DuPont Electronics & Imaging

July 11, 2018

Molecular Design of CMP Consumables for Advanced (≤ 10nm) Processing Technology

CMPUG 2018

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Fellow

Molecular Design of CMP Consumables for Advanced (≤ 10nm) Processing Technology

1) Evolutionary growth of CMP process steps (>10nm)

2) Polymer molecular design at appropriate length scale for technology

3) Microtexture & grooving customizable for each CMP process

Molecular Design of CMP Consumables for Advanced (≤ 10nm) Processing Technology

Evolutionary growth of CMP process steps (>10nm)

- > 10nm technology; more of the same & improved process control
- ≤ 10nm technology; growth of “unique” process & unprecedented process control

Polymer molecular design at appropriate length scale for technology

Microtexture & grooving customizable for each CMP process

Evolutionary Growth in CMP Processing Layers

HP Logic

Number of CMP Process							
19							10-11 Cu
18							Co IM (3)
17							HM (4-12)
16						10-13 Cu (*)	W Plugs
15						Co IM (0-2)	W-TS
14						HM (2-6)	Co-TS
13					8-12 Cu (*)	W Plugs	HM
12					HM (2-4)	W-TS	SAC2
11					W-Plugs	SAC2	SAC1
10					W-TS	SAC1	Co Gate
9					SAC	W Gate	HM
8					W-Gate	HM	POP
7				9-10 Cu (*)	HM	POP	ILD0
6			9-10 Cu	W-Plugs	POP	ILD0	Gate Poly
5		7-8 Cu	W	W-TS	ILD0	Gate Poly	III-V
4	7-8 Cu	W	Al / W Gate	Al/W Gate	Gate Poly	SiGe	SiGe
3	W	Al Gate	POP	POP	HM	HM	HM
2	ILD	ILD	ILD	ILD	STI2	STI2	STI2
1	STI	STI	STI	STI	STI1	STI1	STI1
# CMP Layer	10	12	14	15	18-25	24-30	25- 34
Technology Node	65nm Planar	45nm HKMG	28nm HKMG	20nm HKMG	16/14/10nm FinFETs	7nm FinFETs	5nm GAA

(*) Co/TaN barrier in IM

High Performance Logic

> 10nm more of the same

≤ 10nm unique materials

≤ 10nm process control

≤ 10nm wafer edge

Memory

Number of CMP Process						
16						Cu (X)
15						W via (X)
14						W
13			ILD		Cu (X)	W (X)
12		ILD	Cu (X)		W via (X)	W (X)
11		Cu	W via (X)		W	HM (X)
10		W via (X)	TiN		W (X)	ILD4
9	Cu	TiN	ILD4		ILD3	ILD3
8	W via (X)	ILD4	ILD3	Cu	SoP (X)	SoP (X)
7	W	ILD3	W (X)	W (X)	Poly (X)	Poly (X)
6	ILD3	W (X)	ILD2	ILD	SoN (X)	SoN (X)
5	Ox Buff (X)	ILD2	HM Buff (X)	W	HM Buff (X)	HM Buff (X)
4	ILD2	Poly	Poly	ILD	ILD2	ILD2
3	Poly	ILD1	ILD1	Poly	ILD1	ILD1
2	ILD1	Ox Buff	Ox Buff	Ox Buff (X)	Ox Buff (X)	Ox Buff (X)
1	STI	STI	STI	STI	STI	STI
# CMP Layer	10	14	17	10	14-26	17-32
Node Technology	3Xnm DRAM	2Xnm DRAM	1Xnm DRAM	2X - 1Xnm Planar NAND	3D 32-36L NAND	3D 48-64L NAND

DRAM

> 2Xnm more of the same

≤ 2Xnm process control

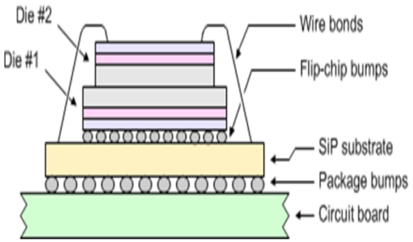
NAND

> 3D/32 more of the same

≤ 3D/32 process control

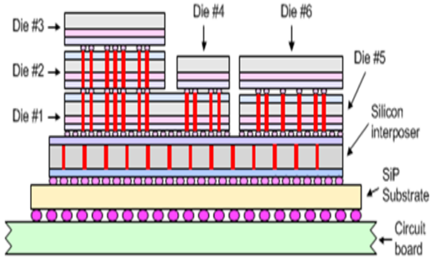
IoT drives CMP into packaging

Conventional Packaging



- No CMP

Adv. Packaging, 3D DRAM



- 2 – 4 Layers CMP
- TSV
- Wafer Thinning

CMP Process Control (≤ 10nm)

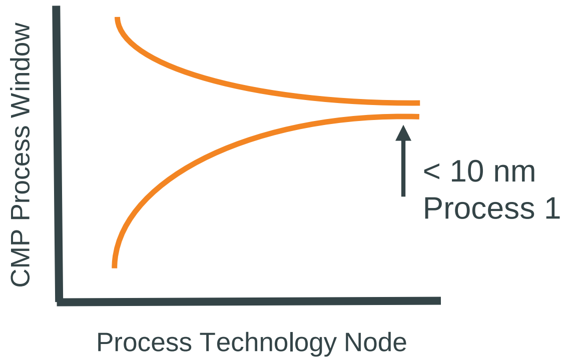
Molecular Design

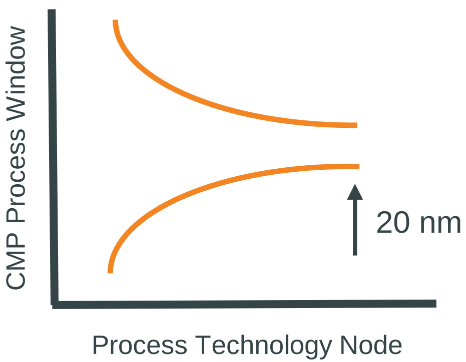
+

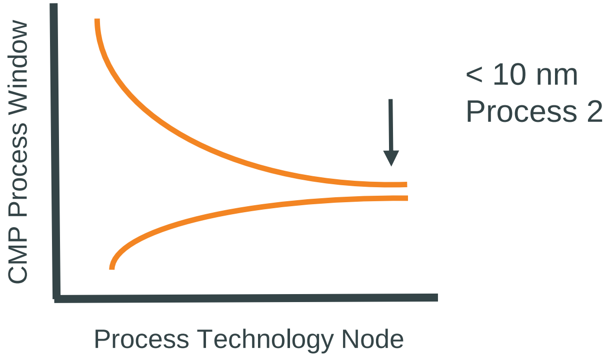
Micron Scale Texture

+

Macro Scale Groove







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Evolutionary growth of CMP process steps (>10nm)

Polymer molecular design at appropriate length scale for technology

- Hardness replaced by understanding of molecular structure
- SAXS determination of CMP pad process entitlement

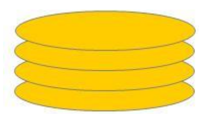
Microtexture & grooving customizable for each CMP process

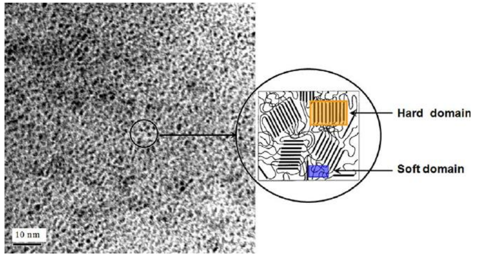
Polyurethane Polymer Chemistry 101

Discovered in 1920s by Otto Bayer;

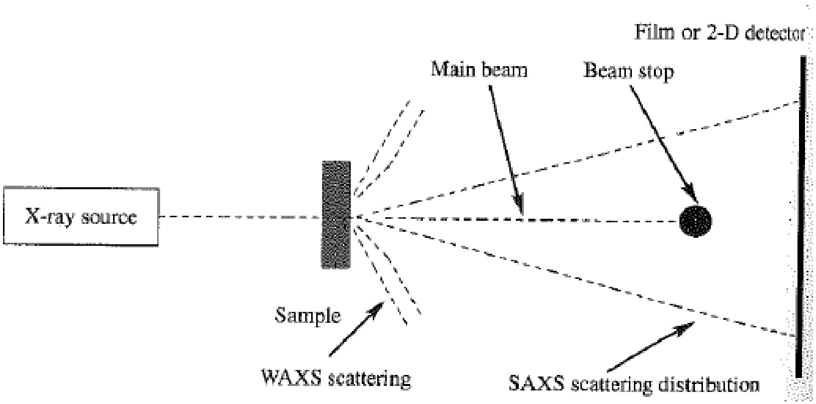
- hard segment (diisocyanate, diamines, and short-chain diols)
- soft segment (polyols)

Component A
Component B
Component C
→ Reaction → Product





Small-Angle X-Ray Scattering (SAXS)

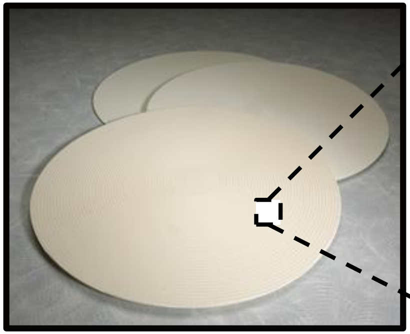


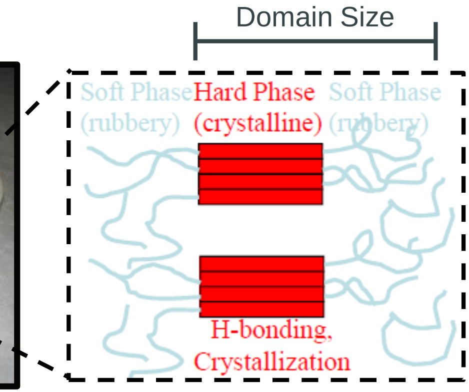
SAXS directs a beam of X-rays at a sample and measures the scattering caused by X-ray interactions with the electron clouds of the sample material

Scattering is collected on a 2-D detector and can be converted to a 1-D intensity vs. scattering angle (Q) plot

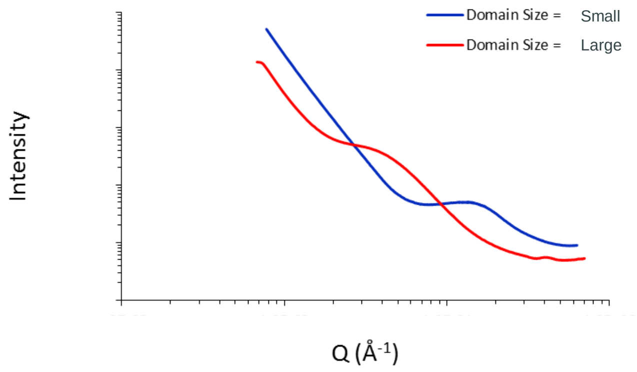
Polyurethane CMP pads are made of alternating hard and soft phase segments

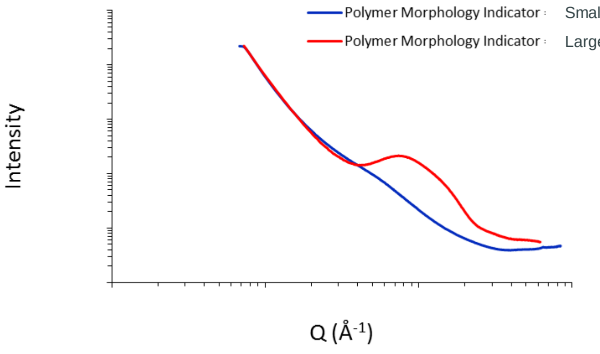
Structure in the sample is identifiable in 1-D SAXS patterns through the appearance of a Bragg peak

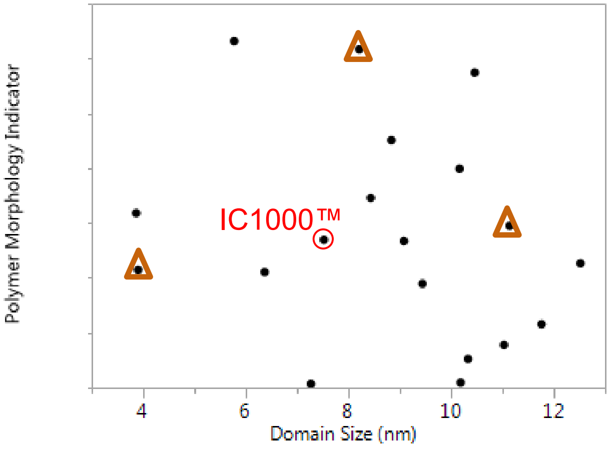




Nanoscale Details from SAXS Data







Above plots detail differences in azimuthally-averaged 1-D SAXS patterns for large and small domain sizes (top left) and high and low polymer morphology indicators (top right)

Plot on left shows proprietary Dow® X-ray scattering analysis from industry-leading CMP pad formulations

Δ Similar hardness to IC 1000™

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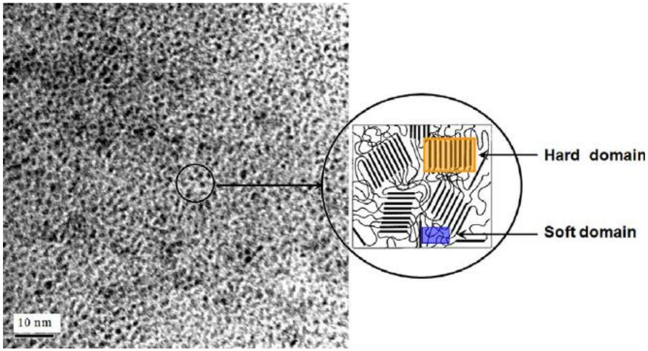
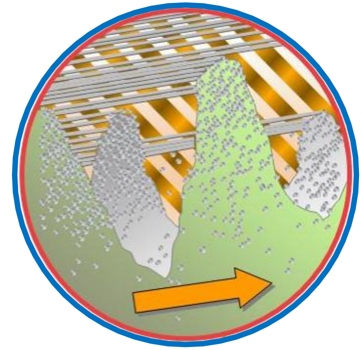
Microtexture & grooving customizable for each CMP process

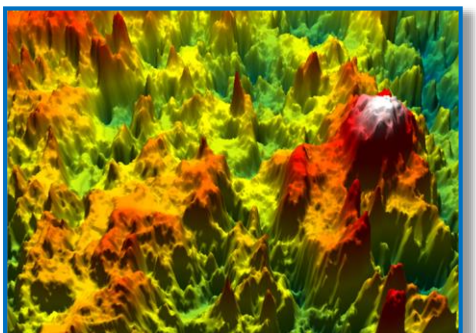
- Conditioning produced texture specific to process (pad, slurry)
- Upwards of 1,200 groove design models potentially required
- Hydrodynamic models expedite optimized solution
- Particle size interaction

Molecular Design Across All Length Scales





Mechanisms of CMP Material Removal, Defect Formation and Pad Wear



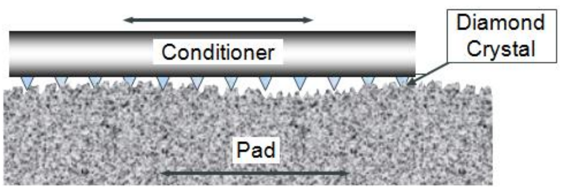
Pad Texture Formation, Characteristics and modeling

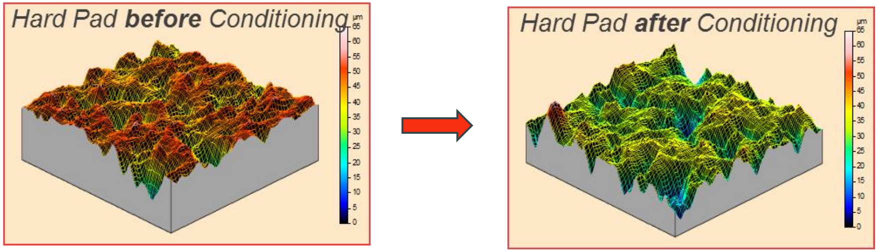
Slurry Flow Dynamics at Wafer, Groove and Texture Scale

Optimizing Capability & Uniformity via Micro-Texture

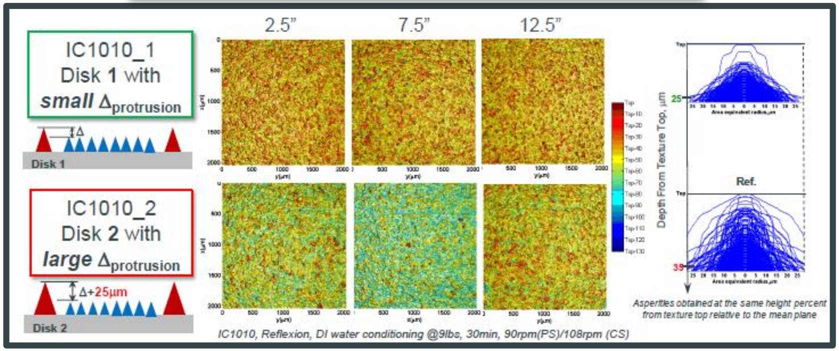
Advanced characterization capabilities enable precise quantification:

- Pad micro-texture morphology, uniformity and consistency throughout lifetime
- Conditioning disk diamond uniformity and wear characteristics

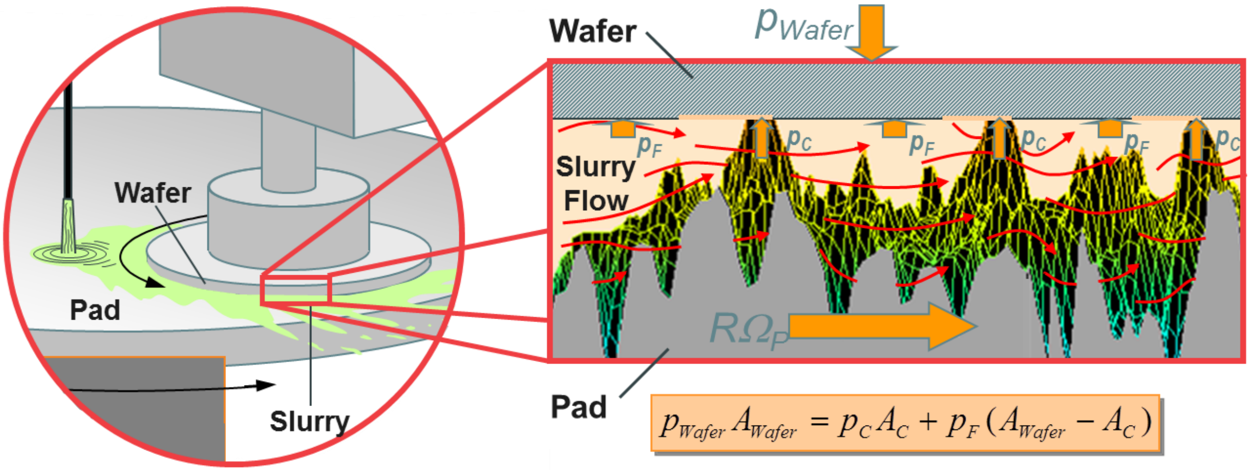




Parameters to improve texture variation



Slurry Hydrodynamics and Pad-Wafer Contact



$$p_{Wafer} A_{Wafer} = p_C A_C + p_F (A_{Wafer} - A_C)$$

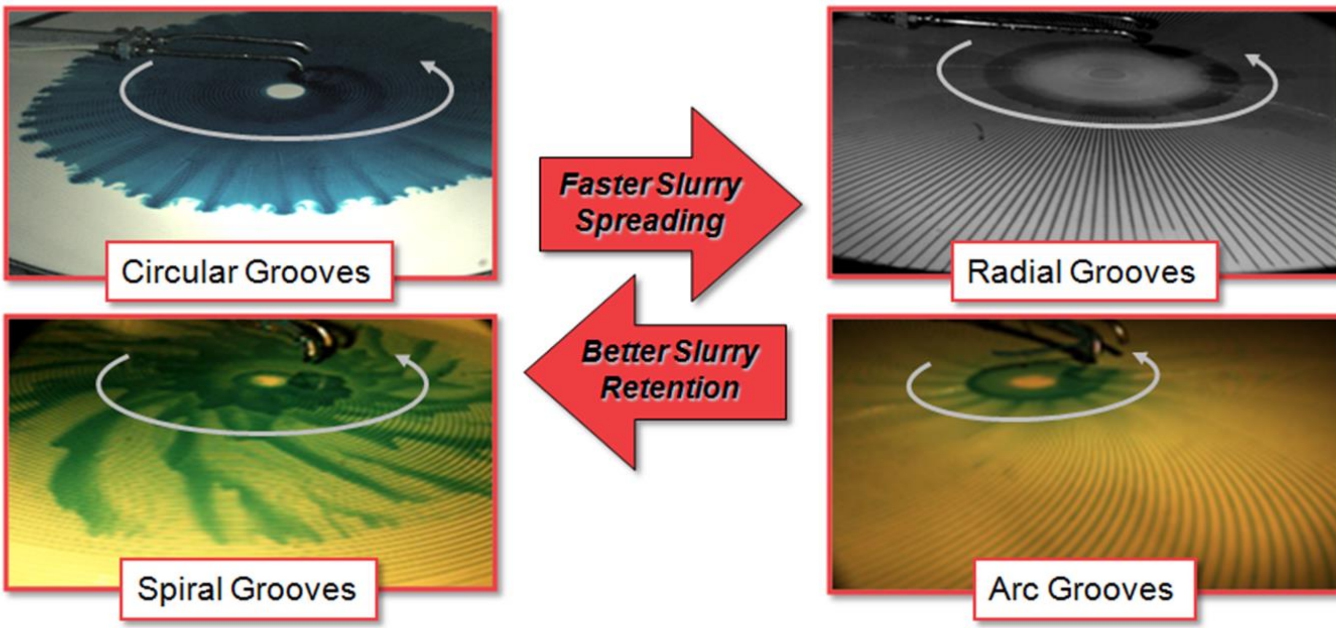
Elevation of wafer above pad is determined by force balances

- Applied polish pressure (pWafer) acts downward
- Contact pressure of asperities (pC) acts upward, at contact points
- Fluid pressure of flowing slurry (pF) acts upward, everywhere else
- Wafer elevation on pad equilibrates where forces sum to zero
- Wafer elevation determines pad-wafer contact and peak stresses

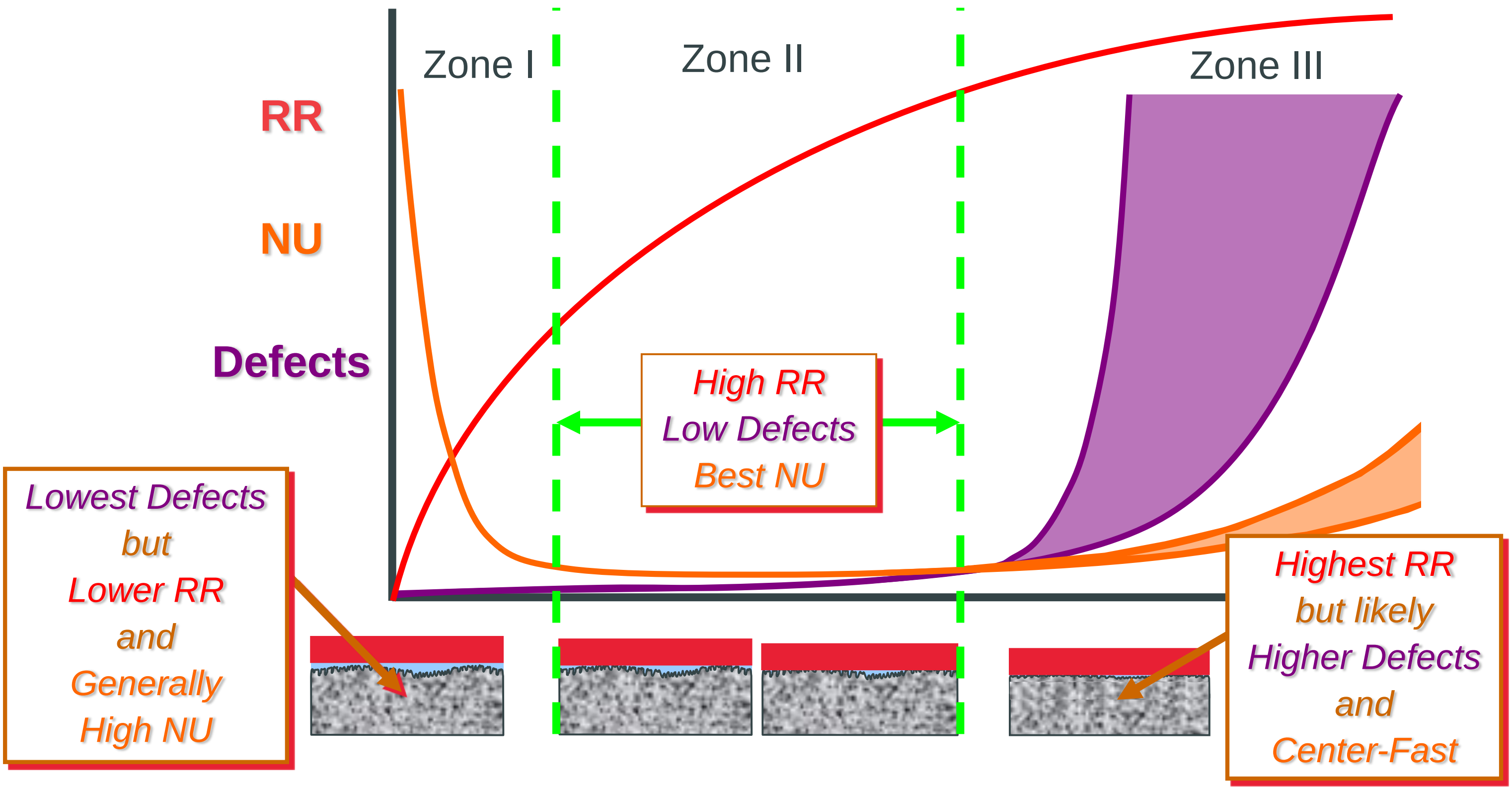
> 1,200 Groove designs & model for optimization

Optimal groove design enables full entitlement

- Stability of process control
- Slurry minimization
- Defect reduction

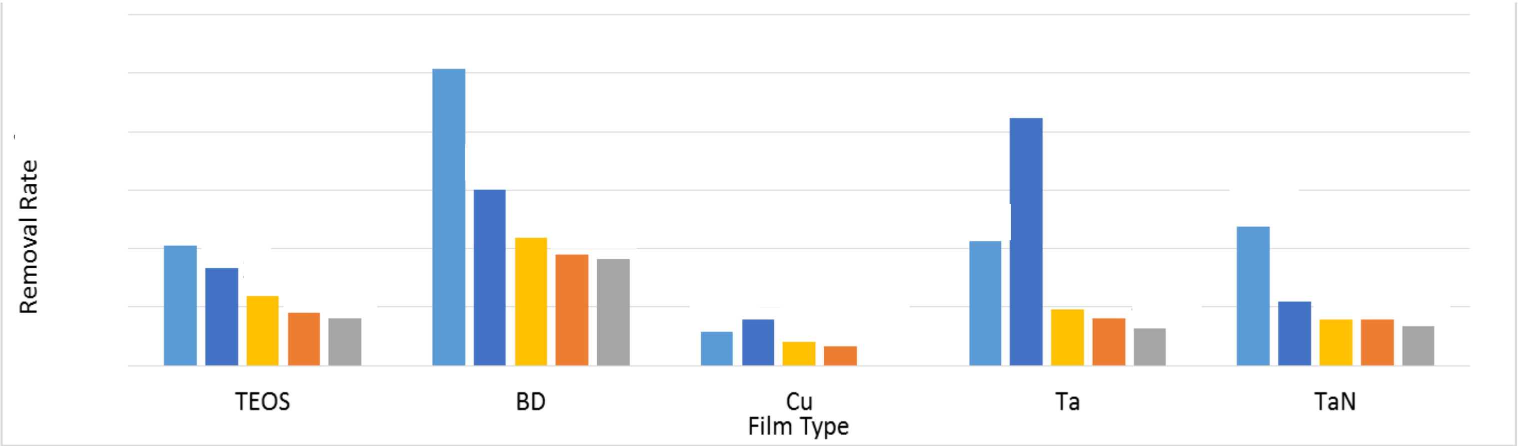


Implications of Hydrodynamic State on CMP Metrics



Optimal hydrodynamic regime balances ALL critical CMP metrics

Particle Size Interaction



- Same Exp. pad, same conditioning recipe, different nano-particle (slurry optimized)
- Nano-particle size range from 20 to 150 nm, aspect ratio from 1 to 2
- > 100% RR difference

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Acknowledgements

DuPont Electronics & Imaging

CMP Technologies R&D

- Applications R&D Team
- Pad R&D Team
- Slurry R&D Team

Thank You