PAPER B

Advances in the CMP Process on Fixed Abrasive Pads for the Polishing of SOI-Substrates with High Degree of Flatness

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Advances in the CMP Process on Fixed Abrasive Pads for the Polishing of SOI-Substrates with High Degree of Flatness

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ABSTRACT

The new approach using Fixed Abrasive (FA) pads for polishing thick film Silicon-on-Insulator (SOI) wafers after bonding and grinding process [1] has been further developed. The aim is a practicable industrial manufacturing process, where the major specifications especially in long term stability and removal rate should be achieved. In base line studies a stable removal rate on suitable level has been reached, while the degeneration of the total thickness variation (TTV) was limited to a clearly smaller value than that being typical for the standard stock removal polishing. The overall removal in these tests was adjusted to 2-3 µm, which removes all sub surface damage (SSD) from wafers ground by ultra fine grinding wheels with very small average abrasive particle size. The process has been able to remove all visible grindlines after removing less than 1.5 µm. In another test with a further developed high density FA pad, removal rates up to ~0.6 µm/min were achieved. The polished samples were further processed and characterized by capacitive thickness measurements gauges, optical surface inspection tool (“Magic mirror”), atomic force microscopy (AFM) and optical reflection measurements.

INTRODUCTION

The manufacturing of thick film silicon-on-insulator (SOI) substrates currently faces a limitation when concerning low TTV values. While grinding tools are able to provide wafers with flatness values of less than 0,5 µm TTV, the subsequent polishing needed for removing the grindlines as well as SSD often degenerates the wafers to a level above 1 µm TTV. This is caused first by the high amount of material removal needed in order to remove all damage and residues from conventional grinding and second by the inability of conventional polishing to take care of the special edge shape formed during the SOI manufacturing process. A strong emphasis to round the edge of the SOI device layer can be seen. Together with the general non-uniformity of the process this results in elevated TTV values when applying the often required stringent edge exclusion of 3 mm based on the handle wafer diameter. Due to the required edge grinding of the upper device wafer this often leads to an actual edge exclusion of only 1 mm to be met for the CMP processing.

The introduced combination of grinding with ultra fine wheels leading to low SSD and the use of FA pads leads to strongly reduced material removal being needed by polishing on the one hand and to greatly increased uniformity due to the extreme good capability of FA pads for planarization and uniform removal on the other hand.

EXPERIMENTAL

Polishing was done on a Strasbaugh 6DS-SP Planarizer with 6” wafers ground on a Strasbaugh 7AF back grinding tool equipped with a #325 coarse wheel. Fine grinding was done mainly on #4000 fine wheel, providing a reduced sub surface damage (SSD). The resulting TTV was ~0.7 µm. Experimental FA Pads, further developed towards the needs of silicon polishing from 3M were used for CMP. The micro replicated posts on the surface were about 125µm wide and 50 µm high, containing the abrasive material in a resin-like matrix. The density of posts resulted in around 10% contact area with the wafer under processing and about 30% contact area for the high density pad version respectively. The polishing time was typically set to be 300s but varied in some cases for removal rate studies. The prior developed standard parameter set [1] was further adjusted in order to optimize removal rate and stability of the process. Also the pH-values have been varied to investigate the process behavior and to find the optimum point for effective processing.

PRINCIPLE MECHANISMS

First tests with FA pads showed already good values, both in terms of TTV as well as removal rate. This performance however has to be ensured for the entire lifetime of the pad. While conventional pads are continuously conditioned to provide a clean and defined surface, fixed abrasive pads are self-conditioning. As the used particles are leaving the posts in which they are embedded, the surrounding matrix material has to wear off with appropriate rate in order to always expose sufficient amount of fresh abrasives. The correct balance of this procedure has to be found for each process application the FA pads are used for. On the other hand the wear rate of the matrix material should provide a decent lifetime of the pads in order to keep costs reasonable.

Besides the mechanical also the chemical part plays a major role in the adjustment of the removal rate. On FA processes it has been seen that the pH-value of the used lubricant is of great influence [1]. In conventional silica-slurry polishing of silicon a strong peak in removal rate at pH ~11 [2] has been found. As ceria (CeO_2) particles are in use with fixed abrasive pads, a different mechanism of removal can be expected. It is known that ceria supports the removal of silicon oxide [3] and FA processing on oxide resulted in elevated removal rates pH ~12 [4]. From the investigation about pH dependence of silicon removal it is suggested that for higher pH than 11 a different mechanism of removal takes place, involving intermediate oxide and silanol formation [2]. An optimized removal rate for silicon FA CMP is thus expected at different pH.

RESULTS AND DISCUSSION

First baseline polishing Tests

After the first encouraging results [1], long term stability has been evaluated with more wafers. The conditions of the process have been kept at similar level in order to obtain changes in the pads’ behavior. Removal and uniformity were measured for fresh pad as well as for a pad being used for around 8 hours and 30 minutes referring to polishing about 100 silicon wafers.

While the uniformity showed continues superior behavior, the removal rate dropped from 0.4 µm/min to about 0.2 µm/min, only half of the promising starting value.

The reason for this degeneration in removal rate was investigated by SEM analysis of the used pad. It was clearly seen that the posts were wearing off under processing as expected. However the density of exposed abrasive particles seemed to be lower on used areas, when observing the posts in detail (Figure 1). After this feed back to 3M, another pad with slightly different formulation (Pad B) was provided for further base line polishing studies.

<u>Base line processing with Pad B and adjusted process parameters</u>

Pad B was further used with slightly adjusted set of process parameters. Nearly 100 Wafers were polished under similar conditions and removal rates, total removal and TTV was studied. Under processing the pH-value of the lubrication liquid was varied from pH 11.5 – 12.5 to find the optimum value. As seen from Figure 2, very stable processing in terms of removal rate was achieved. The only existing variation is caused by different pH-values of the lubrication liquid in the single runs (indicated by the vertical black lines; Fig. 2); an aging effect was not seen.

Within single test runs under constant pH-value, removal rate uniformities of below 1% were seen, responding to 60 nm total variation. The strong influence of the pH-value is visible, however a mean removal rate of clearly above 0.3 µm/min was reached at all times. When plotting the removal rate versus the pH-value, a peak similar to conventional slurry-based CMP [2] is visible, but around pH 11.9 (see Figure 3).

The TTV indicates as well a stable process, even though the incoming material was not flat enough to present the benefits of FA to full extent (Fig. 4). Many wafers improved in TTV.

Also time was varied during the base line run as well as both ground and previously polished wafers were processed to study the so-called bulk rate of the process. Figure 5 shows, that a constantly high bulk rate is achieved with the FA pad under investigation, independent of process time. The removal can thus be adjusted according to the needs of the substrates (Figure 6). Finally, an FA pad with increased contact area (30% instead of 10%) was tested. The removal rate was 40% higher, while the pad showed similar behavior in terms of TTV.

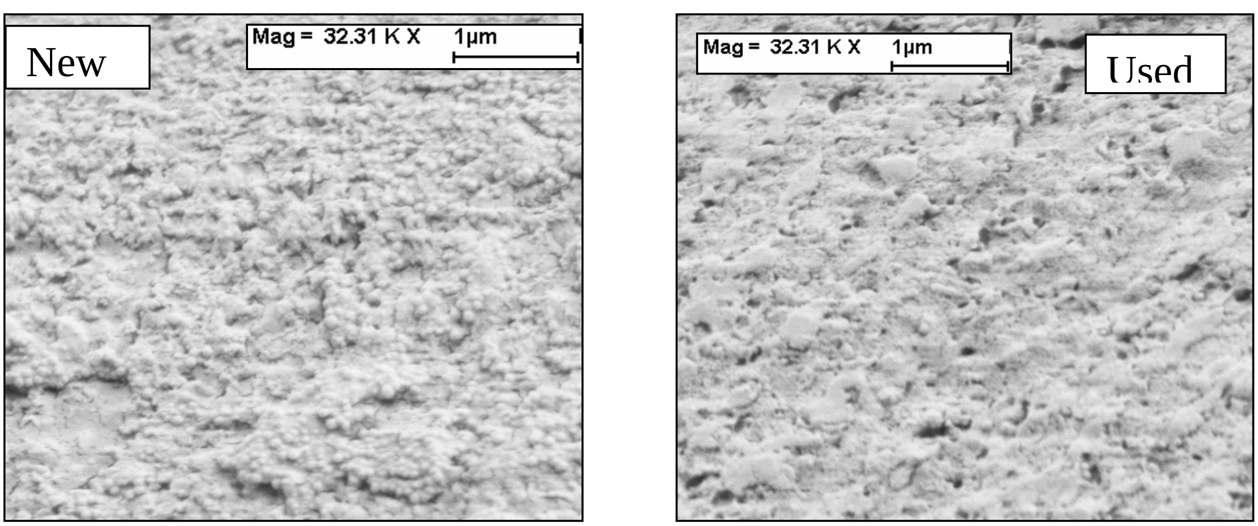

Figure 1: SEM images of new and used posts of the FA pad. More abrasive particles on the left.

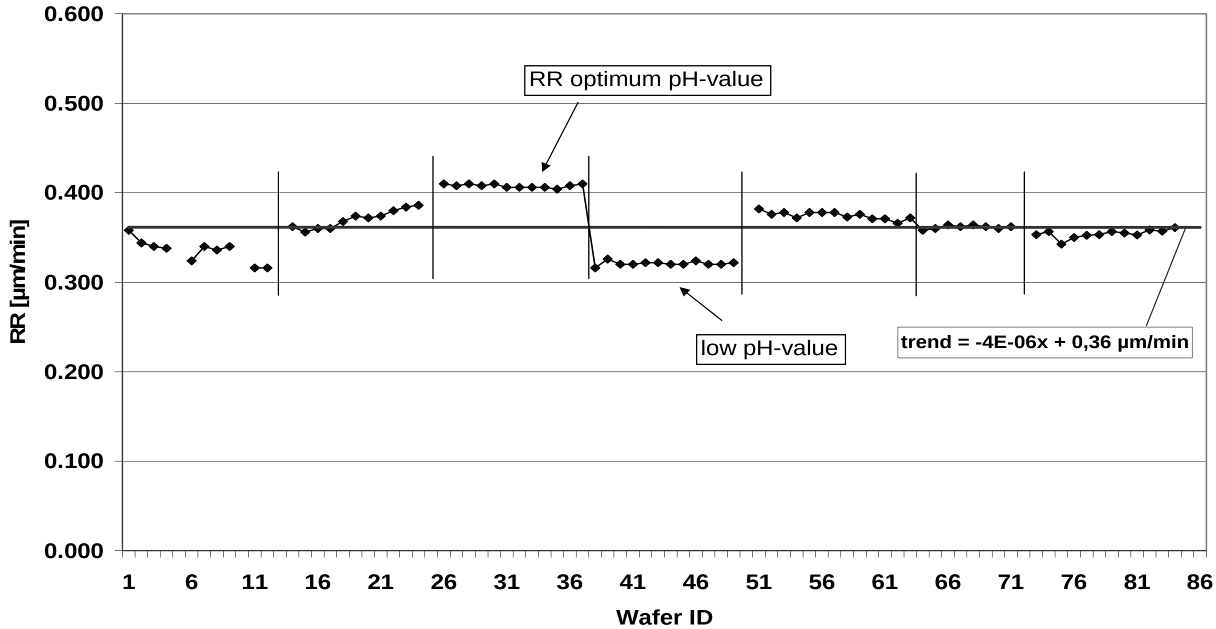

Figure 2: Base line removal rate with FA pad (Pad B). A stable RR is achieved varied only by the change of pH-value.

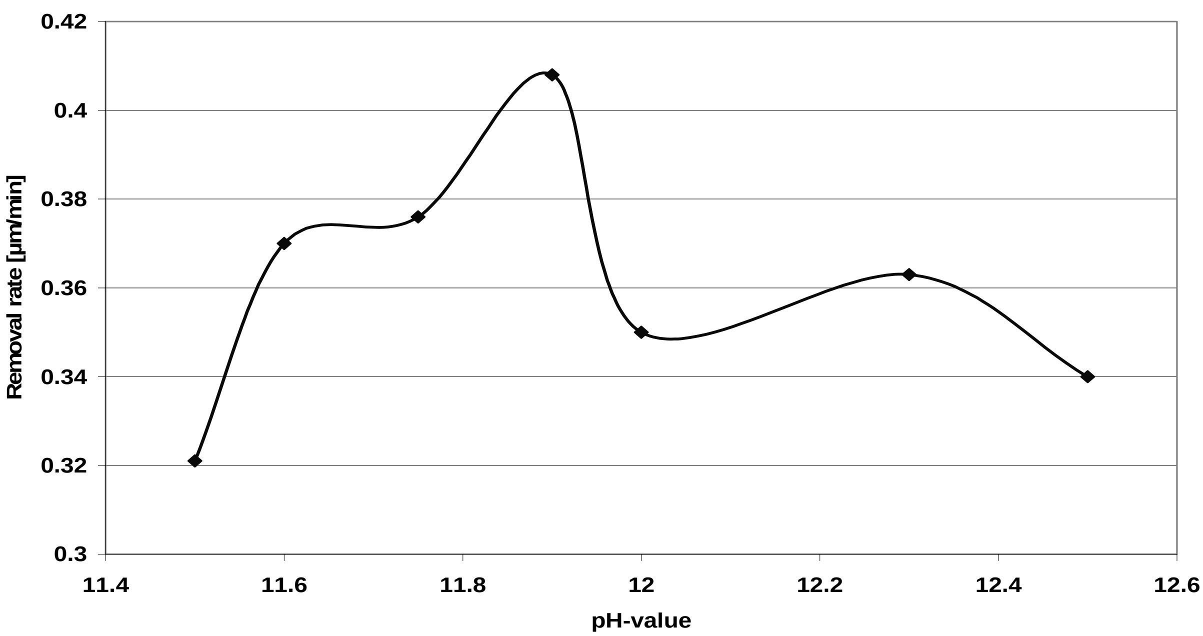

Figure 3: Dependence of the removal rate on pH-value of the lubrication liquid.

Confidence about the extraordinary planarization capabilities of FA pads was gained, when inspecting wafers after 4 minutes polishing in the “Magic Mirror”. This sensitive optical surface inspection tool shows smallest curvature on the wafer, like remaining grindlines and is used frequently for adjusting the necessary removal for high finished surfaces. While, in conventional polishing more than 5 µm material removal for damage-free surfaces are needed, about 1.3 µm removal was enough for fixed abrasive polishing to take off all visible grind marks (Fig. 5).

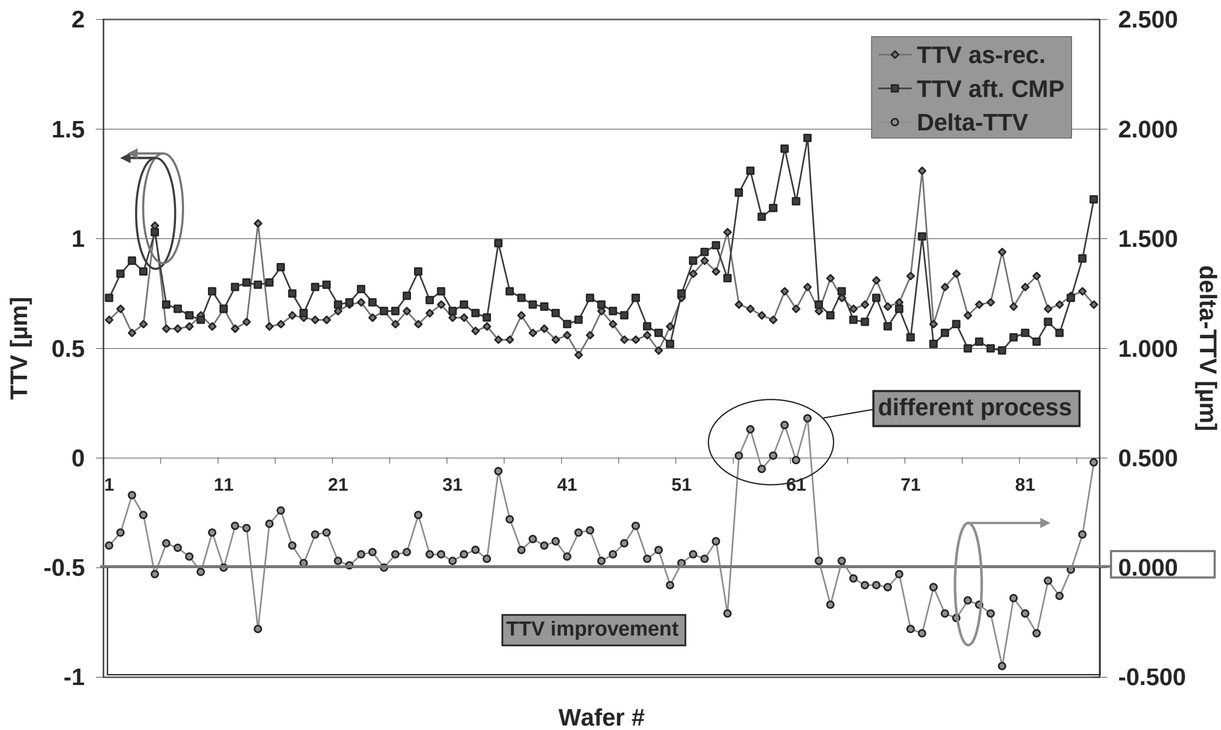

Figure 4: TTV and its change under FA polishing. Untypical for conventional processing is the bigger amount of wafers with improved flatness after CMP.

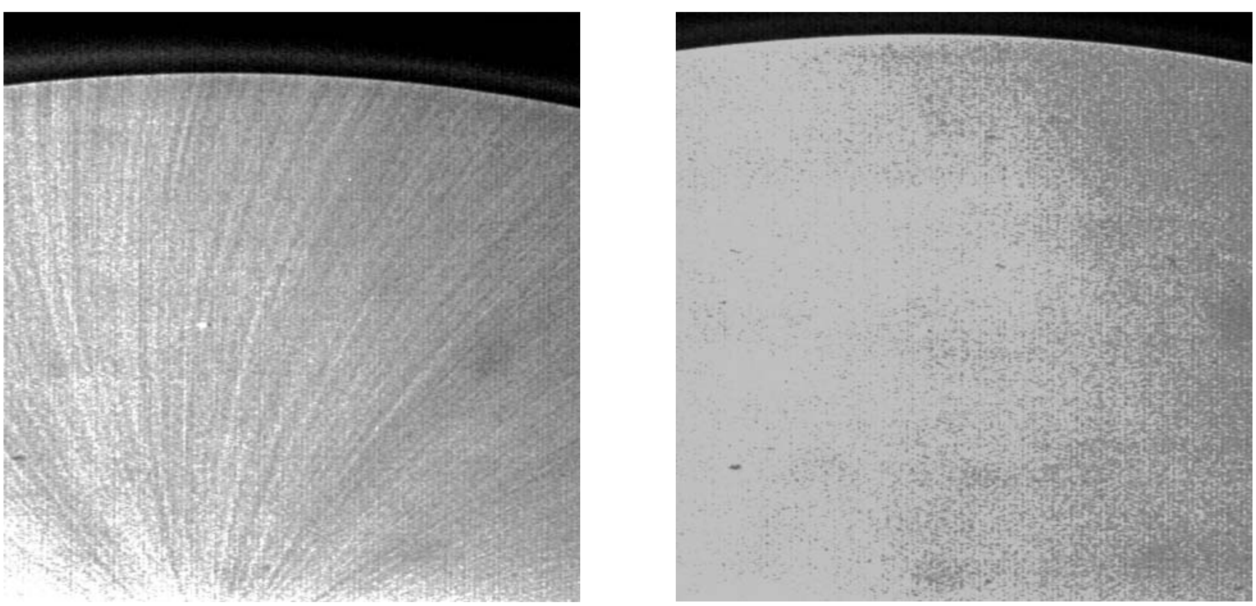

Figure 5: Magic Mirror images of a ground wafer (left) and a wafer being polished by FA for 240s (right). After less than 1.5 µm removal all grindlines have vanished, while conventional slurry-based polishing with standard pad requires more than 5 µm for total damage removal.

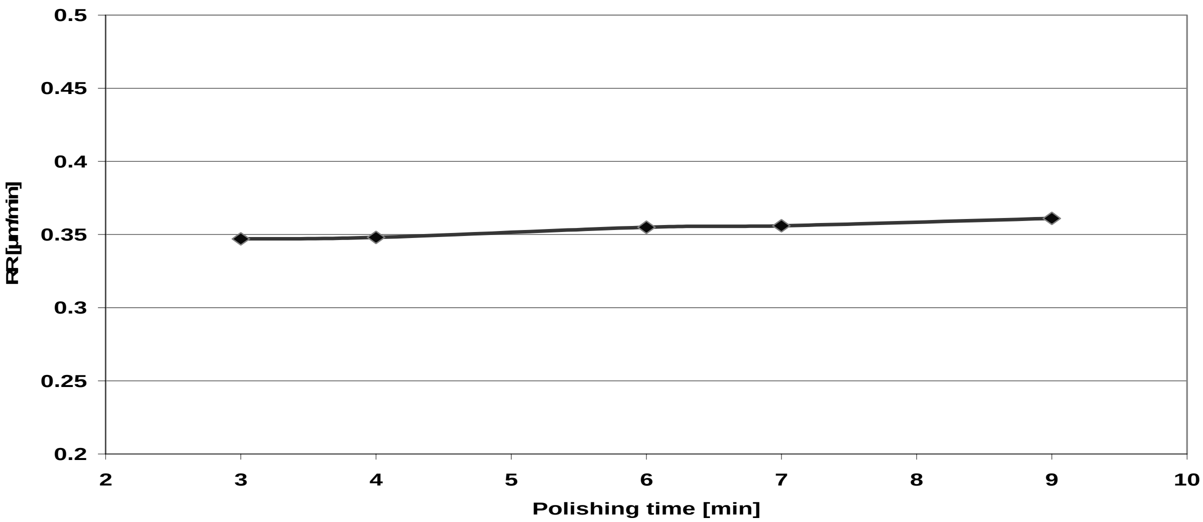

Figure 6: The removal rate of FA polishing is almost independent from the processing time.

CONCLUSIONS

The fixed abrasive polishing for silicon - especially SOI- has been developed further. Long term stability can be reached while TTV behavior of the process is still superior. With high density FA pads removal rates of standard silicon polishing can be reached, while simultaneously removal is independent from the applied processing time. A stable bulk removal can be observed. With the seen pH dependence of the removal rate it is suggested, that the mechanism of abrading silicon is of different nature than in conventional polishing, suggesting more detailed studies. The surface quality of the polished material is also of very high level. After less than 1,5 µm removal, grindlines are not visible anymore in the Magic Mirror. Together with the newly established grinding process with ultra fine wheels (#4000 and higher) the total needed polishing amount can be greatly reduced leading to very flat thick film SOI-substrates.

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