1 Introduction

MiNaLab is a cleanroom laboratory excelling in micro- and nano-fabrication. It is operated as a resource for students and researchers. As a user MiNaLab laboratory you have a responsibility for the safety, work conditions and success of others. This responsibility starts with the contents of this document which must be known and complied with at all times.

The MiNa laboratories offer 440 m2 of cleanroom area and more than 50 tools for the fabrication and analysis of structures with dimensions in the micro or nanometre range. This environment requires that all users have sufficient knowledge on how to behave and act in our cleanroom.

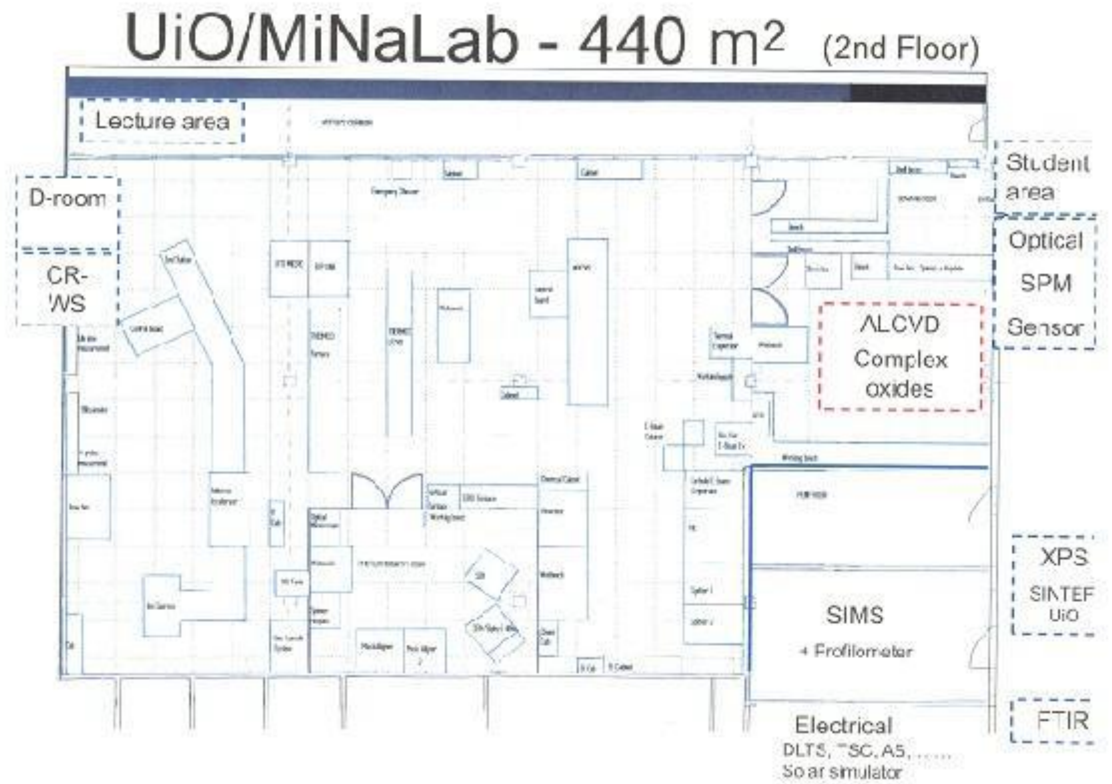

Figure 1 UiO MiNaLab cleanroom area

This document can be considered as a general instruction manual on the basic usage and safety aspects MiNaLab cleanroom. Primarily it regards the safety and work conditions, but also the technical design and maintenance of the cleanroom. It also describes the potential dangers and general information connected with the usage of the cleanroom. The document is applicable in equal respect for all laboratory employees, as well as temporary and long-term guests. It governs the safety as well as the rules which must be followed for admittance and usage of the cleanrooms and tools.

2 Document history

Revision	Date	Prepared	Approved	Description
A	03-08-2010	Mikael Sjödin		Initial revision
B	06-06-2017	Halvor Dolva	Viktor Bobal	Text added to paragraph 3.13 Cleanroom rules: Use of headphones that are too large to be worn at the inside the hood is not allowed. Minor editorial updates.

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3 Cleanroom

3.1 Why cleanroom?

What is a cleanroom and why are they used in semiconductor factories? Manufacturing of structures and devices with critical dimension in the micrometre (10^{-6} m) to nanometre (10^{-9} m) range puts very tough demands on the fabrication environment, in order to assure reasonable yield figures. The demands on the environment could be formulated in terms of contamination reduction, where we use an extended definition of contaminants, formulated as “A substance or a condition occurring at the wrong place at the wrong moment”. Hence a contaminant could be e.g.

- Particles (dead or viable)
- Chemicals (toxic, reactive, explosive...)
- Vibrations
- Static electricity
- Noise
- Radiation (electromagnetic, radioactive)
- Magnetic fields
- Climate (temperature, humidity, pressure)

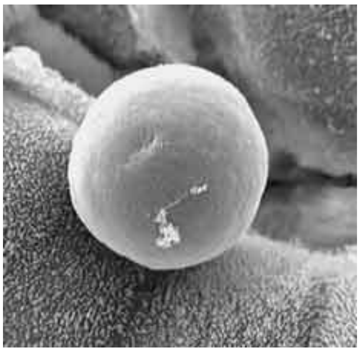

Figure 2 SEM picture of a particle

The cleanroom provides an environment featuring contamination control in a broad sense. Our cleanrooms are designed to keep the most damaging contaminants at a low level. We will here discuss a few of those. When we refer to a cleanroom, it is a cleanroom for semiconductor manufacturing, keeping in mind that there are cleanrooms optimized for other purposes, which hence obey other design rules.

3.2 Particle control

Small structures fabricated in the fields of microelectronics, photonics or MEMS, are all sensitive to submicron particles (and greater particles). Particles adhering to wafers during specific process steps may reduce yield, affect the performance of the device, or do damage in other ways. Any particle at a size comparable to or larger than the critical dimension of the device or structure is bad for the yield. Especially critical are photolithography steps, where the presence of a particle on a mask will be reproduced to all wafers fabricated. A classification of particulate contaminants is shown in Figure 3.

Approximately 75% of all particles in a cleanroom come from the people working there. The remaining particles are generated from ventilation, room furniture and tools. Humans can generate more than 100 000 particles per minute at rest, and more than 1 000 000 particles per minute when walking. Particles can be inorganic or organic solids like dust, fibres, pollen, etc., but also viable particles like bacteria, mould or fungus. Aerosols are also particles in a cleanroom context. Examples are saliva emitted during sneezing or oil mist.

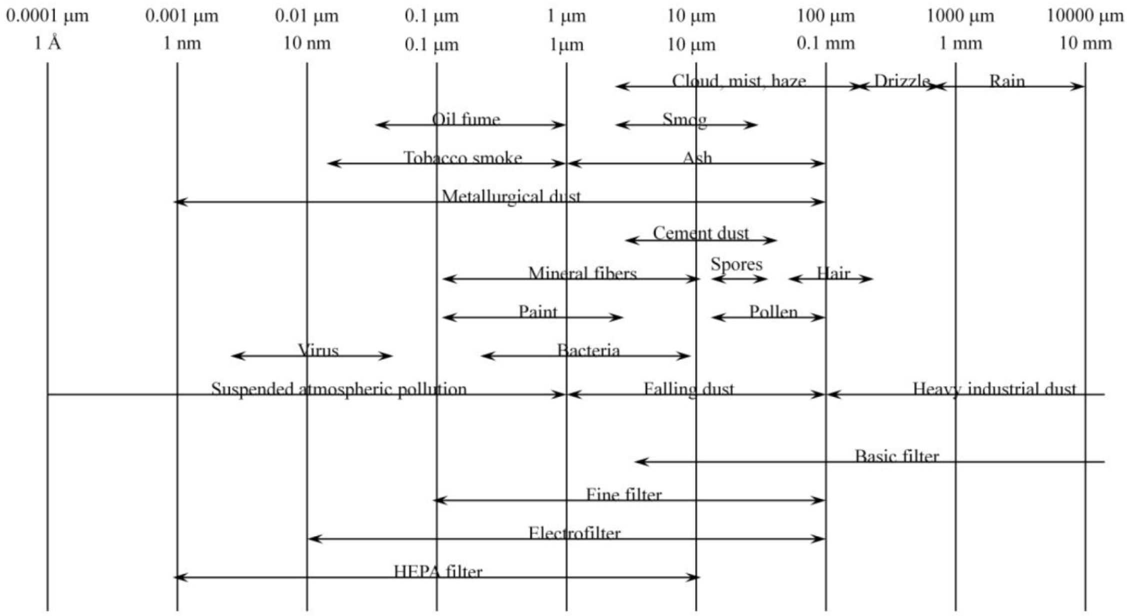

Figure 3 Particle size classification

3.3 Cleanroom behaviour

In order to limit the number of particles in the cleanroom, cleanroom garments, which trap and hold the particles emitted by the human body, will be used. A correctly used outfit helps to drastically reduce the spreading of particles, but each user is also responsible for further reduction of particle generation and spreading.

Every person generates particles. A person walking at normal pace will generate around 5 million particles per minute! In order to limit the number of particles spread to the cleanroom, special garments are used. These garments act as particle filters between the lab user and the cleanroom.

Table 1 Particles generated by people

Activity	Particle generation (> 0.5 µm/minute)
Sit or stand without motion	100 000
Sit, small arm or head motions	500 000
Sit, arm-, leg or head motions	1 000 000
Rise up	2 500 000
Slow walk	5 000 000
Medium slow walk	7 500 000
Fast walk	10 000 000
Gymnastics	25 000 000

The cleanroom garment is a particle filter worn to protect the cleanroom environment from the contaminations coming from the human body. The filtering function will only work properly if the garments are worn correctly and are free from moisture and stains. It is also important to choose garments of correct size.

The garment is a particle filter and is not designed to withstand chemicals. The use of appropriate personal protection equipment (e.g. chemical resistant gloves and eye protection) is compulsory when you work with chemicals. Please note that the cleanroom garments are expensive and that it is important to be careful and avoid contaminating them.

3.4 Cleanroom principles

The cleanroom is designed and operated so that the introduction, generation, and retention of particles inside the cleanroom are minimized.

The addition of particles to the cleanroom is mainly limited by air filtering. A cleanroom cannot be cleaner than the air entering it. Ventilation control and air filtering ultimately determines the lowest achievable particle concentration levels in the cleanroom.

People also introduce particles to the cleanroom when they enter, as do the items they bring with them. By entering through airlocks and dressing into cleanroom garments such as hood, mouth cover, gloves, cover boots and coveralls, particle introduction is reduced. Correct procedures for dressing into cleanroom garment, the cleaning of items, etc., will also improve cleanliness.

Particle generation inside the cleanroom is suppressed by the use of cleanroom garment, the exclusion of particle generating materials, correct working procedures, etc. Common materials such as paper, pencils, and fabrics made from natural fibers are often excluded; instead they are replaced by cleanroom compatible versions. Cleanrooms for microelectronic purposes are not necessarily sterile (i.e., free of uncontrolled microbes) and more attention is given to airborne particles.

Retention of particles is suppressed by dilution of the cleanroom environment with recycled filtered air flushed in a unidirectional air flow and by cleaning of the cleanroom.

Desired set points for temperature, humidity, and pressure are maintained in the cleanroom through ventilation control.

Since photosensitive chemicals are used in photolithography, parts of the visible light spectra must be excluded from photolithography areas. This is achieved by using yellow fluorescent lamps and covering any windows with yellow transparent film.

3.5 Cleanroom classifications

Cleanrooms are classified according to the number and size of particles permitted per volume of air. The old standard, US FED STD 209E, referred to the number of particles of size 0.5μm or larger, permitted per cubic foot of air.

The new standard ISO 14644-1, specify the decimal logarithm of the number of particles of a certain size or larger permitted per cubic meter of air. So, for example, an ISO class 5 cleanroom has at most 105 = 100 000 particles per m³ of the considered particle sizes.

MiNaLab is classified as Class 100 000 cleanroom.

Table 2 US FED STD 209E cleanroom standards

Class	**maximum particles per cubic feet**					**ISO equivalent**
	≥0.1µm	**≥0.2µm**	**≥0.3µm**	**≥0.5µm**	**≥5µm**	
1	35	7	3	1		ISO 3
10	350	75	30	10		ISO 4
100		750	300	100		ISO 5
1 000				1 000	7	ISO 6
10 000				10 000	70	ISO 7
100 000				100 000	700	ISO 8

3.6 Ventilation

The overall ventilation system in most cleanrooms is comprised of three parts: Make-up-air (air entering a cleanroom from outside), air circulation and exhaust ventilation.

Circulation fan units supply air to the cleanroom through high efficiency particulate air filters (HEPA-filter). The filters are positioned in the cleanroom ceiling, and remove a large fraction of the particles in the air flow passing them. The specification for a HEPA-filter is the removal of at least 99.97% of all particles at size 0.3µm. The Air in the cleanroom has an overpressure to prevent outside air to contaminate the cleanroom.

3.7 Climate - Temperature and humidity

Temperature control of the cleanroom air is important for several reasons. One is the strong influence the temperature has on most chemical reaction rates, which becomes most evident in wet chemistry processes and the handling of resists and developers in lithography. Another aspect is the thermal expansion of materials, which might become influential in accurate dimension control over large distances, e.g. in stepper or e-beam lithography exposures. For this reason those tools are often equipped with special climate controlled chambers.

Accurate humidity control is fundamental for reproducibility in viscosity at spinning of photo and e-beam resists or polymers, due to the absorption of water.

In a photolithography area the desired temperature and humidity are slightly higher than in other areas of the cleanroom. The air supply to such areas is often equipped with more extensive air-conditioning systems, including active humidification.

It is also important that the temperature and humidity is kept at an appropriate level for the comfort of people working in the cleanroom.

3.8 General media

House gases, exhaust systems, electrical power, cooling water and ultra-pure water , compressed air, tool vacuum and liquid nitrogen are media common to the MiNaLab (and most microelectronic cleanrooms).

3.9 House gases

A gas that is delivered through a piping system to several utilization points in the facility, from one gas bottle or tank installation, is a house gas. Common to the MiNaLab is the distribution of nitrogen (N_2), oxygen (O_2) and Hydrogen (H) from a supply storage located exterior to the housing of the cleanroom.

Nitrogen is used as process gas, technical gas (dry pumps, shaft purge in spinners, etc.) or for blowguns, rinser/dryer, etc. The purity requirements on the nitrogen may differ from application to application, why parallel nitrogen lines with different purity are common. The nitrogen is drawn from a cryogenic tank with liquid nitrogen, fed through evaporators and then delivered to the cleanroom. Depending on purity requirements, in-line filters and getter purifiers are installed on the lines.

Oxygen is used as a process gas in dry etchers, oxidation furnaces, etc.

Argon is used typically in dry etchers and sputters, or in other processes where nitrogen is not inert. The installation can be a gas bottle or cryogenic tank, depending on the magnitude of consumption.

In addition to the gases above, other house gases may be installed, depending on the activities and needs in the cleanroom. Not uncommon house gases are hydrogen (for wet oxidation, and epitaxy processes), silane (silicon precursor in deposition processes) and helium (technical gas and more seldom process gas).

3.10 Special gases

Special gases are tool specific, or locally installed, process gases. The name also refers to a market segment within the gas industry aimed at the microelectronics industry, usually with high requirements on purity.

A typical installation contains the gas bottle connected to a gas panel, which is located in an exhaust ventilated gas cabinet. The gas cabinet are located in the service and media area, a dedicated storage building adjacent to the main building.

Most special gases are either etchant gases, or precursor gases for elements in deposition processes.

Note! Operating valves or other components on gas installations is generally forbidden.

The only exception is for trained service personnel and licensed users of a specific tool, if that is stipulated in the operating instructions of that tool.

3.11 De-ionized (DI) water

De-ionized water is available at almost all wet benches.

De-ionized water which is also known as de-mineralized water is water that has had its mineral ions removed, such as cations from sodium, calcium, iron, copper and anions such as chloride and bromide. Removal of ions causes resistivity of water to increase, providing a convenient measurement for the exact extent of deionization. Ultrapure deionized water has a theoretical maximum resistivity of 18.31MΩcm.

Even though it is possible to get this ultra-pure water just by simply opening the tap, it does not mean that it is free or that the source is unlimited. Even if some processes require extensive and careful rinsing, you are asked to ensure that no water taps are left open or that rinsing baths are left flowing unnecessarily.

3.12 Entry and Exit to the cleanroom

The best method of changing into cleanroom garments is one that minimizes contamination getting onto the outside of the garments. One such method is described below, and assumes that a facemask, hood, coverall and overboots are used. It requires that the garments are put on from the top down. Some of the suggested procedures may be unnecessary in lower classes of cleanrooms, and further procedures can be introduced later on if necessary.

Sticky cleanroom mats or flooring are often used in the approach to the change room. They work by removing dirt from the soles of footwear as personnel walk over them. Make sure you take several steps on the sticky mat and don’t walk around it.

1. Watches and rings should be removed. They can harbour dirt, produce chemical and particle contamination, and are liable to tear gloves. Rings that are smooth may be kept on if the ring (and under the ring) is kept clean.
2. Select the garments to be worn and check the size and that the packaging is free from tears and faulty heat seals.
3. Cross over from the pre-entry area into the change zone. The demarcation between these two zones is a crossover bench. Personnel should stop at the mat and put their footwear three times to the mat, to make certain that it is clean and the minimum of contamination is tracked into the next zone.
4. A facemask (if required) and hood is put on, the hair must be tucked in and the studs, snaps or ties at the back of the hood are adjusted for comfort.
5. Personnel should sit on a bench in order to correctly put on the cleanroom footwear (over boots). While still sitting on the bench, the legs of the cleanroom garment and the footwear should be adjusted for comfort and security.
6. If required, protective goggles can now be put on (or when entering the cleanroom). These used not only for safety reasons but to prevent eyelashes and eyebrow hair falling onto the product.
7. The garments should be checked in a full-length mirror to see that they are worn correctly. Check that the hood is tucked in and there no gaps between it and the coverall. Check that no hair or hair net can be seen.

8. Low particle working gloves should now be put on, without the outside of them becoming contaminated. Make sure to grip the gloves at the edge of the cuff and not the top i.e. fingers.
9. Personnel may now proceed into the cleanroom.

3.13 Cleanroom rules

Please obey the following recommendations of proper cleanroom behaviour:

- Plan your work in the cleanroom well. Book tools and order chemicals in advance to avoid re-entering the cleanroom.
- Persons suffering from cold or eczema should not enter the cleanroom.
- A good personal hygiene is required in order to enter the cleanroom.
- Remove rings and wristwatches if they can damage the gloves or make openings in your garment.
- No beverages or food, including chewing gum, are allowed in the cleanroom.
- Do not bring paper protocols in to the cleanroom.
- Do not bring pens or pencils (which are not cleanroom compatible) into the cleanroom.
- All movements should be slow and well planned.
- Avoid touching any clean surfaces, such as loading stations.
- Avoid creating crowds as contamination then will be concentrated.
- Do not scratch yourself through the garment, as this will cause increased particle generation.
- Avoid talking near your component/product.
- Do not carry items close to your body. Carry them high and in front of you.
- All components/products stored in the cleanroom have to be covered, preferably stored in closed boxes. Please note that long-term storage is not allowed in the cleanroom.
- Garments that are wet or stained have substantially reduced filtering effect and have to be exchanged immediately.
- Use of headphones that are too large to be worn at the inside the hood is not allowed.

When leaving a cleanroom, personnel shall discard their disposable items, such as mask and gloves, but reuse their hood, coverall, over boots etc. on re-entry. If the garments are not to be re-used, they should be placed in a separate container for dispatch to the cleanroom laundry. The garments are normally sent to get washed once a month.

If the garments are to be used again on re-entry, they should be removed so that the outside of the garment is contaminated as little as possible. The cleanroom footwear should be removed, one at a time, at a crossover bench. The coverall should than be unzipped and removed using the hands within the garment to remove it over the shoulder and down the waist. In a sitting position, one leg is now removed. The empty arm and leg of the garment should be held so that they do not touch the floor. The other leg can now be removed. The facemask and hood can now be removed.

Garments so be used again should be stored in a personel box to prevent contamination.

3.14 Cleaning the cleanroom

Why does a cleanroom need to be cleaned? For one, the cleanroom clothing does not stop dispersion, and a person can disperse, when wearing cleanroom clothing, over 100 000 particles/min (particles ≥ 0.5µm). The tools also disperse millions of particles. Many of the larger particles will easily settle by gravity onto horizontal surfaces and smaller particles are thrown from the air stream onto surfaces. Dirt can also be brought into a cleanroom through foot-borne transfer. That's why cleanroom surfaces get dirty and must be cleaned otherwise the contamination is transmitted to the product. Cleanrooms can appear to be clean but can, in terms of cleanroom requirements be very dirty. The human eye will not see a particle smaller than 50µm.

The main force that holds particles to the cleanroom surfaces is the London-van der Waal´s force, this being an inter-molecular force. Electrostatic forces can also attract particles to a surface, and depends on the type of materials used within the cleanroom. The methods that are generally used for cleaning a cleanroom are: vacuuming (wet or dry), wet wiping (mopping or damp wiping) and picking-up with a tacky roller.

The methods used to clean cleanrooms will vary according to the standard of cleanliness of the room and its layout. It's therefore necessary to tailor the cleaning method to the cleanroom and the following information may assist this.

- If you can see any dirt in a cleanroom it is neither a clean room nor a cleanroom and must be cleaned.
- Cleaning a cleanroom can generate many particles. To minimize contamination generated by the cleaning process the air conditioning should be fully on and your products well protected.
- Cleaning must be done slower than would be the case in the home, which will minimize the dispersion and ensure more efficient cleaning.
- Use overlapping strokes of the wiper (or a mop) never rub. A cleanroom will always appear clean to the eye and it is not easy to ensure that every piece of the surface is cleaned, except by an overlapping pass method.
- If a damp wiper is used then it should be folded, and as the cleaning proceeds it should be refolded to give a clean surface. After all surfaces of the wiper are used it should be replaced.
- If you want to damp the wiper, use tap water diluted isopropanol (IPA) 5% - 10%. Avoid using De-ionized (DI) water since it is aggressive (corrosive).
- MiNaLab cleanroom hire specially trained cleaning staff.

4 Process tools

The cleanroom is equipped with a variety of advanced process tools. For each processing tool in the cleanroom, there is a responsible person. The responsible person performs maintenance work, repairs, calibrations and other technical work concerning the operation of that tool. In order for a cleanroom user to be allowed to independently run any particular processing tool, the tool responsible person must issue a “license”. The license is preceded by an education on the tool. The education is given by either the tool responsible person, or by an instructor appointed by him, and varies in scope and length with the complexity of the tool. During the driving license session you will be informed about all practical details on the tool handling.

You should never touch any tool that you have not been trained for. In addition to the risk of damaging the tool, you also run the risk of hurting yourself! It is also important to know how the specific tool is used by others. It’s important that you follow the tool instructions to assure the safety and quality.

Contamination of one piece of tool may easily spread and “cross-contaminate” a complete process line, and cause costly and time consuming service work. Special care regarding choice of materials is important when working with high temperature process steps, vacuum and plasma tools. Information about safety and cleaning of the tool is included in the user’s license training.

Please inform the responsible person immediately if you observe any damage or functionality problem of the equipment in use. It is up to each user to clean and reset the process tool after use.

- We recommend new users to follow an already experienced user during some sessions of processing on the actual tool, before contacting the tool responsible person for license issuing.
- The fact that you have a license to use the tool does not mean that you are free to introduce any strange or non-approved materials without contacting and getting approval from the person responsible for the tool.
- It is strictly forbidden to perform any service work, or experimental processing, without first consulting the tool responsible person.