High Performance, Eco-Friendly SPM Cleaning Technology using Integrated Bench-Single Wafer Cleaning System

Fuping Chen [1, a *], Haibo Lei [2 b *],Xiaoyan.Zhang [1, a], Wenjun.Wang [1, a] , Shena.Jia [1,a] ,Jane.Wang [1,a], Jason.lee [1, a], YY.Kim [1,a], Bruce.lee [1, a], Sally-ann.Henry [1,a], David Wang [1,a] , Yu Zhangyu [2,b],Tao Zhang [2,b], Jun Huang [2,b], Fang Li [2,b], Chunwei Wang [2,b], Hong Li [2,b], Yi Yang [2,b]

[1] ACM Research (Shanghai), Inc.Building 4, No1690 Cailun Rd, Zhangjiang High Tech Park, ZShanghai, China 201203

[2] Shanghai Huali Microelectronics Corporation, No100 Gubo Rd, Pudong New Area, Shanghai, China 201314

[a] Email:fuping.chen@acmrcsh.com [a]Xiaoyan.Zhang@acmrcsh.com, [a]Wenjun.wang@acmrcsh.com, [a]Shena.Jia@acmrcsh.com,[a]Jane.Wang@acmrcsh.com, [a]jason.lee@acmrcsh.com, [a]yy.kim@acmrsch.com, [a]bruce.lee@acmrcsh.com, [a]sallyann.henry@acmrsch.com, [a]davidwang@acmrcsh.com, [b]zhangyu_td@hlmc.cn, [b]zhangtao@hlmc.cn, [b]huangjun@hlmc.cn, [b]lifang@hlmc.cn, [b]wangchunwei@hlmc.cn, [b]lihong@hlmc.cn, [b]yangyi@hlmc.cn [b]leihaiboi@hlmc.cn

Batch SPM cleaning fails to meet current clean specifications, and single wafer cleaning alternatives cause severe damage to the environment. To address this dilemma, ACM developed its Ultra-C Tahoe as an eco-friendly option for post-implant, post-CMP and post-etch clean. The data collected demonstrates how the Ultra-C Tahoe meets 28nm requirements while saving more than 80% of SPM chemistry.

Abstract

Batch SPM systems do not meet the current clean specification/requirements below 28nm. Single wafer SPM systems use a high volume of chemistry which runs to drain, while meeting the cleaning specifications below 28nm. The work in this paper describe the use of a batch SPM system and a single wafer clean in an integrated system, Ultra-C Tahoe which results in meeting the technical specification and using less that 80% of the SPM chemistry used in single wafer systems. The data collected shows this new system meet the specifications, whilst saving more than 80%of SPM chemistry.

Introduction

Conventional organic photoresist strip processes were developed using a combination of dry and wet treatments. However, dry treatments based on reactive plasma ashing have been shown to present issues, such as plasma induced damage, resist popping, incomplete resist removal, and byproduct redeposition that requires follow up with a wet strip/clean. To avoid plasma issues, wet stripping processes based on aggressive acid chemistries, such as aqueous mixtures of sulfuric acid and hydrogen peroxide (SPM at 80°C -150°C) were developed [1]. [3].

Today's SPM bench-only wet process cannot achieve the cleaning performance required for technology nodes below 28nm, due to high particles and defects on the wafer, leaving SPM single wafer processing as the only solution. The single wafer SPM process requires the mixture to be heated to high temperatures with only a fraction of the hot SPM touching the wafer surface and most of the SPM spinning off the wafer. [4]This chemistry goes to drain. This results in a large amount of sulfuric acid consumption and disposal of waste that is expensive and harmful to the environment. [6]. As shown in Figure 1, this paper proposes a new proprietary SPM cleaning system and process method named Ultra-C Tahoe, which is a new, eco-friendly technology combining a traditional bench . SPM cleaning module and a single wafer cleaning module into one wet-clean system. The wafers are run through a sulfuric acid–peroxide mixture (SPM) tank for cleaning and quick dump rinsing (QDR) in the bench module,

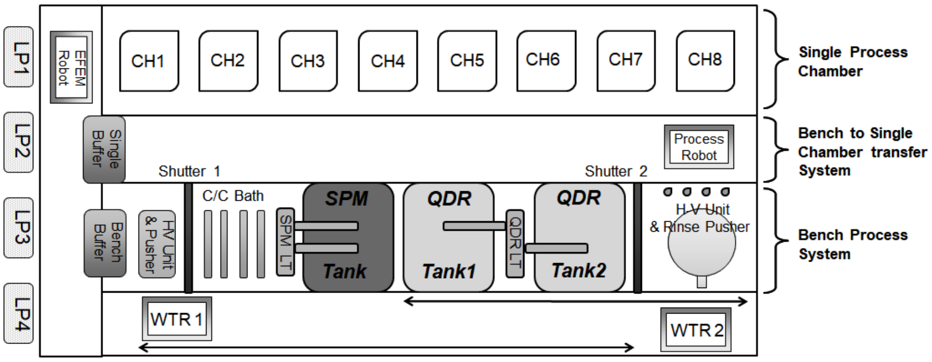


Figure 1: Simplified apparatus of Ultra C Tahoe Cleaning System.

where the sulfuric acid and peroxide are recirculated. After cleaning in the bench module, wafers are transferred to the single wafer module for advanced cleaning while still being kept in a "wet" state during the transfer process.

Experiment

Tests were carried out with the ACM Ultra-C Tahoe cleaning tool, a single wafer SPM cleaning tool, and a traditional wet bench tool. The 12inch wafers were processed with SPM (H_2SO_4:H_2O_2) cleaning and then followed by SC1 (NH_4OH, H_2O_2, H_2O mixing), and assisted with N2 jet spray cleaning technology. The use of N2 jet spray can enhance the removal of particles from the surface of the wafer. SC1 is required to remove viscous SPM and hygroscopic sulfur (S) residues sticking to the surface, creating particulate defects that are hard to remove after drying. SC1 is used in both wet bench and single wafer systems.

The SPM chemical mix ratio is set as 4:1, with temperature 120°C; The SC1 chemical mix ratio is set as 1:2:50, with temperature 60°C. The wafer is kept in a "wet" state between the QDR and single wafer process to prevent the wafer surface drying out and forming watermark defects or to absorb ionic and particulate pollutants from the external environment.

In the Ultra-C Tahoe SPM module, the sulfuric acid–peroxide mixture (SPM) is recycled, and the SPM bath chemical is only changed based on a pre-defined lifespan or on the number of wafers processed. The SPM chemical consumption used by Ultra-C Tahoe is reduced by over 80% compared to the single SPM wafer system. Table 1 shows a comparison of chemical consumption based on the following recipes:

Table 1: Comparison of chemical consumption based on the following recipes

Items		Single Wafer SPM	Ultra C Tahoe (Bench+Single)	Remark
Capacity / day (both based on same output 2K wafer)		2000	2000	*Single Wafer SPM recipe: SPM90S+SC30S+SCN30S, WPH 80pcs, Uptime 95% *Ultra C Tahoe recipe: SPM300S+QDR300S+SC60S+SCN60S,WPH 90pcs, Uptime 95%
SPM Bath Volume (L)		/	40	
H2SO4 Dosing Volume (L)		/	160	
Wafer Loading Size		1sls	12sls	
SPM Mix Ratio (H2SO4:H2O2)		2:1	4:1	
Chemical Usage/pcs	H2SO4(L)	0.9	0.096	*Tahoe SPM life time: 12hrs (total 240L /day)
	H2O2(L)	0.45	0.024	*Single SPM flow rate: 0.9lpm (process time 1.5min)
Chemical Waste/day	H2SO4(L)	1800	192	
	H2O2(L)	900	48	
Chemical Waste Saving/day (Calculated by Waste per day)	H2SO4(L)		1608	1800-192
	H2O2(L)		852	900-48
Waste Saving/day (Calculated by Wast per day)	H2SO4(L)		89.33%	1608/1800
	H2O2(L)		94.67%	852/900
Total H2SO4 saving Vol L /year			586920	1608L x 365 day

Ultra-C Tahoe System consisting of Bench Module: 300sec SPM process following by a 300sec QDR process and Single Module: 60sec SC1 rinse following by a 60sec N2 spray SC1 process.
Competitor Single Cleaning system recipe: 90sec SPM process following by a 30sec SC1 rinse, and a 30sec N2 spray SC1 process
Based on each tool set processing 2000 wafers per day, calculations show the Ultra-C Tahoe can reduce Hydrogen Peroxide (H_2O_2) by 852 liters per day which is a 94% saving vs a single wafer SPM system. Sulfuric acid (H_2SO_4) reduction is 1608 liters per day (586, 920 liters per year) a 33% saving vs a single wafer SPM system.

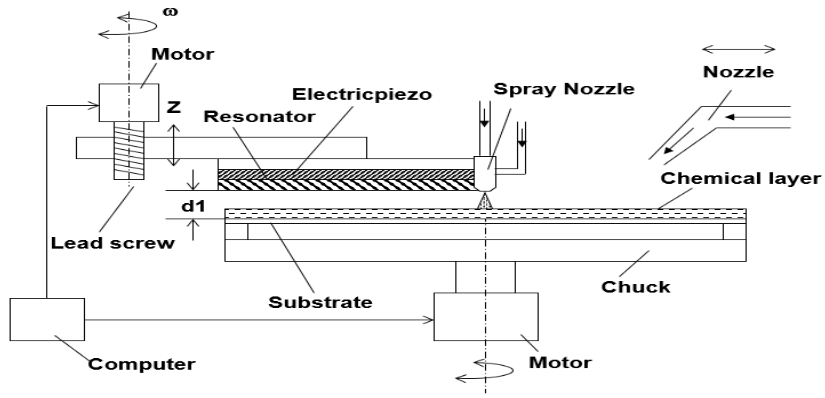


Figure 2: Single Wafer cleaning apparatus using megasonic device or N2 spray device

The single chamber structure, as show in Figure 2, is flexible and can be configured for different process requirements to dispense standard clean (SC1), hydrofluoric acid (HF), or other process chemicals. It can accommodate up to four arms. Options include an N2 jet spray arm or megasonic cleaning with ACM Research's Smart Megasonix™ arm [2] [4]. The system also offers an isopropyl alcohol (IPA) drying function that can be applied to patterned wafers. No H2SO4 is used during the single wafer cleaning step, thereby reducing chemical use and minimizing waste.
*Test 1:*Wafers were processed through the Ultra-C Tahoe SPM and QDR followed by the Tahoe Single wafer DIW and N2. The same wafers then sat in the FOUP for 3hrs before the wafers were processed using the Tahoe single wafer SC1, DIW and N2. The same wafers were then run through the batch SPM and QDR followed by Tahoe single wafer SC1, DIW, N2.
Test 2: Particle adder tests were processed comparing Ultra-C Tahoe, a single wafer SPM cleaning tool, and a wet bench cleaning tool using blanket wafers with a particle count <100ea@40nm and measured on a KLA-Tencor Surfscan SP3 prior to and after cleaning. In this test, the particle adder count was calculated using a formula [Post-Pre]
Test 3: Another set of wafers were used for defect removal efficiency tests and processed in Ultra- C Tahoe and a traditional wet bench tool with a scrubber on blanket photoresist ashed wafers, to compare the post particle count of the two different cleaning technology methods. Ultra-C Tahoe SPM bath chemicals were recycled. Wet bench cleaning was performed with fresh SPM chemical and was followed up with a single wafer scrubber clean assisted with N_2 jet spray DIWCO_2 water. Post cleaning particle count was measured on a KLA-Tencor Surfscan SP3 with 50nm and 30nm metrology recipe.
Test 4: Resist removal efficiency tests on 28nm logic device WELL loop pattern structure wafers post ash were used for the tests and defects and cleaned in the Ultra-C Tahoe were measured using the KLA bright-field defect inspection tool. In these tests, the WELL process was implanted with 2.7X 1013 ions/cm2 at 205KeV energy.
Test 5: Ultra-C Tahoe cleaning tests with insitu-bench cleaning and different single cleaning sequence on blanket wafer:

a. Bench process in the Bench-Single integrated cleaning tool: SPM + Hot QDR, followed by Single process in the Bench-Single integrated cleaning tool: SC1+N2 Spray SC1+N2 Dry

b. Bench process in the Bench-Single integrated cleaning tool: SPM + Hot QDR, followed by Single process in the Bench-Single integrated cleaning tool: O3+SC1+N2 Spray SC1+N2 Dry.
c. Bench process in the Bench-Single integrated cleaning tool: SPM + Hot QDR, followed by Single process in the Bench-Single integrated cleaning tool: DHF+O3+SC1+N2 Spray SC1+N2 Dry.

The 19nm particle count were measured on a KLA-Tencor Surfscan SP5 prior to and after cleaning. In this test, the 19nm particle adder count was calculated using a formula [Post-Pre].

Result and Discussion

Comparison test results between Stand-alone Bench: Stand-alone Single: Ultra-C Tahoe integrated cleaning tool are shown. Figure 3A, shows the particle adders after the wafers have been run through the Tahoe Bench SPM and QDR and Tahoe Single module DI rinse and N2 Dry is 297~331ea@40nm. After storage in a FOUP for 3 hours and being processed using in the single wafer Tahoe using SC1 rinse+N2 Spray SC1, DIW rinse and dry, and the particle adder count shown in Figure 3B decreased to 117~130ea@40nm particle size. In Figure 3C, running the process sequence on the Ultra-C Tahoe integrated SPM + QDR and Tahoe Single: SC1+N2 Spray SC1+N2 Dry, cleaning particle adder count decreased to -1~ -9ea@40nm. This shows that once the residues are dried, it is impossible to remove the residues without running the whole SPM and SC1 process. Figure 3D shows the summary of the results. The key conclusion for getting better defect removal performance is to keep the wafer surface in a "wet" state between the post bench SPM cleaning process and the pre-single wafer cleaning process.

Figure 3A

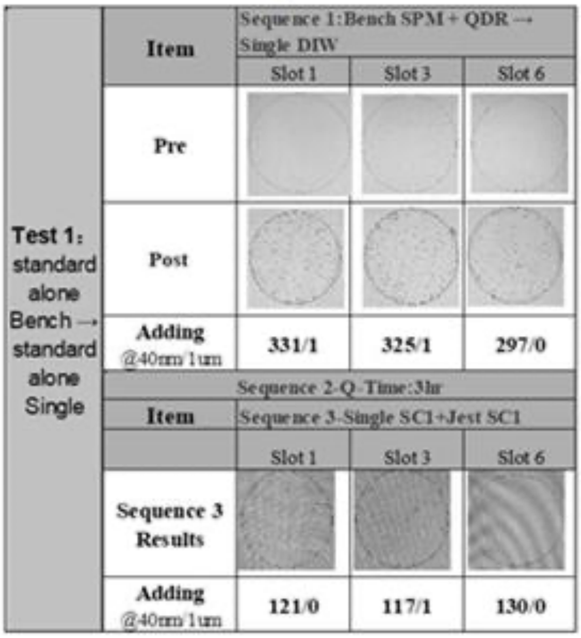
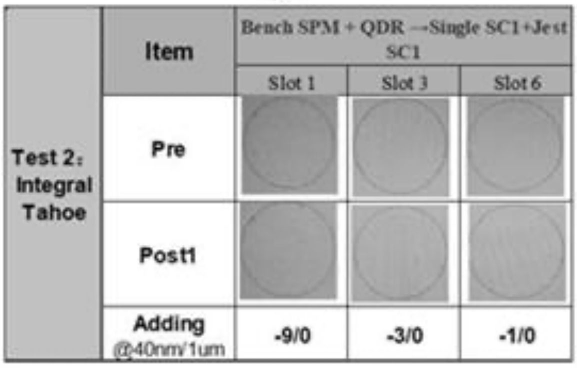


Figure 3B



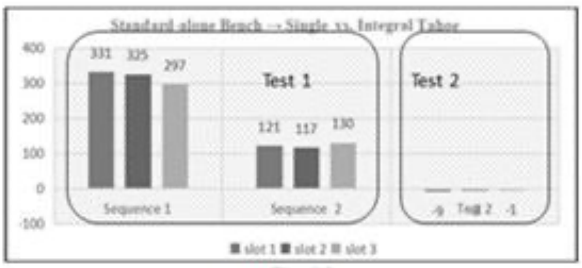


Figure 3C

Figure 3: Cleaning performance comparison between Stand alone Bench vs. Stand alone Single Wafer and Ultra-C Tahoe integral cleaning.

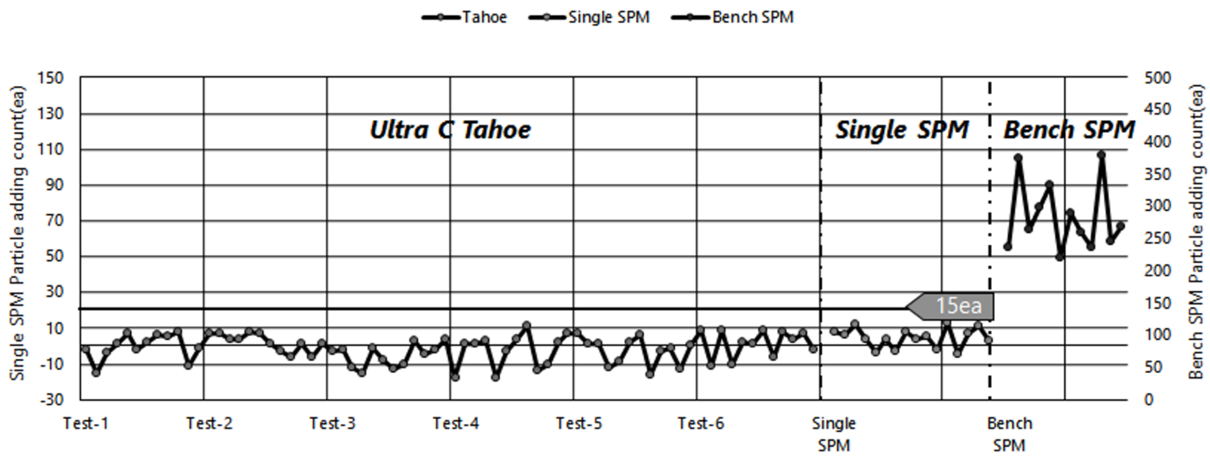


Figure 4: Particle adder performance between Ultra C Tahoe, Single Wafer SPM and Bench SPM.

Test 2 results comparing particle adder tests of the Ultra-C Tahoe, the Single wafer SPM, and the Wet bench SPM cleaning systems and are shown in Figure 4. The tests results indicate that particle adder counts for the post Ultra-C Tahoe process is less than 15ea@40nm, which is comparable with single SPM cleaning performance particle adders. Wet bench was around 200-400ea@40nm, which was much worse than both Ultra- C Tahoe and single wafer SPM cleaning systems.
Test 3 results of the blanket photoresist ash post wet strip clean efficiency comparison are shown in Figure 5. Ultra-C Tahoe clean (SPM chemical recycled with different chemical lifetime) post particle count was <10ea @50nm particle size, <50ea@30nm particle size, while the wet bench clean post particle was around 20ea@50nm, 70~100ea@30nm even when combined with single wafer scrubber clean after bench processing. Ultra-C Tahoe cleaning efficiency is much better than wet bench cleaning.

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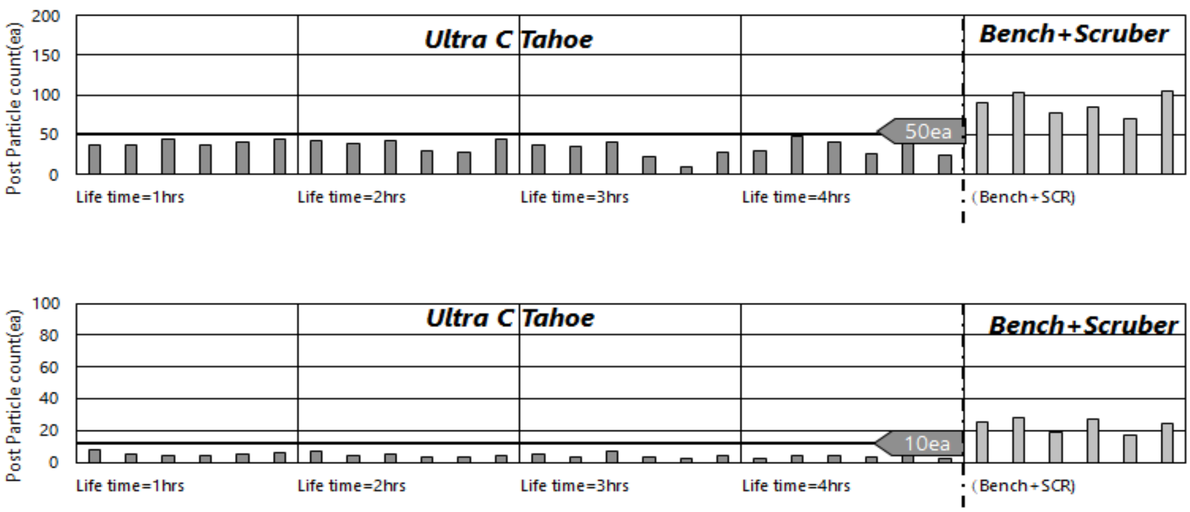

Figure 5: Residue removal performance comparison between Ultra-C Tahoe and Bench SPM with Scrubber

The 28nm logic device WELL loop pattern wafer post ash process results are shown in Figure 6, bright-field defect inspection results show that there is no particle and polymer residue after the Ultra-C Tahoe cleaning process.

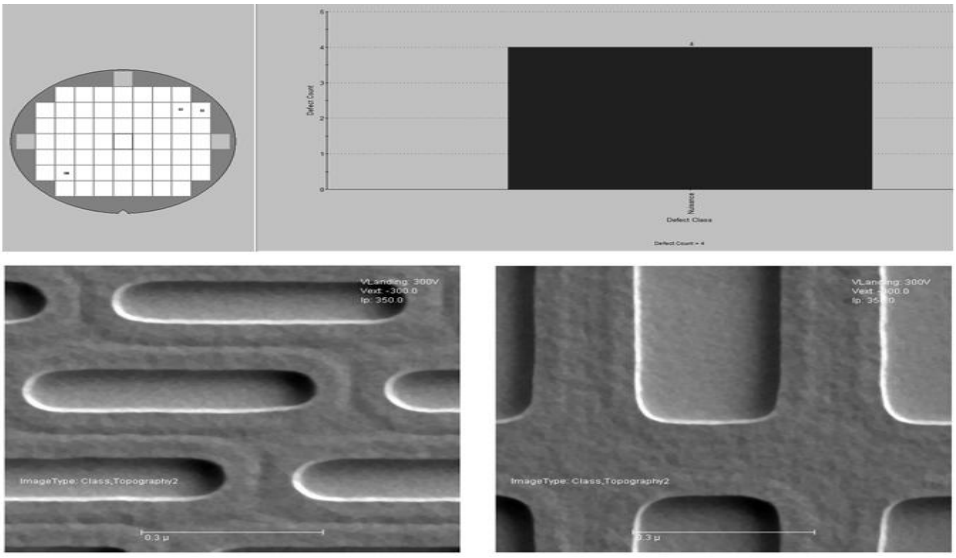

Figure 6: Logic device WELL loop pattern structure wafer defect and SEM image after Ultra C Tahoe cleaning.

Figure 7A and Figure 7B show the defect results are comparable on WELL loop pattern structures after the Ultra- C Tahoe and the single wafer SPM process. The test 4 results from the Integrated Ultra-C Tahoe with Bench cleaning and different single cleaning sequence on blanket wafers showed the single cleaning process with SC1-N2 Spray SC1, resulted in a few particle adders.

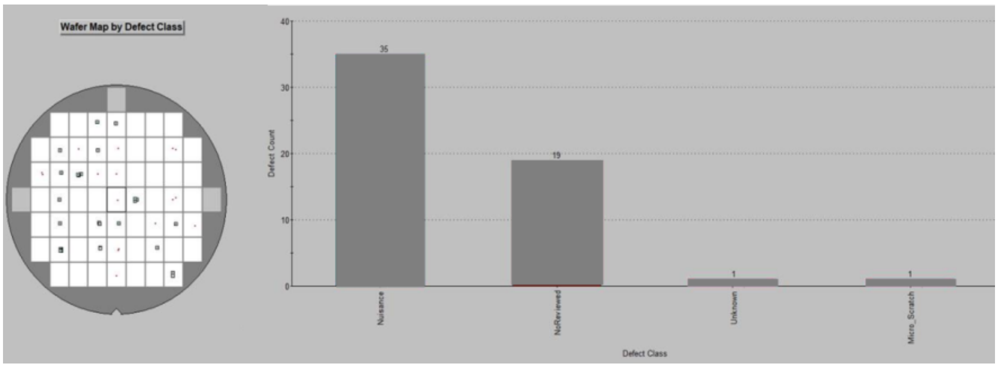

Figure 7A: Wafer defect performance of WELL loop pattern structures post Ultra-C Tahoe cleaning.

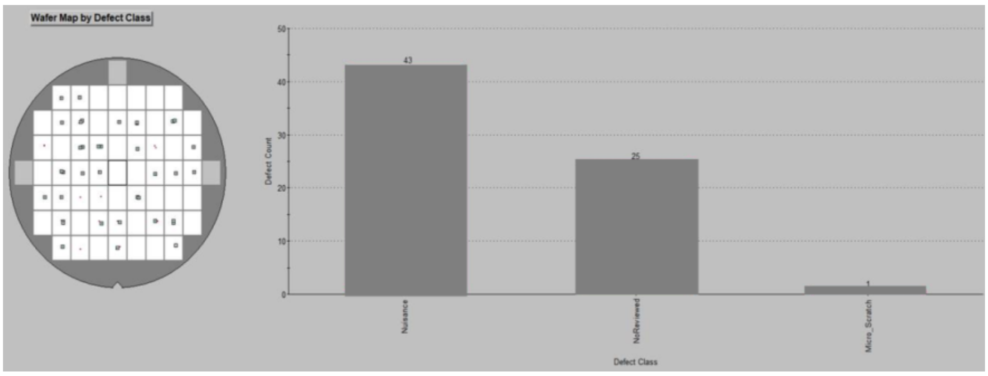

Figure 7B: Wafer defect performance of WELL loop pattern structures post Single SPM cleaning.

The single cleaning process with O3 -SC1-N2 Spray SC1 can enhance particle removal. The single cleaning process with DHF-O3-SC1-N2 Spray SC1 has the best particle removal efficiency. The DIO3 and SPM combination cleaning process shows a positive cleaning effect. HF will undercut

particles attached on the wafer surface, and DIO3 will further oxidize the carbon by-products and conditioning the wafer surface.
The results from test 5 confirm the use of DIO3 and or dHF and DIO3 on the single wafer system inprove the PRE as shown in Figure 8

Item	Bench process	Single process	PRE Count		POST Count		Delta (Post-Pre)					PRE
			19nm	1um	19nm	1um	19-30nm	30-40nm	40-60nm	>60nm	Total	Total
Bench-Single integrated cleaning process	SPM-Hot QDR	Test 1: SC1-N2 Spray SC1-DIW+N2 Dry	521	0	528	0	-11	7	3	-2	-3	1%
			301	0	308	0	-8	11	9	-7	5	-2%
		Test 2: O3 -SC1-N2 Spray SC1-DIW+N2 Dry	281	0	202	0	-62	-8	-7	-2	-79	28%
			272	0	198	0	-55	-5	1	-15	-74	27%
		Test 3: DHF- O3 -SC1-N2 Spray SC1-DIW+N2 Dry	261	0	191	0	-56	-3	-8	-3	-70	27%
			283	0	198	0	-84	-8	-3	-2	-97	34%

Figure 8: Integrated Ultra -C Tahoe cleaning test incorporated bench cleaning with different single wafer cleaning sequences.

Conclusion

A new SPM cleaning process method has been proposed in this paper. This new, eco-friendly technology combines traditional bench SPM cleaning and single wafer cleaning in the same equipment, using a two-step approach to optimize the advantages of wet bench and single wafer cleaning. After the bench SPM process is completed, the wafer is transferred into the single wafer process chamber for cleaning with a “wet” surface state during the whole transfer progress. This new cleaning technology, the Ultra- C Tahoe system, achieves a cleaning efficiency that is comparable to the single wafer SPM cleaning while, at the same time, the Ultra-C Tahoe allows the SPM to be recycled, reused and it greatly reduces the consumption of sulfuric acid. The Ultra-C Tahoe has proven to be effective in semiconductor cleaning process of 28nm node and below.

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