Solid State Phenomena
ISSN: 1662-9779, Vol. 314, pp 41-46
doi:10.4028/www.scientific.net/SSP.314.41

Submitted: 2020-04-22
Revised: 2020-07-09
Accepted: 2020-08-03
Online: 2021-02-09

Wafer Container Monitoring Concerning Airborne Molecular Contaminations along a 300 mm Power Semiconductor Production Flow

Peter Franze[1,a*], Germar Schneider[1,b] and Stefan Kaskel[2,c]

[1]Infineon Technologies Dresden GmbH & Co. KG, Koenigsbruecker Strasse 180, 01099 Dresden, Germany

[2]Chair of Inorganic Chemistry I, Technical University of Dresden, Bergstrasse 66, 01069 Dresden, Germany

[a]peter.franze@infineon.com, [b]germar.schneider@infineon.com, [c] tefan.kaskel@tu-dresden.de

Keywords: AMC, airborne molecular contamination, FOUP, FOUP management, chemical analysis, power semiconductors, CRDS, mass spectroscopy, electrochemical conductivity measurements

Abstract. The focus of the study was to understand the behavior of airborne molecular contaminations (AMC) within the 300 mm wafer containers called front-opening unified pods (FOUPs) in a high-volume fabrication facility for power semiconductors of Infineon Technologies Dresden. A main goal was to implement new concepts and strategies to prevent the different power semiconductors from any yield losses driven by AMC. It could be shown, that there is a strong dependency of the concentration and the type of the determined contaminations on the investigated process steps.

Introduction

Organic and inorganic contaminations on the one hand and particles on the other hand are already known as main reasons for the yield loss of semiconductor devices. Especially the production of power semiconductors require various types of different materials within the manufacturing process, like noble metals, organic (resist or adhesives) and inorganic components (gases for the dry etch processes or dopants) [1, 2]. An additional issue within a 300 mm wafer facility is the fact, that all silicon substrates are transported in closed wafer containers (FOUPs). Gaseous contaminations, which are coming out of the processes, can directly attack the critical layers on the chips [3]. Therefore, new container management concepts have to be developed. Special interest within this study was on the behavior of acid and basic airborne molecular contaminations (AMC) within the process flow of a high-volume power technology within the wafer fabrication area of Infineon Dresden. The gaseous contaminations can be transferred from process tools to the FOUP atmospheres and to the wafers. Due to this fact, a deep knowledge of the AMC levels within the FOUP atmospheres is required to assure stable yields and to prevent all reliability issues driven by AMC caused corrosion processes in the chip structures [4]. The analysis of the AMC levels along the process flow of the selected 300 mm power technology within this study was performed with the goal to get a first knowledge about the AMC concentrations and to make sure that the FOUP cleaning processes are placed at the optimal process steps within the entire process flow. Within this study, the focus was on the acid gases hydrogen fluoride HF and hydrogen chloride HCl, the basic gas ammonia NH_3 and the dopant gas diborane B_2H_6. The gases HF and HCl are summarized within the group AMC-1, whereas NH_3 is declared as group AMC-2. The third investigated group AMC-3 includes the dopant gas B_2H_6. One of the main challenges of the study was the implementation of a new and innovative concept for the in-situ-analysis of the most critical AMC components within the atmospheres of the 300 mm wafer containers of the wafer fabrication site Infineon Dresden. The comprehensive investigation of the contamination levels and of the root causes of the AMC components is performed for the first time within a 300 mm fabrication area for high-volume manufacturing of power semiconductors. The AMC levels at different processes like dry etch, wet, implantation or special thinning processes were unknown so far. The new implemented FOUP analyzer equipment offers the possibility of analyzing many different containers before and after critical work steps along the power semiconductor process flow. The results attained out of the FOUP investigations are the base for an optimized wafer container strategy regarding future AMC levels prediction within the process flow. Another important effect of the implemented in-situ-analyzer platform are savings in terms of personal staff, equipment, material and also time effort in the analytical laboratory of Infineon Dresden. The automated analytical process enable the cost savings in personal staff and equipment compared to the special shaking tests that previously had to be carried out for sampling and for which time- and cost-intensive methods were used to analyze them, like ICP-MS (inductively-coupled mass spectrometry) or HPLC (high performance liquid chromatography).

Experimental

In 2011, Infineon Technologies started its ramp-up program for the first worldwide high-volume power semiconductor fabrication facility based on 300 mm wafers at the site Dresden. Within the 300 mm cleanroom several dedicated FOUP types (Entegris A300 type for Front-End and ShinEtsu 300EX type for Back-End applications) for the different process flows are used to assure highest yield and quality level avoiding contamination or corrosion of the wafer out of the process or the different wafer container. Therefore, it is of special interest to achieve a general knowledge of the AMC levels within the FOUP atmospheres. A fully automated FOUP analyzer platform (APA 302 LF) based on a system of company Pfeiffer Vacuum/France and equipped with special defined sensors could be established with the possibility for online analytics of all relevant acid and basic AMC components within the gas phase of different wafer containers. The FOUP analyzer offers the additional possibility for manually sampling with a special lab-in-fab function which is connected to the analyzer platform. Subsequently, the samples obtained with the help of this lab-in-fab function can be used for offline analyses of volatile organic contaminations from the FOUP atmospheres.

The platform is equipped with an optical laser spectroscopy measurement system using cavity ring-down spectroscopy (CRDS) with a detection limit of 0,01 ppbv to determine the most critical acid (group AMC-1) and basic AMC components (AMC-2) in this case. Therefore, a laser pulse is cached between two high-reflective mirrors in evacuated cavity filled with sample gas. The sample gas which is equivalent in this case to a sample of the FOUP atmosphere causes an intensity decrease of the laser pulse. This decrease can be used to immediately calculate the trace gas concentrations in the gas sample [5].

The analysis of dopants like boron or phosphorus in the gas phase is very challenging and not investigated until today. Therefore, another measurement system is used within the FOUP analyzer platform especially for the detection of the dopant gas diborane (AMC-3). Instead of an optical system, a cell for the measurement of the electrical conductivity by using an electrolyte is implemented. The measurement cell is purged with the gas sample. Chemical reactions between the trace gas and the electrolyte lead to a potential difference between the electrodes inside the cell. This difference is proportional to the trace gas concentration. With this measurement system, it is possible to detect gas concentrations down to ranges of about 30 ppbv [6].

The analyzing systems offer the opportunity to replace the existing, manually performed chemical analyzing methods by high-sensitive and fully automated working measurement systems. The measurements of the different AMC components are performed in parallel and take only around two minutes.

Other AMC components of interest were the condensable compounds or VOC (volatile organic compounds). For instance, the condensation of those VOC on the surface of the lens systems of lithography tools can lead to aberrations [7]. Organic adhesives are used within special process steps at Infineon Dresden, but the AMC levels due to the outgassing VOC are unknown so far. To determine them, the additional sampling system (lab-in-fab function) of the FOUP analyzer platform has to be used. With the help of so-called Tenax tubes, which contained a highly porous powder, the VOC from the FOUP air could be adsorbed. After this, the tubes were analyzed with TD GC-MS (thermodesorption gas chromatography – mass spectrometry) to identify the organic components with a detection limit of 0,02 ppbv.

To get the general knowledge of the AMC levels within the FOUP atmospheres, the main amount of the most important process steps was investigated by performing pre- and post-process measurements. The production of power semiconductor devices requires several hundreds of process steps, where the most important operations were investigated regarding the AMC levels by using the FOUP analyzer platform. At each of the dedicated processes, five lots (FOUPs containing product wafers) have been analyzed to distinguish the development of the AMC concentrations along the process flow.

Results

Within the manufacturing of power semiconductor devices, critical defects and yield losses can occur because of increased AMC levels within the atmospheres of the wafer containers. The knowledge of these levels and the implementation of control strategies are therefore of high importance for the chip manufacturer. Based on the amount of productive lots along the process flows, a single group of process flows for a special power technology group has been chosen for the first AMC investigations (see Fig. 1 and Fig. 2).
The FOUP analyzer platform which has been described was developed to determine the AMC levels before and after dedicated critical process steps. With the help of this special equipment, more than 150 FOUPs containing production wafers could be analyzed to get an overview and first understanding regarding the concentration levels of AMC within the wafer container atmospheres.
For the most critical AMC groups 1 and 2 (acids and bases), a strong dependency of the concentration level on the process itself could be found along the supply chain (see Fig. 1 and Fig. 2).

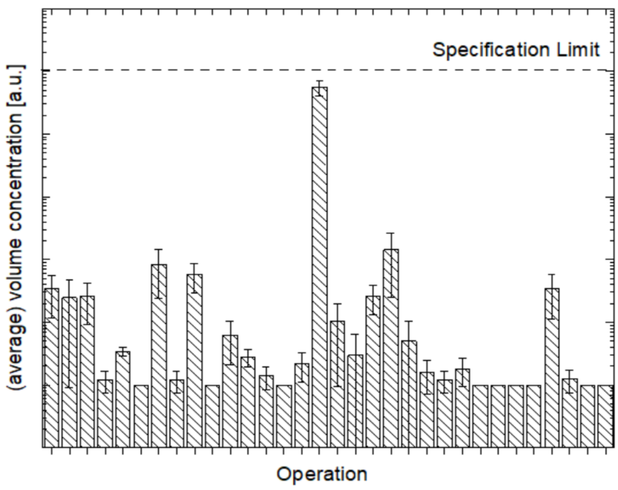

Figure 1: Concentration levels of AMC-1 contamination along the supply chain of one power technology group.

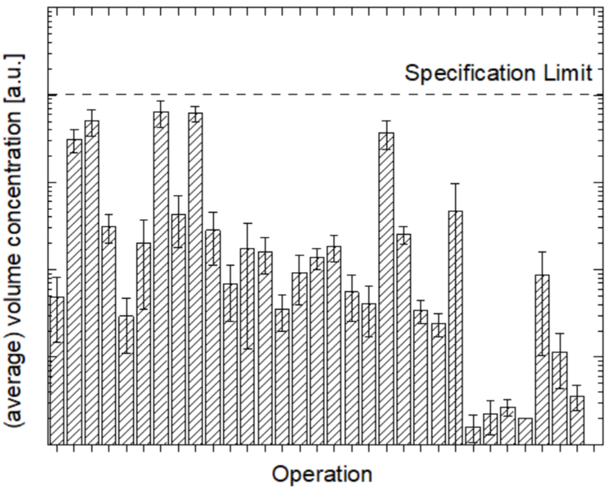

Figure 2: Concentration levels of AMC-2 contamination along the supply chain of one power technology group.

All the concentrations were measured after the corresponding process steps. Because of the investigation of five FOUPs at every work step, a differing spread of the concentrations could be found. Nevertheless, the different contamination levels along the supply chain are observably.

To track the different concentration levels of the AMC of one single power semiconductor product along its process flow, a FOUP with non-productive development wafers were investigated with the analyzer platform. All investigated process steps showed different AMC levels in terms of the most critical AMC groups 1 and 2 (see Fig. 3).

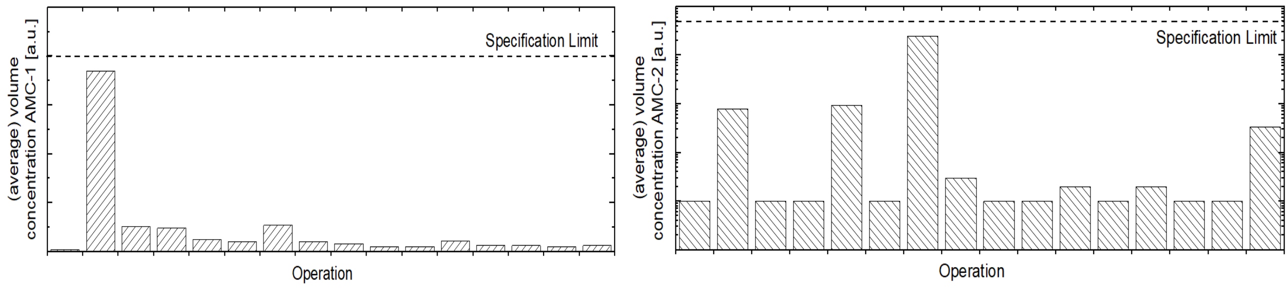

Figure 3: Concentration levels of contaminations out of AMC groups 1 and 2, found along the supply chain within one FOUP along the supply chain of a single power semiconductor product using non-productive wafers.

For the investigation of the VOC levels within the FOUPs, four different FOUPs with product wafers have been analyzed at process steps with an expected higher VOC level and also nine empty FOUPs with different holding times after their cleaning for getting a baseline level. The quantification of the amounts of the VOC was performed with n-hexadecane as external standard. The following diagram (see Fig. 4) shows each the two components with the highest amount within the FOUP atmospheres for every FOUP holding time respectively investigated process step. Similar amounts of VOC could be found within all FOUPs, independent of work step or holding time.

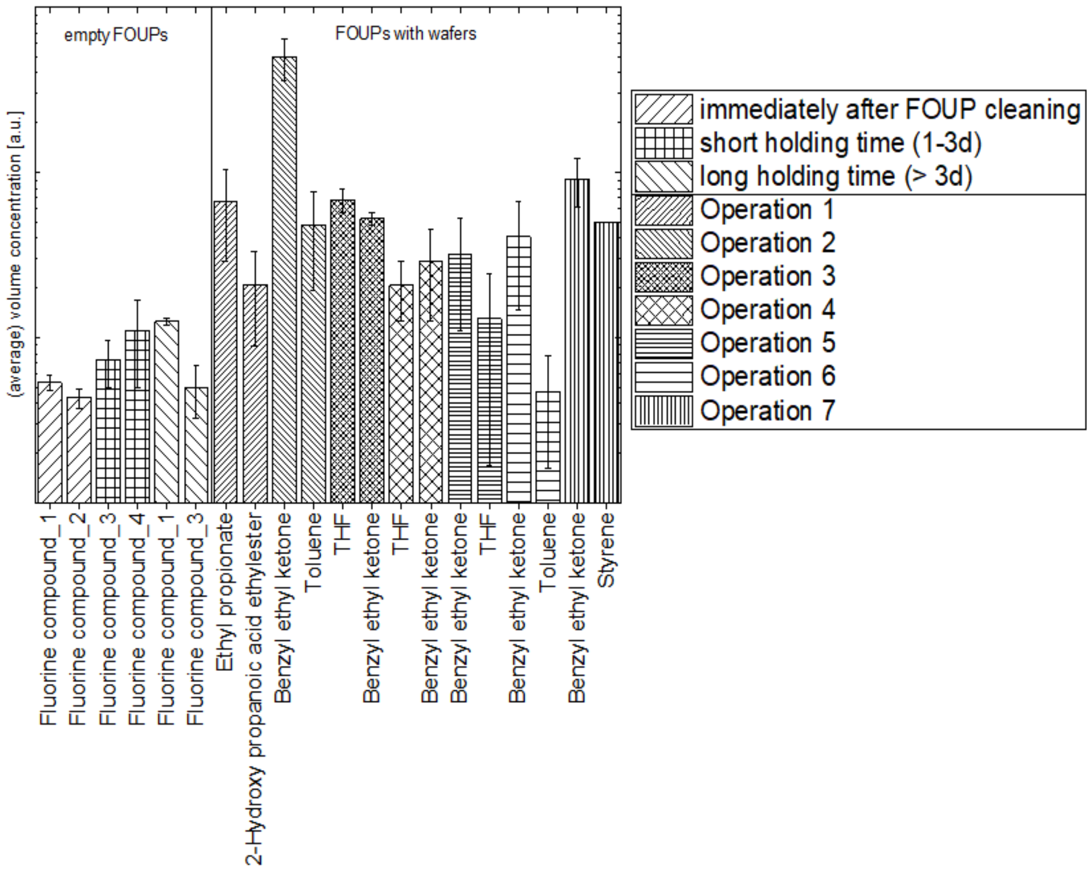

Figure 4: Concentration levels of VOC within different empty FOUPs and FOUPs including product wafers at dedicated work steps within one power technology.

Contaminations of wafer substrates with dopant materials are of special criticality regarding their influence on the electrical behavior of the contaminated chip structures and devices. If dopants diffuse to undoped areas, they can change the electrical behavior there and lead to yield losses. For example,

boron as one of the most common dopant materials in semiconductor fabrication is able to alter the already present doping of the substrate. Therefore, also the concentration levels of dopants are of special interest to assure stable yields and device reliabilities.
Within this study, first in-situ-measurements regarding dopant levels in 300 mm wafer containers were performed using a special sensor system which was installed in the FOUP analyzer platform. Until now, such analyzes required much more effort because of the usage of conventional analytical methods like ICP-MS (inductively-coupled plasma mass spectrometry), which are more time- and cost-intensive.
Special dopants (summarized within AMC group 3) could be found at dedicated process steps along the process flow of the investigated power semiconductor technology of Infineon Dresden. Therefore, the control of the FOUP atmospheres is also important regarding dopant levels (see Fig. 5).

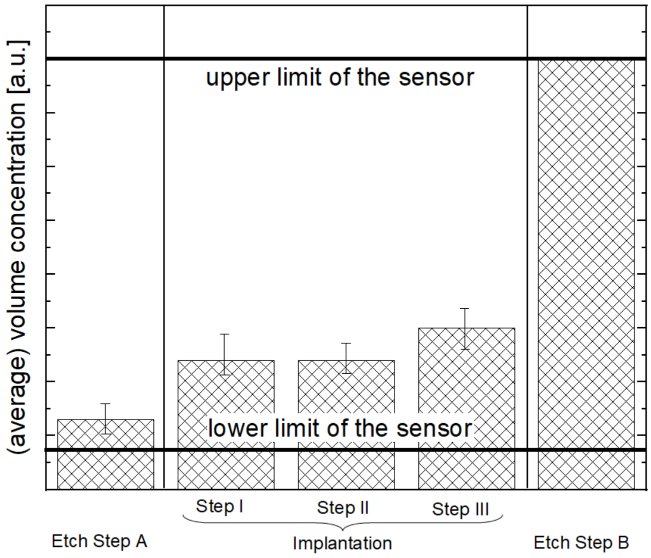

Figure 5: Concentration levels of contamination out of AMC group 3, found within special work steps of the supply chain.

The higher detection limit of the used dopant sensor system could be the reason for the discovery of dopants only at dedicated steps of the process flow compared to the mentioned results above regarding AMC groups 1 and 2. Nevertheless, as shown in Figure 5, in some steps like ion implantation or especially etch steps high amounts of dopants could be detected which must regarded concerning their influence on the product. Also in this case, Infineon defined clear container concepts to assure always the highest yield level by reducing negative influence from dopant cross contamination.
Based on all results which could be attained out of the investigations of the analyses of AMC within many different process steps, a first understanding of the behavior of the most critical AMC groups could be developed. Within the container strategy, different container types have been used only in several segments of the whole process chain to avoid any cross contaminations especially caused by metals and dopants like boron. But until now, the wafer containers could only be applied without any analytical validation. With the results obtained out of this study and the implementation of the automated container analyses, it is possible for Infineon Dresden to evaluate the cleanliness of the FOUPs and therefore to achieve stable and better yields.
The results could also assure that all levels of AMC within the different segments are uncritical to the corresponding yields of the power semiconductor products.

Conclusion

Within this study, a deep understanding of the behavior of the most critical AMC components in the high mix, high-volume 300 mm power semiconductor fabrication facility of Infineon Dresden could be achieved. A strong dependency of the concentration and the type of the determined contaminations on the investigated process steps could be shown. All concentrations of the investigated contamination groups are in an uncritical range regarding the risk of yield loss caused by AMC

induced corrosion processes, because the concentration levels are below customer specific limits defined by Infineon Dresden.
The results obtained out of the performed investigations for FOUPs with product wafers along the process flow are the base for the implemented methods to prevent any yield loss. Out of the results of this study, a fully automated system for AMC monitoring and control for different dedicated FOUP types is implemented in the fabrication facility. This work was an important step towards an intelligent FOUP management system for AMC. The investigation of the root cause of the determined AMC and the analysis of the AMC levels will be transferred to other 300 mm power technologies to always assure the highest quality and yield levels of the products.

Acknowledgment

This research was supported by the EU project iDev40. The project iDev40 has received funding from the ECSEL Joint Undertaking (JU) under grant agreement No 783163. The JU receives support from the European Union’s Horizon 2020 research and innovation program. It is co-funded by the consortium members, as well as grants from Austria, Germany, Belgium, Italy, Spain, and Romania.

References

[1] G. Schneider, T. Wagner, M. Kraft, 2015. Use of simulation studies to overcome key challenges in the fab automation of a 300 mm power semiconductor pilot line comprising thin-wafer processing. In: 2015 16th Annual SEMI Advanced Semiconductor Manufacturing Conference (ASMC), Saratoga Springs, NY, USA, 3-6 May 2015. New York: IEEE.

[2] G. Schneider, et al., 2016. Contamination control for wafer container used within 300 mm manufacturing for power microelectronics. Solid State Phenomena, 255, p. 381.

[3] I.-K. Lin, H. Bai, B.-J. Wu, 2009. Surface deposition of ionic contaminants on silicon wafers in a cleanroom environment. IEEE Transactions on Semiconductor Manufacturing, 22 (2), p. 321.

[4] International Technology Roadmap for Semiconductors, 2014. ITRS 2011 Edition. [online] Available at: <https://web.archive.org/web/20150110005856/ http://www.itrs.net/Links/ 2011ITRS/ Home2011.htm> [Accessed 3 December 2019].

[5] Picarro Incorporated, Cavity Ring-Down Spectroscopy (CRDS). [online] Available through: <https://www.picarro.com/company/technology/crds> [Accessed 3 December 2019].

[6] Honeywell Analytics, Honeywell Gas Book [e-book] Morristown, USA: Honeywell Analytics. Available through: <https://www.honeywellanalytics.com/~/media/ honeywell-analytics/documents/ english/11296_gas-book_v5_0413_lr_en.pdf?la=en> [Accessed 3 December 2019].

[7] M. Keller, 2013. AMC: Luftgetragene chemische Kontaminationen. Lounges 2013/Vision Pharma 2013, Karlsruhe, Germany, 5-7 February 2013. Stuttgart: Fraunhofer IPA.