Oxide CMP

Numerical Study on Polishing Behavior during Oxide CMP (Chemical Mechanical Planarization)
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2004
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NOMENCLATURE

Roman Symbols

$C_c$ Cunningham correction to Stokes’ drag law
$C_D$ Drag coefficient
$F_D$ Drag force
$K_p$ Preston coefficient
M.R.R Material Removal Rate
$P$ Pressure
$R$ Removal rate
Re Reynolds number
$u, u_c$ Slurry velocity
$u_p$ Abrasive particle velocity
$V$ Local velocity
WIWNU within wafer non-uniformity

Greek Symbols

$\rho$ Slurry density
$\rho_p$ Abrasive particle density
$\sigma$ Normal stress
$\tau$ Shear stress
$\mu$ Molecular viscosity of the slurry
$\lambda$ molecular mean free path
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**Fig. 19** Removal rate of the TEOS wafer with pad (a) without groove and (b) with grooves

**Fig. 20** Removal rate and non-uniformity of the TEOS wafer when pad with and without groove is used
1. **CMP**

CMP: eccentric motion

(1) 

(2) Computational Fluid Dynamics

(3) Runnel

Multi-phase: abrasive particle

Lagrangian Model

Navier-Stokes

Discrete Phase Model

k-ε

ILD CMP

M.R.R

WIWNU
Fig. 1 Schematic of rotational CMP tool
2. CMP Modeling

2.1 Slurry model

\[
\frac{dz}{dt} = K \cdot \frac{N \cdot ds}{A \cdot dt}
\]

\[
R = K_p \cdot P \cdot V
\]

\[
\tau = \sigma \cdot k \cdot R
\]
\[ \dot{\rho} \nabla \rho = -\frac{1}{\rho} \nabla p + \frac{\mu}{\rho} \nabla^2 \rho \]

\[ \nabla \cdot \dot{\rho} = 0 \]

\( \sigma \) (normal stress), \( \tau \) (shear stress). Newton \( \dot{\rho} \) (mesh) 

Navier-Stokes Asperity contact Model, Mixed lubrication Model, Hydrodynamics lubrication Model. 

CMP Asperity contact Model, Mixed lubrication Model, Hydrodynamics lubrication Model. 

CMP (Fig.2). Asperity contact Model, Mixed lubrication Model, Slurry. 

Coppeta, Rodgers, Radzak. Slurry. 

(5). 

Hydrodynamic lubrication Model (abrasive particle). 

Hydrodynamic lubrication Model.
Fig. 2 Various generalized lubrication regime
2.2 Mathematical model

\[ \nabla \cdot V = 0 \]

\[ \rho \frac{DV}{Dt} = -\nabla p + \mu \nabla^2 V \]

(Cartesian Coordinate)

\[ \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \]

\[ \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = -\frac{1}{\rho} \frac{\partial p}{\partial x} + \nu \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) \]

\[ \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = -\frac{1}{\rho} \frac{\partial p}{\partial y} + \nu \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) \]
2.3 Discrete Phase Model

Discrete phase model

Lagrangian

\[
\frac{du_p}{dt} = F_D(u - u_p) + g_s\left(\rho_p - \rho\right)\rho_p + F_i
\]

\[
F_D = \frac{18\mu C_D \text{Re}}{\rho_p D_p^2 24}
\]

\[
\text{Re} = \frac{\rho D_p |u_p - u|}{\mu}
\]

\[F_D(u - u_p);\]

\[u;\]

\[u_p;\]

\[\mu;\]
\[ F_D = \frac{18\mu}{D_p^2\rho_p C_c} \]

\[ C_c = 1 + \frac{2\lambda}{D_p} \left[ 1.257 + 0.4 \exp\left(-1.1 \left( \frac{D_p}{2\lambda} \right) \right) \right] \]

\( \rho \): 
\( \rho_p \): 
\( D_p \): 
\( C_D \): 

1 \( \mu \)m \( \lambda \) Stokes’s drag 

\( C_c \): Conningham correction to Stokes’ drag law

\( \lambda \): 

\( \rho \): 
\( \rho_p \): 
\( D_p \): 
\( C_D \):
Fig. 3 Schematic view of pad with groove
3.1 概要

FVM (finite volume method) および CMP で、Navier-Stokes 方程式を解く。mesh size は 2, 3, 4 の 3 サイズを用いる。k-ε モデルを用いて、上風向き (upwind) による SIMPLE メソッドを用いる。Re の値は、50 から 500 の範囲を用いる (Fig.4, 5)。 SIMPLE メソッドは、10% の条件で使用される。

12,000 から 14,400 の間で変動、3 サイズで 100,000 から 373,296 の間で変動、(8) の場合など、

0.6 m/s の場合など、

0.6 m/s の場合、2

0.6 m/s の場合、3

0.6 m/s の場合、3.14 rad/s (30 rpm) の場合、

3.14 rad/s (30 rpm) の場合、

3.14 rad/s (30 rpm) の場合。
**Fig. 4** Schematic diagram of groove and micro holes

**Fig. 5** Micro-pores on conventional pad
0.22 kg/m•sec  1069 kg/m$^3$  1.7 g/cm$^3$  135 nm

3.2 CMP

Fig. 6  Fig. 7  Fig. 8  Fig. 9

Logitech PM5 CMP-Polisher

rpm, 6.5 psi  110 ml/min

HS-1200, Hanhwa oxide slurry, Korea

PECVD; Plasma Enhanced Chemical Vapor Deposition

TEOS; Tetra Ethyl Ortho Silicate

(2×2cm$^2$)

Rodel IC1400(K-)

Nanometrics, AFT Model 200
Fig. 6 Schematic diagram of CMP process

Fig. 7 Picture of CMP tool
4. 현재 실험 결과

4.1 254 및 381 μm

Fig. 8. 254 및 381 μm의 실험 결과를 보여 주는 그림. IC1400 및 K-게이트를 사용한 실험을 진행한 결과, 254 μm 및 381 μm의 두께를 가지는 플라스마를 생성할 수 있었다. 50 μm의 두께로도 실험을 수행할 수 있었다. [4].

Fig. 9(a) 및 (b)는 254 μm 및 381 μm의 두께를 가진 플라스마의 형상을 보여 주는 그림이다. [4]

Fig. 10(a) 및 (b)는 streamline 및 groove의 형상을 보여 주는 그림이다. groove의 형상을 보여 주는 Fig 10(b)의 그림이다.
**Fig. 8** Computational 2D geometry and grids between wafer and pad (a) without groove and (b) with groove.
Fig. 9 Concentrations of distributed abrasive particles in the pad (a) without groove and (b) with groove in 2D
Fig. 10 Streamlines in the pad (a) without groove and (b) with groove in 2D
Fig. 11 Velocity Vector distribution without groove in 2D
Fig. 12 Velocity Vector distribution with groove in 2D
Fig. 11. 2\(\frac{1}{2}\) \(\text{grad} \) (gradient) \(\text{grad} \). Fig. 12. Groove \(\theta\) \(\text{grad} \). Fig. 10. \(\text{grad} \) \(\theta\) \(\text{grad} \). Fig. 12(b) \(\theta\) \(\text{grad} \). Fig. 13(a) (b) \(\theta\) \(\text{grad} \). Fig. 14 \(\theta\) \(\text{grad} \). 

(gradient) \(\theta\) \(\text{grad} \). 

(gradient) \(\theta\) \(\text{grad} \). 

\(\text{grad} \) \(\theta\) \(\text{grad} \). 

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\(\text{grad} \) \(\theta\) \(\text{grad} \). 

\(\text{grad} \) \(\theta\) \(\text{grad} \). 

750 Pa. 

\(\text{grad} \) \(\theta\) \(\text{grad} \). 

\(\text{grad} \) \(\theta\) \(\text{grad} \). 

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\(\text{grad} \) \(\theta\) \(\text{grad} \).
Fig. 13 Distribution of relative static pressure of the wafer surface on the pad (a) without groove and (b) with groove in 2D
Fig. 14 Distribution of shear stress on the wafer surface on the pad (a) without groove and (b) with groove in 2D
4.2 3

Fig. 15(a) (b) 3

µm . 2

Fig. 16(a) (b) 2

µm . 2

Fig. 17

µm.
Fig. 15 Computational 3D geometry and grids between the wafer and pad (a) without groove and (b) with grooves
Fig. 16 Distribution of relative static pressure of the wafer surface on the pad (a) without groove and (b) with groove at 3D geometry
Fig. 17 Distribution of shear stress on the wafer surface on the pad (a) without groove and (b) with groove at 3D geometry
4.3 Definition of M.R.R and WIWNU

- **M.R.R** (Material Removal Rate)
- **WIWNU**

Fig. 18

- **M.R.R**
- **WIWNU**

Fig. 19

K-åé¿ì°¡ IC1400 °ú 2,440 Å/min

Fig. 20

K-åé¿ì°¡, 2,440 Å/min

Fig. 18 Definition of M.R.R and WIWNU
Fig. 19 Removal rate of the TEOS wafer with pad (a) without groove and (b) with grooves
Fig. 20 Removal rate and non-uniformity of the TEOS wafer when pads with and without grooves are used
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Abstract

Numerical Study on Polishing Behavior during Oxide CMP

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In this paper, slurry fluid motion, abrasive particle motion, and roles of groove patterns on the pads are numerically investigated in the 2D and 3D geometries. The simulation results are analyzed in terms of experimental removal rate and WIWNU (within wafer non-uniformity) for ILD (inter level dielectric) CMP process. Numerical investigations reveal that the grooves in the pad behave as uniform distributor of abrasive particles and enhance the removal rate by increasing shear stress. Higher removal rate and desirable uniformity are numerically and experimentally observed at the pad with grooves. Numerical analysis is very well matched with experimental results and helpful for understanding polishing mechanism and local physics.