Effect of Surfactant on Package Substrate in Chemical Mechanical Planarization

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The demand for pattern miniaturization on package substrates has been steadily increasing. One technical innovation for the package substrate manufacturing process was chemical mechanical planarization (CMP). In conventional wiring, it was possible to remove extraneous copper through only the etching process. However, etching defects occur with narrower line widths. As the package substrate has a Cu hybrid structure through Cu plating and copper clad laminate (CCL) removal, it is necessary to apply the CMP to remove excess copper. However, defects are generated by the CMP process due to mechanical and chemical effects from the slurry. This study investigated the surfactant effect on Cu dishing and erosion in patterns with approximately 10/10 μm line width and spacing. The conventional Cu slurry without a surfactant had severe erosion (0.58 μm) in Cu patterns of 4/6 μm and deep dishing (4.2 μm) in Cu patterns of 14/16 μm . However, the experimental results showed that the friction force during CMP decreased, with smaller dishing and erosion as surfactant concentration increased. Finally, globally planarized Cu patterns were realized with an erosion range of 0.22 μm to 0.35 μm and a dishing range of 0.37 μm to 0.69 μm with 3 wt.% surfactant.

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1. Introduction

The demand for electronic package technology that can mount semiconductor elements more effectively is increasing due to the demand for increasingly lighter, smaller, multi-functional mobile devices and electronic goods resulting from recent advancements in the information and communication industries.¹⁻³ Previously, signals were transmitted through wire bonding used to connect the chip to the substrate. However, this method faces a number of problems such as decreased signal transmission speed, decreased high frequency wave characteristics, and an input/output (I/O) pad increase resulting from high resistance as the overall wiring length increased.⁴ Recently, efforts have been made to address the weaknesses induced by wire bonding through improved high density integration, high speed signal transmission, electrical conductivity, and heat conduction characteristics through the copper plating process and by vias and wiring on the package substrate.⁵

The fabrication of narrower and shallower wires on the package substrate has been limited due to the application of a sustainable etching process that has been used previously. In order to realize fine patterns below 10 μm on the package substrate, the chemical

mechanical planarization (CMP) process is considered one of the best planarization technologies for the semiconductor process.⁶

The package substrate has a copper hybrid laminating structure, fabricated through a repetitive plating and removal process on the copper clad laminate (CCL). Recently, CMP technology was introduced to remove extraneous copper from the substrate surface.^{4,7} The package substrate was made by laser ablation of a dielectric material comprised of epoxy resin and glass fiber, which then goes through a Cu plating and CMP process. The typical types of defect that can be generated during the CMP process as it removes the plating film are shown in Fig. 1. The main defects are a Cu dishing resulting from the differences in material removal rates, and dielectric erosion from the dynamic relationship of the process elements with an excessive removal phenomenon. These defects can affect the processing or structural characteristics, leading to wiring short circuits during the laminating process.⁸

Accordingly, excessive Cu dishing and dielectric erosion must be minimized in order to realize a finer line width.⁸⁻¹² One solution to minimize these defects is the use of a surfactant, described herein.

Surfactants are generally used to reduce surface tension by forming

Fig. 1 Dielectric erosion and Cu dishing after Cu CMP

Fig. 2 Effects of micelle structure (left) on the CMP process (right)

micelle structures around the hydrophobic or hydrophilic regions of a molecule. The surfactant possesses both a hydrophilic head group and hydrophobic tail. Fig. 2 shows the micelle structure formed by the hydrophobic tails sticking together with the hydrophilic head groups facing outwards. On the projecting Cu areas contacting the CMP pad, the surfactant's micelle structure collapses, allowing removal of the Cu by the mechanical action of the abrasive particles with the pad during the CMP process. However, the recessed Cu regions are protected from chemical reaction by the micelle structures. The surfactant was also added onto the slurry to verify how effectively the projecting copper on the package substrate was removed during the CMP process. In order to optimize the amount of surfactant, the resultant Cu dishing and dielectric erosion were observed, which could explain the planarity level achieved during the CMP process.¹³⁻¹⁵

2. Experimental Conditions

The CMP has a synergistic effect of chemical dissolution (or passivation) with mechanical abrasion by the slurry between the pad and the package substrate. A kinematic motion results from the relative velocities of the head and platen rotation.¹⁶ The quantity of Cu dishing and dielectric erosion were measured after the CMP using a slurry containing 1 wt.% ammonia, 3 wt.% colloidal silica (70 nm), 5 wt.% organic acid, and 2.3 wt.% hydrogen peroxide relative to deionized (DI) water.

In general, the amount of Cu dishing decreases as the line width

Table 1 The slurry additive compositions

Additive	Concentration (wt%)	
Ammonia	1 wt%	
Colloidal silica(70 nm)	3 wt%	
Organic acid	5 wt%	
Hydrogen peroxide	2.3 wt%	
Surfactant (linear alkylbenzene sulphonate)	#1	Non-additive
	#2	0.1 wt%
	#3	1 wt%
	#4	2 wt%
	#5	3 wt%

Fig. 3 Schematic of the friction monitoring system showing (a) the cross section view, and (b) the top view

decreases in semiconductor device nanopatterns while the amount of dielectric erosion increases. However, excessive dielectric erosion increases significantly as the nanopattern approached fine line widths, while the amount of Cu dishing also increased. To minimize these defects, a traditional anionic surfactant, linear alkylbenzene sulfonate (LAS), was added into the slurry for polishing. The different amounts of surfactant added are shown in Table 1. A pre-CMP package substrate was attached with an adhesive film. The package substrate was comprised of copper patterns with line and spacing widths of 4/6 μm , 6/8 μm , 9/11 μm , and 14/16 μm . To indirectly verify that there has been a change in surface tension and adhesion due to the surfactant, a friction monitoring system was used to measure the frictional force generated at the contact point by the pressure and velocity of the head and platen during the CMP.

Fig. 3 shows a schematic of the monitoring system installed in the CMP equipment. The frictional force is vertical to the head's rotational

Table 2 Experimental conditions

Parameters	Condition or types
Pressure	34.3 [kPa]
Velocity	Head 87 [rpm] / Table 93 [rpm]
Conditioner	Nylon brush
Polishing pad	SUBA 600(X-Y groove)
Slurry flow rate	100 [mL/min]
Process time	5 min

Fig. 4 Amount of dielectric erosion and Cu dishing without surfactant in the Cu CMP

axis without any movement generated in real-time. The frictional force signal is converted by the amplifier and analog to digital (A/D) converter, and then manifested through a sensor.

Fig. 3 shows a schematic of the monitoring system installed in the CMP equipment. The frictional force is vertical to the head's rotational axis without any movement generated in real-time. The frictional force signal is converted by the amplifier and analog to digital (A/D) converter, and then manifested through a sensor correction.¹¹ In order to verify the frictional force change relative to the surfactant amount added in the slurry, a CCL without any micropattern was used. The experimental conditions are shown in Table 2. The package substrate was pressurized under 34.3 kPa with an 87 rpm speed on the polyurethane non-woven pad with X-Y grooves for 5 min. The slurry was supplied from the center of the pad with a 100 mL/min flow rate. Next, the quantity of Cu dishing and dielectric erosion on the package substrate surface after CMP was observed with a confocal microscope to analyze the effect of the surfactant.

3. Results and Discussion

Fig. 4 is a graph displaying the results of no surfactant in the slurry. It can be seen that dishing from 3.46 to 4.19 μm and erosion from 0.39 to 0.58 μm occurred depending on the pattern size. Excessive dielectric erosion was shown in Fig. 4 as the insulator wore away significantly as it approached fine line widths, and the amount of Cu dishing increased as well.

3.1 Friction

To verify the effect of surfactant on the friction force during CMP, a friction force sensor was attached to the testing equipment and its changes were monitored. Fig. 5 shows a change of the average

Fig. 5 The friction force and removal rate according to surfactant concentration during CMP

Fig. 6 Dielectric erosion amount according to surfactant contents

frictional force, displaying a constant decrease as the amount of surfactant increased. This indicates that the surfactant alleviated the frictional force generated at the interface between the copper pattern and the pad during CMP.

3.2 Erosion

Overpolishing is necessary to completely remove Cu residue from the entire surface; however, this makes the dielectric erosion worse. Fig. 6 is a graph presenting the amount of dielectric erosion after CMP relative to surfactant concentration. The dielectric erosion steadily reduced relative to the amount of surfactant. This phenomenon has a good correlation with the frictional force changes during CMP with added surfactant.

Moreover, the amount of dielectric erosion increased consistently with decreasing line widths in Fig. 6 and Fig. 7. The dielectric erosion was worse for narrower spacing compared to wider spacing. Namely, the amount of dielectric erosion increased as the line width became narrower, which is why the narrow patterned insulator could not withstand the polishing pressure, rapidly eroding away.

3.3 Dishing

Fig. 8 shows the amount of Cu dishing after CMP with varied amounts of surfactant. A significant amount of Cu dishing (3.5–4.2 μm) took place without the presence of surfactant. When 0.1 wt.% surfactant was added, the Cu dishing reduced significantly compared to that without surfactant. The amount of Cu dishing gradually reduced to

Fig. 7 Confocal microscope images of the Cu patterns at (a) $4/6\ \mu\text{m}$, (b) $6/8\ \mu\text{m}$, (c) $9/11\ \mu\text{m}$, and (d) $14/16\ \mu\text{m}$ after CMP with 3 wt.% surfactant

Fig. 8 Cu dishing amount according to surfactant contents

approximately $0.5\ \mu\text{m}$ when the amount of surfactant was increased to 3 wt.%. Finally, it was confirmed that the Cu dishing was primarily dependent on the amount of surfactant, regardless of changes in the line width. Moreover, the amount of Cu dishing also depended on the amount of dielectric erosion.

4. Conclusions

This study examined the post-CMP surface defects in copper patterns with line and spacing widths of $4/6\ \mu\text{m}$, $6/8\ \mu\text{m}$, $9/11\ \mu\text{m}$, and $14/16\ \mu\text{m}$ on the package substrate surface. In particular, it was possible to verify that the surfactant in the CMP slurry directly affected the amount of surface defects. Without surfactant, a relatively high frictional force was generated, leading to material overpolishing and generating process defects such as Cu dishing and dielectric erosion. On the other hand, with the inclusion of a surfactant, a relatively low frictional force was achieved, significantly reducing the Cu dishing and dielectric erosion amounts.

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