KLA-Tencor
Accelerating Yield

About the Dynamics of Defectivity Generation in CMP Technology

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Defectivity is one of the major factors affecting CMP performance (&FAB yield), and **scratching is its most troubling component.**

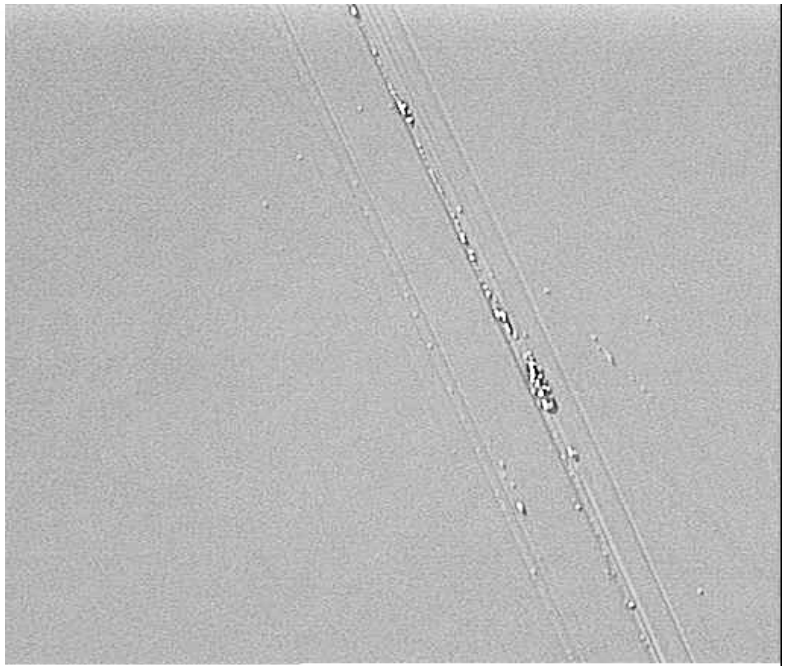
Scratching is especially painful for Cu CMP because **Cu is a soft and easily scratchable material**

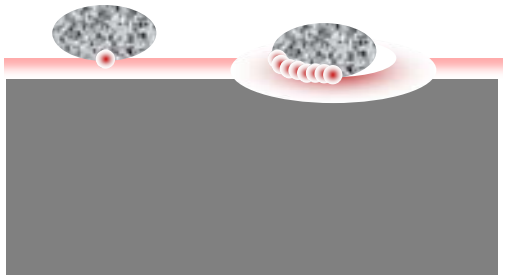
Scratches, even shallow ones, are strong particle retainers

- Due to envelop contact-line (configurational factor)
- Due to higher surface energy (energy factor)
- It seriously complicates cleaning

Identification of the scratching mechanism, the origin and the source of the scratching objects is vital for successful process development.

Both in R&D (process&consumables) and **in production environment (process troubleshooting).**

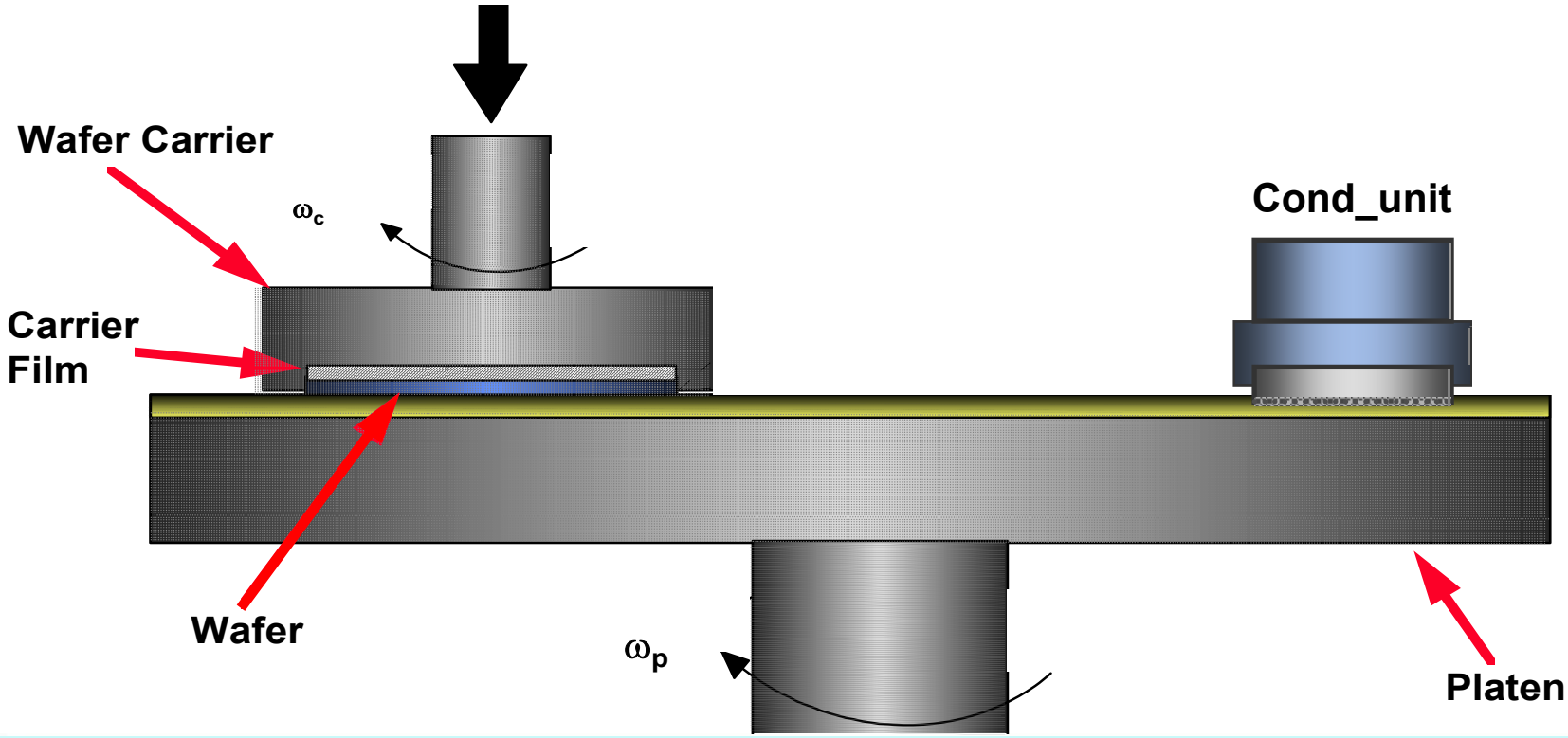




Compensating pad conditioning action is MUST in CMP

A two-object interactive system, with one of them, the wafer, on purpose changing its state, is, in principle, unstable

A third object, providing compensational action, has to be introduced to stabilize it.



Pad Conditioning

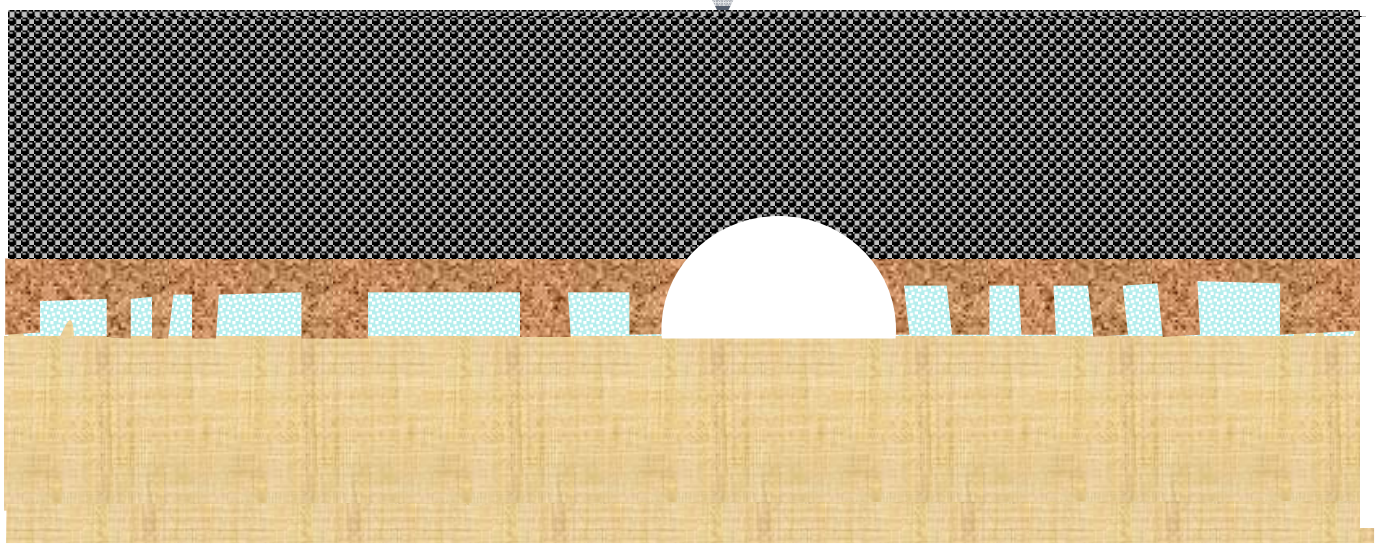
- **Pad Conditioning (PC) is a combo of abrasion and chemical action (DIW in simplest case), applied to the pad surface to clean existing pores and open new ones, to remove process by-products and upper glazed material to compensate for the inevitable pad surface degradation**
- **Too mild PC action does not compensate for the pad/wafer interaction effects and does not provide process stability, over-conditioning causes numerous quality issues.**

Only balanced PC, actively compensating for the wafer/pad interaction effects, provides best stability and uptime.

The compensation is never adequate!

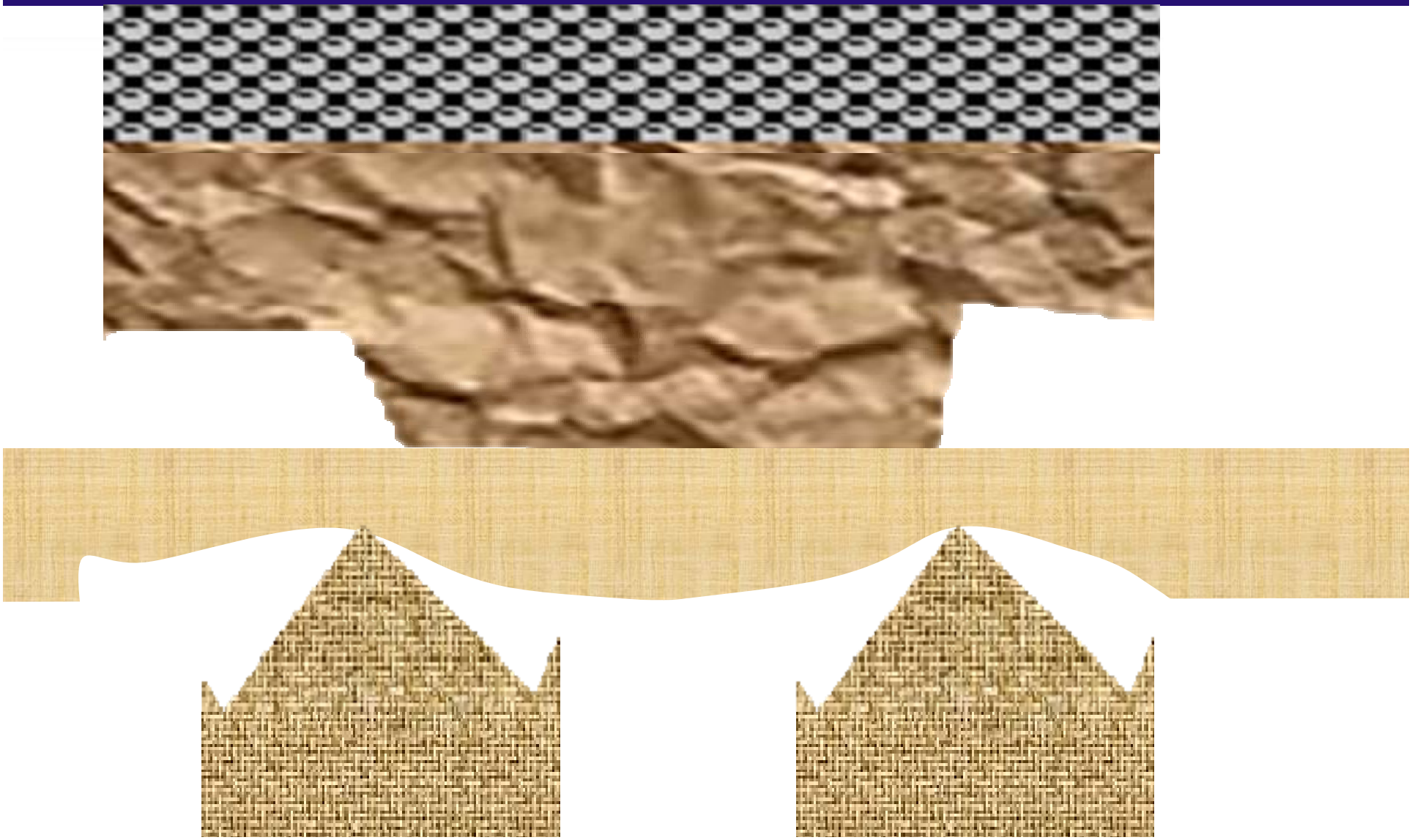
The most frequently used CMP model is very oversimplified and, thereby, misleading

Asperities protrusion/intrusion engagement is the key phenomenon, which has always to be kept in mind, while discussing practically any CMP problem (SHR, PL, D&E, defectivity, selectivity etc.)



The more intrusive and aggressive the asperities the more brutal the impact on CMP performance

How the planarization proceeds



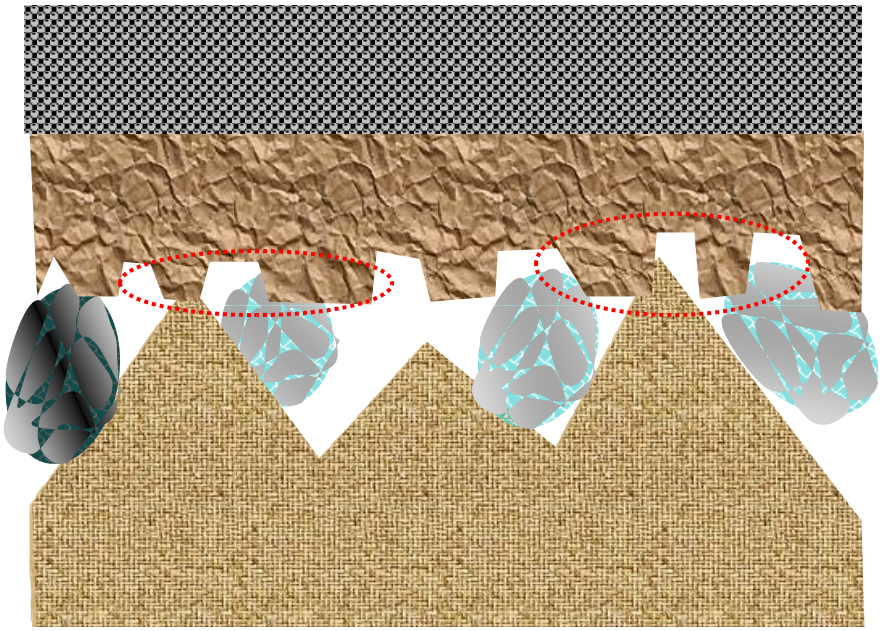
Asperities are the CMP soldiers

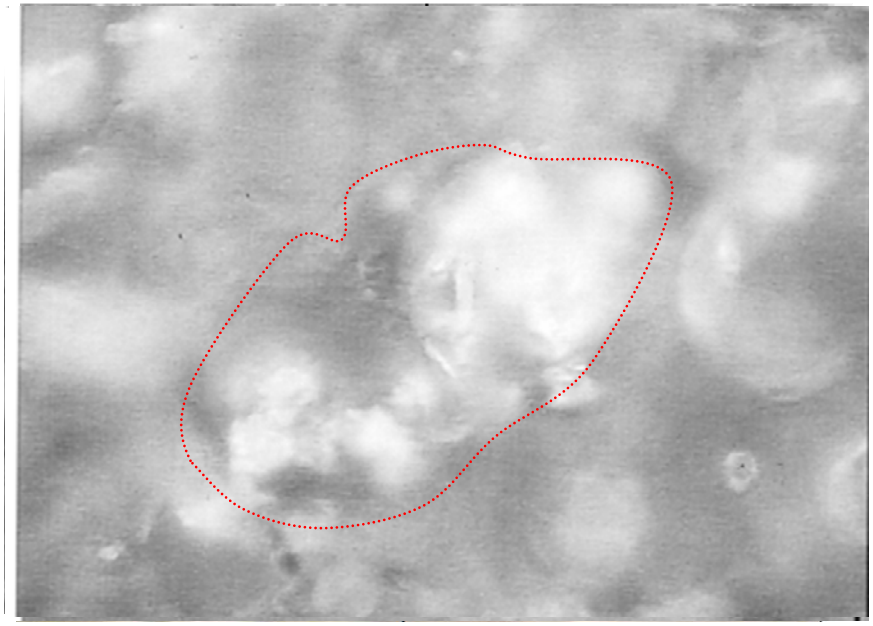
Being involved in all wafer/pad interfacial interactions, asperities are the ultimate key players influencing the overall CMP process performance via:

- **asperities size and shape distribution,**
- **asperities structure and density,**
- **their capability to absorb slurry components and process by-products,**
- **their capability of inducing catalytic action, miscelle agglomeration, corrosion, etc.**

Wafer Engages With The Interfacial Layer, Asperities And Debris…

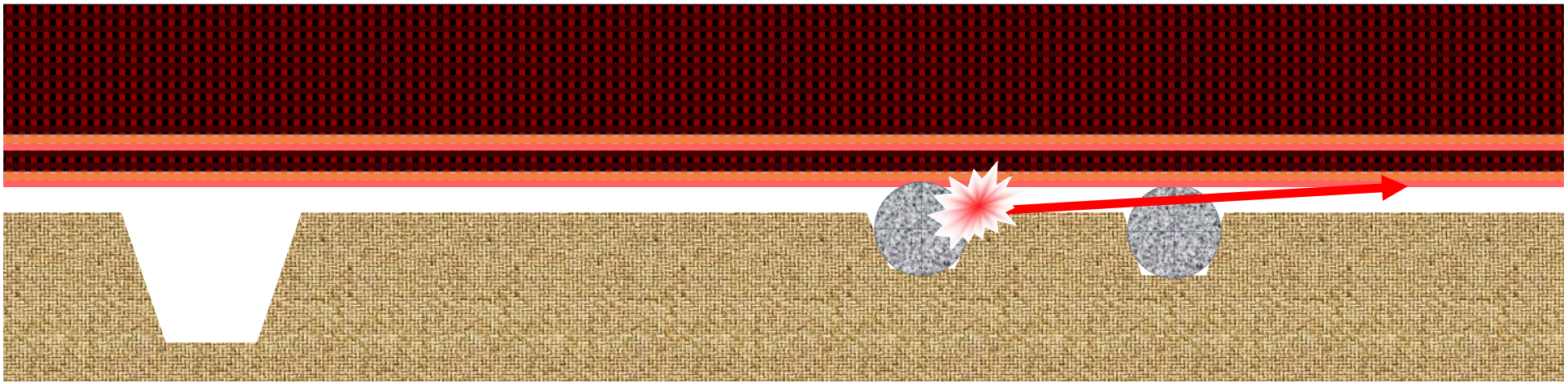
…and NOT with bulk polymer!





Three types of interactions in a system of two surfaces & a hard ball

1. Hard ball (HB) trapped in a deep surface defect ($d > r_{HO}$) – One translational degree of freedom (ODOF) → scratching
2. HO trapped in a shallow ($d < r_{HO}$) surface defect (capable to roll out) - Two degrees of freedom, namely, translation and rolling (TDOF) → HB pattern printing, "Rolling stones".
3. HB trapped in between two defects from both sides – Zero degrees of freedom (ZDOF)→ No motion until stress induced mechanical destruction or strong deformation of one of the participants generates new degree(s) of freedom

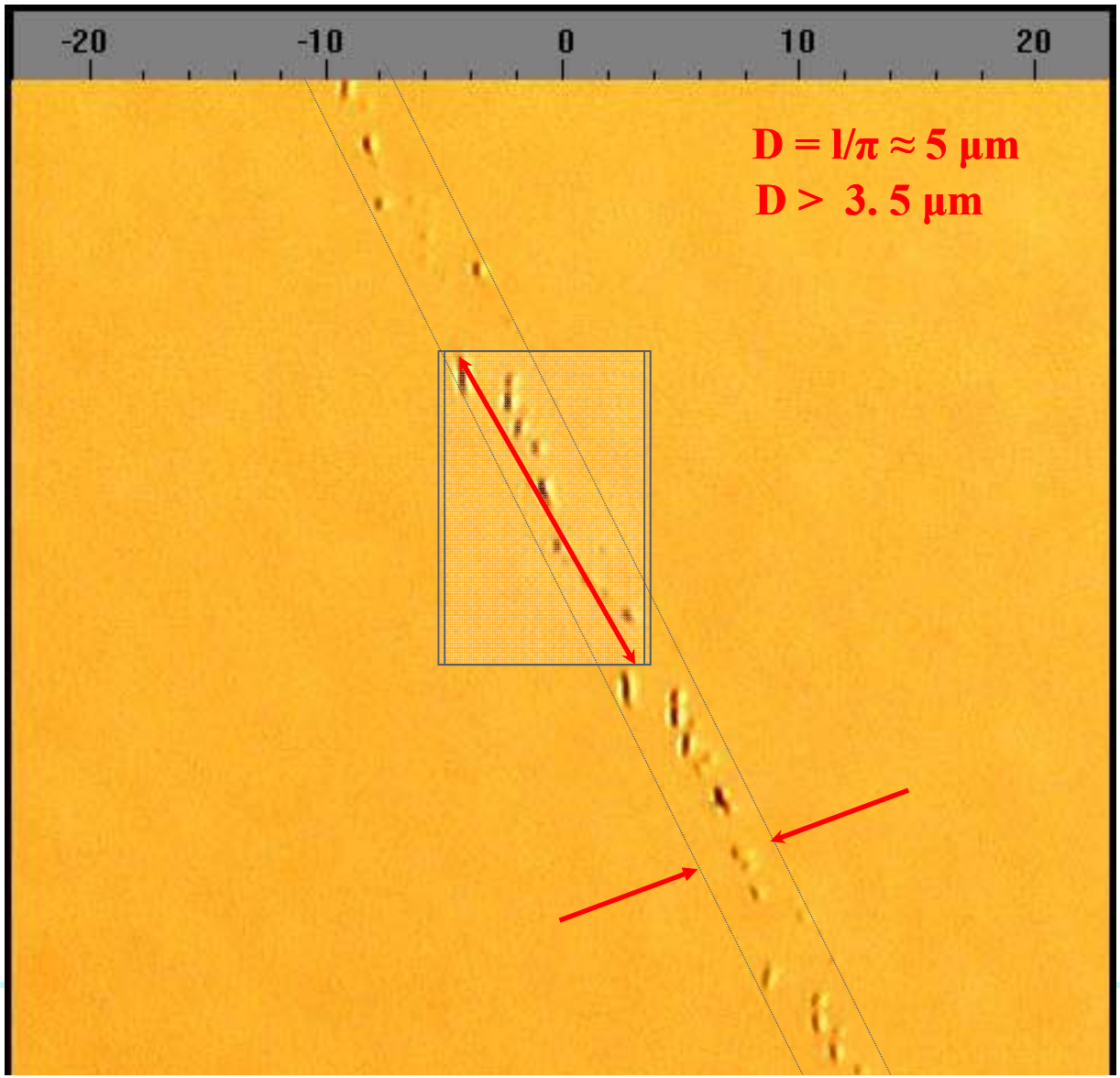


Analyze the details of the particle trajectories in the bubble-chamber analysis fashion

“Chatter”

marks

Knowing the size of the “rolling stone” is important for process development and troubleshooting?



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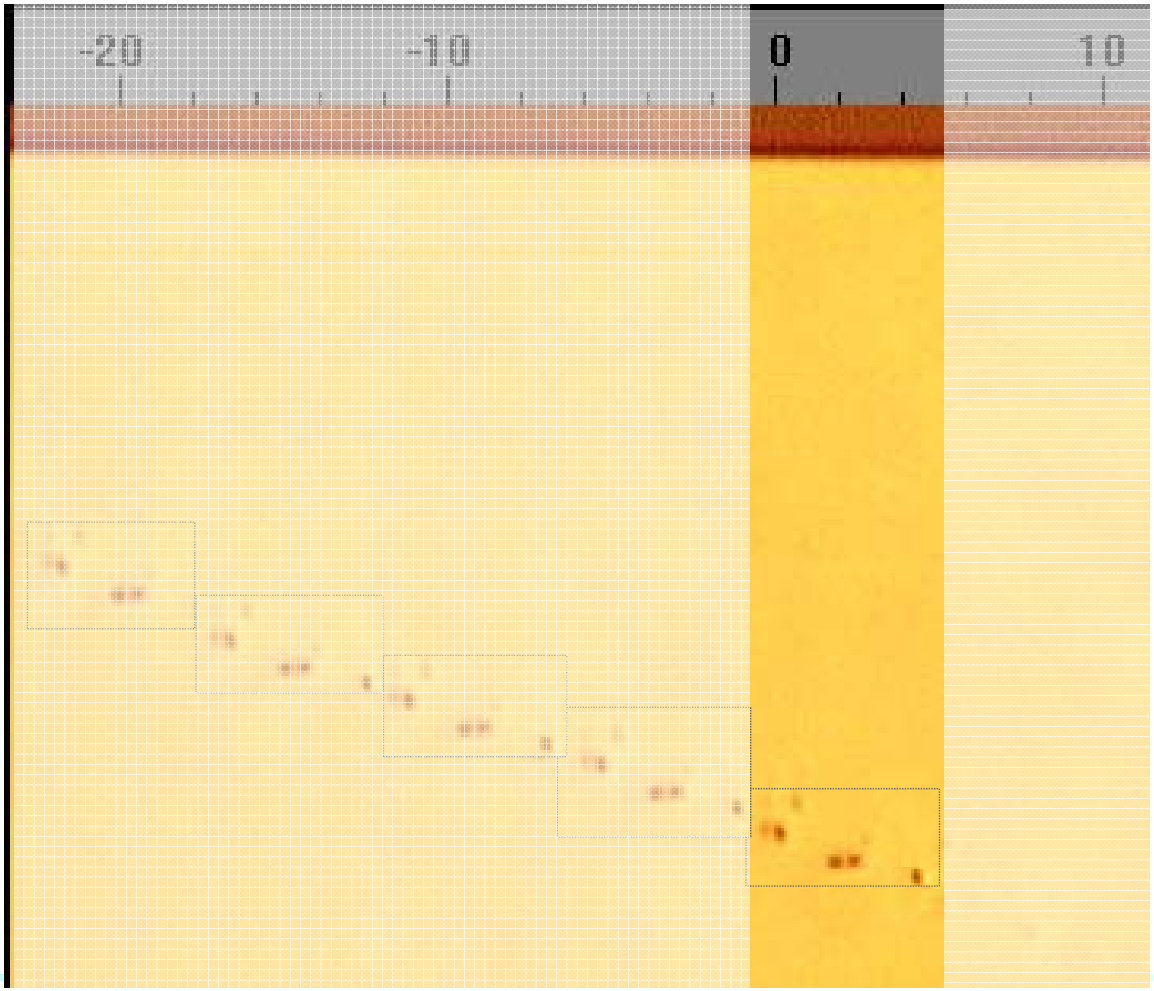
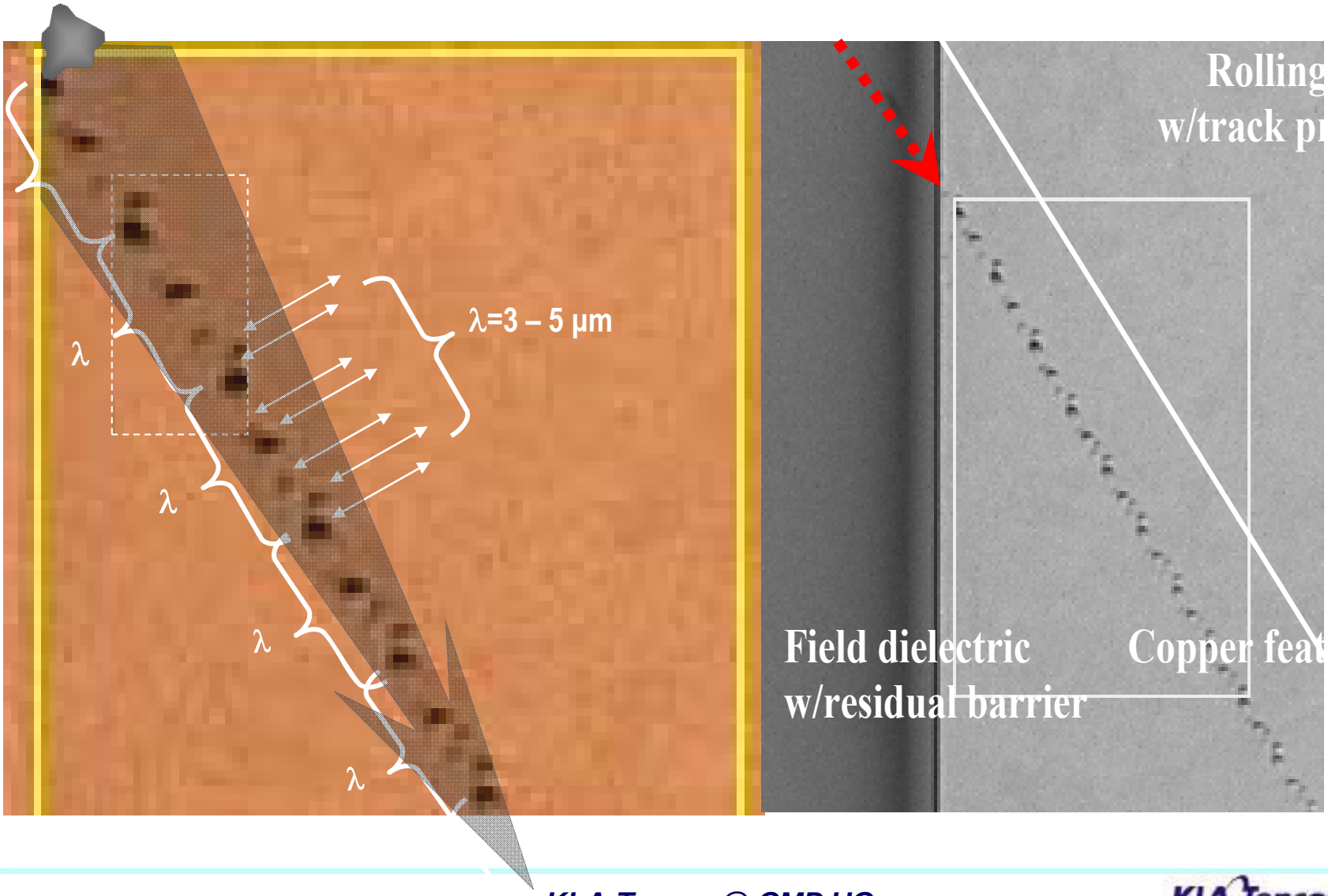
Particle erosion/distortion during rolling



Sliding on the heterogeneous CuDD surface…

…could be accompanied with somersaulting on the soft Cu sections

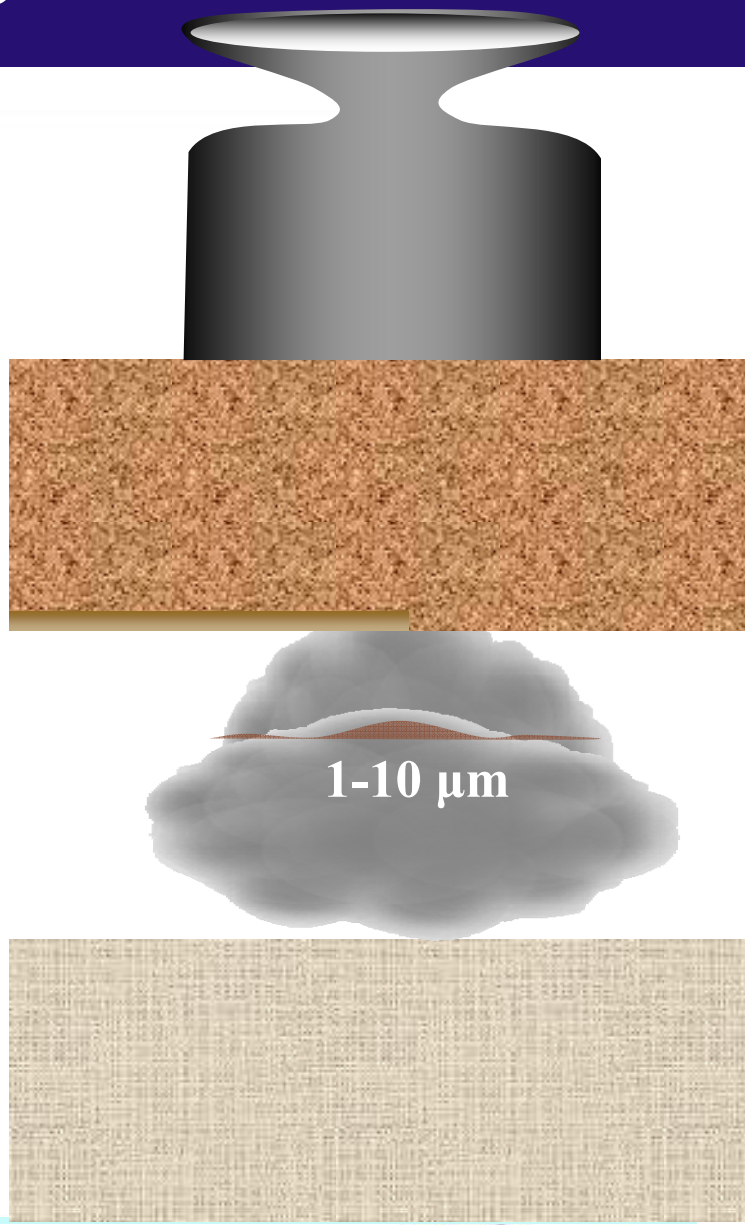
An early published case of “rolling stones”



RS profile

- Shaped like a rough ball ($\lambda/w \approx 3$)
- Sized 1-10 microns
- Hard enough to leave prints on copper, but relatively soft not to damage significantly hard dielectrics (silica).
- Compressed/eroded/deformed, but preserves its integrity while being rolled between the pad and the wafer
- Pops up suddenly, and suddenly disappears
- Causes “shallow” (width>>depth), and frequently bundle scratching in ODOF cases

Now, when we’ve profiled the bad guys let’s consider where they may come from



RS candidates: 1. Slurry aggregates

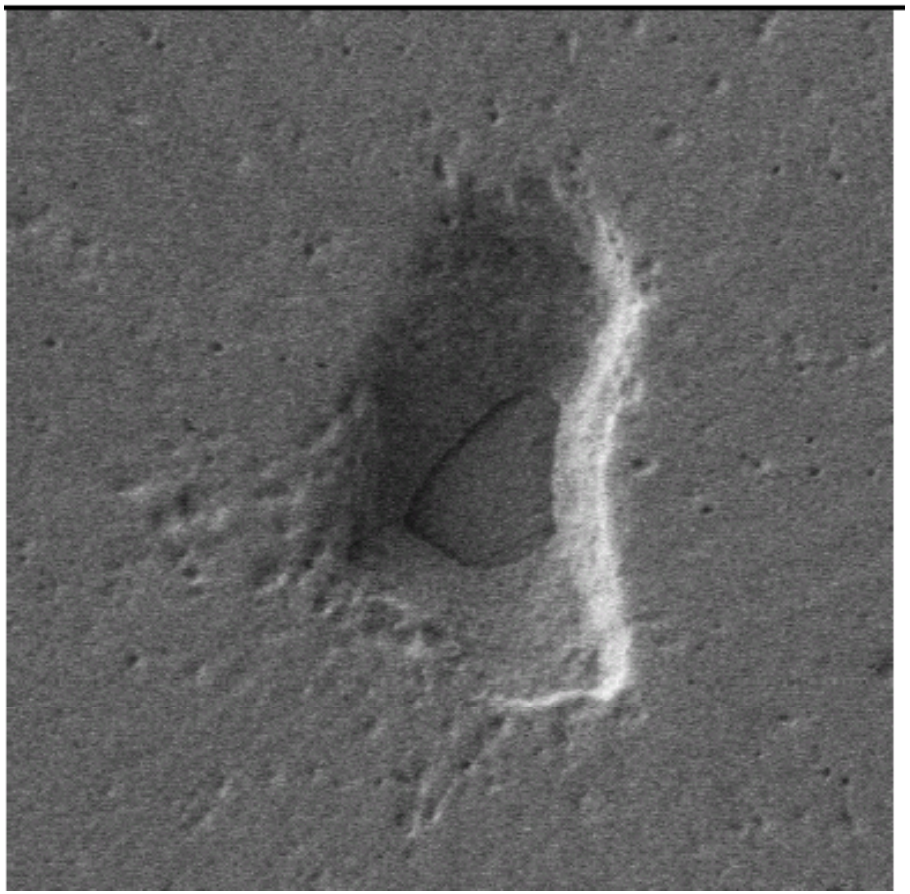
- It requires ~10^6 slurry abrasive particles to build 5 µm aggregates, which is not likely to happen in short period of time between filtering point and point of use.
- Aggregates have loose structure and it is hard to believe that, being rolled between the wafer and pad, they can withstand high pressure and friction and preserve their structural integrity, as RS do.

Slurry aggregates are not the likely candidates for the RS role

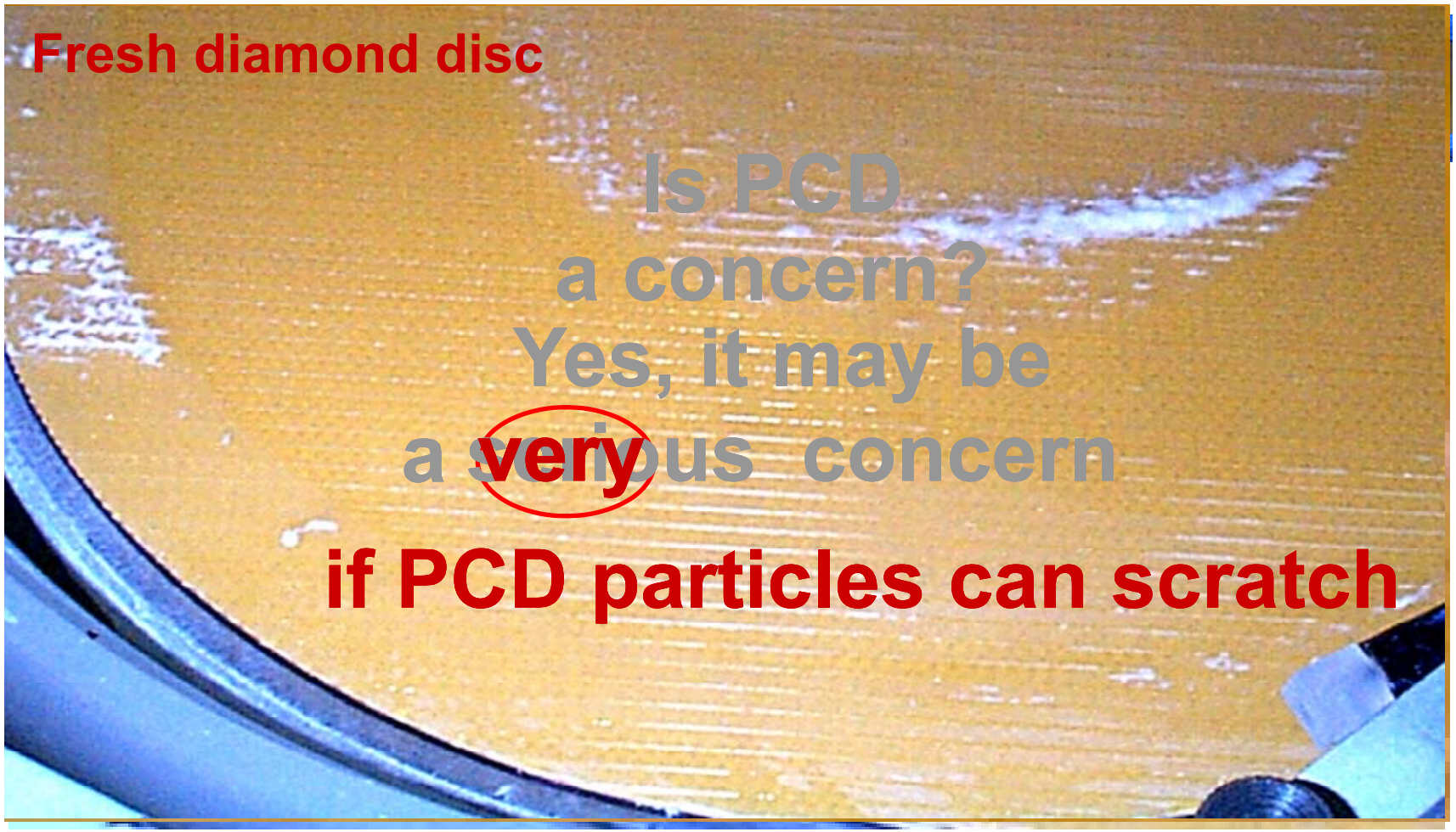
RS candidates:
2. Cu grains

- Copper grains are known to be sometimes pulled out from the layer
- However, the CuDD grains hardly get larger than 1-2 µm, especially for the low interconnect levels

Cu grains also are not very suitable to do the RS job



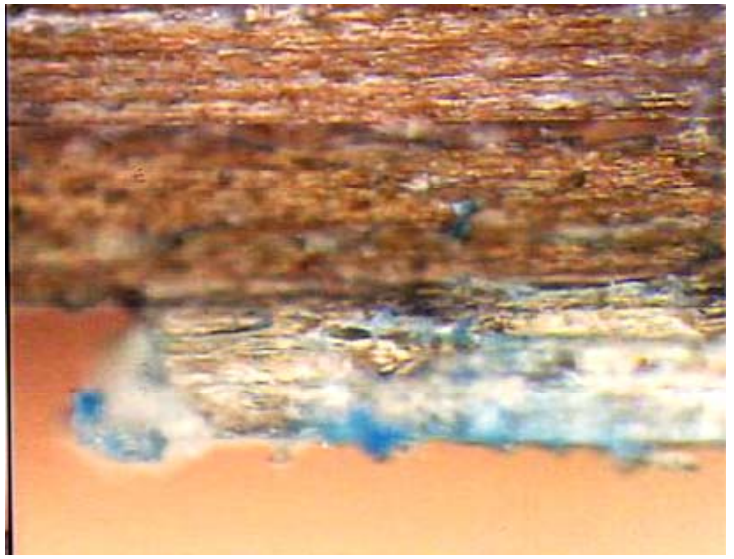
RS candidates:
3. PC debris (PCD)

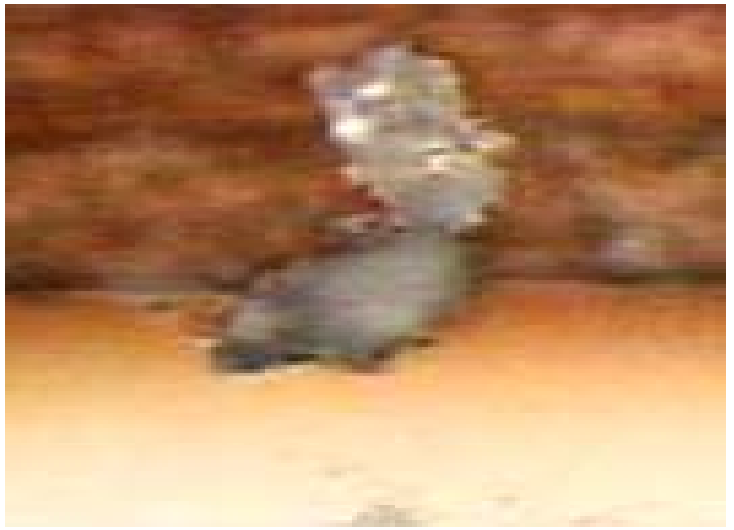


…and PCD does get this capability while being impregnated with process components

- Fractured and cracked PCD species are easily impregnated with slurry agglomerates and process by-products, converting these soft particles into reasonably hard and rough species capable to abrade and imprint.
- In the same time they still preserve some of the polymer framework helping to keep their structural integrity while being rolled between the wafer and the pad.

PCD particles are very realistic candidates for the RS role



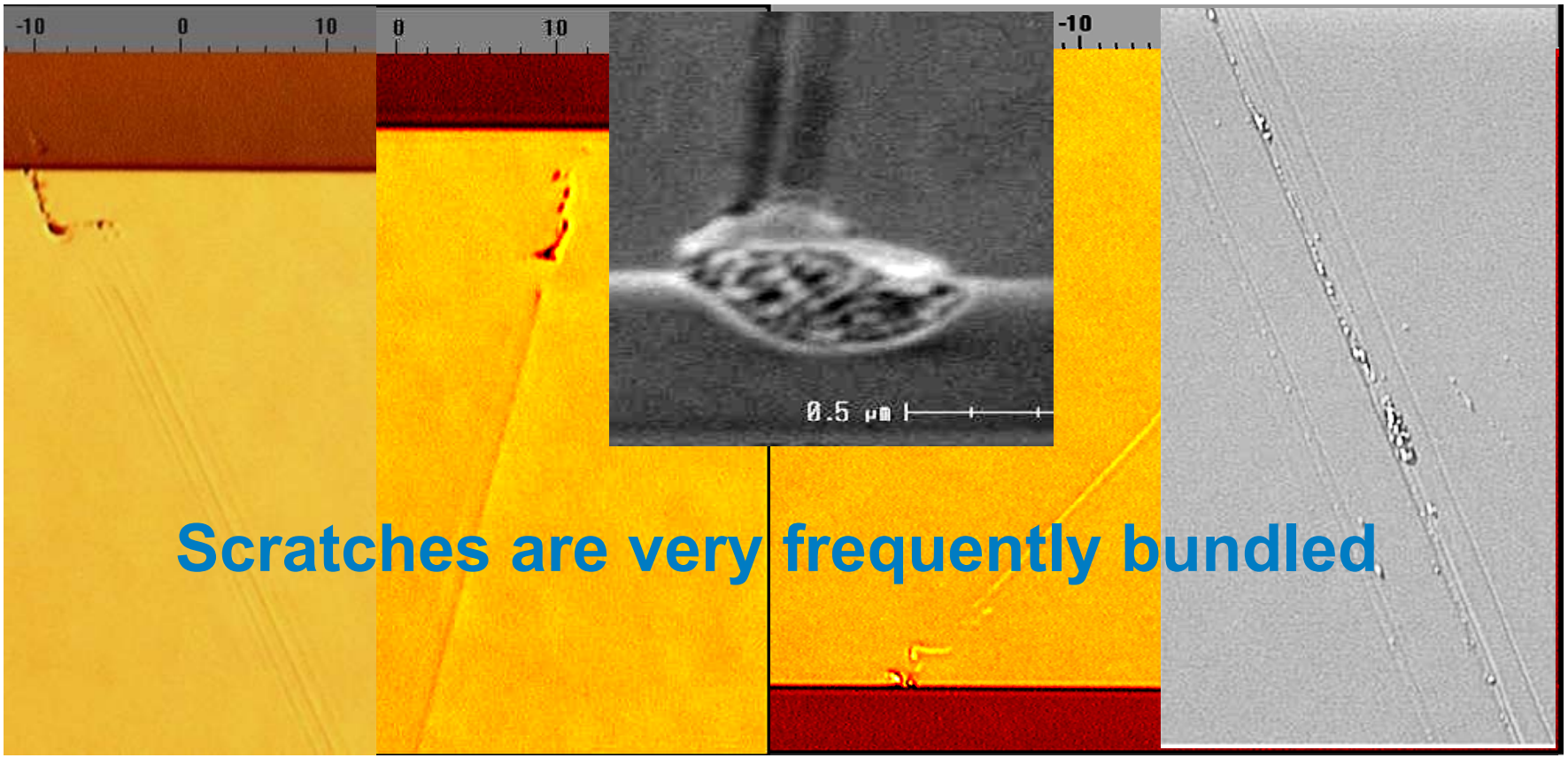


RS candidates:
4. PC_unit precipitation deposits

- PC_unit accumulates slurry precipitate over its surface and edge.
- Getting thick precipitate cracks and delaminates, releasing large particles capable to scratch.

Scratches
(ODOF and ZDOF cases)

ZDOF case- scratchier trapped between upper and lower surface defects



Scratches are very frequently bundled

An important question at the end

Out of three major process phases, namely, BULK, SL and BARRIER&BUFF, which one is the most "scratch productive"?

Considerations

I. Bulk

- RR ~ 100 A/sec (6000 A/min)
- scratch depth ~ 1000 A

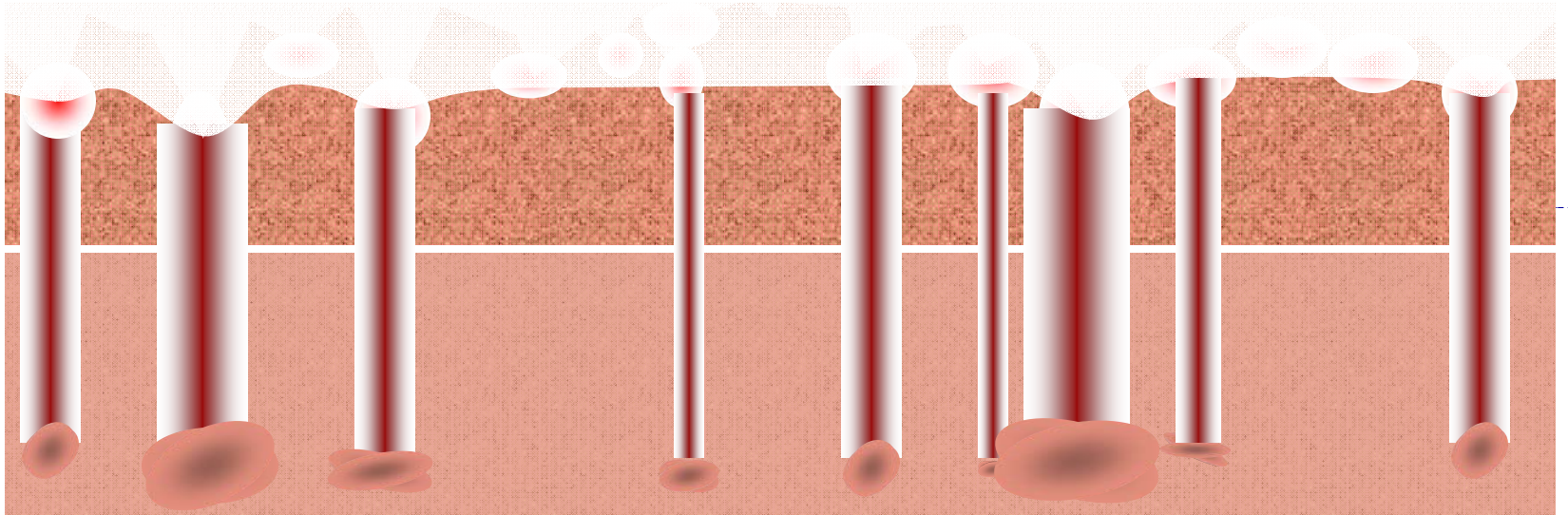
- It requires 10 sec to polish a scratch out.
- Scratch generation is not cumulative. Only the scratches generated at the last 10 seconds of the BULK step are transferred to the SL step, at which, however, they will be anywhere smoothed or removed.

Scratching generated during the BULK step would be not a very endangering matter,

If…

… if early BULK scratches were entirely harmless

And they are not!



An early scratch could be completely polished out except a few deepest spots, but these spots readily undergo stress-induced corrosion and, due to this, look like regular corrosion spots.

The lined up arrangement along the polishing tracks indicates that indeed it is just a decoration of a former scratch deepest points.

Considerations

II. SL

- The heterogeneous surface appears first at this step, and the secondary topography (recess SH) starts to develop.
- Also, scratches induced at this phase, will have little chance to be removed at the next step, especially if high selectivity BARRIER process is used.
- However, everything is mild at SL (DF, amount of material to be removed, RR, pad load etc.), so scratch generation efficiency (frequency, depth, length) is significantly lower and the scratches are much shallower than the BULK ones.

Soft Landing --- Mild (if any) Scratching

Considerations

III. Barrier&Buff (No Copp… al HS case)

B&B step appears to l… most quality endangering one l… e of:

- **Cumulative scra… tion**
- **Poor (CuO) l… possibility of stick-and-slip**
- **High see… /**
- **Expo… terial (Cu, Barrier, DE) surface h… y, resulting in sharp COF and other …ace property undulations.**

B&B are the most endangering CMP steps as far as the scratching is concerned!

Summary

- **Pad conditioning debris and conditioning unit deposits should be seriously taken into account** while considering scratching issues
- **Although BULK scratches are** normally wiped out**, it may leave behind lined up sequences of stress induced corrosion spots.**
- **B&B** potentially are **the most scratch-productive** steps, thereby **PC action at this phase has to be as delicate as possible.**
- **Pad break-in procedure should be never performed at more aggressive accelerative conditions** than the normal process ones.
- **PC action** is critical at each process step and **has to be finely tuned to the lowest possible aggressiveness, in sensitive cases (deep sub-100 nm technology nodes) imposing on extremely tough requirements on the geometry&mechanics of the PC_device and PC_unit**