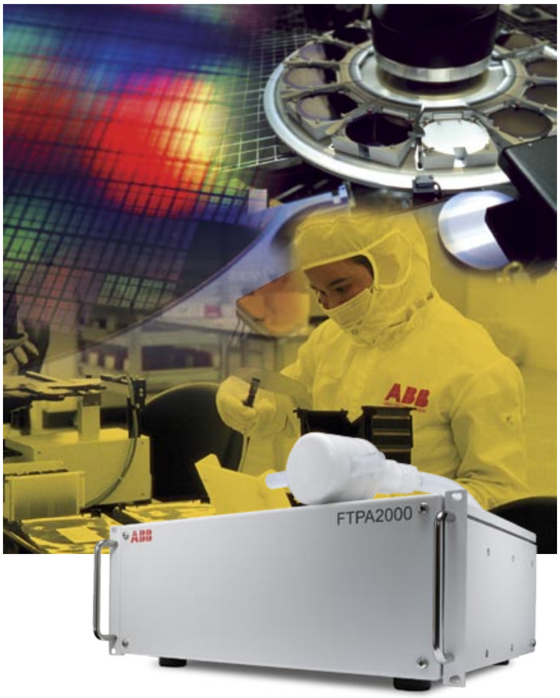
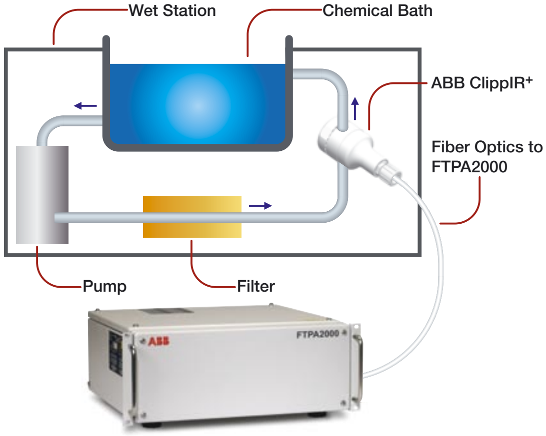
Application Note

AnalyzeIT Wet Process Analyzer

RCA cleaning: SC1, SC2, DHF, BOE, SPM





Quality, throughput, and cost reduction are objectives that drive the semiconductor manufacturing industry. Since keeping processes under tight control is necessary to achieve these goals, close monitoring of chemical concentrations is mandatory for wet processes.

Fourier Transform Infrared (FTIR) spectroscopy is a widely used analytical technique that is ideal for monitoring wet processes. It provides a fast, accurate and highly repeatable solution for in-line monitoring of wet chemistries.

ABB is a global leader in FTIR technology and has dedicated more than 30 years to developing FTIR analyzers. The Wet Process Analyzer (WPA) is based on FTIR technology and has been engineered by ABB to meet the stringent requirements of the semiconductor manufacturing industry.

The WPA is a unique analytical instrument specifically designed for in-line, real-time monitoring of wet processes. It can monitor the chemical concentrations of most critical solutions used in the cleaning, etching, and stripping steps of semiconductor manufacturing, and one WPA can monitor up to eight different streams.

The present article takes a close look at the optimization of cleaning processes using SC1, SC2, DHF, BOE and SPM chemistries. A case study is presented for a typical WPA application.

Analysis Technique

The near-infrared (NIR) portion of the electromagnetic spectrum is located between the mid-infrared (MIR) and visible (VIS) regions. Vibration overtones and additive combinations of fundamental vibrations involving hydrogen atoms dominate this spectral region.

The ABB WPA uses the benefits of FT-NIR spectroscopy along with the non-invasive, patented Teflon Clipp*IR*+ for real-time monitoring of aqueous solutions.

The WPA uses fiber optic cables to transport NIR light from the spectrometer to the monitoring points. This configuration allows the analyzer to be located in any general-purpose area, isolated from hazardous materials and environments, thus significantly reducing the footprint in the wet bench environment.

The limit of detection that can be achieved using NIR largely depends on the spectral features of the chemicals to be monitored. In liquids, substances can be detected in concentrations as low as 100 ppm (0.01%), depending on the chemical matrix.

System Description

1. System configuration

The WPA couples an FTIR spectrometer with a Teflon sampling sensor for non-invasive monitoring. The spectrometer includes a multi-detector module with an optical throughput sufficient to illuminate up to eight different monitoring points simultaneously. Through the use of fiber optic cables, each monitoring point can be located up to 100 meters away from the analyzer. This design offers a superior repeatability of analysis compared to that of opto-mechanical multiplexers. Figure 2 presents a system configuration with five occupied detectors and three free positions.

2. Sampling approach.

The patented Clipp*IR*$^+$ (see Figure 3) enables in-line and real-time monitoring through existing Teflon tubing. It is installed quickly and easily, and does not require installation of an impractical bypass or a cooling unit. Each Clipp*IR*$^+$ is simply clamped onto the external surface of an existing Teflon tube. NIR light from the spectrometer passes through the Teflon tube and then back to one of the eight detectors included in the spectrometer.

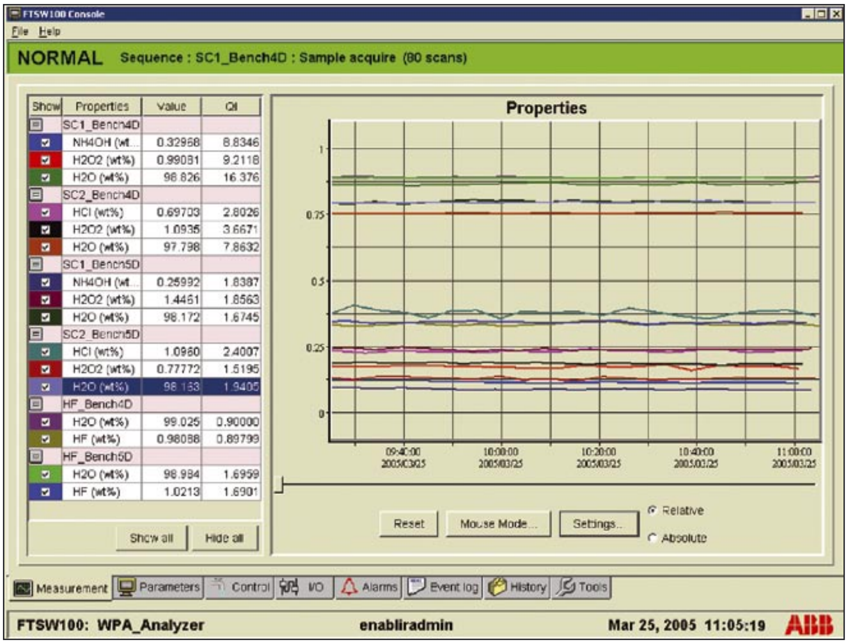
The measurement time for one stream (one solution monitored by one Clipp*IR*$^+$) is 51 seconds (equivalent to 128 scans with a resolution of 16 cm^{-1}) regardless of the number of components measured in each stream.

3. Installation

The Clipp*IR*$^+$ can be installed on any ½ to ¾ in. diameter Teflon tube. The Clipp*IR*$^+$ is installed on sections of the Teflon tube that are free of bubbles in order to maximize analytical performance. Best results are obtained when the temperature is controlled within a range of approximately ±5°C. The Clipp*IR*$^+$ can be used to monitor solutions at temperatures up to 200°C.

Process Control Software

The ABB WPA features the FTSW100 Process Software designed for process monitoring and control. This flexible software performs the real-time monitoring of concentration for each measured component of the cleaning, etching or stripping solutions. Chemical concentrations and trending are displayed in real-time as shown in Figure 4.



NORMAL Sequence : SC1_Bench4D : Sample acquire (80 scans)

Show	Properties	Value	QI
⊟	SC1_Bench4D		
☑	NH4OH (wt...	0.32968	8.8346
☑	H2O2 (wt%)	0.99081	9.2118
☑	H2O (wt%)	98.826	16.376
⊟	SC2_Bench4D		
☑	HCl (wt%)	0.69703	2.8026
☑	H2O2 (wt%)	1.0935	3.6671
☑	H2O (wt%)	97.798	7.8632
⊟	SC1_Bench5D		
☑	NH4OH (wt...	0.25992	1.8387
☑	H2O2 (wt%)	1.4461	1.8563
☑	H2O (wt%)	98.172	1.6745
⊟	SC2_Bench5D		
☑	HCl (wt%)	1.0960	2.4007
☑	H2O2 (wt%)	0.77772	1.5195
☑	H2O (wt%)	98.163	1.9405
⊟	HF_Bench4D		
☑	H2O (wt%)	99.025	0.90000
☑	HF (wt%)	0.98088	0.89799
⊟	HF_Bench5D		
☑	H2O (wt%)	98.984	1.6959
☑	HF (wt%)	1.0213	1.6901

FTSW100: WPA_Analyzer enabliradmin Mar 25, 2005 11:05:19

Figure 4. FTSW100 measurement panel. Monitoring of six streams: two SC1 tanks, two SC2 tanks and two DHF tanks

The analyzer can be linked to a DCS or PLC in order to provide full automation capabilities. The following communication protocols are supported for input/output (I/O) exchange with control systems:

- OPC through Ethernet
- ModBus through serial link (RS232-RS485)
- CanOpen through discrete I/O modules (4-20mA)

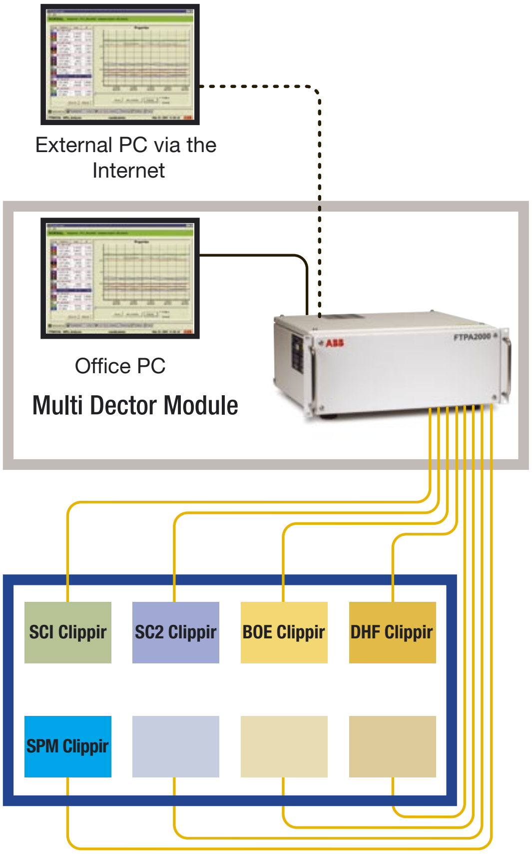


Figure 2. System configuration.

Figure 3. The Clipp*IR*$^+$.

Case Study Results

The wet bench presented in this case study is equipped with a multiple-robot handling system that loads cassettes of wafers side-by-side into reduced cassettes and then moves these through a series of chemical baths.

The wet bench is a 50-wafer tool. Its modular configuration (order of chemical steps, concentrations, temperatures) can be summarized as follows:

1. SPM/QDR
2. BOE/OFR (not used in this RCA process)
3. DHF/OFR
4. SC1/QDR
5. SC2/QDR
6. IPA (not considered in this application note)

Where: SPM: $H_2SO_4/H_2O_2/O_3$ at 120°C, QDR - Quick Dump Rinse, BOE: NH_4F/HF - not used, OFR - Overflow Rinse, DHF - 100:1 = HF: H_2O at 22°C, SC1 - 5:1:1 = H_2O: NH_4OH: H_2O_2 at 50°C, SC2 - 5:1:1 = H_2O:HCl: H_2O_2 at 50°C, IPA - Isopropyl Alcohol.

All rinses are based on a predetermined time (OFR) or number of dump/fill cycles (QDR). All chemical tanks must be changed out periodically. The recipe considered in this application note is called DU_RCA_NINE, a typical concentrated chemistry pre-gate clean recipe with a 40 Å etch target. The bath dump rates for the wet bench are 24 hours for SPM, BOE and DHF and 12 hours for SC1 and SC2.

The chemical usage measurements and calculations were made based on 100% production with no idle time. This equates to approximately 96 runs/day. Table 1 presents chemical costs per gallon .

Chemical	Cost per Gallon
Ammonium Hydroxide (NH_4OH)	$7.87
Hydrogen Peroxide (H_2O_2)	$16.13
Sulfuric Acid (H_2SO_4)	$11.86
Hydrofluoric Acid (HF)	$17.45
Hydrochloric Acid (HCl)	$9.91
Isopropyl Alcohol (IPA)	$7.99

Table 1 – Chemical Costs

A summary of chemical usage and total annual costs related to the wet bench is presented in Table 2 for 100% production.

Table 2 - Chemical Usage Calculations (100% Production - No Idle Time: 96 runs/day)

	H_2SO_4	H_2O_2	HF	NH_4OH	HCl	IPA
Consumption gal/run	0.11	0.34	0.0010	0.030	0.020	0.050
Consumption gal/day	11	33	0.096	2.9	1.9	4.8
Consumption gal/week	74	228	0.67	20	13	34
Consumption gal/year	3800	12000	35	1000	700	1700
Yearly Chemical Costs	$ 45,068	$ 193,56	$ 611	$ 7,87	$ 6,937	$ 13,583

Total Yearly Chemical Costs = $ 267,629

The in-line chemical monitoring of each component in a wet station tank has the benefits of improving the process quality performance, feeding the concentration values to the wet station controller, and extending the bath lives by buffering the single tanks with a replenishment solution injected at regular time intervals or when user-predefined threshold concentration values are detected.

Nowadays, extending chemical bath lifetime is a common target for all production facilities in order to stay competitive within the global market. A reduction in chemical consumption can easily be achieved and costs savings are achieved that substantially impact the Cost of Ownership (CoO) for all wet stations.

The study details how bath lives can easily be extended from a few hours to several days with the use of a chemical monitoring approach and good control strategy. Depending on the process recipe, a reduction of 20% to 30% of the chemical consumption costs can be achieved, as indicated in Table 2.

Table 3 summarizes the RCA cleaning processes, linking the solutions with the chemical components of each solution, the chemical concentration ranges for each component, typical temperature ranges of operation, and the repeatability typically achieved for each RCA application.

Table 3. RCA cleaning steps with related WPA ranges of operation and typical achieved repeatability values.

Process	Chemistry	Measurable Components	Ranges (wt %)	Temperature (°C)	Repeatability (wt %)
Particle Removal	SC1	H_2O_2	0-6	20-70	0.10
		NH_4OH	0-3		0.10
		H_2O	91-100		0.20
Metals Removal	SC2	H_2O_2	0-6	20-65	0.10
		HCl	0-3		0.10
		H_2O	91-100		0.20
Oxide	DHF	HF	0-2	22-28	0.08
		H_2O	98-100		0.20
Oxide Removal	BOE	HF	0-10	22-28	0.15
		NH_4F	22-40		0.10
		H_2O	50-73		0.20
		HF	0-10	22-28	0.10
		NH_4F	0-10		0.10
		H_2O	82-100		0.20
Organic Contaminants Removal	SPM	H_2SO_4	80-90	120-140	0.40
		H_2O	0-20		0.40

[1] Source: Semiconductor Magazine, 2000

Keeping tight control of the chemical concentrations can optimize production yields. In fact, critical wafer manufacturing processes, such as RCA steps, need to be well controlled in order to ensure a complete and efficient process. Cleaning efficiency in wet benches mainly depends on temperature, contact time, and chemical concentrations.

For example, strict chemical concentration monitoring of HF and NHF4 in a BOE bath helps production engineers maintain the chemical specifications within predefined ranges. When predefined concentration thresholds are achieved, the WPA communicates alarm or warning signals to the wet station console. In such cases, the repeatability performance of the chemical monitoring becomes crucial to ensure a stable and reliable process.

The WPA can reach excellent repeatability values. Typical analytical performance in RCA processes is reported in Table 3. These values can very often be optimized to achieve enhanced performance, as indicated in Figure 5 where repeatability values on NH_4F and HF in a BOE bath can be lowered to less than 0.1%. For HF monitoring, the target concentration is considered at 5 wt% and here, the WPA can follow the concentration with an absolute repeatability of 0.03 wt%, corresponding to a relative repeatability of 0.6%.. For ammonium fluoride, the target concentration is approximately 35.5 wt% and the absolute repeatability achieved in this case is lower than 0.07 wt%, corresponding to 0.2% relative repeatability.

Such a highly performing instrument minimizes production damages associated with uncontrolled chemical baths, badly controlled chemical ratios, or mixing steps released based only on flow rates, dosing pumps, number of pumped strokes and so on.

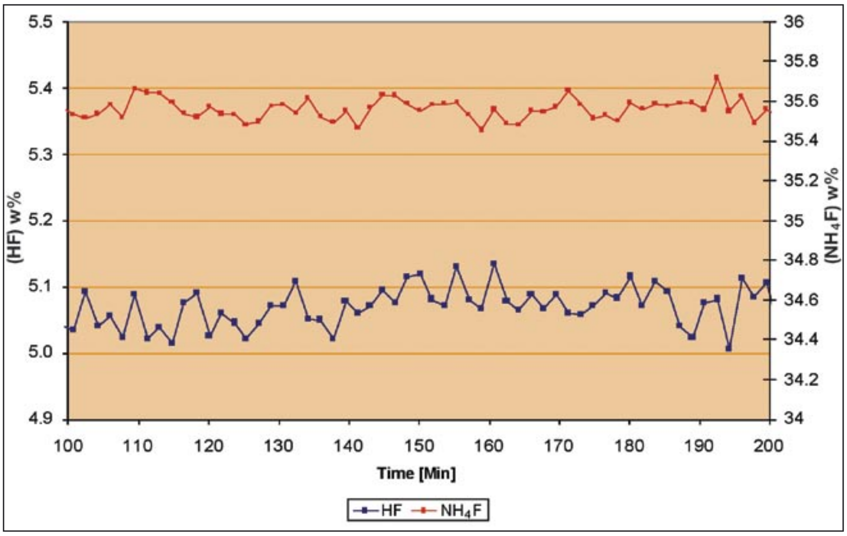


Figure 5. Achieved repeatability (1 sigma) on HF (0.03 wt%) and on NH_4F (0.07 wt%) in BOE monitored with the WPA over a period of 100 minutes.

One of the main parameters that influence the WPA's performance is process temperature stability. For instance, a DHF process controlled with a temperature tolerance of 5°C (±5°C) can typically be monitored with a repeatability of 0.08% for HF. With highly performing in-line heaters (tolerance of around 0.5°C or less), the repeatability at 1 sigma on HF can reach as low as 80 ppm.

Figure 6 shows continuous production monitoring of SC1 and SC2 processes. Production cycles and chemical bath changes are monitored with the WPA. In the SC1 process (Figure 6a), trends of H_2O_2 and NH_4OH are shown. The SC2 process (Figure 6b) monitoring reports trends of HCl and H_2O_2.

In the SC1 process presented, the concentration of ammonium hydroxide decreases over constant periods of time while hydrogen peroxide is not consumed during each single production cycle and remains constant over time. The WPA allows the determination of which component in the SC1 solution is the limiting factor in terms of concentration, allows defining the threshold concentration values (i.e. lower limit on NH_4OH concentration), and permits command of a complete bath change based on concentration limits defined in advance. In the example reported here, SC1 baths are changed when the concentration of NH_4OH goes lower than 0.37. As an additional precaution, a limit on time can also be defined for bath changes.

The SC2 process analysis shows that the process consumes H_2O_2 while the hydrochloric acid concentration trend remains flat over each single production cycle. In this case, the process has been set to operate bath changes at regular time intervals and chemical bath monitoring is used as safety precaution. For example, alarm messages are displayed when H_2O_2 concentration repetitively goes below the value 1.00.

Both ways of operating processes with the WPA drive the chemical management and contribute to extending chemical bath lives as much as possible. Along with the cleaning efficiency of the solutions, the WPA serves to reduce chemical consumption, to ensure wet process quality and higher throughputs, and finally, to enhance overall competitivity reducing costs and increasing production yields.

The ABB WPA shows very stable and reproducible results. Production engineers can rely on the performance of the WPA and adjust production and process performance based on the concentration values provided by the WPA. The repeatability values are calculated as standard deviations on 10 sequential measurements of the static solution and are validated at startup. For example, the repeatability for a BOE process where the concentration of HF must be kept between 4.9% and 5.1% has been controlled with a repeatability of 0.03%, as shown in Figure 5. SC1 processes where the concentration of NH_4OH is allowed to range between 1% and 0.5% need to be controlled with a repeatability of at least 0.1% on NH_4OH.

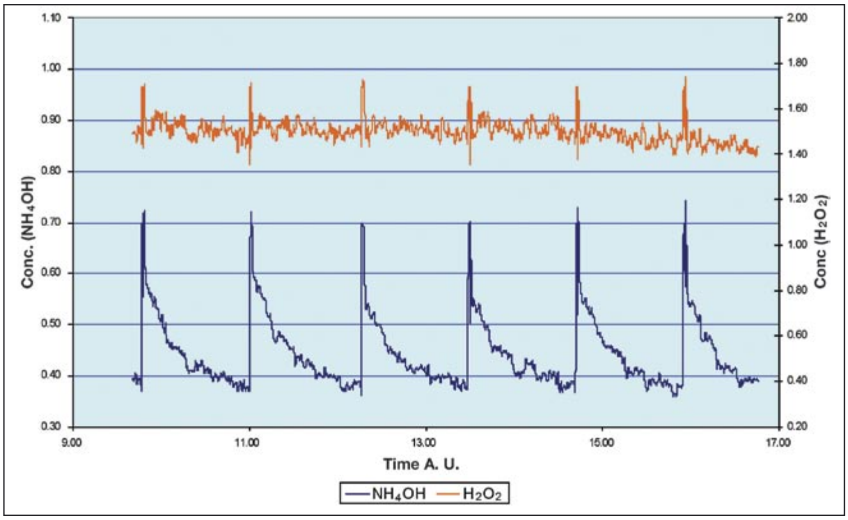


Figure 6a. Production monitoring of the SC1 process with the WPA

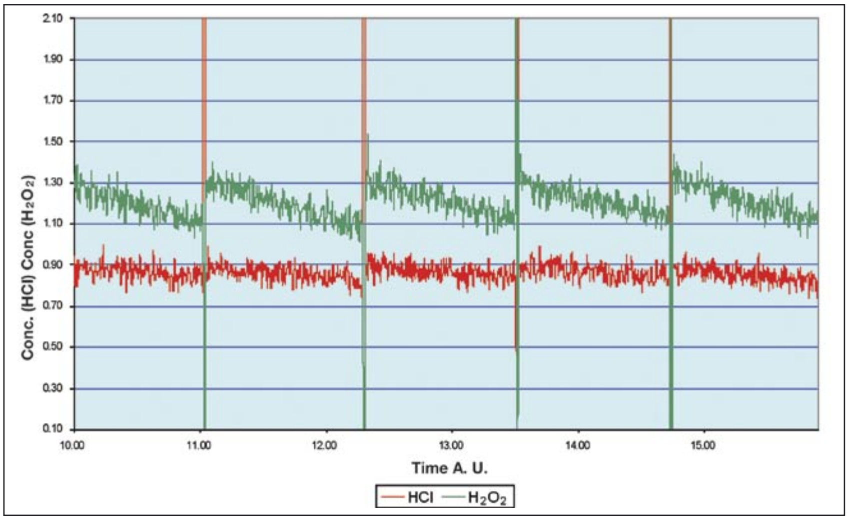


Figure 6b. Production monitoring of the SC2 process with the WPA

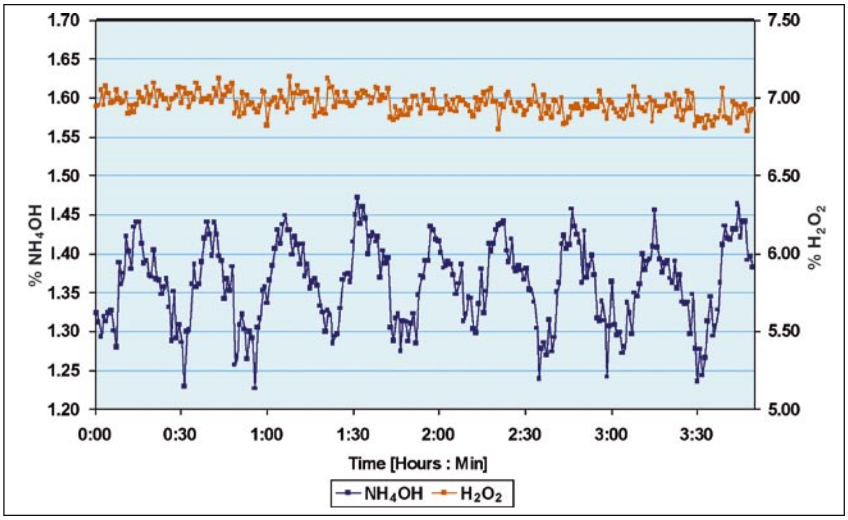


Figure 7. Monitoring of an SC1 process with the WPA. The process includes NH_4OH spiking.

Solution replenishment and spiking of one or more components during the process are very effective techniques for extending chemical bath lives. Figure 7 represents an example of chemical monitoring of an SC1 bath at 60°C, where sequential spiking at constant intervals have been applied.

In this example, concentrations of ammonium hydroxide and hydrogen peroxide in SC1 are monitored and sequential spiking of NH_4OH is applied. The addition of ammonium hydroxide doses is well monitored with the WPA, which shows concentration increases from approximately 1.25 wt% to 1.45 wt% over periods of 15 minutes. Each addition is monitored in real-time, since the analysis time on an individual sensor is less than 1 minute. This feature allows tracking very fast processes.

The concentration of hydrogen peroxide remains almost unchanged during the NH_4OH spiking process. Repeatability on NH_4OH is typically better than on H_2O_2 which can easily degrade.

In SC1, the major process control driving parameter has been found to be ammonium hydroxide. The WPA can monitor concentration variations of the ammonia, feeding back to the operator the concentration values achieved after spiking. The WPA can monitor and control this component very well because of its reduced response time and in-line and real-time sampling approach, and because it provides the necessary repeatability required for tight process control.

The WPA provides the analytical confidence on chemical concentration monitoring and communicates to the wet station the proper signals to start preprogrammed spiking functions or replenishment jobs through a defined set of I/Os.

Controlled wet processes based on continuous monitoring of chemical changes require precise, reproducible and fast chemical monitoring compatible with the Advanced Process Control (APC) standards of the Fab. The WPA can easily be integrated into the wet bench, drive the chemical management of SC1, SC2, BOE, DHF and SPM. It contributes to extending bath lives, reducing chemical waste in the environment, and reducing cost of ownership (CoO) of wet stations.

Thanks to the use of fiber optics and to the multi-channel configuration, one single WPA equipped with five different Clipp*IR*+s, analyzes the concentrations of chemical components in SC1, SC2, BOE, DHF and SPM. The WPA unique design reduces the footprint by a factor of five compared to other infrared analyzers.

Conclusion

The WPA is a reliable and reproducible analytical process instrument. It can be equipped with one to eight Clipp*IR*+, non-invasive in-line sampling sensors that can easily be integrated onto existing process lines with absolutely no risk of contamination.

The WPA is of great value for the optimization of process quality. It allows maintaining process chemical concentrations within predefined limits, preventing wafers from being processed with out-of-specification chemical solutions. It also provides the required confidence on the chemical concentrations during both the mixing or pre-mixing steps and on the recirculation line of process tanks.

Moreover, the return on investment of one single WPA equipped with several Clipp*IR*+ is fast, as it allows end users to save chemicals and reduce chemical waste in multiple baths. The WPA has been shown to provide added value to wet equipment for increasing throughputs, reducing CoO and making wet processes safer and very well controlled.

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