Title
Development of a CMP Pad with Controlled Micro Features for Improved Performance

Authors
Lee, Sunghoon
Kim, Hyoungjae
Dornfeld, David

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Development of a CMP pad with controlled micro features for improved performance

*Sunghoon Lee, Hyoungjae Kim, David Dornfeld
Department of Mechanical Engineering
University of California, Berkeley
Berkeley, CA, 94720, USA
*sunghlee@me.berkeley.edu

Abstract – This paper focuses on the development of a new chemical mechanical polishing (CMP) based on characterization of conventional pads. Based on new design rules, new pads are prototyped and tested with planarity in SiO_2 CMP. The result is compared with the conventional pad and the effect of each pad design is also investigated according to design rules.

INTRODUCTION

In CMP, a wafer is placed face-down under high pressure on the polishing pad in the presence of slurry. After a wafer is exposed to slurry, the chemically reacted surface is mechanically polished by interactions between pad and abrasives [1]. Macroscopically, when fresh slurry is pumped on the pad, it stays temporarily on the pad and is supplied to the pad/wafer interface by rotation. Microscopically, abrasives are backed up by asperities on the pad and make nano-scale scratches on the wafer in a manner similar to plowing [2]. As the removal mechanism is mainly defined by the pad, it is important to understand the influence of the pad on process physics. Although, there has been much research on slurry, very little has been explored for the design and fabrication of pads in spite of its importance. Many defects (such as dishing, erosion, thinning, and micro scratches) are also generated by a conventional CMP pad. This paper characterizes a conventional pad and proposes new pads based on this characterization. Its performance is evaluated with planarity in SiO_2 CMP.

PAD CHARACTERIZATION

Generally, a pad is made of polyurethane. The surface is covered with density 30-50% pores (diameter 40-60μm), and each pore is separated with wall structures (asperities of width 10-50μm). There are peaks and valleys and these are continuously regenerated by conditioning. Based on previous research [3,4], the side view of a pad can be categorized into 3 regions; namely, the reaction region, the transition region, and the reservoir region (Figure 1). The reaction region is mainly composed of wall structures. On the reaction region, pad and wafer have multiple contacts with abrasives such that direct interaction among them can occur. The reservoir region is generally made of pores which provide enough space for new slurry. Fresh slurry supplied to the pad can be held temporarily in the reservoir region, and flows through the transition region to the reaction region. That is, the transition region (pores and walls) is the space for slurry transportation from the reservoir region to the reaction region. Through this means of slurry transportation, slurry is guided by the transition regions, which surround the reservoir regions and are linked to the reaction regions as indicated in figure 2 with white circles.

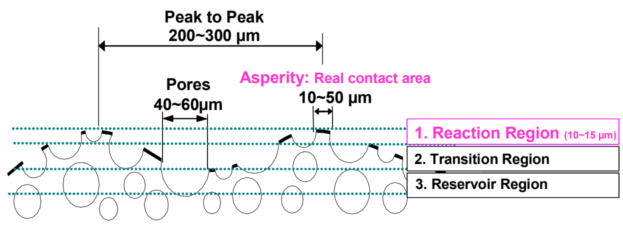


Figure 1 Pad profile

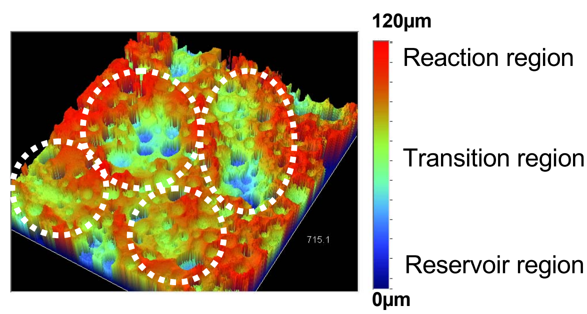


Figure 2 3dimensional pad view

PAD DESIGN AND FABRICATION

Based on the pad characterization, two types of pad designs are provided. Type A pad consists only of an array of cubes. This pad is designed mainly by focusing on the reaction region without consideration of the transition and the reservoir regions; that is, slurry efficiency is not considered. Each cube is 40×40×40μm. In contrast, type B pad is designed to increase slurry efficiency. When the pad rotates, designed features guide slurry to the reaction region (contact area). By designing the shape of features, the reaction region can be controlled. The transition and reservoir regions can be realized through the design of feature location.

Both new pads are composed of two layers; soft and hard. The soft material, with high compressibility and compliance, serves to homogenize the pressure distribution over a wafer. The hard layer, which is backed up by this soft layer, makes contact with the wafer and is used to achieve planarity. To avoid defects, such as over polishing, dishing and erosion, a new pad has constant contact area composed of hard material. Only the isolated hard features make contact with the wafer. The stress is independently applied on the hard contact area and is absorbed by the soft layer. As a result, a uniform stress distribution is acquired across wafer. Figure 3 shows an SEM image of new pads.

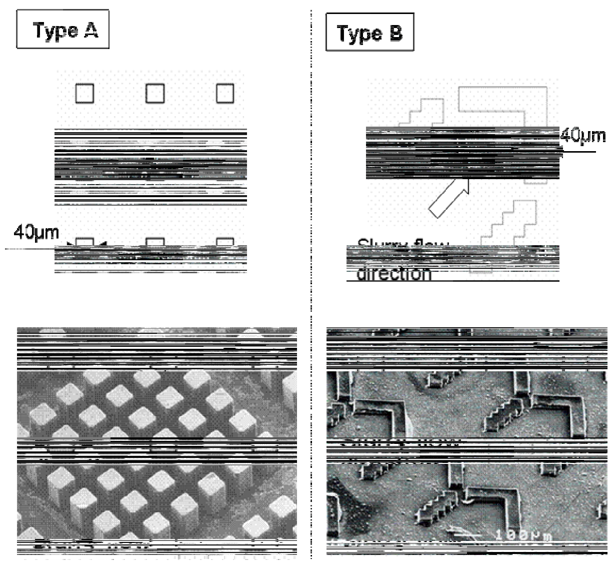


Figure 3 SEM images of type A and B pad

The designed pad is then fabricated with micro-molding technology. New designs are patterned on a 6" silicon wafer with deep reactive ion etching (DRIE). The patterned wafers are used as masters. Then, these are replicated on silicone rubber (PDMS) with a casting process. Upon release, the patterned silicone rubber is used as the mold for the pad. Small pockets (contact area) are filled with a relatively stiff polymer and cured. Then, a more compliant polymer is poured over the stiff polymer. The two layers are demolded as a single piece after curing. Figure 4 details the indirect casting process.

SIMULATION AND EXPERIMENT

To testify the correlation between the pad design and slurry efficiency, a fluid simulation program, FLUENT, is used for slurry flow analysis before the experiment. 1μm gap between a pad and a wafer is assumed. 100ml/min of slurry flows in from the inlet. Other properties are assumed same as conventional slurry.

In type A pad, slurry flows in the space among the cubes. Hence, the flow rate is low. Compared to type A, type B shows 8 times higher slurry flow rate on contact area. When new slurry flows in, the features guide slurry onto the contact area in a similar manner to the transition and reservoir regions of a conventional pad. By controlling the pad feature design, slurry efficiency can be improved. So, pad design should be seriously considered for new pad development. Figure 5 shows the images of the simulation.

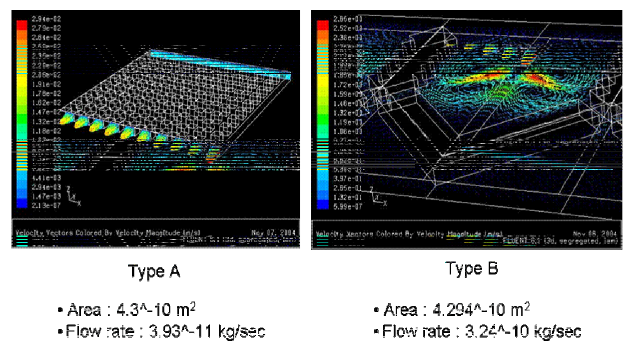


Figure 5 FLUENT simulation

To evaluate experimentally the slurry efficiency and performance of the new pads, the results of type A, type B and IC1000/Suba400 (a conventional pad) are analyzed. A 6 inch wafer is used as the master for pad fabrication, so the overall pad size is limited to 6 inches, and is attached on a plate of a small polishing machine. 3 inch patterned wafers are used for the polishing experiment. These have 14500Å of silicon dioxide film and density patterns ranging from 12% to 100%. Figure 6 shows the specification of the patterns. D-7000 (Cabot Co.) slurry is used. The details of the experiment are listed in table 1. Patterned wafers are polished separately on the conventional, type A and B pads, and the wafer planarity on density 20% and 50% is primarily investigated.

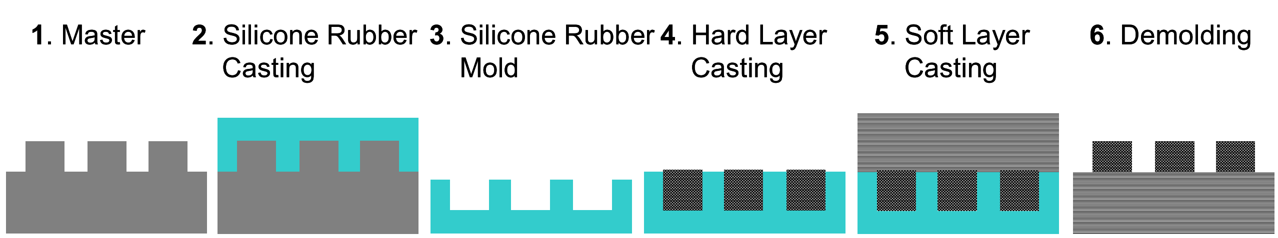
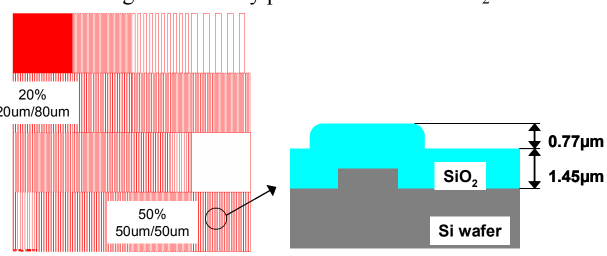


Figure 4 Pad fabrication process

Pad	IC1000/ SUBA400	Type A	Type B
	60rpm		
Wafer	3inch wafer (12-100% density,1.45µm SiO2)		
	30rpm		
Slurry	D-7000 (Cabot Co.)		
	100ml/min		
Pressure	2.7psi		

Table 1 Experiment condition

Figure 6 Density pattern wafer with SiO_2



ILD pattern (MIT mask Version 1.0)

RESULTS

To compare planarity-based performance, material removal rate (MRR) on the patterned and recessed areas is measured separately with a NANOSPEC spectro-reflectometer before and after CMP. The pattern profiles are measured with an Alpha-step profiler and pattern evolutions are compared.

In ideal ILD CMP, only the patterned area should be polished selectively and the recessed areas should remain as they are. However, this is impossible to be realized in an actual CMP process due to elastic deformation of the pad, which leads to pad asperities making contact with recessed areas.

In a conventional pad, the contact area between pad asperity and wafer is 10-50µm. With 20% pattern density, the pattern width is 20µm, and the space is 80µm. With 50% pattern density, the pattern width is 50µm, and the space is 50µm. At the early stage, only the pattern is polished. As the step height decreases, the recessed area is polished caused by pad asperities. As the asperity is smaller than the width of the space area, both the pattern and the space areas are polished together at small step height.

In type A pad, the feature size is 40×40µm. On 20% and 50% density pattern, the width of the recessed area is wider than the entire feature size, so that the recessed area is also polished. As the cubes are isolated from each other, the structure is very weak and easily abraded. After 40minutes of CMP, many of cubes were worn out. So, the pattern was not planarized after 40mins' polishing. The removal rate is also lower than type B and conventional pad. The lower removal rate is due to the low slurry efficiency as predicted in the FLUENT simulation result and abrasion of pad features.

In contrast, the type B pad demonstrates lower removal rate on the recessed area and good planarity. Although MRR of type B is higher than type A, unfortunately, it is smaller than that of a conventional pad; the new pad requires a total polishing time of 20 minutes to match the thickness removed in 10minutes of polishing with a conventional pad. This is attributed to the local stress on the reaction region. Generally, the conventional pad has spherically shaped contact areas. When it is pressed against on a wafer, the local stress on pad asperities is higher than the nominal pressure. In the case of type B, as the contact area is flat surface, the local stress is the same as the nominal stress. So the conventional pad shows higher MRR than type B pad.

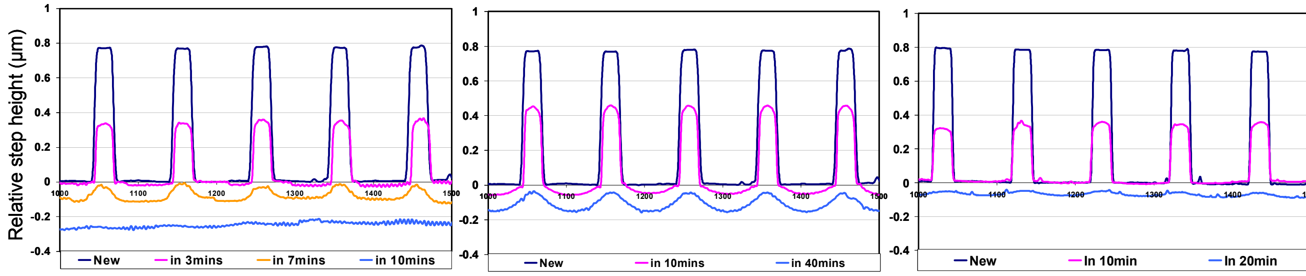
Table 2 depicts the MRR data for the patterned and recessed areas on densities 20 and 50% pattern. Surface profile evolution is demonstrated in figure 7. Although a conventional pad shows high MRR, over-polishing is about 2,500Å after reaching planarization. However, the type B pad doesn't polish the recessed area as much and over-polishing is under 800Å. Hence, only the patterned area is removed and planarization is accomplished with only minimal material removal in the recessed areas.

MRR \ Pad		IC1000 /Suba400 (10mins)	Type A (40mins)	Type B (20mins)
Density 20%	Pattern	10278 Å	8248 Å	7937 Å
	Recess	2448 Å	1371 Å	438 Å
Density 50%	Pattern	8990 Å	5810 Å	4485 Å
	Recess	1450 Å	270 Å	152 Å

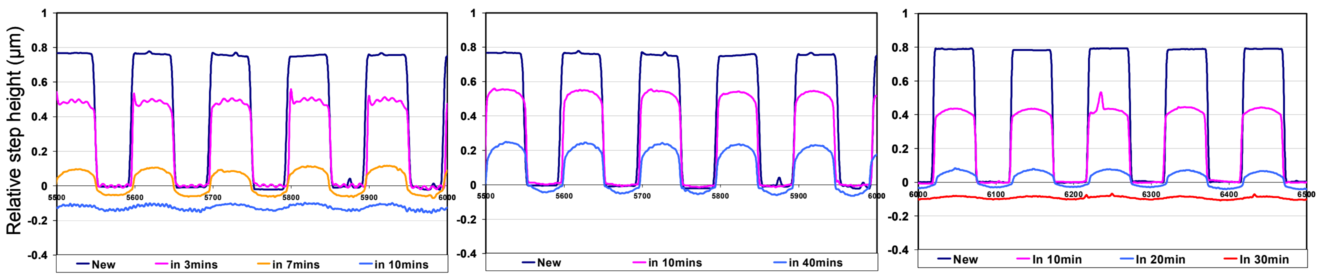
Table 2 MRR data on density 20 and 50%

CONCLUSIONS

In this paper, a conventional CMP pad is characterized and two types of new pads are designed and prototyped. By investigating the results of each pad, the effect of pad design is experimentally explained; specifically, the reaction, the transition and the reservoir region. As shown in the FLUENT simulation and the results of pad type A, the pad design has a major effect on MRR. The planarity could be obtained by controlling the contact area as type



(a) Density 20% - IC1000/Suba400, Type A and Type B



(b) Density 50% - IC1000/Suba400, Type A and Type B

Figure 7 Profile evolutions on each pad

B pad. The pad design is highly correlated to the performance of CMP. By controlling pad features, better MRR and planarity could be achieved in the future. More research is continuing in Cu CMP for a new pad with fewer defects such as dishing and erosion.

ACKNOWLEDGMENT

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