ADVANCES IN REACTIVITY MONITORING FOR SEMICONDUCTOR MANUFACTURING

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ABSTRACT

New semiconductor technologies require much more stringent control of the manufacturing environment. From an air quality standpoint, the control of chemical contamination has become as important as the control of particulate contamination for many processes. Levels of airborne molecular contaminants (AMC) in ambient air are high enough to be problematic if introduced into the facility. However, the types and numbers of chemical species used in the manufacturing of semiconductor devices also mean that there is a greater chance of chemical contamination from internal sources adversely affecting these sophisticated manufacturing processes.

Chemical contamination control strategies are much more complex to design and implement because of the difficulty associated with accurately characterizing the environment's potential to cause damage to materials and processes. Further, once it has been determined that direct chemical contamination control is required, determining how well, or even if, the implemented control strategies are working has been an arduous task.

Reactivity monitoring as described in ISA Standard S71.04 has been used for many years to provide accurate environmental assessments the process and control industries. Many of the same types of contaminants that have to be controlled in these industries are the same as those of concern to the semiconductor industry. Because of this, reactivity monitoring has been accepted as a viable environmental monitoring method by a number of semiconductor manufacturers. An air quality classification scheme based on reactivity monitoring has been established and has gained wide acceptance throughout the semiconductor industry.

Reactivity monitors detect the interaction of contaminant gases on copper, silver, and/or other metals by measuring corrosion film thickness. This monitoring technique can provide information on many contaminants problematic to manufacturing processes. It also provides a direct indication of the potential for AMC-related process effects. This technology has proven especially useful for establishing AMC baselines and identifying contamination episodes and their sources. It can be incorporated into a facility's overall preventive maintenance program and help reduce the number of AMC-related incidents by allowing proactive investigation of potential problems.

Performance monitoring of chemical filter systems allows for timely changeout of media and filters and reduces the cost-of-ownership for these systems. Proper maintenance of these systems also assures that air quality goals are being met.

With any AMC control strategy, continuous monitoring of the environment is necessary to assure compliance with air quality requirements. Reactivity monitors are capable of providing information on AMC levels as low as 1 ppb. A network of monitors that communicate directly with the facility management system can also track the distribution and migration of chemical contaminants in the facility.

This paper will discuss reactivity monitoring and new advances in monitoring technology. Data will be presented from semiconductor manufacturers that have developed AMC assessment and monitoring programs centered around the use of environmental reactivity coupons (ERCs) and monitors (ERMs). Data will be presented from applications illustrating the varied use of, and experience with, this monitoring technology.

KEYWORDS

Airborne Molecular Contamination (AMC), AMC Monitoring, Contamination Control.

INTRODUCTION

Before a determination can be made as to whether airborne molecular contamination (AMC) control is warranted, the environment must be characterized as to its potential for AMC-induced damage or failures. This can be done with real-time gas monitors although this does not necessarily provide an indication of the potential effects of these contaminants. Unless a specific contaminant has been characterized as to its effect(s) on materials and processes, one can only speculate as to what its presence will mean to product reliability and yield. Even if a specific contaminant has been well characterized, e.g. ammonia in lithography processes or chlorine in metallization and salicidation, its control alone does not insure that the process or device will be defect-free. Direct gas monitoring does not take into account the possible synergies - positive and negative - between different chemical species.

Reactivity monitoring, however, can show the effects of AMC on materials and is being used in fabs to perform air quality assessments. Environmental classifications using reactivity monitoring are designed to characterize the destructive potential of an environment and has been accepted as a viable alternative to direct monitoring of low-level gaseous contaminants [1,2,3]. Reactivity monitoring is being used for the characterization of makeup air, identification of “AMC hot spots,” and to track AMC “incidents” within a fab with the ultimate goal of establishing the cause-and-effect relationship between AMC and product yields/losses.

Environmental reactivity coupons (ERCs) are commonly used for evaluating long-term air quality trends inside and outside a facility and in performing environmental surveys as part of the development of an AMC control program. They can also be used to differentiate between classes of chemical contaminants and to provide estimates of AMC concentrations.

The main limitation in the use of ERCs is their inability to provide a continuous environmental classification. To address this, reactivity monitoring has been taken a step farther through the development of a real-time monitoring device employing metal-plated quartz crystal microbalances (QCMs) [4,5]. These microprocessor-controlled devices are able to measure the total environmental corrosion attributable to AMC and can detect changes in AMC at levels <1 ppb. This is regarded as one of the main requirements for any real-time AMC monitoring protocol used in semiconductor manufacturing applications [6].

AMC MONITORING

Air monitoring is central to any environmental control program for achieving and maintaining air quality standards based on the presence (or absence) of gaseous air contaminants. Such monitoring can also provide the short-term data required to manage and mitigate contaminant-specific episodes. In addition to direct application to contamination control programs, air monitoring data may be employed for (1) the evaluation of long-term air quality trends in a facility, (2) research studies designed to determine relationships, if any, between contaminant levels and possible damaging effects, and (3) verification of AMC control equipment performance.

Several characteristics of any measurement technique must be evaluated to determine its appropriateness for use in air quality monitoring. Among the more important characteristics are sensitivity, cost, and complexity. Sensitivity is a particularly demanding parameter for the semiconductor industry where near-ambient levels of many pollutants may be encountered and control levels are approaching the parts-per-trillion (ppt) level. Likewise, cost may be quite important when deciding on a measurement technique, particularly in large surveys. A final point of consideration is the complexity of the technique and the degree of skill and training required to obtain quality results. Other factors deserving consideration are selectivity and portability. These will be discussed to some extent in relation to reactivity monitors.

Environmental Reactivity Monitoring

Even though it is possible to identify and quantify (almost) all chemical species one may encounter in a semiconductor manufacturing facility, the question still remains “What do I do with this information?” To date, there has been little to no data cited or published which provides definitive information as to the cause-and-effect relationship between specific levels of gaseous contaminants and the damage they may cause to semiconductor devices and within cleanrooms. Because of this, a number of manufacturers are turning to environmental

classification via what is referred to as reactivity (or corrosion) monitoring. The validity for this air monitoring technique lies in the fact many of the contaminants targeted for control are corrosive in nature and, therefore, can be easily monitored via reactivity monitoring.

Environmental Reactivity Coupons (ERCs). Although originally developed for the classification of environments for computers and control rooms, ERCs may be used to indicate the presence of chlorine and fluorine compounds, ammonia and many other corrosive materials including ozone, sulfur dioxide, nitrogen dioxide, hydrogen sulfide - all of which have been cited as the cause of a number of AMC-related process effects. ERCs normally contain copper or copper in combination with other metals to provide an environmental assessment (Figure 1). However, studies have shown that while copper coupons are good indicators of corrosive gases in an environment, they are not sufficiently sensitive to many of the contaminants ubiquitous to most semiconductor facilities [7,8,9]. Therefore, the use of ERCs for environmental classifications should include the use of both copper and silver coupons.

Figure 1 – Environmental Reactivity Coupons (ERCs).

ERCs are passive monitors typically exposed to the environment for a period of 30-90 days. The metal coupons are then analyzed to provide a realistic assessment of "average" environmental conditions over time. ERCs are most commonly used for evaluating long-term air quality trends inside and outside a facility and in performing environmental surveys as part of the development of an AMC control program. They can also be used to differentiate between classes of chemical contaminants and to provide estimates of the airborne AMC concentrations.

Environmental Reactivity Monitors (ERMs). One consideration faced in designing an air quality monitoring program is the choice of passive vs. active sampling. The (relatively) immediate feedback of an active monitor is a most desirable aspect and is what often precludes the use of passive monitors. The main limitation in the use of ERCs is their inability to provide a continuous environmental classification. To address this, reactivity monitoring has been taken a step farther through the development of a real-time monitoring device employing metal-plated quartz crystal microbalances (QCMs, Figure 2) [4,5]. These microprocessor-controlled devices are able to measure the total environmental corrosion attributable to AMC. ERMs employing QCMs can detect and record changes in the levels of AMC in the ambient environment at levels <1 ppb. This ability is regarded as one of the main requirements for any real-time AMC monitoring protocol to be used in semiconductor manufacturing applications [6].

Figure 2 – Visual correlation of QCMs to ERCs.

To date, there is only one commercially available ERM (Figure 3) employing copper, silver, and gold-plated QCMs which provides real-time information on the amount of corrosion occurring due to the presence of AMC, conforms to industry standards, and is currently in use in semiconductor manufacturing facilities [10]. This device monitors corrosion on a continuous basis which allows for preventive action to be taken before serious damage due to AMC has occurred.

This device may be wired directly into a central computer system. From there, data can be logged and other triggers can be initialized. By making use of the unit's ability to interface with control systems, up-to-the-minute information on the levels of corrosive contaminants can be obtained. Environmental classification databases can be established and maintained to provide historical data.

Figure 3 – An Environmental Reactivity Monitor

STANDARDS FOR AMC CONTROL

AMC control criteria are often based upon groups of chemical contaminants as opposed to individual chemical species. This is not surprising as many of these were developed from an “industry-wide” perspective. However, individual semiconductor manufacturers, due to competitive pressures, tend to use their own contamination control criteria which has been developed through their own experience, capabilities, and expectations. There is no general consensus on what may be considered acceptable levels of airborne chemical contamination, but the ranges have been narrowing over the last several years and this trend is expected to continue in the near future.

Two standards for control of AMCs will be discussed here. One is an example of what is in the industry today, SEMI Standard F21-95, and one is an example of what has been done in other industries to relate a classification to equipment reliability, ISA Standard S71.04.

SEMI Standard F21-95 [11]

The purpose of the SEMI Standard titled *Classification of Airborne Molecular Contaminant Levels in Clean Environments* is to classify microelectronic clean environments with respect to their AMC levels. These standard classifications are used in the specification of semiconductor clean environments (including process tool environments) and of contamination control and measurement equipment performance. This standard determines environmental classifications by the maximum allowable gas-phase concentration of four specific contaminant categories - acids, bases, condensables, and dopants. This classification system is shown in Table I. The combination of a quantitative class for each of the four categories yields a classification describing the environment.

Table I - SEMI Standard F21-95: *Classification of Airborne Molecular Contaminant Levels in Clean Environments*

Material Category	Classification 1*	Classification 10*	Classification 100*	Classification 1,000*	Classification 10,000*
Acids	MA-1	MA-10	MA-100	MA-1,000	MA-10,000
Bases	MB-1	MB-10	MB-100	MB-1,000	MB-10,000
Condensables	MC-1	MC-10	MC-100	MC-1,000	MC-10,000
Dopants	MD-1	MD-10	MD-100	MD-1,000	MD-10,000

As stated, these environmental classifications can be very useful to describe what levels of contaminants are in the cleaned space, but there is no correlation to equipment reliability, product reliability, and/or process yields. There is also the complexity of interpreting what the synergistic effects of those contaminants will be.

ISA Standard S71.04 [12]

It has long been known that electronic/electrical equipment failure is possible due to the corrosive effects of certain contaminant gases. A classification system for the protection of electronic equipment employing reactivity (or corrosion) monitoring was developed by the Instrument Society of America (ISA). Standard S71.04-1985 - *Environmental Conditions for Process Measurement and Control Systems: Airborne Contaminants*, covers airborne contaminants that affect electrical/electronic equipment and establishes airborne contaminant classes. Environmental classifications have been established according to the type of contaminant. Within each classification, severity levels have also been established. These are shown in Table II.

The synergistic effects of all contaminants present are seen in the total angstroms of corrosion on the reactivity coupons. Then the total number of angstroms measured on the reactivity coupons are related to reliability of the electronic equipment in that space. These reliability statements will not be shown here because they do not directly relate to semiconductor processing and semiconductor facilities would desire to operate at much lower levels than are shown in this standard. However, this shows how reactivity monitoring can determine the aggressiveness of an

environment and allow process details and product quality to be predicted from environmental classifications. This has already been done to some degree and is described in the next section.

Table II – Classification of reactive environments

Severity Level			G1 Mild	G2 Moderate	G3 Harsh	GX Severe
Copper Reactivity Level (in Å)			< 300	< 1000	< 2000	≥ 2000
	Contaminant	Gas	Concentration (ppb)			
Reactive Species	Group A	H_2S	< 3	< 10	< 50	≥ 50
		SO_2, SO_3	< 10	< 100	< 300	≥ 300
		Cl_2	< 1	< 2	< 10	≥ 10
		NO_X	< 50	< 125	< 1250	≥ 1250
	Group B	HF				≥ 10
		NH_3	< 1	< 2	< 10	≥ 25,000
		O_3	< 500	< 10,000	< 25,000	≥ 100
			< 2	< 25	< 100	

AMC Control Specifications

While the SEMI and ISA standards provide classification schemes for airborne molecular contaminants, they do not correlate cleanliness classes to semiconductor product yields or reliability. The Semiconductor Industry Association's (SIA) "National Technology Roadmap For Semiconductors,"[13] and SEMATECH's Technology Transfer 95052812A-TR [14] present recommendations which can be used to develop gas-phase contaminant specifications. The current SIA roadmap states that there is now consensus that, as device geometries approach 0.18 µm and beyond, the percentage of process steps affected by nonparticulate or molecular contamination is expected to increase [15] Because of this trend, environment control technology requirements indicate target levels of ambient acids, bases, condensables, and dopants for specific process steps.

This environmental analysis method is currently being used by a number of semiconductor manufacturers, and has been described in literature [1,2,16]. Reactivity monitoring classification schemes have been proposed (Table III) which directly correlate corrosion rates to environmental classifications and these are currently being refined based on the results of testing and the specific needs of the microelectronics industry. Generally speaking, the copper and silver corrosion rates should be class C2/S2 or better unless otherwise agreed upon.

The individual corrosion films which can be quantified when using ERCs may be used to further characterize the environment and to determine the proper AMC control strategies. Based upon the recommended control levels listed above and test results from laboratory and field-exposed ERCs, acceptance criteria relevant to these applications have been determined. These criteria take into account total corrosion as well as the relative contribution of each individual corrosion film. The most commonly cited control specifications for the individual corrosion films are listed in Table IV. These specifications are more general in their application and are often used for the characterization of an environment prior to the implementation of specific AMC control measures.

Where chemical filtration is being employed to maintain the interior concentrations of gaseous pollutants as low as possible, total corrosion rates <15-20 Å / 30 days have been routinely attained. Subsequent gas monitoring has indicated pollutant levels to be at or below the limits of detection for the analytical techniques employed. This "no detectable pollutants" scenario is being used to set up environmental classification systems based on reactivity monitoring. It is felt that if an environment exhibits corrosion rates corresponding to a C1 or S1 classification, there is nothing else which can be done, economically, to improve the environment.

Table III – Environmental classifications for semiconductor cleanrooms					
Copper Corrosion			Silver Corrosion		
Class	Air Quality Classification	Corrosion Amount	Class	Air Quality Classification	Corrosion Amount
C1	Pure	<90Å / 30 days	S1	Pure	<40Å / 30 days
C2	Clean	<150Å / 30 days	S2	Clean	<100Å / 30 days
C3	Moderate	<250Å / 30 days	S3	Moderate	<200Å / 30 days
C4	Harsh	<350Å / 30 days	S4	Harsh	<300Å / 30 days
C5	Severe	∃350Å / 30 days	S5	Severe	∃300Å / 30 days

Table IV – General reactivity monitoring acceptance criteria for semiconductor cleanrooms			
Copper Reactivity Acceptance Criteria		Silver Reactivity Acceptance Criteria	
Copper Corrosion Reaction Products	Corrosion Film Thickness	Silver Corrosion Reaction Products	Corrosion Film Thickness
Copper Sulfide, Cu_2S Copper Oxide, Cu_2O Copper Unknowns	0Å / 30 days <150Å / 30 days 0Å / 30 days	Silver Chloride, AgCl Silver Sulfide, Ag_2S Silver Oxide, Ag_2O	0Å / 30 days <50Å / 30 days <50Å / 30 days
Total Copper Corrosion	<150Å / 30 days	Total Silver Corrosion	<100Å / 30 days

DATA FROM SEMICONDUCTOR MANUFACTURING FACILITIES

As mentioned previously, typical uses of reactivity monitoring with ERCs and ERMs have been for the characterization of outdoor air used for ventilation, the identification of “hot spots” within a manufacturing facility, and the effectiveness of various preventive measures. Reactivity monitoring is also being used to track AMC “episodes” in semiconductor fabs for the purpose of developing the cause-and-effect relationship between AMC and product yields/losses. The charts and tables below illustrate some of the types of information which have been obtained from the use of reactivity monitoring.

Outside Air Monitoring with ERCs

It can be seen in Table V that the total copper and silver corrosion for all of the ERCs exceeded the general copper and silver acceptance criteria of <150Å/30 days and <100Å/30 days, respectively. This indicates that the makeup air for this facility may need to be treated in order to prevent chemical contaminants from be distributed throughout the facility.

From an examination of the individual corrosion films, the detection of a silver sulfide (Ag2S) film without a corresponding copper sulfide (Cu2S) film usually indicates the presence of oxidized forms of sulfur (e.g., SO2, SO3). When both films are detected - as is the case for all four sets of ERCs - this usually indicates of the presence of active sulfur compounds (e.g., elemental sulfur, hydrogen sulfide, organic sulfur compounds) as well. When both films are present and the amount of Cu2S is greater than 50% of the total corrosion (all ERCs shown), this is further evidence of the presence of active sulfur compounds in the subject airstream. From this, it is estimated that the active sulfur concentrations are in the range of 3-10 ppb and the sulfur oxides are in the range of 10-100 ppb.

Silver chloride (AgCl) was detected on each of the silver ERCs which indicates the presence of (an) inorganic chlorine compound(s), e.g., chlorine, chlorine dioxide, hydrogen chloride. On each silver coupon, this accounted for more than 50% of the total corrosion. Estimates of chlorine concentrations are 1-5 ppb.

Table V – Site Survey ERC Data – Outside Air

ERC Location	Copper Corrosion					Silver Corrosion				
	Total	Cu_2S	Cu_2O	Cu-Unk	Class	Total	AgCl	Ag_2S	Ag-Unk	Class
Property line (outside air)	16,380	16,195	634	0	C5	275	192	83	0	S4
Rooftop air intake	553	406	87	59	C5	163	116	46	0	S3
Ground-level air intake (1)	606	388	159	59	C5	416	378	38	0	S5
Ground-level air intake (2)	436	249	167	0	C5	442	247	66	129	S5
MUAH – intake	15,698	15,348	350	0	C5	375	298	76	0	S5

Facility Monitoring

Once the need for controlling AMC has been established, and control levels have been suggested, it is still necessary to determine the current air quality of the space to be protected. This includes an assessment of the quality of the air inside the cleanroom as well as the quality of the air outside the facility.

Table VI and VII shows the data from a number of ERCs used as part of an environmental assessment in and around a semiconductor fab. The outside air was shown to has significant levels of reactive sulfides, sulfur oxides, and inorganic chlorine species which were being introduced into the facility through the make-up air handlers (MUAHs) and distributed throughout the fab through the recirculation air handling units (RAHUs).

As shown in the copper corrosion analysis results, those ERCs exposed directly to the outside air ("O") averaged 30 times the amount of total corrosion formed on the ERCs exposed to recirculation air ("O/R" and "R"). Examination of the individual corrosion films showed that sulfide corrosion (Cu_2S) dominated. This was not unexpected as there was a power plant, a pulp and paper mill and a chemical plant within sight of this facility. Based on these results, it was estimated that hydrogen sulfide was present at levels □50 ppb and/or sulfur dioxide levels were □300 ppb. Copper sulfide corrosion was only evident in two areas inside the fab - Etch Bay and MVA - which indicated that the hydrogen sulfide was being effectively diluted with cleaner air in the recirculation airstream to levels <3 ppb.

Table VI - Site survey reactivity monitoring data (U.S. semiconductor fab) – Outside Air

CCC Location	Source of Air*	Copper Corrosion (Å)				Silver Corrosion (Å)			
		Total	Cu_2S	Cu_2O	Cu-Unk	Total	AgCl	Ag_2S	Ag-Unk
Fence Line (outside air)	O	16,380	16,195	634	0	275	192	83	0
Cooling Tower (roof)	O	16,336	15,759	577	0	380	256	124	0
Loading Dock (east)	O	8,177	8,033	144	0	259	133	86	39
Loading dock (south)	O	6,202	6,058	144	0	268	149	55	63
Fab MUAH - Intake	O	15,698	15,348	350	0	375	298	76	0
Rooftop air intake	O	553	406	87	59	163	116	46	0
Ground-level air intake	O	606	388	159	59	416	378	38	0
Ground-level air intake	O	436	249	167	0	442	247	66	129
Average Value		**8,049**	**7,805**	**283**	**15**	**322**	**221**	**72**	**29**

*O = outside air, R = recirculation air

Table VII - Site survey reactivity monitoring data (U.S. semiconductor fab) – Recirculation Air									
CCC Location	Source of Air*	Copper Corrosion (Å)				Silver Corrosion (Å)			
		Total	Cu_2S	Cu_2O	Cu-Unk	Total	AgCl	Ag_2S	Ag-Unk
Etch Bay	R	369	121	248	0	334	177	114	44
Films	R	198	0	198	0	391	11	254	126
MVA	R	481	364	117	0	473	353	76	44
Sub-Fab, Diffusion	R	216	0	216	0	339	21	199	118
Sub-Fab, WETS area	R	196	0	196	0	266	33	183	49
Sub-Fab, Photolithography	R	179	0	179	0	256	19	153	84
Inspection Building	O/R	227	0	227	0	523	59	398	65
P&T Building	O/R	290	101	189	0	227	173	39	15
Average Value		**270**	**73**	**196**	**0**	**351**	**106**	**177**	**68**

*O = outside air, R = recirculation air

Examination of the silver reactivity data similarly indicated the presence of sulfide corrosion (Ag_2S). The data also indicated the presence of chloride corrosion (AgCl), which in most cases was the dominant corrosion film. Again, this was not unexpected. The facility's utility building which was adjacent to the fab, held cooling towers on its roof. The source of the chlorine was suspected to be the chlorinated water used in the cooling towers which was being introduced into the fab through the MUAHs.

Chlorine corrosion was evident on every silver coupon, and even though there was a reduction n the amount chloride corrosion between the inside and outside ERCs, the inside levels were still almost 60% of the outside levels. This indicated that chlorine was being distributed through the fab through the air handlers at levels high enough to be problematic. Inorganic chlorine levels - inside and out - are estimated to be in the range of 1-2 ppb (expressed as Cl_2).

This environmental assessment can be used to determine what effect, if any, these chemical contaminants may be having on materials and processes. It is being used as the basis for a proposal for the addition of chemical filtration in the makeup air handlers (MUAHs).

Recirculation Air Monitoring

Figure 4, below, shows an example of information which can be obtained through the use of ERMs. Process engineers wanted to determine if detectable levels of corrosive AMC where present. One 24-hour monitoring period showed a fairly regular pattern of AMC episodes which appeared to be correlated to the daily process tool schedule. Once this correlation was established and confirmed, facility and maintenance personnel wanted to see if the AMC episodes could be significantly reduced in magnitude or eliminated altogether. Among the items to be checked were process gas lines and chemical feed lines, performance of the installed chemical filtration systems, tool maintenance logs and, adherence to standard operating procedures.

Figure 5, below, shows this data and several subsequent days' monitoring data which indicated that their AMC mitigation efforts were successful and resulted in a reduction of the copper reactivity rate from a Class C5 to a Class C1 based on the environmental classification scheme described above.

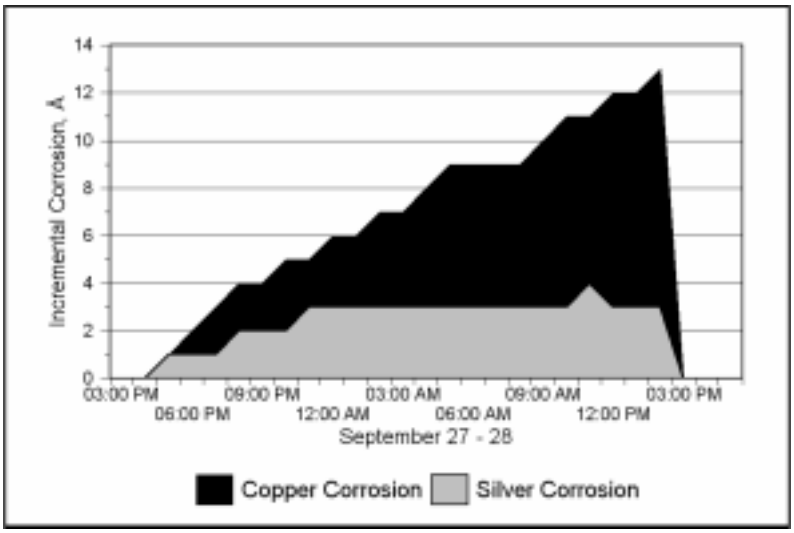

Figure 4 – ERM data showing regular patter of AMC Episodes.

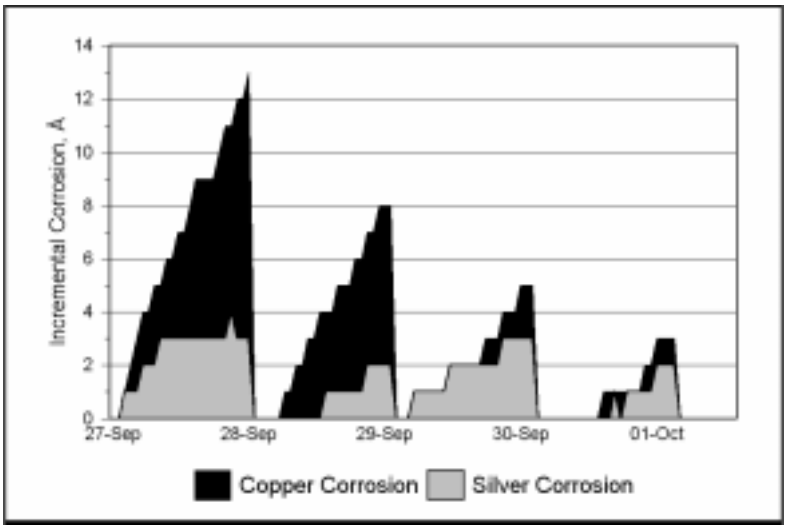

Figure 5 – ERM data from subsequent days showing effects of mitigation efforts.

AMC Control System Verification

Table VIII shows the data from ERCs located up-and downstream of a chemical filtration system installed in one of four MUAHs at a wafer fab. The filtration system performance specifications called for AMC levels to maintained at or below the C2/S2 classification and for chlorine to be removed completely from the air.

Examination of ERM data indicated that the copper and silver reactivity rates were Class C1 and S2, respectively. As can be seen below, the ERC data verified that no chlorine was being introduced into the fab through the MUAH. This data was sufficient evidence to justify the installation of chemical filtration in the remaining MUAHs and to use ERMs and ERCs for system performance verification.

Table VII - ERC monitoring of wafer fab chemical filtration system

Coupon Location	Silver Corrosion			
	Total	AgCl	Ag_2S	Ag-Unk
A – upstream	321	93	159	69
A – downstream	31	0	26	5
Efficiency	90%	100%	84%	93%
B – upstream	504	252	204	48
B – downstream	76	0	45	31
Efficiency	85%	100%	78%	35%
C – upstream	264	126	108	30
C – downstream	42	0	16	26
Efficiency	84%	100%	85%	13%

SUMMARY

Environmental reactivity monitors have been shown to be a very useful tool for characterising enuironments and developing classification schemes. As both a real time monitor and a passive one, reactivity monitoring is a cost effective and valuable tool for the semiconductor industry.

ERMs and ERCs have been presented here for three main purposes: 1) assesment of air quality outside and inside a facility, 2) tracking of AMC episodes, and 3) verifying AMC centrol equipment performance. In the data presented, contaminants of concern were identified in the outside air as well as that inside the facility. Cyclic episodes were tracked and efforts to stop them were shown to be successful. Finally, perfomrance of AMC control systems were verified to reduce concentrations and remove the targetted AMCs.

Reactivity monitoring is a proven method to classify environments. A classification scheme is already being utilzed and revised by the semiconductor industry toward the end of standardizing acceptable levels. Further deuelepements and refinings of this classification scheme will aid semiconductor facilities in maintainig high yields and protecting products.

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