Applications of AMC

Chris Muller of Purafil, Inc. looks at practical applications of assessment, control, and monitoring of AMC for microelectronics manufacturing

The term airborne molecular contamination (AMC) covers a wide range of contaminants present in cleanroom air. These can be in the form of gases, vapours or aerosols. Their chemical nature can be organic or inorganic and includes acids, bases, polymer additives, organometallic compounds, condensables and dopant-containing species. The main sources of AMC in cleanrooms are the ambient (outdoor) environments, process chemicals, tool emissions, and construction materials.

In microelectronics manufacturing, AMC represents a wide range of chemical types that can result in a large number of potential processing problems. AMC can impact almost all aspects of sub-micron device fabrication, from overall fab operation to final device performance. The shift to copper interconnects, 300mm wafers, and device geometries >0.18 micron is quickening the shift to AMC-free manufacturing environments. AMC control has become an essential design requirement for all new semiconductor manufacturing facilities.

AMC control is not a new problem to disk drive manufacturers either. As flying heights approach contact, contamination has become a major concern. Corrosion is catastrophic to the thin metallic films on disk media and recording heads.

Implementing AMC control

The necessity to control AMC is now shared by both microelectronics and disk drive manufacturers with each sharing a common goal - process improvement and yield enhancement. The optimum control of AMC has evolved into a three-step process. (1) ASSESSMENT of the air quality both outside and inside the facility to identify potential target contaminants. (2) Selection and qualification of an AMC CONTROL system. (3) Ongoing MONITORING of both the controlled environment and the performance of the AMC control system.

AMC assessment

Before AMC control is specified, the environment must be characterised as to its potential for damage to materials, processes, and devices from various chemical contaminants. Semiconductor and disk drive manufacturers are using reactivity monitoring to perform air quality assessments [1-3]. Environmental classifications have been established that are designed to characterise the destructive potential of an environment (Table 1). These classifications are being refined based on the results of testing, input from these industries, and the specific needs of each industry [4,5]. The ultimate goal is to establish cause-and-effect relationships between AMC and product yields/losses.

Individual corrosion films can be quantified and used to further characterise the environment and assist in determining the proper AMC control strategies. Relevant acceptance criteria have been determined that take into account total corrosion and the contribution of each individual corrosion film. These specifications are more general in their application.

AMC control

The goals of improving production and having fewer defects and less rework all point to an increased requirement for reducing and maintaining lower AMC levels in the cleanroom manufacturing environment. There are currently no industry standards that address AMC with specific control criteria for individual contaminants. Semiconductor manufacturers have SEMATECH's International Technology Roadmap for Semiconductors [6] that offer some guidance on sensitive process steps and the contaminants of concern. Disk drive manufacturers have maintained R&D programs that continually look into the technologies that would be required 8-10 years into the future [7].

Although each manufacturer has their own specific set of guidelines with respect to AMC control, the broad guidelines for

Table 2 General acceptance criteria for cleanrooms

Copper corrosion reaction products	Corrosion film thickness	Silver corrosion reaction products	Corrosion film thickness
Copper sulphide, Cu_2S	0Å /30 days	Silver chloride, AgCl	0Å / 30 days
Copper oxide, Cu_2O	<150Å / 30 days	Silver sulphide, Ag_2S	<50Å / 30 days
Copper unknowns	0Å / 30 days	Silver oxide, Ag_2O	<50Å / 30 days
Total copper corrosion	<150Å / 30 days	Total silver corrosion	<100Å / 30 days

Table 1 Environmental classifications for cleanrooms

Class	Copper corrosion air quality classification	Corrosion amount	Class	Silver corrosion 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

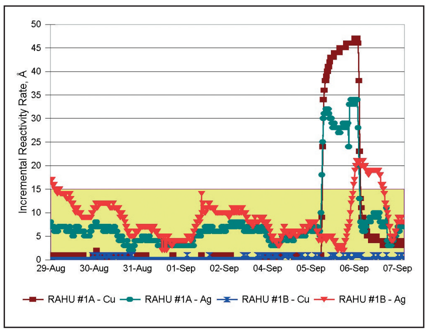

Fig. 1 ERM network data

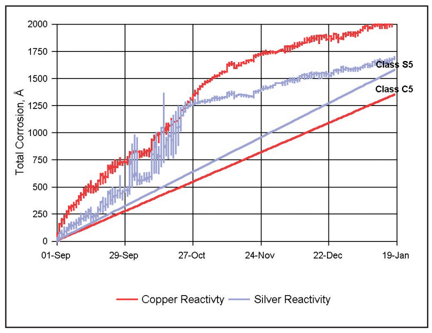

Fig. 2 ERM data for outdoor air

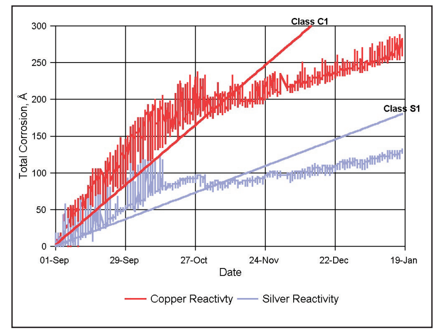

Fig. 3 Cleanroom air quality data

applying AMC control at the deep submicron level are:

- All makeup air units serving process areas, and all recirculating systems serving areas where wafers are processed, stored, or handled. For disk drive manufacturing:
- All makeup air handlers serving class 100 or better cleanroom areas.

Makeup air systems must typically be designed to control SO_x, NO_x, ozone, VOCs, and some site- specific contaminants such as chlorine (cooling towers, coastal locations), organophosphates (pesticides) and ammonia (agricultural activities). Chemical filtration equipment in recirculation systems must be designed to remove a wide array of acids, bases, hydrocarbons and other VOCs. As a rule, organic compounds - although perhaps not the most damaging - are the most abundant types of AMC found in these facilities.

AMC monitoring

Once an AMC control strategy has been decided upon and implemented one must be able to monitor the success or failure of meeting specified AMC control criteria. Where chemical filtration is being used, an AMC monitoring program must be able to provide the following information:

- Type(s) of contaminants present and their relative levels.
- Air quality information correlated to specific air cleanliness classifications.
- Chemical filtration system performance assessment.
- Verification of the attainment of specified or standard AMC levels.

In general, the air quality in cleanroom manufacturing environments should be class C2 / S2, without evidence of active sulphur or inorganic chlorine contamination, unless otherwise agreed upon. This typically indicates an environment sufficiently well controlled as to prevent AMC-related process effects and direct control of chemical contaminants may not be required.

If an environment exhibits reactivity rates corresponding to a C1 or S1 classification, there is little else that can be done, economically, to improve the environment. Where Purafil chemical filtration technology is being employed to control AMC, total corrosion rates <15 - 20Å / 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.

CASE STUDY - DRAM MANUFACTURER

Environmental assessment data

This manufacturer's facility is located near an airport, a coal-burning power plant, a chemical plant and a paper mill. There were concerns that elevated levels of corrosive gases (predominantly sulphur species) could be introduced into the facility through the makeup air handlers. Site cooling towers were also considered as a potential source of AMC (chlorine). It was suspected that significant levels of nitrogen oxides and ozone were also present in the ambient air.

Monitoring confirmed that the outside air showed extremely high copper and silver reactivity rates indicative of a class C5/S5 environment. This air was estimated to have concentrations >50 ppb and 100-300 ppb, respectively, for reactive sulphur and sulphur oxides, and >10 ppb for chlorine.

Environmental reactivity coupons (ERCs) were placed inside the facility to determine to what extent these contaminants were being introduced into the cleanroom areas. Reactive sulphur (as H_2S) was evident only in one area and the indoor levels of sulphur oxide contamination were estimated to be in the range of 10 - 100 ppb. However, chlorine contamination was evident in every location monitored with the indoor levels almost 60% of the outside levels. This indicated chlorine was present at levels potentially high enough to be problematic (~2-10 ppb).

Real-time environmental reactivity monitors (ERMs) were installed in the make-up and recirculation air systems. Monitoring data collected more than a year after the initial assessment indicated that the outside air was still class C5/S5. This pointed out the potential for AMC-related process effects and chemical filters were added to all makeup air handlers to reduce AMC from the outside.

AMC control strategy

As mentioned above, reactivity monitoring indicated the presence of chlorine contamination in almost all areas of the facility. To reduce the potential for this and other chemical contaminants from being introduced from outside the facility, chemical filters were installed in each of the makeup air handlers.

Prior to filter installation, reactivity monitoring indicated that the AMC levels were higher in the interstitial area (where the makeup air is introduced) than in the subfab. After installation, the opposite was observed. Subsequent monitoring has verified an overall reduction in the total AMC load and specifically chlorine. Internal sources of chlorine emissions were identified and steps have been taken to monitor and control these sources.

AMC monitoring results

A network of ERMs has been established to provide monitoring for several process areas. The copper and silver reactivity monitoring data is collected and trends in the data were compared to incident report logs.

The AMC event tracking logs were examined and it was found that incremental peaks in the copper and/or silver reactivity monitoring data correlated with specific reported events. For those events where a time was given for the reported incident, in most cases the ERM data showed an increase in the incremental reactivity rate before the event had been reported. This meant that the ERM network could be used as an "early warning system" and prevent AMC-related events that could cause damage to in-process materials and/or stop production due to an evacuation of the process area/or the fab itself. Some of this information is shown in Table 3.

Based on the monitoring data obtained and comparison with the AMC event tracking logs, an incremental reactivity rate of 15Å has been established as a baseline against which future AMC "episodes" will be compared (Fig. 1). The use and refinement of the ERM network is continuing with the ultimate goal being to detect, in real-time, any AMC/chemical contamination episodes which could negatively impact production yields. Achievement of this goal could facilitate prompt root cause investigation resulting in corrective actions reducing production impacts and in-process material losses as deep sub-micron manufacturing levels are approached.

Chemical filter performance

ERM data was provided from monitoring upstream and downstream of the filters in one of the makeup air handlers. These filters were assumed to be approaching their adsorptive capacity based on the length of time they had been in service and monitoring was performed to validate this assumption. The data indicated that the chemical filters are removing less that 60% of the total AMC present in the makeup air. This verified that the filters were nearing the end of their service lives and that replacement was warranted.

CASE STUDY - DISK DRIVE MANUFACTURER

Environmental assessment data

This company was concerned about AMC and its effect on potential upgrades to their facility. This facility is located in an industrial section of a large metropolitan area. Multiple sets of ERCs were placed in a number of locations throughout the facility. ERM data was also collected continuously over the entire monitoring period.

Both the ERC and ERM data indicated class C5/S5 outdoor air with high levels of sulphur and chlorine contamination (Fig. 2). The AMC levels were estimated to be 10-50 ppb and 10-100 ppb, respectively, for the sulphur species. Inorganic chlorine was detected at levels estimated to be >10 ppb. Nitrogen oxides and ozone were not monitored but were anticipated to be at levels high enough to be of concern.

AMC control strategy

Reactivity monitoring was used to establish baseline data for the specification and design of a new chemical filter system. The system was to be evaluated to test its ability to remove specified contaminants as well as those identified by reactivity monitoring.

A two-stage chemical filtration system was placed on the fresh air inlet supplying ventilation air to a mechanical room housing a recirculation air handler. The chemical filter system contained dry-scrubbing media designed for the removal of (among other things) acid gases and VOCs. 85% ASHRAE-grade filters in the recirculation air handlers were replaced with pleated combination chemical/particulate filters designed for the removal of VOCs and acid gases.

ERCs were placed at the fresh air inlet, in between the first and second stage of the two different dry-scrubbing media, at the discharge of the chemical filter system, in the mechanical room, and in the cleanroom. After verifying that the proper filter media had been installed and the unit was operating properly, coupons were removed at two-week intervals.

ERMs were placed at the fresh air inlet, the discharge of the chemical filter system, in the mechanical room, and cleanroom. Monitoring data verified that these chemical filters were removing the specified contaminants as well as providing Class C1/S1 air in the cleanroom (Fig. 3). Active sulfur and inorganic chlorine contamination was removed completely within the system.

AMC monitoring results

ERCs and ERMs are being used for continuous assessment of the environment and the performance of the chemical filter system. Multiple sets of ERCs were used to gauge performance against specific types of AMC and to track changes in AMC types and relative levels. A network of ERMs was installed and is data is currently being logged through the facility monitoring system.

Reactivity monitoring data were collected over a 90-day period to evaluate the effectiveness of the chemical filter system against the contaminants identified in the outside air. The chemical filters systems are reducing the levels of AMC by more than 95% and providing a Class C1/S1 environment (Table 4). Examination of the total and individual corrosion films data indicate that active sulphur and inorganic chlorine contaminants (expressed as Cu_2S and AgCl, respectively) were removed completely within the AMC control system.

Summary and conclusions

With the rapid pace of technological advancements, microelectronics manufacturers have fully recognised the fact that sensitive electronics and electrical components will be damaged if they are exposed to AMC. The existence of AMC in semiconductor fabs is widely accepted and documented, however, we are just beginning to understand the impact of contaminant levels on manufacturing processes and product yields. Most fabs have only recently begun to take measures to prevent AMC from being introduced into the cleanroom or to control AMC that is already there.

Because of shrinking bit sizes, lower flying heights, alternative substrates, and smoother disk surfaces, today's high-performance drives are increasingly susceptible to AMC. As the disk drive industry progresses, manufacturing will need to be performed under cleanroom conditions that are comparable to those required for the production of leading-edge DRAM technology. Drive components will also need to be fabricated in cleanrooms that meet tougher air quality standards and industry-wide standards will need to be established for the control of AMC.

Direct correlations between process yield and individual contaminant concentrations are either rare or not published. Rapid technological progress and extremely fast

Table 3 AMC event tracking log

Area(s) investigated	Incident reported /identified	Area(s) monitored	Event started	Event peak	Peak value
	PGMEA leak	RAHU Inlet (2)	14:10	13:28*	24-43Å Cu
Etch	Leak repairs in progress on scrubbed exhaust lateral	RAHU Interstitial	03:30	07:00	140Å Ag
Etch	Broken exhaust line on vacuum pump in subfab.	RAHU Interstitial	11:30	0:30*	353Å Ag
Etch	Cl_2 odour reported in FAB one day after event started. Broken exhaust line on vacuum pump in subfab.	RAHU Inlet	0:00	08:00**	128Å Ag
	P-trap replaced on HCl drain.	RAHU Inlet	10:30	08:28*	47Å Cu

**event peaked the following day **event peaked two days after*

Table 4 Summary of chemical filter performance

ERM monitoring location	Copper reactivity*	Reduction	Class	Silver reactivity*	Reduction	Class
Fresh air inlet	435		C5	362		S5
Chemical filter discharge	21	95.16%	C1	9	97.58%	S1
Mechanical room	57	86.97%	C1	28	92.24%	S1
Cleanroom	11	97.49%	C1	23	93.62%	S1

**Å / 30 days*

product development are constantly shrinking plant and equipment cycle times. "Next generation" semiconductor devices and disk drives will require the strict control of AMC in order to assure productivity, competitiveness, and profitability. Both industries are actively addressing AMC and its control, each according the specific requirements of their own manufacturing processes and concerns.

An assessment of the outdoor air quality should be one of the first steps towards establishing any AMC control program. An air quality classification based on reactivity monitoring scheme has been established and has gained wide acceptance throughout the semiconductor and hard drive industries.

In these industries, the control of corrosive gases in the cleanroom manufacturing environment is of primary concern. Even if direct control of contaminants (i.e., chemical filtration) is not employed as part of a facility's overall AMC control program, continuous monitoring of the environment is necessary to assure compliance with any air quality criteria.

ERMs have proven especially useful for establishing AMC baselines and identifying AMC episodes and their sources. When incorporated into a facility's preventive maintenance program, they have been shown to reduce the number of AMC-related incident that are reported. They can also help reduce the number of reported health and safety incidents by allowing proactive investigation of potential problems. The ultimate goal is to eliminate production down-time due to AMC.

It is performance monitoring of chemical filter systems for which ERCs and ERMs have gained their widest acclaim. This allows for the timely changeout of media and/or filters and reduces the cost-of-ownership. Proper maintenance assures that air quality goals are being met and AMC-related process effects are significantly reduced or eliminated.

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For further information conatct Purafil Inc. tel: +1 770 662 8545; website: www.purafil.com