Task ID: 425.032
Task Title: Fundamentals of Advanced Planarization: Pad Micro-Texture, Pad Conditioning, Slurry Flow, and Retaining Ring Geometry

Deliverable: Report on the initial wafer-level model relating pad-microstructure and slurry flow evolution to wafer-level planarity.

I. Summary/Abstract

We are investigating the impact of CMP consumables and tool design parameters, on the resulting wafer-level and chip-scale planarity and uniformity. In particular, we are interested in how CMP tool parameters, including retaining ring geometry and design, create or reduce wafer-level uniformity, and interact with slurry flow as well as pad surface microstructure. In the initial wafer-level model reported on here, we have focused on a subset of process and tool parameters as a first step. First, the retaining ring geometry and pad/wafer edge interaction is studied, and a model is implemented to predict the degree of edge polish nonuniformity (or edge roll-off) arising primarily from pressure nonuniformity. Second, other macroscopic sources of wafer-level non-planarity have been implemented, particularly related to previously known relative velocity nonuniformity arising from tool kinetics.

II. Technical Results and Data

The within wafer non-uniformity of the material removal rate has long been a concern in CMP [1]. Pressure distribution is known to be highly non-uniform near the wafer edge, which results in a typical edge roll-off profile [2]; this edge roll-off reduces the yield of the process, particularly of chips near the wafer edge. The edge roll-off may result from the inherent discontinuities of the process tool geometry at the wafer edge. Figure 1(a) shows the wafer carrier configuration of a typical rotary CMP tool. The wafer carrier holds the wafer facing down, which is polished against the polishing pad. Figure 1(b) schematically shows the geometry near the wafer edge. The wafer is surrounded by a retaining ring, which is usually a few millimeters away from the edge of the wafer. In a typical setting, different pressures are applied to the wafer and the ring, with the ring usually under higher pressure to prevent the wafer from slipping out. The pad bends around the wafer edge due to the existence of the gap and retaining ring, thus the wafer edge is polished non-uniformly due to a localized pressure affected by the retaining ring.

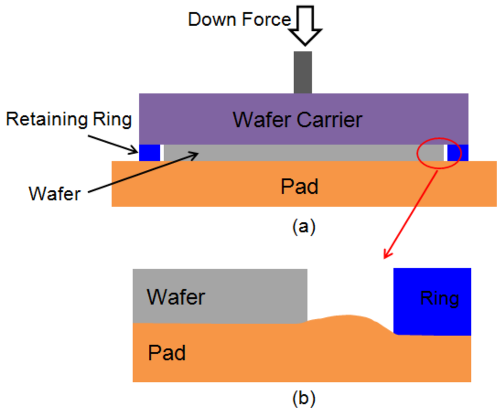

Figure 1: Wafer carrier configuration of CMP: (a) Wafer surrounded by retaining ring. (b) Pad deformation around wafer edge.

The factors causing the non-uniform pressure distribution include gap size, pad effective modulus and reference pressures on the wafer and retaining ring. To understand the detail, we have built a physical wafer-level CMP model based on contact mechanics.

Modeling of Pressure Distribution

In this section, we apply the contact wear model to simulate CMP on the wafer scale. Figure 2 illustrates the model framework. The wafer is assumed to sit face down, and the wafer surface is pressed down onto the polishing pad. For convenience, the surface normal of the wafer is taken as the positive Z direction, corresponding to the conventional "wafer face up" mathematical representation. The pad can be treated as an elastic body. Wafer and retaining are both rigid. When the wafer and the ring are pressed to the pad, the relationship between pad deformation and wafer/ring surface topography can be modeled using a contact wear model [3, 4]. Pad surface displacement $w(x,y)$ and pressure $P(x,y)$ satisfy the following convolution:

$$w(x,y) - w_0 = F(x,y) \otimes P(x,y) \qquad (1)$$

where $F(x,y)$ is the function of deformation response to a point pressure shown by Equation 2.

$$F(x,y) = \frac{1}{\pi E} \int d\xi \int d\eta \frac{1}{\sqrt{(x-\xi)^2 + (y-\eta)^2}} \qquad (2)$$

This deformation response is proportional to $\frac{1}{E}$, where E is the effective modulus of the pad. Here w_0 is the reference plane when the reference pressure is zero. To solve the contact wear problem, the following boundary conditions need to apply.

$$\begin{cases} P(x,y) \geq 0 \\ \frac{1}{S_0} \int_{wafer} P(x,y) \cdot dx \cdot dy = P_0 \\ \frac{1}{S_r} \int_{ring} P(x,y) \cdot dx \cdot dy = P_r \\ w(x,y) \geq z(x,y) \end{cases} \qquad (3)$$

Here P_0 is wafer reference pressure and P_r is wafer reference pressure. $z(x,y)$ is the rigid structure surface defined by wafer and retaining ring.

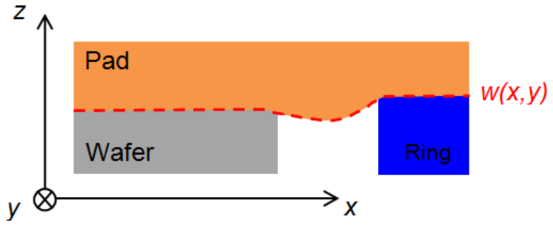

Figure 2: Model framework of pressure distribution.

Using this model, Figure 3 and Figure 4 show a simulation of 300mm flat wafer surface pressure without retaining ring. The wafer reference pressure is 1psi. Pad effective modulus is assumed to be 100Mpa. We can see the edge pressure is much higher than the wafer center. Figure 5 and Figure 6 show a simulation of 300mm wafer surface pressure with a retaining ring. The wafer reference pressure is 1psi and the ring reference pressure is 4psi. Pad effective modulus is 100MPa. The ring width is 20mm, and the gap between ring and wafer is 4mm. We can see that the high pressure region is on the ring. Wafer edge pressure is tuned by the retaining ring, which is not as high as the edge pressure without the ring.

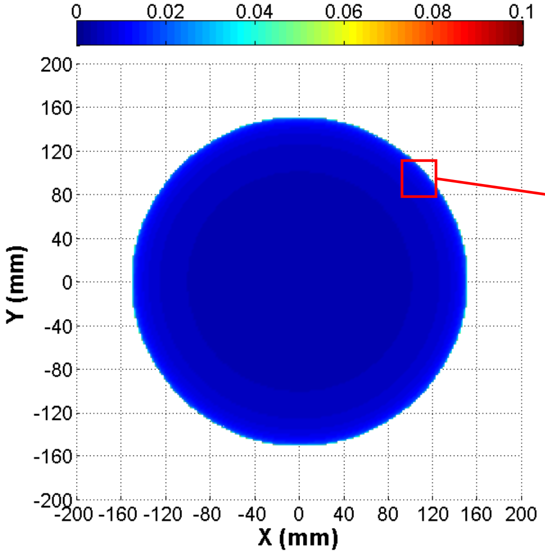

Figure 3: Pressure (MPa) distribution of 300mm wafer in CMP without retaining ring.

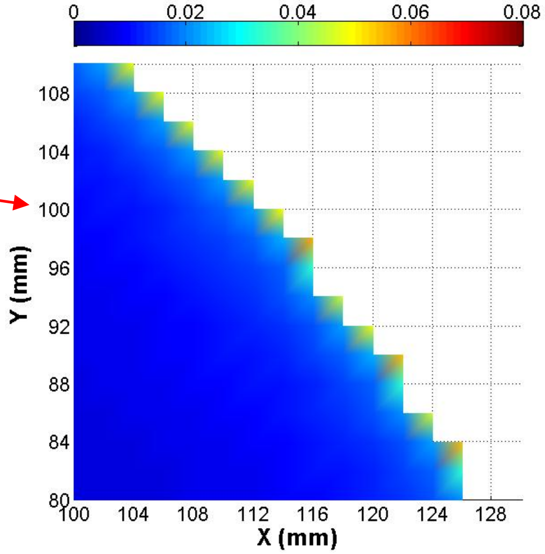

Figure 4: Pressure (MPa) distribution at wafer edge without retaining ring.

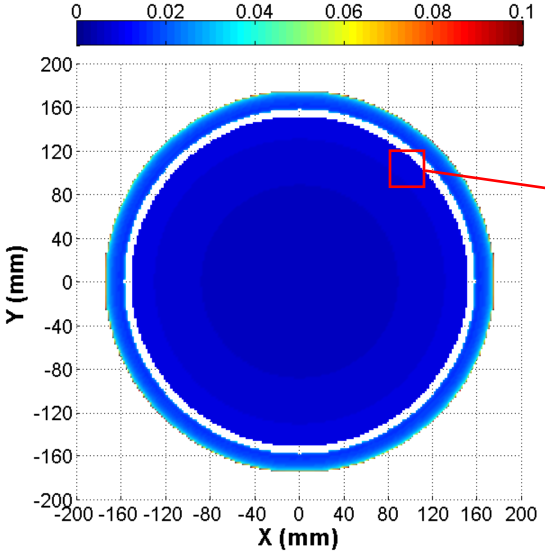

Figure 5: Pressure (MPa) distribution of 300mm wafer in CMP with a retaining ring.

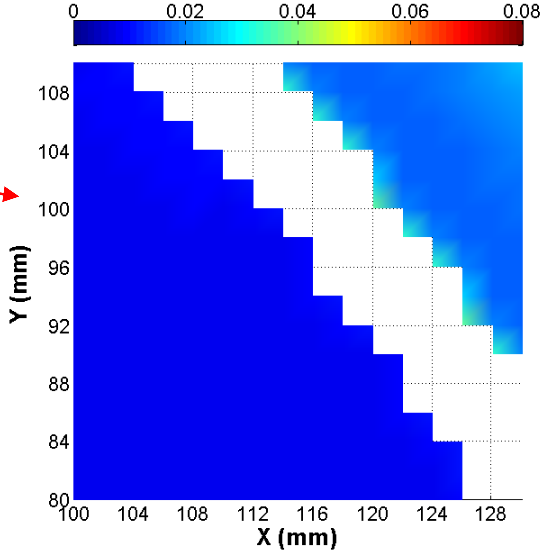

Figure 6: Pressure (MPa) distribution at wafer edge with a retaining ring.

Modeling of Relative Velocity

The velocity distribution is a function of the configuration of the CMP machine. Figure 7 shows the schematic view of a CMP machine and velocity distribution. Considering a point *p* on the wafer surface, the relative velocity of the wafer to the pad can be expressed in vector form as

$$\vec{V}(p) = \vec{\omega}_w \times \vec{r}_w - \vec{\omega}_p \times \vec{r}_p \qquad (4)$$

where $\vec{\omega}_w$ is wafer angular velocity and $\vec{\omega}_p$ is pad angular velocity. $\vec{r}_p$ and $\vec{r}_w$ are the distances between point *p* and the pad center *O'* and the wafer center *O* respectively. Using the offset vector $\vec{r}_0$ between the pad and wafer centers, Equation 4 can be written as

$$\vec{V}(p) = -\omega_p(\vec{k} \times \vec{r}_0) + (\omega_w - \omega_p)(\vec{k} \times \vec{r}_w) \qquad (5)$$

where $\vec{k}$ represents a unit vector in the Z direction perpendicular to the rotation plane.

Figure 8 shows a simulation result of 300mm wafer instantaneous velocity distribution. The rotation speeds of the pad and the wafer are 30rpm and 60rpm respectively. The offset distance between pad and wafer centers is 200mm.

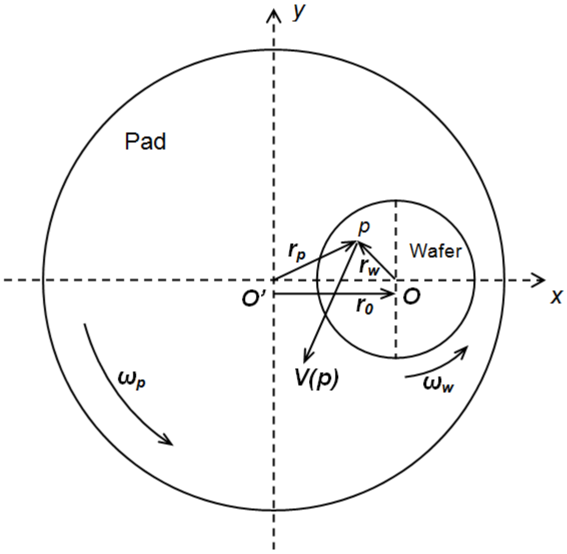

Figure 7: Top view of a CMP machine and velocity distribution.

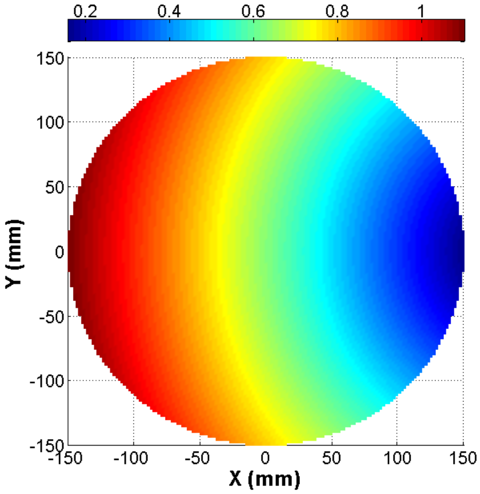

Figure 8: Instantaneous velocity (m/s) distribution of 300mm wafer.

Modeling of CMP Process

With pressure and velocity obtained from the two sections above, the model employs Preston's equation [5] to calculate the instantaneous material removal rate of wafer surface as follow:

$$\frac{dz(x,y)}{dt} = -K_p \cdot P(x,y) \cdot V(x,y) \qquad (6)$$

where K_p is the Preston coefficient and $V(x,y)$ is the relative velocity. Once the removal rate is calculated, the wafer surface can be dynamically updated in CMP simulation.

References

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