

Consumable Approaches of Polysilicon MEMS CMP

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Chemical-mechanical polishing (CMP), one of the dominant technology for ULSI planarization, is used to flatten the micro electro-mechanical systems (MEMS) structures. The objective of this paper is to achieve good planarization of the deposited film and to improve deposition efficiency of subsequent layer structures by using surface-micromachining process in MEMS technology. Planarization characteristic of poly-Si film deposited on thin oxide layer with MEMS structures is evaluated with different slurries. Patterns used for this research have shapes of square, density, line, hole, pillar, and micro engine part. Advantages of CMP process for MEMS structures are observed respectively by using the test patterns with structures larger than 1 μ m line width. Preliminary tests for material selectivity of poly-Si and oxide are conducted with two types of silica slurries: ILD1300TM and Nalco2371TM. And then, the experiments were conducted based on the pretest. A selectivity and pH adjustment of slurry affected largely step heights of MEMS structures. These results would be anticipated as an important bridge stone to manufacture MEMS CMP slurry.

Keywords : CMP, ULSI, MEMS

1. INTRODUCTION

Planarization of MEMS structures is investigated by using CMP process which has been widely used in manufacturing of integrated circuit (IC) devices. MEMS technique which has been derived from semiconductor processes has many application fields and is extensively studied[1]. It includes electronic sensors, mechanical actuators and the advanced medical instruments, etc. The manufacturing method of MEMS structures can be classified by bulk- and surface-micromachining.

In this research, surface-micromachined structure is used as MEMS patterns to investigate the effect of CMP on planarization[2,3]. The size of patterns for the MEMS CMP experiments is designed larger than that of usual IC devices (>1 μ m). Also, various types of patterns were designed to verify the peculiar characteristic of CMP on large structures which is usually used as MEMS structures[4].

Two types of silica (SiO₂) slurry, ILD1300TM and Nalco2371TM, are used for the experiments. These two

slurries have different polishing characteristics. The ILD1300TM is normally used for oxide polishing with fumed silica as an abrasive, and Nalco2371TM which is used to colloidal silica as an abrasive is used for polishing of bare silicon. In this experiment, Nalco2371TM showed higher selectivity than ILD1300TM. Also, different pH condition of the slurry was tested and suitable selectivity was determined by pretest. Because polishing slurry is an important key for a successful CMP application, the experimental results will provide the effect of slurry on MEMS CMP.

2. PATTERNS DESIGN FOR MEMS CMP

The chrome mask was fabricated for making test pattern wafers. Each pattern was designed to the size to be used in MEMS CMP application shown as Fig. 1. A fabricated mask is for 4 inch, divided into 52 areas. Square and Density patterns are designed to 20 mm x 20 mm sizes. The others are 10 mm x 10 mm sizes.

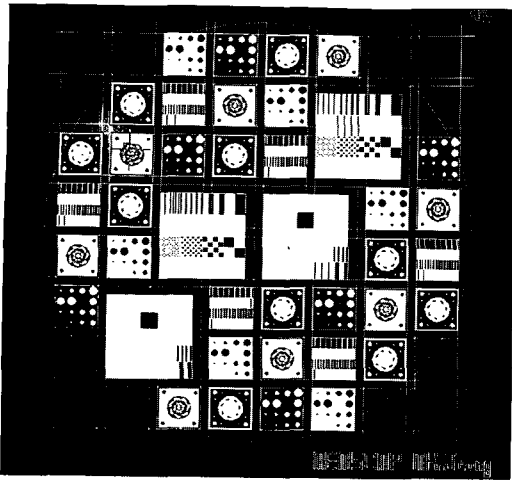


Fig. 1. Designed 4" mask for MEMS CMP.

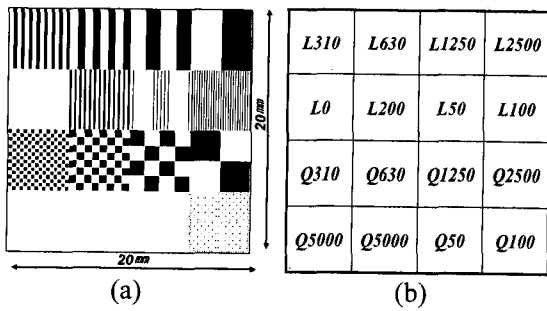


Fig. 2. (a) pattern image and (b) size of square patterns.

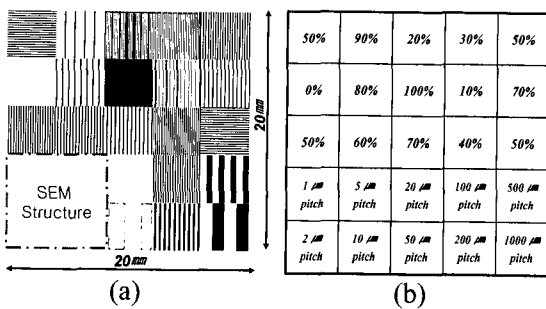


Fig. 3. (a) pattern image and (b) size of density patterns.

Figure 2 shows the die pattern design of the 20 mm x 20 mm scale which has schematic of the pattern, (a) and size of the pattern, (b) respectively. These patterns are used to understand the erosion influences on MEMS structures with the dishing by CMP.

Figure 3 shows the 20 mm x 20 mm scaled die which includes schematic (a) and size (b) of the pattern. It consists the density patterns based on a 100 μm pitch and the grating structures with different pitches from 1 μm

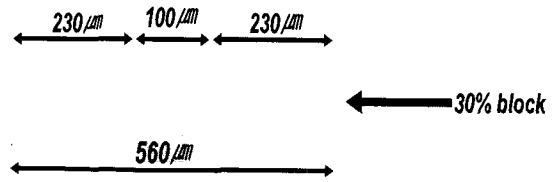


Fig. 4. The cross section of density patterns.

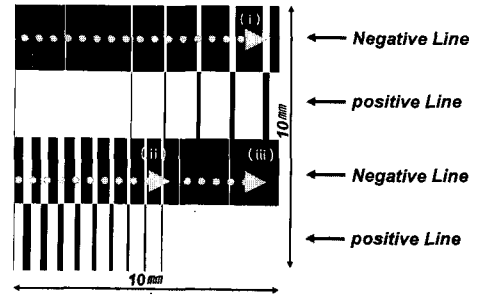


Fig. 5. Schematic of line patterns.

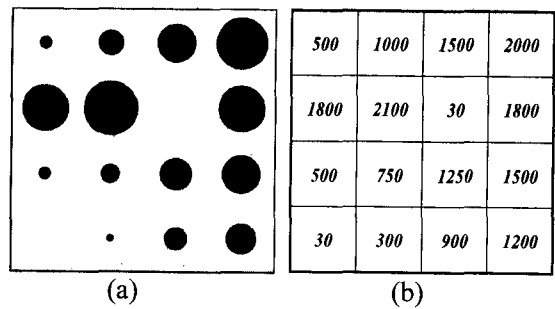


Fig. 6. (a) pattern image and (b) size of hole patterns.

to 500 μm. It is estimated that CMP results can be changed according to the density of MEMS structures. Figure 4 shows an example to express the pattern with 30 % density[5].

Figure 5 shows the die pattern with 10 mm x 10 mm scale which includes (i) part with line widths from 1 μm to 250 μm, (ii) part with line widths from 10 μm to 300 μm, and (iii) part with line widths from 1 μm to 8 μm. Step heights after CMP can be compared according to the line width. CMPed line patterns might have different dishing amounts, resulting from easiness of material removal[6].

Figure 6 and 7 show the die pattern with 10 mm x 10 mm scale. These patterns are composed of various holes and pillars to investigate correlation between planarity and pattern size. The size consists of different 16 holes sized from 30 μm to 2100 μm. Figure 8 shows engine

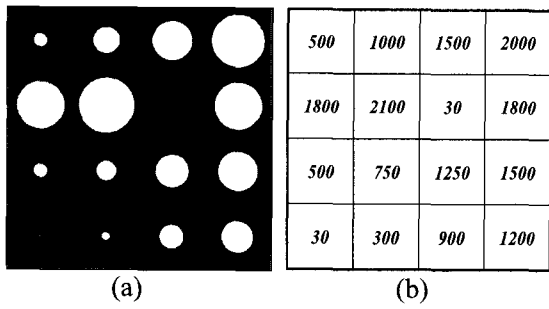


Fig. 7. (a) pattern image and (b) size of pillar patterns.

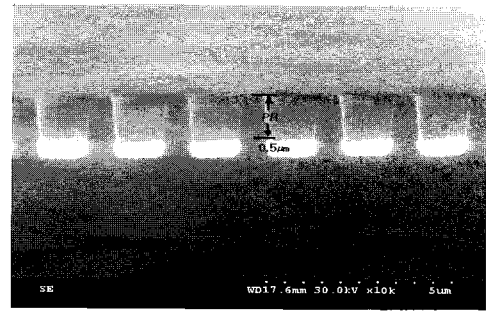


Fig. 10. SEM image of 2 μm density pattern after RIE.

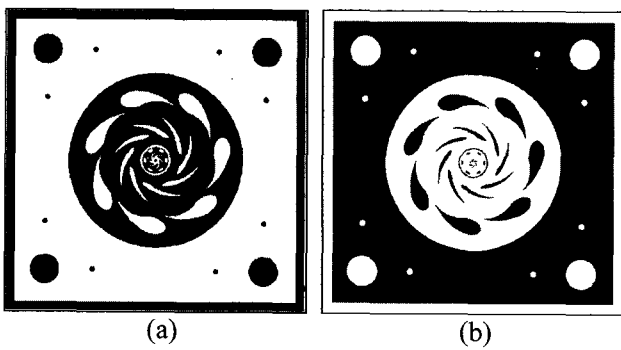


Fig. 8. Engine patterns with negative (a) and positive (b).

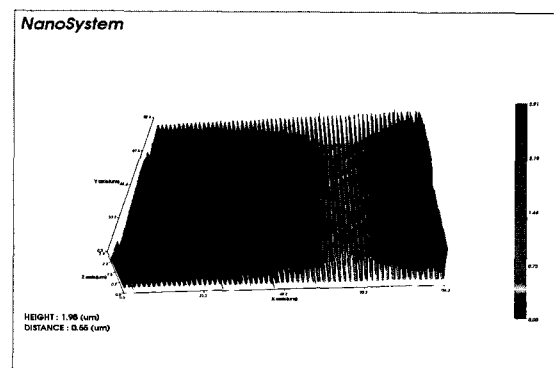


Fig. 11. Measurement result image of 2 μm of a density pattern (after RIE 0.5 μm, PR 1.5 μm).

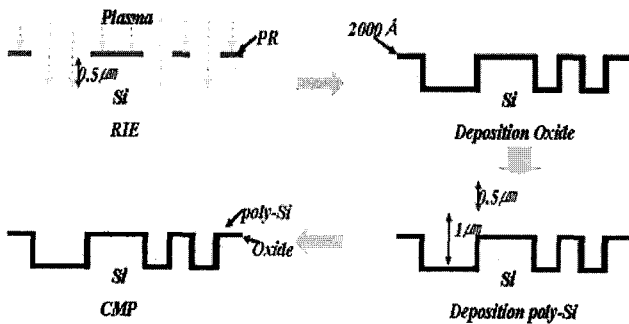


Fig. 9. The fabrication process schematics of test wafer.

patterns with negative (a) and positive (b). With the MEMS patterns expressed above, It is possible to estimate CMP results dependent on pattern size, density and shapes.

Figure 9 shows a manufacturing process of the test wafer for MEMS CMP. First, we prepare a wafer with 4 inch mask designed various patterns using Mask Aligner (MA6 of Karl Suss). Reactive ion etching (RIE), is subsequently applied to obtain 0.5 μm deep trench shown in Fig. 10.

2000 Å thick SiO₂ film is deposited to enhance adhesion with poly- Si of 1 μm thick by LPCVD. Figure 11 shows a step height after RIE process by a 3D non-contact surface profiler (NANOSYSTEM™).

3. PRELIMINARY TEST

The experiment was done in a clean room to minimize the temperature variation. The machine condition was chosen with polishing pressure values of 5 psi (360 g/cm²) and rotational speeds of 60 rpm (table & head) to find the selectivity between Poly-Si and SiO₂ film. Two type of slurry, Nalco2371™ and ILD1300™, were used for the experiments with flow rate of 120 ml/min. Table 1 shows experimental conditions for CMP. As shown in Fig. 12, the experiment is conducted by the polisher equipment POLI-500 (G&P Technology).

For searching material selectivity respectively, the blanket wafer was used with two types of slurry as a function of pH adjustment. In case of Nalco2371™ slurry, it shows the lowest selectivity at pH 2 and the highest selectivity condition at around pH 10. On the other hand, ILD1300™, conventional oxide CMP slurry, shows the lowest selectivity about 2.5 at pH 10.8.

Table 1. Test condition for selectivity.

Equipment	POLI-500
Pad	IC1400-k (Nitta Haas)
Slurry	Nalco 2371™ vs. ILD1300™
Pressure	360 g/cm ²
Velocity	60 rpm
Flow rate	120 ml/min
Material	Poly-Si vs. SiO ₂

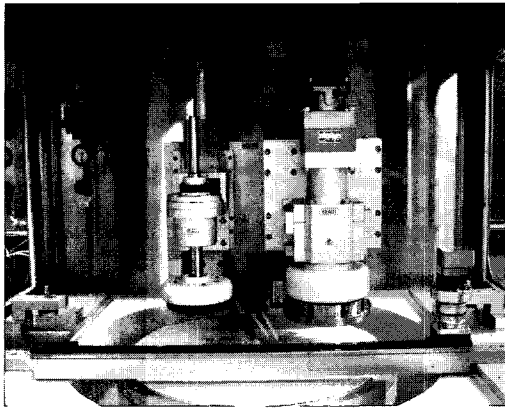
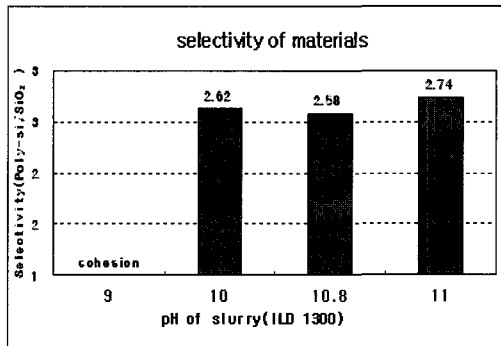
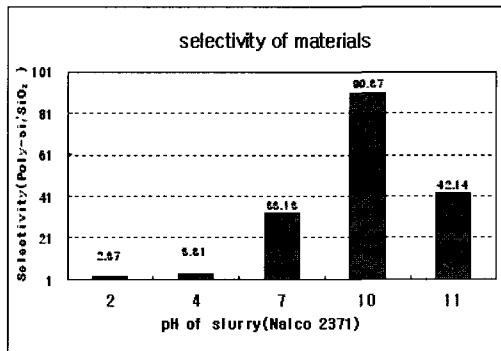


Fig. 12. CMP equipment(GNP POLI-500).



(a)



(b)

Fig. 13. Material selectivity of (a) Nalco2371™ and (b) ILD1300™ as a function of pH.

Especially, in condition of slurry under pH 9, ILD1300™ slurry shows cohesion of abrasive particles as shown in Fig. 13. Through the selectivity test, a colloidal silica slurry, Nalco2371™ had higher selectivity than a fumed silica slurry, ILD1300™.

4. CMP APPLICATION ON MEMS STRUCTURES

Based on preliminary test result, MEMS pattern wafer was CMPed to estimate effects of two types of slurry on planarity. Figure 14 shows a image of pre-measurement before CMP and a step height, 0.5 μm obtained by RIE process.

Two types of slurry are distinguished by particle's property and size. There are Nalco2371™ based on colloidal silica and ILD1300™ based on fumed silica. Particle sizes of ILD1300™ and Nalco2371™ are about 175 nm and 70 nm, respectively. Consequently, CMP results are quite different, resulting from the difference of slurry abrasives. Figure 15 shows images of measurement after 30 sec and 60 sec CMPed with two types of slurries. They explain that both Nalco2371™ and ILD1300™ have similar removal rate on Poly-Si material.

As shown in Fig. 16, measurement results after 90 sec CMPed show surface topography at end point when oxide film advents and could be compared with CMP defects such as dishing and erosion. The surface topography was measured by non-contact surface profiler (NANOVIEW™) after CMP process. The result of CMP indicates that high selectivity slurry has larger dishing amount than low selectivity slurry has. It is generally known as a fact that high planarity of surface

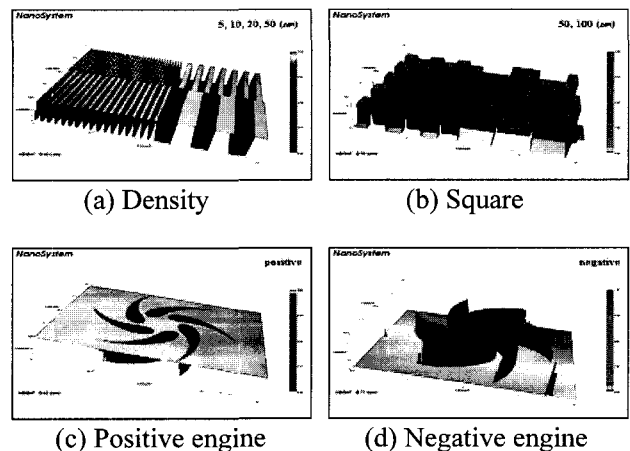
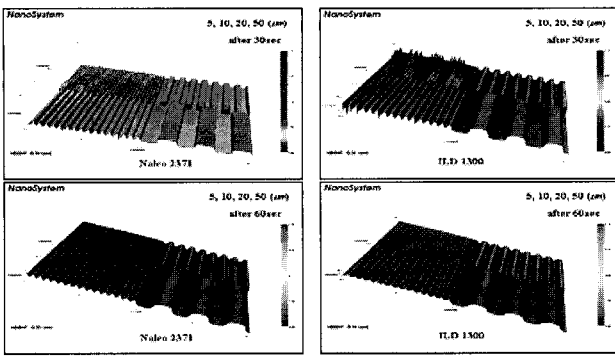
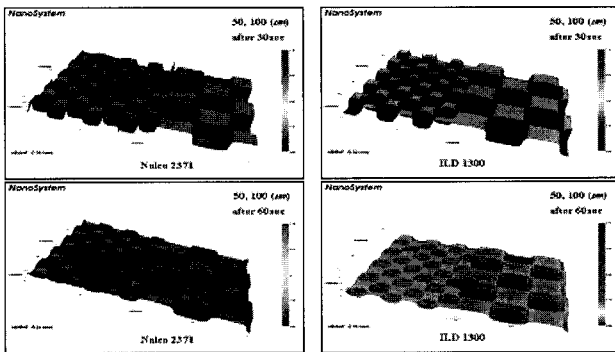


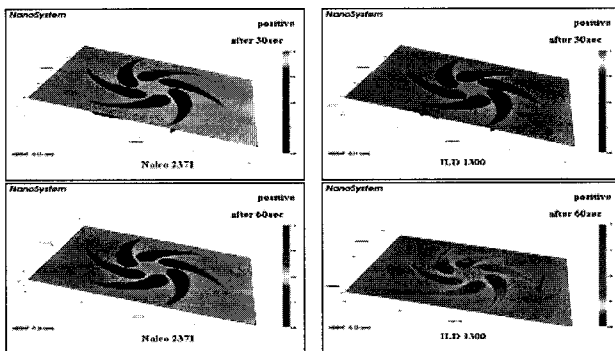
Fig. 14. Image of pre-measurement before CMP.



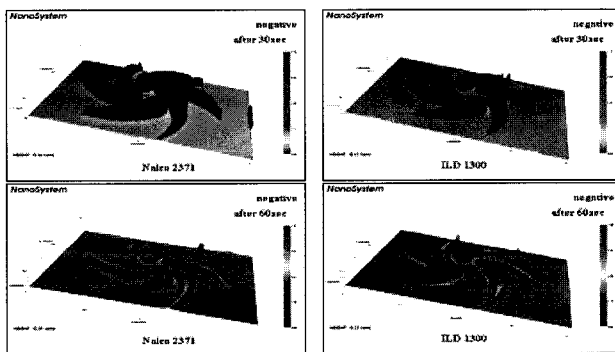
(a) After 30 sec and 60 sec CMP of density



(b) After 30 sec and 60 sec CMP of square

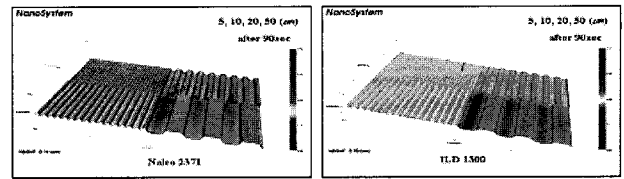


(c) After 30 sec and 60 sec CMP of positive engine

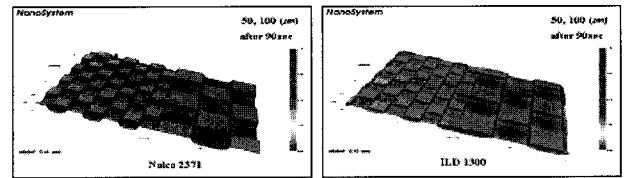


(d) After 30 sec and 60 sec CMP of negative engine

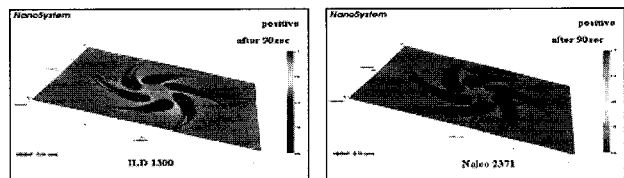
Fig. 15. Image of after 30 sec and 60 sec CMP.



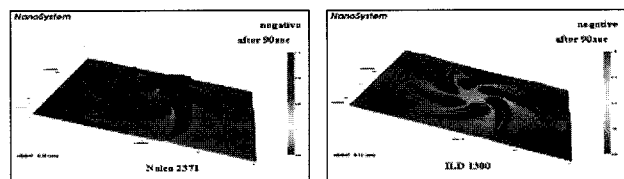
(a) After 90 sec CMP of density patterns



(b) After 90 sec CMP of square patterns



(c) After 90 sec CMP of positive engine



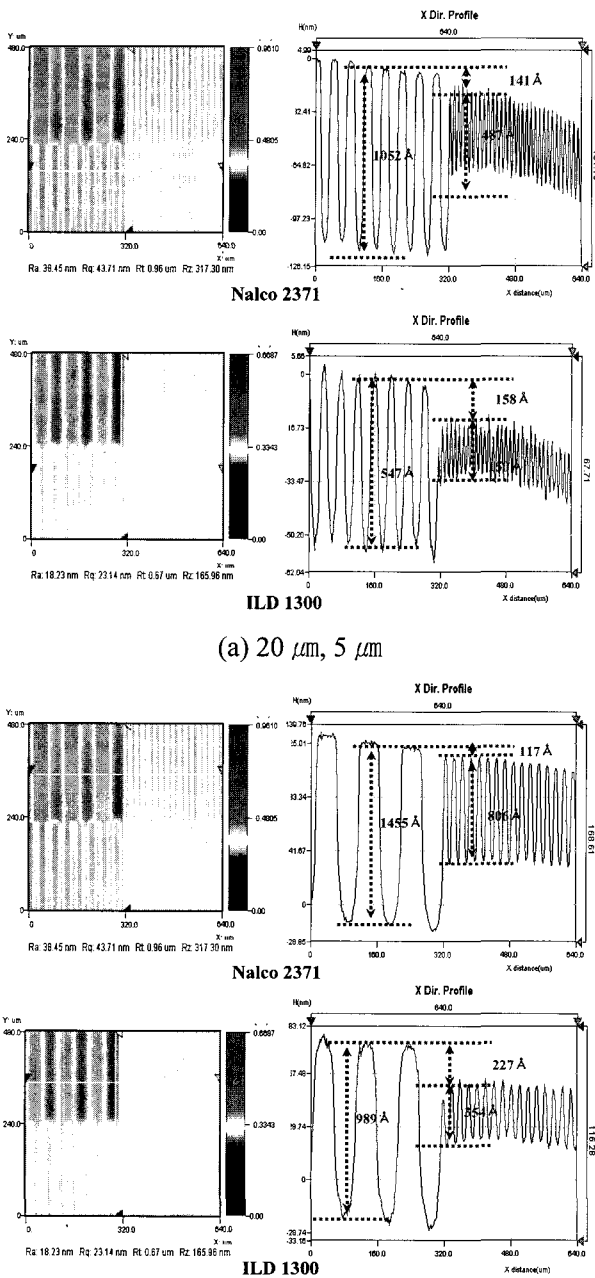
(d) After 90 sec CMP of negative engine

Fig. 16. Image of after 90 sec CMP.

could be achieved with high selectivity slurry (HSS). On the other hand, high selectivity slurry can make damages the poly-Si film of trench area largely.

Figure 17 shows dishing amount of density after 90 sec CMP, resulting in bigger amount of dishing proportional to width of Poly-Si. In this case, Nalco2371TM can generate relatively a larger dishing amount than ILD1300TM. Generally, this problem has encountered in damascene and shallow trench isolation (STI) CMP. Especially, dishing amount of MEMS structures is bigger than that of IC. Dishing arises from the different removal rate on different materials, such as oxide and poly-Si.

Figure 18 shows step heights of various MEMS patterns in after 90 sec CMP. The results could be observed that ILD1300TM had the better planarity, i.e. lower step height than Nalco2371TM in all of patterns generally.



(a) 20 μm , 5 μm

(b) 50 μm , 10 μm

Fig. 17. Comparison of dishing amount in (a) 20 μm , 5 μm and (b) 50 μm , 10 μm width of density pattern.

5. CONCLUSION

Two type of slurry, ILD1300TM and Nalco2371TM, were used for understanding of the planarization performance

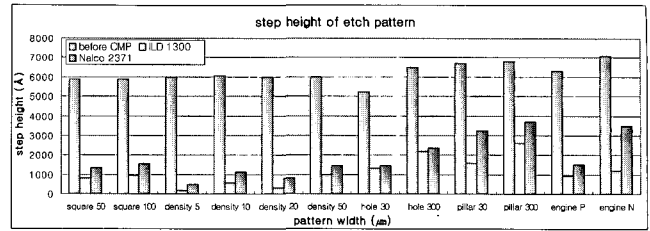


Fig. 18. Step height of MEMS patterns after 90 sec CMP.

of MEMS patterns to find appropriate consumable conditions for CMP of MEMS with large structure. In the preliminary test, a result indicated a big difference of material removal rate between Poly-Si and SiO₂ thin film and selectivity dependent on a function of pH.

Nalco2371TM slurry had larger amount of dishing than ILD1300TM slurry. These results are supposed that the CMP process is largely affected by a different material selectivity of slurry and abrasive characteristics. Therefore, selectivity and pH adjustment of slurry would affect MEMS CMP for obtaining a planarized surface.

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