

## Material & Design Considerations for Zero Defect CMP Pads

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Copper CMP process defectivity shows high correlation to process yield. For a given slurry, mechanical and tribological properties of the pad impact planarization and defectivity performance of the process. Typically, hard pads show higher defectivity and slurry distribution at the wafer-pad interface influences defectivity. Additionally conditioning process generates organic debris comprised of pad material and inorganic constituents such as polish by-products and slurry particles and is a source of significant defectivity<sup>1</sup>. Conventional pad architecture must meet material requirements as well as provide adequate channels for slurry distribution and by-product removal. Significant effort has been made to overcome limitations of conventional pads through investigation of the role of mechanical and tribological properties of polish surface<sup>2-4</sup>. Similarly, efforts have been made to develop an understanding of the role of conditioning and grooving with respect to surface asperities and slurry distribution<sup>5-7</sup>. While significant improvements have been made, key performance limitations of conventional planar pad architecture remain.

A more complete understanding of the complex role of the pad surface-wafer surface interaction is needed to develop next generation pad technology. Surface asperities and non-uniformity of these asperities can lead to non-uniform contact across the wafer-pad interface. The contact non-uniformities lead to pressure non-uniformities and are a source of defects. Two key design requirements dictate that polishing surface provide uniform contact across the wafer surface, and have the ability to transport slurry across the wafer-pad interface. As detailed in previous publications, the Planarizer<sup>TM</sup> design leverages a novel compression compliance mechanism which enables significant advantages with respect to within-wafer (WIW) and within-die (WID) performance<sup>8-10</sup>. Through the capability of the innovative approach, utilization of novel polishing materials is enabled with an associated process space which provides for low defectivity with low slurry consumption. The unique pad architecture decouples wafer and die-scale performance<sup>8-10</sup>. In this paper, we extend the discussion to include benefits of the Planarizer<sup>TM</sup> pad design, along with pad materials and process parameters, in affecting defectivity performance.

CMP process parameters and process recipe sequence has a significant impact on the level of scratches, particles and organic residue on the polish surface. Planarizer<sup>TM</sup> process parameter space is identical to conventional pad parameter space. Initial experiments were conducted to understand the performance dependencies on pad design. Subsequently, pad material experiments were undertaken using the same process recipe parameters and recipe sequence as used for conventional pads. Finally, process was optimized for process recipe and process recipe sequence.

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Design parameters A and B impact slurry distribution ability and local compliance response. Figure 1 displays defectivity response for wafers polished using a baseline polishing material on a nominal Planarizer™ design based upon variants of these parameters. Design parameter A shows a response to defectivity while design parameter B does not show a significant response to defectivity. A qualitative increase in defectivity is observed with parameter A. The ability to overcome conventional material performance limitations and more importantly, leverage novel materials which are typically more mechanical limiting, requires the ability to circumvent these fluid distribution related contact limitations and other sources of defectivity.

By leveraging the inherent flexibility of the Planarizer™ design attributes, a wider spectrum of materials can be incorporated. The associated materials property margin increase leads to improved overall process performance. The innovative pad design of the Planarizer™ bypasses the traditional approach of a continuous polish surface, thereby enabling significantly more efficient slurry distribution under the wafer surface (in turn eliminating center to edge gradients) and providing more effective removal of polish debris during processing. A detailed fluid film thickness study was conducted using the dual-emission UV enhanced dye fluorescence (DEUVEF) technique.<sup>11</sup> By monitoring the fluid boundary layer thickness as a function of pad design and process parameters, a greater understanding of slurry usage and distribution effectiveness can be established. A direct observation of fluid film thickness was made as a function of down force, table speed and fluid flow rate on both conventional continuous polish layer stacked pads and the novel design of the Planarizer™. Figure 2 displays the normalized fluid film thickness results as a function of process parameters for the conventional pad and two pads of novel Planarizer™ design (but which leverage different design attributes). Note that Planarizer™ design A and conventional pad show similar response to process parameters. Consistent with prior published results, the fluid layer film thickness decreases with increased table speed and downforce, but increases with higher fluid flow rate for conventional pads. However, Planarizer™ design B shows a significantly different response in fluid layer thickness. As shown in Figure 4c, note particularly that a flat response of the fluid layer thickness can be achieved as a function of flow rate with a suitable choice of design criteria. Figure 3 displays the corresponding results of Cu wafers processed at the lower flow rates. Note that the removal rate shows expected response to slurry flow rate, and defectivity is quite stable down to below 100 ml/min. At the 50 ml/min condition, an incremental increase in WIWNU and defectivity is observed. The core flexibility of the Planarizer™ architecture enables process performance capability on par with that of conventional pads at significantly lower slurry flow.

With the understanding of fluid layer thickness dependencies as a function of Planarizer™ design attributes, additional experiments were conducted aimed at improving performance with conventional and novel pad materials. Via materials modifications in the friction coefficient and nature of polymer backbone chain, the defectivity response can be modulated while maintaining planarization performance. Figure 4 displays the normalized defectivity performance for pads across material property parameter A and B. A significant improvement in defectivity performance can

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be achieved by modulating material parameter B. Defectivity performance superior to the conventional pad architectures is readily achieved.

CMP process parameters and process recipe sequence have a significant impact on overall defectivity. Best defectivity performance, is achieved by optimizing pad design in conjunction with choice of polish material and process conditions. Figure 5 displays the normalized defectivity performance for two key parameters of the polish process for a given combination of pad design and materials selection. Results show that optimum process space with respect to defectivity is film dependent, copper CMP process shows best results at low-low combination of the process parameter and process sequence space while oxide CMP process shows best results at high-high combination of process parameter and process sequence space.

Figure 6 displays a comparative performance breakdown of the conventional pad to the Planarizer<sup>TM</sup> technology with respect to rate, uniformity, rate stability, planarity, defectivity and slurry usage/cost for the copper CMP application. As indicated, while the removal rates of the novel design are on par with that of the conventional design, the novel pad design yields overall performance benefits on WIWNU, defectivity, and slurry consumption. With further modifications and optimization of the overall system, zero CMP induced defect levels might be obtainable.

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		Design Space		
Design Parameter A	High	TBD	TBD	1.5
	Medium	TBD	TBD	1.3
	Low	1.1	TBD	1.0
		Low	Medium	High
		Design Parameter B		

Figure 1: Normalized nominal defect count for pad variants based upon two key pad design parameters.

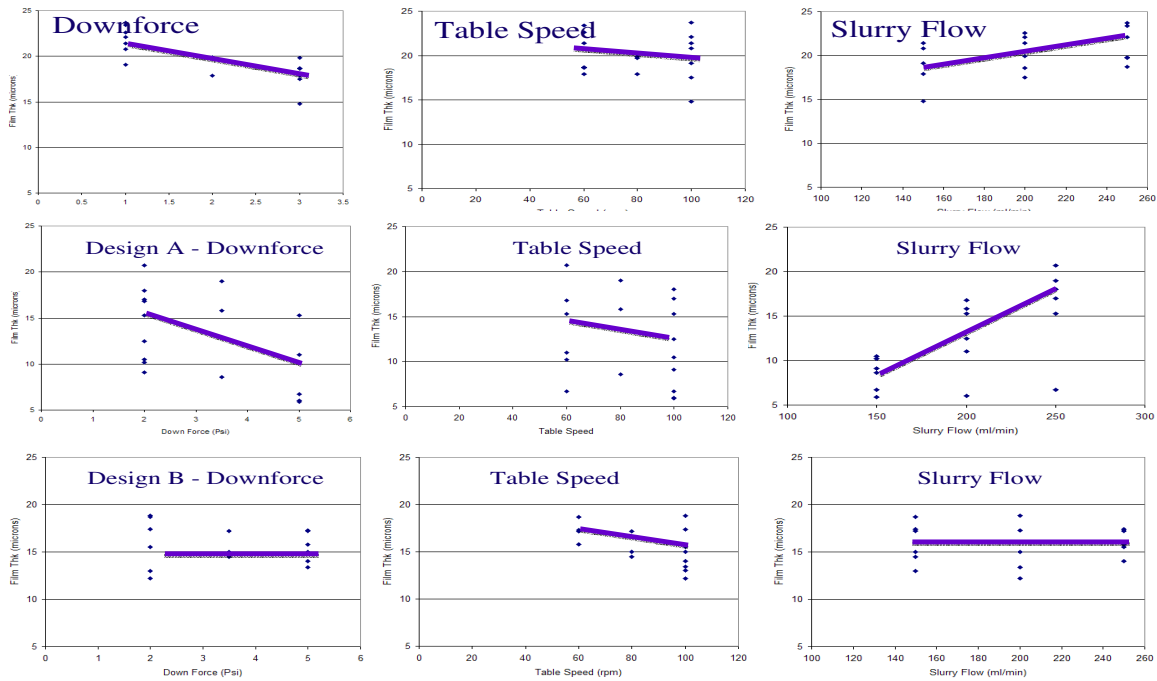


Figure 2: Normalized fluid boundary layer thickness as a function of three key process parameters (downforce, table speed and slurry flow rate) across three different pad architectures: Conventional continuous-surface, stacked pad (top row), Planarizer™ pad with design set A (middle row) and Planarizer™ pad with design set B (bottom row).

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Material Space			
Material Parameter A	High	1.5	TBD
	Medium	1.3	0.9
	Low	1.0	TBD
		Low	High
			Material Parameter B

Figure 3: Normalized nominal defect count for pad variants based upon two key pad material parameters.

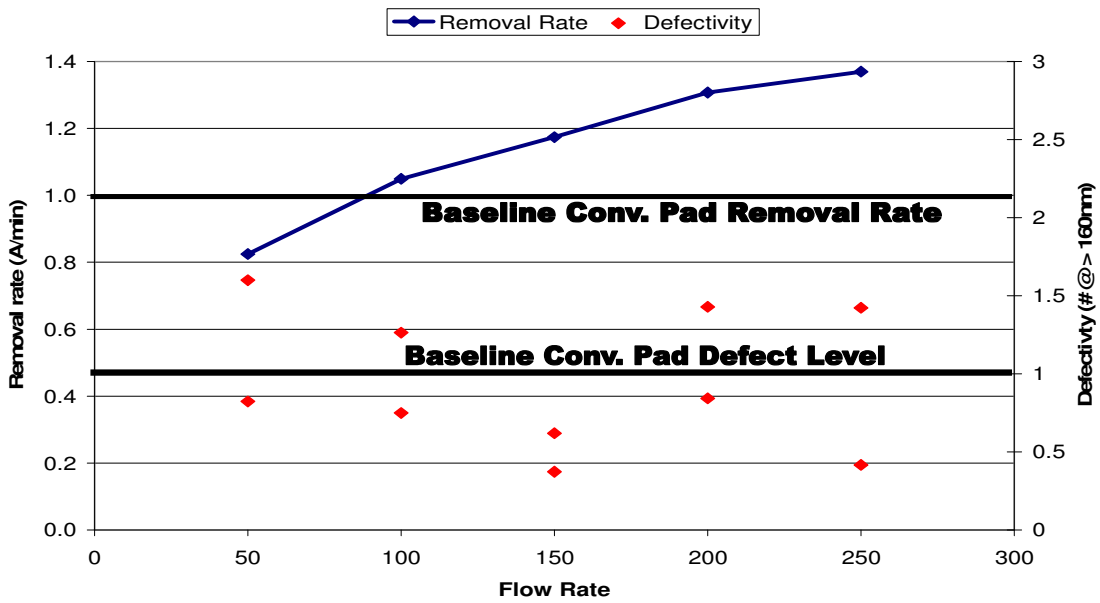


Figure 4: Normalized wafer-scale response for removal rate, uniformity and defectivity as a function of fluid flow rate for the Planarizer™ based upon design attribute set B.

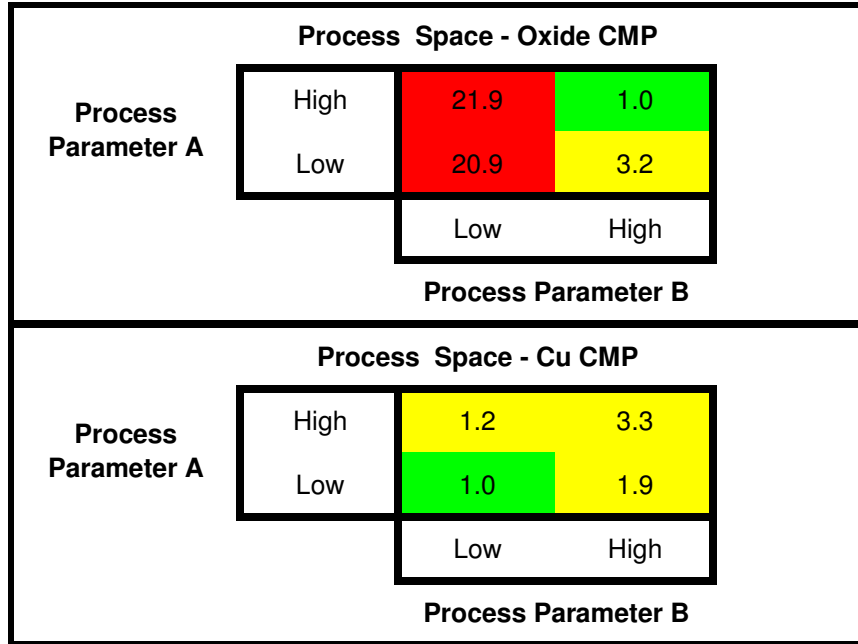


Figure 5: Normalized nominal defect count as a function of two key process parameters across two different slurry applications: a) oxide CMP, b) copper CMP.

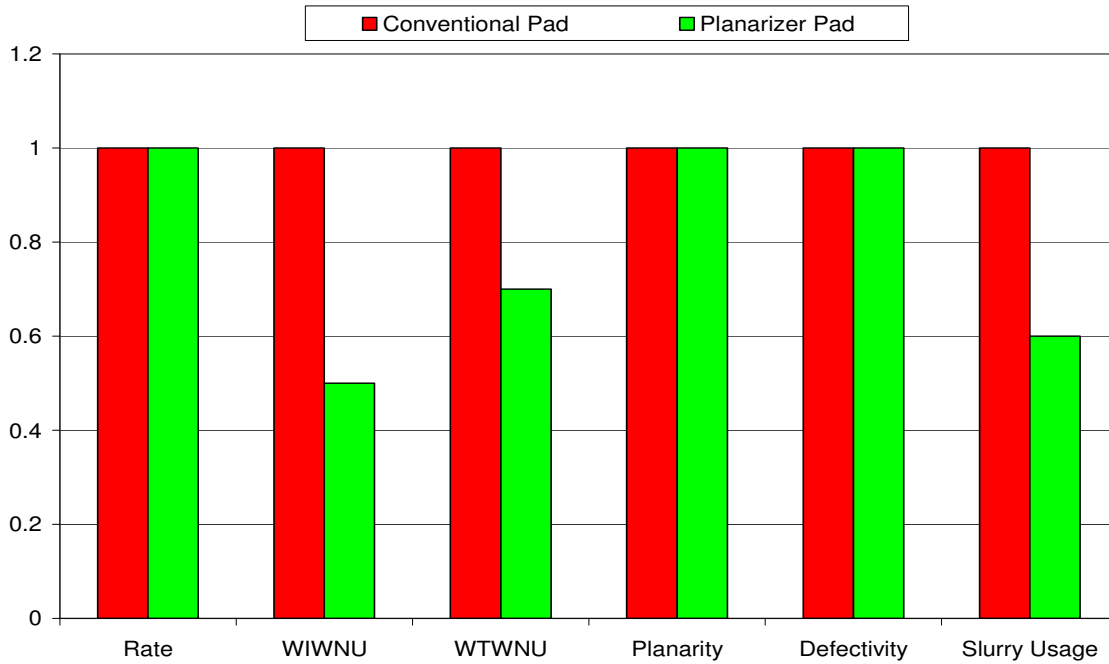


Figure 6: Summary results comparison of the Planarizer™ vs. the conventional pad for rate, uniformity, rate stability, defectivity and slurry usage.