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POLISHING OF SILICON WAFERS

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Abstract: *During the wafer polishing operation a number of dynamic forces are in operation that may affect overall pad life and removal rates. In an effort to examine some of these forces and attempt to gain a better understanding of them, a model has been developed and is presented here in the spirit of experimentation*

Key words: *silicon wafers, polishing, pad, head, scraping*

1. INTRODUCTION

For the sake of this discussion the model has been restricted to a urethane-impregnated pad on a single – side polisher with a single head and a single wafer (Dobrescu & Anghel, 2008).

The *X* axis is defined as a line intersecting the center of the polishing pad and the center of the polishing head. The *Y* axis is defined as a line intersecting the center of the pad and perpendicular to the *X* axis (Chang, 1995).

2. POLISHING PAD DYNAMICS

Further, the following definitions should be made:
R = distance from center of pad to point P (x, y).
r = distance from center of head to point P (x, y).
k = distance from center of pad to center of head.
ϕ = Angle R makes with X axis.
β = Angle r makes with X axis.

Referencing figure 2 we know that for any point P (x, y), there is an x and y such that:

$$y = R \cdot sin\phi \quad (1)$$

$$x = R \cdot cos\phi \quad (2)$$

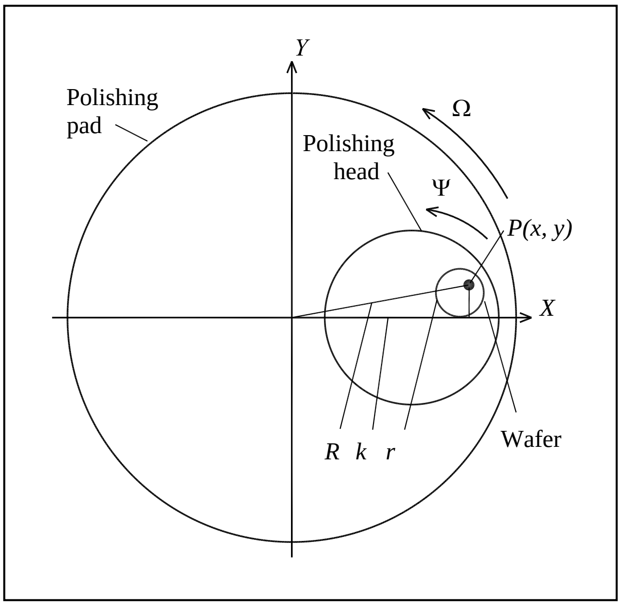

Fig. 1. Distance definitions

We can see from figure 1 that point P (x, y) can be expressed in terms of the angle ϕ or the angle β.

Point P (x, y) expressed in terms of the angle β:

$$x = k + r \cdot cos\beta \quad (3)$$

$$y = r \cdot sin\beta \quad (4)$$

Furthermore we see that:

$$R \cdot sin\phi = r \cdot sin\beta \quad (5)$$

$$R \cdot cos\phi = k + r \cdot cos\beta \quad (6)$$

The angular velocity of the pad will be called Ω and the angular velocity of the head will be called Ψ. We will also assume that Ω and Ψ are constant over time (Dobrescu et al., 2010). Both are expressed in radians per minute.

We therefore have (figure 2):

$$\Omega = \frac{d\phi}{dt} \text{ (pad)} \quad (7)$$

$$\Psi = \frac{d\beta}{dt} \text{ (head)} \quad (8)$$

We want to find the *x* and *y* components of the velocity for point P (x, y). We find that:

- For the wafer:

$$V_{wx} = \frac{dx}{dt} = \frac{dx}{d\beta}\frac{d\beta}{dt} = -r \cdot sin\beta \frac{d\beta}{dt} = -\Psi \cdot r \cdot sin\beta \quad (9)$$

$$V_{wy} = \frac{dy}{dt} = \frac{dy}{d\beta}\frac{d\beta}{dt} = r \cdot cos\beta \frac{d\beta}{dt} = \Psi \cdot r \cdot cos\beta \quad (10)$$

- For the pad:

$$V_{px} = \frac{dx}{dt} = \frac{dx}{d\phi}\frac{d\phi}{dt} = -R \cdot sin\phi \frac{d\phi}{dt} = -\Omega \cdot R \cdot sin\phi \quad (11)$$

Substituting from equation (5) we get:

$$V_{px} = -\Omega \cdot R \cdot sin\phi = -\Omega \cdot r \cdot sin\beta \quad (12)$$

$$V_{py} = \frac{dy}{dt} = \frac{dy}{d\phi}\frac{d\phi}{dt} = R \cdot cos\phi \frac{d\phi}{dt} = \Omega \cdot R \cdot cos\phi \quad (13)$$

Substituting from equation (6) we get:

$$V_{py} = \Omega(k + r \cdot cos\beta) = \Omega k + \Omega r \cdot cos\beta \quad (14)$$

A look at the difference in pad and wafer velocity for point P (x, y) shows:

$$\Delta V = V_p - V_w = (V_{px} - V_{wx}, V_{py} - V_{wy}) \quad (15)$$

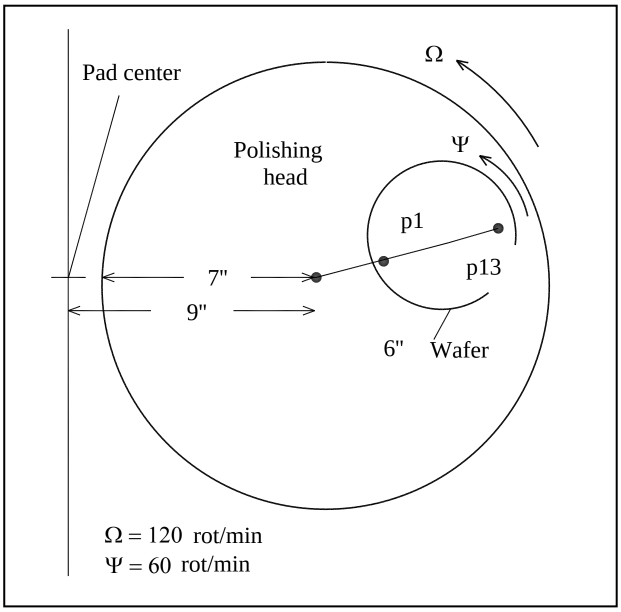

Fig. 2. Examples to see how this affects wafer polishing

Point	Rad	S_{min}	S_{max}	S_{ave}	% diff.
p1	0.5″	6597.5	6974.4	6787.4	-
p2	1.0″	6409.0	7162.9	6791.5	0.06
p3	1.5″	6220.5	7351.4	6798.2	0.16
p4	2.0″	6032.0	7539.9	6807.5	0.30
p5	2.5″	5843.5	7728.4	6819.4	0.47
p6	3.0″	5655.0	7916.9	6834.1	0.69
p7	3.5″	5466.5	8105.4	6851.3	0.94
p8	4.0″	5278.0	8293.9	6871.2	1.24
p9	4.5″	5089.5	8482.4	6893.8	1.57
p10	5.0″	4901.0	8670.9	6919.1	1.94
p11	5.5″	4712.5	8859.4	6947.1	2.35
p12	6.0″	4524.0	9047.9	6977.8	2.81
p13	6.5″	4335.5	9236.4	7011.3	3.30

Tab. 1. Magnitude of the scraping vector

Now lets us consider some specific examples to see how this affects wafer polishing.

Suppose we are polishing 152.4 mm (6″) wafers on a machine with a d_i = 920.75 mm (36.25″) platen size and 355.6 mm (14″) carriers. Rotation speeds will be set at Ψ = 60 rot/min (377 radians/minute) and Ω = 120 rot/min (754 radians/minute). Let k = 228.6 mm (9″).

A series of 13 points can be examined across the 152.4 mm (6″) wafer. The points will start with point p1 (inner edge of wafer) with a radius of 12.7 mm (0.5″) and end with point p13 (outer edge of wafer) with a radius of 165.1 mm (6.5″), with increments of 12.7 mm (0.5″) between (figure 2).

As seen in Table 1, there is a differential in polishing between inner wafer edges to outer edge by as much as 3.3 %. What may be more important to note however, is the wider range of S_{min} and S_{max} as we move out across the wafer?

The wafer path on the polishing pad is a good news/bad news situation (Trumpold et al., 1994). As seen in the previous discussion, the scraping effect can be equalized by setting the two rpm's equal to each other. The bad news is that when this is done, one point on the wafer tracks in the same path every 2π.

A considerable number of polishing theories has been expressed in the form of mathematical algorithms supported by experimental data. The development of dynamic models is based on the statistical analysis of experimental data.

The path point p7 would take given the parameters in our example. Variables: Ψ = 60 rot/min, Ω = 120 rot/min, r = 88.9 mm (3.5″), k = 228.6 mm (9″), d_i = 920.75 mm (36.25″), simulated Lapsed Time 5 seconds.

The path point p7 would take when setting Ω = Ψ. Variables: Ψ = 60 rot/min, Ω = 60 rot/min, r = 88.9 mm (3.5″), k = 228.6 mm (9″), d_i = 920.75 mm (36.25″), simulated Lapsed Time 5 seconds.

The main advance of dynamic modeling over conventional mathematical models is that because the dynamic models are supported by the database system and knowledge based system, they contain much more polishing knowledge, not only conventional data but also fuzzy information, such as polishing experience and industrial expertise, etc. Another important feature of the dynamic models is that they, when developed, can be improved and updated according to feedback from applications of the system (Chen et al., 1998).

Because the dynamic model is computerized it is possible to incorporate it into other computer system, such as the main CIM system. Thus it can be the input of the polishing technology into an advanced manufacturing environment.

3. CONCLUSION

With respect to polishing wafers, a uniform scraping can be achieved across the surface of a wafer by allowing the rotational speed of the pad to equal the rotational speed of the carrier or head.

When the two speeds are different and when a wafer is held rigid with respect to the polishing head, a differential is found in scraping/polishing across the surface of the wafer, with the inner edge having the lowest polishing effect and the outer edge having the highest. The increase across the wafer is linear.

In this example it varied by as much as 3.3%. This figure will, of course, change depending upon the individual variables. For example, the affect of this on a 152.4 mm (6″) wafer at a 1.5 μ removal rate over 30 minute cycle time could create as much as a 1 – 2 μ slope across the wafer.

More important than the average scraping magnitude, S_{ave}, may be the S_{min} and S_{max} values that a wafer point passes through. This could have a magnifying effect on the polishing differential.

It is found that when Ψ = Ω or Ω = iΨ we get a situation where the wafer tracks in its own path. This may possibly result in reducing overall pad life and reducing effective removal rate.

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