Semi-Empirical Modeling of Removal Rate Distribution in Copper CMP Process

LMAS

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Objectives

- Development of a semi-empirical MRR distribution (SE-MRRD) model for copper CMP process.
- Consider the effect of machine design and consumable properties.
- Use the data gathered from process set-up.
- One machine-One model.
- Prediction of Within Wafer Non-Uniformity (WIWNU).
- More practical and flexible model than the physical CMP models.
- Statistical and physical approach on experimentally gathered average MRR distributions.
- Provide the information on MRR distribution for developing CMP simulator.
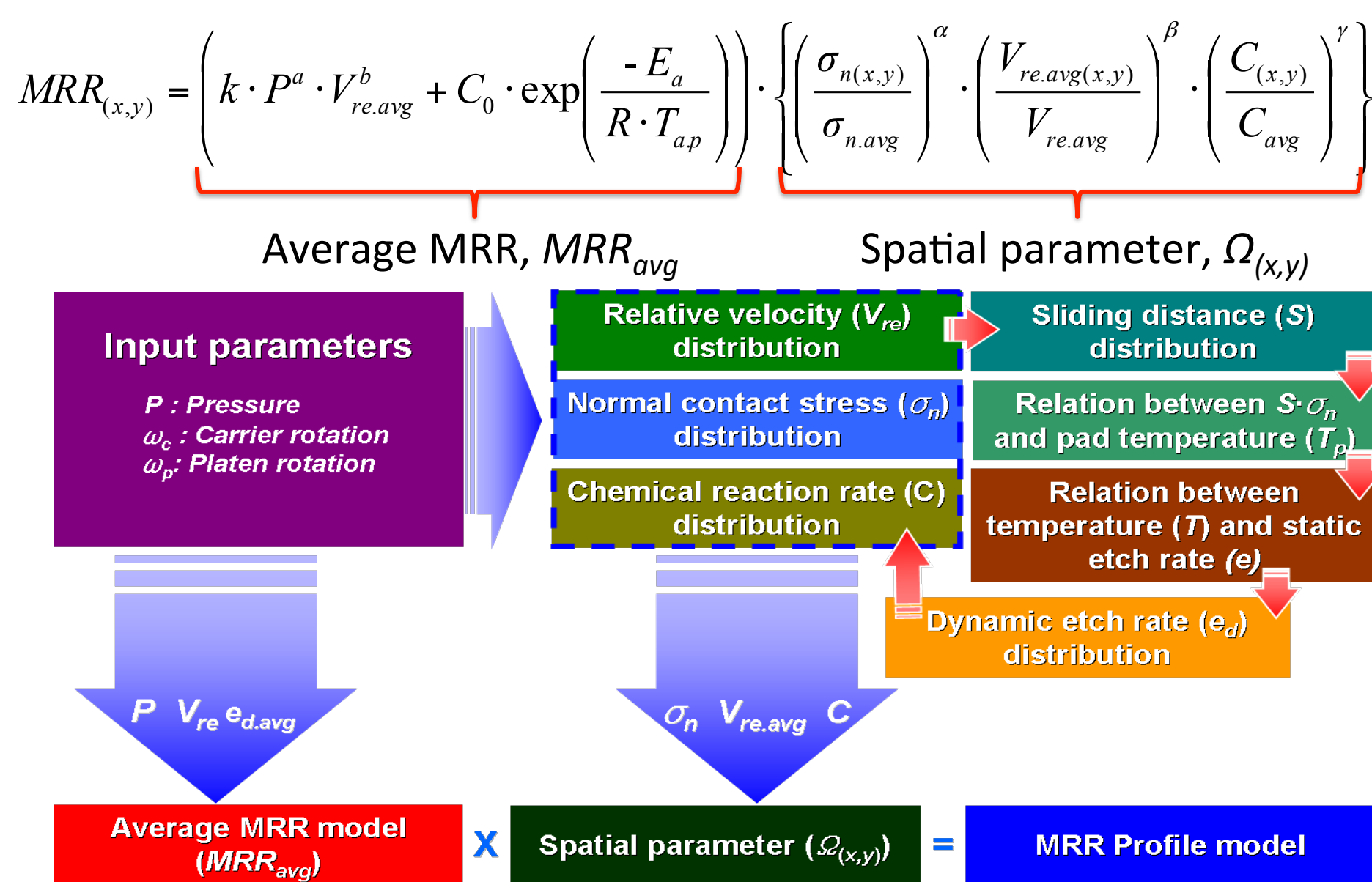
Introduction

- Uniformity of material removal rate (MRR) originates from "Spatial Distribution" of process variables.

$T(r,\theta)$: temperature distribution or chemical reaction distribution — Kinematical analysis / Finite Element Analysis / Experimental data

$S(r,\theta)$: sliding distance or velocity distribution — Kinematical analysis

$P(r,\theta)$: pressure or stress distribution — Finite Element Analysis

$MRR(r,\theta)$: removal rate distribution
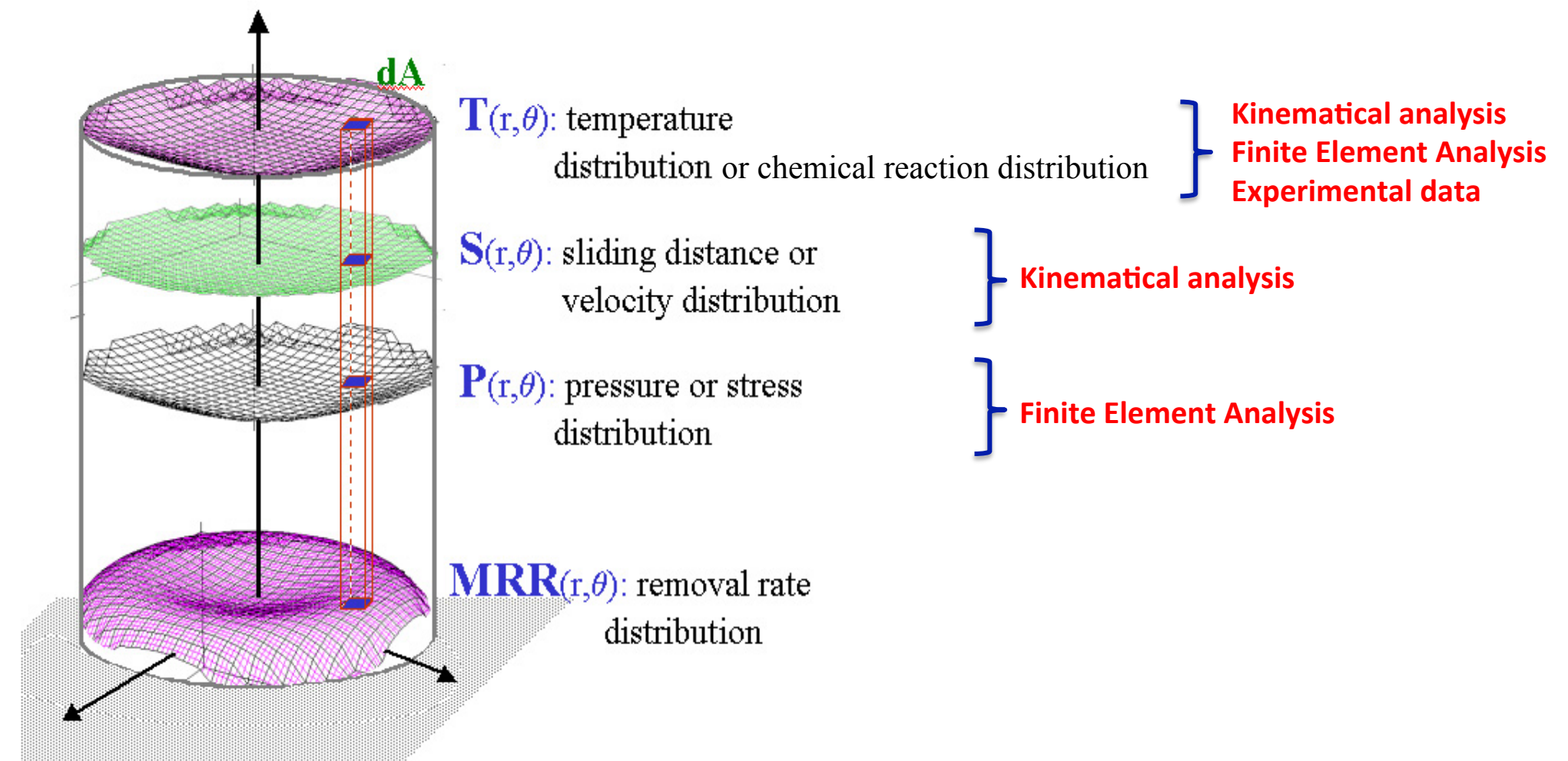
Kim and Jeong, Journal of ELECTRONIC MATERIALS, Vol. 33, No. 1, 2004

SE-MRRD Modeling

- MRR distribution model

$$MRR_{(x,y)} = \left(k \cdot P^a \cdot V_{re.avg}^b + C_0 \cdot \exp\left(\frac{-E_a}{R \cdot T_{ap}}\right) \right) \cdot \left\{ \left(\frac{\sigma_{n(x,y)}}{\sigma_{n.avg}}\right)^\alpha \cdot \left(\frac{V_{re.avg(x,y)}}{V_{re.avg}}\right)^\beta \cdot \left(\frac{C_{(x,y)}}{C_{avg}}\right)^\gamma \right\}$$

Average MRR, MRR_{avg} Spatial parameter, $\Omega_{(x,y)}$

Input parameters
P : Pressure
ω_c : Carrier rotation
ω_p : Platen rotation

- Relative velocity (V_{re}) distribution
- Normal contact stress (σ_n) distribution
- Chemical reaction rate (C) distribution
- Sliding distance (S) distribution
- Relation between $S \cdot \sigma_n$ and pad temperature (T_p)
- Relation between temperature (T) and static etch rate (e)
- Dynamic etch rate (e_d) distribution

P V_{re} $e_{d.avg}$ σ_n $V_{re.avg}$ C

Average MRR model (MRR_{avg}) X **Spatial parameter ($\Omega_{(x,y)}$)** = **MRR Profile model**

Experimental Setup

- Experimental setup for copper CMP

IR camera / Pressure (P) / Carrier / Slurry / Wafer / Pad / Platen / ω_c / ω_p / CMP machine / IR thermal imaging camera / Polishing head / Carrier / Polishing pad / Slurry nozzle

Parameters	Conditions
Pressure and rotation of carrier and platen (Pressure / Carrier / Platen)	20.68 kPa / 40~120 rpm / 80 rpm (fixed) 20.68 kPa / 80 rpm (fixed) / 40~120 rpm 20.68 kPa / 40 rpm/40 rpm 20.68 kPa / 120 rpm /120 rpm 13.79 kPa~27.58 kPa / 80 rpm / 80 rpm
Process time	60 seconds
Polishing pad	IC1000/SUBA400 stacked pad (Nitta Haas Inc.)
Slurry	H_2O_2 based colloidal silica slurry (10 nm of mean abrasive diameter, pH 7.2)
Slurry flow rate	150 ml/min

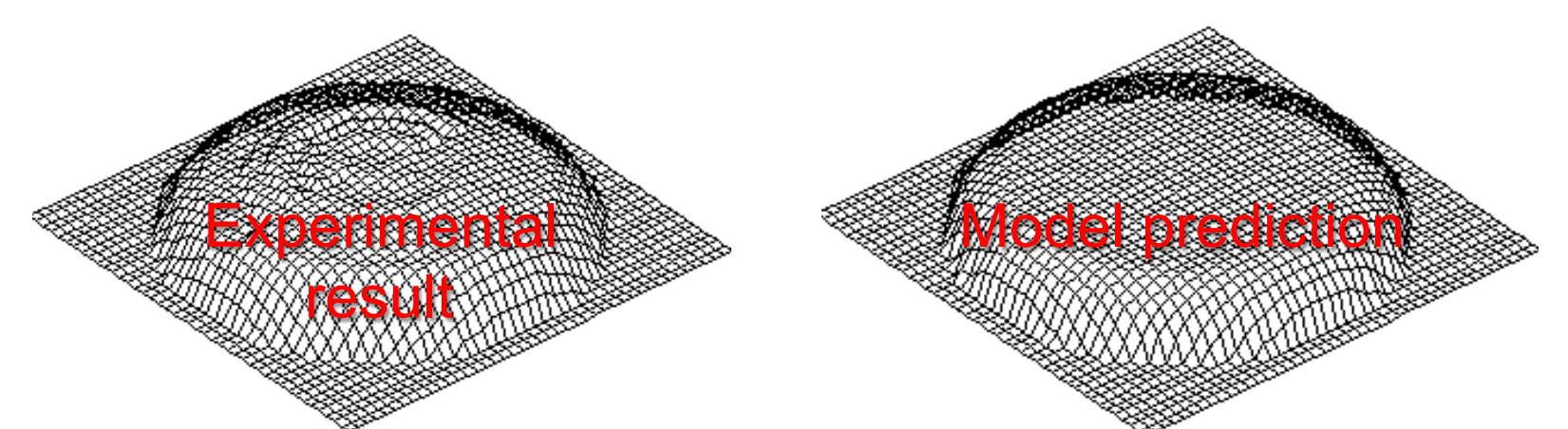## Results (I) - Blanket Wafer

- Experimental Result and Model Prediction
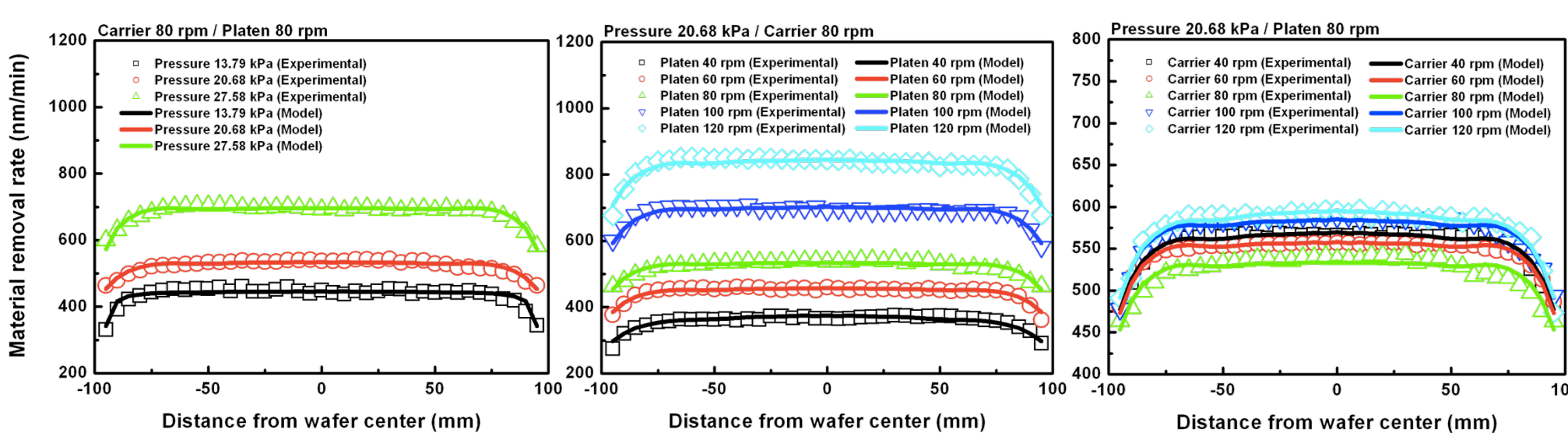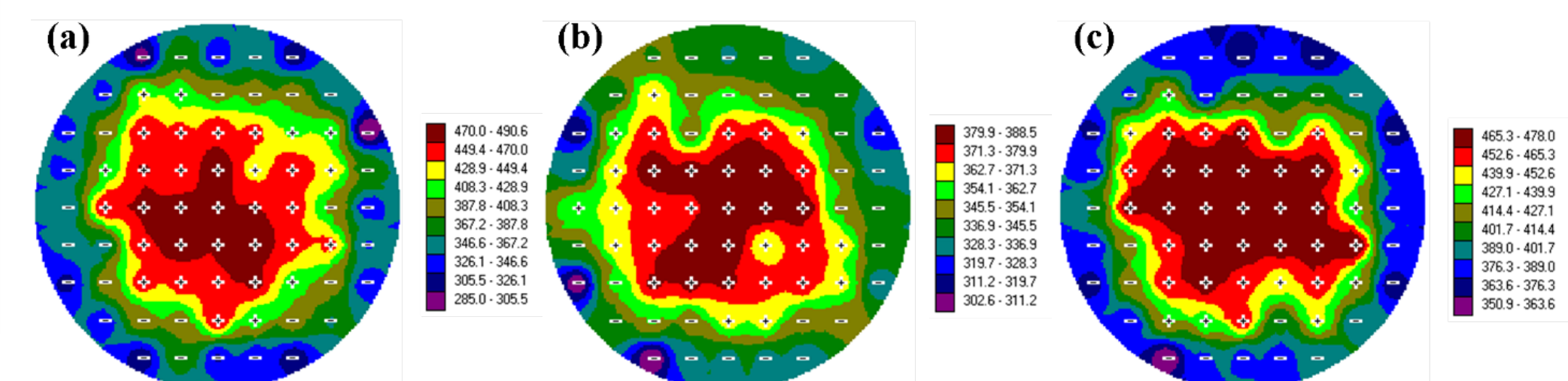

- Modeling of Within Wafer Non-Uniformity (WIWNU)

27.58 kPa   34.47 kPa
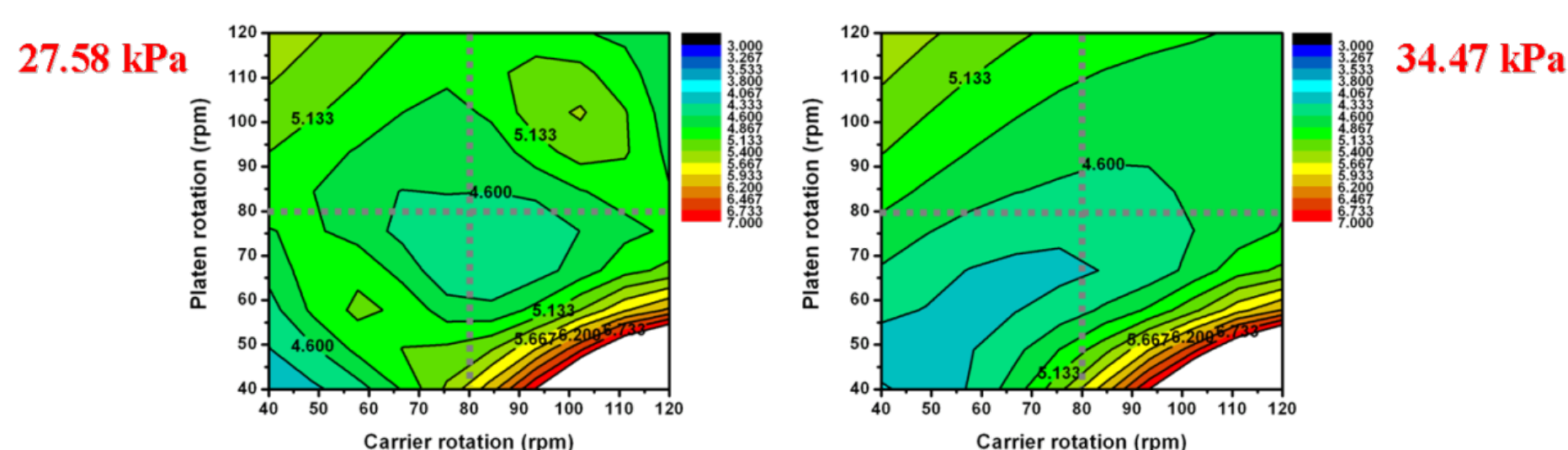
Results (II) - Patterned Wafer

- Prediction of 3D-MRR Distribution in Blanket Wafer

Experimental result   Model prediction

- Step Height Reduction Rate Profile of Patterned Wafer

(a) 10% Density, (b) 50% Density, and (c) 90% Density after CMP for 30 sec. (3psi/H80P80rpm)

(a)   (b)   (c)

Conclusions

- MRR distribution in copper CMP could be expressed with the combination of normalized stress distribution, velocity distribution, and chemical reaction rate distribution (spatial parameter, $\Omega_{(x,y)}$).
- α, β and γ in the spatial parameter are 2.24, -0.526 and 0.349, respectively. It is important to control the normal contact stress in copper CMP process.
- The R-squared statistic indicates that the model as fitted explains 81.1% of variability in experimental data.
- The SE-MRRD model will facilitate process optimization and provide information that can contribute to the development of a wafer-scale CMP simulator.

Future Works

- Further modification of SE-MRRD model.
- Characterization of MRR distributions in copper CMP and SiO_2 CMP.
- Prediction of MRR distribution in 450 mm wafer CMP.

SiO_2 CMP results

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