Analysis of Large Pad Surface Contact Area in Copper CMP

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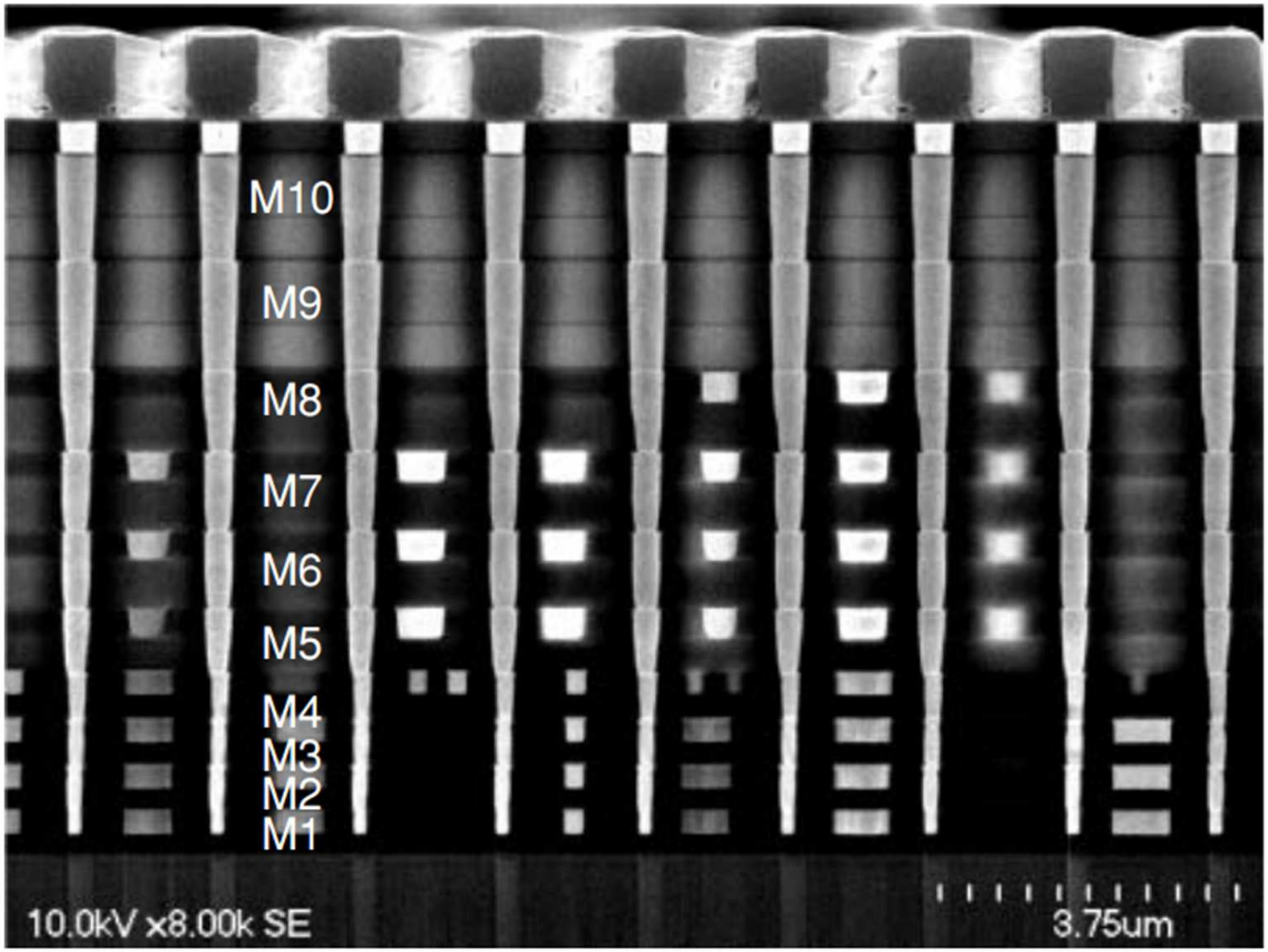
Introduction, Previous Work and Objective

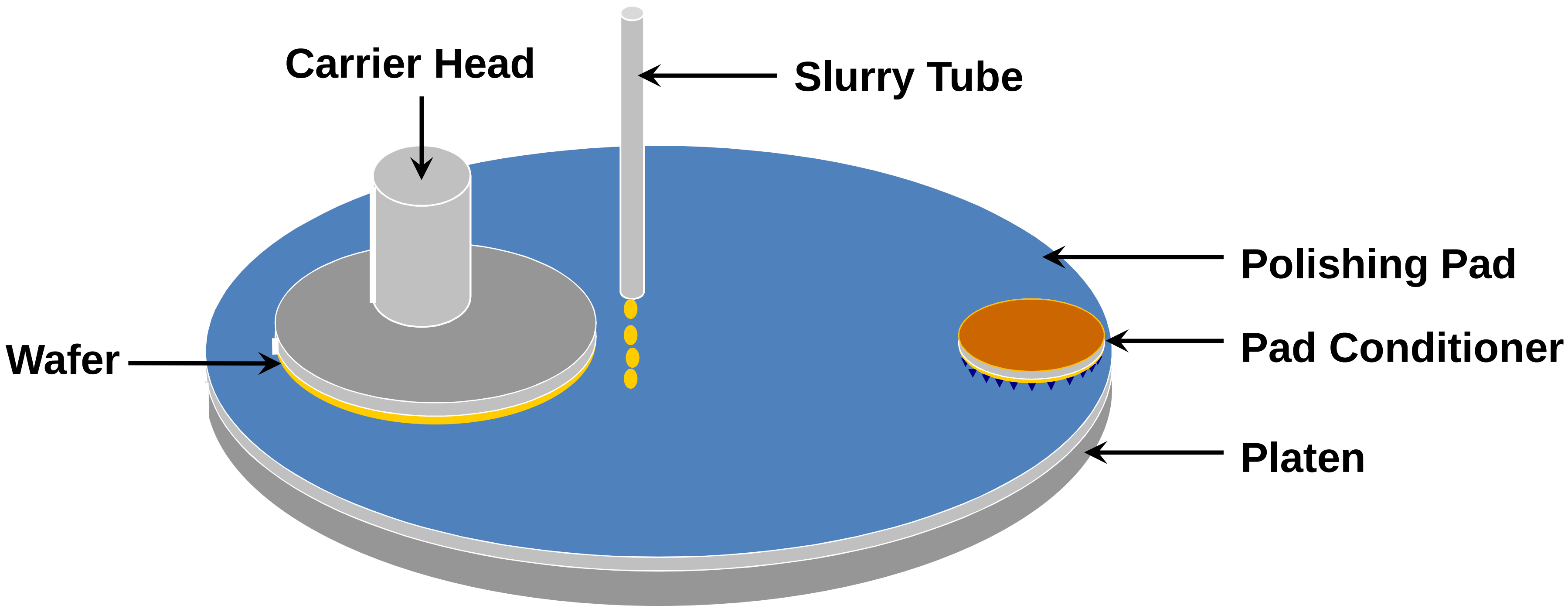
Why Do We Need CMP?



Multilevel (10-level) Interconnect Network

Source: T. Ohba, Fujitsu Sci. Technol. J., 38, 17 (2002).

How Does CMP Work?



Generalized Schematic of a Rotary CMP Tool

Why is Pad-Wafer Contact Area Important?

- **There have been numerous reports that pad-wafer contact strongly impacts material removal rate.**
- **Majority of previous work has shown that:**

THE SMALLER THE PAD-WAFER CONTACT AREA,
THE HIGHER THE MATERIAL REMOVAL RATE

- **However one investigation has claimed the opposite effect to be true!**

Previous Work

Mejia* *et al*.: J. Electrochem. Soc. 150 (2003) G76

- **Found that:**
  - ✓ **Total pad-wafer contact area increases as a function of pad immersion time in pH-adjusted water.**
  - ✓ **Local pressure on the wafer surface is reduced as immersion time and contact area increase.**
  - ✓ **PETEOS material removal rate is consequently reduced.**

*** Sematech/SRC ERC Ex-Student**

Previous Work

Bushan: Principles and Applications of Tribology, John and Wiley & Sons, New York (1999)

- **Found that:**
  - ✓ **Real contact pressure in CMP is closely related with pad surface roughness and its composite elastic modulus.**
  - ✓ **Real contact pressure is not related to the applied load.**

- **Accordingly:**
  - ✓ **Rougher surfaces cause faster asperity wear and thus increase the real contact area.**
  - ✓ **Removal rate drops due to declining real contact pressure.**

Previous Work

Jeong *et al*.: J. Adv. Mech. Dsgn. Sys. Mfg. 6 (2012) 113

- Found that:
  - ✓ Pad surface wear increases the total real contact area.
  - ✓ This in turn lowers the average of the real contact pressure at a given applied down force.
  - ✓ The reduction of the real contact pressure leads to a decline in material removal rate.

Previous Work

Sun* *et al*.: Jpn. J. Appl. Phys. 49 (2010) 026501

- **Found that:**
  - ✓ **The more aggressive the conditioning process, the lower the total pad-wafer contact area.**
  - ✓ **Pads with lower contact areas cause PETEOS removal rate to go up during CMP.**

*** Sematech/SRC ERC Ex-Student**

Previous Work

Liao* *et al*.: Jpn. J. Appl. Phys. 52 (2013) 018001

- **Found that:**

  - ✓ **Total pad-wafer contact area decreased dramatically at higher conditioning forces.**
  - ✓ **This led to a sharp increase in the local contact pressure.**
  - ✓ **This consequently caused significantly higher PETEOS removal rates during CMP.**

*** Sematech/SRC ERC Student**

Previous Work

Nair *et al*.: ICPT 2012, October 15-17, 2012, Grenoble, France

- **Found that:***
  - ✓ **After a certain critical point, total pad-wafer contact area does not contribute to TEOS material removal rate.**
- **Did not specify as to contact size is considered to be 'large' and what is considered to be 'small'.**

* **Blue symbol on Slide 13**

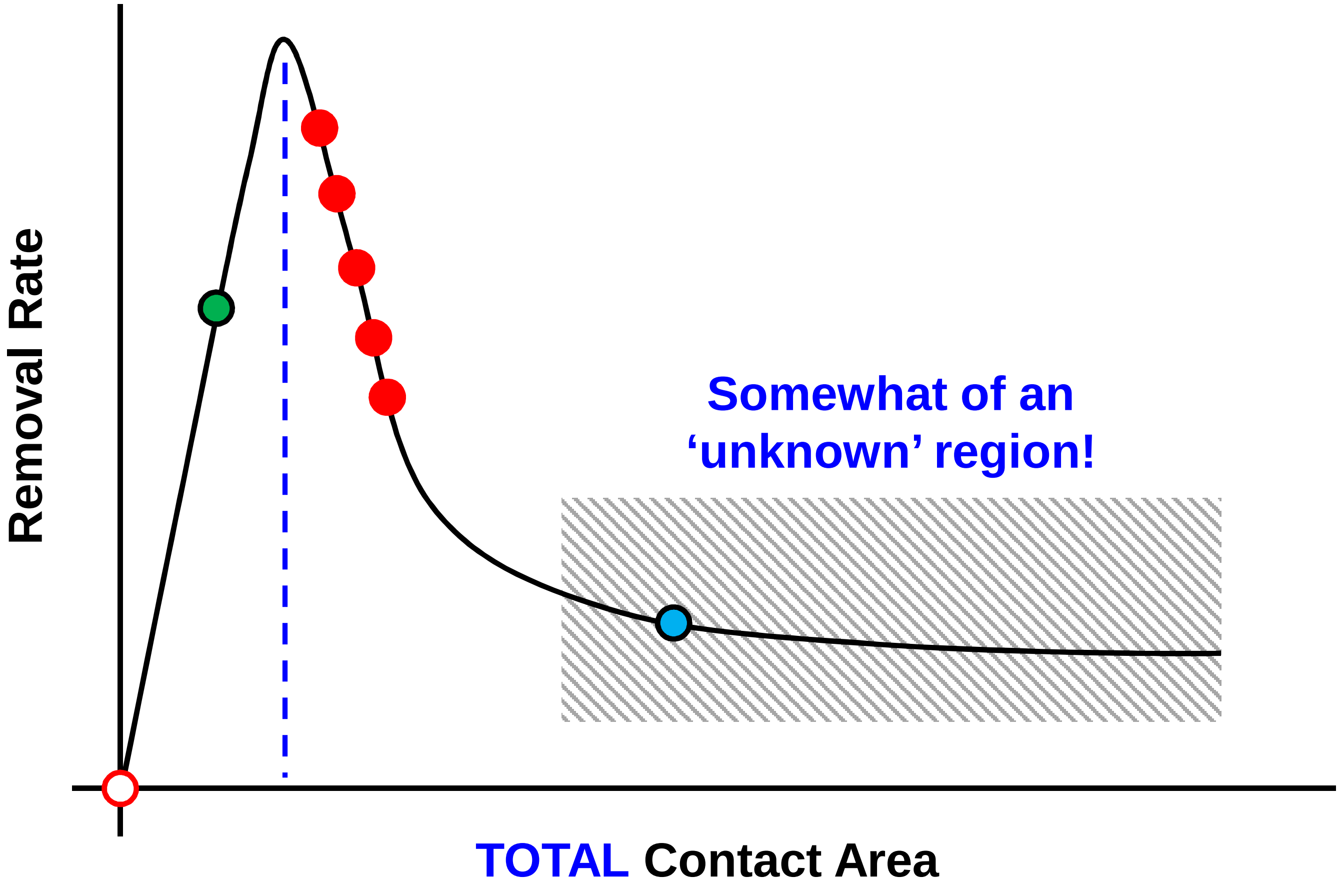
Previous Work

Park *et al*.: J. Electrochem. Soc. 155 (2008) H595

- **Found totally opposite trends:***
  - ✓ **The lower the total pad-wafer contact area, the lower the PETEOS removal rate.**

*** Green symbol on Slide 13**

Summary of Previous Work



Why Are We Focusing on ‘Large’ Contact Area?

- **The relationship between contact area and material removal rate in CMP can be complicated.**
- **All previous work has focused on the TOTAL contact area, even though contact areas are very different in size and their characteristics. As such, each contact area should not be treated the same way.**
- **We believe that contact areas need to be studied and classified more carefully.**
- **In this study we are going to classify contact areas as being ‘SMALL’ and ‘LARGE’. Sum of small and large areas is assumed to equal the total contact area.**

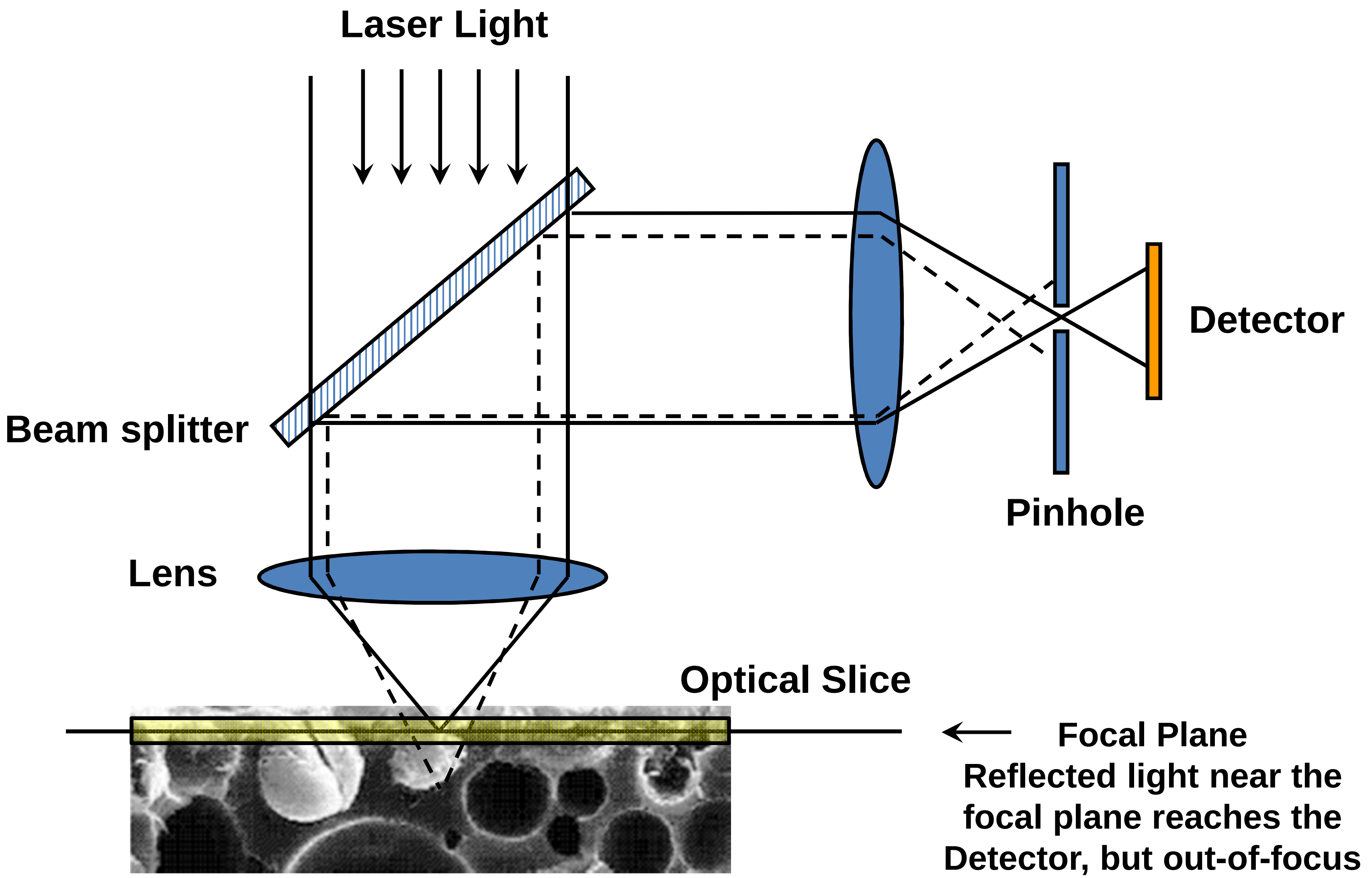
Laser Confocal Microscopy

Laser Confocal Microscopy

Zeiss LSM 510 Meta NLO

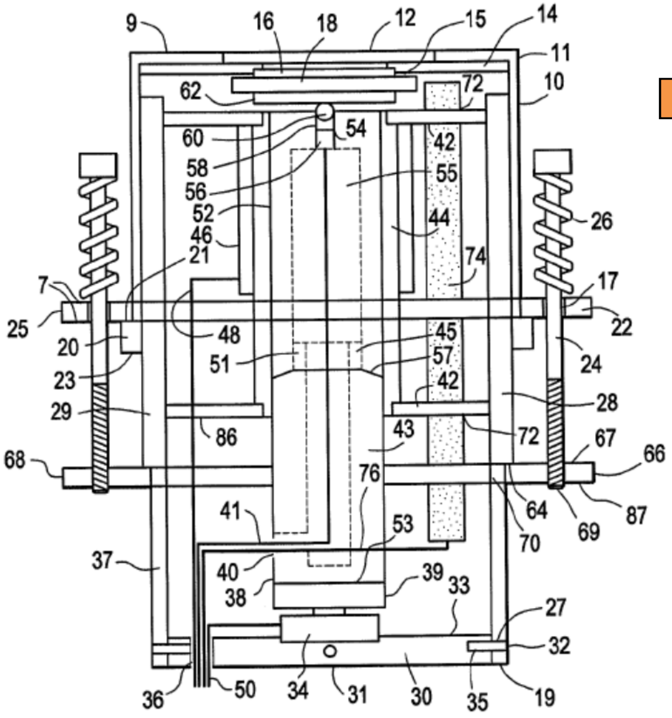
Pad surface contact area and topography analyses were performed through laser confocal microscopy.

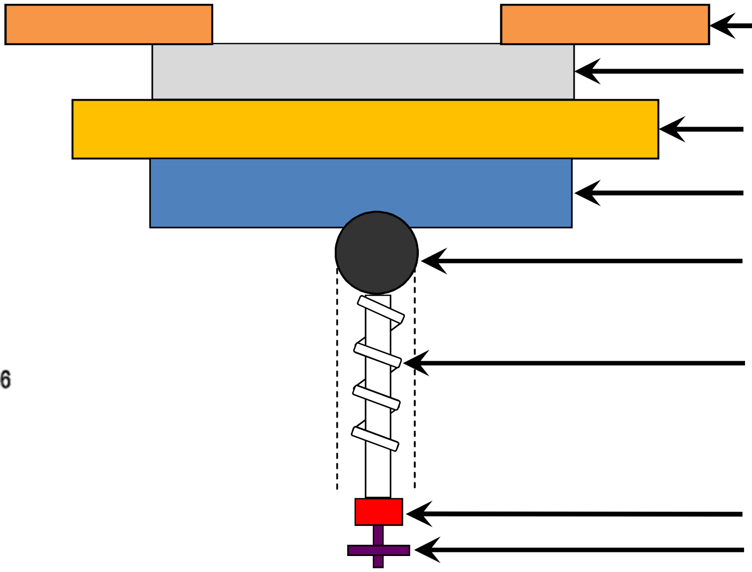
How Does a Laser Confocal Microscope Work?



Focal Plane
Reflected light near the focal plane reaches the Detector, but out-of-focus light does not.

Confocal Microscope Pad Sample Holder





Mounting Ring

Sapphire Window

Pad Sample

Miniature Stage

Ball Bearing

Spring

Load Cell

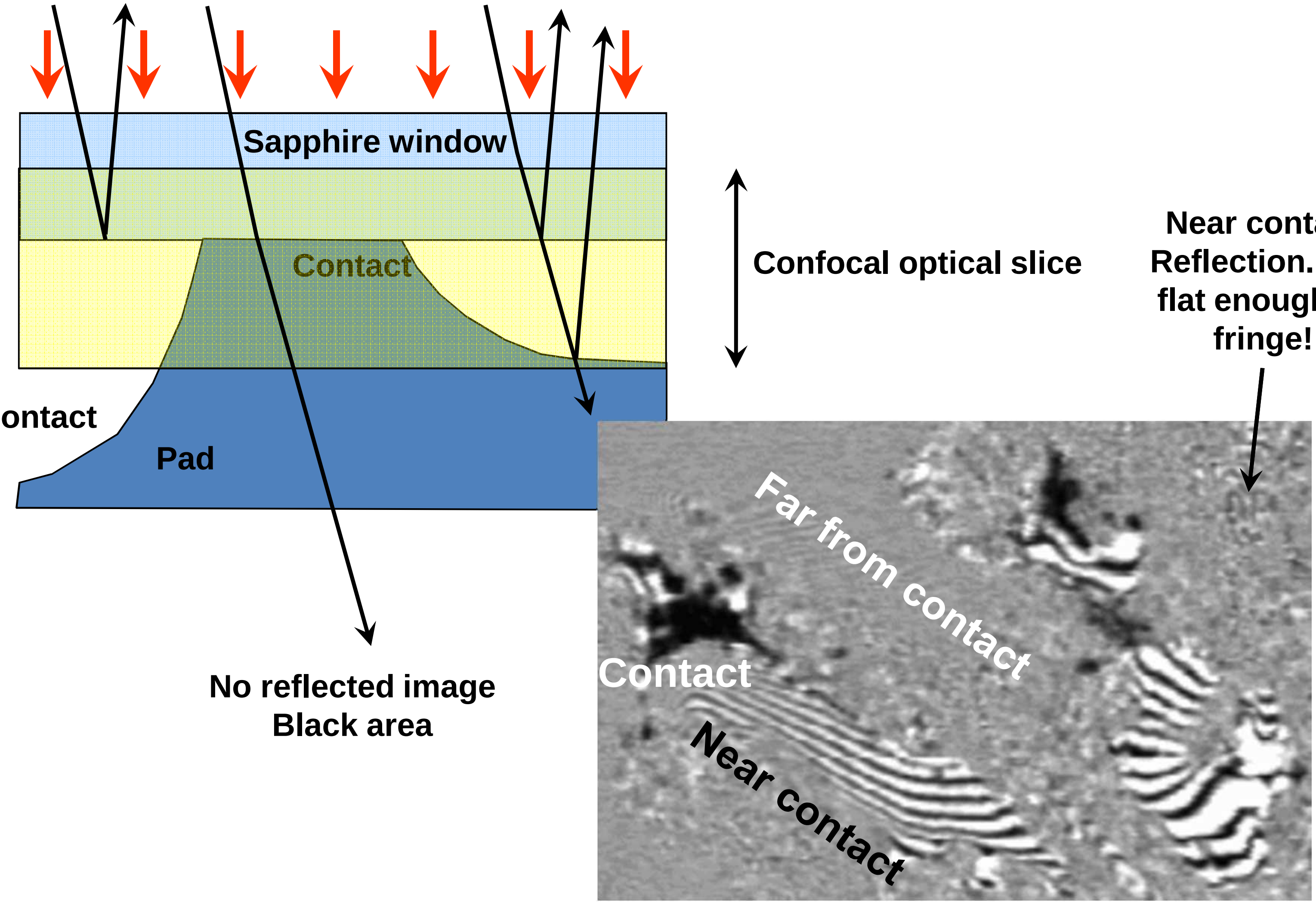
Threaded Screw

Source: L. Borucki,
US Patent Nos. 7,869,027 and 7,839,496

Confocal Contact Area Measurements

Near contact reflection or interference fringes (zebras)

Load



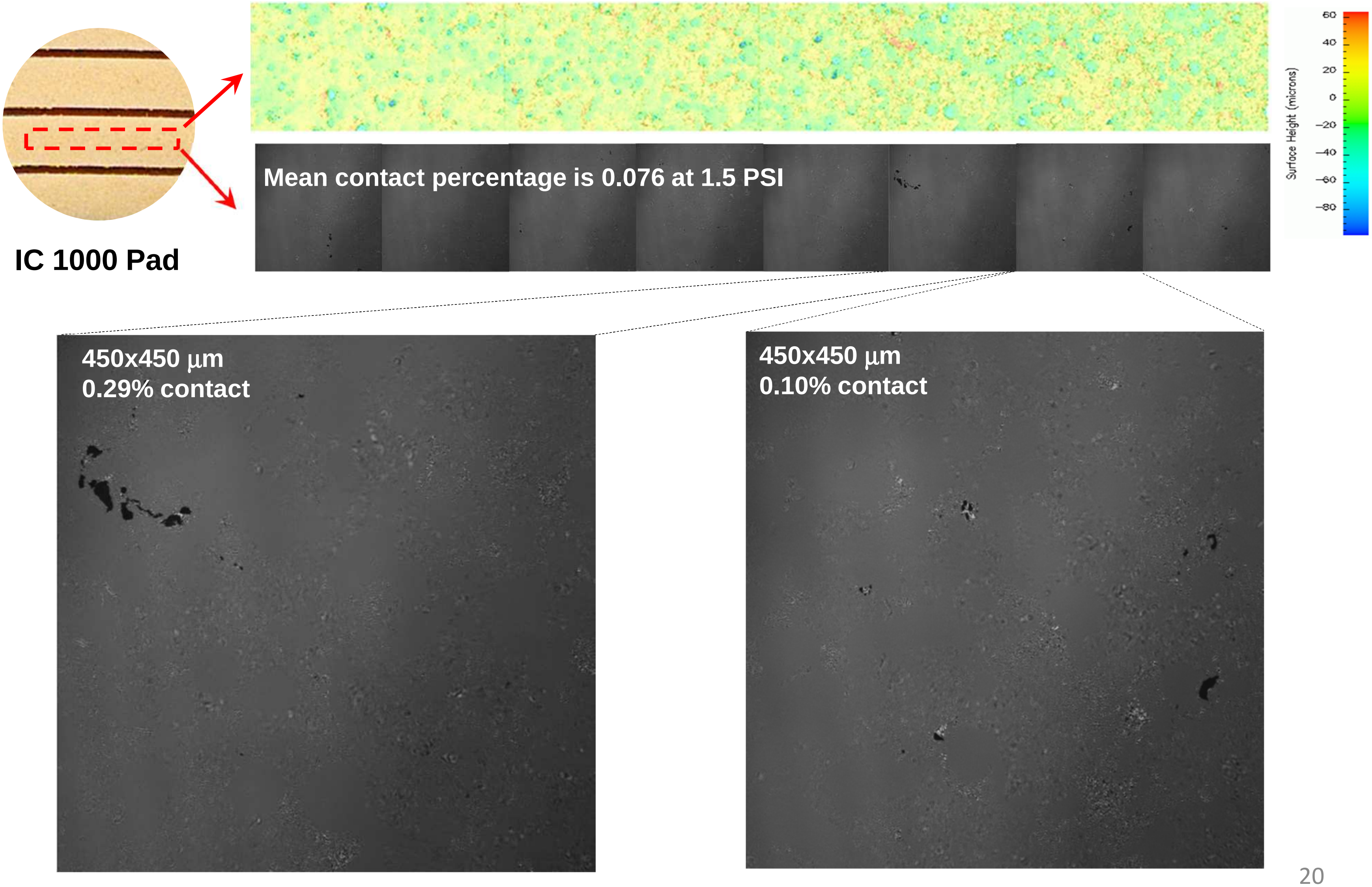
Confocal optical slice

Near contact Reflection. Not flat enough to fringe!

Far from contact

No reflected image
Black area

Topography and Contact Area Images



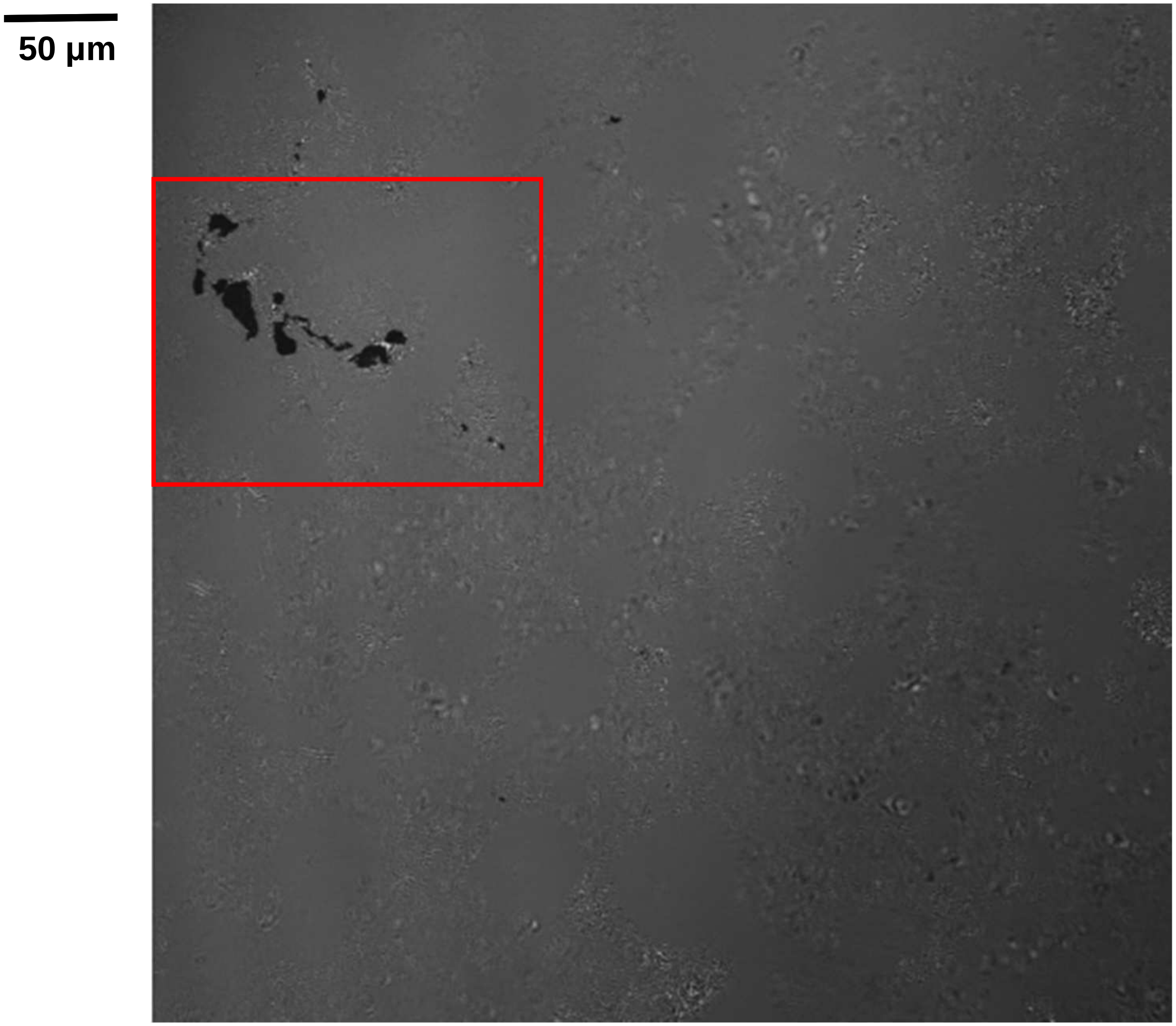
IC 1000 Pad

Mean contact percentage is 0.076 at 1.5 PSI

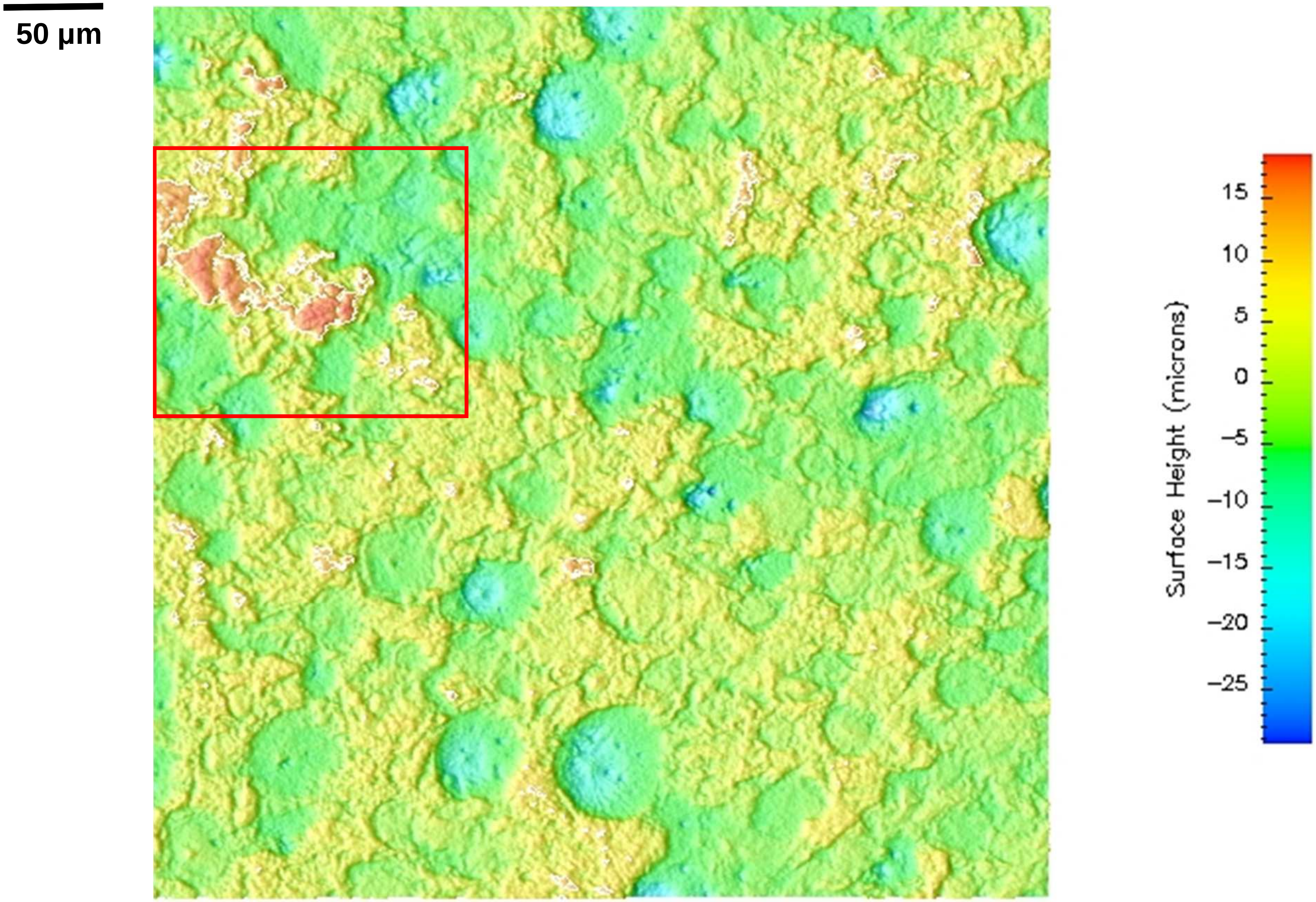
450x450 µm
0.29% contact

450x450 µm
0.10% contact

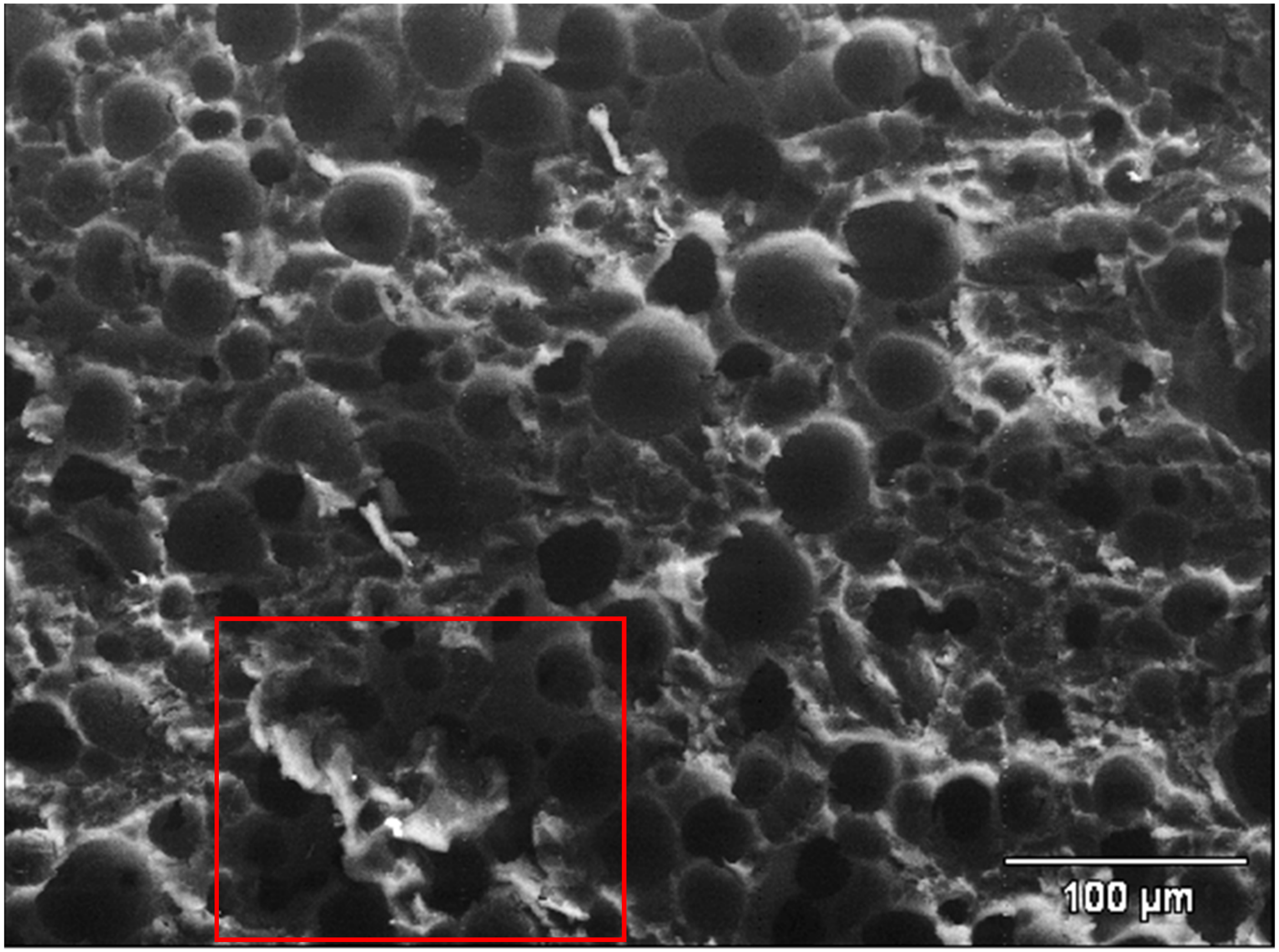
Example of LARGE Contact Area



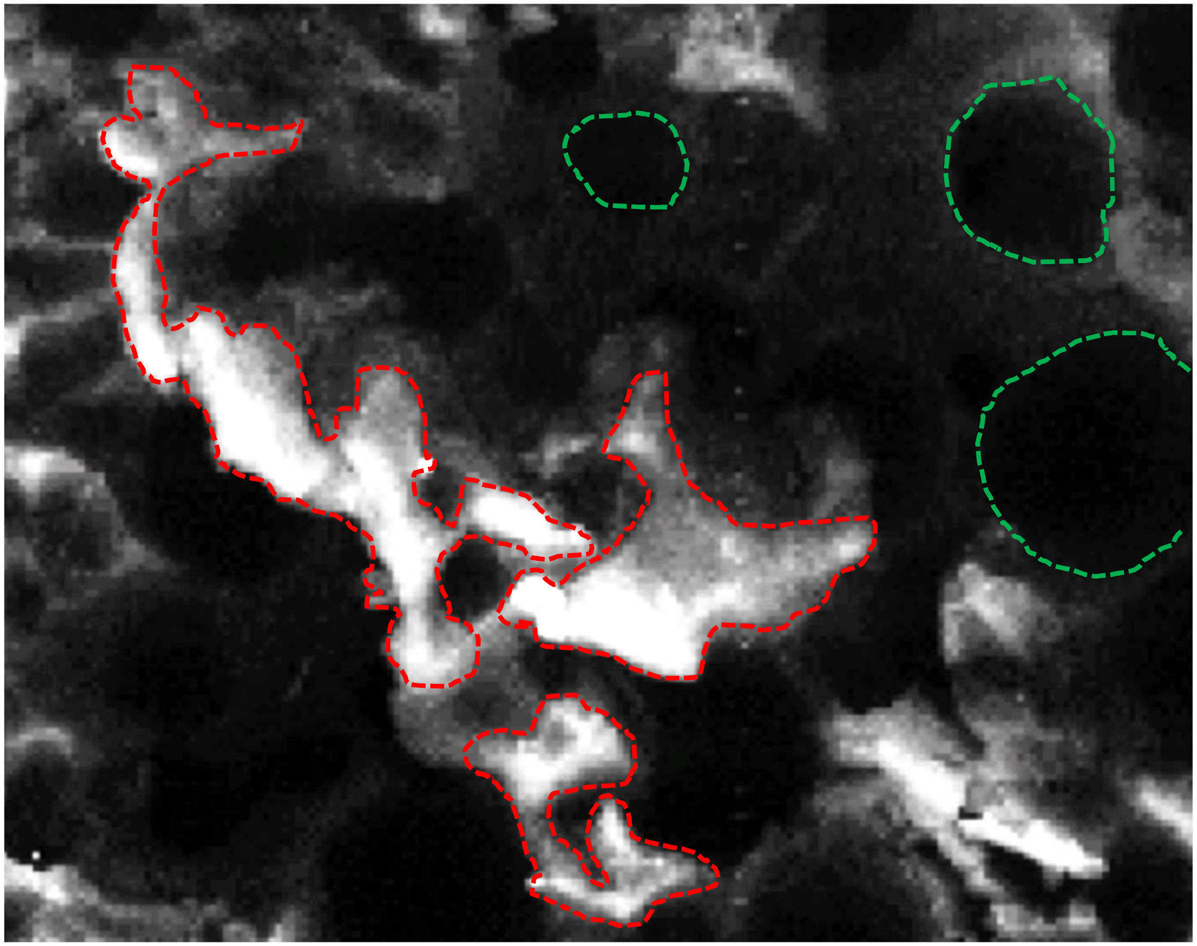
Topographic Analysis of LARGE Contact Area



SEM Analysis of a LARGE Contact Area



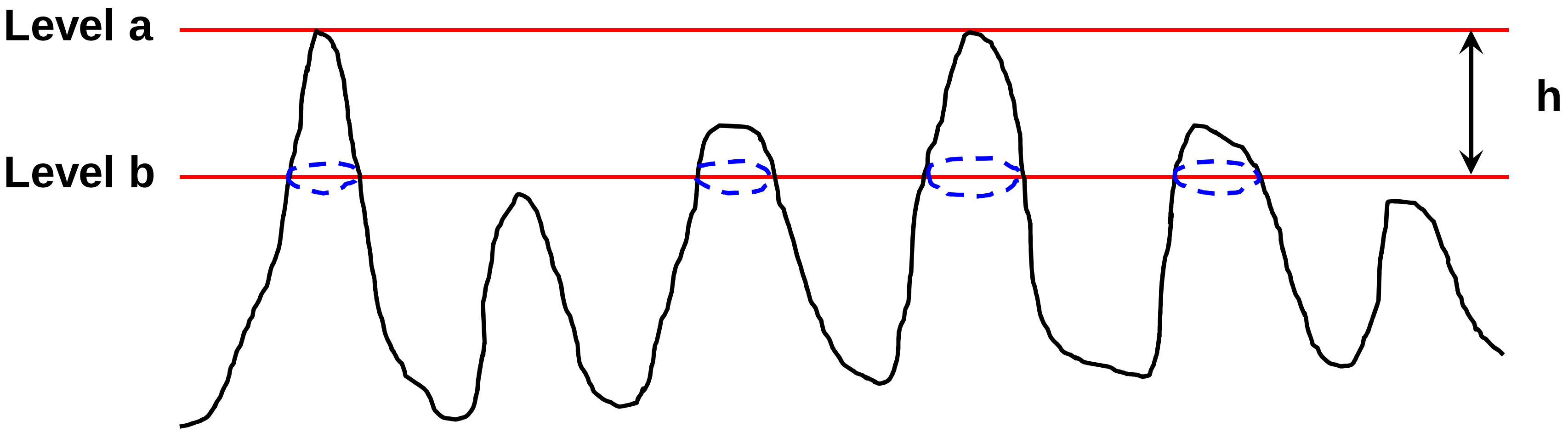
Detailed SEM Image of a LARGE Contact Area



The SEM image shows that the individual large contact area corresponds to collapsed pore walls and loosely attached pad debris, suggesting that the large contact area may not be fully supported.

Simulating the Young’s Modulus

Steps Involved in Simulating the Young's Modulus



- **Measure pad topography using laser confocal microscopy without applying any load.**
- **Assume elastic contact between the wafer and the pad asperities.**

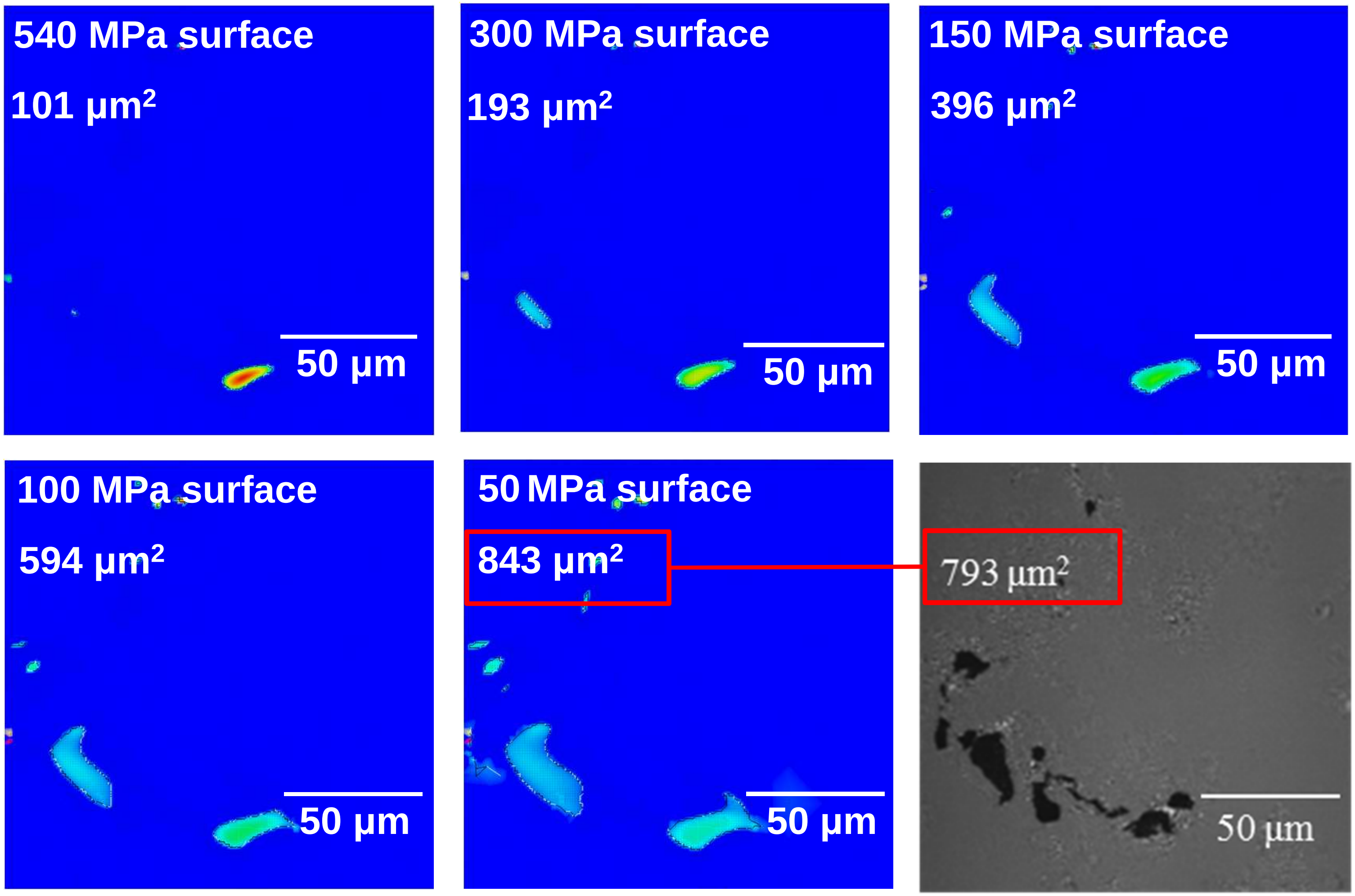
Borucki (2009).

Steps Involved in Simulating the Young’s Modulus

- **Perform a load balance based on the Greenwood and Williamson elastic model.**
  - ✓ **Assume a certain value for the Young’s modulus.**
  - ✓ **Calculate the pressed displacement ‘h’ of the summits from height level ‘a’ to some height level ‘b’ at a certain load.**
- **Contour the contact at height level ‘b’. Obtain the simulated contact area for each asperity at level ‘b’.**
- **Sum up the areas of all contact contours to obtain the simulated total contact area.**
- **Compare simulated vs. measured contact areas. Increase or decrease the Young’s modulus and simulate again until the two contact areas are close enough.**

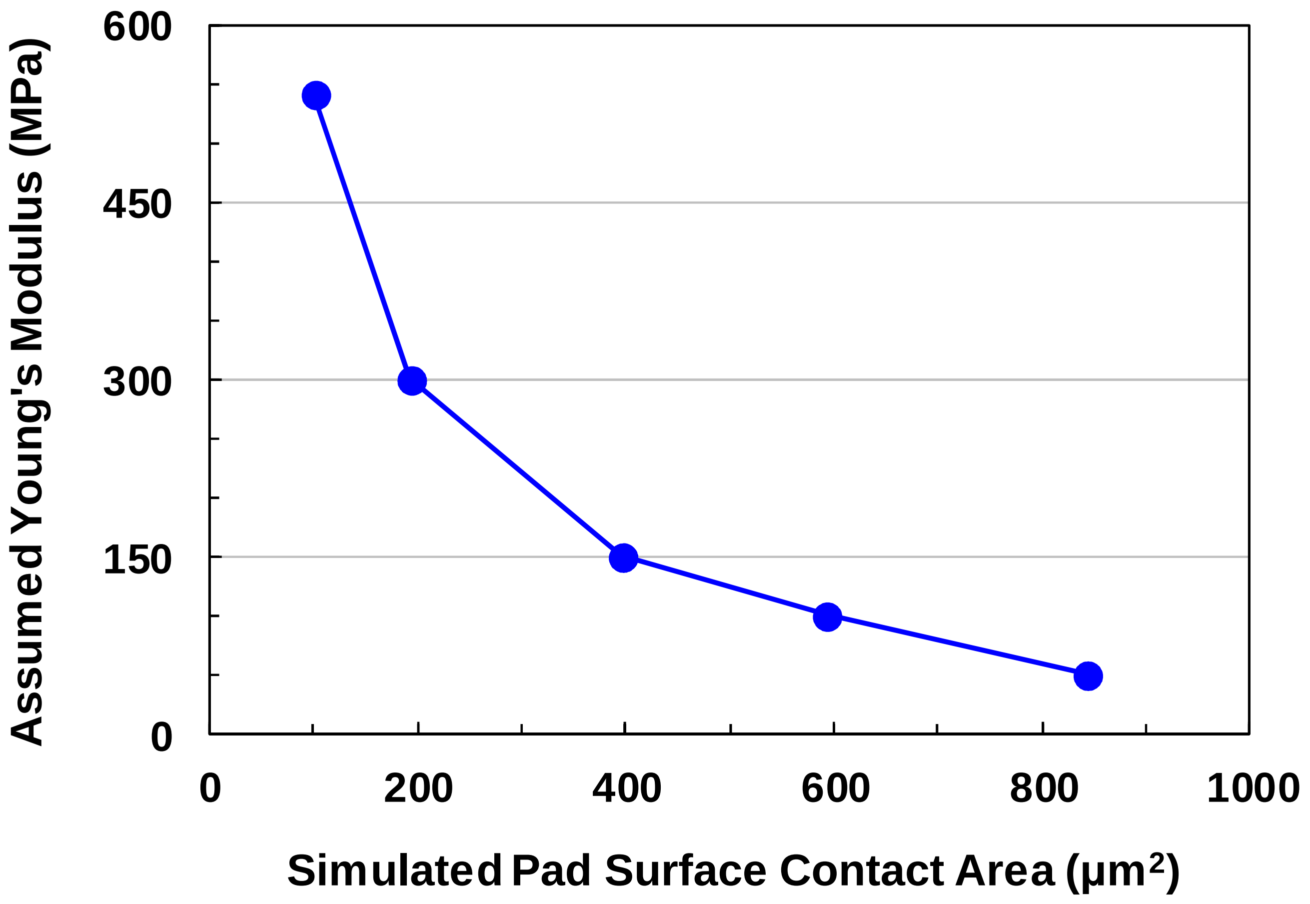
Borucki (2009).

Simulation Results



Borucki (2009).

Young’s Modulus vs. Surface Contact Area



Borucki (2009).

Implications of Individual ‘LARGE’ Contacts

- **Individual large contact area corresponds to very low values of Young’s modulus (i.e. about 50 MPa).**

- **Such low values indicate that the pad material is soft and the summit underlying the individual large contact area is not fully supported (as seen in the SEM image) and likely consists of fractured pore walls and loosely attached pad debris.**

- **As the soft material is very compliant, the large contact area implies much lower contact pressures compared to small contact area induced by fully supported pad asperities.**

- **As a result, large ,and low-pressure, individual contacts become easily lubricated and contribute less to removal rate than small, high-pressure contacts.**

An Experimental Case Study

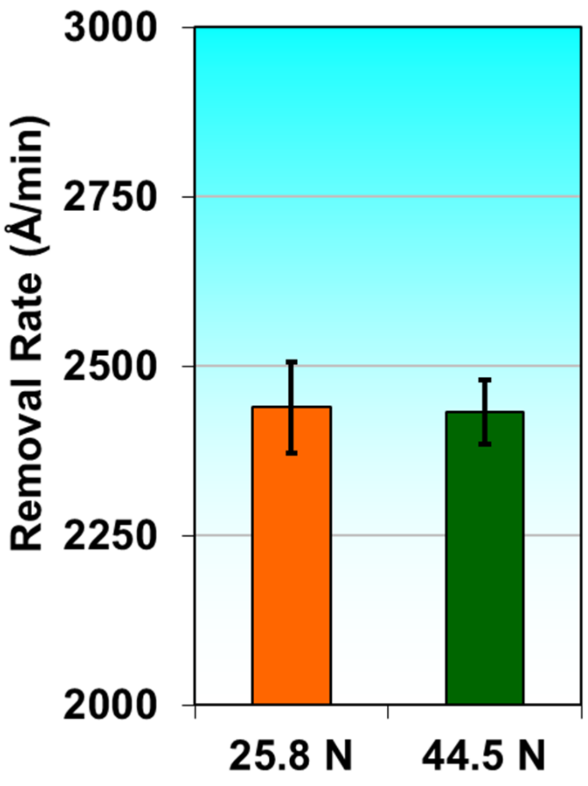
Araca APD – 800 Polisher & Tribometer

Experimental Conditions

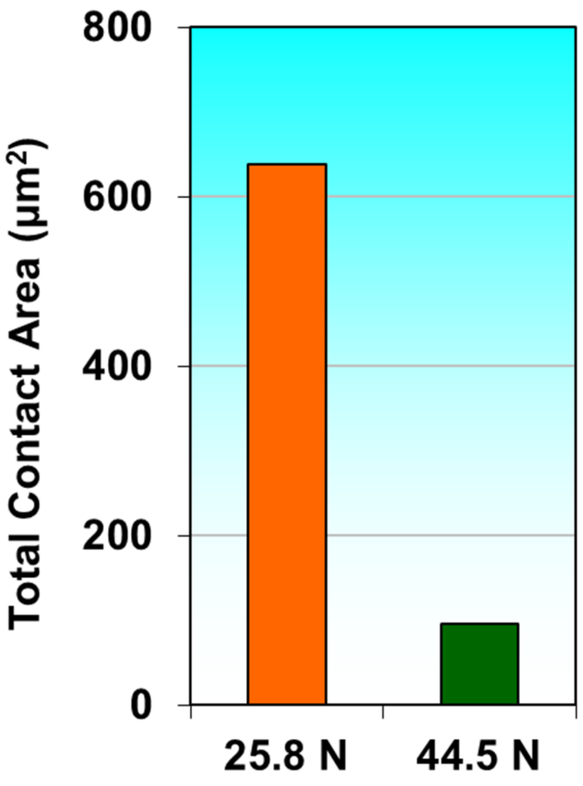
- Pad
  - ✓ IC1000 K-groove pad with Suba IV sub-pad
- Slurry
  - ✓ 7 volume parts of Hitachi Chemical HS 2H635-12 slurry + 7 volume parts of DI water + 6 volume parts of ultra pure 30% hydrogen peroxide
  - ✓ Flow rate: 300 ml/min
- Wafer
  - ✓ 200-mm blanket copper wafers

- Pad Conditioning
  - ✓ 3M A2810 disc rotating at 95 RPM and sweeping at 10 times/min
  - ✓ In-situ pad conditioning at 25.8 and 44.5 N
- Wafer Polishing
  - ✓ Polishing pressure: 1.5 PSI
  - ✓ Sliding velocity: 1.0 m/s
  - ✓ wafer polishing time: 1.5 minute

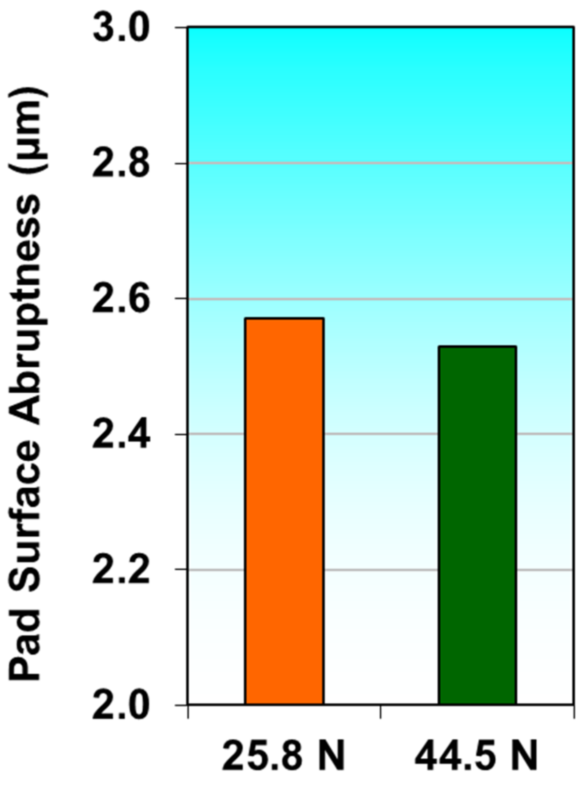
Removal Rate, Total Contact Area and Pad Surface Abruptness



$\mathrm{RR}_{25.8\ \mathrm{N}} \sim \mathrm{RR}_{44.5\ \mathrm{N}}$

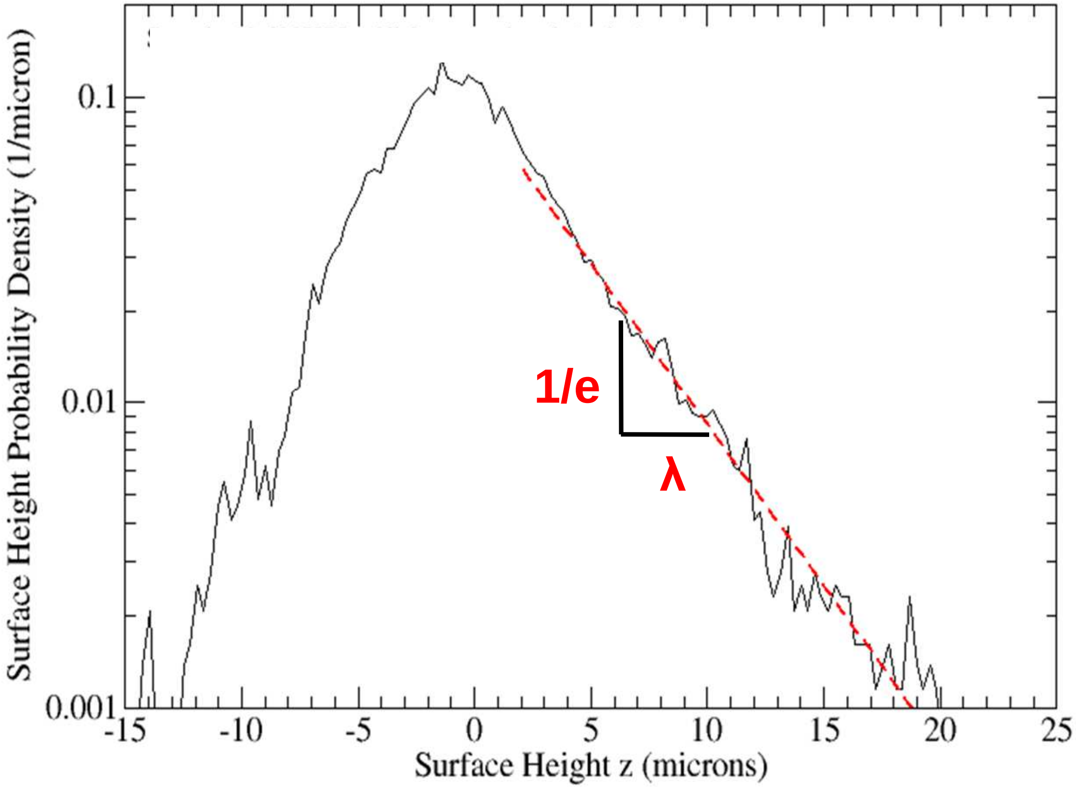


$\mathrm{CA}_{25.8\ \mathrm{N}} > \mathrm{CA}_{44.5\ \mathrm{N}}$



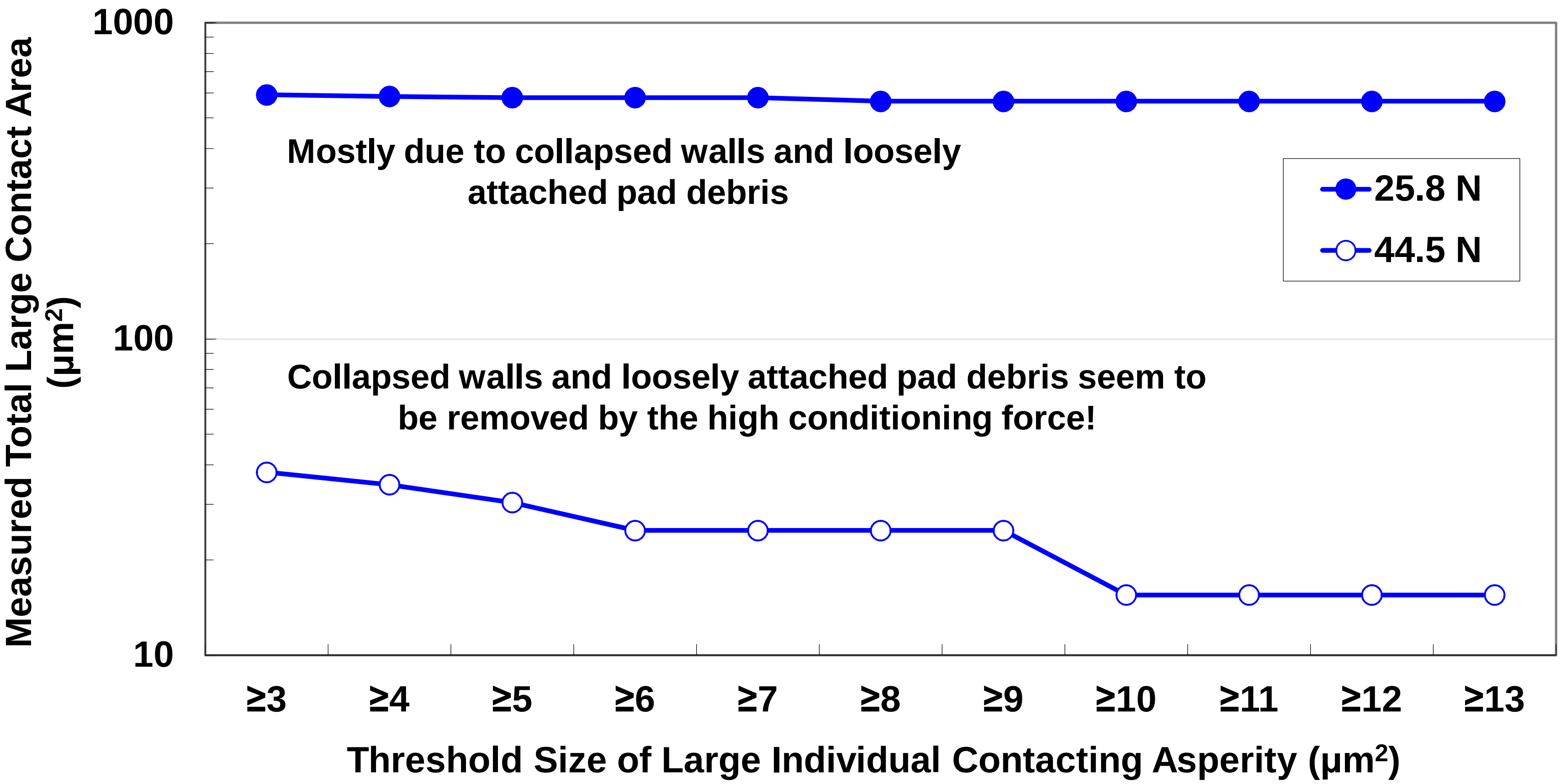
$\lambda_{25.8\ \mathrm{N}} \sim \lambda_{44.5\ \mathrm{N}}$

Pad Surface Abruptness (Lambda)



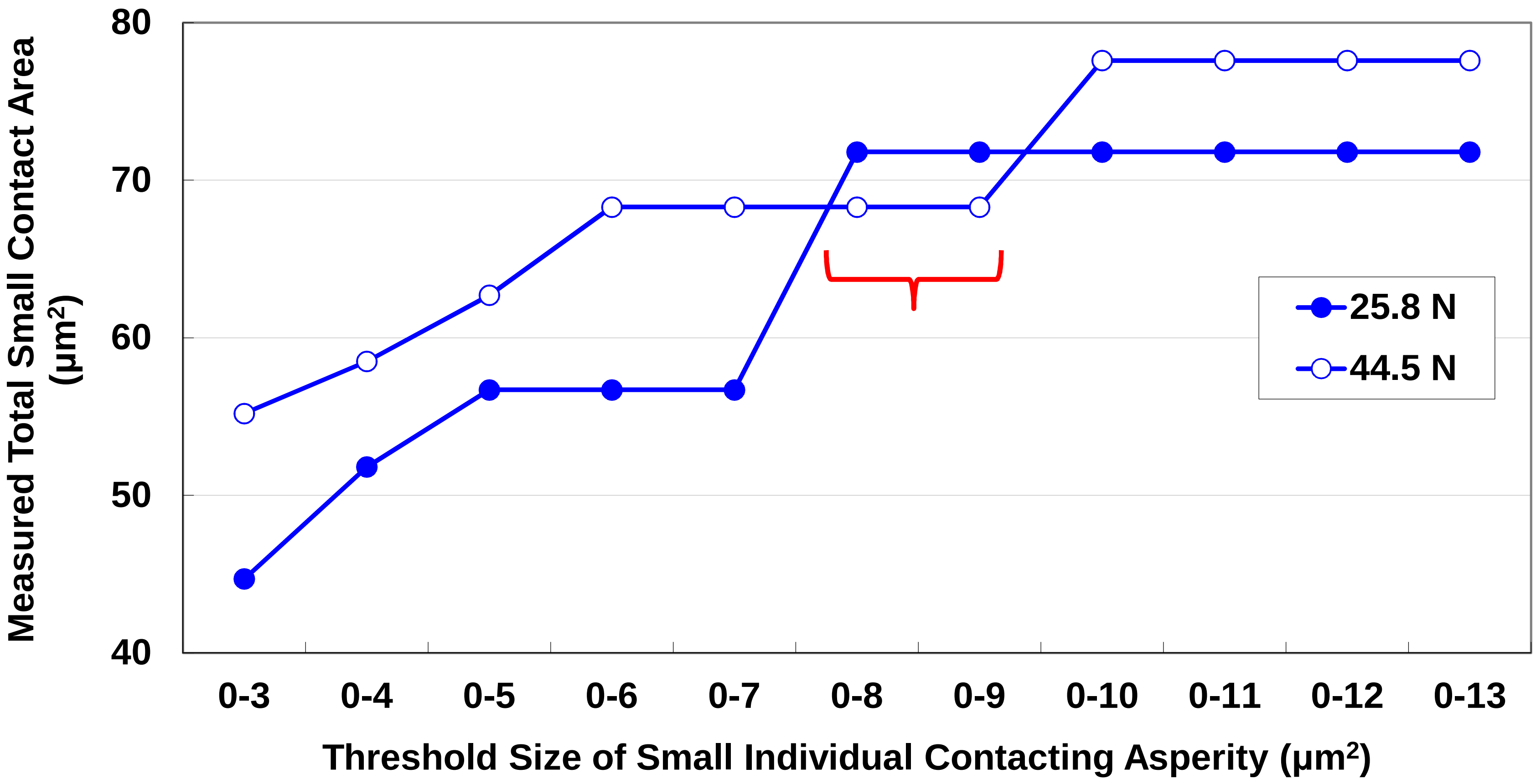
- When asperity summits have exponentially distributed heights, then the right hand tail of the PDF will be linear on a log scale.
- The pad abruptness factor (λ) is the distance over which the tail drops by a factor of e.
- A pad with larger λ means a rougher pad contacting surface. This should result in higher removal rates.
- In our case (previous slide), RR trends are consistent with Lambda trends.

Measured Total Large Contact Area Based on Contacting Asperity Threshold Size



Regardless of threshold size selected to define 'LARGE' individual contacting asperities, there is a significant difference in the large contact area measured between 25.8 and 44.5 N conditioning forces, but no change in RR.

Measured Total Small Contact Area Based on Contacting Asperity Threshold Size



Pads conditioned at 25.8 and 44.5 N, share similar small contact area values when 0 – 8 or 0 – 9 square micron ranges are selected to define the size of 'SMALL' contacting asperities.

Summary

- Individual large contact area seems to be induced by collapsed pore walls and loosely attached pad debris.
- Simulations indicate that individual large contact areas correspond to very low values of Young's modulus.
- A case study was presented to illustrate the role of the individual large contact area in copper CMP.
- Results confirmed that individual large contact area had minimal contribution to removal rate and indicated that the removal rate was mainly caused by small contact area for copper CMP.
- The case study showed that (on an IC-1000 pad) individual contact areas smaller than 9 square micron contributed to removal rate.
- Threshold values that may define 'SMALL' and 'LARGE' individual contact areas for different pads and processes need to be further investigated.

Acknowledgement

- **SRC Engineering Research Center for Environmentally Benign Semiconductor Manufacturing**