Myfab User Manual

Myfab - The Swedish Research Infrastructure for Micro- and Nanofabrication, 2017

Publisher: MYFAB

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Print: ARKITEKTKOPIA AB, 2017

Paper: Multiart Silk 300g (cover), Multiart Silk 130g (inlay)

Copies: 2000 ex.

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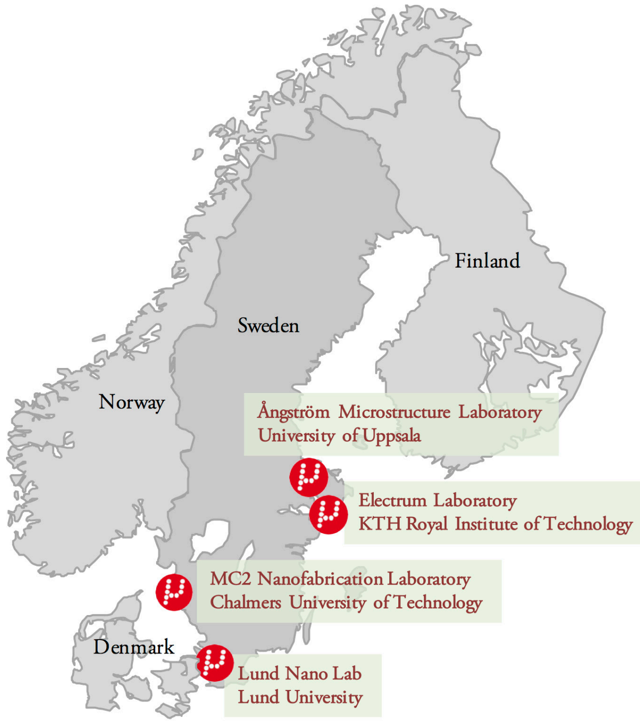
MYFAB WEBPAGE
http://myfab.se/



Myfab is the Swedish research infrastructure for micro/nanofabrication and characterisation. Its distributed infrastructure offers an wide platform for both academic and commercial interests in Sweden, Europe and around the world. You will have access to the best equipment available in Sweden, affording your research and technical development the possibilities they deserve.

The Myfab network includes:

- Myfab Göteborg: MC2 Nanofabrication Laboratory, at Chalmers University of Technology
- Myfab Lund: Lund Nano Lab, at Lund University.
- Myfab Stockholm: Electrum Laboratory, at KTH Royal Institute of Technology
- Myfab Uppsala: Ångström Microstructure Laboratory, at Uppsala University

Myfab is supported by the Swedish Research Council and by the four Myfab universities. Chalmers is host for Myfab. Each Myfab laboratory shall represent the whole infrastructure and provide guidance to the tools and expertise of all laboratories. All tools and related information is made available through the web-based Myfab LIMS system.

The main tasks of Myfab are:

- to provide the prequisite for world-leading research.
- to provide user-fee based open access to the infrastructure to users from academy, institute or industry.
- to provide adequate user training and user support,
- through Myfab's expert staff provide process advice, support and service.
- to identify and plan necessary investments, in particular in case of expensive investments and/or resource-intensive equipment national coordination is important.
- to provide seamless access to the whole distributed infrastructure on equal conditions.
- to bring funding and its application to a strategic level, beneficial to Swedish research.

As a user of one or more Myfab laboratories, you will be responsible for the safety, working conditions and success of others. This responsibility starts with this document (including relevant appendices), and you must be familiar and compliant with its contents at all times.

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TABLE OF CONTENT

INTRODUCTION

The Myfab laboratories offer 5,400 m2 of cleanroom area and over 700 tools for the fabrication and analysis of structures with dimensions in the micro/nanometer range. This environment requires that all users have sufficient knowledge on how to behave and act in our cleanrooms.

This manual may be considered a general instruction manual on the basic usage and safety aspects common to all the cleanroom laboratories in Myfab. It is not possible to give a complete framework for all possible situations, but with this manual we try to address and describe the most important aspects. The manual is equally applicable to all laboratory employees and users. It governs the safety as well as the rules which must be followed for admittance and usage of the cleanrooms and tools.

This manual primarily covers safety and working conditions, including potential dangers. However, it also deals with important information on using the cleanroom. The first chapter describes cleanroom basics (their technical design and maintenance) while Chapter 2 informs the new user about administrative guidelines for starting up work quickly and effectively. Users will interact regularly with the Myfab LIMS website, the most important features of which are described in Chapter 3. To maintain the cleanroom quality specifications, all users must know and at all-time follow the common rules of cleanroom practice, described in Chapter 4. As safety is of utmost concern, Chapter 5 covers the safety hazards in our cleanrooms and Chapter 6 directly address the importance of working with chemical safety, to prevent accidents. There is also essential information for the user to help minimise adverse effects in the event of an accident (Chapter 7).

In addition to the general part of the manual, the four Myfab laboratories have their own site-specific safety rules and instructions in the appendices. A user who have participated in the introduction course on one site can obtain access to another site by adding up with those local rules and information as described in their appendix.

Anyone who violates the lab usage or safety regulations, or in any way exposes him/herself or others to danger, will be denied access to the laboratory, by order of the executive management.

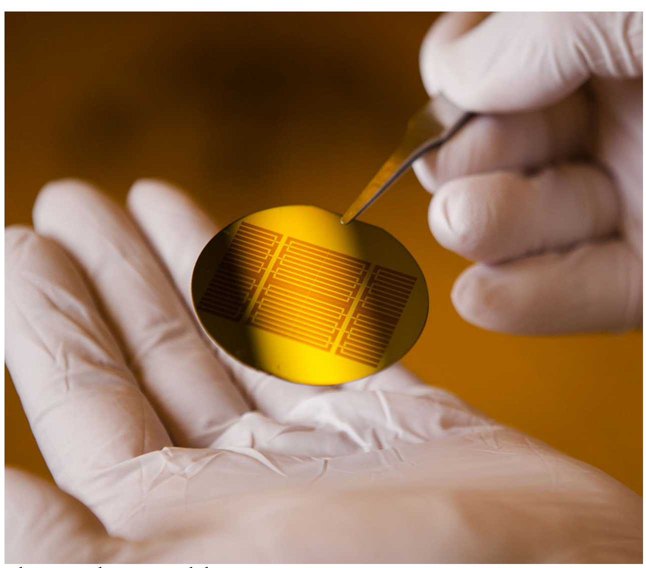


Photo: Nils Bergendal

1 CLEANROOM BASICS

1.1 Why do we need Cleanrooms?

Fabricating structures and devices with critical dimensions in the micrometer (10^{-6} m) to nanometer (10^{-9} m) range sets the bar very high for the fabrication environment. Thus, "contaminants" (such as particles or vibrations) harmful to certain process steps or the performance of end products, must be eliminated or significantly reduced. Important climate parameters (temperature, humidity, pressure) must be controlled to fine tolerances, if stable and reproducible process conditions are to be maintained.

Please note that the cleanroom, as described in this text, is intended for semiconductor processing and micro/nanofabrication. The considerations and technical solutions described here may not be the same as those for other scientific or commercial fields; ones where, say, sterility and microbe control may be primary concerns.

1.2 Cleanroom Environment

1.2.1 Particle Control

Small structures fabricated in the fields of microelectronics, photonics or microelectromechanical systems (MEMS), are all sensitive to submicron (and larger) particles. Particles adhering to wafers during specific process steps may reduce yield, affect device performance, or cause other kinds of damage. Any particle with a size comparable to, or larger than, the critical dimension of the device or structure is potentially bad for the yield. Figure 1 shows different types of particle contamination that can be generated by cleanroom users.

Figure 1: Sources of particles from cleanroom users.

Cleanrooms are designed and operated so that introduction, generation, and retention of particles is minimised. The addition of particles to a cleanroom environment is limited mainly by filtering intake air. Ventilation control and air filtering ultimately determine the lowest achievable particle concentrations in a cleanroom.

Particles are also introduced by people entering the cleanroom and the items they bring in. This effect can be reduced if users wear proper cleanroom garments (such as coveralls, hoods, masks, gloves and booties), as well as by entering through air locks and proper cleaning of all items introduced from outside. Humans can generate over 100,000 particles per minute at rest and over 10,000,000 particles per minute when walking quickly, see Table 1.

Activity	Particle generation
Sitting or standing still	100,000
Sitting, with arm, leg or head movements	1,000,000
Standing up	2,500,000
Walking quickly	10,000,000

Table 1: Particle generation (> 0.5 µm/minute) by cleanroom users; the main source of particles.

The garments act as particle filters between the lab user and the cleanroom, trapping and holding the particles emitted by the human body. A correct outfit will reduce the spreading of particles, but each individual is also responsible for further reduction of particle generation and spreading by practicing a correct behavior. Figure 2 shows how particle levels near the entrance of a cleanroom correlates with working hours and human activities.

Particle generation inside the cleanroom is suppressed by observing correct working procedures and eliminating particle-generating materials. Common materials such as paper, pencils, and fabrics made from natural fibres are normally excluded and replaced by cleanroom-compatible equivalents. Retention of particles is suppressed by diluting the cleanroom air through recirculation and filtration, as well as frequent cleaning.

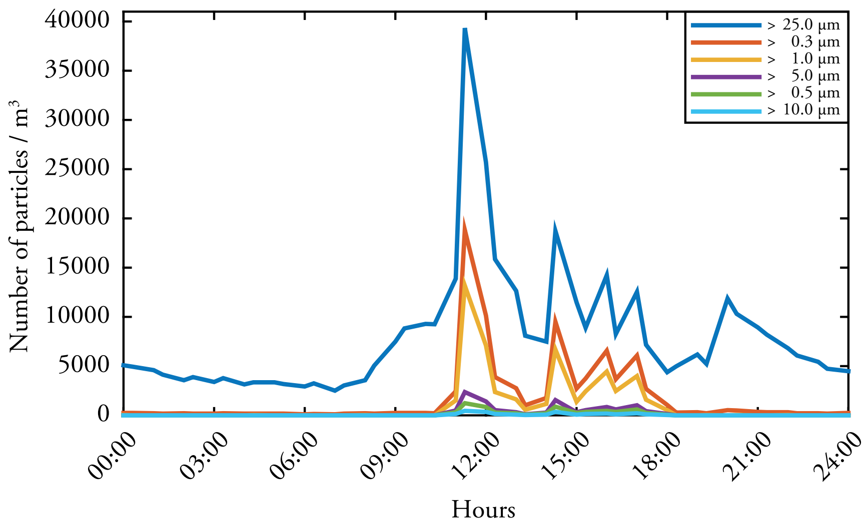


Figure 2: Particle-level diagram at different times of the day.

1.2.2 Cleanroom Classifications

Cleanrooms are classified according to the number and size of particles permitted per volume of air. The ISO standard is based on the decimal logarithm of the particle density, see Table 2. The older US FED 209 standard, which referred to the maximum number of particles in a cubic foot of air, is still in use. Depending on the specific activities and requirements, the classification varies within and between the Myfab cleanrooms.

Simplified ISO 14644-1 airborne particle cleanliness classes (maximum level of particles / m³)								
ISO class	1	2	3	4	5	6	7	8
Corresponding Fed Std	-	-	1	10	100	1,000	10,000	100,000
No. of particles ≥0.5 µm	-	4	35	352	3,520	35,200	352,000	3,520,000
No. of particles ≥0.1 µm	10	100	1,000	10,000	100,000	1,000,000	-	-

Table 2: Cleanroom classification table comparing the Federal Standard to the ISO Standard. There is one more ISO class (9) which is considered "office space".

1.2.3 Climate, Temperature and Humidity

Temperature control is important for several reasons. One is the strong influence of temperature on most chemical reaction rates. This becomes most evident in wet chemistry processes and the use of resists and developers in lithography. Another aspect is the thermal expansion of materials, which may affect critical distances; in stepper or e-beam lithography exposures, for example. These tools are therefore often equipped with special climate control chambers.

Accurate control of humidity and water absorption is fundamental to reproducible viscosity in spinning processes that use photo and e-beam resists. Some cleanroom climate control systems operate at relatively low humidity levels, which may call for extra precautions to prevent electrostatic discharge problems (see Section 1.2.5). Accurate humidity control, requiring active humidification, is frequently applied only to the most sensitive areas, such as photolithography, whilst the humidity in other areas is kept below an upper limit. It is also important to note that temperature and humidity should be kept at an appropriate level for the comfort of those working in a cleanroom.

1.2.4 Vibrations

Vibration is especially harmful in processes in which small structures are patterned or inspected; lithography exposure, electron microscopy, scanning probe microscopy and the like. Vibration is generally reduced by increasing the mass of the structure in combination with soft damping and vibrational isolation. Since local conditions vary, different vibration reduction solutions have been chosen for the various Myfab cleanrooms:

- In Gothenburg and Stockholm, cleanrooms are firmly attached to the bedrock with piles or mild steel pillars.
- In Lund, the cleanroom provides three independent anti-vibration platforms made from heavy metal plates resting on air-filled dampers.
- In Uppsala, the bedrock was too deep so the cleanroom was fixed to a "concrete block" floating in the clay.

1.2.5 Static Electricity and Electrostatic Discharge

Differences in electrical potential between two objects may lead to an electric current when the objects come into contact, or a spark when they come close to each other. Electrostatic discharge (ESD) may cause severe damage to electronic devices and precautions should be taken to avoid building up electrical potential differences. This is achieved by earthing material, tools and workers in the labs.

Floor, walls and ceilings should have a conductive surface and surfaces and tools should be earthed to the same electrical potential. Lab users should wear garments of fabric woven from conductive fibres. Work benches in sensitive areas may be covered with ESD mats, which similarly dissipate any charge gradually. The risk of ESD damage may be reduced by using ion generators, ionising the air to neutralise charge accumulated on insulating surfaces. Another option is to maintain relatively high humidity and let the moisture dissipate any electric charge.

1.3 Media and Support Systems

1.3.1 Ventilation

The cleanroom ventilation system is one of the most essential elements of particle reduction and climate control. In most cases, this consists of three parts: make-up air (outdoor air), air circulation, and exhaust ventilation (exhaust fumes from equipments and so on) as illustrated in Figure 3.

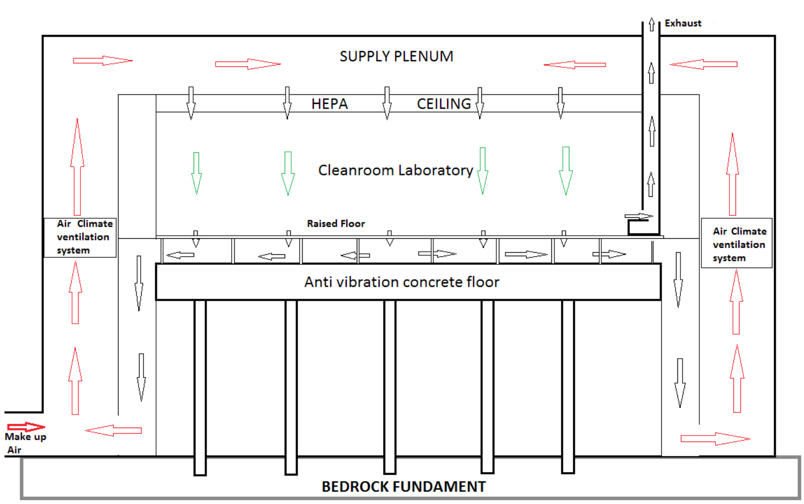


Figure 3: Typical cleanroom air circulation system.

Circulation fan units supply air to the cleanroom through high-efficiency particulate air (HEPA) filters, or ultra-low penetration air (ULPA) filters. Located in the cleanroom ceiling, these filters remove particles from the air drawn from the cleanroom after it has been pre filtered and temperature/humidity-regulated in the fan units. Moreover, the cleanroom is kept at an overpressure to prevent the inflow of non filtered air.

Exhaust ventilation is used to remove harmful fumes and excess heat. The main exhaust flow is through fume hoods, wet benches and tools which use toxic or flammable gases, often at high temperature. All Myfab labs have two or more separate exhaust systems; one system for corrosive applications, another for non-corrosive. Some tools may be connected to a toxic exhaust. In case of a power failure, the exhaust fans are normally powered by a backup diesel generator. Some labs have automated distribution of exhaust capacity as required via utilisation points. Others have static positions on their dampers.

Failure of an exhaust fan will turn the cleanroom into an unsafe work environment. Any sign of low capacity or failure on the exhaust must be reported to lab staff. Tools requiring an exhaust, and which are fitted with alarms or interlocks, must not be tampered with or operated if an exhaust failure is indicated. Without compensation, the exhaust ventilation would generate a net loss of air in the system. Make-up air is the addition of pre-conditioned and pre-filtered outside air added to the recycling flow. The amount of make-up-air should exceed the total exhaust flow to also compensate for the air leakage and maintain an overpressure inside the cleanroom. Depending on design, classification and so on, the overpressure may be in the range of 5-40 Pa.

1.3.2 Gas Distribution - House Gas and Special Gas

A gas that is delivered through a piping system from one gas bottle or tank installation to several utilisation points in the facility is a house gas. All Myfab laboratories distribute nitrogen (N_2), oxygen (O_2) and hydrogen (H_2) from supplies located outside of the main building in which the cleanroom is located.

- Nitrogen is used as a process gas, technical gas (in dry pumps, for shaft purging in spinners, etc.) and for blow guns, rinsers/dryers, etc. As purity requirements differ greatly between applications, parallel N_2 lines are common. The N_2 is supplied from a cryogenic tank with liquid nitrogen (LN2), fed through evaporators and distributed inside the cleanroom. Depending on purity requirements, in-line filters and other, more advanced, purifiers are installed for the most demanding process applications.
- Oxygen is used as a process gas in dry etchers, oxidation furnaces, etc. For any facility with moderate consumption, the O_2 is drawn from gas bottle.
- Hydrogen is a typical carrier gas in epitaxy processes and a process gas in wet oxidation processes. H_2 may be supplied from gas bottles or a H_2 factory.

Depending on the activities and needs in a specific cleanroom, other house gases may include:

- argon (dry etchers and sputtering tools, or in processes where nitrogen is not inert),
- silane (silicon precursor in deposition processes),
- hydrides such as arsine and phosphine (metalorganic vapor phase epitaxy and aerotaxy),
- helium (a technical gas and less commonly, a process gas).

A special gas is a tool-specific, or locally installed, process gas, usually with high standards of purity. Most special gases are either etchant gases, or precursor gases for elements in deposition processes.

In some cases, LN2 is needed for cooling. This is available to users in some Myfab laboratories (see local conditions). Only Dewar vessels may be used, due to the high evaporation rate from open containers. The LN2 suppliers remotely monitor the tank levels, delivering more LN2 as needed.

1.3.3 Deionised Water

Deionised water (DI water) is available at almost all process benches. It is also known as demineralised water, as its mineral ions (such as cations from sodium, calcium, iron and copper, plus anions such as chloride and bromide) have been removed. This causes the resistivity to increase and provides a convenient measure for the degree of deionisation; ultrapure deionised water has a theoretical maximum resistivity of 18.31 MΩcm. Cleanroom processes require large amounts of DI water (> 18 MΩcm), which is normally distributed from a tank in the media basement. In addition to processing, a lot of DI water is often used to humidify the air supplied to the cleanroom in the colder times of year.

The DI water is distributed to the various points of use from a loop through the cleanroom. By maintaining a continuous flow in this loop, conditions for bacteria growth and particle generation are suppressed. Particle levels in the loop are further reduced by a particle filter.

1.3.4 Electrical Power

Cleanroom operation requires a lot of electricity. Major power consumers are the ventilation system and some process tools, such as furnaces.

In case of a power failure, a diesel-powered emergency generator should ensure continued power supply to important systems, such as exhaust fans, sensors for toxic or hazardous materials and alarm systems. The emergency power cannot supply power for continued tool operation, but some instruments (such as e-beam lithography tools) may be connected to an uninterrupted power supply (UPS) for safe shut-down.

1.3.5 Compressed Dry Air and Vacuum

Compressed dry air is mainly used for pneumatic valves and safety functions at the process benches. Tool or house vacuum is used for spinners, chucks, vacuum tweezers and so on. Vacuum cleaning in the labs is by means of a central vacuuming system.

2 ADMINISTRATIVE GUIDELINES

2.1 Laboratory Access

2.1.1 Preparations and Application

The basic administrative conditions for academic user access may differ between Myfab labs, but for commercial users there must always be a formal contract between the user company and the selected Myfab site. For a new user or group starting on a new project, a common practice is to offer a preparatory meeting with lab staff to verify that the project is feasible and resolve any practical issues. Once the formal and practical preparations have been made at research group/corporate level, individual users may apply for access electronically on Myfab LIMS.

Applicants should normally have approval from their supervisor. It is also highly recommended (and in some cases required) that a "practical coach" is assigned to the user applicant. In well-established user groups, this should be someone internal, but other solutions may be needed for small or inexperienced groups. Information about the project, supervisor, contact data, and other details must be completed on the Myfab LIMS homepage before work commences in the cleanroom.

2.1.2 User Introduction

All new users must attend a set of introductory lectures, lab tours and on-site demonstrations so they know how to work safely and efficiently in the cleanrooms. This training is given by cleanroom staff and covers the basics of cleanroom practices, chemical safety, emergency systems, evacuation plans, cleanroom infrastructure and administrative tools such as Myfab LIMS. Alongside this manual, the user introduction should provide all the necessary basic knowledge for safe and thoughtful use of the labs.

Once the user introduction and all necessary authorisations are complete, the user's lab access keycard will be activated. The new user is then free to enter the cleanroom unescorted, but must not use any tools until the appropriate operator licences have been obtained according to the instructions in Section 2.2.1.

Figure 4: Cleanroom introduction course.

2.1.3 Access Suspension, Termination, and Reactivation

User access is normally valid until the user or supervisor informs the lab staff that it should cease. If a user subsequently requests reactivation of their access, the procedure generally depends on the duration of inactivity. Users remain registered in Myfab LIMS (so no need for a fresh application) and, if the break has been short, immediate reactivation is normally possible. However, after a longer hiatus (or inactivity) users must repeat all introductory training needed for lab and tool access.

Safety violations and bad practices can lead to suspension or even termination of user access. The lab management reserves the right to decide in these matters.

2.2 Tool Access

2.2.1 Operator Training and Operator License

Laboratory access is merely a permission to enter and be present in the cleanroom. To use the instruments, a user must receive training and obtain an operator licence for each tool needed in their project. Some restrictions may apply to specific user categories (such as undergraduate students), type of activity (such as wet chemistry), and working outside office hours.

Operator training is provided by those responsible for the tool in question or a designated instructor in the specific instrument. Names and contact data are available in Myfab LIMS and training is scheduled mutually by the instructor and user. Depending on the complexity of the tool, the duration of operator training may be anything from under an hour to several hours. Sometimes, longer training sessions are divided into several sessions covering demonstration, hands-on training and a final test. The person responsible for the tool is fully authorised to issue (or not) the requested licence, once the training is complete.

New users, particularly in large and established research groups, are encouraged to get acquainted with the most complex or advanced tools and processes before they apply for the corresponding licences. This can be done by repeatedly joining and watching an experienced group member operating these tools. This will by no means replace the formal training with the appropriate instructor, but the time required for this can be significantly reduced

You may apply for a licence on LIMS, or contact (e-mail, phone or directly) the person responsible for the tool and suggest a time for training. The following information should be provided:

- your background and previous experience;
- the name of your research group and supervisor;
- the planned use of the tool.

During your licensing session, you will be informed of all practical details relating to handling of the tool. You will then be registered to go on using this tool on your own.

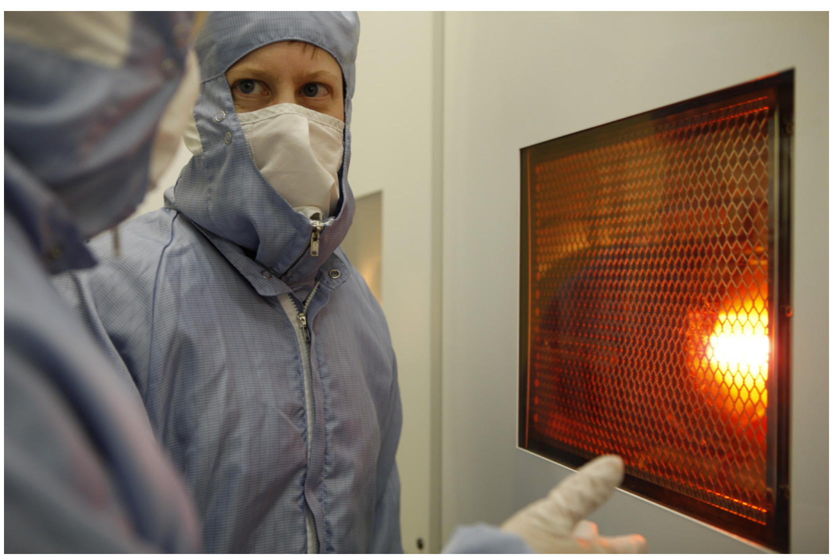


Figure 5: A new user receives operator training.

2.2.2 Tool Booking and Logging

An operator licence is permission to operate a specific tool. It also means the tool will be available for that user to book in Myfab LIMS. Booking is compulsory for all major equipment; failure to do so is a serious violation and may result in your suspension. To optimise availability and efficiency, booking restrictions may apply and allocation to individual users may be limited.

Some labs have compulsory logging of tool sessions. This will always apply when user-fee is based on logged usage time of the tool. However, we always encourage users to log their activities. Even a brief "OK" may prove valuable in a subsequent troubleshooting situation.

User, engaged in several projects, must carefully book the work performed in Myfab LIMS on the correct project. This is especially important for institute or industrial project (i.e. for all commercial projects), since the user fees differ. If samples or materials produced in Myfab is to be sold, the corresponding project must be an industrial project.

2.2.3 Tools at Other Myfab Laboratories

As an active user at one of the Myfab labs, you will have our entire infrastructure at your disposal. Brief information on available resources appears in the equipment list for each laboratory. Typical situations where there is a need to use resources at other labs might be that a requested tool is down for repair (backup), or that the required capability is not offered (complement) by the base laboratory. Whenever there is a need to use external resources, your first step should be to look into opportunities offered by other labs within our infrastructure. The equipment lists (accessible through Myfab LIMS) provides an initial overview, but a final decision often requires a direct, in-depth discussion with the person responsible for the required tool at the receiving lab (see equipment list). Resources outside your base node may be reached on-site or remotely.

On-site access is to be preferred for extensive or repeated use of a secondary site. In this case, the user should attend the site-specific user introduction in order to gain access to the lab. With the relevant operator training and operator licences, the users will be allowed to book the tools they need.

The remote access option is normally recommended for urgent (backup) or isolated activities, evaluation trials and standardised processing. In this case, the work is done by a staff member at the secondary site and the user does not need to be active at this lab. The user may simply choose to specify the process and send the material to be processed. Alternatively, the user may bring the material in person, if presence on-site is deemed important. In this case, however, the user may only enter the secondary site as a visitor, and must be escorted at all times. A few processes have been standardised to a level which makes remote access very straightforward; optical mask generation and ion implantation, for example.

2.3 Language

English is the language used in all Myfab laboratories. It is therefore an absolute requirement that all users must have a good knowledge of this language and proven ability to communicate in speech and writing. Any failure to do so may compromise lab safety. Management will deny lab access to applicants who lack adequate communication skills.

2.4 Acknowledgements to Myfab

All Myfab users benefit from having access to state-of-the art laboratories, and we all need to communicate and explain to a wide audience the importance of support to Myfab, in order to maintain and develop quality and service of the national research infrastructure.

The Swedish Research Council supports Myfab through an operations grant, which also subsidizes the academic user fees.

Therefore we request all Myfab users to give acknowledgement to Myfab in their publications of all kinds: articles, letters, conference presentations, poster, thesis etc.

Example - a user which has used all four laboratories:
"Myfab is acknowledged for support and for access to the nanofabrication laboratories at Chalmers, KTH, Lund University and Uppsala University".

3 MYFAB ELECTRONIC INFRASTRUCTURE

There are two websites that support all users within Myfab by offering information and access to equipment:

- Myfab webpage: www.myfab.se
- Myfab LIMS
  - Electrum Laboratory: http://lims.electrumlab.se/default.aspx
  - Lund Nano Lab: http://booking.ftf.lth.se/default.aspx
  - Nanofabrication Laboratory: http://labbokning.mc2.chalmers.se/Default.aspx
  - Ångström Microstructure Laboratory: http://lims.msl.angstrom.uu.se/default.aspx

Only registered users are allowed to see and use all available information. Registration is via the Myfab LIMS homepage and access is valid for both websites.

3.1 Myfab Website

The Myfab website is the main web portal for new users to access micro/nanotechnology at any of the four largest cleanrooms in Sweden. Those interested may find information on such topics as: process help, training, education, process examples, contact persons and much more. The various ways of working with Myfab are described. These might involve process service or research collaboration, as well as other ways in which Myfab can offer a new user interesting and attractive conditions to "realise their nano-visions". It is easy to check the various platforms in the different infrastructures and see which site might be the best partner for technological support. All equipment at the different sites is easy to find and inspect and there are examples of completed devices and research activities, plus some ongoing activities.

3.2 Myfab LIMS

Tools may be booked through Myfab LIMS, a Laboratory Information Management System developed by Myfab. Myfab LIMS is a platform for the four laboratories within Myfab, but is also used at several other cleanroom facilities in Europe.

You will require a username and password to access Myfab LIMS. These are normally given once you have completed the introduction course. You may also apply for access to Myfab LIMS and a specific laboratory, by browsing to the Myfab LIMS website and entering the required information. Each user must be associated with at least one project which is financing activity in the lab. Each user is placed on an appropriate user level (user, project leader, project manager or administrator).

The main purpose of Myfab LIMS is to help you gain access to lab resources (tool licences, tool bookings) and information about tool management (instructions, tool status, recipes, process control). For this functionality, Myfab LIMS needs to store information about users and tools in its database. For more general booking rules, see section 4.4. Myfab LIMS is also used to administer laboratories (managing of users, tools, licences, runs, finance, invoicing, statistics, processes and so on).

A process, documentation, and run-sheet module is under development and will enable users to document and keep control of their processes and processing. This option will have functions such as process storing parameters and construction of process sheets.

3.2.1 Menus in Myfab LIMS

After logging in on Myfab LIMS, you will see your home screen. A brief list of the tools allocated to the user will be shown in the left-hand column, as well as local information. The menus My Profile, Bookings Calendar and Siblings are shown in the top right-hand corner.

- My Profile: This is where you manage your account info, find an iCal-link for your private calendar, find your project numbers and much more.
- Bookings Calendar: In Bookings Calendar, you can book and see your licenced tools, plus all other bookings for all equipment in the cleanroom, see figure 6. The various tools appear in the top left-hand scroll menu.

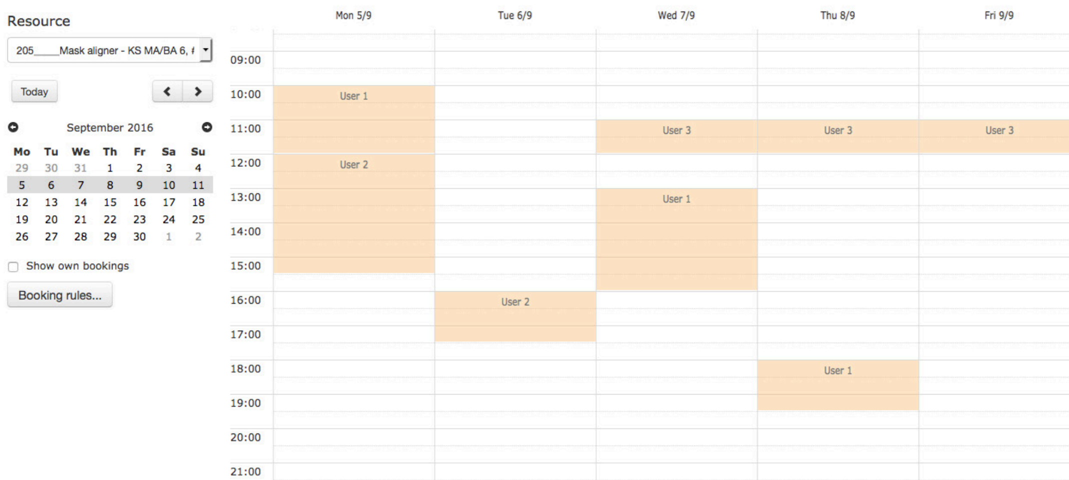


Figure 6: Booking window in the Myfab LIMS system.

- Siblings: By using the Siblings command to change the laboratory you are viewing, you can also see tool and user information for the other Myfab laboratories.

In the top left-hand corner are the three menus for Tools, User, and Info:

- Tools menu: The Tools menu provides all the information about tools, such as booking rules, tool status, logs, personal and tool schedule. Under My Licenced Tools, you can access the bookings calendar and reserve time with your licenced tools, and also see who is tool responsible. There is also technical information and operating procedures. Under All Tools, you can apply for new licences for tools which you have not yet a licence for, see figure 7.
- User menu: In User Menu, the user personal data is stored under My Profile, and should be kept updated with e.g. e-mail address, telephone number, photo etc. by the user. You can also find contact information and send messages to other users of the laboratories, and view statistics of your tool bookings.
- Info menu: This allows you to find important information, such as a list of chemicals used in the lab.

There are additional items for those responsible for a tool, and/or projects.

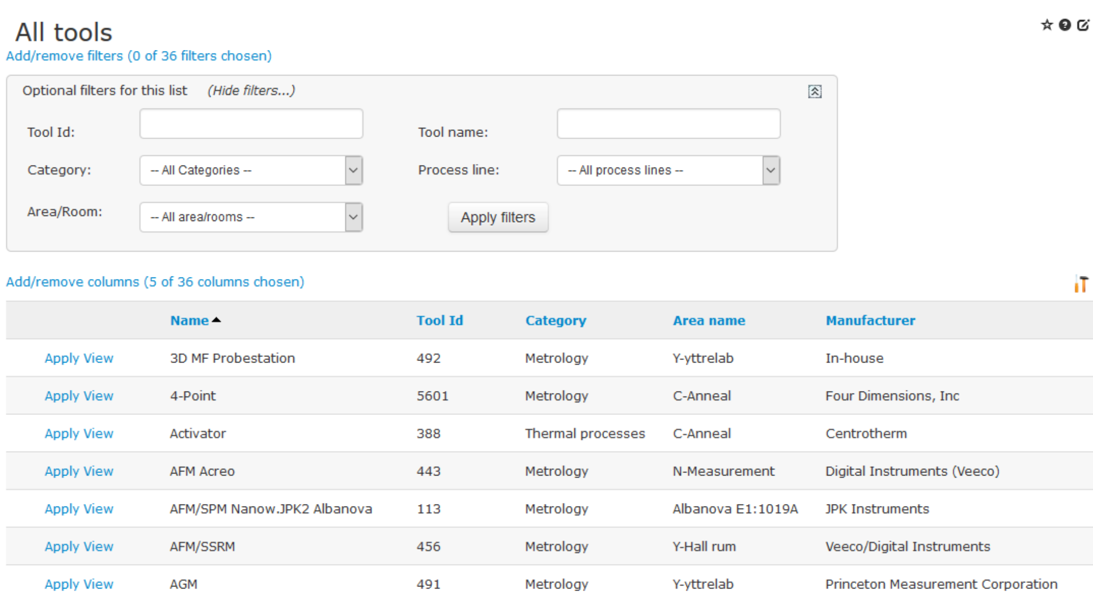


Figure 7: Tool information window.

4 RULES AND WORK INSTRUCTIONS

4.1 Cleanroom Entry and Exit

A cleanroom session should be properly planned and prepared. To avoid unnecessary exits and re-entries, be sure you have booked the right tools and ordered the chemicals you need. Before leaving your office to go to the lab, you should remove unnecessary sweaters and the like so that you will be comfortable under your coveralls in the controlled environment of the cleanroom. Do not enter the cleanroom if you have a heavy cold or eczema.

To reduce particle contamination, facial cosmetics should be minimised and smoking should be avoided immediately prior to entering the cleanroom. Exposed watches and rings should be removed if they have sharp edges or are not sufficiently clean.

4.1.1 Dressing and Undressing

The best method of changing into cleanroom garments is one that minimises contamination to the outside of those garments. The example below assumes that a facemask, hood, and booties are being used and requires the garments to be put on from the top down. Some of the suggested procedures may be unnecessary in lower categories of cleanrooms. Equally, further procedures may be added for cleanrooms used to make highly contaminant-sensitive products.

- The entrance to the changing zone may be a line on the floor, a door, a crossover bench, or any combination of these. If a bench is used, footwear should be dealt with as the bench is crossed. Failing that, a cleanroom mat or flooring should reduce the introduction of contamination to the next zone. Be sure to take several steps on the mat.
- Put on a hairnet if required or desired.
- If a hand-washing system is installed, you should preferably wash your hands before handling the cleanroom garments. Other parts of the body, such as hair and face, should not be touched once your hands have been washed.
- If you need a new set of garments, select the right size and ensure that the packaging is free from tears and faulty heat seals.
- Put on a facemask (if required) and hood. Your hair must be tucked in and the studs, snaps or ties at the back of the hood adjusted for comfort.
- Remove your coveralls from their packaging. Unfold and put them on without touching the floor. One way of doing so is to grab both wrists and both ankles of the garment and put in first one leg then the other.

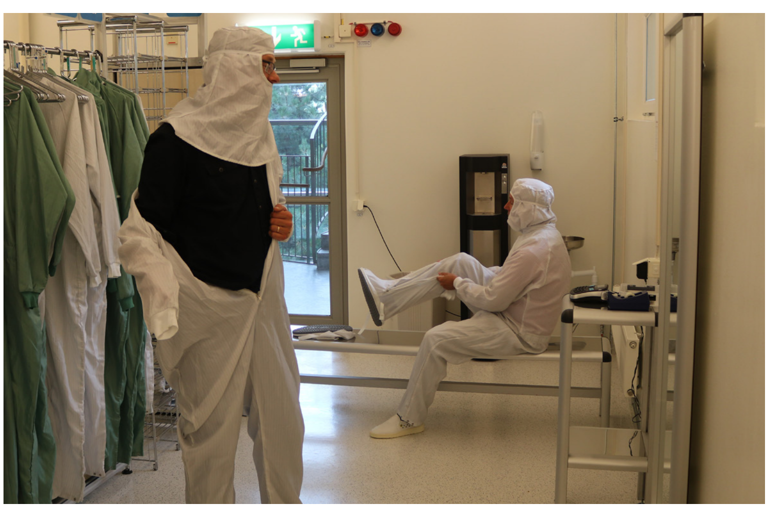


Figure 8: People in the gowning area. It is important to put on the clothing in a specific, proper order.

- Sit on a bench to put on the cleanroom footwear; the legs of the coveralls and the footwear should be adjusted for comfort and safety.
- Check your cleanroom garments in a full-length mirror to ensure they have been put on correctly. Check that the hood is tucked in and that there are no gaps between hood and coveralls. Check that no hair or hairnet is visible. 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 the correct size. If required, protective goggles should be put on (or possibly when entering the cleanroom). These are not only for safety reasons; they also prevent eyelashes and eyebrow hairs from falling out.
- Put on cleanroom gloves, without contaminating their outside. Be sure to grip the gloves at the edge of the cuff and not at the top (the fingers). Gloves should cover your sleeves.

When leaving the cleanroom, you should discard any disposable items such as gloves and hairnet. Hood, coveralls, booties and so on should normally be stored for further usage. If the garments are not to be re-used, they should be placed in a separate container for dispatch to the cleanroom laundry. Cleanroom garments are normally washed once a week.

If the garments are to be reused, they should be removed so that the outside of the garment is contaminated as little as possible. Coveralls should be unzipped and removed using your hands inside the garment to bring it over your shoulders and down to the waist. After removing one leg, the empty leg and arms of the garment should be held to prevent them touching the floor while you remove your other leg. The hood and facemask are removed, and garments to be reused should be stored on hangers to prevent contamination.

Note that cleanroom garments are expensive; it is important to be careful and avoid contaminating them.

4.1.2 Bringing Materials into the Cleanroom

Samples to be processed or characterised, cleanroom notebooks and other personal belongings are frequently brought into cleanrooms. All such items must be cleaned prior to lab entry. Wipes and cleaning solution for this are provided at the lab entrance. Each user who brings material to be processed or characterised using any of the lab tools must ensure that its composition, any previous processing and its cleanliness conform to the lab and tool regulations.

Common materials such as paper, pencils, and fabrics made from natural fibres are normally banned. Cleanroom-compatible equivalents are available. Chemicals and technical tools must be approved by the lab staff before they may be taken into the cleanroom.

If a user is at all uncertain, lab staff should be consulted.

4.2 General Cleanroom Rules

As a user in a Myfab cleanroom, you are responsible for maintaining a good environment in cooperation with hundreds of other users, working in various fields and with different requirements. To make this possible, certain basic rules and guidelines must be observed by all users at all times. For example:

- No beverage or food, including snuff and chewing gum, are allowed in the cleanroom.
- Avoid rapid movements.
- Avoid touching any clean surfaces, such as loading stations.
- Avoid crowding in one part of the room, as this will increase local contamination.
- Do not scratch yourself through your garment, as this will increase particle generation.
- Avoid talking when you are close to sensitive objects (such as samples or tool components).
- Do not carry sensitive objects close to your body. Keep them elevated and in front of you.
- All components or products stored in the cleanroom must be covered, preferably in closed containers. Please note that long-term storage is not allowed in the cleanroom.
- Wet or soiled garments have substantially reduced filtering effect and must be changed immediately.

4.3 General Work Procedures

Any user with access to the cleanroom is free to enter all common lab areas and book and operate all instruments for which he/she has a valid operator licence. Service areas and lab areas dedicated to specific user groups should not be entered, unless there is a specific need and explicit permission has been given.

Users or user groups with a temporary need to bring experimental setups into the cleanroom must have prior approval from the lab staff and be allocated a specific location.

A vital condition for maintaining a good cleanroom environment, is that all surfaces (floors, benches, equipment and so forth) must be kept clear of all nonessential material. All objects must be stored in suitable, dedicated locations when not being used. Any individual setup which is left unattended and not associated with an ongoing booking in Myfab LIMS, must be approved by the lab staff. A note should also be posted, informing other users regarding contact data and start and stop times. Any items left in common areas which do not comply with this instruction may be removed by lab staff, with no compensation for loss or damage.

4.4 Tool Operation

All tools available in the cleanroom and throughout Myfab are listed and described in Myfab LIMS. Each tool has a responsible person who maintains it and supports its users. To become a user of a particular tool, you should contact its responsible person (see LIMS for contact data) regarding operator training and licensing. As soon as an operator licence has been issued, you are free to book and run that tool. However, you are still obliged to consult lab staff if you are not fully confident in operating the instrument.

Unauthorised tool usage may damage an instrument as well as posing a safety hazard. It is also important to know the specific uses of a particular tool and any restrictions that may apply. This will avoid such thing as contamination issues (especially important in high temperature, vacuum and plasma processing). The operator training covers all these issues, including cleaning and other procedures after use and should prepare the licenced user to operate the equipment according to high standards of safety and quality. Nevertheless, please note that the operator licence is only a permit to use the tool according to established procedures and stated instructions. Short-term users may not qualify for training and licensing on some of the more complex and demanding tools.

The following rules apply to equipment use in the Myfab laboratories:

- A lab user is only allowed to operate tools for which he or she has been trained and registered as a licenced user in Myfab LIMS.
- If a tool has compulsory booking requirements, reservations must encompass the entire user session. This should include time for preparatory setup and subsequent cleaning or resetting to idle state.
- If booking is optional, a user who has not made a reservation must leave the instrument if requested by another user with a valid booking.
- As a general rule, a booking is invalidated if no activity has started within 30 minutes from the scheduled start time. If no attempt to cancel the reservation is made, it will be charged. Another user may then use the tool under certain conditions specified by the local site.
- Any tool operation that is not in strict agreement with written and oral instructions communicated to the user must have prior approval from relevant lab staff.
- Any request to develop new processes, introduce new material combinations, modify hardware or change tool settings (if not explicitly allowed) must be approved by the relevant responsible person. This is also required for longer process runs or high consumption of gases and/or chemicals.
- Simple troubleshooting, as described in the tool instructions, may be carried out by a licenced tool user. Other problems, or when a repair is needed, must be reported immediately to the relevant responsible person.
- If required, tool sessions should be logged in Myfab LIMS, or in a separate logbook, with relevant information about what was done and how the tool or process performed.
- After use, the tool should be left clean and in its idle state, ready for the next user.
- Users are responsible for familiarising themselves with all updated information and revised instructions available through Myfab LIMS. It is particularly important to search actively for updated information if you have not used a tool for a long time (several months).

4.5 Processes and Process Integration

Most of the tools provided by Myfab are intended for material processing. In an extensive process sequence, one tool session is often equivalent to one process step. Important process tools within Myfab should have well-defined and documented standard processes. These should be used for equipment qualification and be designed to meet the needs of frequent users. However, a specific project may require development of a new process, or modification of an existing one. This is normally done by the user after approval from the relevant responsible person.

4.6 User Specific Lab Area, Equipment and Material

Depending on available capacity, some Myfab laboratories make surplus cleanroom space available for user groups to rent. Access to these areas may be restricted for regular users. As an integral part of the cleanroom, however, all regulations intended to maintain a safe and high-quality environment also apply to these areas.

4.7 Working Outside Office Hours

Working alone in the cleanroom is strictly prohibited. This means that all lab activities outside normal working hours require the presence of at least one additional approved user, known as a "lab buddy". Users who intend to work odd hours should notify the lab staff of their attending lab buddy. When the activity in the cleanroom is limited to only two users, each person has a mutual responsibility for the other and must coordinate their work in, and exit from, the lab.

Your lab buddy must be an experienced and approved user. Lab buddies must be present in the lab so that they may assist you in the event of an accident. For this system to work effectively, lab buddies must maintain close contact with each other (NOT by mobile telephone). Your lab buddy should be nearby, especially if you are about to use chemicals in the wet benches outside normal working hours. Additional procedures and restrictions may be applicable to special tools. You will be informed of this when you get your tool licence training. Prior lab experience is a requirement of those who want to work outside office hours. We strongly recommend that you work during normal office hours.

Please be aware that local rules may apply at individual Myfab labs.

4.8 Visitors

Visitors may be taken to the visitor's corridor, which offers a good view of the cleanroom area. Lab users may offer this type of tour for small groups without prior approval from the lab management. However, as a guide, you are always responsible for the safety and conduct of your visiting group. Visitors may only enter the cleanroom as an exception and then only after prior approval by the lab management. Prior to the visit, these guests must be given a brief introduction to cleanroom practices. All photography requires the approval of the lab management.

5 WORK ENVIRONMENT AND SAFETY

5.1 Safety policy

The Myfab laboratory environment is challenging and interdisciplinary from a technical point of view. Many tools and processes use hazardous chemicals or gases, operate at high temperatures or voltages and so on; conditions that pose a risk to the health and wellbeing of those operating the equipment. Myfab recognises that expertise in specific processing must be combined with necessary understanding of relevant risks in the working environment. The expertise of those working in the Myfab laboratories is the basis of a safe working environment.

Myfab laboratories must comply with all Swedish laws on the working environment and keep track of any new or amended regulations notified by the Swedish Work Environment Authority. A guiding principle to be observed in all Myfab laboratories is that it should not be possible for a single mistake or error to cause an accident. This simple but effective statement has been applied in drafting specific rules for various lab situations:

- Tools used to handle toxic substances at elevated temperatures, or explosives or flammable gases must be constantly supervised on-site.
- New and potentially dangerous processes must be approved by the laboratory management.
- Repair or modifications of tools must be performed by authorised personnel.
- Potentially hazardous work is recomended to be conducted during office hours.

If, despite preventive measures, an incident, or accident occurs then this must be reported to the laboratory staff for investigation. This is to prevent similar occurrences from taking place in future. An incident or accident report should be written according to the rules of the relevant laboratory. Moreover, to avoid potential accidents, all our users are encouraged to inform lab staff whenever any dangerous practices or situations are observed. Myfab will never allow procedures or processes if these entail scenarios which, in the event of a mistake or accident, might have severe consequences.

5.2 Risk assessment in the work environment

Work environment risks are based on the probability of unintentional and undesirable events, relative to subjects or activities in the cleanroom environment which could negatively impact health.

A negative outcome of an event in an economic context is simply net loss of money, but impacts on health or environment are more complex to measure or rank by severity. It is generally accepted that injuries, which cause severe pain for a long period, have permanent impact on the quality of life, or prove fatal, are severe consequences. Preventive actions must be taken to reduce either the probability of such an accident (change of procedure, modification of equipment and the like), or its consequences (for example using protective gear, detecting harmful chemicals).

The wet bench might serve as an example: These offer good protection against airborne chemicals, but no protection against splashes. A splash may be produced by simple handling mistakes, such as dropping an item into a container. The probability of such an event is not negligible, but the consequences can easily be reduced by using proper face-protection.

Swedish law requires a risk assessment for any work involving hazardous chemicals. The practical procedure for conducting a risk assessment is different in the various labs, but they all include a study of the Safety Data Sheet (SDS) of chemicals and/or gases to be used, and filling out the risk assessment form in KLARA.

The risk assessment must be approved before any actual work with the chemical is started. Any modification of a chemical experiment (such as changing a temperature or concentration) must be reflected in an updated risk assessment.

Concerning long-term effects of inhalation or skin exposure, the threshold limit value (TLV) for airborne chemical substances is defined as a maximum concentration in parts per million (ppm). Three types of TLVs for chemical substances are defined:

- Threshold Limit Value - Time Weighted Average (TLV-TWA): Average exposure based on an 8h/day. 40h/week work schedule.
- Threshold Limit Value - Short Term Exposure Limit (TLV-STEL): Spot exposure for a duration of 15 minutes. that cannot be repeated more than four times per day.
- Threshold Limit Value - Ceiling (TLV-C): Absolute exposure limit that should not be exceeded at any time.

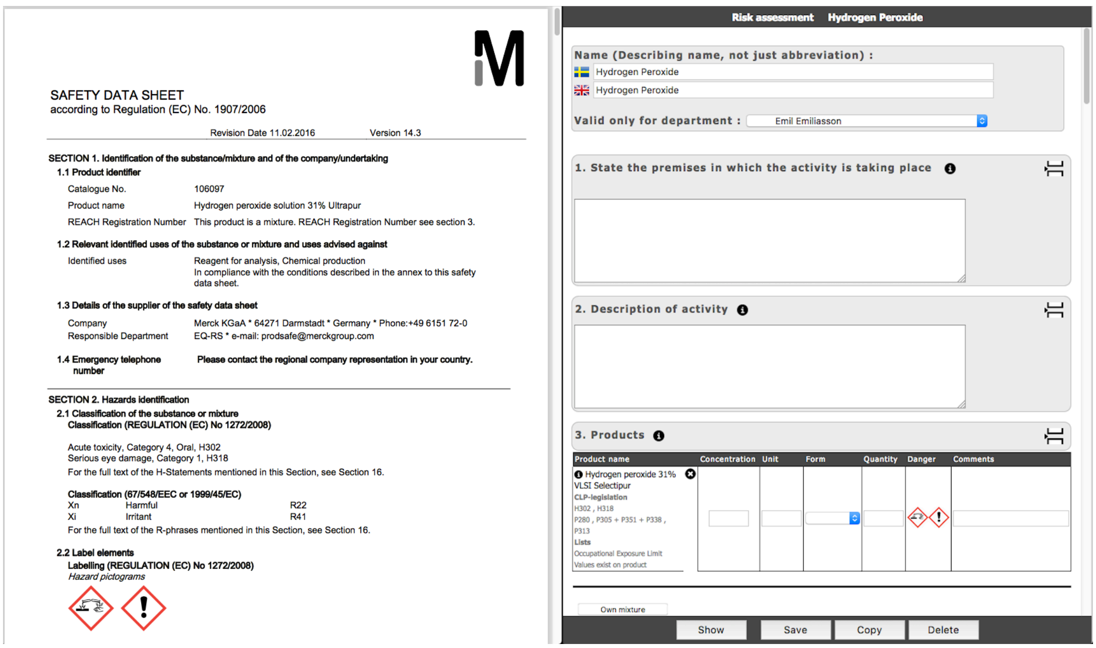


Figure 9: Reading the SDS and conducting a risk assessment is important in all types of chemical work.

5.3 Work environment risks

5.3.1 Chemicals

A major working environment risk is exposure to hazardous chemicals. Chemicals are therefore deemed the most critical hazard to users in a cleanroom facility. Chemicals can be of different types, corrosive, toxic, flammable etc. and in different states, solid, liquid or gaseous. The most common chemicals in a cleanroom are liquids and gases. A more extensive explanation of liquid chemicals, waste management and safety can be found in Chapter 6.

5.3.2 Harmful solids

Some of the metals and semiconductors used in cleanroom processes are harmful and should be treated with great caution. Always read the SDS before use! Harmful solids include:

- Nickel (Ni): shows limited evidence of carcinogenic effects but may cause sensitisation by skin contact.
- Chrome (Cr): highly toxic in contact with skin and if swallowed. Also harmful if inhaled.
- Indium Phosphide (InP), Gallium Arsenide (GaAs), and other compounds and elemental semiconductors: these are toxic elements and require dedicated processing and waste handling.

Important rules when working with harmful solids and contaminated tool parts:

- Always wear protective gloves and visor/goggles. Avoid direct contact with skin.
- Take precautions against dispersal and accumulation of particles. Work in a fume hood or use a respirator.
- Solid residues and/or contaminated tool parts that are being replaced (boats, shields and so on) should be treated as hazardous waste.

5.3.3 Process gases

Various dangerous gases are used in the cleanroom. Toxic, corrosive and flammable gases are used in various applications. There are two main risks arising from hazardous process gases:

- Leakage that may expose users to a toxic or corrosive gas.
- Fire induced by leakage or technical fault in tools that use flammable gases.

Cabinets, distribution boxes, and point-of-use boxes that contain toxic, flammable, or corrosive gases are connected to exhaust ventilation. One or more gas detectors are also installed in each unit. Any leaks detected will be displayed on a monitor and, if necessary, trigger evacuation alarms. For some tools, gas distribution (target gas and concentration-dependent) may also be interlocked.

5.3.4 Electrical hazard

Our cleanrooms are fitted with a vast array of electric tools and power consumption per square meter of cleanroom is significant. Accidents involving electric shock may result in anything from discomfort to instant death. Current strength and path through the body determine the outcome of an electric chock. An electric current passing from hand to hand or hand to foot will most likely prove fatal if in the range of 50-500 mA. Higher currents do not normally kill instantly, but will burn internal and external organs.

5.3.5 Fire hazard

Within a given area, the combination of chemical use, flammable process gases, high density of electric tools and tools operating at higher temperatures all increase the risk of fire.

A fire is a very serious matter and fire prevention must always be a priority. As there may be toxic gases and chemicals present, a fire can have serious consequences for a cleanroom and its occupants as well as the surrounding environment. Our facilities are equipped with automatic fire alarms, smoke detectors and sprinkler systems.

5.3.6 Laser Radiation

Some tools utilise laser radiation. Laser radiation causes instantaneous damage if the eyes are exposed to it and the incoming radiation is sufficiently intense. This means that eyes may be damaged by direct reflection of low-intensity laser beams or diffuse reflection of high-power ones. The radiation is not necessarily in the visible spectra so always be sure to protect your eyes with laser safety glasses or a face shield. As well as the risk to eyes, short and long-term effects like burns or cancer may result from (prolonged) skin exposure.

Lasers are usually labelled with a safety class number, which indicates the danger level:

- Class I/1: Inherently safe, usually because the beam is enclosed.
- Class II/2: Safe during normal use; the eyes' blink reflex will prevent damage. Usually up to 1 mW power.
- Class IIIa/3R: Usually up to 5 mW. There is a small risk of eye damage within the blink reflex time. Staring into the beam for a few seconds is likely to cause (minor) eye damage.
- Class IIIb/3B: Can cause immediate severe eye damage upon exposure. Usually lasers of up to 500 mW.
- Class IV/4: Can burn skin and, in some cases, even scattered light can cause eye and/or skin damage. Many industrial and scientific lasers are in this class.

The powers above are for visible-light, continuous-wave lasers. Other power limits apply for pulsed lasers and invisible wavelengths. If possible, the path of the beam should be covered. People working with class 3B and class 4 lasers must protect their eyes with safety goggles designed to absorb light of a particular wavelength.

Rooms with laser applications have yellow/orange warning lights above their entrance door. When the lights are on, the laser is in use. Do not enter!

5.3.7 UV Radiation

UV light sources are common in areas where lithography processes are carried out. One of the problems of working with UV radiation is that the symptoms of overexposure are not immediately felt. Those exposed to UV radiation might not realise the hazard until after the damage has been done. People working with UV light must therefore protect their eyes with safety goggles designed to absorb light of a particular wavelength. There are 3 classes of UV light:

- UV-A (near UV): Lowest damage potential, with wavelengths in the 320-400 nm range. Damage from high exposure may be cataracts.
- UV-B (mid UV): Mid to high damage potential, with wavelengths in the 290-320 nm range. Damage from high exposure is skin and eye damage and an increased risk of cancer.
- UV-C (far UV): Highest damage potential, with wavelengths in the range 190-290 nm. Damage from high exposure is skin and eye damage.

5.3.8 X-ray Radiation

X-ray is a high-energy electromagnetic radiation with wavelengths of 10 to 0.01 nm and energies in the 120 eV to 120 keV range. They are shorter in wavelength than UV rays and easily penetrate many materials.

This type of radiation is emitted from diffractometer tools and ion implanters, among other things. These tools are normally shielded, but manipulation of the hardware or an unsafe operation may reduce the efficiency of safety measures and expose personnel to X-ray radiation. The physical consequences of exposure can be mutagenic or carcinogenic.

5.3.9 Cryogens

Liquid nitrogen (LN2), liquid helium (LHe) and solid carbon dioxide (dry ice) are examples of cryogens. Cryogenic chemicals present a safety hazard due to their extreme cold. Users should be familiar with this hazard and use appropriate cryogenic gloves and designated personal protective equipment against the freezing effects. Under no circumstances should a user get cryogenic liquids on their bare skin; severe injury may result.

All cryogens listed above can displace the oxygen in the air as they evaporate. Therefore, you must only use them in well-ventilated rooms, after analysing the amount of air that might be displaced by use of the proposed cryogen.

The filling process must be watched continuously to avoid overfilling. There is always a risk of suffocation when handling large amounts of LN2 indoors. The evaporated nitrogen may replace much of the oxygen if the room is small or the ventilation insufficient. Major spillages must always be avoided, as one litre of LN2 will turn into over 700 litres of gas when evaporated. Major spillages will also cause severe damage to the floor. Liquid nitrogen is extremely cold, 77K (-196 °C) and may cause severe injury by freezing skin and underlying tissue. It is especially dangerous if LN2 is spilled into a confined space, such as the inside of your shoes or gloves, or splashed into your eyes.

5.3.10 Nanomaterials

Nanomaterials are materials smaller than 100 nm in at least one dimension, including nanoparticles, nanotubes, and nanowires. Despite there being no consensus on the minimum or maximum size of nanomaterials (with some authors restricting their size to as low as 1 to ~30 nm), a logical definition would put the nanoscale between microscale (100 nm) and atomic/molecular scale (about 0.2 nm).

The hazards associated with handling of nanomaterials are still under debate. We require our users to keep updated on the potential risks of their materials and take appropriate precautions during handling.

6 CHEMICALS

6.1 Chemical Hazards

Fundamental to the safe use of a given chemical is a knowledge of its properties. This information is available from experienced colleagues, laboratory staff, the person responsible for the tool where the chemical is used and, in particular, from the supplier's SDS. Only chemicals that are approved by the laboratory management may be used in the cleanroom.

If a new chemical is needed, a request together with the supplier's SDS and details of how this chemical will be used safely, should be presented to the appropriate lab staff.

If the chemical has dangerous properties and the laboratory management concludes that the risks cannot be reduced by using suitable tools, procedures and protective gear, then processing involving that chemical may be prohibited. Similarly, Myfab will not allow use of dangerous or environmentally unfriendly chemicals if there are better alternatives. All our laboratories are working to find less dangerous alternatives for the chemicals used.

Hazardous properties for chemicals should be marked on bottles using a special set of pictograms. The pictogram symbols have been revised in recent years, so different pictograms may apply. The current chemical symbols are shown in Figure 10.

Figure 10: Pictograms for chemical hazards (as of 2014).

The cleanroom supplies a set of standard chemicals as well as non-standard ones. All non-standard chemicals are user or project specific, meaning that the user or project pays for and has the exclusive right to use the chemical. All standard chemicals are of Very Large Scale Integration (VLSI) quality unless the only available grades are not. Below is a description of typical wet chemicals used in the Myfab cleanrooms.

6.1.1 Acids

Acids are corrosive substances and will damage human tissue. The eyes are particularly vulnerable to exposure. Acids may only be used in dedicated wet benches and fume hoods. Acids can cause chemical burns to the skin if exposed. They may also be toxic, cause rapid heating through exothermic reactions (and thus cause thermal burns to the body) and they may even trigger explosions. Some examples include:

- Hydrofluoric acid (HF).
- Hydrochloric acid (HCl).
- Sulphuric acid (H_2SO_4).
- Nitric acid (HNO_3).
- Ammonium fluoride (NH_4F).
- Perchloric acid ($HClO_4$).
- Acetic acid ($C_2H_4O_2$).

Hydrofluoric Acid

HF is essentially a gas dissolved in water. The vapour pressure of HF at room temperature is high and highly toxic, corrosive fumes will be released. The toxicity of HF is due to its fluoride ion content which, when it penetrates the skin, can cause the destruction of deep tissue layers. Chemicals such as HF, NH_4F and mixtures of these (BOE, BHF), may differ in concentration, vapour pressure and volatility, but the fundamental toxicity is the same.

Dilute HF must be treated with the same caution as concentrated HF, as symptoms of exposure may appear anything up to 24 hours later. Ensure that in-date HF-specific safety products are close at hand where HF will be used. It is imperative to go to hospital as soon as possible after an accident involving HF. See section 7.3.4 for more information about chemical safety products.

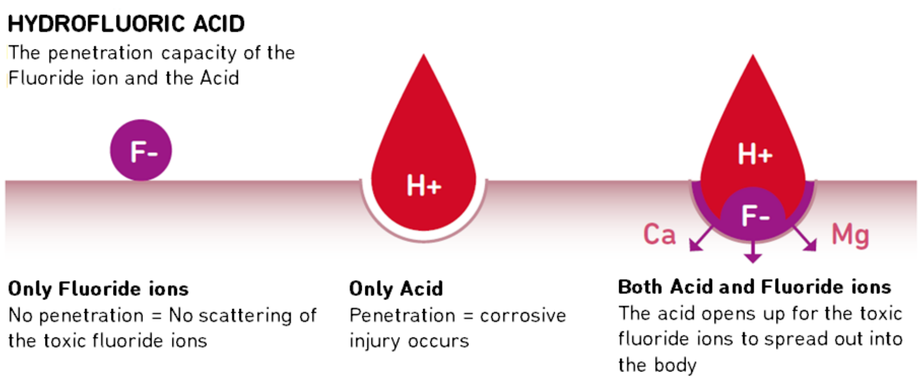


Figure 11: Penetration of HF into the skin, compared to stand-alone H^+ or F^-. Figure taken with approval from Medical Care Systems.

Piranha

Piranha (also known as 7-up) is a mixture of sulphuric acid and hydrogen peroxide. Piranha is used mainly to clean wafers of photoresist residues or other organic contaminants. When mixed, sulphuric acid and hydrogen peroxide creates a highly exothermic reaction and the temperature of the mixture will initially rise to at least 120°C. The hydrogen peroxide will decompose to produce highly reactive oxygen radicals. These radicals will oxidise most species containing carbon and the sulphuric acid is an excellent solvent for oxidised carbon species.

If hot piranha solution contacts the face in an accident, the result will probably be instant, permanent damage to the eyesight and disfiguring skin burns. The solution must be prepared and used with caution, always wearing proper protective gear. Always add the hydrogen peroxide to the sulphuric acid when mixing piranha solution!

6.1.2 Bases

Bases are corrosive substances and will damage human tissue. The eyes are particularly vulnerable to exposure, since bases are difficult to rinse off. Bases may only be used in dedicated wet benches and fume hoods. Common bases in the Myfab labs are:

- Tetramethylammonium hydroxide (TMAH).
- Potassium hydroxide (KOH).
- Sodium hydroxide (NaOH).
- Ammonium hydroxide (NH_4OH).
- Ammonia (NH_3).
- Photoresist developers (typically containing NaOH or TMAH).

Tetramethylammonium hydroxide

TMAH is considered as a very dangerous chemical, and must be handled with the greatest care. In addition to being a highly corrosive liquid, TMAH is very toxic. It can be fatal not only when swallowed but by minor skin exposure. Absorption through the skin is very rapid, so the key to limiting harmful effects is to limit the risk of exposure. TMAH will cause burns to any area of contact. The liquid can produce toxic, corrosive vapours which may cause blindness.

6.1.3 Organic solvents

Isopropyl alcohol (IPA) and acetone are the most commonly used organic solvents in any microelectronic cleanroom. IPA is a general cleaning agent for wafers and equipment. Acetone is used for such things as removing resist and cleaning wafers and resist-contaminated equipment. Health-related risks are fairly low when handling IPA and acetone. However, they are both flammable liquids and should be treated with respect when heating is involved.

Other organic solvents used within Myfab are more or less toxic, carcinogenic or mutagenic. These solvents should always be avoided if less toxic or carcinogenic alternatives are available (for example, ethanol should be preferred before toxic methanol). For some solvents, the health-affecting properties are not known or fully understood. This may also be true for chemicals other than organic solvents; such chemicals should be treated as toxic. Always consult the SDS before starting to use a new chemical. With very few exceptions (such as IPA), the use of organic solvents must be confined to ventilated workstations. For the sake of simplicity, all organic solvents should be considered flammable.

6.1.4 Photoresist and other organic chemicals

Special organic chemicals like photoresists, epoxy resins, and adhesives are also used in the cleanroom. Mostly, these are not as acutely corrosive or toxic as acids. However, if they are handled incorrectly over a period of time, long-term exposure to the skin or respiratory system may result, with known or unknown consequences.

Most photoresists are mixtures of solvents, novolac resins and photoactive compounds. The resulting mixture can be toxic, flammable and/or irritant. Since fumes evolved during use of photoresists, polymers and the like must not be inhaled, these chemicals should only be used in approved ventilated areas.

Dedicated workstations such as spinners or ovens are fitted with exhaust ventilation; if there is any odour then there is a technical problem with the equipment or the handling procedure.

6.1.5 Sensitising Chemicals

Some chemicals are known to induce sensitisation from prolonged skin exposure (H-statement H334) or contact with the respiratory system (H317). Sensitisation is an allergy-like condition with low tolerance to epoxy, and other chemicals and allergens. According to regulations, all users handling sensitising chemicals must undergo training in their use and pass a risk assessment. If the user is to handle certain sensitising chemicals, medical check-ups should be offered. For other chemicals, such check-ups are obligatory. The relevant legislation can be found on the Swedish Work Environment Authority website: www.av.se (AFS 37).

6.1.6 Oxidising agents

Because of their chemical structures and compositions, oxidisers have excess oxygen which may be liberated, especially at higher temperatures. The primary hazard associated with this class of compounds lies in their ability to act as an oxygen source and thus readily stimulate the combustion of organic materials.

Oxidisers are grouped into four classes (see below) based on their ability to affect the burn rate of combustible materials, or undergo self-sustained decomposition.

- Class 1: Oxidising materials whose primary hazard is that they may increase the burn rate of combustible material with which they come into contact (nitric acid <40%, 25% H_2O_2, ammonium persulphate and so on).
- Class 2: Oxidising materials which will moderately increase the burn rate or which may cause spontaneous ignition of combustible material with which they come into contact (nitric acid >40%, sodium hydroxide, sodium permanganate, etc.).
- Class 3: Oxidising materials which will cause a drastic increase in the burn rate of combustible material with which they come into contact or which will undergo vigorous self-sustained decomposition when catalysed or exposed to heat (fuming nitric acid, hydrogen peroxide >52% and so on).
- Class 4: Oxidising materials which can bring about an explosive reaction when catalysed or exposed to heat, shock or friction (perchloric acid>72%, ammonium permanganate and so on).

Hydrogen Peroxide

Hydrogen peroxide is a strong oxidiser and may react violently when mixed with other chemicals. Using hydrogen peroxide in mixtures is therefore limited to mixtures such as piranha solution, or other well-known recipes.

6.2 Protective Gear

Protective gear is available and must be used for all approved processes where such gear is deemed necessary. If it is not available for some reason, then the process may not be used and lab staff should be informed. The need for protective gear for a specific process must be examined before work commences. This is accomplished by reading the written instructions for that process, and/or verbal directions from the instructor of that application.

Protective gear for chemical handling can be:

- goggles or face visor protection,
- chemical gloves,
- apron,
- arm covers or sleeves,
- protective booties.

As a general rule, chemical gloves and face visor/goggles must be worn at all times for all work with wet chemicals. For eye protection, a face visor is preferable to goggles and a protective apron is always recommended.

Figure 12: Typical protective gear for the cleanroom. Different labs use different colours and fabrics, but the principles are the same.

6.3 Routines for handling of chemicals

The following rules apply to all handling of chemicals in the cleanroom:

- Put on chemical gloves and a protective face visor/goggles before starting work with chemicals at the wet benches.
- Inspect your chemical gloves carefully. If they are discoloured or damaged, they should immediately be discarded and replaced. Rinse your gloves carefully before placing them into the rubbish bins.
- If required, put on a chemical apron, sleeves, and chemical protective cover booties.

- Do not introduce previously unknown chemicals without prior approval from the lab management. The purchase of chemicals should be arranged through the lab staff.
- Inspect beakers, labware and so on for damage before use. Discard if necessary.
- Some containers and beakers are allocated to certain chemicals and must not be used for anything else.
- Mixing and use of chemicals is restricted to ventilated work areas.
- Never mix chemicals without prior knowledge of the consequences.
- Use small quantities of chemicals where possible.
- Apply the acid into water rule, known as the "AAA Rule": Always Add Acid.
- Do not disturb people who are working with chemicals.
- Special training and full attention is required when working with hazardous chemicals like HF, piranha and TMAH.
- Chemicals containing HF and KOH solutions may only be used in plastic containers (PP, PE, Teflon, etc.).
- Ensure that flammable chemicals (such as acetone or propanol) are not used near hot surfaces. Even small amounts may cause fire.
- Minimise the heating of chemicals and if necessary, keep well below boiling point. For example, max. 50°C for acetone.
- Open containers containing NH_3 and HCl must not be placed next to each other. The chemical reaction between their vapours will generate solid particles in the cleanroom.
- Chemicals in containers that are not clearly labelled should be disposed of immediately. Mark the container "unknown content" and call the lab staff.
- Some chemicals should be re-used. Pour these back into their bottles and carefully rinse the container with DI water.

6.4 Chemical cupboards

Chemicals and chemical waste must be stored in ventilated cupboards. Only compatible chemicals may be stored in the same cupboard. If you want to store a mixture of different chemicals, please consult the staff in charge for further assistance. Mostly, there are two different types of cupboard assigned to storage of chemicals:

- Acid cupboards: Inorganic acids, bases, oxidising or water-based chemicals, as well as non-toxic inorganic salts should be stored in such cupboards. These cupboards are connected to the acid exhaust system.
- Solvent cupboards: These cupboards are assigned to storage of organic solvents only. Solvent cupboards are connected to the solvent exhaust system.

Some cleanrooms have dedicated cupboards for toxins, bases, and photoresists (see local conditions).

6.5 Ventilated Work Areas

Wet benches and fume hoods represent two different technical solutions to the problem of handling chemicals safely. Solutions to this problem should generally incorporate:

- a way to separate the user from any harmful airborne pollutants,
- a surface to work on,
- a way of disposing of chemicals after use,
- a choice of materials compatible with the intended chemicals.

Ventilated work areas are connected to one of two available exhaust systems; acid exhausts in polypropylene (PP) and solvent exhausts in sheet metal (check local conditions). When working at high temperatures or with large volumes of chemicals or fuming chemicals, you must use a fume hood with the correct extraction system.

There are typically two independent drainage systems.

- Acid drainage is used for acids, bases, and DI water. The effluent is drained to a neutralising tank on the level below the cleanroom.

- Solvent drainage is used for organic solvents, with the possible exception of halogenated solvents (please consult laboratory staff). The waste is drained to a waste storage tank.

Keep in mind the following working principles:

- Never use acids or bases on a solvent work area, or vice versa.
- Respect the ventilation guard. If the alarm is on, the ventilated work area is not providing sufficient protection against airborne chemicals.
- Do not place beakers or containers of chemicals closer than 15 cm from the front edge of the work area.
- Beware fire hazards! Flammable chemicals must be handled with caution. Consult the SDS for properties of the chemicals you are handling. Organic solvents are always flammable. Do not leave beakers or containers of organic solvents unattended near possible sources of ignition like electrical equipment, especially not hotplates.
- Think of other users' safety! Clean the ventilated work area after use. Do not leave chemicals, beakers, warm hotplates etc. unattended. If it is necessary to leave before a process is complete, a note with your name, contact information, chemical contents and the date must be clearly visible.
- Keep the bench clear of all unnecessary items that might disturb airflow.

Common functions in ventilated work areas are drain valves, heated chemical baths, ultrasonic baths, etc. These functions are operated from a control panel on the bench front. Protective gloves are used to protect your hands. Always assume they might be contaminated with chemicals. Such contamination should not be transferred to the control panel. Rinse gloves with DI water before touching any buttons on the panel, or handling new beakers.

6.5.1 Fume Hoods

A fume hood is an exhaust-ventilated workspace with a see-through, height-adjustable sash that is designed to protect people from fumes and chemical splashes. The exhaust ventilation constantly draws air into the fume hood. If the air velocity in the hood opening is at least 0.5 m/s, airborne chemicals will not escape into the

Figure 13: A fume hood in use. Make sure the sash is below the safety line and that you are wearing the proper protective gear.

room. The sash gives excellent protection against splashes. Typically, fume hoods require airflows in the range 500-800 m^3/h, depending on the hood geometry and design principle.

Most fume hoods are fitted with ventilation guards that monitor the air velocity (directly or indirectly by measuring the pressure in the hood). If the velocity or air volume decreases to an unsafe level, an audible alarm normally sounds.

Keep in mind the following fume hood working principles:

- Low exhaust capacity in the fume hood may be locally induced (sash opened too high) or due to a problem with overall capacity (failed exhaust fan).
- Use the fume hood with the sash opened to the minimum height your work requires.
- Always use the sash as splash protection. In other words, position the sash so that you are working whilst looking through it.
- Beware fire hazards! A fire in a fume hood will not initially be picked up by the smoke detectors, since the exhaust effectively removes the smoke. If the fume hood is connected to a PP duct, the fire may propagate through the exhaust ducts.
- The cross-sectional geometry of large containers or pieces of equipment placed in the fume hood may result in insufficient airflow in front of the object. Air will escape above and on the sides of the object, but fumes may diffuse out from its front. If the object is placed on 5 cm spacers, air will also flow under the object and your protection will improve.

6.5.2 Wet Benches

A wet bench is an exhaust-ventilated work table. The height and depth of the wet bench make it suitable for working in an upright position. The top surface is perforated to allow air flow through the worktable and recessed chemical baths are suitable for handling cassettes of wafers. The baths are covered by lids that flip-up to open. When a lid is open, air flows through an open section surrounding the container.

Some benches have HEPA-filters attached above and around the ceiling area where the bench is located. The filters provide clean air to the bench surface and, if the air supply is in balance with the bench exhaust, vapours are effectively removed. A wet bench offers much cleaner handling of wafers than a fume hood. The latter draws ambient cleanroom air in an uncontrolled manner; the air is not drawn directly from the HEPA-filters, and will pass the operator, picking up particles.

Wet benches provide good protection against harmful vapours in the baths, but are less effective for chemicals handled on top of the work surface. The maximum safe working height is 200 mm (local regulations may exclude handling of chemicals on the upper surface). Above the stipulated maximum working height, vapours from the container can escape into the room. A safe working distance from the bench edge is 15 cm or more.

Work is carried out with chemicals in the line of sight without any transparent screen between the chemicals and the user. If something is dropped into a container, splashes may reach the user. A face shield / safety glasses is therefore required and an apron is always recommended (in some cases compulsory; consult local rules).

If the perforation in the upper surface is covered by papers, beakers or other items, airflow through the bench will be reduced. As the air supplied to the bench from the filter ceiling is constant this may then exceed the exhaust flow and the excess air will "roll" over the front edge of the bench, possibly carrying vapours from the bench chemicals into the circulating air system.

6.6 Waste management

It is extremely important to use the correct drain or container for your used chemicals, since mixing of these chemicals would create a risk of explosion in the waste-handling facility. All ventilated work areas with their etching and cleaning baths and so on, are connected to the proper waste drain or container. If you have waste chemicals and are unsure about what to do with them, place them in a plastic waste container and contact lab staff for advice. Never discharge any materials in the drains if you are not sure they belong there. Some chemicals should always be collected in waste bottles after use, for final disposal by lab staff.

Information on how a certain chemical should be disposed of is presented in the SDS and a complete register of all chemicals is found in the KLARA database as well as Myfab LIMS.

Leaking chemical containers should be treated as a major safety risk. They may cause severe personal injury and/or material damage, particularly if chemical groups are mixed.

Bear this in mind when your work is completed:

- Warm chemicals must be cooled down before disposal.
- Do not dispose of used chemicals if you are unsure how to do it. Store in closed bottles and contact lab staff for advice. This is particularly applicable to concentrated, unmixed chemicals.
- Users are responsible for cleaning up minor chemical spills. Please contact lab staff if a major spillage occurs.
- Rinse labware and place in its designated place.
- Chemical gloves should be rinsed and put back in their designated place, without touching any surface outside the ventilated area.

Liquid chemical waste, which cannot be poured into the chemical drains or bottles plus solid chemical waste should be removed to the waste storage room for destruction. Chemical waste containers must always be labelled with the owner's name, department, the complete chemical name (not abbreviations or trade names) and the concentration of constituents if the waste is a solution. Make sure you have sufficient information on the compatibility of any chemicals you intend to mix.

Do not mix your chemical waste with that of the others, even if they are compatible with your chemicals. You are only allowed to mix your own chemical waste products and only if they are compatible.

Figure 14: Certain chemicals are classified as environmentally harmful and should be stored in special bottles for destruction. Others may be poured into the sink (local rules).

7 ALARMS AND EMERGENCY

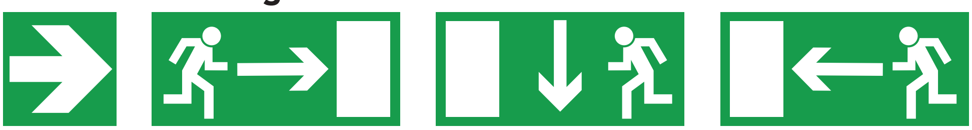
7.1 Alarms

Alarm systems in the Myfab laboratories may be divided into the following categories:

- Fire alarms: Smoke detectors, manual activation, sprinkler systems and any heat detectors.
- Gas alarms: Sensors for detecting specific hazardous gases.
- Operational alarms: Faults or deviations within the cleanroom infrastructure.

These alarm systems will trigger an internal alarm notification system. Typically, the highest alarm level is total evacuation of the cleanroom. This is indicated visually by red lights and audible signals from bells, sirens or horns. Fire alarms and certain concentration levels of hazardous gases will trigger the total evacuation alarm. Operational alarms are indicated visually by blue lights (there may also be an audible signal; check local conditions) and do not necessitate evacuation. The total evacuation alarm will not only be signalled to cleanroom users; it will also trigger necessary actions in the infrastructure regarding ventilation, house gas distribution, tool shutdown, and so on. The alarm system and alarm scheme for each Myfab lab are described in the lab specific appendix.

7.1.1 Evacuating the Cleanroom



An evacuation alarm must result in an immediate response from the cleanroom user:

- Without delay, go to the nearest emergency exit and leave the cleanroom. Emergency exits are marked with green and white signs as per international standards. All clean zones have emergency exits in the same room where work is carried out. There are at least two alternative exits from all locations in the cleanroom. When evacuating, do not waste time removing your cleanroom garment; leave it on. Do not delay evacuation by trying to conclude work that otherwise might be spoiled.
- During evacuation, be sure that other users follow your example. Help them, if necessary and possible. If possible, account for the whereabouts of any missing colleagues.
- Go to the assembly point and await further instructions. Do not leave the assembly point unless laboratory staff authorise this action.

Consult the lab-specific appendix for details of your assembly point and what to do after an evacuation.

7.2 In Case of Emergency

112 is the dedicated public emergency number in Sweden for obtaining help from all the emergency services. The SOS Alarm centres are contactable 24 hours a day and co-ordinate dispatch of the emergency services.

When your 112 call is answered, the SOS Alarm operator will ask you questions. Stay as calm as possible and try to describe clearly what has happened, where it happened, who needs help and why. Is there a fire? Is anybody in danger due to the fire? Or is somebody in need of police intervention? In the event of an accident, the operator needs to know if anybody is injured and, if so, how many injured people are there and the nature of their injuries. Describe clearly the location where help is needed and tell the operator your name, address and telephone number.

The SOS Alarm operator must have this information as quickly as possible to determine what help is needed and to dispatch the correct emergency service to provide the necessary assistance. The SOS Alarm operator may also need more information while help is on its way, so stay put and remain on the line as long as requested.

In case of a chemical accident, you must give the concentration, volume, and exposure-time of the chemical concerned. This information will help physicians to be well prepared for an ongoing rescue. If medical attention is necessary due to chemical exposure, the SDS of that chemical should be given to the physician. Never go to the hospital yourself, call the ambulance instead!

Actions in case of a serious personal accident

- Give first aid.
- Call for an ambulance. Dial 112.
- Give the address of your location (see local information, or last page in the manual).
- If a chemical accident, also give the chemical name, concentration, volume, and exposure time.
- Assist the injured person and send someone to meet the ambulance and paramedics.
- Guide the paramedics to the injured person.
- It is compulsory for at least one person to accompany the injured person to the hospital, if no lab staff is available, a user should do this.
- It is important that rinsing is continued during transportation to paramedics/hospital, using a handheld bottle.
- If no lab staff is available, contact a relative of the injured. Each group has a register with this information.

7.3 Emergency Aids

7.3.1 Fire Extinguishers

Fire extinguishers are mounted at various locations around the cleanroom. These locations are marked with an additional sign (see figure above). Extinguishers are typically carbon dioxide type due to their non-destructive properties. Cleanroom users are not normally expected to use fire extinguishers, but different rules are in force at the various labs.

7.3.2 First Aid

First Aid boards with basic First Aid gear, band aids and the like, are placed in various locations (not inside the cleanroom). Familiarise yourself with the location and contents of the First Aid kit.

7.3.3 Chemical Safety Aids

After exposure to chemicals, the appropriate action could vary depending on the chemicals involved. Relevant information can be found in the SDS and should be studied carefully for all chemicals you intend using.

There are three types of chemical safety aids. Water based eye and emergency showers, calcium gluconate gel, and the hand-held chemical showers Diphoterine and Hexafluorine. Chemical injuries should always be inspected by a medical specialist.

Emergency Shower

Emergency showers should be used for flushing off chemicals in case of a chemical accident and are available close to chemical handling areas. When handling wet chemicals, you should always be aware of the location of the nearest emergency shower. The proper way to deal with chemical exposure is to start using the shower without removing your clothing. Once inside the shower remove the clothing and continue rinsing. If splashes reach your eyes, it may only be a matter of seconds before there is permanent damage. Hence, eye rinsing must be your first priority.

Eye Shower

The only way to remove harmful chemicals from your eyes and limit the damage is to rinse the eyes in an eye shower. The success of this action depends on two things: how soon after the exposure rinsing commences, and how thoroughly it is done. Rinsing should be continued for at least 20-30 minutes. During rinsing it is imperative to open the eyelids as much as possible, directing the water flow into, and around, the whole eye. This is awkward to do, so the injured person may need assistance opening their eyes. Guide him or her to the eye shower; remove any contaminated clothing that might hinder the rinsing. Be firm but calm. If and when your colleague is able to continue rinsing unassisted, help them remove contaminated clothing and rinse other parts of their body that have been exposed to the chemical.

Diphoterine and Hexafluorine

In addition to ordinary eye showers, some labs have installed hand-held chemical showers. These chemicals neutralise the spilled chemical instead of diluting it, as with water. Due to the properties of these chemical showers, there is much less need for rinsing to save an eye or other body parts. There are two types of liquid:

- Diphoterine: This consists of a chemical with both amphoteric and hypertonic properties. This means it can both neutralise OH^- and H^+ ions and it will also "draw out" the chemical, see Figure 15. These properties make diphoterine a good substitute for water when neutralising acids and bases and, to some extent, even oxidisers and solvents.
- Hexafluorine: Consists of a similar chemical as diphoterine, but instead of neutralising OH^- ions it is engineered to accept F^+ ions. This makes hexafluorine a good alternative for neutralising compounds containing fluorine (like HF) as well as being good for neutralising regular acids (but not bases and oxidisers).

Start rinsing as soon as possible and remove clothing and/or contact lenses. Continue washing the uncovered areas as quickly as possible. If you cannot find the neutralising solution, wash with water! It is important to start washing as soon as possible. Do not reuse clothes that have been stained with chemical residues.

Calcium Gluconate Gel

Calcium gluconate gel (HF-gel) is used to treat skin burns from HF. It must always be available and within reach whenever HF is used. If skin is exposed to HF, rinse with plenty of water for a few minutes, or with one bottle of Hexafluorine if available. Dry the exposed area and immediately apply the HF-gel liberally all over the wound, massaging for at least 15 minutes. The HF-gel provides extra calcium ions; these bind to free fluorine ions before they can penetrate your body and cause damage. Repeat the treatment every 15 minutes until reaching medical care.

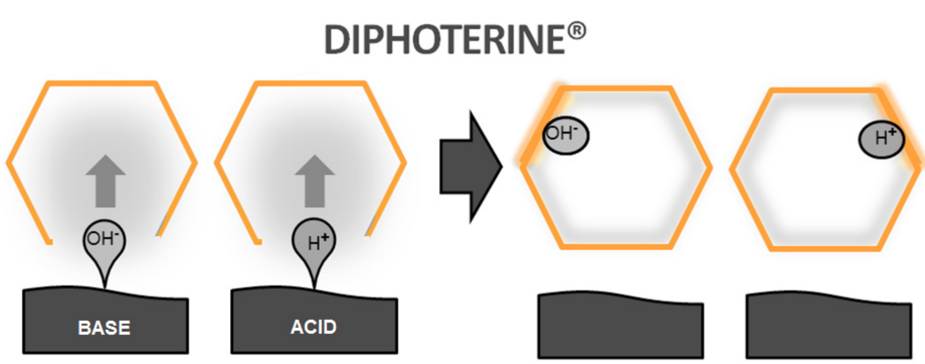


Figure 15: Diphoterine neutralises both acids and alkalis and, to some extent, solvents and oxidisers. Figure taken with approval from Medical Care Systems.

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Actions in case of a serious personal accident

- Call for help.
- Give first aid.
- Call for an ambulance.
- Give the address of your location (see below).
- If a chemical accident, also give the chemical name, concentration, volume, and exposure time, if known.
- Assist the injured person and send someone to meet the ambulance and paramedics.
- Guide the paramedics to the injured person.
- It is compulsory for at least one person to accompany the injured person to the hospital, if no lab staff is available, a user should do this.
- It is important that rinsing is continued during transportation to paramedics/hospital, using a handheld bottle.
- If no lab staff is available, contact a relative of the injured person. Each group has a register with this information.

Emergency number

112

Swedish Poison Information Centre

010-456 6700

Emergency contact information for the different Myfab sites:

Electrum: KTH, Royal Institute of Technology Electrumlaboratoriet Isafjordsgatan 22-24 164 40 Kista Emergency/on duty number: 070-648 60 32 St Erik eye clinic: 08-672 31 00	**MC2:** Chalmers University of Technology Microtechnology and Nanoscience - MC2 Kemivägen 9 412 96 Göteborg Chalmers Fastigheter emergency number: 031-772 49 37
MSL: Uppsala University Ångströmlaboratoriet Regementsvägen 1 752 37 Uppsala Akademiska Hus emergency number: (018) 683 204	**LNL:** Lund University Physics Department, Division of Solid State Physics Sölvegatan 14C 223 63 Lund