ROUGHNESS HEIGHTS MODEL FOR CMP CHIP SCALE SIMULATION

27th CMP Users Meeting, Dresden, 14.10.2011

Sascha Bott[1], Boris Vasilev[1], Johann W. Bartha[2]

[1] Fraunhofer Center Nanoelectronic Technologies CNT
[2] Dresden University of Technology / IHM
Dresden, Germany

sascha.bott@cnt.fraunhofer.de

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AGENDA

- Motivation for CMP characterization, modeling and simulation
- Modeling approach chip and feature level
- Long scale effects on chip level
  - Global heights model
- Short scale effects on feature and chip level
  - Extended Greenwood-Williamson model
- Roughness heights model
- Pad stack experiments
- Summary and outlook

sascha.bott@cnt.fraunhofer.de

Motivation for CMP characterization, modeling and simulation

- CMP process characterization strategy in semiconductor industry

New process set-up (consumables, polish parameters)

→ Pre-CMP measurements (Thickness, Profiler, AFM)

→ Planarization experiments with **CMP test wafers** (height evolutions)

→ Post-CMP measurements (Thickness, Profiler, AFM)

→ Data extraction

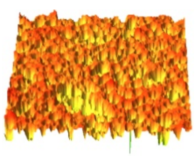
→ Model calibration

→ Model application on product chip

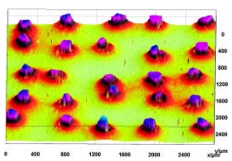
→ Process optimization

→ Design optimization (DfM)

pressure, velocity, …



pad,



conditioner, …

Source: Kahng, Samadi, IEEE Trans. Comput.-Aided Des. Integr. Circuits Syst., **27**, 3 (2008)

dummy strategies, design rules

high throughput, high yield, low running costs

low initial costs, short time to market, wide portfolio

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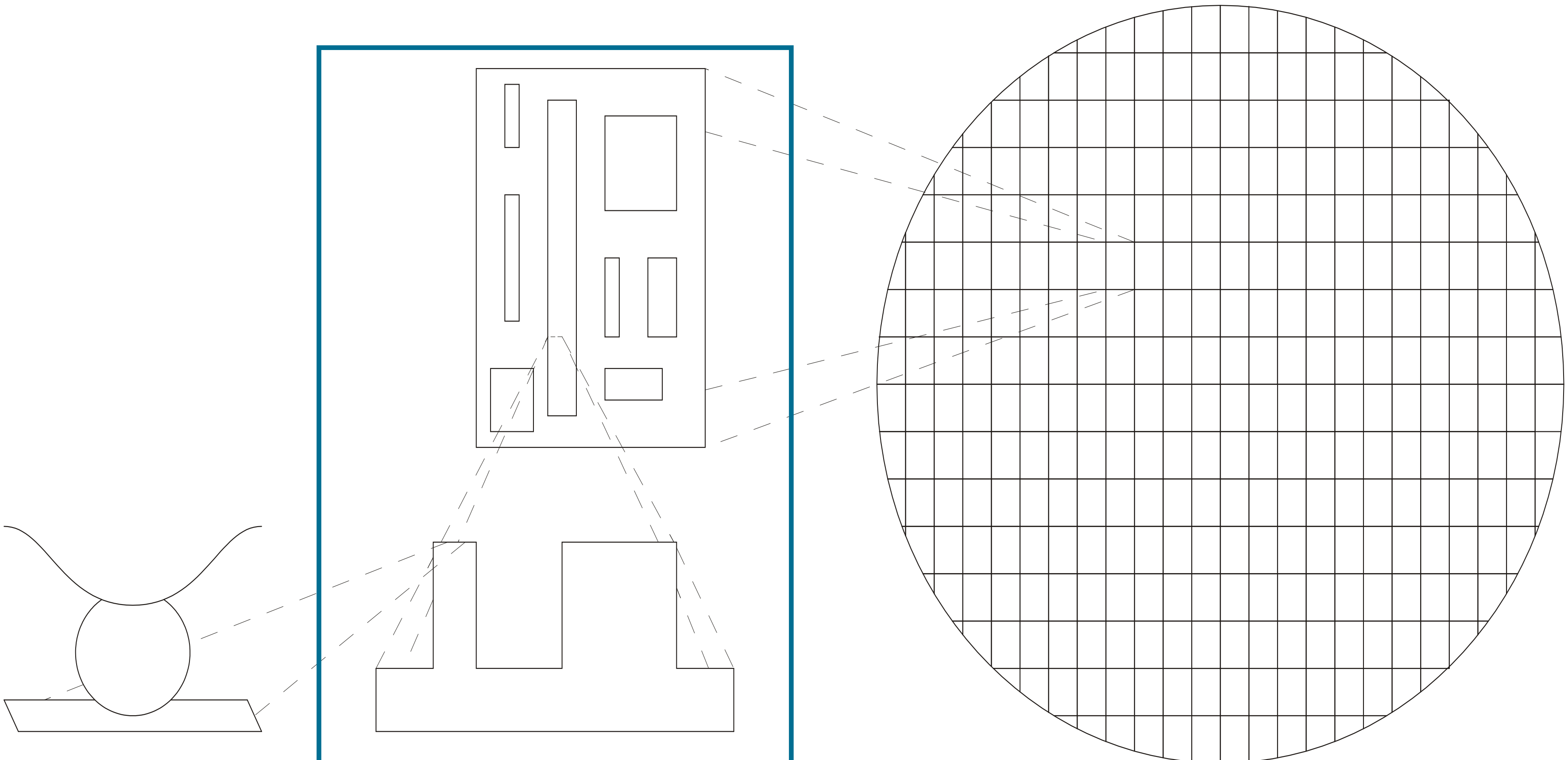
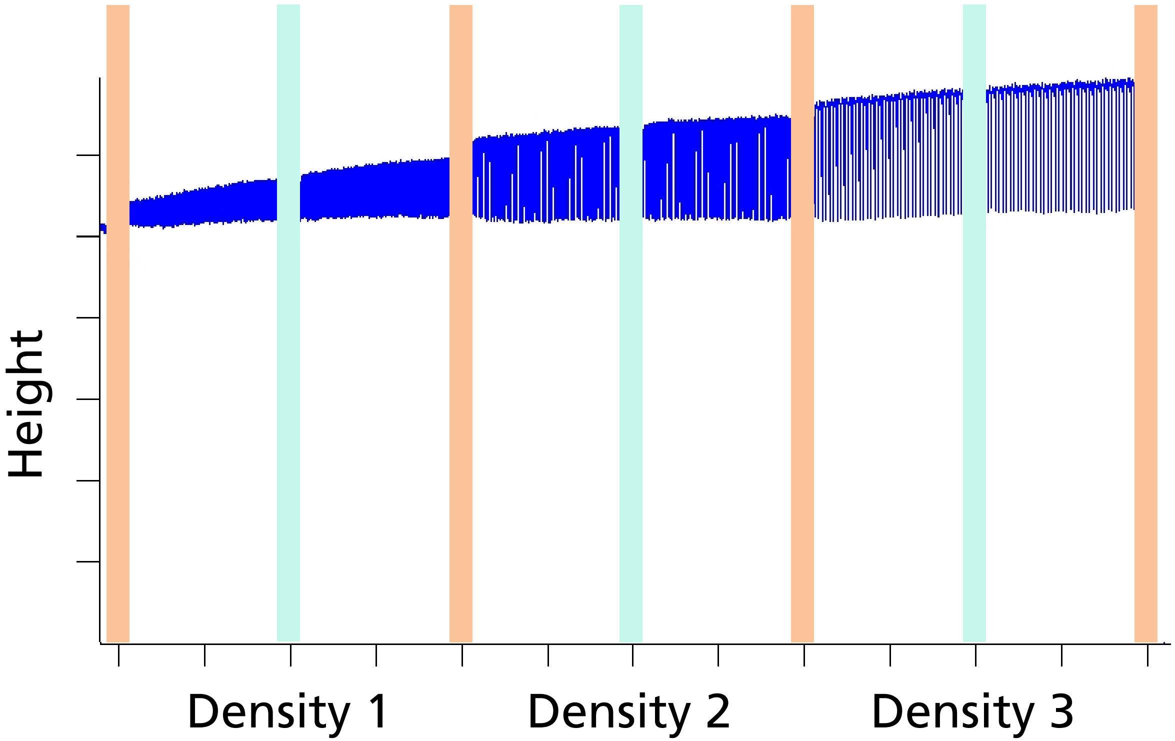
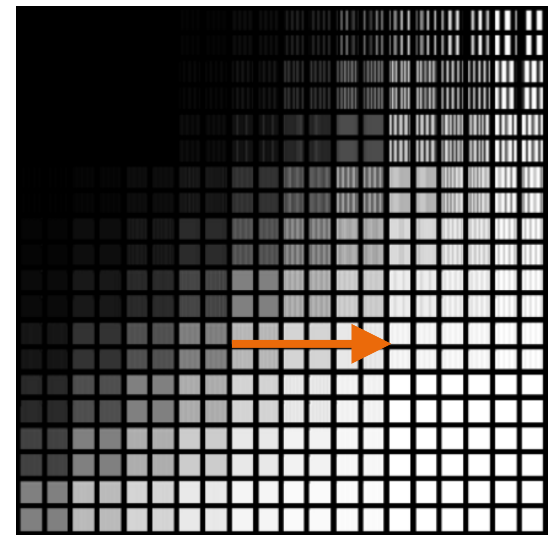
Modeling approach chip and feature level



Long scale effects on chip level



CNT/IHM test chip



- Profiler scan along test chip showing long range interaction
- Planarization time 60 s

→ Model for long range interaction is needed, Global heights model

Bott, S.; Rzehak, R.; Vasilev, B.; Kuecher, P. & Bartha, J. W.: A CMP Model Including Global Distribution of Pressure
IEEE TRANSACTIONS ON SEMICONDUCTOR MANUFACTURING, **2011**, *24*, 304-314

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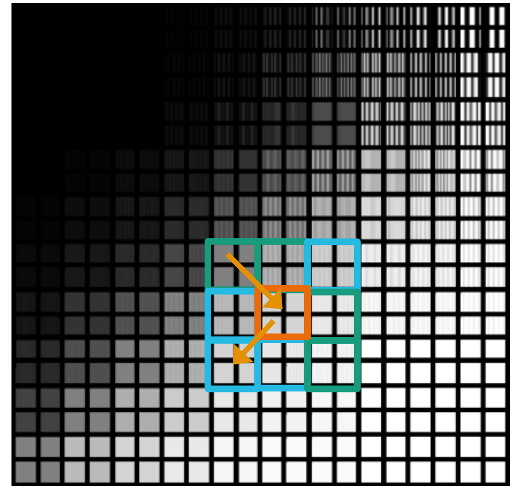
Global heights model

- Long range pressure distribution

$$P_\rho = P + \Delta P_\rho$$

pressure on a density patch in test chip | *nominal pressure* | *redistributed pressure*



pressure distribution schematic

Global heights model

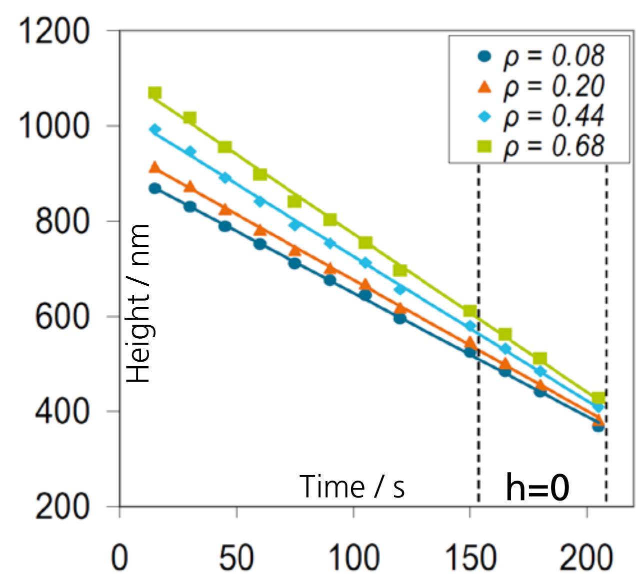
$$p(x) = \left(\frac{E}{D} (z(x) - \langle z \rangle_C) + \langle P \rangle_C \right) \chi_C(x)$$

local pressure | *local height* | *mean height of contact* | *mean contact pressure*

until global planarization $\Delta P_\rho \neq 0$

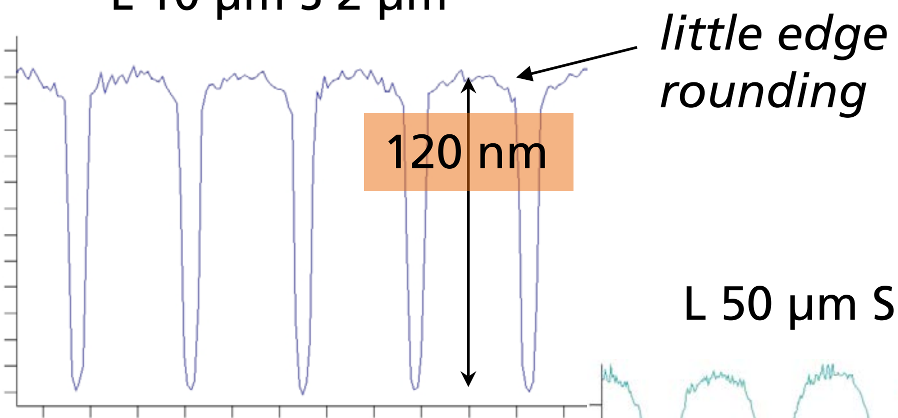
- Better description of the process physics by
  - Height incorporation
  - Use of *layout* density
  - Continuous reevaluation of force balance

mean heights evolution

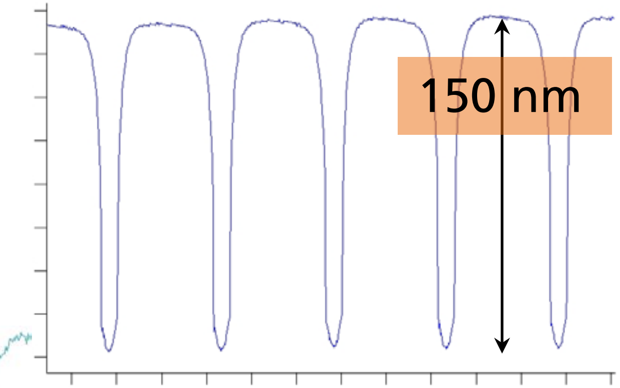


Short scale effects on feature and chip level

L 10 µm S 2 µm

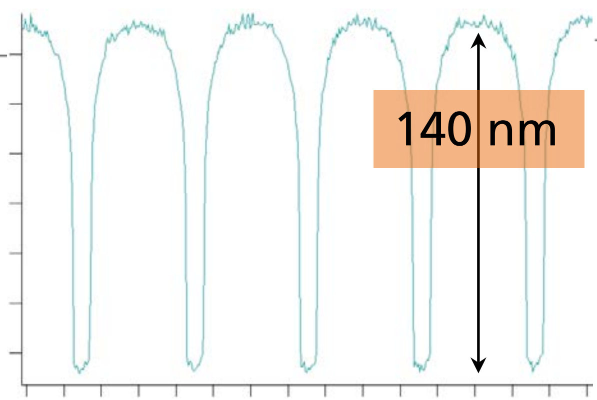


L 100 µm S 20 µm



- Density 83.3 %
- Planarization time 60 s

L 50 µm S 10 µm



→ Model for short range effects, Extended Greenwood-Williamson Model

Vasilev, B.; Rzehak, R.; Bott, S.; Kuecher, P. & Bartha, J. W.: Greenwood–Williamson Model Combining Pattern-Density and Pattern-Size Effects in CMP *IEEE TRANSACTIONS ON SEMICONDUCTOR MANUFACTURING*, **2011**, *24*, 338-347

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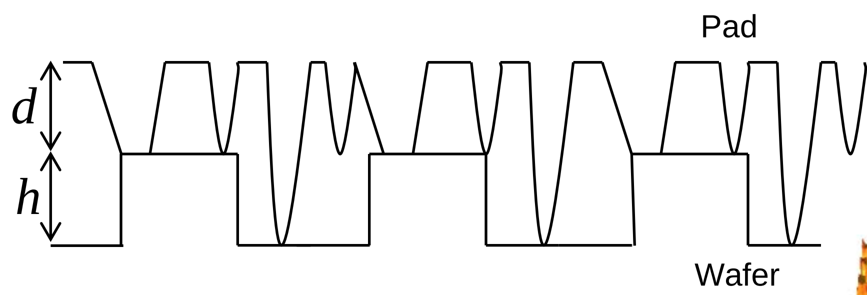
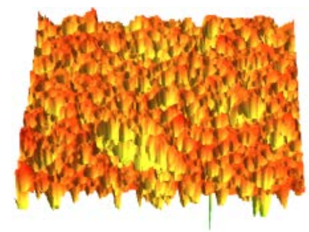
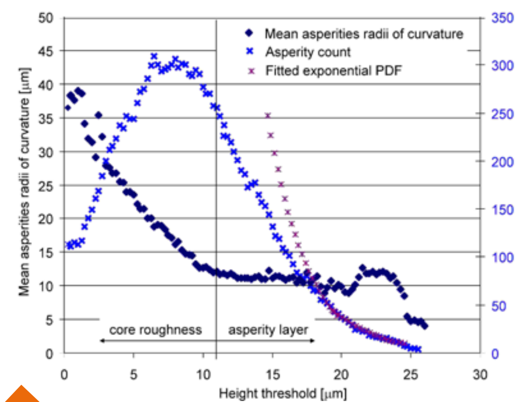
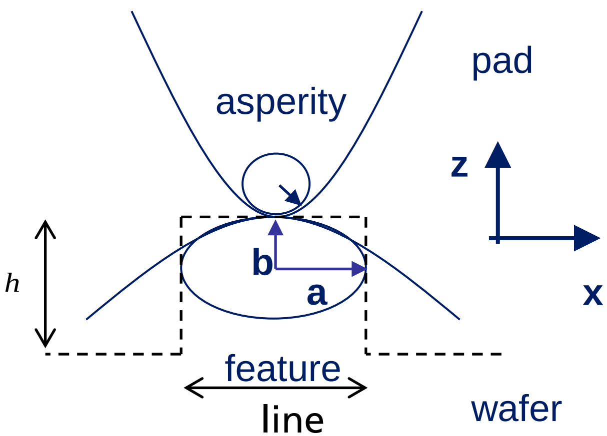
Extended Greenwood-Williamson model



Pad characterization







Feature curvature

Asperity curvature

Asperity number distribution

Asperity height distribution

$$\kappa_{eff} = \kappa_{Asperity} + \kappa_{feature} = \frac{1}{R_{asperity}} + \frac{4\alpha h}{line\ width^2}$$

Effective curvature

$$F^{UP} = \frac{4}{3}\rho_{eff} \quad E^* \frac{1}{\sqrt{\kappa_{eff,UP}}} \quad N\int_{d}^{\infty}(z-d)^{3/2} \quad \phi(z)dz$$

$$F^{DOWN} = \frac{4}{3}(1-\rho_{eff})E^* \frac{1}{\sqrt{\kappa_{eff,DOWN}}} \quad N\int_{d+h}^{\infty}(z-d-h)^{3/2}\phi(z)dz$$

- Better description of the process physics by
    - Greenwood-Williamson theory
    - Extracted pad roughness parameters
    - Consideration of feature size and shape

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Roughness heights model

Combination of Extended Greenwood-Williamson GW and Global heights GH model

- Continuous long range pressure distribution from GH model
- Pad roughness incorporation from GW model
- Feature size and shape from GW model
- Layout density and local height information from GH model
- Fast calculation from GW model, similar to Standard density model (MIT, etc.)

→ Improved simulation of local heights and steps as well as global steps

sascha.bott@cnt.fraunhofer.de

Pad stack experiments

Aim

- obtain more information about the interaction length – IL – parameter
- show the influence of the pad parameters D (thickness), E (Young's modulus) and pad stack

Experiments

- Process parameters
  - p – 20 kPa
  - Table speed – 63 rpm, carrier speed – 62 rpm
  - Conditioner – 62 rpm, in situ 100 %
  - Klebosol 30N50 (colloidal silica slurry)
- 3 pad stacks
  - Pad A (D_1, E_1), Pad B ($D_2 > D_1$, E_2), Pad C ($D_3 = 2\ D_2$, E_2)

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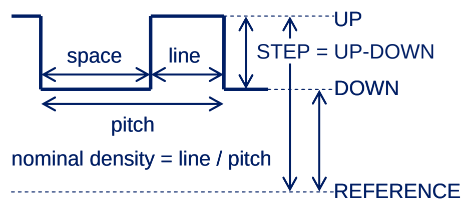
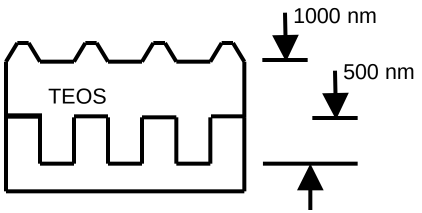
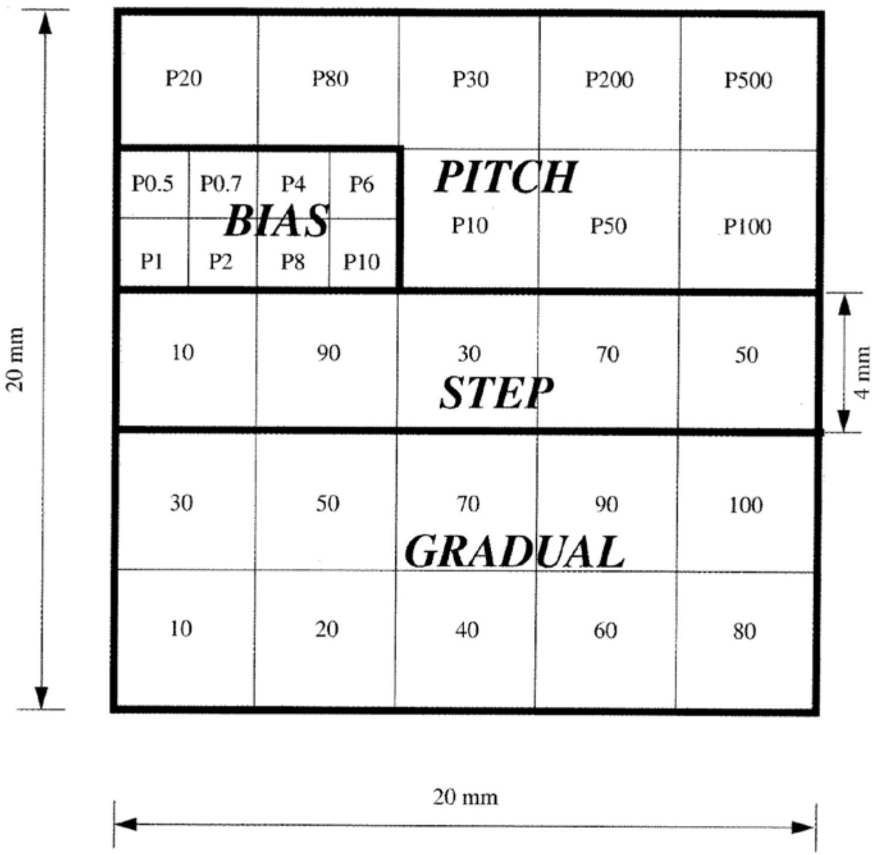
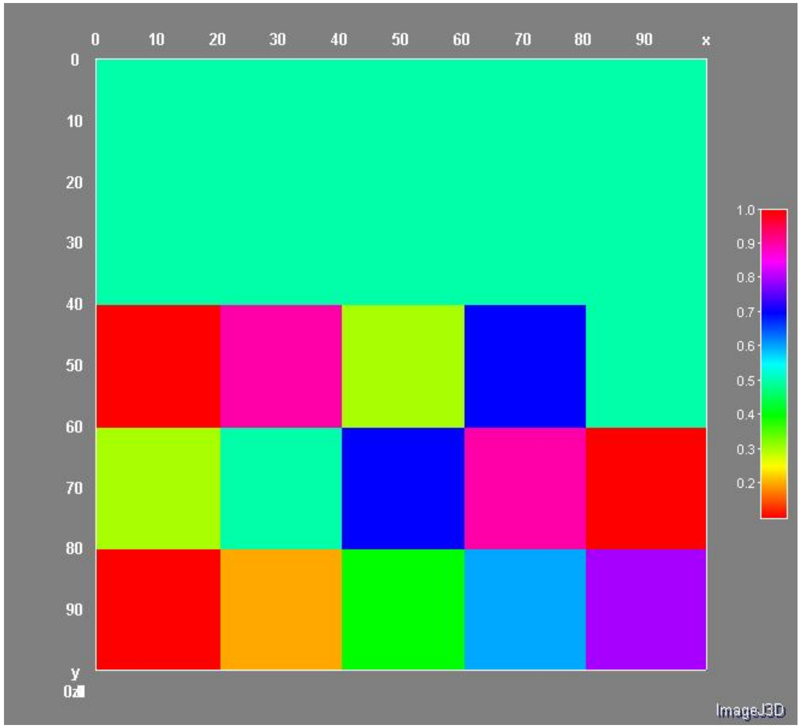
Pad stack experiments

Silyb test chip









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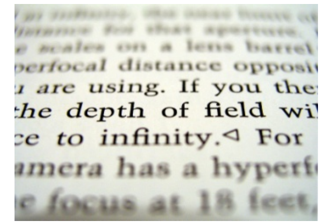
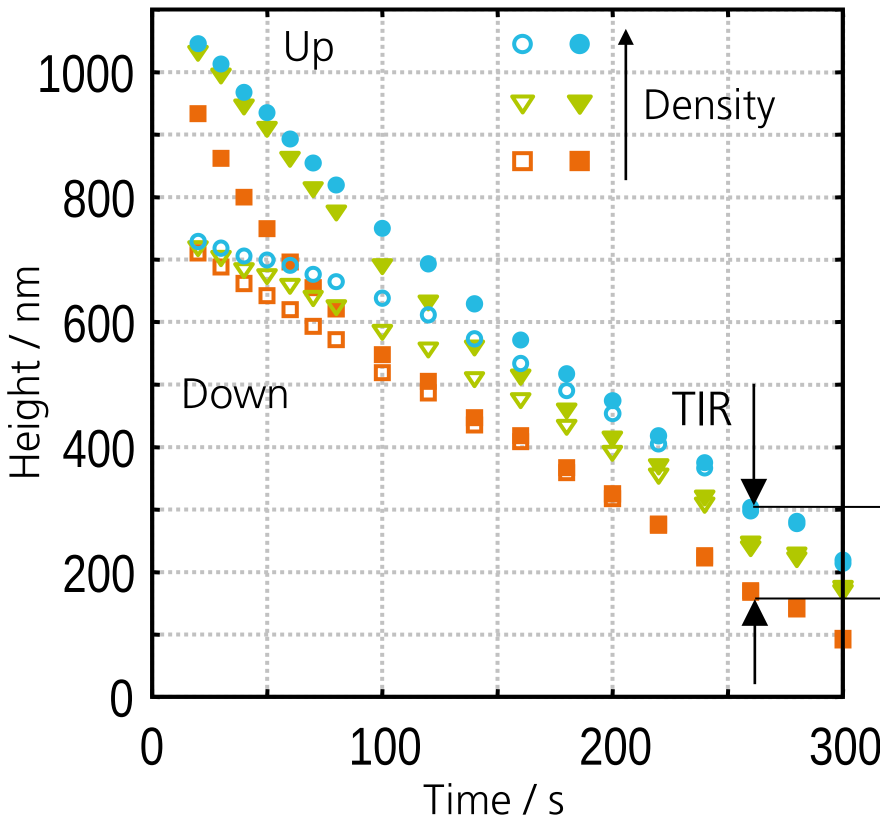
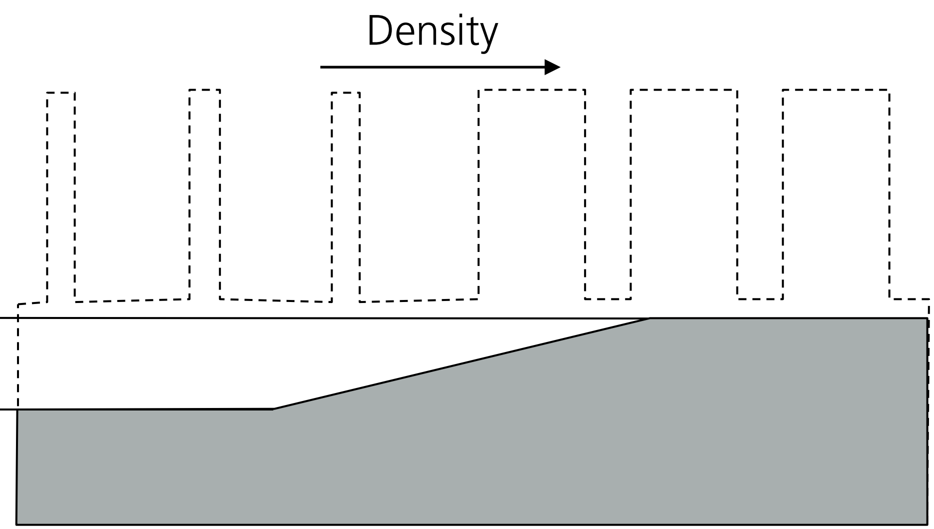
Pad stack experiments

- Important CMP measure: within die non-uniformity (WIDNU) → Total indicated range (TIR)



important for lithography and subsequent processes





$TIR = f(t)$ *depending on when the process is stopped different TIR are obtained*

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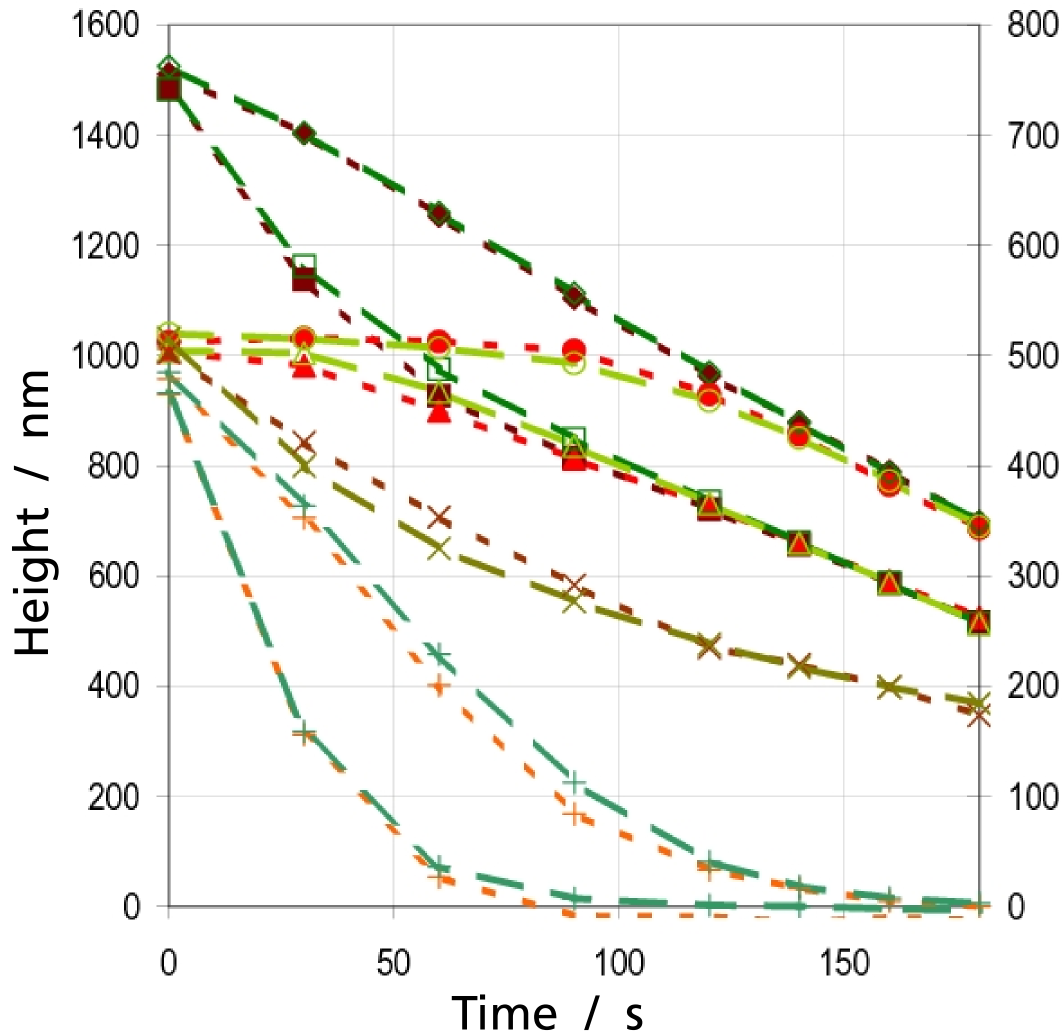
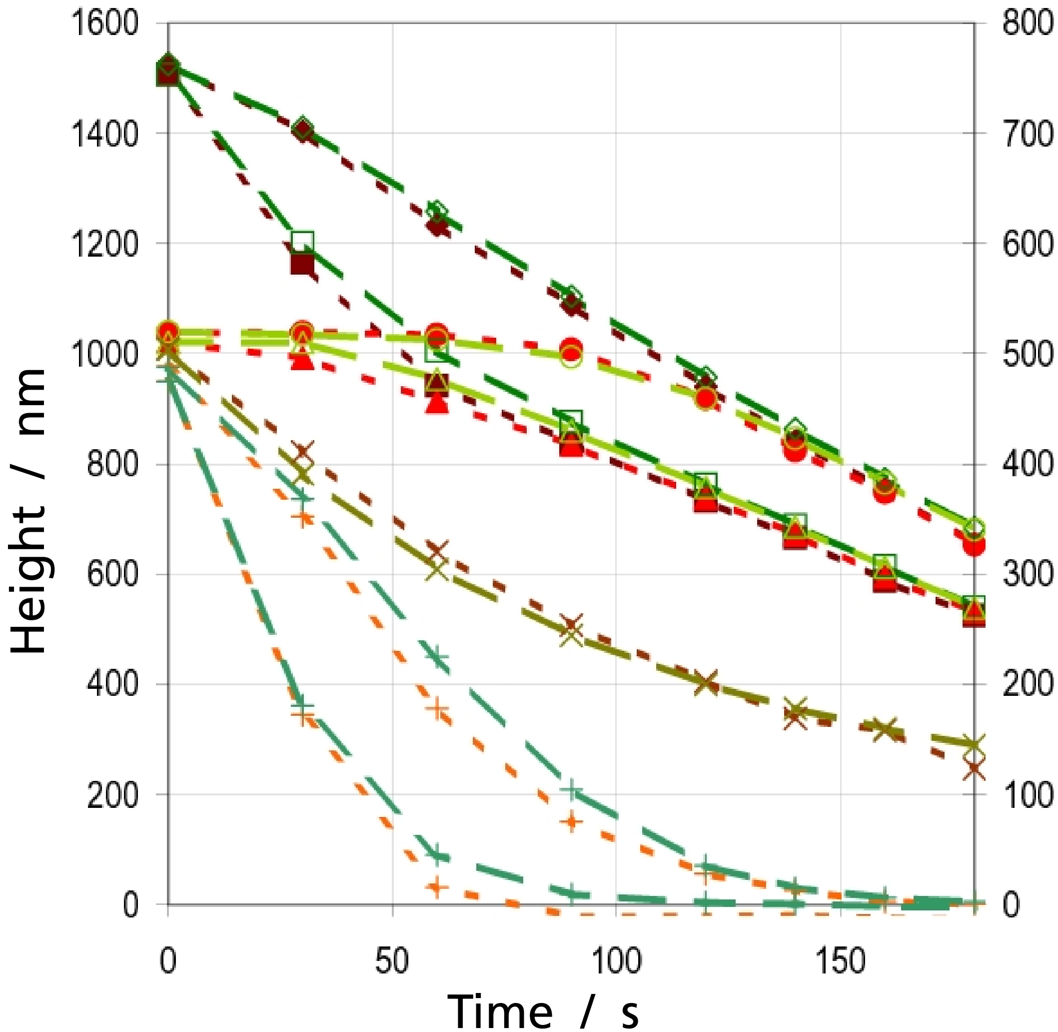
Pad stack experiments

- Pad C (D_3, E_2)
- Fit with Roughness heights model (model derivation not shown)
- Fit parameters
  - Pad roughness parameters σ, α
  - Blanket removal rate RR
  - Interaction length IL
  - → IL = 1250 µm



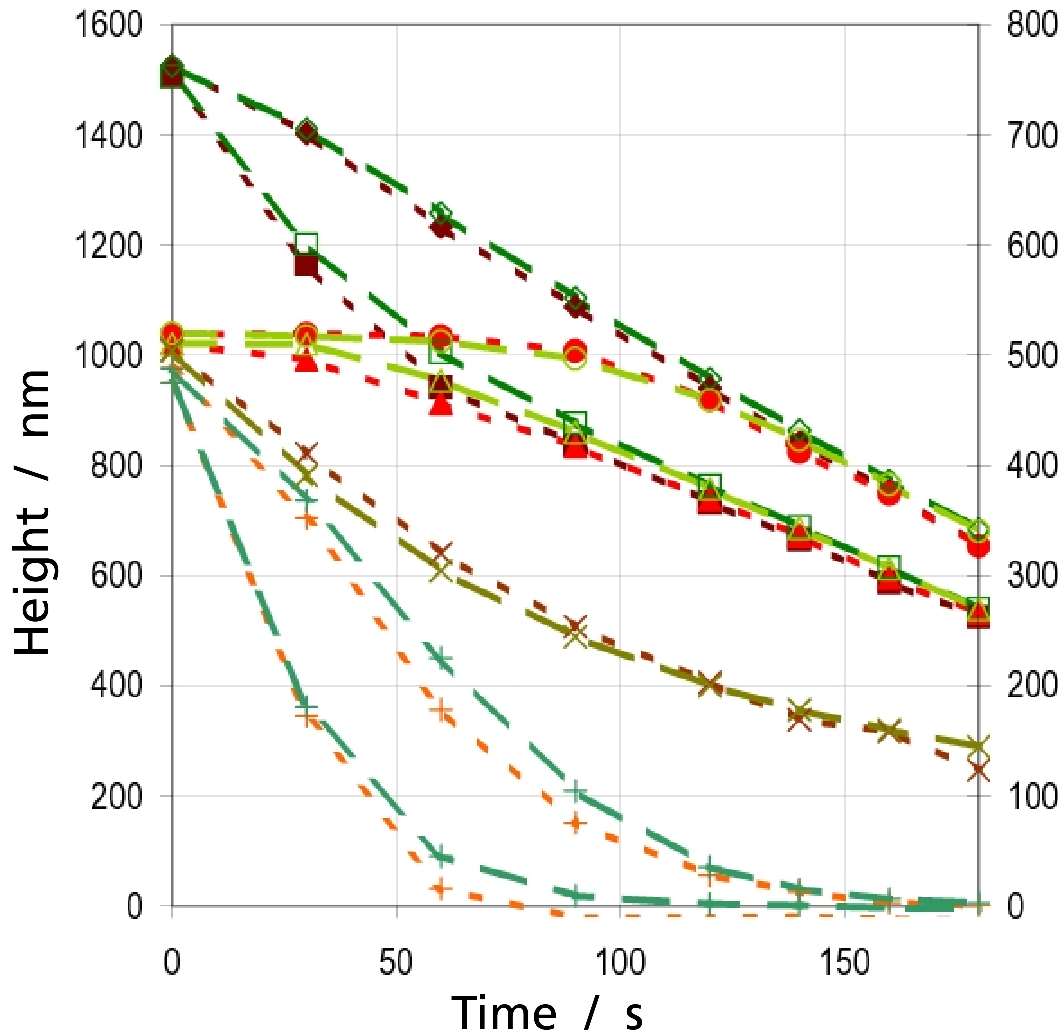
Pad stack experiments

- Pad B (D_2, E_2)
- Fit parameters
  - Same conditioning → pad roughness parameters σ, α fixed
  - Same material and process → blanket removal rate RR fixed
  - Interaction length IL → thinner pad → less bending → higher IL
  - → IL = 1550 µm
  - → IL = f(E, D), E = const.



Pad stack experiments

- Pad A (D_1, E_1)
- Fit parameters
  - Similar conditioning → pad roughness parameters σ, α fixed
  - Same material and process → blanket removal rate RR fixed
  - Interaction length IL → thinner pad, different material → IL ?
  - → IL = 1550 µm
  - → IL = f(E, D), E ≠ const.



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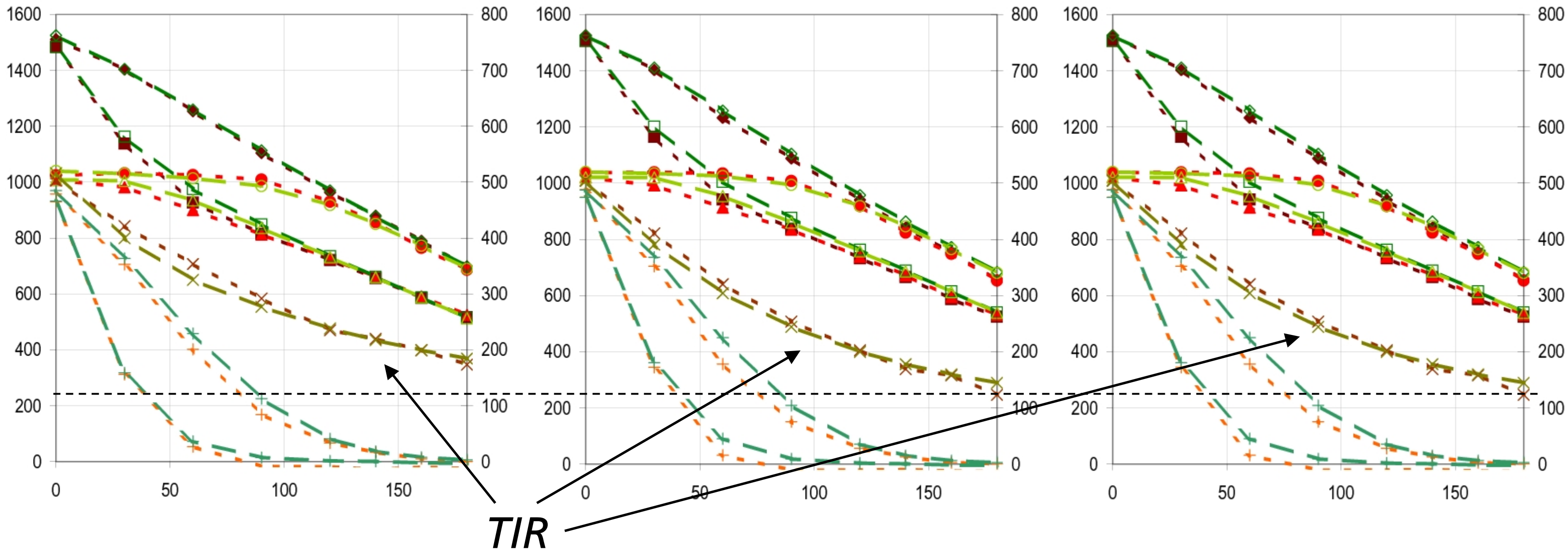
Pad stack experiments



	Pad C	Pad B	Pad A
■	Pad C	Pad B	Pad A
■	IL = 1250 µm	IL = 1550 µm	IL = 1550 µm
■	D_3, E_2	$D_2 = D_3/2$, E_2	$D_1 = < D_2$, E_1

Summary and outlook

- CMP characterization, modeling and simulation is valuable for various applications
- Long and short scale mechanisms are incorporated for an appropriate model accuracy
- Equipment and consumable influences need to be understood, e.g. conditioning on roughness

  → Roughness parameter extraction methodology is established at Fraunhofer CNT
- Further pad property influences need to be better understood

  → IL = f(E,D,…)
- Chemical influence investigations can be addressed using the developed *Roughness heights model*

sascha.bott@cnt.fraunhofer.de

Thank you for your attention

sascha.bott@cnt.fraunhofer.de

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