CMP Process and Consumables Evaluation with PadProbe®

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Abstract

The PadProbe® with simultaneous real-time measurements of PadFriction and PadWear was used to evaluate a copper CMP process and consumables.

During conditioning, PadFriction reaches its optimum level. Any further continued conditioning has to be eliminated, as it wears the pad without any improvement to its surface. The moment when PadFriction is stabilized at its optimum level defines the end-point of conditioning.

Monitoring PadWear allows for determination of pad life and can trigger an alarm signal when the critical wear level is reached, for example, based on the depth of pad grooves.

When PadFriction drops out of the process window, there are two common causes: if PadWear is close to its critical level the pad has to be replaced, if PadWear is still low the conditioner has to be replaced.

The observed correlation of the in-situ measured PadFriction with post-polish measured Removal Rate and Non-Uniformity of Polishing confirms the PadProbe® usefulness for in-situ process control. Several types of conditioners were tested on two types of pads. The simultaneous measurements of PadWear and PadFriction allowed us to effectively choose the optimum conditioner-pad combination.

Keywords: CMP, PadProbe, pad friction, pad wear.

Introduction

In semiconductor manufacturing, chemical mechanical planarization (CMP) is one of the least stable processes. Its performance stability is affected by a large number of variables, including process parameters and consumables. CMP is also one of the most expensive processes, with most of the cost of ownership in the CMP consumables, such as slurry, polishing pad and pad conditioner. In the industry practice, CMP process and consumables evaluation, as well as CMP process control, rely heavily on feedback from metrology measurement of polished wafers. In many cases, it means waiting for post-polish wafer electrical and defectivity tests before a problem be addressed on a polishing tool. Thus, it is widely desired that in-situ monitoring of CMP process can be established. By using the PadProbe®, the real-time friction between pad and wafer can be monitored, which provides information on pad surface properties and slurry flow dynamics on the pad, which are directly related to polishing performance. In addition, by monitoring pad wear rate, the end-of-life for both pad and conditioner can be readily determined.

Experimental Results

The PadProbe® was installed on the CMP machine made by Ebara Corporation.

PadWear was measured during polishing and conditioning. The results, presented in Fig. 1, show measurable wear during ex-situ conditioning and no wear during pad polishing. Monitoring pad wear allows the process operator to determine when it reaches its critical level, and so to know exactly when to replace the pad.

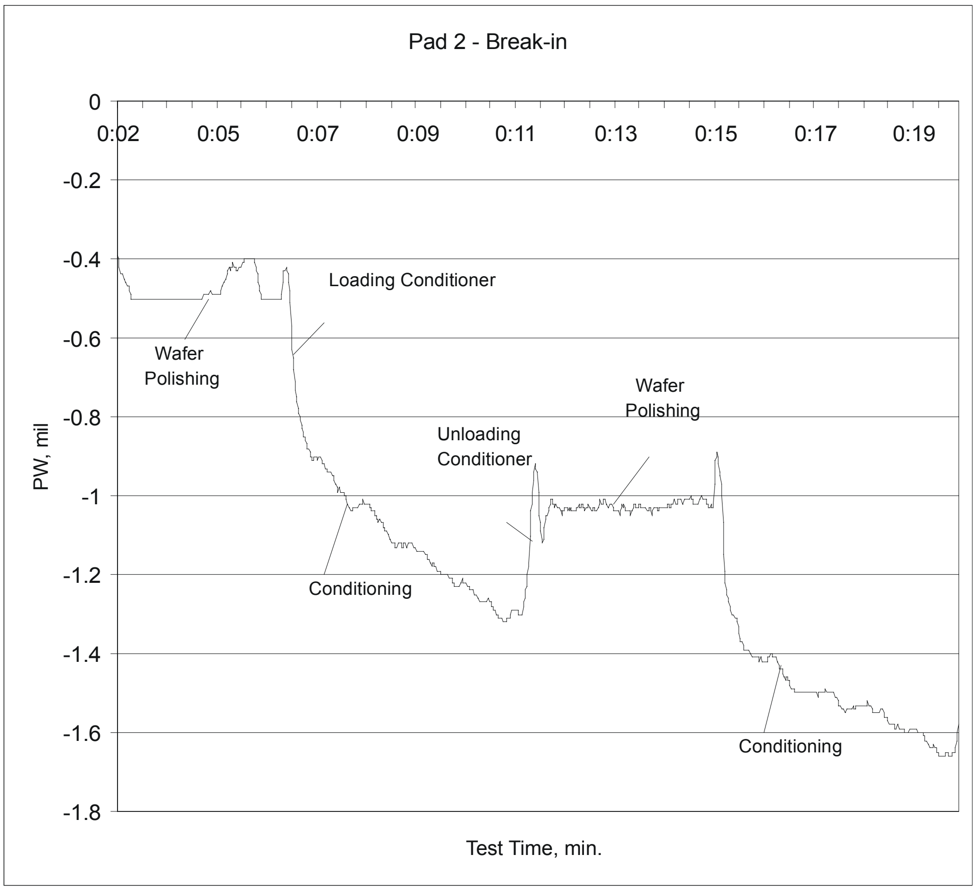
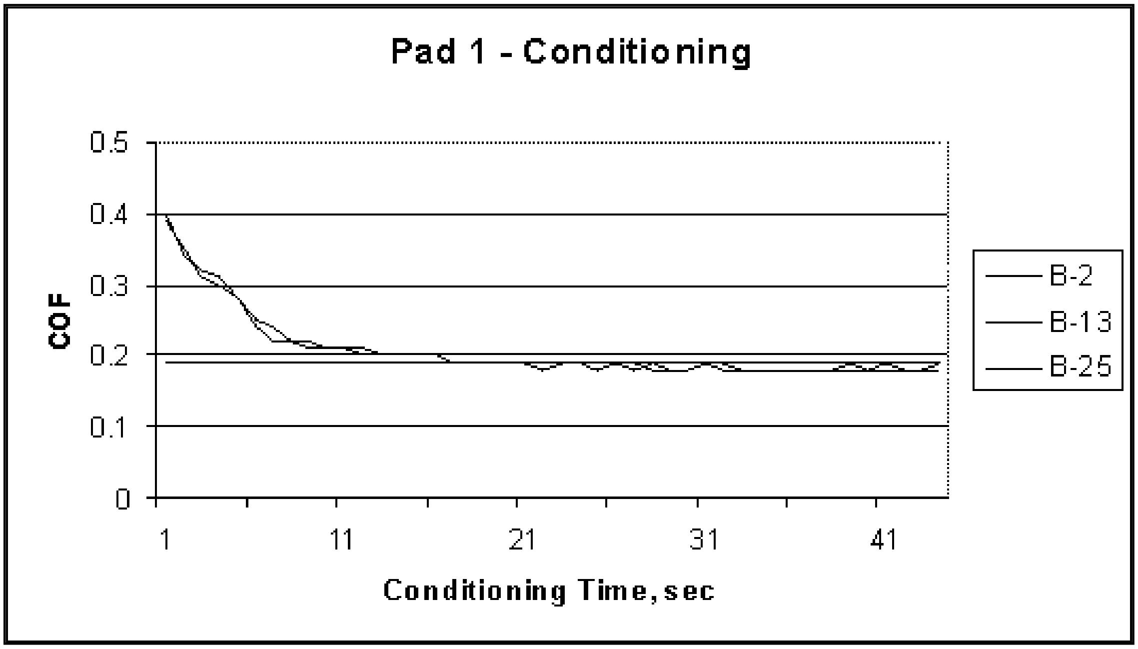


Fig. 1. PadWear Dynamics During Polishing and Conditioning

PadFriction was measured during pad conditioning. The results are presented in Fig. 2 for two similar pads. Out of 25 wafers polished on each pad, three (2nd, 13th and 25th) were blanket monitor-wafers that are presented in the plots. During conditioning PadFriction changed in a quite repeatable way, reducing from about 0.4 to about 0.2 and then stabilizing. The exceptions were blanket wafers #2 that were started on a preconditioned pad and so had the 0.2 level of friction coefficient from the beginning. As the friction stabilization took place within less than 20 s, the rest of the 45-s conditioning time was not only wasted in terms of polishing productivity, but also produced excessive pad wear. Thus, use of the PadProbe® to monitor the end-point of conditioning and to stop conditioning when PadFriction is saturated may dramatically reduce pad consumption.



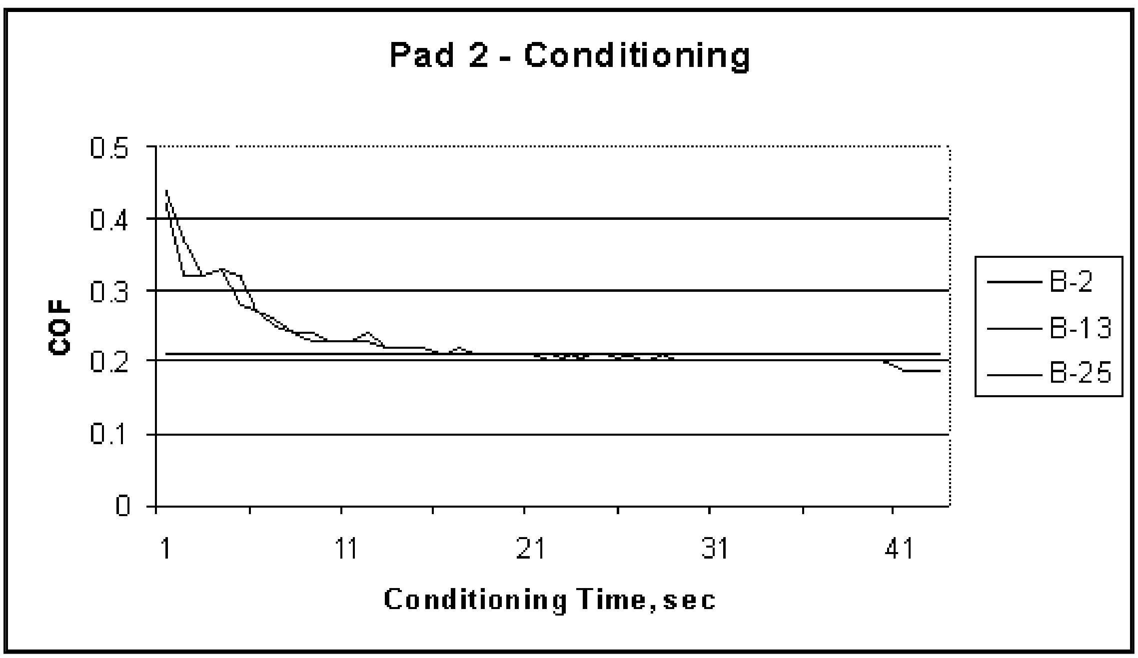


Fig. 2. PadFriction During Conditioning

PadFriction was measured during polishing of the blanket wafers 2, 13 and 25, while product wafers were polished in between. Four series of polishing tests were conducted, with and without ex-situ conditioning, each on two pads. The PadFriction plots for each of the four series are presented in Fig. 3. The data is summarized in the next-page table.

Table: Polishing Test Data

Wafer #	CMP Parameter			
	PadCOF @ polish	PadCOF @ condit	RR	WIWNU
Pad 1, No Conditioning				
Pd1-2B-NoCond	1.00	n/a	1.00	1.00
Pd1-13B-NoCond	1.23	n/a	0.90	1.06
Pd1-25B-NoCond	1.29	n/a	0.89	1.16
Pad 1, Ex-Situ Conditioning				
Pd1-2B-ExCond	1.05	1.00	0.95	1.09
Pd1-13B-ExCond	1.08	1.04	0.93	1.05
Pd1-25B-ExCond	1.11	1.03	0.93	1.08
Pad 2, No Conditioning				
Pd2-2B-NoCond	1.00	n/a	1.00	1.00
Pd2-13B-NoCond	1.31	n/a	0.94	1.07
Pd2-25B-NoCond	1.34	n/a	0.88	1.12
Pad 2, Ex-Situ Conditioning				
Pd2-2B-ExCond	1.04	1.00	0.95	1.06
Pd2-13B-ExCond	1.08	0.96	0.97	1.03
Pd2-25B-ExCond	1.09	0.95	0.97	1.04

The following observations can be made from the table and Fig. 3:

- without conditioning, both pads exhibited substantial degradation in removal rate RR and within-wafer-nonuniformity WIWNU, which was well reflected in PadFriction,

- with ex-situ conditioning, both pads had stable process characteristics of RR and WIWNU, reflected in the stable PadFriction,

- there is a correlation between PadFriction (measured at the end of conditioning or beginning of polishing) and common process parameters of RR and WIWNU.

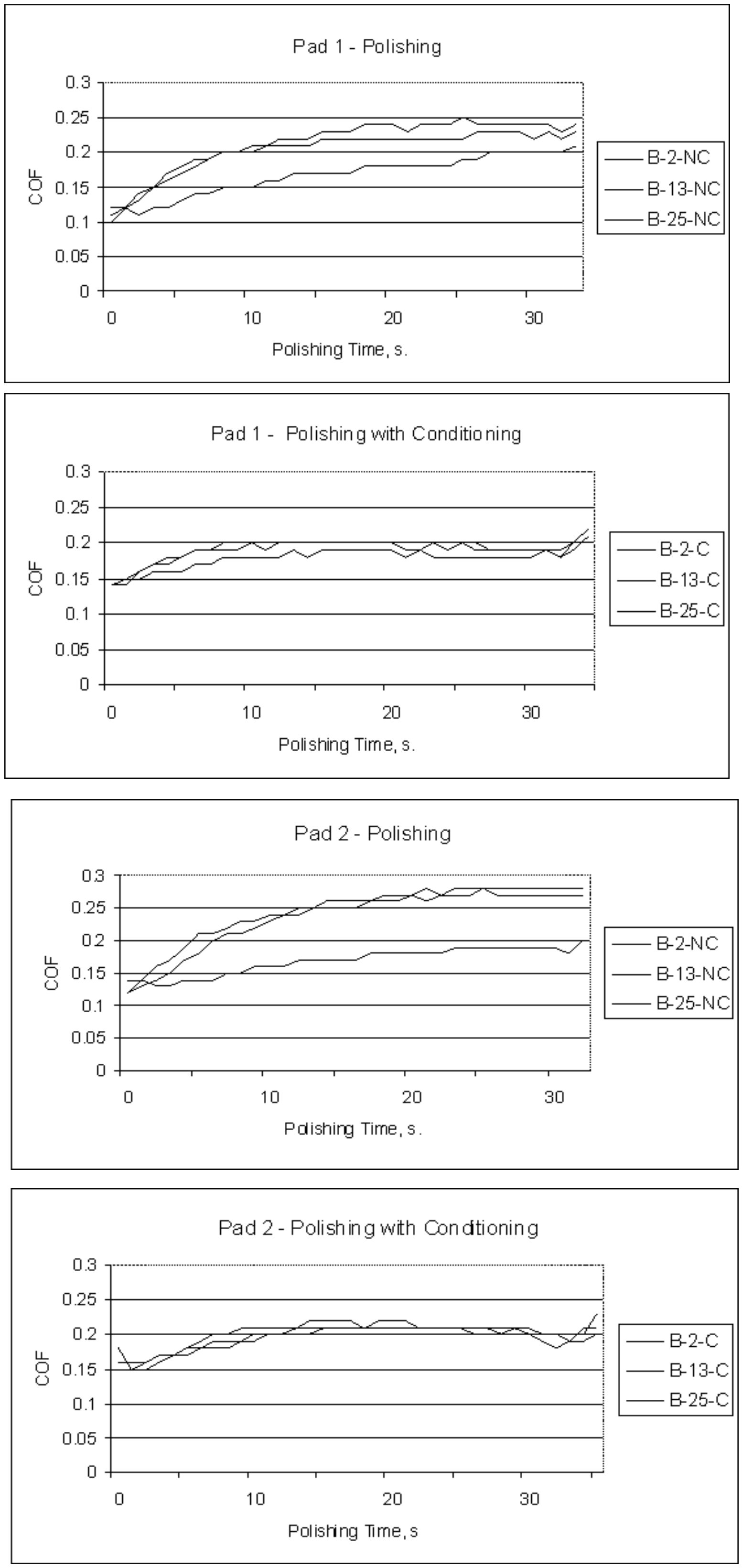


Fig. 3. Polishing Tests With and Without Conditioning

Effectiveness of PadProbe® for Fabs

There seem to be three ways of utilizing the PadProbe® in the Fab for significant cost savings:

1. Monitoring PadWear and producing an End-of-Pad-Life signal

As pads of the same type can differ in their durability by a factor of 2, the current industry practice of replacing all pads "blindly", based on a conservatively chosen number of wafers processes on them, leads to an at least 2-time excessive use of the expensive pads. Thus, "smart" pad replacement based on actual dynamic PadWear data may save pad expenses.

2. Monitoring PadFriction and producing the End-of-Conditioning signal

As pad conditioning in the typical copper process is completed after less than 20 s, while the process continues for 45 s, use of the PadProbe® to monitor the end-point of conditioning and to stop conditioning when PadFriction is saturated may reduce the consumption of both pads and conditioners by 2 times.

3. Monitoring PadFriction and producing the Out-of-Process signal

As PadFriction seems to correlate with the removal rate and non-uniformity of polishing, its monitoring with the PadProbe® and producing an alarm signal when it slips out of the process range, may allow for substantial yield improvement by not producing defective wafers. Indeed, if during process development, the optimum range of PadFriction is established at the same time with and correlated to the optimum ranges of RR and WIWNU, any out-of-range deviations of the continuously monitored PadFriction will be sufficient to stop and adjust the process and thus, avoid making defective wafers.