Application of Fixed Abrasive Pad using Hydrophilic Polymer in STI CMP

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1. Introduction

DRAM has many cells consisting of one capacitance and one CMOS [1]. It is necessary for each cell to be isolated electrically for the independent work. The shallow trench isolation (STI) structure has been widely adopted on chip fabrications for the isolation of each cell [2,3]. It is made as filling a trench with dielectric materials. After deposition process for the filling of the trench, a residual film on the active region is removed by .the chemical mechanical polishing (CMP) [4]. The STI CMP, however, involves several issues such as trench dishing, oxide erosion and oxide rounding. For the reduction of dishing, even though the reverse etch mask technology has been introduced, it takes a disadvantage of increasing the step of process. Silicon nitride as the stop layer has been used to reduce dishing in CMP, because the silicon nitride has a high material selectivity against other materials. The dishing can be reduced as etching silicon nitride after the STI CMP. It takes an advantage from the viewpoint of the simplicity of process. In this paper, the fixed abrasive pad using hydrophilic polymers is introduced for the improvement of the pattern selectivity in STI CMP.

2. Deviation of pattern selectivity

Patterns with different density on the die have significantly an influence on the results of CMP. Fig. 1 shows the pattern profiles after CMP, and it indicates that the step height is a sensitive function of pattern densities.

Fig.2 shows the mechanism of over-polishing. This sensitivity of the pattern density causes the local region within a die to be over-polished. Consequently, it is one of reasons that expand regions for dishing to be generated. To reduce the effect of pattern density, the semiconductor design uses dummy patterns which are not concerned with the electrical operation. These dummy patterns, however, have a limit due to the

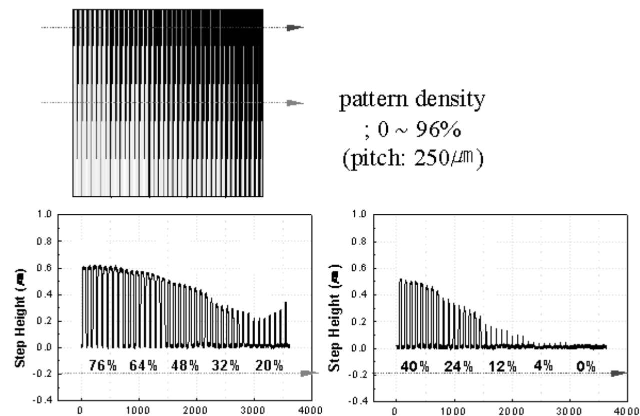


Fig. 1 Pattern profile as a function of pattern density

sacrificial capacitance. If the CMP results are independent on the pattern density, the over-polished regions will be able to be reduced, and defects such as dishing, erosion and rounding can be also reduced. In order to solve these issues, this paper introduces the effect of abrasives, pressure and relative velocity on the pattern selectivity.

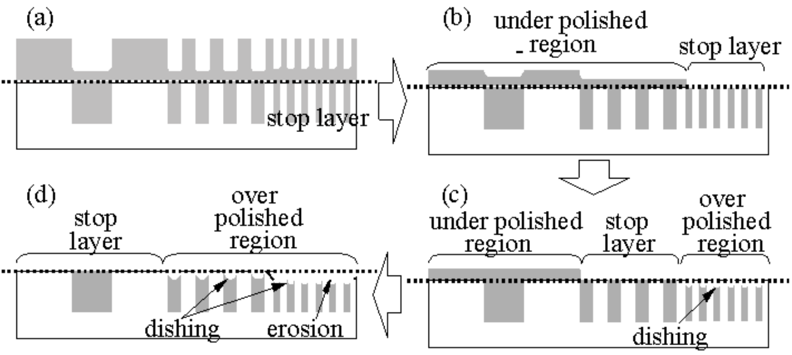


Fig. 2 Schematic diagram of over-polishing

The selectivity is generally classified as the material and pattern selectivity. The material selectivity is defined as the ratio of the removal rate of other materials to that of the specific material. For example, if the removal rate of TEOS is 3000Å/min and that of Si_3N_4 is 300Å/min, the material selectivity between two materials is 10:1.

The purpose of CMP is that the patterns on a wafer are removed to be flat, but the space between patterns is also removed during CMP. The pattern selectivity has been defined as the ratio of the removal rate at pattern to that at space between patterns. The pattern selectivity is 60:1 when the removal rate is 3000Å/min at the pattern and that is 50Å at the space. However, it is difficult to evaluate the pattern selectivity of entire die, because the die consists of regions having different densities. Therefore, this paper reports the deviation of pattern selectivity (DPS) for the evaluation on the pattern selectivity in the STI CMP. The DPS is defined as follows. The pattern selectivity is, first, defined as the ratio that it is the step height of the patterns at each density to that of the patterns at the highest density or the widest pitch within a die [eq 1]. The region with the highest density is used as the reference, because the removal rate is reduced as increasing of the density. That is to say, the DPS says how the results of the polished patterns within a die are deviated from the reference [eq. 2]. If the density is not influence on the CMP, the step height will be the same regardless of the pattern density, and the DPS shows zero. Consequently, as the DPS increases, the pattern density has a higher effect on the result of the CMP.

$$P.S. = \frac{\text{R.H. at each pattern density}}{\text{R.H. at the highest pattern density}} \quad [1]$$

$$DPS = \frac{\Sigma\,(1-(P.S.)_i)^2}{N} \quad [2]$$

($(P.S)_i$.: pattern selectivity at each region, R.H.: relative height, N: number of regions)

3. Characteristics of pattern selectivity

It is necessary to consider the pattern selectivity to evaluate on the CMP parameters such as abrasives, pressure, relative velocity. To evaluate the effect of the pattern selectivity on abrasives, the concentration of cerium oxide abrasive is varied from 0.5 to 2.0 wt%, and the silicon oxide abrasive from 4 to 13 wt%. The pressure is fixed as 300 g/cm^2 and the relative velocity is 30/30 rpm. The polishing time is controlled to be the same total removal volume as each experimental condition makes difference on the removal rate.

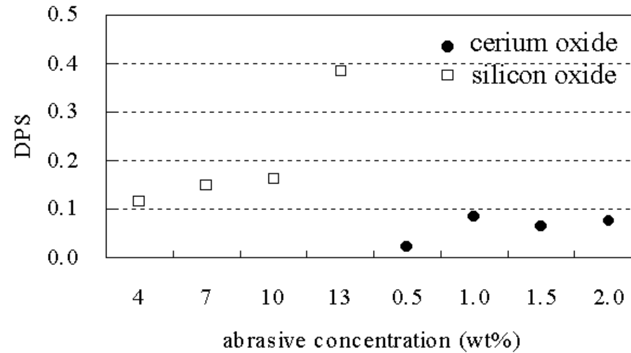


Fig. 3 Results of DPS as a function of abrasive concentration

Fig. 3 shows that the cerium abrasive has a better characteristic in terms of the pattern selectivity than the silicon oxide abrasive, and the DPS reduces as decreasing of the abrasive concentration. These results explain that more abrasives give worse influence on the pattern selectivity. This fact is also explained from the results as a function of the relative velocity (Fig.4). All experimental conditions including the concentration of abrasives are the same, and the relative velocity is only varied. As a result, the DPS increase as the relative velocity goes up. It is explained that the dynamic motion of abrasives gives a bad influence on the pattern selectivity. If the concentration of abrasives could be decreased without the reduction of the removal rate, over-polished regions within a die can be decreased.

The CMP process requires that the polishing pad should be conditioned to create sufficient surface roughness. The decay of the removal rate in the absence of conditioning is well known. The polishing pressure is changed to consider the relationship between the pattern selectivity and the contact area of the asperity on the pad. The contact area of the asperity on a pad will be expanded as the polishing pressure goes up. The polishing pad is conditioned with the electroplated diamond disk to be the same asperity. Fig. 5 shows the results of DPS as a function of the polishing pressure. The DPS is shown the highest when the pressure is 650 g/cm^2. Therefore, the asperity on a polishing pad has an effect on the pattern selectivity. It is expected to improve the characteristic of pattern sensitivity as reducing the abrasives in slurry and the asperity on a polishing pad.

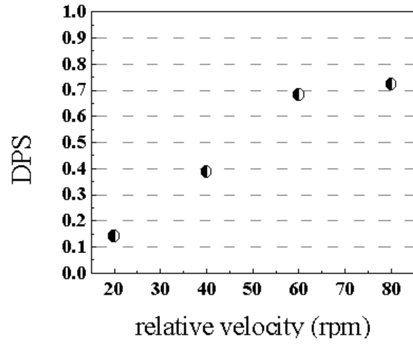


Fig. 4 Results of DPS as a function of relative velocity

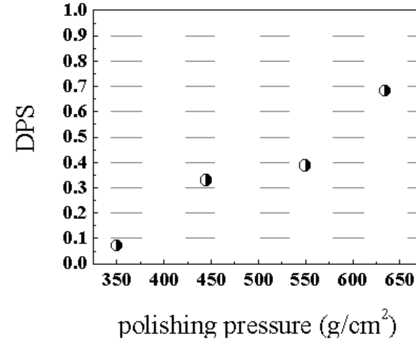


Fig. 5 Results of DPS as a function of polishing pressure

4. Fixed abrasive pad using hydrophilic polymer

The fixed abrasive pad using hydrophilic polymers is manufactured, and the cerium oxide abrasive is adopted because it has the high removal rate at the low concentration [8]. In the fixed abrasive pad, the special conditioning concept is needed to supply new abrasives to the wafer surface. It is very important to improve wafer-to-wafer non-uniformity between wafers. According to researches on the fixed abrasive pad, patterns on wafer play as diamond grits in regenerating new surface of pad. New abrasives can emerge from the surface of a fixed abrasive pad through this conditioning mechanism [5,6]. However, this conditioning using the patterns may have its limitations because the patterns are polished during CMP. This paper introduces the fixed abrasive pad using hydrophilic polymers with the swelling characteristic for the self-conditioning. The swelling mechanism is as follows. The hydrophilic polymers have hydrophilic radicals such as hydroxyl(-OH), carboxyl(-COOH), carbonyl group(-CO) etc [7]. When the hydrophilic polymers are in contact with an aquatic solution, the hydrophilic radicals along polymer chain attract water. Then, the polymer chain expands due to the permeation of water, and expanded polymers are easily removed by the friction force between a pad and a wafer (Fig. 6).

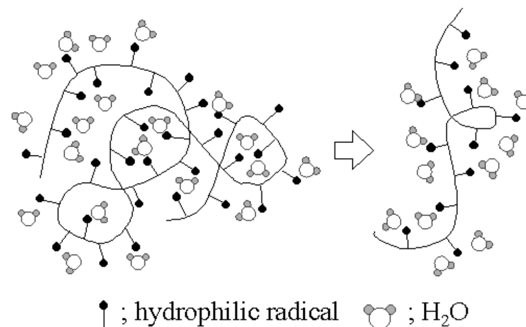
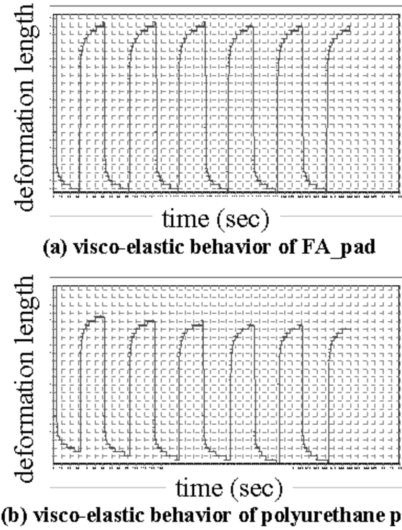


Fig. 6 Swelling mechanism of hydrophilic polymer

The manufactured fixed abrasive pad is performed on the visco-elastic behavior (Fig. 7). The

characteristic of the visco-elastic is very important for the repeatability between wafers. As a result, the visco-elastic curve of the fixed abrasive pad moves down about 1 um comparing with the polyurethane pad, about 4 um. It means that the visco-elastic characteristic is improved due to the harder polycarbonate film.



(a) visco-elastic behavior of FA_pad

(b) visco-elastic behavior of polyurethane pad

Fig. 7 Visco-elastic behavior of fixed abrasive pad comparing with polyurethane pad

5. Pattern selectivity of fixed abrasive pad

To evaluate on the fixed abrasive pad, the STI wafers designed by MIT are applied, which consists of patterns with different pitches and densities. The experiments are carried out on a rotary CMP machine, as given in Table 1.

Table 1. Experimental Condition

	FA_pad	Conventional CMP
Pressure	300 g/㎠	300 g/㎠
Relative velocity	60 / 60 rpm	60 / 60 rpm
Pad	FA_pad	IC1400™
Slurry	DI water	Fumed silica (13wt%, pH10.8)
Conditioning	Brush	diamond disk

Fig. 8 shows the results of the step height as a function of the density. The step heights of polished patterns are randomly distributed in the conventional CMP comparing with that of the fixed abrasive pad. The DPS in the conventional CMP is 0.185 larger three times than that in the fixed abrasive. Especially, in

the regions with the density of 30% and 50%, the step height in the conventional CMP is so different even though the regions have the same pattern density. These results are due to the effect of surrounding patterns, but not in the fixed abrasive pad.

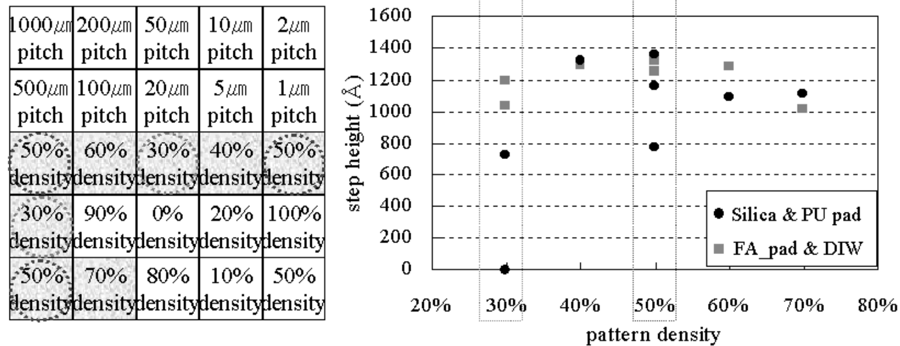


Fig.8 Results of step height as a function of pattern density in STI CMP

6. Conclusion

The pattern selectivity is sensitive to the density of patterns. For the effect of the pattern selectivity, experiments are performed changing the CMP parameters such as abrasives, pressure and relative velocity. It is known that the abrasives in slurry and the asperity on a polishing pad have a bad influence on the pattern sensitivity. To improve the pattern selectivity, the fixed abrasive pad using hydrophilic polymers is manufactured, and then is applied to the STI CMP. As a result, the DPS in the conventional CMP is 0.185, and 0.061 in the fixed abrasive. The patterns have little effect on the surrounding patterns in the fixed abrasive pad. The fixed abrasive pad apparently allows the pattern selectivity to improve for the reduction of dishing.

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