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A 21st Century Approach to Airborne Molecular Contamination Control

Jitze Stienstra Ph.D., Joseph Wildgoose, Jürgen Lobert Ph. D., Christopher Vroman, David Ruede

AMC control in the fab requires not just the knowledge of which contaminants can be harmful, but requires a high level of competency in several disciplines for the careful selection and implementation of products to result in a total solution.

Abstract

The ability to control Airborne Molecular Contaminants (AMC) and their interactions with semiconductor fabrication processes and equipment requires a new, comprehensive approach. Multiple disciplines and competencies are required to bring a systematic understanding to both the challenges and potential solutions. Four steps that comprise the essential elements needed in a multistep, multilevel, integrated approach to data-driven and cost-effective 21st century AMC control are explored in this article.

Introduction

Prior to the advent of DUV lithography and submicron resolutions, AMCs of interest in IC fabs fell into two categories: dopants that condensed on wafer surfaces and changed device performance; and corrosives that led to device failure. While these species were usually well below health and safety levels, they were often at concentrations high enough to have an effect on sensitive circuitry. In some cases they came from glass-based particle filters that were etched and volatilized over time by low levels of fugitive acids and ended up on the wafer surfaces. Corrosives could end up on metal lines or contacts, leading to device failure over time. Where source mitigation was not possible, chemical filters were employed to address these issues.

Over the years, discussions about AMC control in IC fabs have moved from fab-specific concerns to incorporation into industry standards, with a dedicated section in the 2008 ITRS[1] roadmap. The ITRS's latest Yield Enhancement targets for Photolithography cleanroom AMC levels are a testimony to their importance in meeting the challenges of Moore's Law. Chemical filtration has now been elevated to the importance of particles in ISO cleanroom standards.

A Four Step Approach

With the improved understanding of the potential problems from elevated levels of AMC in the IC fabrication process, a four step approach to 21st century Airborne Molecular Contamination control is recommended.

AMC control fabs have moved from fab-specific to industry standards

Step One: Know Your Enemy

Not all volatile species are harmful. Knowing which contaminant at which concentration causes process or equipment problems takes time and resources. Modern fabs are well aware of the need to control a wide range of AMCs at the low parts-per-billion or even parts-per-trillion level to protect very sensitive processes and equipment. Figure 1 summarizes the AMC challenges in photolithography since about 1990 and into the first part of the current century. Photoresist T-topping, which was eventually fully solved through the use of chemical filters, was succeeded by a concern for a range of molecular species, which could form films (haze) and crystalline deposits on optical surfaces [2,3]. In the case of ArF scanner optics contamination[4], data collected by analytical services, filtration, tool and device makers for more than 15 years and consisting of thousands of samples from a large number of fabs was needed to understand this complex phenomenon. And in fact, the effects of low molecular weight Si organic species

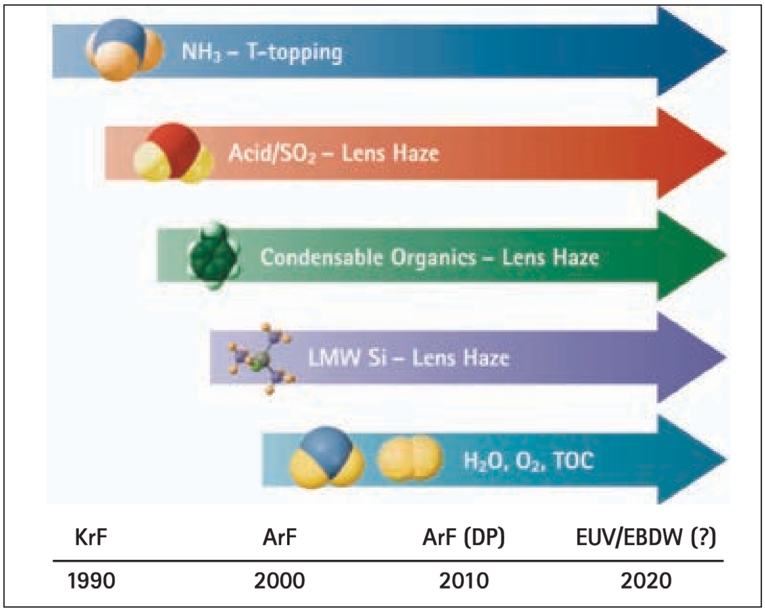

Figure 1. AMC Control Roadmap for DUV Lithography from 1990 to 2020.

on lens haze remain an active area of research.

EUV photolithography is bringing an entirely new range of contaminants into focus, with even simple molecules such as water and oxygen capable of degrading scanner optical surfaces as well as reticles. A lesson learned from the 1990s is that the identification of contaminants and the assessment of the concentrations at which they cause harm is a critical first step in solving the problems. For advanced fabs, that often requires analytical expertise to measure at the parts-per-trillion levels.

Step Two: Understand Your Options

There are several options available to fighting contamination but they can be impractical or cost prohibitive if applied incorrectly. Knowing the cost effectiveness of each option is critical to determine an affordable, long-term AMC control strategy that fits the unique needs of each fab.

AMC control solutions can be grouped into two categories: local vs. global. Local is often referred to as point-of-use (PoU). The key factor here is to apply AMC control immediately prior to the process chamber or wafer, thereby ensuring that process gases are as clean as possible just prior to coming into contact with the process. An important advantage of this approach is that the least amount of gas will be filtered or purified, which often provides scale and cost benefits over alternative solutions.

A global, fab-wide approach can be more cost effective when many tools and processes need to be protected from the same contaminants. This is possible only when gases can be kept clean enough between the chemical filter and the process. In such cases, efficiencies of scale favor a single, larger solution. Installation and maintenance is often easier but incidents and failures can have an impact across the entire fab.

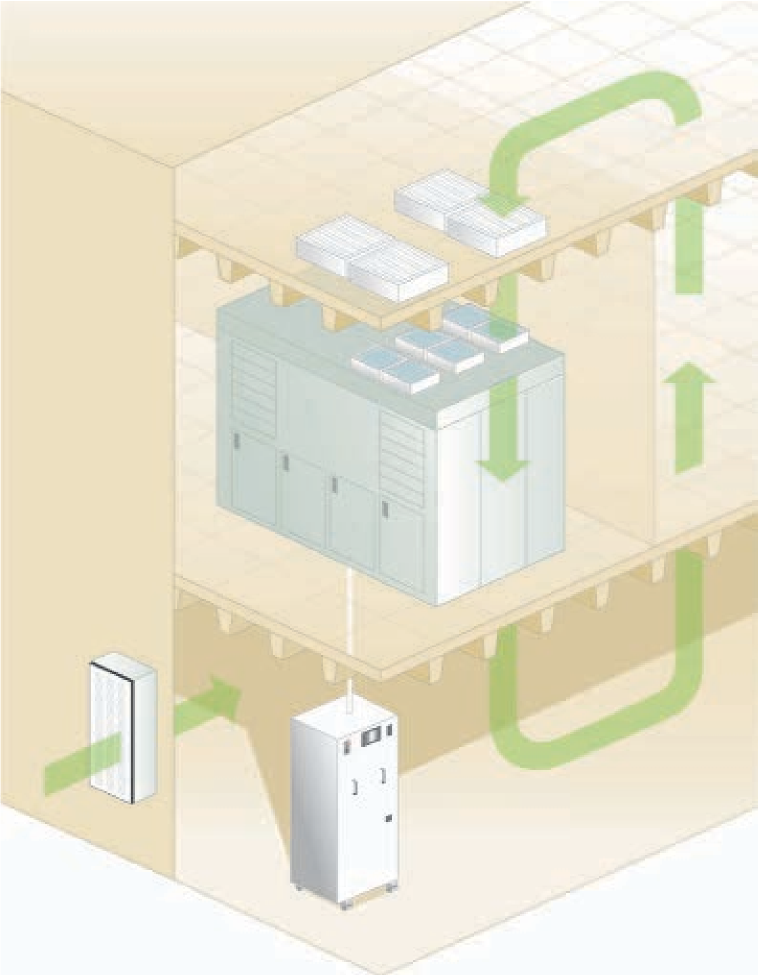

Figure 2. Schematic of a multilevel approach to AMC control depicted in a scanner—including make-up air filters, recirculation air filters, tool enclosure filters and point of use purifiers

ITRS 2008 Table YE9 Technology Requirements for Wafer Environment Contamination Control						
Airborne Molecular Contaminants in Gas Phase: Lithography Cleanroom Ambient (pptV)						
Year of production	2008	2009	2010	2011	2012	2013
Total inorganic acids	5,000	5,000	5,000	5,000	5,000	5,000
Total organic acids	TBD	TBD	TBD	TBD	TBD	TBD
Total bases	50,000	50,000	50,000	50,000	50,000	50,000
Condensable organics*	26,000	26,000	26,000	26,000	26,000	26,000
Refractory compounds**	100	100	100	100	100	100
SMC refractory compounds***	2	2	2	2	2	2

* with GCMS retention times ≥ benzene, calibrated to hexadecane
** Organics containing S, P, Si
*** Surface Molecular Condensable, on wafer, ng/cm²/day

Table 1. 2008 ITRS Roadmap for Lithography Cleanroom Ambient AMC levels

The global approach in combination with a local/PoU approach acknowledges the fact that no matter how effective the chemical filter is, AMCs will be reduced by orders of magnitude, but not entirely eliminated. Even at very low levels they sometimes have an impact, given enough time to build up and to become visible. Haze on scanner lenses is an example of this phenomenon. AMCs need to be controlled better when fab air or gases are in contact with wafers or optics. A combination of air handler and tool enclosure chemical filters, coupled with chemical purifiers ensure multilevel protection of the process and tool, resulting in more effective AMC control than is possible with a single solution. (See Figure 2)

Step Three: Be Aware of Your Environment

AMC problems no longer belong with OEMs and photolithography equipment engineers only. Today's challenges require a larger collaboration within and between companies, and defining ownership is critical to successful AMC control.

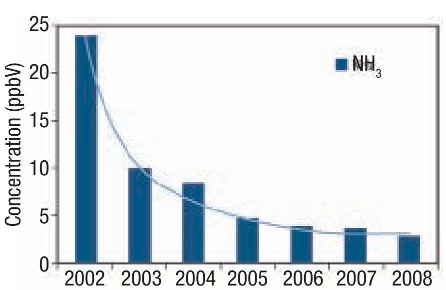

Figure 3. 2002 - 2008 ambient NH_3 levels in photobays (Entegris Analytical Service data)

Figure 3 shows averages of seven years of ammonia (NH_3) data from many fabs world wide. The significant improvement in average NH_3 levels speaks to recent trends to control ambient levels of all AMCs in photolithography. A substantial portion of this improvement was due to the attention paid to sources of AMCs by facility, equipment and process engineers. Another factor for the improvement is the consolidation and closing of smaller, older fabs which typically showed higher NH_3 levels due to older air handler designs and the dense packing of process and metrology tools and their accompanying personnel, all of which contribute to higher AMC levels than found in modern fabs. Similar trends are seen for acids and condensable organics over the same period.

Geographic considerations sometimes need to be considered due to local environmental factors such as rural vs. urban, arid vs. humid and agricultural vs. industrial environments. In the beginning of this century, urbanization as well as increased energy usage and the resulting effect on air chemistry where traditional carbon-based sources are used, could drive fabs that are situated in such areas to consider the use of more stringent environmental controls. This requires facility engineers to be increasingly involved in the strategic planning for contamination control.

Step Four: Plan For The Future

Not all days are the same. Things change, especially at the molecular level, so trust but verify[5]. Trust that strategies once implemented will continue to work to specification, and verify that conditions have not changed, which may render the solution less effective.

As shown in Figure 4, a 30-month AMC monitoring study of a new, high-volume manufacturing fab revealed that AMC levels at start-up were elevated due to a significant amount of condensable organics. These levels subsided over the first few months, and were attributed to new construction materials offgassing— e.g. plastics, coatings, polymer surfaces. Organics decreased steadily for the first half of the study only to reappear toward the end of the study. The make-up of the organic mixture, however, had significantly changed from construction offgassing to process chemistries— photoresist components in particular.

Monitoring the fab's air chemistry over time can help define the most cost-effective solution for long-term AMC control. Effectiveness and affordability need to be considered upfront, by designing the flexibility to adapt changes in AMC composition into the AMC control strategy. Periodic adjustment and fine-tuning of AMC control solutions offer the best protection for fab processes even when conditions and process chemistries change.

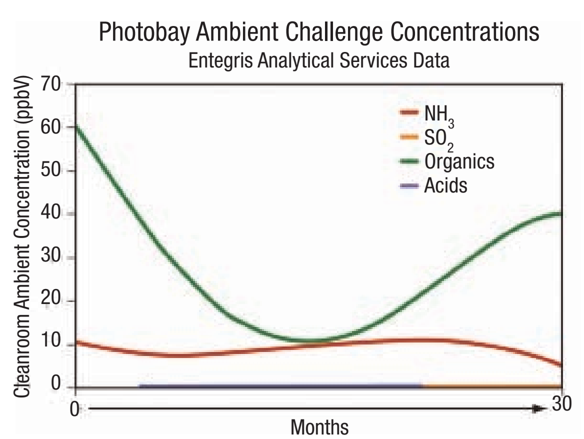

Figure 4. 30-month study of AMCs in a new fab during start-up and production ramp-up

The advent of ArF double patterning and EUV photolithography together with advanced deposition processes will present new and more complex challenges.

Evolving solutions for AMC filtration and analysis as well as process gas purification are needed to build on the gains made in the past two decades.

Summary

Comprehensive AMC control requires quantified knowledge of the potential harmful species inside the cleanroom, analysis of the conditions that exist, and understanding of the options for control when needed. Suppliers with the products and services to provide a total solution as well as the process, equipment and facilities knowledge to apply such solutions to a fab can help minimize risk and continue to re-optimize the elimination of AMC elements in high-volume wafer fabs. A 21st century approach to AMC control requires such expertise and understanding to address the challenges of sub-45 nm node technology. G&I

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