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Investigation of the Airborne Molecular Contamination Behavior in 300 mm Semiconductor Front - End Manufacturing

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Abstract: Front-end manufacturing of power semiconductor devices requires numerous different processes and materials. To control the complexity of fully automated 300 mm manufacturing lines, which typically utilize closed wafer containers, so called FOUPs (Front Opening Unified Pod), a systematic FOUP management concept is mandatory. This concept has to fulfill the quality targets in terms of organic and inorganic contaminants to assure the highest yield level of the semiconductor products. The focus of this study is to understand the behavior of airborne molecular contaminations (AMC) and to define strategies to prevent yield loss driven by AMC. The first step was to achieve a comprehensive knowledge of the AMC level within the different process steps of a selected power technology. Sampling and analysis procedures based on laser spectroscopy, measurements of electrical conductivity and mass spectrometry systems were used to understand the AMC level of the investigated components. A special automated research platform to analyze the gas phase in the FOUPs was used within the 300 mm high volume power semiconductor fab at Infineon Technologies Dresden. A pronounced dependence of the investigated component level on the different production steps was found. First offline root cause analyses due to contaminations of FOUPs with boron were performed using mass spectrometry, and the air filter systems used within the 300 mm cleanroom could be identified as a second source for boron contaminations. Other special experiments investigated the time dependency of the AMC level in the FOUP atmospheres. With this work, Infineon Dresden has established methods and strategies to prevent AMC-caused yield losses.

Keywords: AMC, Airborne Molecular Contamination, FOUP, FOUP Management, Chemical Analysis, Power Semiconductors, CRDS, Mass Spectroscopy, Electrochemical Conductivity Measurements

1. Introduction

Power semiconductor devices are key components within our daily life and used in many different applications like in automotive industry, multimedia and renewable energy applications. They are used to increase the efficiency within the field of storage and transfer of electrical energy. Furthermore, the scale up of IoT (Internet of Things) will create much more upcoming applications for power semiconductors in the future. Driven by the increasing demand for power electronic systems, leading power device manufacturers like the Infineon Technologies AG are aspiring to fully automated 300 mm fabrication lines.

The company Infineon established the first worldwide high volume production for 300 mm power semiconductor technologies at its front-end manufacturing site in Dresden. For the fabrication of several hundreds of various power semiconductor products, many different materials and a complex process logistic are required to avoid any cross contamination. Most of these materials are inorganic (e.g. like

etching gases, dopants, metals) or organic components (e.g. like resists or adhesives) [1, 2].

A deep knowledge of the concentration levels of particles, organic and inorganic compounds, which are all known as main reason for yield losses, is needed. Especially for critical contaminations like AMC (Airborne Molecular Contamination), monitoring and control within all production steps is essential to preserve the production yield. An additional challenge regarding contamination within the 300 mm semiconductor production is, that all wafers are transported in closed containers, so called FOUPs (Front Opening Unified Pod). Within these wafer boxes, the AMC components are able to immediately contaminate the transported substrates like the product wafers [3].

During this study, diverse yield-reducing contaminants were identified and R&D work was spent on methods and procedures to avoid cross contaminations. Regarding the variability of the various contaminations detected, new FOUP management concepts are necessary. A special interest of the work was spent on AMC within the process flow of the 300 mm power semiconductor production flow at Infineon Dresden. The investigation of the AMC levels within the process flow was performed for one main power technology with the goal to define the right FOUP changing strategy and to implement cleaning steps at the optimal process steps to avoid any cross contamination and yield loss. Also, the influence of the ambient cleanroom air has been investigated with additional offline experiments.

In the past, Infineon Dresden has examined the influence of various metal contaminations on the wafer outgoing-yields and derived out of that knowledge a system of so called material zones for the wafer containers, e.g. for critical metals like aluminum or copper. Schneider, et al. (2016) performed already comprehensive investigations regarding the particle and critical AMC levels within some special process steps within power semiconductor manufacturing [4]. The focus of this paper is to study and implement a classification for AMC for detailed process steps within one of the main internal process chains for a high volume technology in power semiconductor manufacturing as well as to investigate the general behavior of AMC within closed wafer containers, FOUPs in this particular case. A second focus is on the investigation of root causes for special dopant contaminations from the cleanroom air filter systems.

One of the first theoretical studies regarding AMC issues was performed in 1997 by Zhu (1997) [5] at the level of atomic interactions. After this, many different investigations to determine and to reduce AMC levels were performed: Frickinger, et al. (2000) tried to reduce AMC levels by efficient purging of FOUPs [6]. Illuzzi, et al. (2003) developed an analytical system for the on-line and real time contamination monitoring, using IMS (Ion Mobility Spectrometry) for total amines and acids and an FID (Flame Ionization Detector) system for organics [7]. Within their studies, they already found the important correlation between the production processes and the AMC concentration levels. The removal of molecular contaminations by using different kinds of filter systems was tested by Yeh, et al. (2004) [8]. They found a combination of different filter types to control organic and inorganic impurities within the cleanroom air. Wu, et al. (2010) generated monitoring data using IMS and IC (Ion Chromatography) for critical HCl contamination by designing special pattern wafers [9]. These contaminations and similar ones like HF can lead to corrosion processes within the metalized chip structures and cause yield loss.

Another important point is to find the root causes of AMC and to find the possible sources for the critical compounds in the process chains. Hwang, et al. (2012) used computational fluid dynamics simulations to identify leaks within the cleanrooms of a fab [10]. Further improved qualitative and quantitative AMC analyzes were performed by Pfeffer, et al. (2016) for contamination limit value definitions within production and to localize AMC sources [11].

The possible sources of boron in the cleanroom are the implantation, wet processes, working material outgassing and chemicals and gases [12]. The most common origin of boron in the cleanroom air are borosilicate HEPA filters, which can react with the HF present in the cleanroom air, resulting in the formation of BF_3. Typical forms of boron in the cleanroom air are BH_3, organic boron compounds, BF_3, BCl_3 and $B(OH)_3$ [13].

2. Classification of Contamination Groups and Analyzing Technologies

2.1. Overview Airborne Molecular Contamination

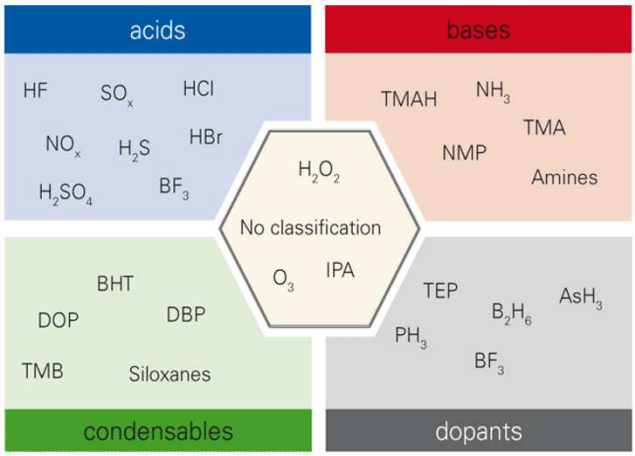

Figure 1. *Classification of critical contaminations by ITRS [14].*

Within the high-volume production of power semiconductors, various kinds of process chemicals are used in various steps of the internal supply chain. The ITRS (International Technology Roadmap for Semiconductors) has defined five groups of AMC and categorized all relevant materials into these groups [14]. An overview of the classification is shown in Figure 1. In this work, one focus is on critical acids and bases, especially chloride and fluoride. Another important part of the work is the analysis of critical dopants, like boron and phosphorus. For this purpose, several

analytical methods and systems are applied to get a deep understanding about the levels of the contaminations within different process steps of power semiconductor technologies in the front-end flow.

2.2. Sampling and Analysis Methods and Technologies

For in-situ analyses of FOUPs containing product wafers within the actual production flow, an innovative measurement system was used, which was especially designed for this kind of contamination control. The analytical system was a demonstrator tool equipped with an optical state-of-the-art laser spectroscopy measurement unit with high sensitivity (see Figure 2). The system can be utilized for the analysis of the most critical acids and bases. These contaminations are categorized as AMC-1 and AMC-2.

The demonstrator tool can be upgraded with a second analyzing system, which is based on measurement cells for electrical conductivity (see Figure 2). These cells are able to measure different kinds of dopants. According to ITRS, dopants are categorized as AMC-3. The quantitative analysis of the dopants represents a major challenge, because the detection limit of the electrical conductivity measurements is much higher than the limit for the optical based laser spectroscopy utilized for AMC-1 and 2.

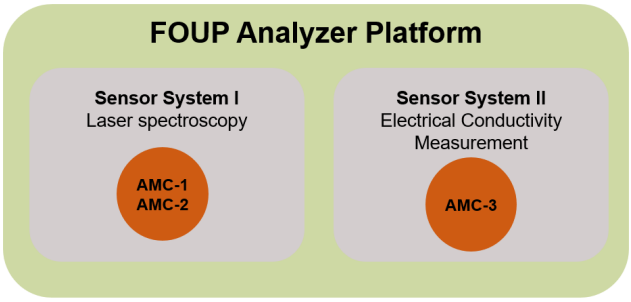

Figure 2. *Scheme of the AMC measurement platform.*

The concentration of smaller gas phase molecules can be measured via the absorption of a specific wavelength [15]. The absorption of trace gases in conventional infrared spectrometers is too small to be measured. This is the reason for their higher detection limits in the range of parts per million at best. With the CRDS (Cavity Ring-down Spectroscopy) technology, it is possible to detect trace gases down to the parts per billion level in seconds by using an effective path length of many kilometers. This is realized with a cavity defined by two or more high reflectivity mirrors (see Figure 3). The beam of a single-frequency laser diode enters this cavity and fills it with light, until a threshold level (after few tens of milliseconds) is reached and the laser is turned off. The light in the cavity begins to resonate between the mirrors, and a photodetector measures the decay of the light intensity (so called "ring-down") caused by the not exactly 100% reflectivity of the mirrors. A second intensity loss mechanism contributes to the ring-down, when a sample gas species is filled into the cavity, which absorbs the laser light (see Figure 4). This accelerates the ring-down time compared to the loss in the cavity without the gas species. Now, the ring-down time of the cavity without gas is continuously and automatically compared by the sensor system to the ring-down time of the trace gas filled cavity. This procedure allows the discrimination of losses caused by absorption due to trace gases and the losses caused by the mirrors. Because of this technology using the ring-down differences, the final concentration of the trace gas is also independent of fluctuations of the laser intensity. By tuning the laser from wavelengths where the gas absorbs the light to wavelengths where it does not absorb, the "cavity only" ring-down time can be compared to the ring-down time when a target gas is contributing to the optical loss within the cavity. When the laser is tuned to several wavelengths where the gas absorbs, a mathematical fit to the light absorption makes it possible to immediately calculate the gas concentration.

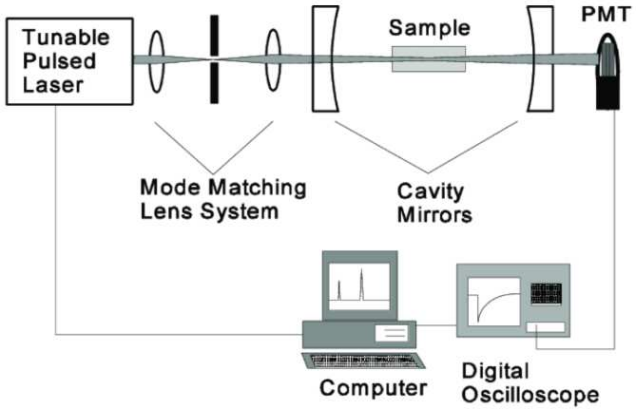

Figure 3. *Schematic of cavity ring-down spectroscopy technique (PMT = Photomultiplier Tube) [15].*

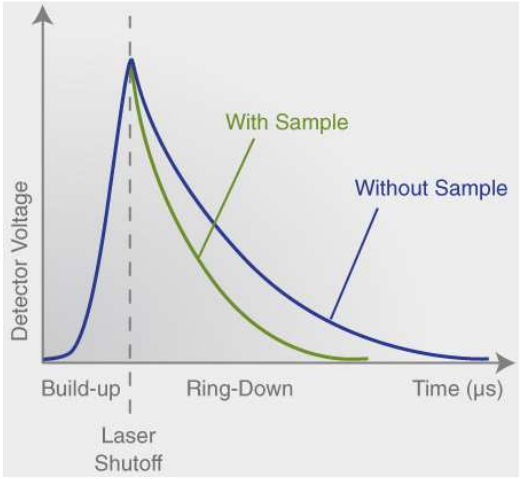

Figure 4. *Light intensity as a function of time in a CRDS system with and without a sample having resonant absorbance. This demonstrates how optical loss (or absorption by the trace gas) is rendered into a time measurement [15].*

Within this study, an electrochemical sensor system is used for the detection of diborane. This sensor includes three gas diffusion electrodes, immersed in an electrolyte (like concentrated aqueous acid or a salt solution) for efficient ion conduction processes between working and counter

electrodes (see Figure 5) [16]. The gas enters the cell through an external diffusion barrier that is porous to gas but impermeable to liquid. At the surface of the working electrode, the specific target gas is either oxidized or reduced. Because of this chemical reaction, the potential of the working electrode alters compared to the potential of the reference electrode. The electrical circuit, which is connected to the measurement cell, has the function to minimize this potential difference by passing a current between the working and the reference electrode. This current is proportional to the target gas concentration.

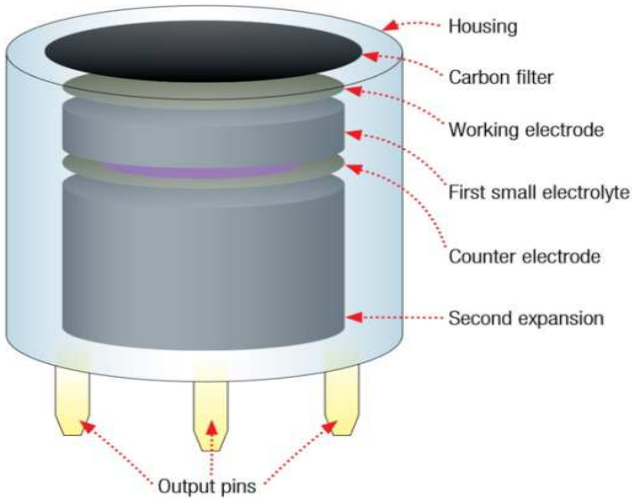

Figure 5. *Schematic illustration of electrochemical conductivity cell [16].*

The specificity of the sensor to the target gas is reached by the choice of the used electrolyte or by installing additional filters within the sensor system. The sensor applied in this study uses a specific electrolyte, which enables the sensor to specifically detect the target dopant gas. Nevertheless, there is the possibility of cross sensitivities with other gases from the investigated FOUP air. For this reason, all results had been validated by a second analytical method.

The third analytical technology, which is used in this study especially for the analyses of boron (AMC-3), is the so called ICP-MS (Inductively Coupled Plasma – Mass Spectrometry, see Figure 6) [17].

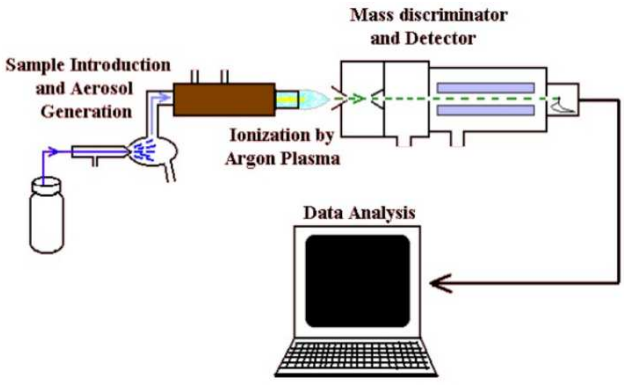

Figure 6. *Scheme of an Inductively Coupled Plasma Mass Spectrometry system [17].*

The generation of ions can be realized in different ways. Within the ICP technology, an argon plasma is generated within a high frequency coil. The gas becomes conductive and is heated up due to its high resistance to temperatures in the range of 6000 to 10 000 K. The sample is than introduced into the plasma as aerosol. The sample molecules dissociate, and free atoms and ions, which are excited because of their collisions with the plasma particles, are generated.

The generated ions are then accelerated and transported into the mass discriminator including a magnetic field vertical to the direction of motion of the ions. Depending on their mass-to-charge ratio, the sample ions move on different curves through the discriminator. By tuning the separating magnetic field, the different mass numbers can be separated and registered at the detector unit. This unit is often realized as PMT (Photomultiplier Tube). With ICP-MS, it is possible to detect concentrations in the range of parts per trillion.

3. Application Example: Contamination Analyses of FOUPs Within Power Semiconductor Production

3.1. Investigation of Acids and Bases Along the Supply Chain

Contaminations on molecular and atomic level can cause critical defects and yield losses within the production of semiconductor devices. Another important fact is, that the production of power semiconductor products requires up to several hundred process steps. Therefore, it is important for the IC (Integrated Circuit) manufacturer to get a deep knowledge of the AMC levels within the production steps of the whole process flow. For attaining this general knowledge of the resulting AMC level in FOUPs after specific processes, measurements were performed pre- and post-process on the majority of the most important process steps along the production route of one main power technology at the Infineon fab in Dresden. With the help of the AMC levels, it was possible to define and establish intelligent monitoring and controlling concepts for the FOUPs in the 300 mm power fab of Infineon Dresden to avoid critical metal corrosion processes within the chip structures. Using the FOUP analyzer platform, many different container analyses have been performed to investigate the behavior of the AMC in the FOUPs. A special focus was on the main AMC groups AMC-1, AMC-2 (acids and bases) and AMC-3 (boron/diborane), so the most critical contaminations like acids, bases and dopants were determined with the help of the described sensor systems of the analyzer platform. More than hundred FOUPs containing productive wafers were measured. The measurements were performed before and after dedicated critical work steps within the process flow of Infineon Dresden. At each step, five FOUPs with productive wafers were measured and the concentration levels of the most critical AMC components were determined.

Figure 7 gives an overview over the average concentration

levels of AMC-2 within the supply chain of one main power technology of Infineon. All concentrations were measured after the corresponding process step.

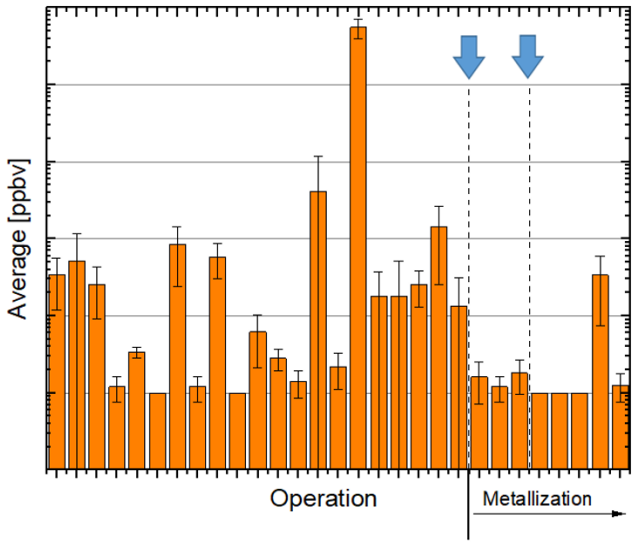

Figure 7. *Concentration levels of AMC-2 contamination along the supply chain of one power technology. The blue arrows indicate the existing FOUP cleaning steps within the process flow.*

It could be shown, that there is a strong dependence of the AMC level on the investigated production step. The analyzed process steps showed very different AMC-2 concentrations within the FOUPs. Because of the investigation of five FOUPs at every work step, a differing spread of the concentrations could be found. Nevertheless, the different levels of AMC along the supply chain are observably.

Similar results could be found for the levels of AMC-1 (see Figure 8). Also contaminations from AMC group 1 showed different levels, strongly depending on the investigated work step.

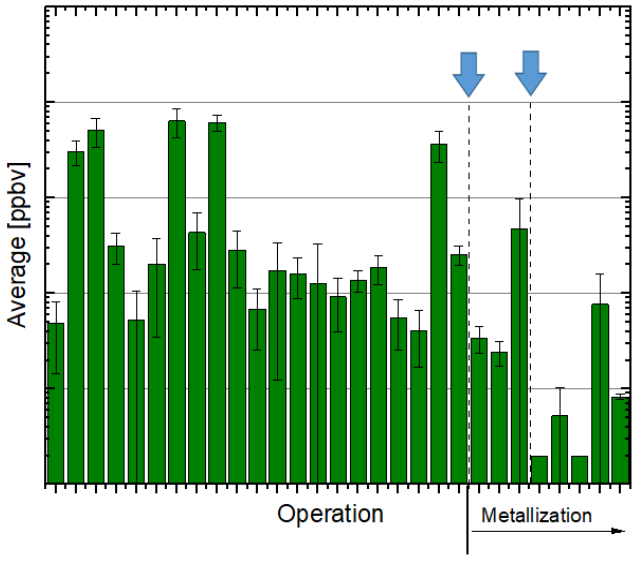

Figure 8. *Concentration levels of AMC-1 contamination along the supply chain of one power technology. The blue arrows indicate the existing FOUP cleaning steps within the process flow.*

The already existing container cleaning steps are marked in both diagrams (Figure 7 and Figure 8). Also, the process area including metallization steps is indicated. For both contamination groups AMC-1 and AMC-2 could be shown, that the concentration levels at all investigated process steps are in an uncritical range regarding the risk of yield loss caused by AMC induced corrosion processes. The two FOUP cleaning steps, which are included between the investigated processes, are placed at the right process steps. These dedicated processes are especially critical regarding AMC driven yield losses. With the help of the included cleaning processes, it is possible to keep the AMC levels in an uncritical range.

In addition to the already presented experiments, we performed analyses at the demonstrator platform with one special development FOUP with productive wafers. With the help of this FOUP, the development of the AMC levels along the process flow of one special power semiconductor product should be tracked. All investigated work steps showed different levels of contaminations regarding the AMC groups 1 and 2 (see Figure 9).

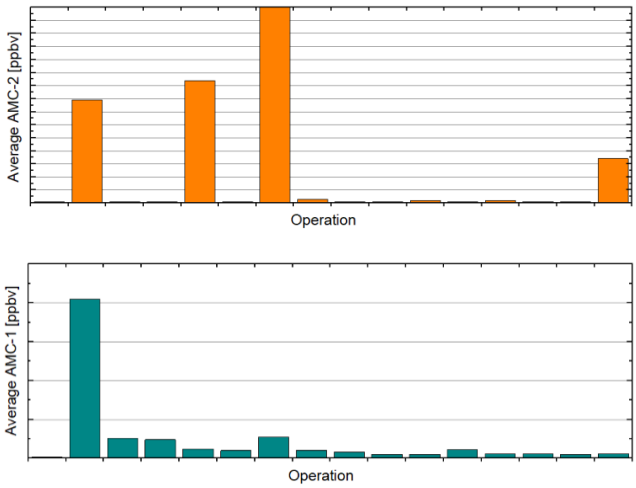

Figure 9. *Concentration levels of contaminations out of AMC groups 1 and 2, found along the supply chain within one special FOUP.*

Within this study, the influence of the holding time (time after the end of the process) of two FOUPs (called FOUP 1 and FOUP 2) has also been investigated to research the development of the concentration levels after critical process steps. Analyses were performed for the two main contamination groups AMC-1 and 2 with a FOUP including test wafers over one day (FOUP 1) after a dry etch step and also with a second wafer-including FOUP over three days after a wet cleaning step (FOUP 2). The observed results from the test over one day are shown in Figures 10 and 11.

Comparing the results, it is remarkable, that the concentrations of the AMC group 2 are first slightly increasing before decreasing to a lower level, in contrast to the AMC-1 results. Similar effects are shown in the literature, e.g. by Barker, et al. (2017) [18].

The concentration in the second FOUP 2 with productive wafers was observed over three days, results are shown in Figures 12 and 13.

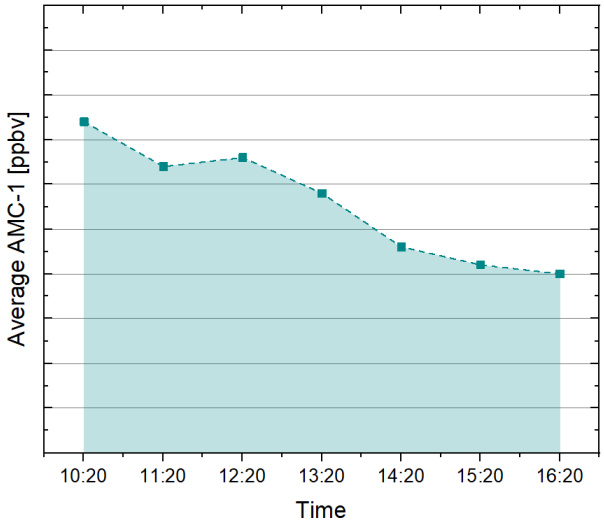

Figure 10. *Concentration levels of contaminations out of AMC group 1 in FOUP 1, depending on the holding time after dry etch process.*

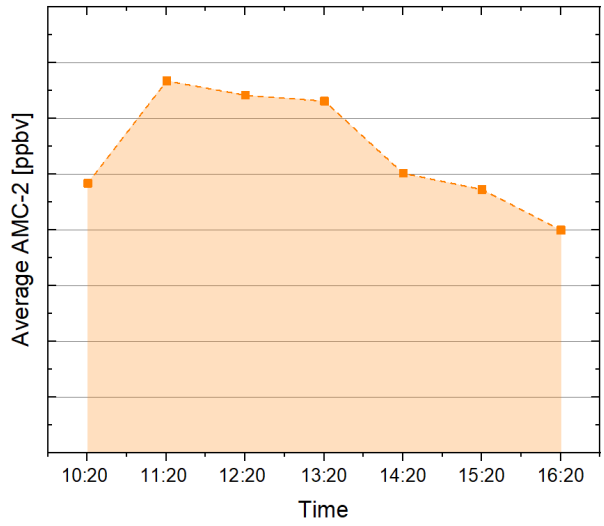

Figure 11. *Concentration levels of contaminations out of AMC group 2 in FOUP 1, depending on the holding time after dry etch process.*

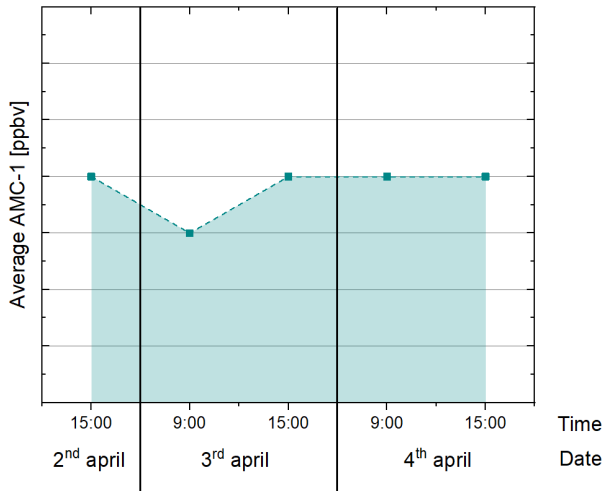

Figure 12. *Concentration levels of contaminations out of AMC group 1 in FOUP 2, depending on the holding time after wet cleaning process.*

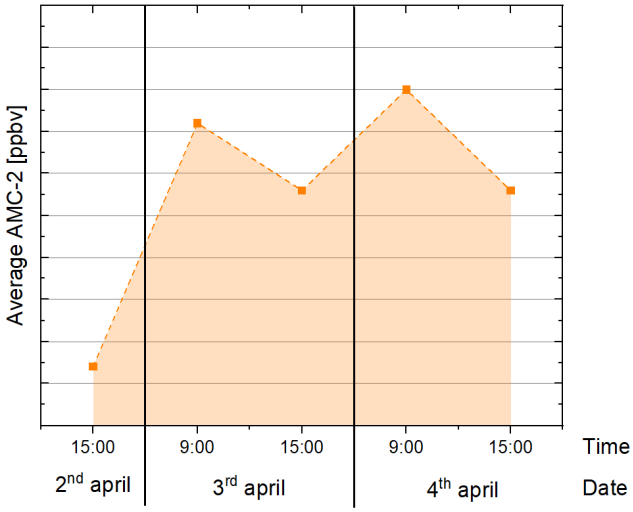

Figure 13. *Concentration levels of contaminations out of AMC group 2 in FOUP 2, depending on the holding time after wet cleaning process.*

The concentrations, which could be found in FOUP 2, were nearly stable over a period of three days. A significant decrease of the concentration levels could not be found. These results emphasize the importance of a dedicated FOUP cleaning concept regarding the decreasing of critical AMC levels within the 300 mm wafer containers at Infineon Dresden.

Other tests were performed along the 300 mm process flow of diverse JFET power semiconductor products. With the help of the FOUP analyzer platform, dedicated work steps were investigated regarding the AMC levels in the FOUPs. The results are shown in Figure 14.

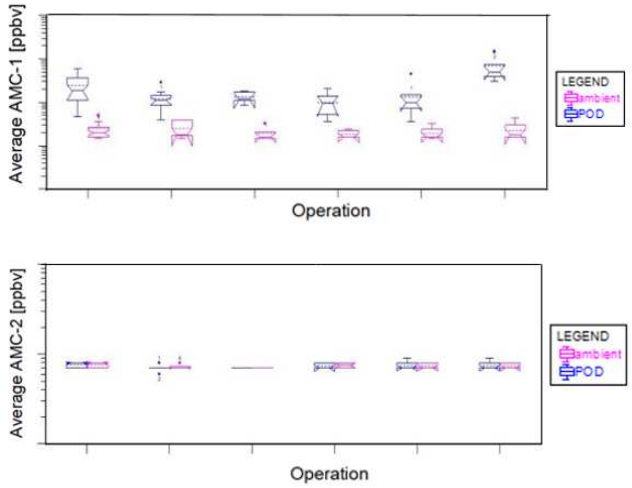

Figure 14. *Concentration levels of contaminations out of AMC group 1 and 2 at dedicated work steps of the JFET process flow.*

It could be shown, that all observed AMC levels are low enough to be uncritical regarding yield and reliability issues.

Based on all observed results out of the investigated process flows of the 300 mm power semiconductor fab of Infineon Dresden, a first understanding of the behavior of the most critical AMC groups could be developed. It could be shown, that there is a strong dependence of the AMC levels on the

investigated process steps. All levels, which were found in this study along the 300 mm power semiconductor supply chain of Infineon Dresden, are in an uncritical range and do not result in yield losses.

3.2. Investigation of Dopants along the Process Flow

Contaminations with dopants are critical regarding their effects on the electrical behavior of the contaminated product structures. Dopants are used within semiconductor fabrication for a controlled change of the conductivity between different areas within the silicon substrate. If the dopants diffuse to undoped areas, they can cause critical differences in the electrical behavior of the product and can lead to higher yield loss. For example, boron contamination in semiconductor manufacturing is critical, because of the ability of boron to alter the present doping on the silicon wafer. Therefore, also the concentration levels of dopants should be known along the process flow to avoid critical yield and reliability impacts.

As mentioned above, the detection of dopants (AMC group 3) was more difficult than the analysis of acids or bases (AMC-1/2). The reason for this was that there is no analytical method so far available on the market, which can measure dopants like boron and phosphorus compounds in the lower ppb region. Because of the usage of diborane as boron source in implantation processes, this component was measured within this study. With the so far available analyzing methods, detecting dopants in the lower ppb range is associated with great effort.

Even the first demonstrators, which have been used in the study to measure dopants, could not deliver data in the very low regions due to the higher detection limit of the sensor. Nevertheless, after several engineering phases, AMC-3 contaminations could be detected along the process flow (see Figure 15).

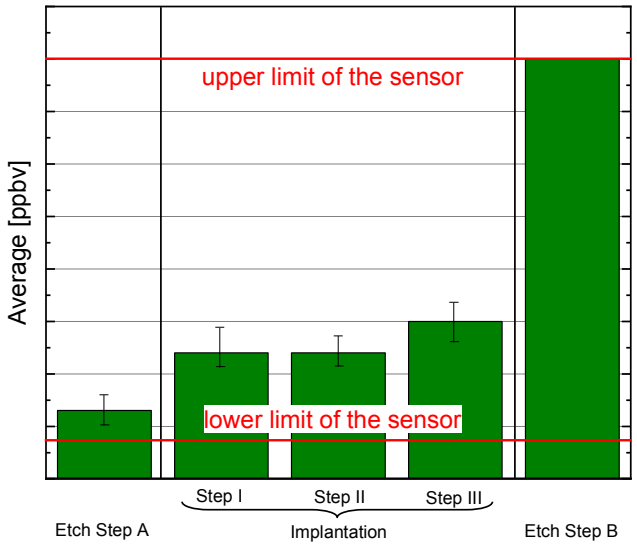

Figure 15. *Concentration levels of contamination out of AMC group 3, found within special work steps of the supply chain.*

In contrast to the already presented levels of AMC-1 and 2, dopant components could be found within FOUPs only at special process steps along the supply chain of the investigated power technology. One reason could be the higher detection limit of the boron sensor system. It is possible, that boron contaminations at other work steps could not be found, because the concentrations at these processes are lower than the sensor's detection limit.

It is also remarkable, that two of the dopant-loaded steps are processes, where no compounds with dopant amount are used as process chemicals. The fact, that two of the dopant-loaded other process steps are not using dopant compounds (in contrast to the investigated implantation steps), emphasizes the importance of a clear dedicated wafer container management system to avoid electrical parameter deviations. The FOUP monitoring and control is consequently also important regarding dopants, and a dedicated FOUP concept was also defined to avoid yield loss caused by dopants at Infineon Dresden.

3.3. Investigation of Hypothetical Boron Release from Implanted Wafers

It is known from literature, that the cleanroom air filters also contribute especially to the boron contamination within the semiconductor production (see 1. Introduction)

To investigate the origin of the contaminations, various tests have been performed at the Fraunhofer IISB (Institute for Integrated Systems and Device Technology) at Erlangen/Germany to find possible root causes for the level of boron in the process flow. To analyze the boron amounts on witness wafers, ICP-MS with VPD (vapor phase decomposition) was used as a sampling method. VPD is an established sample preparation method for the analysis of contamination on wafers. The wafer is stored in a HF atmosphere to become hydrophobic. Then a droplet is guided over the wafer surface. Using VPD preparation, the contamination of the whole wafer surface is concentrated in one 100-150 µl droplet. The boron concentration in the droplet was then analyzed with ICP-MS [19].

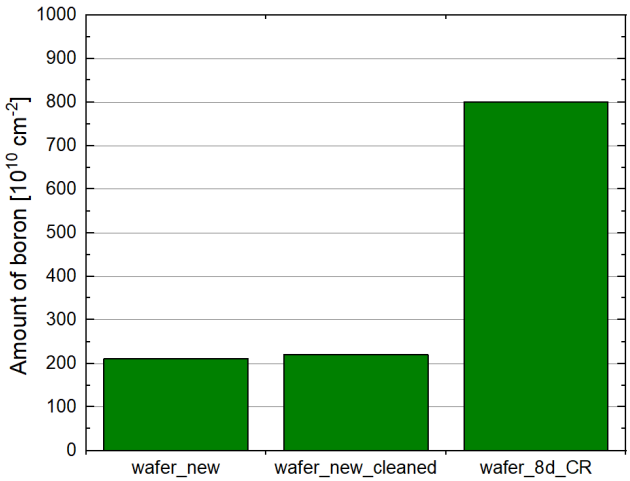

Figure 16. *Amount of boron on monitoring wafers: new, cleaned and 8 days in cleanroom.*

As explained above, boron is used in the implantation

process of wafers. During implantation, the wafer is bombarded with ions, which are incorporated into the crystalline structure of the silicon substrate. Parts of the wafers are masked (e.g. with resist coating from lithography), to assure only selected areas are doped. The first experiment carried out to find possible sources of boron contamination was to check, if coated wafers, which were implanted, would outgas boron on witness wafers. For comparison, two unprocessed wafers were inserted to the cleanroom. One of these wafers was immediately analyzed, the other one was first cleaned and after this analyzed, both by VPD/ICP-MS. Also, one wafer was exposed in the cleanroom for 8 days, as a reference for the boron contamination in the cleanroom air. The results are shown in Figure 16.

The first new wafer shows the same amount of boron contamination like the new wafer after a cleaning step. This similarity indicates, that the boron amount of these two new wafers could be interpreted as base line concentration. Compared to this, the wafer exposed to the cleanroom atmosphere for 8 days shows a high amount of boron contamination (ca. 800E10 cm^{-2}). The source of this contamination are probably the filters in the cleanroom, as explained above.

In another experiment, witness wafers were stored in two different boxes for 11 days next to implanted wafers, which were implanted without coating (FOUP 2) or completely covered with coating (FOUP 3). The parameters of the implantation were 120 keV energy with a dose of 5E15 cm^{-2}. The wafers were then analyzed with respect to boron content using VPD/ICP-MS. Two witness wafers from the same batch were analyzed directly after the implantation step without storing time next to the implanted wafers. Additionally, one implanted wafer was analyzed for comparison as reference.

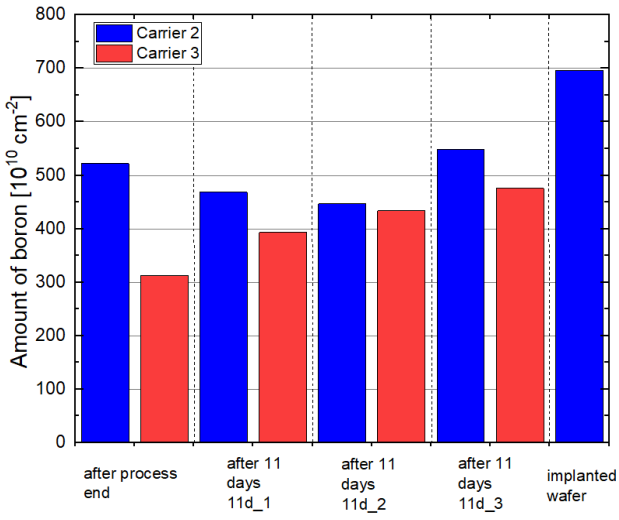

Figure 17. *Amount of boron on witness wafers: immediately after implantation process, after holding time of 11 days next to implanted wafers, and on one implanted (reference) wafer.*

After process end, the amount of boron was higher in the box with the uncoated wafers. The implanted wafer shows only 700E10 cm^{-2} of boron, because the implanted boron is deeper penetrated into the wafer material and cannot be solved by VPD. After 11 days, the amount of boron is slightly higher on the 3 witness wafers stored in box 2 (wafers without coating). But the amount of boron was lower for all the samples than the amount on the cleanroom monitoring wafers (ca. 800E10 cm^{-2}). So the increase in boron contamination might come from the cleanroom environment.

To conclude, no outgassing of boron compounds to witness wafers stored next to implanted wafers was detected, neither in the case of completely coated wafers nor in the case of wafers without coating. This was expected, as it is unlikely that boron ions can react with the coating to form volatile compounds.

3.4. Investigation of Boron Releasing Processes out of Cleanroom Air Filters

Borosilicate HEPA (High Efficiency Particulate Air Filter) filters release boron into the cleanroom air when attacked by hydrogen fluoride. To investigate these mechanisms, samples of filter material (one new and two used) were taken. One of the used filter samples was taken from the middle of a filter unit und one from the edge.

First, the amount of boron released by the filters by leaching them in water (5 ml) has been analyzed. To investigate the release of boron after exposure to defined hydrogen fluoride atmosphere, filter samples were placed into a VPD chamber, where liquid HF is stored. By opening a flap, the HF gets in contact with the air in the VPD chamber and starts evaporating. After 30 minutes, the filter samples were exposed to this atmosphere for varying durations (1, 5, 10 min). The results are shown in Figure 18.

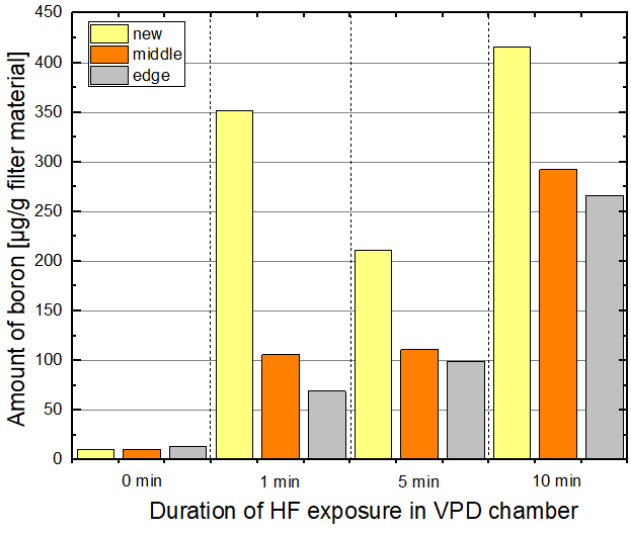

Figure 18. *Amount of boron release from an old and new filter after different duration times in a defined HF atmosphere.*

The observed results show, that the amount of boron leached out from the samples increases with HF exposure. As described in literature, HF is able to dissolve boron out of the HEPA filters.

The new filter releases the highest amount of boron. The

reason for this is, that the older filters were already exposed to HF and are now passivated and therefore do not release high amounts of boron anymore.

It could be found, that the boron contaminations possibly occur during the outgassing processes from the air filters in the cleanroom. The observed results out of the tests performed at the laboratory of Fraunhofer Erlangen are the base for the further experiments performed at Infineon Dresden.

3.5. Research of Root Causes for Boron Contaminations Within the 300 mm Cleanroom of Infineon Dresden

For the ongoing research regarding the root cause of the boron contaminations, different experiments were performed with witness wafers in the 300 mm cleanroom at the Infineon fab in Dresden.

Based on earlier performed experiments at the site of Fraunhofer Erlangen, three dedicated places within the 300 mm cleanroom of Infineon Dresden were selected. At these places, blank silicon wafers have been placed in the cleanroom for one week: one wafer under a new installed air filter, another under an older filter and the third wafer was used as reference and has been placed in the middle of an empty FOUP. After this, all wafers have been analyzed regarding their surface boron content in the cleanroom lab of Infineon Dresden by using VPD/ICP-MS. The results out of these experiments are shown in Figure 19.

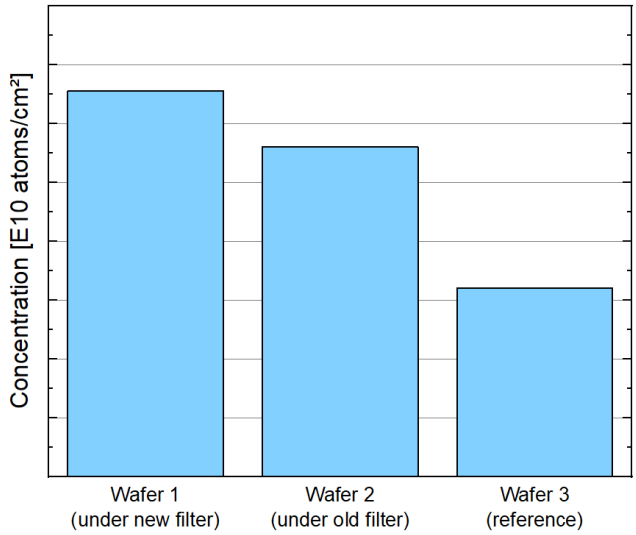

Figure 19. *Amount of boron on wafers exposed in the 300 mm cleanroom of Infineon Dresden: wafer 1 under a new air filter, wafer 2 under an old filter and wafer 3 as reference (left behind in the FOUP).*

Significant amounts of boron could be found on all investigated wafers. The amount on the reference wafer 3 was nearly one half of the amount on wafers 1 and 2 positioned under air filters. As well the wafer 1 as the wafer 2 showed very similar boron amounts. It was assumed for the reference wafer 3, that the boron contamination of this wafer is a result of outgassing processes out of the FOUP. This assumption could be confirmed in additional experiments. On the one hand, the higher boron amounts on the wafers 1 and 2 could come from boron contaminations in the cleanroom air. On the other hand, there is the possibility that the boron is coming from the wafers themselves.

With the following experiments research was focused on answering the question, if the contaminations detected on the wafer surfaces are coming from the cleanroom air, directly out of the FOUPs or from the wafers themselves. Therefore, nine unprocessed blank silicon wafers, which were locked in the cleanroom immediately before the tests, were used. The first five wafers were distributed to several empty FOUP types, which are used in the 300 mm fab of Infineon Dresden. The remaining four wafers were placed again at the selected places within the cleanroom. The observed results show Figure 20.

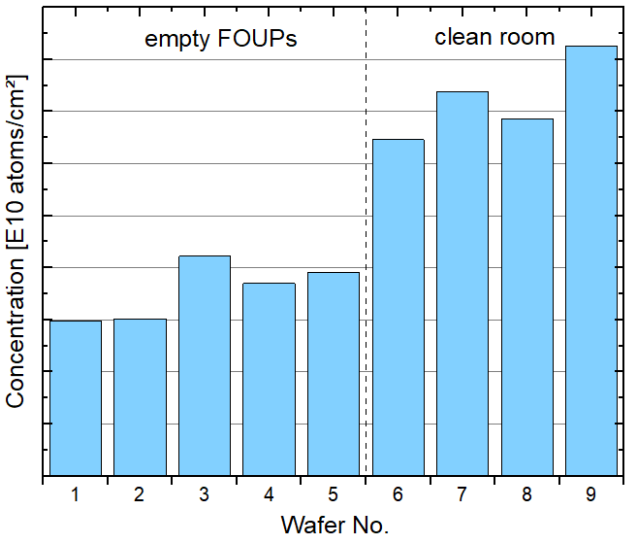

Figure 20. *Amount of boron on wafers laid out in the 300 mm cleanroom and from empty FOUPs: wafer 1 to 5 were left behind in different FOUP types, wafer 6 to 9 were laid out in the cleanroom.*

In analogy to the former results from the cleanroom test wafers, also on all of these wafers have been found boron amounts. The wafers, which were placed in the cleanroom, showed significant higher boron concentrations.

Because of the results out of the tests performed at Fraunhofer IISB and within the 300 mm cleanroom of Infineon Dresden, it could be shown, that the boron contaminations on the wafer surfaces result from outgassing processes from the used cleanroom air filters.

4. Conclusion

Based on all results observed within this study, it was possible to develop a deep understanding of the AMC levels in a high volume 300 mm power semiconductor fab and to implement methods to prevent any yield loss driven by AMC. In parallel, the influence of outgassing processes out of the cleanroom air filters could be studied.

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 fab. This work was an important step towards an intelligent FOUP management concept for

AMC.

5. Outlook

The methods applied in this study to understand and control the AMC level within wafer containers will be transferred to new upcoming technologies for the next generation of power semiconductor technologies. In this way, the FOUP management system of the semiconductor fab will be continuously improved according new technological requirements. Another important work will be spent on advanced data analytics to predict the AMC level within the different process steps. Those new technologies offers new possibilities to optimize the FOUP cleaning combining the analytical results with hundreds of data out of the manufacturing execution system and the huge data bases of the material handling system containing the FOUP localization data at each second in the fab.

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