Modeling of Pattern Dependent Pressure Non-uniformity at Die-scale for an Integrated CMP model

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Contents

• Contact wear model and pattern density model
• FEM modeling
• Result and comparison with pattern density based oxide CMP model (MIT model)
• DOE tests with FEM model
• Future works
Contact wear model and pattern density model
Pattern density effect in CMP

ILD
METAL

high-density region
low-density region

Local planarization in low-density region
Local planarization in high-density region
Global step (global non-uniformity)

Ideal goal

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Contact wear model

\[ w(x, y) = \frac{(1 - v^2)}{\pi E} \int_{w} p(\xi, \eta) \frac{1}{\sqrt{(x - \xi)^2 + (y - \eta)^2}} \, d\xi \, d\eta \]

\[ P = \int_{w} p(\xi, \eta) \, d\xi \, d\eta \]

\[ w(x, y) = f(x, y) + c \quad \text{, } (x, y) \in w \]
\[ w(x, y) \neq f(x, y) + c \quad \text{, } (x, y) \notin w \]
\[ p(x, y) \geq 0 \quad \text{, } (x, y) \in w \]
\[ p(x, y) = 0 \quad \text{, } (x, y) \notin w \]

\[ \frac{\partial f(x, y, t)}{\partial t} = k(x, y) p(x, y, t) v(x, y, t) \]

\[ : \text{ Preston equation} \]

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( O.G. Chekina et al.
Pattern density dependent oxide model

Basic Form of Prestonian Model (empirical):

\[ MRR = K_e PV \]

Pattern density oxide model (semi-empirical):

\[ MRR = \frac{K}{\rho(x, y)} \]

Approximation of the local contact pressure:

\[ p(x, y) = \frac{K}{K_e V} \frac{1}{\rho(x, y)} = k \frac{1}{\rho(x, y)} \]

Accuracy: ~ a few hundred angstroms

Evaluation of Pattern Density

Shape of the window for local density evaluation and weighting function should be known

\[
\rho(x) = \sum \frac{up\_area}{2PL} = \frac{a_1 + a_2 + a_3 + a_4 + a_5 + a_6}{2PL}
\]
Elliptic weight function from pad deformation profile

\[ w(r) = \frac{4(1 - \gamma^2)qr}{\pi E} \int_0^{\frac{\pi}{2}} \sqrt{1 - \frac{r^2}{PL^2} \sin^2 \theta} \, d\theta \]

\[ PD_E = \sum_{i,j} \left( \frac{w(i, j) \times PD(i, j)}{\sum_{i,j} w(i, j)} \right) \]

Pattern

40um x 40um cell
Example of effective pattern density change with PL

PL=320um  PL=640um  PL=960um  PL=1280um

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Example of an effective pattern density map

Initial condition of pressure distribution for topography evolution

1/density

Low removal rate

High removal rate
FEM modeling
Difficulties with FEM modeling

\[
p(x, y) = \frac{K}{K_eV} \frac{1}{\rho(x, y)} = k \frac{1}{\rho(x, y)}
\]

But, p(x,y) can be calculated with FEM…

But, ~ 1E10 meshes for a 3D model,
~ 1E5 meshes for a 2D model

Pad thickness in ‘mm’s.

Die size in ‘cm’s.

Line width in ‘um’s.
Simplification

Real PAD:
- Random pore structure,
- Rough surface,
- Moving over pattern,
- Visco-elasticity

Static model with smooth pad surface without pore:
\[ E', v' = f(E, v, \text{Velocity}, \text{pore density}, \text{pore size} \ldots) \]
Test pattern design

Constant line width (25um)

Constant space (200um)
FEM Model

- Soft layer
- Hard layer

Test Pattern

# element (~100,000)
Contact stress in constant line width model

\[
h/l = 5.98
\]
Contact stress in constant space model

\[ h/l = 6.87 \]
Result and comparison with pattern density based oxide model
Effective density with elliptic weight function

Density map for const. LW pattern with 40um x 40um cells

Density map for const. space pattern with 40um x 40um cells

Shape of elliptic weight function
Density profile with weight function

Constant LW pattern:

Constant space pattern:

Effective pattern density with PL = 1mm:

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PL for the stress distribution from FEM

Density model

\[ p(x,y) = \frac{K}{K_e V} \frac{1}{\rho(x,y)} = k \frac{1}{\rho(x,y)} \]

Square sum error:

\[ \sum_{n=1}^{K} \left( \frac{b}{a \text{ density}(n)} - P(n) \right)^2 \]

PL:

PL value that minimize square sum error
Comparison with pattern density based oxide CMP model

**Constant line width pattern**

- Step weight function with square window
  - (PL = 0.4mm, square sum error = 1.41)

- Step weight function with circular window
  - (PL = 0.85mm, square sum error = 1.91)

- Elliptic weight function
  - (PL = 0.8mm, square sum error = 1.80)

**Constant space pattern**

- (PL = 0.1mm, square sum error = 9.47)

- (PL = 0.1mm, square sum error = 7.43)

- (PL = 0.2mm, square sum error = 8.41)
H/L ratio variation

Constant L/W pattern

Constant space pattern
Pad deformation profile

Constant LW pattern

Constant space pattern
DOE test with FEM model
Pressure effect and pad Poisson ratio effect

linear relation between overall pressure and local contact pressure

no significant effect of pad Poisson ratio
Pad stiffness effect

The stiffer the hard layer, the bigger the WIDNU

The stiffer the soft layer, the smaller the WIDNU

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Pad thickness effect

Constant line width pattern

Soft layer

Hard layer

Constant space pattern
### 2 Level full factorial DOE on FEM model

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- **Eh** = 174 ~ 406 MPa
- **Es** = 30 ~ 70 MPa
- **Th** = 1 ~ 1.6 mm
- **Ts** = 1 ~ 1.6 mm
Basic pad design rule from FEM

Interactions between factors:

Response surface model:

Basic design rule for a stacked CMP pad:

The stiffer the hard layer, the bigger the WIDNU
The thicker the hard layer, the smaller the WIDNU
The stiffer the soft layer, the smaller the WIDNU
The thicker the soft layer, the bigger the WIDNU
Conclusion

- Stress distribution from FEM model shows good correlation with the pattern density based oxide CMP model
- Window size for local contact stress evaluation is dependent on the pattern itself (especially, line space)
- FEM model shows that local contact pressure is dependent upon not only the pattern density but also line width and space
- Pad thickness also has to be considered in CMP modeling along with pad material properties