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SILICON WAFERS ROTATION GRINDING METHOD AND SURFACE GRINDING ON A ROTARY TABLE

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Abstract. Slicing technology is the key to either process, but uncontrolled deep damage (10-50 (µm in depth) and large warpage and thickness variation of the wafers are unavoidable. In the traditional process, lapping is used next for minimizing the depth of the damage layer and the thickness variation. Etching then eliminates the damage layer formed by lapping, but the thickness variation is increased. By mechanic-chemical polishing, the final macro- and micro-flatness is obtained. Using this process, Si-wafers have 1.0 µm of local thickness variation (LTV: 15x15 mm^2) and are supplied for 1 Mbit DRAM processes.

1 INTRODUCTION

The flatness value may be achieved by improvement of the traditional method, but it is not the final target of Si-wafers. For wafers over 200 mm in diameter, two technological disadvantages of the traditional method are exposed. One is the thermal and mechanical inhomogenity of a huge lapping exposed.

The second is the difficulty of improving the stability of the etching rate, both wafer to wafer and within a wafer.

Because of the high normal forces induced when grinding brittle materials, unavoidable elastic deformation of the tool and workpiece occur. This is due to the kinematics of the cutting process, i.e. that the relative trajectories and speeds of the abrasive grains are varied. The elastic deformations caused by high normal forces bring about faults of geometry and surface and the sub-surface damage.

The conventional grinding methods for wafer have the above mentioned characteristics and therefore the wafer quality is limited. With the new rotation method which is integrated in the ultra precision process, it is possible to suppress these disadvantages.

2 THE PRINCIPLE OF THE ROTATION GRINDING METHOD

Figure 1 shows the principle of the rotation grinding method. A wafer is centered on a porous ceramic vacuum chuck. The work piece rotates relative to a cup wheel which also rotates on its own axis. In this way, every point of the planar wafer surface comes into contact with the grinding wheel and the diminution of size is executed on for every point of the wafer. The cup wheel is moved in axial direction until the wafer has reached its final thickness.

Economical reasons require a splitting of the grinding process into a rough grinding and a finishing part. For this purpose, cup wheels with different grit sizes have to be used. In the rough grinding with a D46-cup wheel it is possible to reach high stock removal rates. Finishing with the grit size D7 permits a good surface quality.

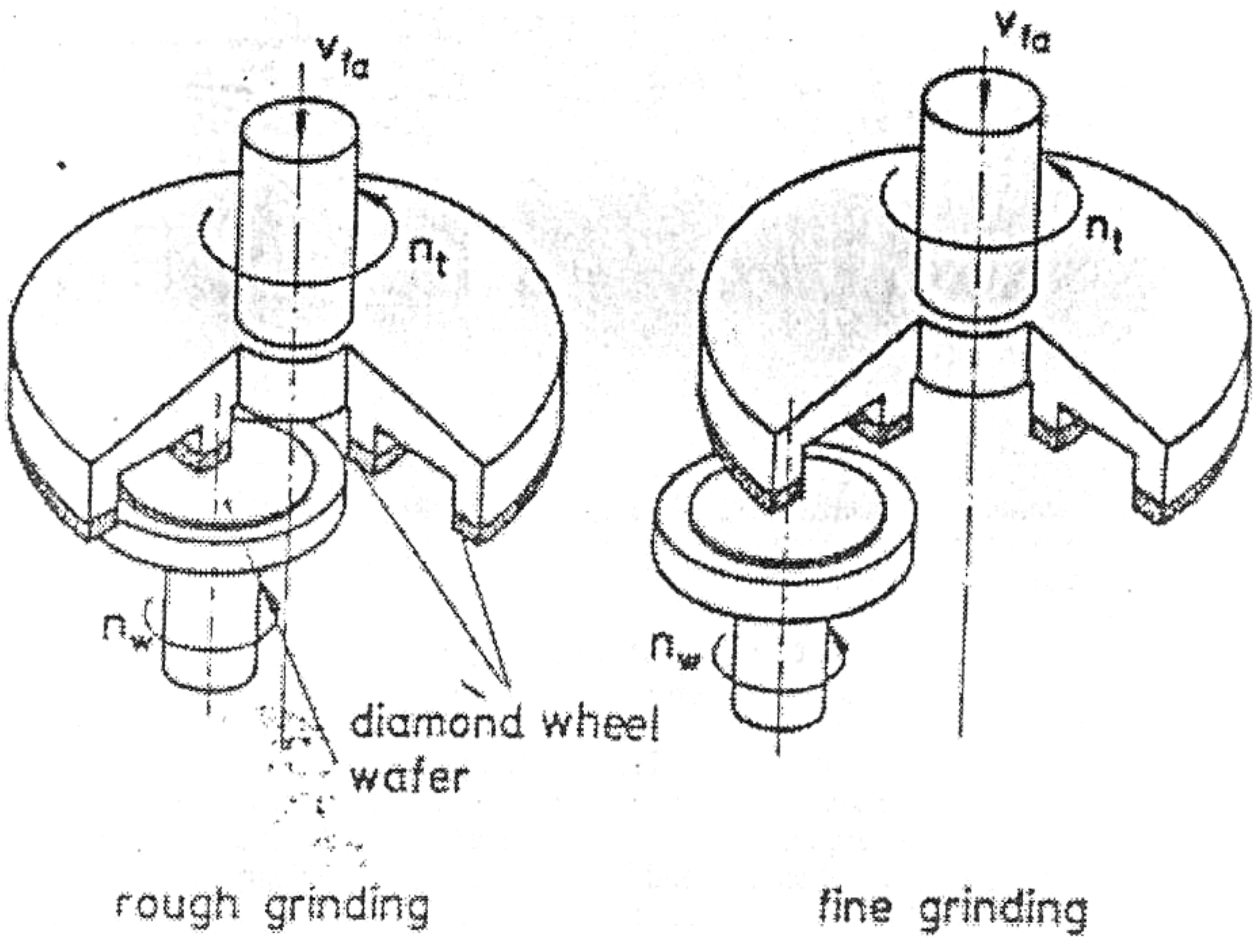

Figure 1. Principle of the rotation grinding method

There are two construction principles for the rotation grinding method with stepped grit size:

a) concentric cup wheels. Two annular grinding wheels are mounted concentrically on one rotating support disk. The inner grinding-ring has the large grit size for rough grinding whereas the outer ring is provided for fine grinding.

The two grinding rings are arranged in such a way that either the rough-grinding-wheel or the fine-grinding-wheel can be put in contact with the work piece whereby the other grinding wheel is not activated.

b) serially joined cup wheel. The grinding process is divided into two or more steps of serially joined cup wheels. The wafer runs through the workstations in order of declining grit size.

In wafer rotation grinding, accurate straightness can be obtained theoretically. But in reality, the rotary axis of the grinding wheel and the work piece are not absolutely parallel because the plane parallelism of the ground wafer face cannot be achieved exactly.

The reasons for this fault are:

- machine deformation as a consequence of grinding forces;
- machine deformation due to thermal influence;
- insufficient adjustment;

- bearing clearance of tolerance.

Because of these reasons, a subsequent adjustment of the spindle is useful. The influence of the angular deviation on the shape of the ground work piece is quite simple.

The angular deviation can be divided up into a radial and tangential component of the angle between z - axis and the rotary axis of the grinding wheel.

If the spindle is inclined in positive α_r direction, the wafer has a convex profile on the wafer surface. In case of an inclination in negative α_r direction, the wafer would have a concave profile. Whether the inclination in a direction is positive or negative makes no difference. The wafer has a cone-like shape.

The spindles deviation is not only limited on a purely α_r or α_t direction, but all combinations between these two components are possible, so that all shapes between convex and concave on one side and "cone-like" on the other side are possible.

A certain relation between α_r and α_t inclination leads to a typical surface-profile which is shown in Figure 2.

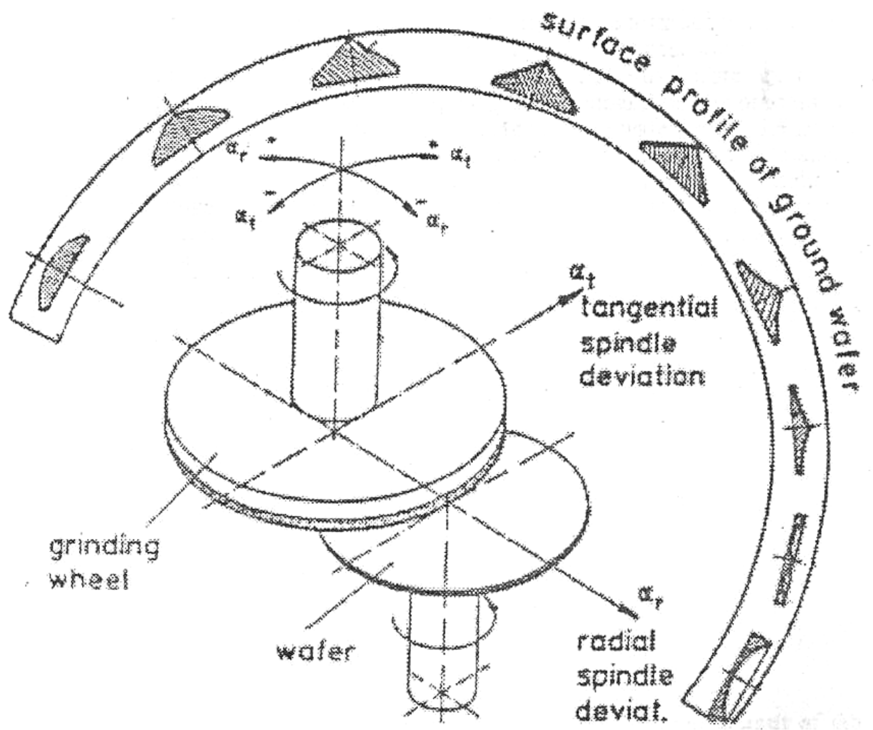

Figure 2. Surface - profile

It is characteristic for grinding in general that the processed surface is not an absolutely homogenous but shows a certain orientation of grinding marks. The aim for every high quality grinding process is to reduce the visibility of the grinding marks although they always exist. The grinding marks depend on the kinematics of the process.

Figure 3 shows an example of the surface of a wafer ground by the rotation method.

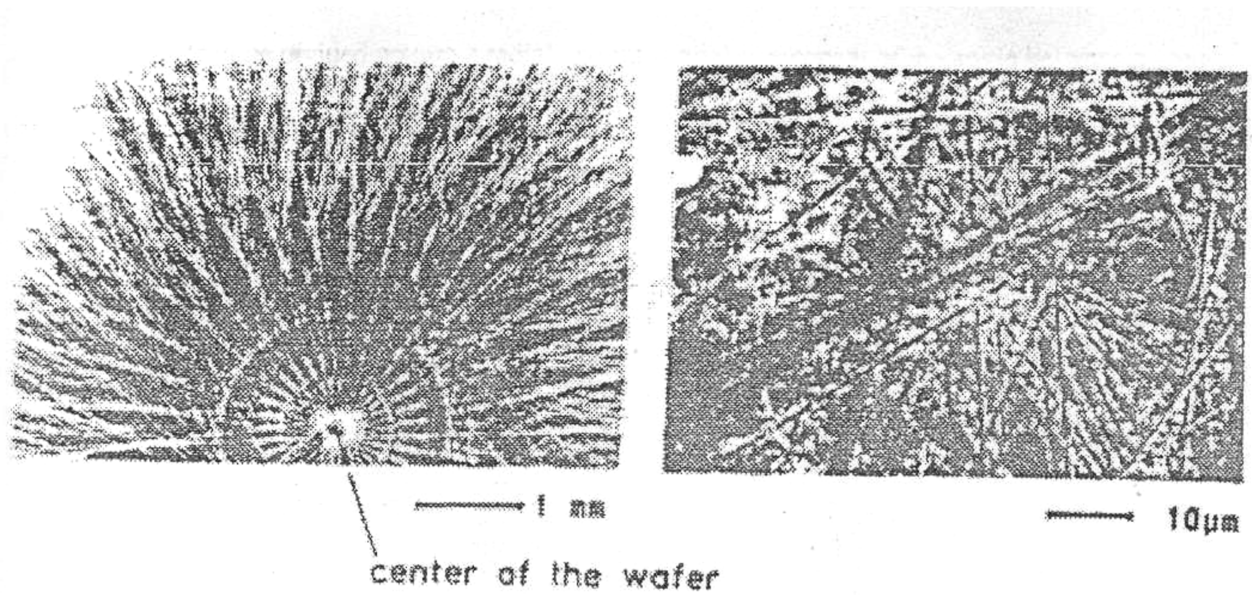

Figure 3. Grinding marks

For the best possible surface roughness the grit size of the grinding wheel should be very fin. However, there are certain limits below which grinding is not longer possible because the self-dressing effect decreases and finally disappears. If a smaller grit size than D7 is utilized to produce smoother surface, the diamond in resin bond tends to be buried by the silicon dust created during the processing.

3 SURFACE GRINDING ON A ROTARY TABLE OF SILICON WAFERS

Single-sided surface grinding operations can be applied to removal diffusion layers or to reduce the thickness of completely processed semiconductor wafers (thinning). The wafer thickness is reduced from 450 - 600 µm down to approximately 150 - 380 µm. After the thinning process, the parallelism may not exceed a TTV-value of 5 µm, in certain cases of 3 µm. In pure thinning surface roughness's R_{max} of greater than 2 µm are generally not permitted. The advantages of surface grinding compared to lapping are the high material removal rates and the lower level of crystal damage. In addition, grinding is a cleaner process and has good potential for automatisation in which fully integrated cassette-to-cassette manufacturing can be achieved.

4 COMPARISON BETWEEN FACE TANGENTIAL GRINDING AND FACE PLUGE GRINDING

All specially developed grinding machines for semiconductor manufacture have vertically oriented diamond cup wheels (Figure 4). They differ in process kinematics and the number of simultaneously machinable wafers which are fixed on vacuum chucks. Depending on the depth of cut a_p and the table feed speed v_{ft} face tangential grinding processes can be further classified into "reciprocation grinding" and "creep feed grinding". In the first case, the material removal takes place in several cuts each with low depths of cut (1 - 10 µm) and a high table feed speed (up to 8000 mm/min) whereas creep feed grinding is characterized by high depths of cut (100 - 200 µm) and low table feed speeds (100 - 300 mm/min). In face tangential grinding with a rotary table it is favorable to have the process conditions: contact length, contact area and grinding forces remain constant since this directly affects the form accuracy attainable.

In face plunge grinding, the rotating compound grinding, wheel which covers the entire wafer surface is fed continuously in axial direction (Figure 4). Shortly before reaching the final thickness, the axial feed is disengaged. Subsequently a tangential finishing process takes place in which the fine-grained diamond outer ring is engaged as the wafer leaves the grinding zone. In face pluge grinding, the engagement conditions concerning cutting speed v_c and cutting length l_{ck} vary within the wafer surface and the grinding layer. Furthermore, the grinding forces in pluge rough grinding are approximately an order of magnitude higher than those for tangential grinding due to the large wheel / wafer contact area A_k.

Therefore, the final tangential finishing process diminishes form inaccuracies which result from deflections of the machine tool. In this final operational step, very smooth surfaces can be obtained by using a fine grained outer ring. In tangential grinding, multi-step process as described above can only be realized on a multi-spindle machine tool system.

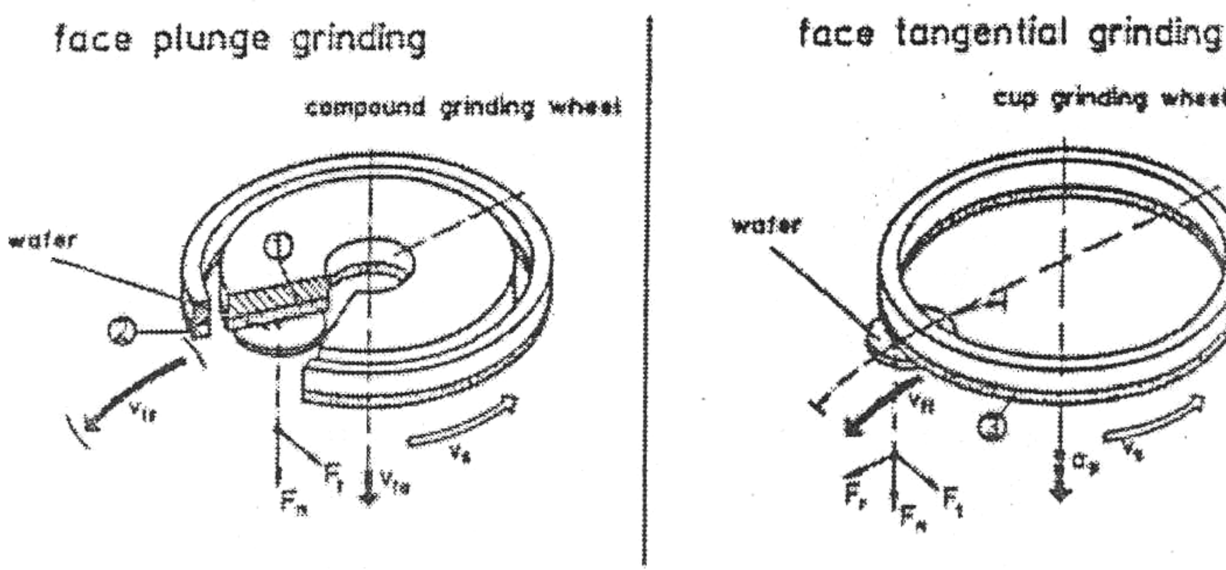

Figure 4. Kinematics of face plunge grinding and face tangential grinding

As shown in Figure 5, face plunge grinding results in smaller depths of damage than that for tangential grinding. The normal component F''_n ranges between 2 and 36 N/cm^2 depending on the "process kinematics and the material removal rate. The highest values of area-related grinding forces have been obtained in tangential reciprocation grinding. The influence of the feed speed on the depth of damage and the forces per unit area is higher than that of the depth of cut for the same material removal rate. The forces per unit area in grinding of the {100}-wafers have been found without exception to be higher than those of the {111}-wafers for all conditions investigated. The roughness R_Z and depth of damage H_D showed no significant variation for both crystal orientations.

Even at material removal rates of up to 1000 µm/min, considerably low depths of damage were found with face plunge grinding. This can be explained by the large number of diamond grains which are engaged simultaneously. This causes low level process-induced stresses and damage in the crystal material although the material removal rate is remarkably high. The material removal process is governed by micro-plastic abrasion. Brittle chipping and cracking at the wafer surface usually associated with coarse abrasion occurred less often in face plunge grinding. Face plunge grinding is thus a very efficient abrasion process for roughing. In tangential grinding at Q''_w = 1000 µm /min, more than 90 % of the wafers fractured during grinding or in subsequent processing for damage measurement. It was therefore not possible to evaluate depths of damage.

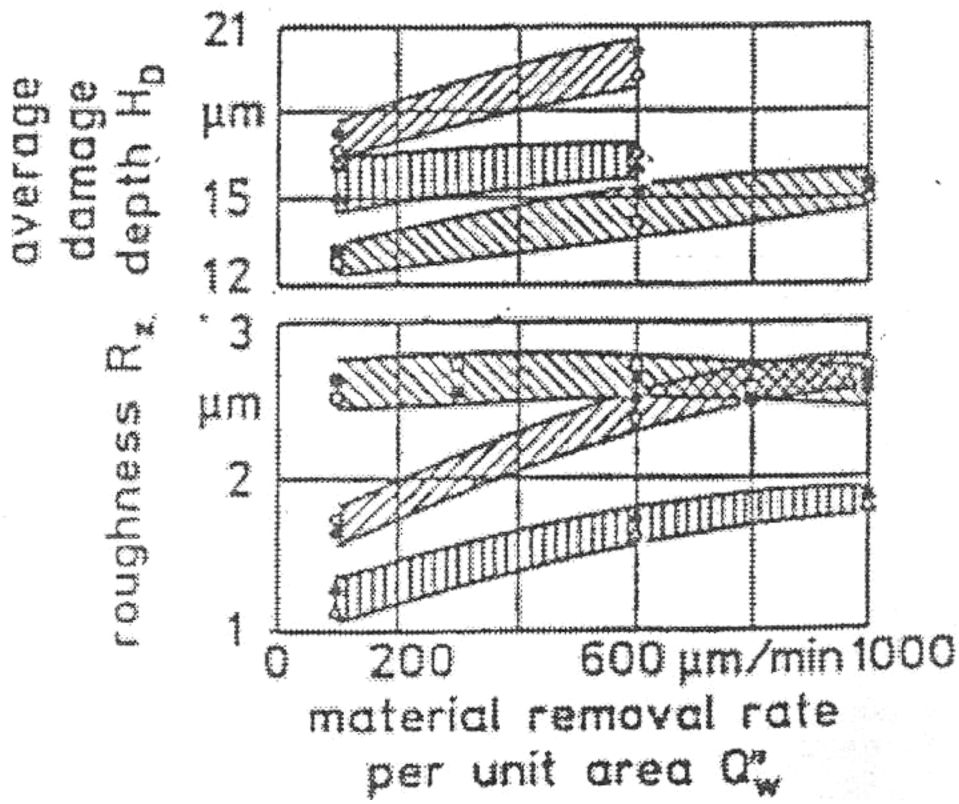

Figure 5. Surface roughness and depth of damage as a function of the material removal rate for various grinding processes

5 CONCLUSIONS

Especially for large wafers (200 mm and more), rotation grinding with a cup-wheel represents future technology, because the geometrical contact zone is small (thermal induction) and the tool is defined in its geometry. To reach values of less than 0.5 µm for the TTV, an automatic adjustment of the tool spindle will be necessary. The objective is to obtain a nearly perfect wafer quality after this step to reduce the polishing process expense.

The topography of the abrasives, in particular the larger ones, is reflected on the wafer surface in the form of arc-formed grinding grooves. Thus, a final tangential grinding process as a finishing operation is indispensable for high form accuracies and surface qualities.

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