EVALUATION OF A PROTOTYPE CMP MACHINE FOR IMPROVING THE GLOBAL PLANARIZATION BY MEMS

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ABSTRACT
Planarization using Chemical-mechanical Polishing (CMP) is a key technology for fabricating advanced Integrated Circuits (IC) and Micro Electro-mechanical Systems (MEMS). In MEMS fabrication, CMP is used for various applications with an emphasis on surface micromachining. However, due to the much larger structures, wafer level global planarity requirements are harder to fulfill. There are two effects competing against each other. On one hand, creating the process pressure by exerting a force to the wafer at its center favors a greater inside pressure. On the other hand, due to the CMP pad's compliance, the pressure is distributed asymmetrically, resulting in a maximal pressure peak at the wafer's rim. To achieve a constant removal rate and thus an optimal global planarization, the pressure should be uniform over the entire wafer. However, this may only be achieved if the wafer profile is adjusted appropriately. One way to adjust the wafer profile and, if necessary, even the profile of the CMP plate is to use appropriate tools. They are available in a prototype CMP machine specifically developed for this task. This paper presents an evaluation of the capabilities for such a machine prototype regarding the global planarization.

INTRODUCTION
CMP, originally developed for the semiconductor industry, is widely used in the fabrication of MEMS. However, MEMS often feature larger geometries compared to integrated circuits, in order to fulfill mechanical functions [1, 2]. Particularly for fabricating MEMS with a great building height requiring High Aspect Ratio Micro Structure Technology (HARMST), there are two challenges when applying CMP [3]. The first is achieving a local planarization, i.e. a minimal step height between structures and embedding material. The second is reaching a global planarization, which means that the material removal during the CMP process between the wafer's center and its rim is the same (Fig. 1).

In general, a CMP process is carried out on a rotary table. During the process, a range of variables are affecting each other substantially [4]. The main factors are the wafer holder, the polishing pad, and the process parameters (Fig. 2).

While an optimal local planarization typically is accomplished through appropriately matching the CMP slurry, the pad features, and the applied process pressure, reaching a global planarization much more strongly depends on the machine itself and its mechanical properties.
To achieve a constant removal rate and thus an optimal global planarization, the pressure must be uniform over the entire wafer. One way to optimize the global planarization is to use appropriate tools. They are available in a CMP test machine specifically developed for this task. The machine features a significant level of flexibility in order to provide an optimal global planarization as well as a sufficient surface quality for a wide spectrum of MEMS applications considering the materials involved and the magnitude of the structure geometry.

**MACHINE CONCEPT**

To achieve a high uniformity of the pressure over the entire wafer, a two-prong approach was pursued: to adjust the contour both of the wafer holder, as well as of the plate. To adjust the wafer contour, a special piezo wafer holder developed by Noah Technology (former IGAM) in Magdeburg, Germany was used. Figure 3 schematically depicts its adjustment capabilities.

![Figure 3. Deformations of the wafer holder](image)

To perform the actuation, the wafer holder consists of concentric piezo elements, with a piezo disk at the center, surrounded by concentric piezo rings (Fig. 4).

![Figure 4. Schematics of piezo chuck](image)

By appropriately exciting the piezo elements, either a convex or a concave wafer contour can be achieved. The total topography variation of the piezo chuck is specified to be ±8 µm. In addition, a retaining ring is equipped with screw adjustable spring bolts. As a result, two or three independent pressure elements, respectively, and an adjustable retaining ring may be adjusted appropriately. Holding the wafer during the CMP process is accomplished either through a backing film or through vacuum suction.

Not only the wafer chuck, but also the polishing plate may change its contour (Fig. 5). As in the case of the wafer holder, a flat plate, as well as various degrees of concave or convex contours may be chosen. The adjustment is accomplished pneumatically. Two plates with two different ground states were supplied: one is flat and only capable of changing into convex contours. The other one is concave, allowing a concave (Fig. 5a), flat (Fig. 5b), or convex a contour ranging from convex to concave (Fig. 5c). The specification for the plate with a concave contour in its unpressurized state is as follows: at the plate center, the maximal concave profile results in a features a protrusion of 50 µm.

![Figure 5. Deformation of polishing plate: a) initially convex, b) deformed plane and b) deformed concave state](image)

The adjustable, pneumatically actuated plate as well as the whole CMP machine were developed by FLP Microfinishing, Zörbig, Germany. The Noah piezo wafer holder is integrated in it. Figure 6 depicts the machine at its test location inside the cleanroom of the Institute for Microtechnology (imt).

![Figure 6. CMP machine in the imt’s clean room](image)
MACHINE VERIFICATION
As a preparation for evaluating the machine capabilities with respect to global planarization, measurements of real tool deformations were conducted. First, the warping of piezo elements on the wafer holder was measured (Fig. 7).

The results showed an achievable maximal disk/ring expansion of 16 µm by all rings and both chucks (4 in and 6 in). Thus, the specification for a chuck adjustment of ± 8 µm was fulfilled. Although all elements should elongate equally, a minor deviation in elongation between the individual elements was measured and averaged ±1 µm.

Polishing plate measurements were conducted on a plate which was flat when unpressurized. For the tests, two CMP pads were used: a soft felt polishing pad and a hard polyurethane CMP pad (Fig. 8). The maximal achievable displacement of the plate was greater than 100 µm. Since the plate actuation range is independent of the original state of the plate, the results show that the specified limits (+50 µm to -20 µm) can be achieved.

EXPERIMENTAL
CMP tests were carried out to investigate the removal. Each tool set (wafer holder and polishing plate) was activated separately; this way the respective influence could be tested. For the tests, Si wafers coated with 50 nm Cr and 400 nm NiFe were used. The first tests were done with a piezo chuck and a solely excited center disk (Fig. 9a). The excitation of 100 V is accordant to an element elongation (r1) of 16 µm. This led to an increasing of the applied pressure in the center of the wafer and a corresponding concentration of the removal (Fig. 9b). To expand the removal from center to the wafer rim after four minutes of processing, a second element was excited additionally (r1, r2). This generated a removal broadening from the wafer center (after ten minutes). In order to remove a remaining coating on the wafer edge, element 3 is excited solely. After 20 minutes the whole wafer coating was removed.

By engaging the piezo-actuated disk at the center or the edge of the wafer holder, a controlled removal was achieved. Both chucks (4 in and 6 in) were subjected to the same investigations, showing correspondent impact on the material removal.

For the tests of the polishing pad, a plate initially plane was pneumatically warped to the maximal curvature. As a result, a removal localized at the wafer’s center was achieved (Fig. 10).

After the tests with the separately actuated tools, tests with simultaneously exciting both, the wafer holder and the polishing plate were conducted. This led to a noticeable decrease in
polishing time and thus 30 percent less process time. Table 1 depicts the results. The wafer surface after CMP was compared to the state as delivered, which was polished for Si and lapped for Al₂O₃.

**TABLE 1. Results with coated wafers**

<table>
<thead>
<tr>
<th>Wafer</th>
<th>Si</th>
<th>Al₂O₃</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Polished</td>
<td>CMP</td>
</tr>
<tr>
<td>Average thickness [µm]</td>
<td>527.6</td>
<td>517.4</td>
</tr>
<tr>
<td>Max. difference in thickness [µm]</td>
<td>8.08</td>
<td>6.25</td>
</tr>
<tr>
<td>Average thickness deviation [µm]</td>
<td>8.1</td>
<td>1.5</td>
</tr>
</tbody>
</table>

After the functionality and capability tests with bulk wafers, first preliminary processes on patterned wafer were conducted. For this purpose, the electroplated permalloy structures embedded in photoresist (AZ) on the Al₂O₃ wafers were used. The structure height distribution on the wafer was measured after electroplating. With a tool adjustment corresponding to these measurements, the CMP process was carried out. The main challenges were to planarize both larger and smaller structures without damage and delamination, and still achieving a global planarization. Planarization results achieved with patterned wafers are shown in Table 2.

**TABLE 2. Results with patterned wafers**

<table>
<thead>
<tr>
<th>Wafer</th>
<th>Si</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Process step</td>
</tr>
<tr>
<td>Average structure height [µm]</td>
<td>&gt;30</td>
</tr>
<tr>
<td>Max. height difference [µm]</td>
<td>10 - 20</td>
</tr>
<tr>
<td>Average step height [µm]</td>
<td>4 - 8</td>
</tr>
</tbody>
</table>

Fig. 11 shows a structure height distribution over the wafer before and after CMP. After electroplating, the structures on the wafer edge were much higher than in the center (Fig. 11a). After CMP, an improvement in global planarization is clearly visible with an average step height between the structures of 2.5 µm (Fig. 11b).

**CONCLUSIONS**

The tests showed that differences in material removal between the wafer center and the wafer rim could be achieved by appropriately adjusting piezo-actuated elements and deforming the polishing plate. Improvement in global planarization could be determined by both coated and patterned wafers. Functional tests showed a high application potential of both tools, piezochuck and polishing plate, for improving global planarity through a CMP process.

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**REFERENCES**


