Minienvironment solutions: special concepts for mask-systems

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Abstract

Cleanroom technology is a principle pre-condition and the enabling technology for contamination free manufacturing. With the transition from large cleanroom facilities for semiconductor manufacturing to localized encapsulated cleanroom solutions which are called minienvironments the traditional cleanroom technology is extended into a new field of applications. With view to the highest requirements in semiconductor industries and especially in the mask area, extraordinary concepts and solutions has to be developed and applied. In this contribution the fundamental considerations about the different concepts for minienvironments are outlined and reviewed. A set of various parameters involved in a design process for a state of the art minienvironment are given and discussed in detail. The resulting different concepts are presented and the strength of each concept is discussed. The resulting minienvironment solutions are demonstrated on three characteristic examples and options, alternatives and the advantages of the individual concepts are mentioned. Based on the current status of minienvironment technology an out-look is given about future challenges and open questions to be solved.

Keywords: minienvironment, contamination control, temperature stability, extreme dry air, nitrogen atmosphere, re-circulation system

1. Introduction

To generate and maintain clean and defined production conditions, large and expensive high quality cleanroom facilities have been constructed and used in the past. Based on the technical developments with larger substrates, shrinking feature sizes and by applying new technologies to improve out-put and process yield, the requirements for cleanliness and contamination control increase extremely. These trends in combination with the constraint of continuous cost reduction lead to the development and introduction of various types of system related localized cleanroom solutions for semiconductor systems, which are called in general minienvironments and are defined in the standard SEMI E44 [1]. Today, these minienvironments are common in mask and wafer processing and should protect the valuable products against particle contamination, unfavourable influences from atomic molecular contaminations causing chemical effects and electrostatic discharges, could lead to material modifications (oxidation, silicon carbide formation, …) and especially haze formation on masks [2, 3].

Depending on the unique processes in mask production and related lithography applications, different concepts for minienvironments have been investigated and applied in the past for different types of mask and wafer systems. These general concepts are not only limited to air filtration generating particle free environmental surroundings in the minienvironments down to cleanroom class ISO 1 today [4]. Also other parameters and environmental conditions like air-flow, pressure, temperature, humidity, electrostatic discharge (ESD), inert gas atmosphere, organic/molecular contamination, and costs have to be considered. All these parameters and influences lead to the decision about the applicable minienvironment concept to protect the mask and substrates in the best possible way.

As mentioned above, the type of minienvironment depends closely on the special process conditions inside a system. To ensure, that the best concept and method will be applied for the minienvironment design, such considerations must be implemented very early in the design phase of a system itself. Also combinations of different concepts could be sometimes needed to accomplish the given requirements, for example the extreme cleanliness with the protection against organic contamination and with increased temperature and humidity stability. Also parameters given from the surrounding installation location like limited space (footprint) and room height could affect a minienvironment

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significantly in design and costs. Therefore, a minienvironment is very system specific and depends on various parameters.

At the moment only general guidelines are available, which describe for 300 mm wafer process and metrology equipment possible measures (type of filters, materials, …) to reach a minimum level of cleanliness [5, 6, 7]. The move forward to ISO 1 cleanroom conditions requested in the ITRS for the year 2010 [8] is one action to reach lower contamination levels for air-born particles. But it gives no further information and indications about how to reach and how to guarantee it over the whole life-time the over-all cleanliness of a system.

New methods and technologies like EUV lithography, E-beam write, material processing with lasers, nano-scale sensitive metrology and nano-technology in general will further increase the requirements for cleanliness and contamination free process environments. This will generate gaps between the currently available technologies and the future needs. Today, many subjects are under discussion like, what will come below ISO 1, or the availability of a sensitive and fast routine air-born particle measurement method below 100 nm, or how to detect reliable and fast chemicals at trace levels, and how to correlate surface effects detected by very sensitive surface metrology systems with the environmental parameters (in and outside the minienvironment) to find the route cause of process deviations.

Based on the available technology this contribution will give an overview about the current status for design and concepts of minienvironments. This will be demonstrated and discussed at dedicated examples with view to the special requirements for different kinds of applications, like for mask handling, mask writing and mask storing. Special requirements are highlighted and data will be presented about the technical solutions and challenges behind. The first example will deal with an minienvironment with ISO 1 requirement for mask handling, which is totally integrated in the mask system itself. A second example shows a stand-alone minienvironment, which could be used for e-beam or laser write systems, where a long-time temperature stability of ± 0,1K is needed in the whole enclosure. The last example describes the concept of a much more complex system with XCDA re-circulation especially for mask storing. All presented concepts will be compared and the advantages of the individual concepts will be outlined. At the end of the contribution the currently open questions and upcoming challenges will be discussed and approaches for possible solutions will be suggested.

2. Concepts

2.1. Considerations and parameters for the successful system design of a minienvironment

2.1.1 Definition and basic considerations

According to the SEMI standard E44 per definition a minienvironment is a “localized environment created by an enclosure (a physical barrier) to isolate the product from contamination and people.” [1]. The general function of an active minienvironment is to maintain and create controlled conditions and to avoid and reduce contaminations. Generally, the sources of contaminations could be localized in the surrounding environment (installation location and conditions) and/or generated inside the minienvironment itself, for example robotics and moving mechanical parts. Therefore, before choosing an appropriate concept of minienvironment design different considerations has to be taken into account involving also the complete itself. First the basic question has to be answered, if only product protection is required (s. SEMI E44 above) or also the protection of humans is mandatory. Second, the installation environment and conditions in the cleanroom facility have to be taken into account like: cleanliness, air-flow concept, possible AMC sources, available floor space and height of the room, presence of further possible contamination sources, etc. In a third subsequent step the special process requirements which should happen inside the minienvironment have to be considered and analysed in detail: necessary cleanliness inside the minienvironment, special air-flow and over-pressure concept, sensitivity of the product to electrostatic charge, airborne molecule contaminants, possible risks of cross contamination, vibration sensitivity, …. All of these considerations have to be taken into account very early in the equipment design process, because measures to reach a given target specification for the minienvironment, for example ISO 1, could affect basically the design and concept of the complete system and a re-work of the concept could be very expensive and time consuming.

2.1.2 Airborne Particles

Cleanliness in semiconductor manufacturing is mostly associated with airborne contamination, which means normally particles. But, airborne contamination is a combination of airborne particles with sizes down to 100 nm (see definition of cleanroom classes according to DIN EN ISO 14644-1 [9]) and airborne molecule contaminants which could be inorganic and organic molecules with dimensions below 100 nm, typically between 0.2 and 5.0 nm. For the "real" particles high efficient ULPA filters (Ultra Low Penetration Airfilter, according to DIN EN 1822-1 [10]) with particle collection efficiencies of 99,99995% for an U16 filter class are commercially available and today used as standard component in semiconductor systems. These filters remove particles effectively to generate conditions down to cleanroom class ISO 1 according to DIN ISO EN 14644-1 [9]. For example, this means particle counts per cubic meter of air must be below two particles with 200 nm in diameter and less then ten particles of 100 nm diameter. As a descriptive comparison in a cube of 10 x 10 x 10 kilometers ten small particles of only 1 mm in diameter and two particles with 2 mm must be found and classified.

Additionally, compared to the standard glass fibrefilter material used for cleanroom facilities, the usage of PTFE material (polytetrafluoroethylene, trade mark: Teflon) shows a further positive effect for the cleanliness in semiconductor minienvironments. The reasons for this are the higher filtration efficiency, the lower most penetrating particle size (MPPS) of approx. 90 nm and the chemical composition without Boron and high resistivity against aggressive and hazardous materials and gases sometimes present in semiconductor manufacturing equipments. Measurements of the collection efficiency in dependence of the particle size verifies for both filter materials the theoretical prediction, that below the MPPS the efficiency increases up to nearly 100% due to the small particle sizes, the micro-structure of the filter materials and the increasing influence of the van der Waals interaction and the Brownian motion as predominant filtration mechanisms [11]. Below a typical particle size of approx. 20 nm the efficiency drops down dramatically and nearly all smaller particles pass through the filters. Therefore, according to the current definition of the cleanroom classes cleanrooms and minienvironments are clean for particles based on the current filtration technology. But with view to future requirements additionally to the airborne particle contamination other types of contaminants and contamination sources must be taken into account.

2.1.3 Airborne molecular contamination

As mentioned above, airborne contamination consists of airborne particles and of inorganic and organic contaminants which are referred as airborne molecular contamination (AMC). Therefore, with decreasing feature sizes down to nanometer dimensions and more sensitive processes and materials, the airborne molecular contamination gain more and more importance and interest. The effect of molecular contamination could be dramatic for example in: change of the surface properties (hydrophobicity), lower breakdown voltage, unintentional doping, haze degradation of optics and masks, oxide growth rate and quality, post-CVD defects, delamination, etc.

According to the SEMI standard F21-95 [12] different AMC species are classified and divided into acids (A: HCL, HF, HNO3, H2SO4, …), bases (B: NH4, amines, gases from photoresist, stripper, and solvents, …), condensables (C: organic compounds with boiling point above 150°C, referred as VOC (volatile organic compounds)), and dopants (D: Phosphor, Boron, Arsenic). The route cause of AMC in a minienvironment could be, as for particles, located externally in the surrounding environment (AMCs generated by other process systems, e.g.) or internally and could be related to the process itself or the materials used in a minienvironment. Outgasing is here seen as one of the major sources for organic contamination (flame retarder (organophosphorus), siloxanes, polymer/plastic additives (plasticizers, antioxidants), …) and the selection of the construction materials is one of the critical decisions in the early design phase of a semiconductor equipment. Therefore, the minienvironment itself could be the reason for AMC caused by outgasing filter material, sealings, … and also a wrong design concept could lead to an enrichment of AMC over time and at special locations inside the minienvironment. In dependence of the technical requirements and the surrounding contamination level different types of filter materials could be used, for example activated carbon particles treated with different chemicals to adsorb the different chemical contaminants. In dependence to these pre-conditions, mostly the mechanical design of fan-units and filters itself must be adapted to the special requirements like: required pressure drop, needed absorption capacity, expected life-time, given air humidity, usage of inert gases, possible physical dimensions (area and thickness), maintenance access for the frequent exchange (in a filter-fan-unit positioned in the air-inlet (advantage: easy to exchange) or between fan-unit and particle filter), …. With increasing sensitivity of the process to all mentioned and probably new contaminants at molecular level in future the requirements for AMC filtration will become tighter and new concepts must be considered here in future, for example plasma treatment.

2.1.4 Cleanliness and air-volume requirements

Closely related to the required cleanroom class inside a minienvironment is the question about the appropriate air-volume which has to be provided by fan-units for a given minienvironment volume. To reach lower cleanroom classes from ISO 8 to ISO 6 with turbulent air-flow the number of air changes per hour for a given volume is an appropriate indicator to reach the targeted cleanroom classes, for example 80 air changes per hour for cleanroom class ISO 6. For higher cleanroom classes starting with ISO 5 with vertical uni-directional air-flow with 0.3 – 0.4 m/s air-velocity the air change number increases up to more then 500 times per hour. As an example, for a 2 x 2 x 2 meter minienvironment volume an air volume of approx. 4.000 m^3 per hour must be provided by high efficient fan-units. To accomplish this air-volume also other design parameters of a minienvironment become more and more of importance, like: size of the air-outlet area, air-flow-concept, over-pressurization, etc. Therefore, to reach class ISO 1 conditions the filter-fan-units has to provide the necessary volume of ultra pure air and the air-flow concept must be designed to remove effectively particles generated in the minienvironment.

2.1.5 Air-flow concepts

As mentioned in the previous section the air-flow concept is closely related to the targeted cleanliness. The air-flow concept inside a given equipment defines the direction (vertical and horizontal) and air-velocity for different parts (handling, buffering, …) and locations (storage, measurement, …). In the past the concepts are developed based on the results and experiences gained at large cleanroom facilities with view to cleanliness and ergonomic conditions as working environment. For minienvironments the classification is equal like for cleanrooms, but due to the special and different requirements the classification of a minienvironment must be based on a more complex basis. The small and compact dimensions to save footprint, the moving robotics inside and the influence of other contamination sources which could not be removed from the minienvironment lead to the application and development of special air-flow concepts which must be modified and adapted to the given requirements. Therefore, a air-flow concept for a dedicated equipment must be developed with view to each individual system.

In most cases semiconductor equipments are fully packed with process and metrology chambers, storage and buffering locations to reach a minimized footprint and generate a maximized throughput of wafers and masks. To fulfil the requirement of a vertical uni-directional air-flow for high cleanroom classes two different concepts could be applied: a) covering the complete air-outlet area with particle filters, like mostly used in the past for high quality cleanrooms or in pharmaceutical industries, or b) the usage of a laminarisator. This concept of a laminarisator works with more efficient fan units, particle filters with higher collection efficiency, an over-pressure plenum and a special air-outlet. The filter-fan-units are providing the particle free air in a over-pressure vessel (plenum) where a constant over-pressure in the complete volume is build-up. This over-pressure causes, that a defined air-stream with dedicated air-velocity will leave a semi-transparent gauze mesh homogenously over the whole air-outlet area (Fig. 1). The advantage of this concept is, that to reach the required air-volume and air-purity special high efficient fan-units and high efficient ULPA filters could be used which reduce the costs due to the lower the number of filter-fan-units needed. Additionally, any kind of geometry for the air-outlet could be realized and other system specific requirements like integration of AMC filtration could be accomplished more effective.

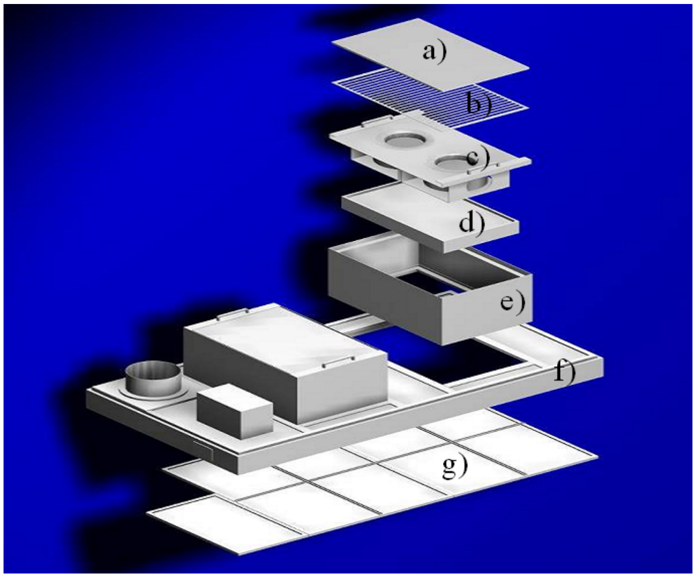

Fig. 1: Principle parts of clean-air-management-system (CAMS) build as a laminarisator (from top to bottom: a) pre-filter (not mandatory in cleanrooms), b) protection grid, c) fan-units on mounting plate, d) particle filter, e) filter-fan hood, f) plenum (over-pressurized vessel), and g) semi-transparent gauze mesh spanned over a frame as air-outlet to the minienvironment.

Independent of the concept which has been selected, an uni-directional flow coming from the air-outlet will be disturbed and transformed in a turbulent air-flow immediately after the first inter-action with the installed components (robots, chambers, …) in the minienvironments. In this case the way and the direction of the air-flow has to be guided in the right way to provide the clean air to every point inside the minienvironment to avoid "death zones" and to remove all particles generated in the minienvironment. Typical particle sources here are handling-robots, mechanical moving parts (stages, shutters, …), devices using compressed air (air-knifes, grippers, …), electronic devices also beneath substrate level with internal exhaust-fans for cooling, etc. All this must be considered to prevent cross-contamination and to guarantee finally the cleanliness of the critical area where wafer and masks are located.

For simple system designs, the air-flow could be mathematically simulated, but for real more complex systems this will not be suitable due to the various parameters and their interaction which could not be treated all at the same time by an appropriate theoretical model. Therefore, an extended experience in system design and knowledge of the physical laws is essential to develop concepts of minienvironments, which work afterwards without additional time- and money consuming measures to reach the specified cleanliness and parameters.

2.1.6 Over-pressure

A further technical fundamental leverage is to generate an over-pressure in a minienvironment relative to its surrounding to avoid the penetration from particle from outside. Typically, the over-pressure should be maintained during normal operation within a range from 1 to 5 Pa and after restart of a minienvironment these conditions should be re-covered within 1 minute. For more complex systems with different production areas (handling, processing, storage, …) or minienvironments with additional safety requirements for products and humans, for example with chemical and process exhausts, a more sophisticated concept with pressure-cascades has to be taken into account. For example a system containing a process/storage area where a high cleanliness is needed and generated by a horizontal air-flow and an adjacent handling area with lower cleanliness requirements but with the need of a vertical air-flow to remove particles generated by robotics and other handling parts. To protect the substrates in the more sensitive area an over-pressure must be generated and further measures like active pressure control, exhaust-fans or flaps have to be implemented to guide the air in the right way. Also special installation conditions like through the wall, where between clean- and grey room areas pressure differences up to 10 Pa could occur, must been taken into account in the early system design, because special measures to tighten a system to reach the necessary pressure values could be later cost extensive and are in some cases not possible to retrofit.

2.1.7 Environmental parameters: temperature and humidity

Only the clean-air concept of a minienvironment is sometimes not sufficient and other environmental parameters like temperature and humidity must be considered for the overall minienvironment concept. Semiconductor equipment is normally installed in common cleanrooms with a predefined temperature and humidity within specified tolerances. Typically the temperature in a semiconductor cleanroom is 21°C +- 1 °C and the humidity is approx. 45% +- 5%. For an "open" minienvironment these conditions in combination with the system specific parameters (heat loads, open wet benches …) will determine the conditions inside a system.

But with increasing process requirements and more sensitive processes tighter tolerances have to be maintained over short and also long time over more than 24 hours. In this case the minienvironment solutions become more complex and expensive, because the concept of a closed loop re-circulation systems has to be applied. Also a mixture of open and locally closed system is possible in the case, that the minienvironment is open and temperature stabilized to +- 0.1 °C and critical components are integrated in a closed loop air or nitrogen re-circulation system due to enhanced stability requirements down to +- 0.05°C. For this kind of more complex technical solution, the needed sub-components like pumps, filters, valves, etc. normally could not be all integrated in the equipment itself due to the limited available space. Therefore, critical sub-components responsible for highest parameter control and with shortest supply-lines must be placed closed to the process inside the equipment and the non-critical components should be put centralized in separate supply-units based in the neighbouring grey-room area or the basement.

2.1.8 Electrostatic discharge

Another and mostly neglected aspect for a minienvironment concept are the possible problems with electrostatic discharge (ESD). According to SEMI E78 [13] different classes for production areas are defined and in the SEMI standards F43 and F129 [14][15] the procedures how to assess, control and measure the electrostatic charges are described. To reduce electrical charges at a substrate surface different influences has to be considered starting with the materials which should be selected with view to the conductivity of their surfaces. In the past it was also well known, that the level of electrostatic charging is related to the humidity in the atmosphere and is lower at higher humidity. Today, with the development and availability of ionizers generating positive and negative charges these kind of devices could be integrated easily in a semiconductor equipment which makes a minienvironment more independent from the surrounding conditions. Selecting this alternative is effective but very expensive and works only if the air-flow concept in the system is considered properly. A third possibility is to reduce the air-flow induced charging of surfaces by lowering the air-velocity in the minienvironment down to 0.1 to 0.2 m/s and to avoid further turbulence generation. This concept is passive and well suited for storage equipment (stocker) where the substrates are exposed over a long time to atmospheric conditions and no further particle sources are present close to the storage location.

2.1.9 Safety for products and humans

In general, all semiconductor equipment must be in compliance with the common SEMI safety standards: S2, S6, S7, S8, S9, and S10 [16][17][18][19][20][21]. Additionally, a further SEMI safety standard S11 exists especially concerning topics related to minienvironments [22]. These are safety considerations to protect the users of minienvironments (operators, service engineers, …) and the products inside. For example for closed loop nitrogen re-circulation systems special protection mechanisms (inter-locks, oxygen sensors, independent separate control unit, …) and procedures (floading, re-covery, …) have to be implemented in case the system fails and human intervention is necessary. On the other hand product protection is required in case the equipment fails (power interrupt e.g.) and the substrates should be protected by an independent running minienvironment until a human intervention will recover the system or secure the valuable wafer and masks. Also all safety relevant items related to installation (installation tools, e.g.) and earth-quake protection has to be taken into account in the design phase of a minienvironment. Therefore, the design of a minienvironment must take care about all needs of human and product safety and protection and that in a very early stage.

2.1.10 Installation and maintenance

In the early design phase of a minienvironment considerations related to installation and maintenance of the minienvironment itself and the equipment should be involved. This starts with questions related to ergonomic for example how to install the filter-fan-units on top of an equipment (by human beings or special lifting tools) and end with the service concept how to replace filters below the cleanroom facility ceiling in about 3 meter height. Technical solutions like room side change (RSC) installations for filters are available and could be used. Also with view to the more frequent exchange interval of AMC filters the way how to exchange these filters (from the minienvironment or from outside: top or side) should be considered early in the concept phase to avoid increased tool downtime caused by extended time to remove an assemble parts necessary for the exchange procedure.

2.1.11 Control, monitoring and automation

Compared to other industries like in pharmaceutical productions, where in-situ monitoring and documentation of the cleanroom conditions is mandatory, in semiconductor manufacturing monitoring of the cleanroom conditions is still in the individual responsibility of each manufacturer himself. The SEMI standards and the Sematech Guidelines give a strong technical background, but how to implement the measures and in which frequency (permanent, one time per year, weekly, daily, statistically, …) the control has to be done is still an individual question. Also the parameters which have to be controlled and where in a minienvironment is not clearly defined and only basic requirements are described. Today with the availability of modern technologies and techniques for high sensitive and miniaturized sensors and more effective data transfer of production sensitive data could be collected and used to monitor and control continuously the parameters of a minienvironment. This kind of monitoring could be used to correlate the minienvironment date and to optimize the tool uptime, yield and to get early indicators for system failures and predictable down-times. Also the integration of sensors into the system itself with pre-defined measurement locations for example for particles (like it is in pharmaceutics mandatory) could help to identify problems in-situ and guarantee the tracebility to find the root cause for process excursions and product failures. Therefore, monitoring of minienvironments could be a pre-active part of process control and could save money and valuable production time. A common understanding in the community is still present, but how to define and setup a common standard is still an open question.

2.1.12 Cost of ownership

Minienvironments are considered for a long time as necessary but expensive add-on for process equipment without any added value for the equipment itself. Today, cleanliness is seen as basic requirement and as enabling pre-condition to reach best performance and yield. To find the best balance between performance and costs different aspects have to be considered such as purchasing price, cost for spare parts, consumables and consumption [23].

A more and more important aspect today is the energy efficiency of equipment and reduced energy costs. With only few filter-fan-units in a minienvironment the energy consumption of one system is nearly negligible compared to other energy consuming processes. And the estimation of the energy consumption of all installed minienvironments in a facility shows that the total value is much lower compared to a complete high class cleanroom with hundreds of filter-fan-units in the ceiling. With increasing cleanroom requirements and complexity of a minienvironment, for example for extreme dry air or nitrogen re-circulation systems, the total costs increases and a localized solution could help to reduce the necessary efforts and costs to make a minienvironment more efficient. The usage of state of the art fans, electronics and control systems could also safe energy even in case of higher purchasing investments, therefore the details have to be clearly estimated and considered to find the right balance for a decision.

To find the best way and judge which costs for a minienvironment are justified a risk analysis has to be considered. In dependence how critical the products and processes are seen the failure of a minienvironment could cause expensive down-time of an equipment and in worst case damage of the valuable products inside the system. As integrated part of an equipment this has to be taken into account carefully and must be a fundamental part of the equipment model and the overall cost analysis.

2.1.13 System qualification and acceptance

With view to the importance of a proper working minienvironment the qualification and acceptance of all specified functions is essential. Therefore, the clear and unambiguous specification for all required functions of minienvironment is pre-conditions for the further success of a system. Gaps or the lack of clarity in the specification could be the reason for delay of the acceptance and cause expensive and time-wasting re-works and modifications at still installed equipments. Not only the first acceptance of a minienvironment in the vendor factory before shipment and subsequent acceptance at the buyer location has to be considered seriously. Also the re-qualifications during a system life-time for release for production after down-time, maintenance, modifications, … are important for equipment efficiency and has to be considered carefully.

Some items mostly neglected in specifications and acceptance criteria for minienvironments are nebulous definitions and unclear procedures how to evaluate and judge the results. Also sometimes missing is the clear differentiation between the two different conditions “at rest” and “in production” (acc. DIN EN ISO 14644). In the pharmaceutical and medical industry this difference is essential and mandatory for accept and release of cleanrooms and equipment for usage in production. In the semiconductor industry, the frontier between the two possible states of a minienvironment is not strictly used and mostly not clear defined. Therefore, the acceptance of an equipment could become critical and could be the reason for long lasting open issues.

2.1.14 Final remark

Based on the different technical requirements and possibilities to reach the defined specifications and functions of a minienvironment the design of a minienvironment must be seen as a complex multi-parameter equation with several degrees of freedom, which has to be solved based on knowledge and experience in the best possible way to find an acceptable balance between technical and commercial considerations. All technical requirements, options and alternatives described in the previous sub-sections give only a rough overview over a spectrum of possibilities and should not be seen as a complete compilation. In the following chapter three basic design concepts are explained, which could be found typically in common wafer and mask manufacturing fabrication: a) fully integrated minienvironment, b) external minienvironment with temperature control and stabilization, and c) closed-loop minienvironment as re-circulation system for extreme dry air or nitrogen atmosphere. The basic principals are outlined and the advantages and disadvantages of the concepts are discussed.

3 Examples of system concepts

3.1 Integrated minienvironment

In the past, with the transition to 300mm wafer processing and the related mask manufacturing a step towards enclosures and minienvironments was done first for the wafer and later for the mask systems. As outlined before, integrated minienvironments are a fully absorbed in the equipment concept and a part of the system itself. Therefore, integrated minienvironment design should be taken into account in the earliest stage of equipment concept and design according to the Sematech Guidlines. A detailed description about such kind of minienvironments which are specified for cleanliness down to class ISO 3 to 2 could be found in the Sematech documents [5][6][7], which reflects the technical common positions.

Today the ITRS emphasizes the need for tighter contamination control limits to increase yield and productivity of process equipment and stipulate starting with 2010 cleanroom class ISO 1 inside the minienvironments. Additionally, new process requirements coming from immersion and EUV lithography and new materials request new solutions which go beyond the solutions described and applied in the past.

Especially, for the critical handling and storing of masks the lowest defect density values are required due to the exposure of the substrates to the surrounding minienvironment. To find an acceptable balance between the best possible cleanliness and lowest costs a compromise is found in the concept of an open system architecture of an integrated minienvironmnet. For this the air is taken from the surrounding cleanroom (typical installation conditions: ISO 5 turbulent), is filtered and passing the minienvironment volume and leaving the system at the bottom reflowing into the surrounding cleanroom or to the sub-fab, respectively. This concept is focused to the supply of particle free air and as an option the removal of atomic molecular contamination. All other environmental parameters like temperature and humidity are not controlled and must be taken as determined from the surrounding cleanroom and in conjunction with the system specific facts.

In this concept as shown in the scheme in Fig. 2 nearly particle free air is generated by using high efficient PTFE ULPA U16 particle filters and the airborne molecular contaminants are removed by AMC filters tailored to the special requirement of the installation surrounding (given contaminant levels of: acids, bases, and VOC, for the litho area, e.g.). To reduce service time to exchange the AMC filters special adapter frames are used to put the AMC filters in the air-inlet of the filter-fan-units and make them easily and fast removable. The vertical uni-directional air-flow from top is then generated over the complete tool ceiling area by using a laminarisator.

In dependence of the complexity of a minienvironment different levels of control and monitoring could be integrated. The easiest and static way which is normally applied for simple systems like equipment front-end modules (EFEM) for substrate handling works with fixed rotational speed for the fan-motors and only an optical element (LED) indicates if the fan-speed deviates from the given value (s. also Sematech). In more complex systems additional sensors could integrated to monitor the conditions inside a minienvironment, but do not change the minienvironment parameters dynamically. Typical sensors used for this purpose are air-velocity and differential pressure sensors, which measures continuously and in case a control limit is passed (for example pressure drop due to an opened equipment panel) an error message is send via interface to the equipment control unit. To control a minienvironment dynamically the signals from the sensors are collected by an integrated central electronic unit and according to a defined program minienvironment parameters will be changed and set automatically, for example increase of the rotational speed of the fan-units in case of a pressure drop to compensate the loss of air and to maintain the over-pressure to avoid particle penetration from outside. Additionally, exhaust fan-units controlled statically or dynamically could be used to influence the more complicated air-flow inside a minienvironment to remove generated particles and to prevent cross-contamination inside.

The advantage of this concept is to reach the highest cleanliness requirements down to cleanroom class ISO 1 with: a) full integration into the equipment functions and design, b) effective and flexible AMC filtration (if considered at a minimum as an option in the early design phase), c) no need for additional footprint, because the filter-fan-units and laminarisator is fully integrated in the equipment footprint itself, d) installation of an ionisation-bar below the air-outlet to distribute the generated ions effectively in the minienvironment, and e) lowest possible costs for realisation due to optimized system integration (no additional and separate sub-system). Therefore, in dependence of the given requirements these concept could be a perfect balance between technical solution and commercial considerations. The disadvantages are: a) temperature control could be included, but only with higher energy consumption and increased equipment height, and b) humidity control or other atmospheric conditions are not possible, due to the openness of the system.

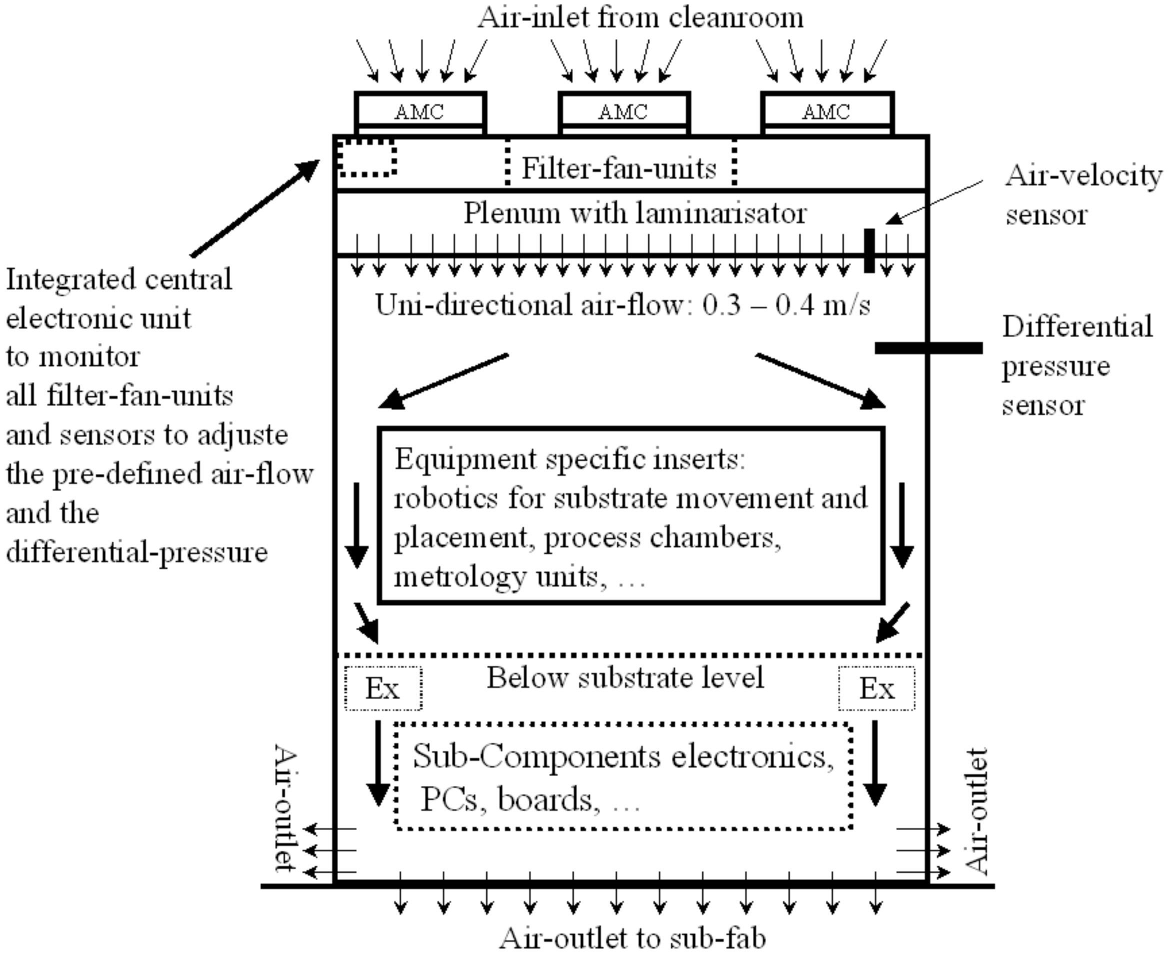

Fig. 2.: Minienvironement with Clean-Air-Management-System (from top to down): Air-inlet, AMC filters in the air-inlet with adapter-frames for easy exchange, filter-fan-units, plenum with laminarisator to generate an uni-directional homogenous vertical air-flow, equipment specific components, boundary between substrate level and volume below, additional exhaust fan-units (Ex) to influence the air-flow and to transport the generated particles to the air-outlets at the bottom of the minienvironment, plus different sensors to control the minienvironment conditions and an integrated electronic control unit to monitor the sensors, adjust parameters and maintain the pre-defined minienvironment conditions and provide a hardware (display with touch-screen) and software interface for failure reporting and GEM/SECS communication.

3.2 External minienvironment with temperature control and stabilization

In this second example an open system is reviewed again, but now as external minienvironment and with additional requirements for temperature control and stability to maintain sensitive manufacturing processes stable over a long time. In opposite to the previously described integrated minienvironment this kind of concept is an enclosures to place a complete equipment inside. Typically (s. Fig. 3a), this kind of concept is used for larger systems which need also temporary human access for interaction (loading, adjustments, …) and has to be placed inside an enclosure or for systems for which the design of an integrated minienvironment is more problematic and expensive due to their complexity, for example e-beam systems or laser-processing equipment.

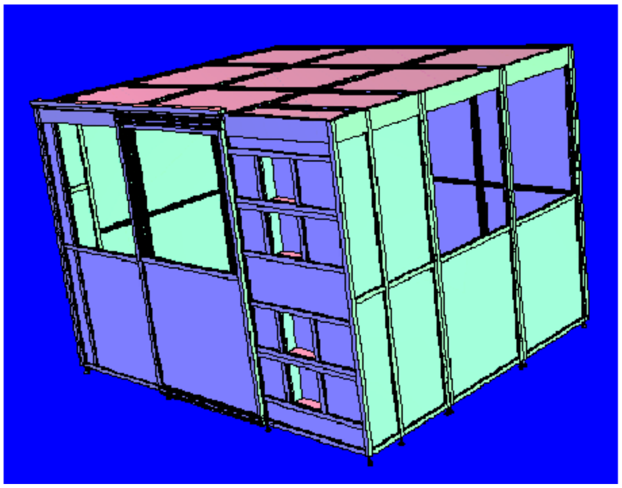

Fig. 3a: Enclosure with integrated filter-fan-units and heat-exchangers in a separate unit inside the enclosure (right corner in front).

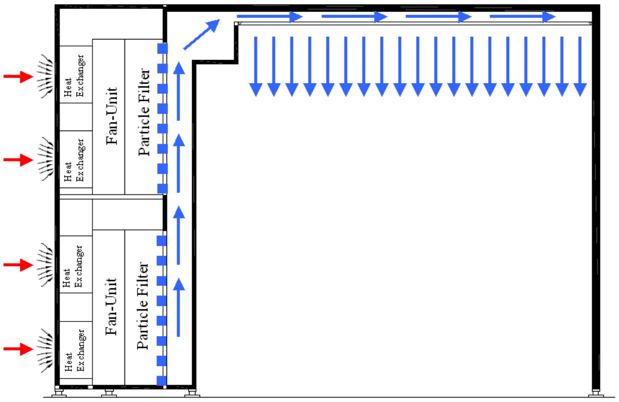

Fig. 3b: Air-flow concept with a compact and in the footprint integrated unit containing the heat-exchanger, filter-fan-unit, plenum and laminarisator.

As for the integrated minienvironment filter-fan-units are used to generate the particle free air and a laminarisator distributes this air uniform over the complete equipment (Fig. 3b). But additionally and more important in this case is the integration and active control of the heat-exchangers with closed cooling-water loop to reach and stabilize the a balance between provided cooling capacity and air-volume (not only the air-change numbers needed for the cleanroom class). The concept is based on an estimation taking into account the total energy balance inside the minienvironment by assuming the maximum heat load of the equipment and from the minienvironment itself (fans, electronics, …). The integrated temperature sensor below the laminarisator and control unit will then take care, that the appropriate cooling capacity will be provided accurately, which makes long-term temperature stabilization down to +- 0.1°C inside the minienvironment possible.

The advantage of these concept is: a) the size of the minienvironment could be adapted to the equipment dimensions and human access space requirements (load locks, service area, …), b) the adaption to given installation requirements (limited room height, reduced cleanliness demands for the surrounding room, e.g.), c) reduced costs (purchasing and energy) compared to a complete climate controlled cleanroom. Disadvantages to mention: a) availability of cooling water of 18°C, b) availability of a installation location with pre-defined temperature conditions between 20 – 25°C, and b) due to the open system architecture, which works only energy efficient in case the installation room is not to large. Therefore, this kind of localized minienvironment solution could be favourable for small to mid sized manufacturing facilities, where high quality cleanroom space is limited or the upgrade of existing cleanroom capacity is expensive or in principal not possible due to other restriction like given buildings and infrastructure.

3.3 Closed-loop minienvironment as re-circulation system for extreme dry air or nitrogen atmosphere

As a last example a concept for a more complex closed-loop re-circulation system is presented. This kind of concept offers the possibility to generate high cleanliness of class ISO 1 in combination with AMC and VOC filtration in a large available minienvironment volume of approx. 25 m^3 to store masks or other sensitive substrates. In dependence of the technical requirements the system could be configured to work with extreme dry clean air (XCDA) with relative humidity down to 3% or with a inert gas atmosphere like nitrogen.

Shown in the flow-diagram in Fig. 4 the system is configured for XCDA generation and usage. In the primary loop the air of the minienvironment itself is re-circulated by filter-fan-units with PTFE ULPA U16 particle filters (s. yellow line). The second loop is used to generate the dry air and re-circulate it back into the first minienvironment loop (s. light green lines). To reach the lowest level of humidity in the minienvironment loop a portion of the re-circulated air from the minienvironment is taken and guided to the dehumidifiers for removal of the humidity. To maintain an over-pressure in the minienvironment relative to the surrounding and to compensate leakages a controlled volume of fresh air (s. blue arrow) is taken and mixed with the air coming from the minienvironment. To achieve a 7 day 24 hour capability the dry air generation is split into two parallel branches that works in that way, that one dryer is working to generate the dry air, whereas the second dryer is regenerating his adsorbing material. Due to the fact that the AMC filtration for acids and bases is working only with air with normal humidity the AMC filter units are placed before the dehumidifiers. In opposite the VOC filtration is more effective for dry air and the VOC filters are therefore placed afterwards the dryers.

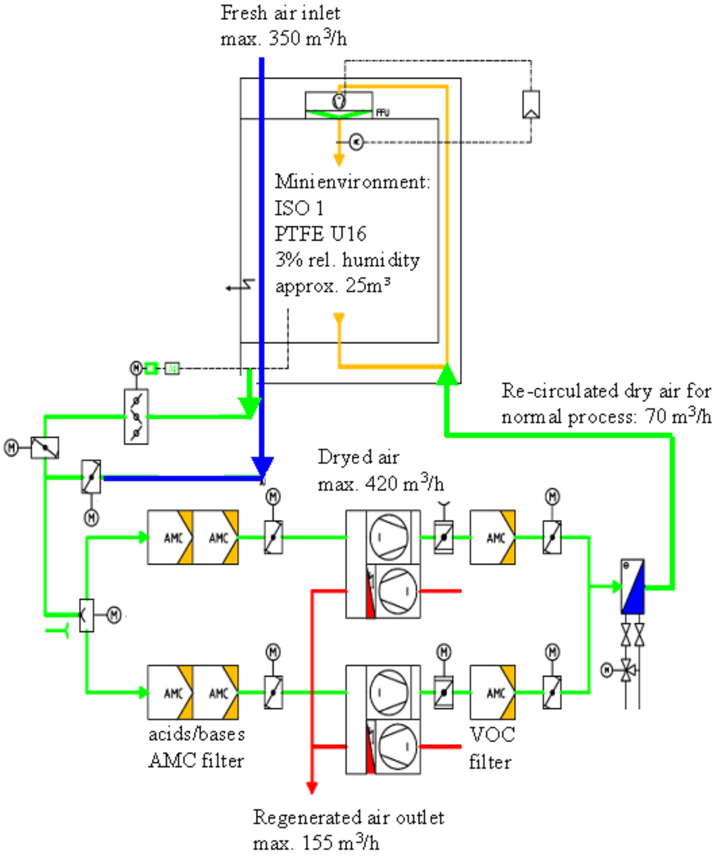

Fig. 4. Flow diagram showing the different closed loops of the air-re-circulation system of the minienvironment itself (yellow arrow) and the air-drying loop with AMC filters and dehumidifiers (light green).

The advantage of such kind of complex system is to generate special and defined atmospheric conditions in a closed high class minienvironment. With only minor modifications of the concept the design could be also adapted to inert gas atmospheres like nitrogen. In this case more safety relevant measures like inter-locks, oxygen sensors and separate independent control circuit for the nitrogen system has to be implemented. Disadvantages are caused by the complexity of the system: a) high price, b) high costs and efforts to maintain the system, c) high costs for spare parts like AMC and VOC filters, d) high energy costs to generate the XCDA continuously, and e) enough space to place all necessary sub-systems in the grey-room or sub-fab. Therefore, such kind of concept is from technical point of view feasible, but only realistic in case the technical benefits outbalance the commercial constraints.

4. Outlook

The fundamental considerations how to setup a concept and how to design a state of the art minienvironment are summarized in chapter 3. What has to be applied and how it works and what are the advantages of the different concepts are demonstrated in the subsequent chapter 3. The question is now, what will be needed in future and how could this achieved ?

As in the past, with the introduction of new lithography technologies in semiconductor manufacturing tighter and new requirements for the contamination control will occur. This will be related to the common questions of airborne particles and how to reduce it, but the questions will be more and more extended to the field of airborne molecular contaminations. Also the questions how to deal with any kind of contaminations at surface will be a main topic in future and requires new answers.

With the introduction of new technologies like EUV lithography currently the requirements for cleanliness and contamination control will increase dramatically. The traditional way how to handle and treat masks will change fundamentally and new concepts have to be found and applied. “Zero defect” requirement and the basically change of mask design make the development of new strategies how to transport, inspect, clean, process and store masks in a favourable ambient atmosphere like XCDA or inert gases mandatory. This will include about thinking of cleanliness below the current ISO 1 classification and particle sizes below 100 nm and what does it mean to come to a practicable approach to measure, justify and classify the new specifications. Also the questions about the current challenges for AMC control and which contaminants will become relevant in future will gain an increasing importance and will need research to reach a fundamental understanding of the processes and parameters involved. Discussed in this way must be, like in pharmaceutics, how to detect, classify and quantify the trace contaminations and how to monitor it continuously.

With transition from micro- to nano-electronics the situation will become more and more dramatically and new concepts for contamination control must be considered. Not only (like in the past) with view to product protection, maybe now also with view to protection of humans in close contact to the new processes and nano-materials. A better technical understanding of the interaction of the new materials is needed, but also a better understanding how the new materials will affect the production processes and the surrounding needed. Probably this will lead (not in short time to be expected) to a shift in paradigms and a more sensitive understanding about the upcoming problems and possible solutions. Therefore, mask and lithography technologies must be seen as a key-innovator at the fore-front of today technical development and as a pioneer in nano-technology to overcome challenges and to provide suitable solutions for the future.

5. Summary

Cleanroom technology is a principle pre-condition and the enabling technology for contamination free manufacturing. With the transition from large cleanroom facilities in semiconductor manufacturing to localized encapsulated cleanroom solutions which are called minienvironments the traditional cleanroom technology is extended into a new field of applications. With view to the highest requirements in semiconductor industries and especially in the mask area extraordinary concepts and solutions has to be developed and applied. As an essential out-come of this review of current minienvironment technology a list of items to be considered and the related parameters for the design process is discussed. Critical parameters, alternatives and options are highlighted and typical pit-falls in the specification and acceptance procedures are out-lined. Special design concepts are presented and discussed with view to possible applications and their advantages. Therefore, today each specific equipment has it’s own requirements for an appropriate minienvironment solution and the best compromise between fulfilment of the defined technical specifications and the commercial aspects has to be found. Based on the current status of minienvironment technology an out-look is given about future challenges and open questions to be solved.

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