first removed to increase adhesion, and then the barrier layer is removed to prevent diffusion. The final step of over polishing copper, barrier layer, and dielectric is to remove defects such as scratches, dicing, and erosion that occurred in the previous step. With 14 nm technology, issues with power, power density and reliability suggest the need for new materials and technologies in copper interconnects [3]. Currently, a soft pad is used instead of a hard pad to remove the copper line recess and adjust the scratch on the barrier CMP [4, 5].

BACKGROUND

Many physical models showed a soft pad effect on the CMP. The model developed by Shi et al. predicted the nonlinear pressure dependence of the polishing rate using the polishing pad [6]. Recently, Barre et al. The 300 mm copper and tungsten blanket wafer polishing describes the boundary lubrication method of the soft pad. Huang et al. reported the application of soft pads in polysilicon and SiN polishing to solve challenges over 7 nm [7].

This study evaluates the tribological behavior of commercial soft pads. First, we analyze the pressure applied to MRR, non-uniformity, and polished copper roughness and the effect of polishing concentration. The exponential growth rate of MRR according to the applied pressure, abrasive concentration, and sliding rate is calculated and compared with the criteria. The scratching phenomenon with squeal noise was observed and attributed to stick-slip-induced friction. Furthermore, the consistency of soft pad polishing with and without brush conditioning is analyzed based on pad surface roughness, polished copper surface roughness, and surface elemental composition.

EXPERIMENTAL

Coupons with dimensions of 4 cm × 4 cm were cut from a 12-inch blanket copper wafer. Diamond dressers are typically applied to condition the hard pad. In this experiment, a commercial brush conditioner made of nylon was selected to remove abrasive debris of a soft pad instead of a diamond dresser. The slurry for a copper film for a laboratory was prepared from 2 wt% colloidal silica (ACS nano 2080s, Ace Nanochem, Korea) diluted with a diameter of about 80 nm, and then 1 wt% of glycine and 0.1 wt% of benzotriazole (BTA) additive. Due to its labile properties, hydrogen peroxide was mixed with slurry before all experiments. In order to find out the effect of the abrasive concentration, 2 wt%, 4 wt%, and 6 wt% colloidal silica were deployed.

Polishing experiments were carried out with a 100-mm wafer polisher (Poli-400, GnP Technology, Korea). Before the first polishing, DE-ionized water (DIW) was injected into the pad center to adjust 240s of water, the pad was wetted and flattened through slurry control of 120s. As pad conditioning was completed, the slurry was transferred with the polisher head downward. The coupon wafer was chucked onto the surface of the grinder head with a vacuum membrane. Next, the polishing head was rotated with the platen at a constant speed for 60-second polishing, and the copper film was rinsed with DIW for 10 seconds, and the surface was cleaned by gently rubbing with a brush. At the end of each experiment, the pads were cleaned with 300s of water conditioning and sealed in a clean plastic bag with water before the next use. The thickness of the copper film was measured with a four-point probe (CMT-SR5000, AIT Co., Korea) before and after polishing to calculate MRR. The average MRR and non-uniformity were calculated by measuring 20 points of copper film along the same wafer centerline.

The abrasive coefficient of friction (COF) and temperature were collected as integrated sensors with a frequency of 10 Hz in the abrasive machine. The copper film topographic image was scanned in the tapping mode of atomic force microscopy (AFM) (NX10, Park System Corporation, Korea). The scanning area was 5 mm × 5 mm at a frequency of 1 Hz. Open-source software image J analyzed the surface area ratio of copper oxidation and Cu-BTA complexes in AFM images. Optical microscopy (OM) (Olympus Corporation, Japan) was used to study surface scratches. The portable surface roughness tester measured the pad section curve with a line scan. High resolution field emission scanning electron microscope (HRFE-SEM) (JSM-IT800, JEOL Ltd.) was used to investigate pads before and after polishing and the polished copper film. At the same time, energy dispersion spectroscopy (EDS) mapping was performed to detect element composition and distribution.

DISCUSSION

The applied pressure is a manageable but important parameter in the CMP, regardless of the target material and consumables. In addition, the abrasive concentration of the slurry affects the number of active abrasives and local pressure at the nanoscale. concentration of the slurry affects the active abrasive numbers and local pressure at the nano-scale. As shown in Figure 1, the applied pressure significantly improves the MRR and non-uniformity compared to the abrasive concentration in soft pad polishing. Pan *et al.* [8] proposed an empirical exponential expression for copper CMP temperature further supports the involvement of a larger number of particles in abrasion when the slurry contains a larger amount of abrasives.

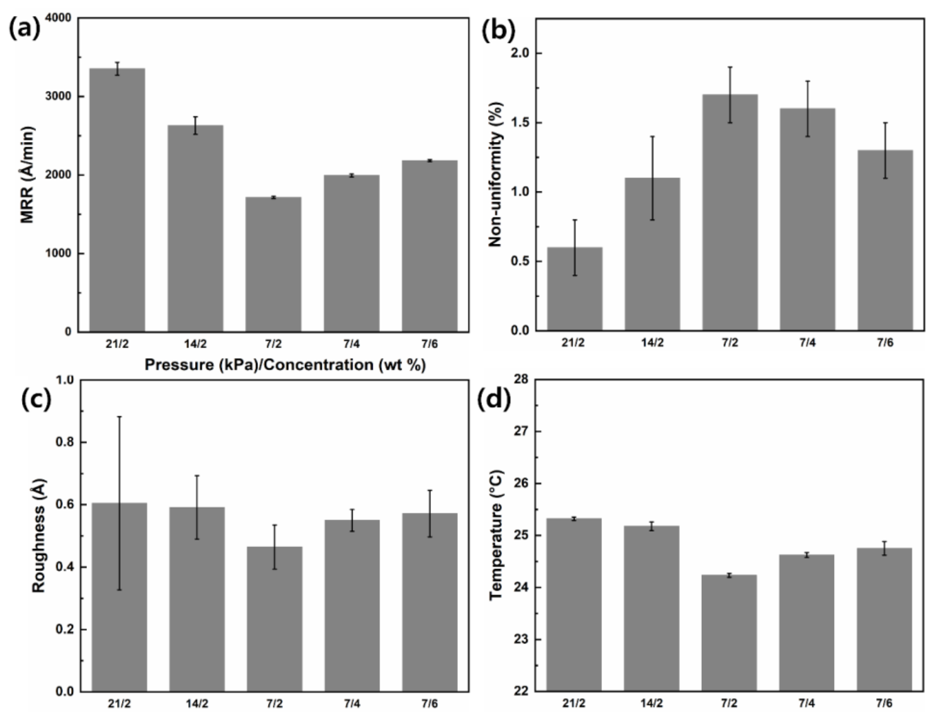

Fig. 1 (a) MRR, (b) non-uniformity, and (c) surface roughness of the polished copper film and (d) pad surface temperature in Experiments A and B.

The soft pad commonly participates in buff CMP to achieve local and global planarization. That highlights the importance of non-uniformity and roughness, critical to dishing and erosion.

The top view AFM image of the polished wafer is shown in Figure 2. Black spots were corrosion and white spots were particle residues. Without scotch brush scrubbing, oxidized copper and copper-BTA complex is left behind and is indicated by a dotted line in the AFM image. The surface area ratios are listed under the AFM image

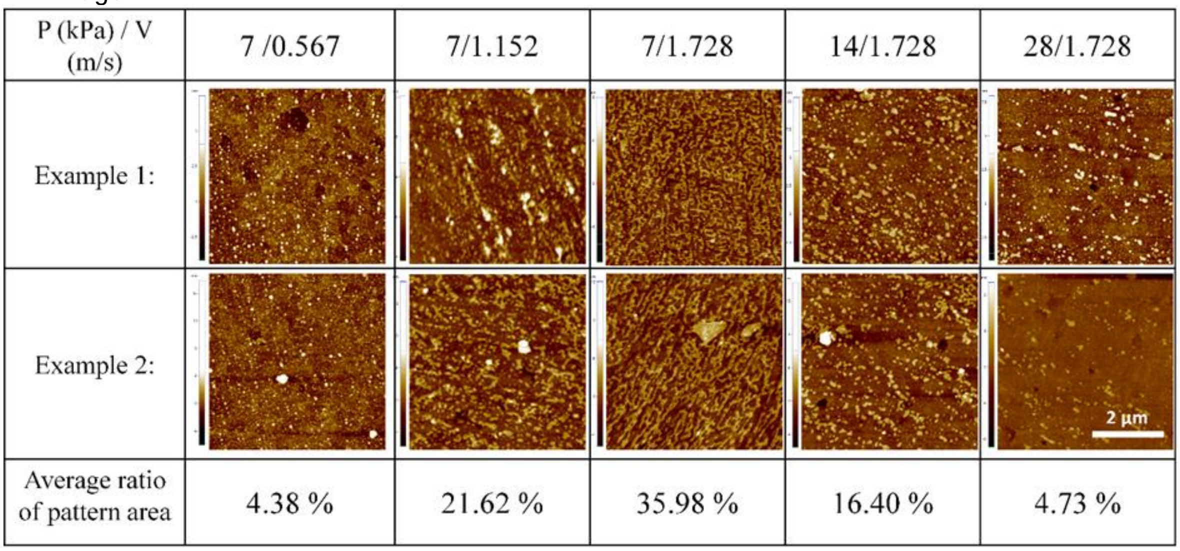

Figure 2. Sliding velocity and applied pressure effect on the topography of the polished copper films.

Conclusions

Soft pad buff CMP was adopted to reduce defects due to advanced technology. Higher MRR and higher wafer-level non-uniformity were achieved with high application pressure and high concentration of abrasive materials in the slurry. Tribology behavior was determined according to the Stribeck curve and Prestonian equation by monitoring COF and MRR changes with different applied pressures and sliding speeds. The friction force remained in the partial lubrication system, and the exponential influencing factors of the applied pressure and sliding speed were found to be around 0.64. Despite the low hardness, scratches occurred due to stick-slip friction with squeal noise at the start and end of the process. In the brush conditioning process, the pad roughness increased, resulting in minor pad surface roughness removed after polishing. Without brush conditioning, polishing debris accumulated on the pad surface and decreased the MRR, resulting in retention of a larger amount of organic elements on the copper film because of insufficient mechanical abrasion

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