PadProbe™ for Monitoring and Control of Pad Surface

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A novel PadProbe™ has been developed for CMP machines of all rotational, orbital and linear types. This completely non-invasive instrumentation can be easily installed on the table of any polisher within minutes, with neither design integration into the polisher nor any changes in already-developed planarization processes.

The PadProbe™ allows for either periodic or continuous in-situ, in-process control of two crucial CMP parameters:

- Pad Wear (dynamics of Pad Thickness Changes) and
- Pad Condition (dynamics and level of Pad Friction).

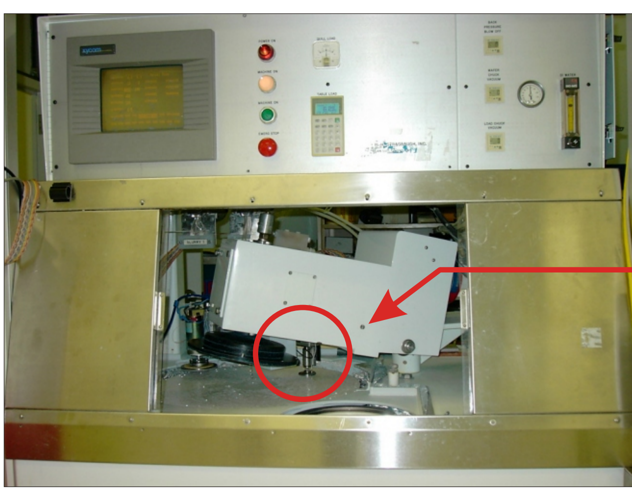
This reliable, inexpensive probe is very effective in the fab environment for the following:

1 - shows when to start and when to finish ex-situ pad conditioning,
2 - shows when either more or less conditioning is required,
3 - shows when pad is worn out and has to be replaced,
4 - helps improve wafer-to-wafer uniformity of polishing by maintaining the pad in the same optimal condition.

Pad life is currently conservatively estimated by the number of polished wafers. The direct, real-time measurements of the Pad Wear will allow for exact determination of the time to replace the pad.

Pad surface condition is currently estimated by the results of wafer polishing. The direct real-time monitoring of pad surface will allow for better control of a conditioning process. Pad Condition, defined as coefficient of friction of the pad surface, depends on contacting materials (wafer, pad, chemicals, byproducts), surface roughness (wafer pattern, pad conditioning), relative speed, contact pressure, temperature, presence of water or slurry, its flow rate, distribution (pores, grooves), viscosity. Therefore, Pad Condition is the most comprehensive parameter characterizing the state of the pad surface.

Examples of the typical experimental data correlating Pad Wear (shown as pad thickness change), Pad Condition, Wafer Removal Rate (RR), and within the wafer non-uniformity (WIWNU) are shown on the graphs on page 3 for wafers polished with ex-situ pad conditioning. The experiment included polishing of 4 groups of wafers, each group consisting of 3 blanket PTEOS wafers, with pad conditioning between the groups and without conditioning within the groups.



An initial portion of the graphs from the beginning T0 to moment T1 on the time scale corresponds to the pre-conditioning of a just-installed pad with a conditioner. During this procedure the Pad Thickness reduces, the Pad Condition increases and reaches its initial working level, designated as 100%, at the time T1', after which it practically does not change. The second portion of the graphs from T1 to T2, as well as the portions T3 to T4, T5 to T6, and T7 to T8 correspond to polishing procedures, not accompanied with in-situ conditioning. During these periods of time the pad surface gets clogged with particles and gradually loses its quality, but not its thickness. Therefore, the Pad Thickness stays substantially constant, while the Pad Condition gradually drops to the level close to 70% of the initial working level. The ex-situ conditioning procedures (periods T2 to T3, T4 to T5, and T6 to T7 on the time scale) restore the polishing properties of the pad, and corresponding areas on the graphs are similar to the one described above for the interval T0 to T1. Thus, Pad Thickness reduces (Pad Wear increases) during every conditioning procedure, while Pad Condition rises during conditioning and then falls during polishing.

When the polishing pad is worn out, its thickness reaches a certain level when the pad has to be replaced. This is defined as the critical wear level.

The graphs also reflect how the wafer RR and WIWNU change in the course of the above described polishing and conditioning periods. The RR and WIWNU measurements were performed ex-situ and represented with bars. Pad surface conditions define the removal rate (for the given combination of materials and process parameters), with the latter increasing when pad is conditioned and decreasing when pad loses its quality during polishing. Pad surface conditions also define WIWNU, which substantially increases during polishing and drops after conditioning. During the experiment, after polishing the second group of wafers the pad was under-conditioned (period T4 to T5) and the Pad Condition didn't reach the level of 100%. As a result, both RR and WIWNU for the group 3 were worse than for other groups. Thus, there is a strong correlation between Pad Condition, RR, and WIWNU.

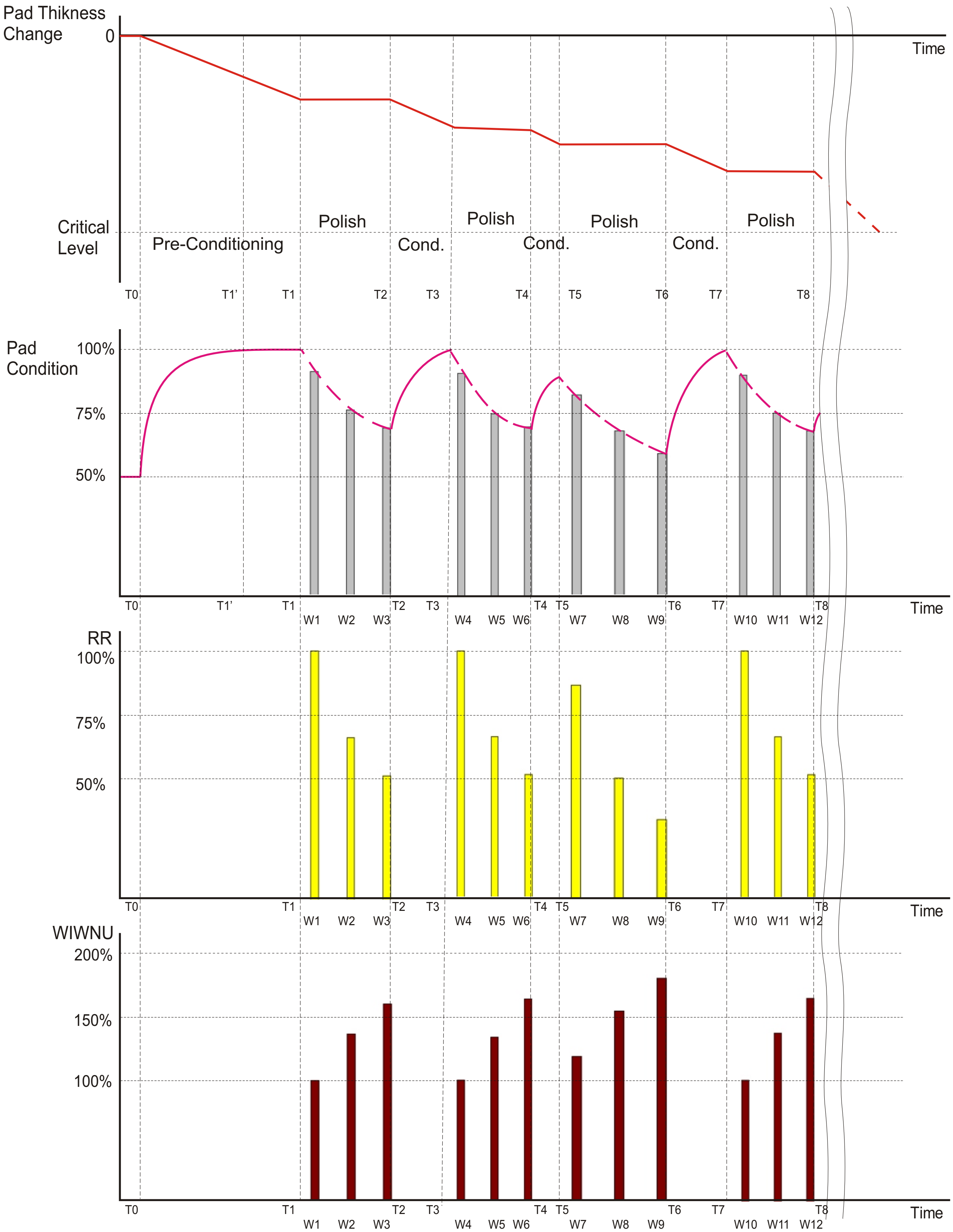
With time, Pad Condition level can gradually decrease, e.g., due to pad surface erosion, despite continuous conditioning. After Pad Condition reaches certain critical threshold, when conditioning cannot bring pad surface back to the state, which provides allowable RR and WIWNU, the pad has to be replaced.

The data measured with the PadProbe™ has very good correlation with the removal rate and WIWNU, which are the most important characteristics of polishing.

Tables 1-3 on page 4 show estimated potential effects of the PadProbe™. Real-time monitoring of the pad thickness and surface conditions allows for extended pad use, as long as both parameters are above the critical threshold, thus increasing pad life. This allows for an increased number of wafers polished with one pad, less frequent pad replacements, and thus results in substantial savings on pads cost (Table 1) and reduced equipment down-time (Table 2).

As mentioned above, during pre-conditioning of new pads, the Pad Condition reaches 100% level at the moment T1', and remains constant afterwards. Shorter pre-conditioning, stopped once Pad Condition reaches 100%, can result in additional process time savings and increased pad life (Table 2).

Better polishing results due to improved wafer-to-wafer repeatability with the Pad Condition monitoring reduces number of defective wafers (Table 3).


Pad Thikness Change
0
Time
Critical Level
Pre-Conditioning
Polish
Cond.
Polish
Cond.
Polish
Cond.
Polish
T0
T1'
T1
T2
T3
T4
T5
T6
T7
T8
Pad Condition
100%
75%
50%
W1
W2
W3
W4
W5
W6
W7
W8
W9
W10
W11
W12
Time
RR
100%
75%
50%
Time
WIWNU
200%
150%
100%
Time

EFFECTIVENESS OF PadProbe™

Table 1

Effect of Accurate Determination of Critical Pad Wear and Time for Pad Replacement					
	Without PadProbe	With PadProbe			
Number of polished wafers per pad	600	700	800	900	1000
Pads per 10,000 wafers	16.7	14.3	12.5	11.1	10.0
Cost of pads per 10,000 wafers (assumed pad price $500)	$8,333	$7,143	$6,250	$5,556	$5,000
Pads cost saving per 10,000 wafers	-	$1,190	$2,083	$2,777	$3,333

Assumptions: Currently, pad is replaced after a conservatively predetermined number of polished wafers, while the PadProbe will allow the fab to safely increase the number of polished wafers for as long as pad wear is smaller than the critical wear

Table 2

Effect of Time Saving due to Less Frequent Pad Replacements and Shortened Pre-Conditioning					
	Without PadProbe	With PadProbe			
Number of polished wafers per pad	600	700	800	900	1000
Pad replacements per 10,000 wafers	17	15	13	12	10
Total down-time due to pad replacement per 10,000 wafers, hr	8.5	7.5	6.5	6.0	5.0
Time saved on pad replacements per 10,000 wafers, hr	-	1.0	2.0	2.5	3.5
Number of pad pre-conditionings per 10,000 wafers	17	15	13	12	10
Total time of pad pre-conditioning, per 10,000 wafers, hr	4.3	3.0	2.6	2.4	2.0
Time saved on shortened pre-conditioning per 10,000 wafers, hr		1.3	1.7	1.9	2.3
Total time saving per 10,000 wafers, hr	-	2.3	3.7	4.4	5.8

Assumptions: Pad price - $500, Wafer price - $ 1,000
Pad replacement time - 30 min.
Pad pre-conditioning time: without PadProbe - 15 min., with PadProbe - 12 min

Table 3

Effect of Reduced Number of Defective Wafers per Pad due to Determination of Pad Condition					
	Without PadProbe	With PadProbe			
Reduction in pad-caused defected wafers, per pad	-	1	2	3	4
Wafers cost saving per pad (assumed wafer cost $1000)		$ 1,000	$ 2,000	$ 3,000	$ 4,000
Cost saving per 10,000 wafers (assumed $1000/wafer, 1000 wafers/pad)		$ 10,000	$ 20,000	$ 30,000	$ 40,000
Cost saving per 10,000 wafers (assumed $5000/wafer, 700 wafers/pad)		$71,429	$142,857	$214,286	$285,714

Assumptons: Currently, non-optimal pad condition is not detected and causes defected wafers, while the PadProbe will allow the fab to avoid defected wafers, as long as PadCondition stays constant