1. Introduction

Integrated circuits are a part of everyone’s life today. They are used in building of all kinds of electronic devices from a radio to the most sophisticated satellites. These integrated circuits are constructed on semiconductor wafers and are later diced and assembled into their final assemblies. Manufacturing of semiconductor wafers to meet the ever increasing demand and quality needs is a constant challenge.

One of the important processes in manufacturing of semiconductor wafers and Integrated circuits is grinding process. Grinding is done to reduce the thickness and improve the surface quality of the wafer at a high throughput. Hence, its use in wafer manufacturing is increasing. Grinding is finding some newer applications in the manufacturing process such as partially replacing lapping and polishing operations. The grinding operation is generally used in two places. The first place is to remove the waviness from the initial sliced wafer and to restore parallelism between the front and the back surface. Secondly, the grinding is done on the backside by a process called “backgrinding” after construction of circuits on the front side.

One phenomenon in wafer grinding is the generation of grinding marks. The depth and the orientation of grinding marks play an important role in determining the quality of the wafer produced. Even though the grinding marks produced by wafer grinding are uniform with radial alignment, the orientation of the grinding marks varies significantly for the sliced die. This causes variation in the die strength of the wafer produced. It is important that the surface quality and the die strength of the wafer produced by grinding process be optimized. To achieve this we need to understand thoroughly the process of semiconductor wafer grinding and predict the generation of grinding marks.

This paper studies the most commonly used semiconductor wafer grinding process namely, the cup wheel grinding (in other words “wafer grinding”, “backgrinding” or “surface grinding”). It first presents an analytical model to predict the locus of the grinding lines and the distance between two adjacent grinding lines. Then the locus and distance of grinding marks predicted by the model are compared with experimental results.

2. Development of Mathematical Model

The literature most relevant to grinding marks includes analyses on vertical-spindle surface grinding using conventional wheels [Shaw, 1996], diamond cup wheel grinding of parabolic and toroidal surface on ceramics for mirrors [Zhong and Venkatesh, 1994; Zhong and Nakagawa, 1996], and precision cylindrical face grinding using a narrow ring superabrasive wheel [Shih and Lee, 1999]. These analyses are instrumental to the model development for wafer grinding, but cannot be applied directly.

Fig. 1 shows the setup of wafer grinding. The grinding wheel is modeled as a single-point cutter and it removes the work material from the edge to the center along the curve MO as shown in Fig. 2. Two coordinate systems are used to define all the points on the wafer and the grinding wheel as shown in Fig. 2. The origin of the grinding wheel’s coordinate system $U-V$ is at the center of the grinding wheel and the origin of the chuck’s coordinate $X-Y$ is at the
center of the chuck. The grinding wheel coordinate system is offset from the chuck’s coordinate system along the $Y$-axis by a distance $K$. In this case $K$ is equal to $R$, the radius of the grinding wheel. The grinding wheel revolves about its center $O_1$ at $N_s$ rev/sec. The wafer revolves about its center $O$ at $N_c$ rev/sec. and the wafer has radius $R_w$. Thus, there are four input parameters in this model: $R$, $N_s$, $N_c$, and $R_w$.

For the grinding wheel in Fig. 2, any point on the edge of the grinding wheel can be defined with respect to the $U$-$V$ coordinate system by following equations

$$u = R \cos(2\pi N_s t)$$

(1)

$$v = R \sin(2\pi N_s t)$$

(2)

where, $t = 0$ is set initially at coordinates $(R, 0)$.

The points in the $U$-$V$ coordinate system can be transformed to the $X$-$Y$ coordinate system by following equations

$$x = u = R \cos(2\pi N_s t)$$

(3)

$$y = v - k = R \sin(2\pi N_s t) - K$$

(4)

The time taken for point $P$ with coordinates $(R, 0)$ in the $U$-$V$ coordinate system starting with time $t = 0$ to reach point $M$ at the edge of the wafer can be calculated using basic geometry as shown in Fig. 2.

Thus, the range of $t$ lies between

$$t_1 \leq t \leq \frac{1}{4N_s}$$

where $t_1$ is,

$$t_1 = \frac{1}{2\pi N_s} \left( \frac{\pi}{2} - 2 \arcsin \left( \frac{R_w}{2R} \right) \right)$$

(5)
and the time at which the nth grinding mark starts is given by

\[ t_n = \frac{1}{2\pi N_s} \left( \frac{\pi}{2} - 2 \cdot \arcsin \left( \frac{R_w}{2R} \right) \right) + \frac{n-1}{N_s} \quad \text{where} \quad n = 1,2,3, \ldots \tag{6} \]

However the above-described point P is not the point on the profile of the grinding mark. This point P is offset to P’ on the wafer due to the simultaneous revolution of wafer as shown in Fig. 3. Angles \( \theta_0 \) and \( \Delta \theta \) and the distance \( r \) (r = OP = OP’) with respect to the chuck’s coordinate system are necessary to calculate the coordinates of point P’. These parameters are defined by pure geometry as shown in following equations

\[ \theta_0 = \arctan \left( \frac{y}{x} \right) \tag{7} \]

\[ \Delta \theta = 2\pi N_c (t - t_i) \tag{8} \]

\[ \theta = \theta_0 - \Delta \theta \tag{9} \]

The distance of point P’ from the origin O can be found out from the coordinates of P as P and P’ should lie at the same distance from the origin O or on the same circle.

\[ r = \sqrt{x^2 + y^2} \tag{10} \]

Thus, the coordinates of P’ can be written as \((x_1, y_1)\)

\[ x_1 = r \cdot \cos(\theta) \tag{11} \]

\[ y_1 = r \cdot \sin(\theta) \tag{12} \]

3. Validation of the Model

The model was validated using the experimental results of Pei and Strausbaugh [2001] and Oh et al. [2001]. The grinding conditions used in these experiments are shown in Table 1. Fig. 4 shows some magic mirror pictures of ground wafers and the corresponding graphs of grinding marks generated by the presented model. From the figure it can be seen that the graphs have a very close resemblance with the grinding marks on the wafer surface. Both the curvature and the distances match to a close extent. The grinding marks were generated for one chuck revolution initially. In case of very high chuck speeds the grinding marks that fall in between the first and second grinding mark of the first revolution of the chuck were generated by using Eq. 6.

Table 1. Grinding parameters used in experiments

[Pei and Strausbaugh, 2001; Oh et al., 2001]

<table>
<thead>
<tr>
<th>Grinding wheel speed ( N_s ) rev/s (rpm)</th>
<th>Chuck speed ( N_c ) rev/s (rpm)</th>
<th>Grinding wheel radius ( R ) (mm)</th>
<th>Wafer radius ( R_w ) (mm)</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>36.25 (2175)</td>
<td>0.6667 (40)</td>
<td>140</td>
<td>100</td>
<td>Fig. 4 a</td>
</tr>
<tr>
<td>36.25 (2175)</td>
<td>9.8333 (590)</td>
<td>140</td>
<td>100</td>
<td>Fig. 4 b</td>
</tr>
<tr>
<td>72.5 (4350)</td>
<td>0.6667 (40)</td>
<td>140</td>
<td>100</td>
<td>Fig. 4 c</td>
</tr>
<tr>
<td>68.8833 (4133)</td>
<td>10.3833 (623)</td>
<td>140</td>
<td>100</td>
<td>Fig. 4 d</td>
</tr>
</tbody>
</table>
4. Conclusion

A mathematical model has been developed to predict the grinding marks on the surface of semiconductor wafers induced by wafer grinding. The grinding marks generated by the model were compared with magic mirror pictures of experimental results. There seemed to be a very close resemblance in terms of curvature as well as the distance between two successive grinding marks.

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References


Fig. 4. Comparison of predicted grinding lines with magic mirror pictures.
(Note: Only about ¼ of grinding lines are drawn.)