CHEMICAL HYGIENE AND SAFETY PLAN

TABLE OF CONTENTS

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CHEMICAL HYGIENE AND SAFETY PLAN
MICROFABRICATION LABORATORY

INTRODUCTION

The ***Micro-Fabrication Laboratory (MFL),*** a laboratory in the Case School of Engineering's **Center for Micro and Nano Processing**, is located in 320 Bingham, is a Class 100 Clean Room facility that provides state-of-the-art capabilities for the research and development of micro mechanical electrical systems and structures (MEMS) technology. The MFL is essentially a high-tech machine shop, containing approximately 25 different pieces of semiconductor fabrication equipment. The equipment is maintained by the MFL technical staff, used and operated primarily by CWRU graduate students engaged in MEMS research and development. A variety of hazardous chemicals (gases and liquids) are used routinely during processing in the CWRU Micro-Fabrication Laboratory (MFL). The chemicals utilized in the MFL could cause serious personal injury if mishandling or accidents occur. An Information Packet for new users of the MFL is available as a guide to general operating procedures and an introduction to safe laboratory procedures (Ref.). You may request a copy from the ***MFL Chemical Hygiene and Safety Officer*** or print a copy from the CWRU MEMS Web page, http://mems.cwru.edu. The information contained in this Chemical Hygiene and Safety Plan is intended to amplify specific aspects of chemical hygiene and safety as related to microfabrication research within the MFL. ***ALL PERSONNEL UTILIZING THE MFL FOR RESEARCH OR OTHER PURPOSES MUST BE AWARE OF THE INFORMATION CONTAINED IN THIS CHEMICAL HYGIENE AND SAFETY PLAN FOR THE MFL.***

ROLES AND RESPONSIBILITIES

All individuals overseeing and working with hazardous chemical substances must accept a shared responsibility for safe operations within the MFL. The individuals and organizations involved in this process include the Dean of the Case School of Engineering, Principle Investigators, the MFL Manager, the MFL Staff, the MFL Chemical Hygiene & Safety Officer, the MFL Users, and the CWRU Department of Occupational & Environmental Safety (DOES). An overview of responsibilities of the CWRU Administration including The Dean, Principle Investigators, DOES, etc. is contained in CWRU "Policies and Guidelines for Chemical, Biological and Radiation Safety" of May 15, 1991 (Ref.). The following outline is intended to provide a descriptive summary of responsibilities for personnel directly involved in operating and using the MFL facility.

CWRU Department of Occupational & Environmental Safety

The CWRU ***Department of Occupational and Environmental Safety (DOES)*** has general responsibility for developing, implementing, and monitoring campus-wide programs in occupational and environmental safety. DOES establish required programs in emergency response, handling and disposal of hazardous waste, compliance with the OSHA Hazard Communication Standard, the OSHA Laboratory Standard, and other regulations. DOES monitors requirements of government regulations in occupational and environmental safety, sets general policy for the University and monitors compliance on behalf of University Departments, Principle Investigators, Laboratory Managers, Chemical Hygiene Officers within specific laboratories, faculty, staff, and students. DOES is a resource for the MFL with respect to compliance, policy, and specific technical issues in the areas of Occupational and Environmental Safety.

MFL Director/Manager and Staff

1. The ***MFL Director/Manager*** is the primary contact person (Primary Investigator) for the entire ***MFL*** facility and is responsible for the overall approval and administration of Safety Policies within the clean-room facility. With the aid of the ***MFL Chemical Hygiene and Safety Officer***, the manager approves

new safety procedures as required, as well as annual review and modification to existing safety procedures. The MFL Manager is also responsible for requesting safety evaluations from DOES, as required for installation of new equipment or annual 'Safety Checks' of existing equipment covered by DOES jurisdiction

2. The ***MFL Staff*** members are assigned to various '**Aisles**' containing selected (and related) pieces of micro-fabrication processing equipment. It is the staff member's responsibility for instructing new users with regard to safety precautions for the use of the various equipment pieces when the user is being trained to operate the specialized equipment in a particular aisle. Additionally, the staff 'police' the clean-room, reporting and correcting any unsafe condition or practice as exhibited by equipment or users, respectively.

MFL Chemical Hygiene and Safety Officer

The ***Chemical Hygiene and Safety Officer*** has the following responsibilities:

1. Administer initial Safety/Hygiene Tour of the MFL Clean-room for all new users of the facilities, with the sole emphasis being the review of safety features and safety equipment in the clean-room.
2. Administer the written ***MFL*** Safety/Hygiene Exam for all new users, prior to a user being permitted to enter the clean-room unaccompanied.
3. Review and update existing safety procedures on an annual basis for relevancy, correctness and compliance.
4. Approve the use of all new chemicals within the MFL.
5. Maintain an inventory of all chemicals and gases used, their utility, and an MSDS for each chemical or gas. This list is also reviewed and updated by the officer on a semi-annual basis.
6. Review and recommend safety protocols for existing process equipment, and implement safety protocols for new equipment as required.
7. Prepare and Dispose of chemical waste in accordance with the ***DOES*** regulations and guidelines.

RELATIONSHIP TO OTHER POLICIES, GUIDELINES, ETC.

The Chemical Hygiene and Safety Plan for the MFL is based on CWRU Policies and Guidelines, Governmental Regulations, and Industry Standards. A list of the principle policies, regulations and standards upon which this Plan is based are outlined below:

- "Policies and Guidelines for Chemical, Biological, and Radiation Safety," CWRU, May 15, 1991.
- "Information Packet for New Users of the Microfabrication Laboratory (MFL)" EECS Dept., CWRU, January 15, 1997.
- "Hazard Communication Standard," US Department of Labor, Occupational Safety and Health Administration (OSHA), 29 CFR 1910.1200.
- "Occupational Exposure to Hazardous Chemicals in Laboratories," US Department of Labor, Occupational Safety and Health Administration (OSHA); 29 CFR 1910.1450.
- Equipment Training Documents and Standard Operating Procedures relevant to MFL, created by MFL Staff.

The publications outlined above are readily available in the MFL. Further background sources of information that pertain to health and safety in microelectronics research and manufacturing are outlined in the attached bibliography. Any questions pertaining to availability or content of these publications can be directed to the ***MFL Chemical Hygiene and Safety Officer***.

INFORMATION FOR NEW USERS OF THE MFL

New Users to the ***MicroFabrication Laboratory (MFL)*** must satisfy the following conditions before laboratory privileges will be granted:

1. Compliance with all Case Western Reserve University Safety Policies as directed by ***Department of Occupational and Environmental Safety Services'*** regulations and guidelines.
2. Users must receive a Safety Tour of the ***MFL*** Clean Room areas and pass a written safety test before any fabrication tool training may begin. The ***Chemical Hygiene and Safety Officer*** will present both the tour and administer the examination.
3. All users must submit a process design for device fabrication to the ***MFL Director/Manager*** before any training and processing may begin. Administrative paper requirements will also be handled by the ***MFL Director/Manager***, and must be satisfied prior to any use of the MFL Clean-room facility.

No exceptions to these guidelines will be granted.

CHEMICAL ORDERING

All orders for new chemicals and reorders for existing chemicals intended for use in the MFL facility must be approved by the MFL ***Chemical Hygiene and Safety Officer*** prior to order placement. Only those orders for chemicals initiated by approved users of the MFL facility will be considered for approval. This review shall address whether or not new hazards may be introduced to the MFL and development of new or modified storage and handling procedures is needed. An adequate Material Safety Data Sheet (MSDS) must be provided to the MFL CHSO from the chemical supplier prior to the use of any new chemical substance in the MFL facility.

MFL CHEMICAL INVENTORY

The MFL ***Chemical Hygiene and Safety Officer*** will maintain an inventory of chemicals approved for use in the MFL. This list shall be displayed at the entry to the MFL and shall be maintained in the introduction to the compilation of Material Safety Data Sheets (MSDS) associated with chemicals approved for use in the MFL.

Only those chemicals listed on the MFL Chemical Inventory are approved for use in the MFL facility. A copy of the Chemical Inventory list shall be provided to ***DOES*** upon request, to keep them informed of any new chemicals introduced to the MFL. Any new, approved chemicals to be used in the MFL will be entered into the inventory sheet, and an MSDS retained for any subsequent necessity, i.e. disposal purposes.

CHEMICAL DELIVERY

Chemical use in the MFL is subject to approval by the ***MFL Director/Manager*** and ***Chemical Safety and Hygiene Officer***. Approved chemicals entering the facility are generally of two categories:

1. **Clean Room packaged**
2. **Non-Clean Room packaged.**

Regarding all chemicals in the previously listed categories: all deliveries should be made to the rear entrance of the MFL, Room 320, and placed into the 'back hall.' The receiving party should then enter the MFL, gown up according to all Clean Room procedures, and proceed to the 'back hall.'

Once there, **Category (1)** Chemicals may be unpackaged and stored in the following manner: simply un-package the chemicals, place them on the chemical cart or in a rubber chemical tote with a handle, and move them to the appropriate storage cabinet. Discard the clean room packaging in the refuse container in the 'back hall.'

Category (2) Chemicals should be delivered in to the facility as follows:

1. Open the container in which the chemical bottles, jars, etc… were delivered.
2. Apply 2-propanol (also known as isopropanol, or IPA) onto a Beta-Wipe, and wipe the exterior of the chemical container, including the bottom.
3. Wipe all the containers and place them on the chemical cart or in a rubber chemical tote with a handle, and move them to the appropriate storage cabinet.

Discard all boxes or other packaging out the back door **WITH THE EXCEPTION OF BOXES IN WHICH GLASS BOTTLES WERE DELIVERED**, which include Nitric and Sulfuric Acid, some photo-resists, Butyl Acetate etc. These boxes must be retained for disposal of the empty acid bottles, per the ***Department of Occupational and Environmental Safety Services'*** regulations and guidelines.

In addition, all box labels should be defaced.

The ***Chemical Safety and Hygiene Officer*** will be responsible for the disposal of empty glass bottles in the MFL.

If you have any questions contact the ***Chemical Safety and Hygiene Officer***.

<u>MATERIAL SAFETY DATA SHEETS (MSDS)</u>

A ***Material Safety Data Sheet*** or ***MSDS*** for each chemical identified on the MFL chemical inventory, which are those chemicals used in the MFL, must be maintained on file and readily available to users of the MFL. An ***MSDS*** is a document that outlines such categories as:

1. Material properties
2. Hazard information
3. Emergency measures
4. Personal Protective Equipment required for safe handling of the material

The information contained in an adequate ***MSDS*** is described in the *<u>OSHA Hazard Communication Standard</u>* and the *<u>American National Standard Institute (ANSI) Standar</u>*d for the preparation of ***MSDS*** (Refs). The following outline represents the information typically included in an adequate MSDS:

- Chemical supplier information (company name, address, emergency phone number, etc.)
- Chemical composition, information on ingredients
- Hazards identification
- First aid and Fire-fighting measures
- Accidental release measures
- Handling & storage
- Exposure controls, personal protection
- Physical & chemical properties
- Stability & reactivity
- Toxicological information
- Ecological information
- Disposal information
- Transport information
- Regulatory information

<u>LABELING</u>

<u>Chemical Container Labeling</u>

All chemical containers are to be labeled according to applicable NFPA regulations. In general, all vendors of chemicals to the MFL are in compliance with these regulations. When chemical aliquots are transferred to new containers, these containers must subsequently be labeled with an appropriate HMIS Label, according to NFPA Regulations.

Work Area Labeling
Chemical Hoods are labeled for specific use, and chemical incompatibility charts are available. The CWRU ***Department of Occupational and Environmental Services*** create general chemical handling guidelines with respect to chemicals common to all labs within the University. Specific Guidelines for compatibility and use of chemicals are contained within the Procedures and Equipment Section of this document.

CHEMICAL DELIVERY
All chemicals must be received (logged in) by the ***Chemical Hygiene and Safety Officer,*** except routine delivery of compressed gases, which may be accepted administratively by approved MFL Staff members.

CHEMICAL STORAGE
All chemicals are to be stored in the appropriate location. The MFL has storage cabinets for the following classifications of chemicals:

1. Acids
2. Corrosives (Bases)
3. Oxidizers
4. Organic Solvents
5. Flammable materials requiring refrigeration

Additionally, small quantities of organic solvents in 500ml squirt application bottles may be stored temporarily in the Solvent Hood, located in the ***Sputtering/Etch Aisle*** of the ***MFL Clean room***. These solvents must be stored in either pre-labeled bottles specific for the solvent, or have an attached NFPA appropriate label.

GAS HANDLING

The ***MFL*** utilizes hazardous and toxic gases in the fabrication of thin films for MEMS devices. Gases are housed in cabinets specifically designed for safe storage of these materials: cabinets are located in the ***MFL Clean-room*** and in an exterior storage are on the ground floor of Bingham Building, exterior to the actual building. The gases in exterior storage include:

1. Hydrogen (H_2)
2. Oxygen (O_2)
3. Silane (SiH_4)
4. Ammonia (NH_4)
5. Chlorine (Cl_2)
6. Sulfur Hexafluoride (SF_6)
7. Freon 23 (CHF_3)
8. Freon 116 (C_2F_6)
9. Argon (Ar)

The following procedures are for gas cylinder replacement:

Gas Bottle 'Swap' Procedure: Hazardous Gases

Close low pressure valve using switch located on the control panel

1. Close cylinder valve, located at the top of the cylinder.
2. Open vacuum valve.
3. Open vent valve keep valves open until pressure is lowered to 20-30 inches of Hg.
4. Close vent valve.
5. Close vacuum valve.
6. Open purge valve for 5 seconds.
7. Close purge valve.
8. Repeat steps 3-8 five (5) times. On the last repetition, omit steps 7 and 8.

9. Remove tank
10. Place empty tank in the proper storage area, chained into a cylinder rack.
11. Install new tank
12. Open vacuum valve.
13. Open vent valve. Maintain valve open position until pressure is lowered to 20-30 inches of Hg.
14. Close vent valve.
15. Close vacuum valve.
16. Open tank valve.
17. Open low pressure valve.

Gas Bottle 'Swap' Procedure: Non-Hazardous Gases

1. Close tank valve
2. Close gas supply valve
3. Remove tank
4. Place empty tank in the proper storage area
5. Install new tank
6. Open vent valve
7. Slowly open tank valve until you hear gas escaping keep the valve open for 10 seconds
8. Close the vent valve
9. Open the tank valve all the way
10. Open the gas supply valve

Hazardous Gas Line Safety Considerations

The hazardous and non-hazardous gases are supplied throughout the Clean Room via special stainless steel tubing. The lines are prepared and routed according to the following safety guidelines.

1. Fusion Welding of Tube and Pipe

All gas lines are welded using an AMI Model 207 microprocessor-controlled power supply weld tool with AMI Model 9 Series tube welding heads and cables for fusion welding of tube. All non-hazardous gasses are supplied in 1/4 " x 0.035 " wall T316 SS Electro-polished tubing. All hazardous gasses are supplied in 3/8" x 0.035" wall T316 SS Electro-polished double wall tubing design. The larger diameter tubing houses smaller diameter inner tubing. The hazardous gases are supplied via the inner tubing. A vacuum is pulled between the outer and inner tubing, and monitored with a pressure gage.

2. Preparation of the Weld Joint

The ends of the tube are cut square to the tube axis for good fit between tubing sections. If the ends are not square, they tend to separate when the weld head is closed resulting in a gap. The ends are then 'faced' with a prepping tool and then de-burred. The end result should be a square, machined end with no gap, no chamfer, no burrs, and no inner diameter (ID) tubing scratches.

3. Criteria for a Good Weld

Welds should be fully penetrated and smooth. Penetration should be even around the entire ID circumference without thin spots or any visible joint.

<u>PERSONAL PROTECTIVE EQUIPMENT</u>

All users must wear approved safety glasses when in the ***MFL Clean room***, without exception. Additionally, no open-toed shoes, shorts, dresses, skirts, "Capri" style pants, sleeveless shirts or blouses, should be worn beneath the clean room uniforms supplied by the MFL.

<u>Respirator PPE</u>

Full-face mask respirators are required for the following activities within the MFL:

1. Refilling the Sulfuric Acid reservoir in the Acid/Base Neutralizer system
2. Cleaning of vacuum pumps in the MFL
3. Quartz Furnace tube washing process

NOTE: Only MFL Staff members execute these procedures.

Respirator Fit Testing done by DOES

The Department of Occupational and Environmental Safety Services will conduct respirator Fit Testing after a physical examination is administered by University Health Services.

PPE for Chemical Hoods

Because of the use of some very hazardous chemicals within the ***MFL Clean room***, and specifically the Photolithography Aisle, users are required to utilize the following PPE when executing any procedure within the Chemical Hoods in the Aisle. ***You should review all written documentation on a procedure, and any MSDS for chemicals used in that procedure, before requesting training and User Approval for a particular process.***

In general, any processing performed in the Chemical and Develop Hood, Metal Etch Hood and RCA Clean Hood, require the use of appropriate PPE. More specifically, the execution of ***Piranha Organic Clean***, ***BOE, Aluminum Etch, Metal Etch, RCA Clean, Photo-resist Developing*** or ***Lift-Off Bath Procedure*** requires the use of the following PPE:

1. Safety glasses, or chemically resistant splash goggles.
2. Chemically resistant Face Shield
3. Blue, PVC, chemically resistant apron.
4. Trionic, aqueous acid/base resistant gloves

These PPE should be put on in the following order:

1. ***Safety glasses, or chemically resistant splash goggles***. **NOTE!** Safety glasses are required at all times when working in the MFL.
2. ***The Blue, PVC, chemically resistant apron.*** **BE SURE THAT YOU TIE BOTH APRON STRINGS, INCLUDING THE WAIST STRING.** There should be no risk of exposure by doing so, and you sacrifice a level of protection by not tying up the strings. Generally, the shoulder level apron string is already tied and knotted, so this can just be slipped over your head. If you are not dexterous enough to tie the strings with gloves, just ask someone to help!
3. ***The Chemically resistant Face Shield.*** Place this on your head and adjust the ratchet headband to your proper head-size. The crown of the headband should rest flush on your head.
4. ***The Trionic, aqueous acid/base resistant gloves***. The gloves should slide over the sleeves of the Blue, PVC, chemically resistant apron.

NOTE! These items are chemically resistant, and have an extended degree of impermeability to the highly acidic and basic chemicals and chemical solutions used in the Photolithography Aisle processes. However, if a serious splash occurs you should rinse and remove, or simply remove, the affected equipment as soon as possible, and if necessary seek treatment such as the Emergency Eye Rinse or Emergency Shower Rinse, located right outside the Photolithography Aisle.

In case of a minor splash or contact, equipment may be left in the sink of either chemical hood, since the material in these hoods is much more chemically resistant and durable to spills and splashes. Contact the MFL Staff regarding the affected equipment, and we will remove the affected equipment and provide you with new equipment, so your processing may continue without extended interruption.

TOXIC GAS MONITORING

The System 16 is a hazardous gas monitor system manufactured by ***Zellweger Analytics – MDA Scientific, Inc***. It is used to monitor for leaks within the MFL Clean Room, of toxic gases used for MEMS device fabrication.

The system 16 has programmable dual alarms, labeled Level 1 Alarm and Level 2 Alarm. These alarms warn of detection of monitored gases. The setting for the Level 1 alarm is one-half the (TLV) Threshold Limit Value. The setting for a Level 2 Alarm is one TLV.

When monitored gas concentration reaches alarm levels at any one of twelve (12) monitoring locations, the System 16 will trigger a flashing blue light alarm and an accompanying audible alarm. The monitor system will print out the detection condition (i.e. a Level 1 or Level 2 alarm), store it in memory, and activate the appropriate information on alarm levels and response to alarm conditions.

Additionally, in response to toxic gas detection the following automated responses occur:

1. Mass flow control (MFCs: automated gas flow valves) relay contacts close and ALL process gases, toxic and non-toxic, are shut down at their source container.
2. The facility air handlers, which provide positive pressure to the laboratory for environmental control, shut down.
3. The lab then goes to "negative pressure" with all air being exhausted from the laboratory environment and toxic gas storage cabinets, through the facility wet scrubber system, to outside atmosphere.
4. The Bingham Building alarm system will signal a chemical release and direct all personnel to evacuate the building.

The System 16 will also facilitate these automated responses in the event of a power failure.

The analyzer sub-assemblies in the System 16 use a Chemcassette detection method. This is a tape specially formulated to react with a specific gas or group of gases. The target gas in the sample flow reacts with the tape of the Chemcassette. The reaction produces a stain with a density proportional to the gas concentration. The stain is optically measured, digitally interpreted, and reported by the System 16 as a precise concentration Level in parts-per-million (ppm) or parts- per-billion (ppb).

This optical detection system is calibrated once every month and whenever the Chemcassette tape roll is replaced. This procedure uses a vendor supplied optical standard to calibrate the optical detection system to insure that the system will correctly quantify and verify gas levels during normal detection operations and signal any appropriate alarms. The calibration method is documented in the ***Zellweger Analytics - MDA Scientific*** supplied manual for this system.

The following page lists toxic and hazardous gases, location of the Point Modules (apparatus used to detect gasses), and the Level 1 and Level 2 alarm levels that are monitored by the System 16.

Material Safety Data Sheets (MSDS) are available for review, upon request of the ***Chemical Safety and Hygiene Officer.***

The following chart lists pertinent information with regard to the MDA Toxic Gas Monitoring system:

Point Module	**Location**	**ALARM 1 Level**	**ALARM 2 Level**

A1	SiC Reactor Chamber	50 ppb: B_2H_6	100 ppb: B_2H_6
A2	SiC Reactor Gas Chamber	50 ppb: B_2H_6	100 ppb: B_2H_6
A3	SiC Reactor Room	50 ppb: B_2H_6	100 ppb: B_2H_6
A4	SiC Reactor B_2H_6 Cylinder	50 ppb: B_2H_6	100 ppb: B_2H_6
B1	SiC Reactor PH_3 Cylinder	50 ppb: B_2H_6	100 ppb: B_2H_6
B2	LPCVD Source Cabinet	2.5 ppm: SiH_4	5.0 ppm: SiH_4
B3	LPCVD Cylinder Cabinet	2.5 ppm: SiH_4	5.0 ppm: SiH_4
B4	LPCVD Load Station	2.5 ppm: SiH_4	5.0 ppm: SiH_4

Point Modules A1, A2, A3, and A4 are open to SiH_4, PH_3 and B_2H_6 detection.
Point Modules B1, B2, B3, and B4 are open to SiH_4, PH_3 and DCS (DiChloroSilane) detection.

EMERGENCY RESPONSE

Introduction

The implementation of the MFL Chemical Hygiene Plan is the responsibility of the ***Chemical Hygiene and Safety Officer***, as directed by all associated Vice Presidents, Deans, Chairpersons, the MFL Director, Principal Investigators and all other supervisory personnel. These personnel will be accountable for the health and safety of employees engaged in activities under their supervision. This responsibility cannot be delegated. Supervisors must realize that it is their responsibility to ensure that workers are educated about safety issues and comply with safety rules. Supervisors must simultaneously promote and insist upon safety.

The Department of Occupational and Environmental Services will assist supervisory personnel in establishing and maintaining a safe working environment. The department will initiate the establishment of standards and regulations for safety, education, information monitoring and recommendations for improvements. Safety Services will also maintain and provide facilities to ensure safety.

Emergencies and General Response Procedures

In case of emergency in the MFL or associated Clean Room Facility the following phone numbers should be utilized, in association with the succeeding General Emergency Procedures.

CWRU Emergency Telephone Numbers:

1. Emergency (Injury, Fire, Life-endangering spill). . . . 368-3333
2. Security Department . . . . ……….368-3333
3. Department of Occupational and Environmental Safety
   a. Radiation Safety Division. 368-2906
   b. Safety Services Division. 368-2907

General Emergency Procedures

i. Alert those working in the critical areas.
ii. Call for help - Dial 368-3333.
iii. Give description and location of the event as clearly as possible.
iv. Indicate if an ambulance is needed.
v. Specify location where the caller will meet ambulance attendants, fire fighters or police.
vi. Do not hang up the phone.

In case of chemical splash:

1. Move victim(s) to nearest emergency shower station.
2. While flushing affected area with water, remove the source of the chemical hazard and any contaminated clothing.
3. Continuing flushing for at least 15 minutes.
4. Seek immediate medical attention by calling 368-3333. Explain to security the nature of the accident.

5. In case of a chemical splash into the eyes, flush them in an eyewash station or running portable eyewash for at least 15 minutes.
6. If a chemical comes in contact with the skin, rinse thoroughly with water by using a safety shower or faucet.

In the event of an accident, serious illness, or injury, and in accordance with **CWRU Procedure Number 1-6a**, ***"Supervisors and employees are not to diagnose, treat or administer emergency medical care to another employee unless they have medical certification for such treatment. Supervisors and employees may not move the ill or injured employee; but efforts may be made to provide privacy, warmth and comfort for the employee until emergency services arrive."*** Call CWRU Security (368-3333). Remember: All injuries are potentially dangerous. It is better to err conservatively and have the injury inspected as soon as possible by appropriately trained medical personnel.

If it is necessary to contact any MFL Management or Staff members in the event of an emergency, please refer to the following list for contact and "pager" telephone numbers:

Dr. Li Chen	Manager	216-308-7967
Ed Jahnke	Staff Member	216-346-9851
Ron Jezeski	Staff Member	216-372-6963

Report all incidents to your department chairperson and the Manager of Safety Services in writing.

Students who suffer injuries in the lab must report to their supervisor (professor) or teaching assistant after receiving assistance. Minor injuries can be treated at the University Health Service. For serious injuries and/or ambulance call 368-3333.

Faculty or staff members who suffer relatively minor injuries during working hours (8:30 a.m.- 5:30 p.m.) can receive treatment at the University Health Service (368-2450). At all other times report to the Emergency Room of University Hospitals.

First Aid Procedures

These first aid tips are intended as emergency measures only. **IF YOU ARE NOT FAMILIAR WITH FIRST AID PROCEDURES, YOU SHOULD CONTACT AN MFL STAFF MEMBER IMMEDIATELY OR CONTACT CAMPUS SECURITY. DO NOT ATTEMPT FIRST AID PROCEDURES IF IT PRESENTS ANY SAFETY RISK.** Promptly consult University Health Services after first aid is applied. All minor non-trivial injuries should be reported to responsible personnel, such as department heads or safety coordinators, and the University's Workers' Compensation Administration.

1. **Bleeding.** Rubber gloves must be worn when handling bleeding individuals. Control bleeding by direct pressure with the hand over a gauze or cloth. Elevating a bleeding arm or leg may be helpful. Apply pressure to pressure points between the wound and heart, if necessary. Some people have a mild shock reaction when they see their own blood. If this happens, have the person lie down and elevate their legs.
2. **Burns.** Application of ice or cold water can lessen the amount of pain and blistering. Do not apply ointments, butter, or similar substances. Major burns require medical care.
3. **Electric shock.** Disconnect power to device or apparatus before touching victim. Mouth-to-mouth resuscitation and external cardiac massage (cardiopulmonary resuscitation or CPR) may also be required. ONLY trained people should do this. Dial 368-3333 for an ambulance.

4. **Inhalation of Toxic Materials** (gases, vapors, fumes, mists and dusts). Anyone who has inhaled irritating or toxic materials should be immediately removed to fresh air and emergency medical services should be called to the scene (call 368-3333). Do not give mouth-to-mouth resuscitation.
5. **Head injuries.** If the victim is dazed or unconscious, call 368-3333 for an ambulance.
6. **Back injuries.** The patient should not be moved unless a life-threatening situation exists. Call 368-3333 for an ambulance.
7. **Shock.** A person in shock should lie down with legs elevated, unless there is bleeding from the head. Keep the victim warm.
8. **Eye Splash.** Flush eyes immediately with running water for 15 minutes at an eyewash station. If contact lenses are worn, remove them before flushing eyes. The injured person should then be sent to medical services.
9. **Small cuts and abrasions.** Clean with soap and water and cover with a band-aid or sterile dressing.

Emergency Response Plan

During the course of normal operations in the ***MFL Clean-Room***, it is recognized that it may be necessary to respond to emergency conditions within the Clean-Room lab space. The following conditions have been generally recognized as requiring emergency response from all personnel in the lab in the event that any of these conditions are present:

1. Loss of power (do not pull the fire alarm)
2. Fire (engage the Fire alarm and Hazard Gas Shut-Off button)
3. Hazardous gas leak (engage the Hazard Gas Shut-Off button)
4. Hydrogen alarm sounds
5. Large chemical spill OUTSIDE a chemical hood (e.g., breaking a bottle of chemicals on the floor)
6. You notice another Lab-User is unconscious
7. Non-gas chemical exposure
8. Physical injury
9. Medical emergency
10. Loss of fume hood exhaust

All personnel, especially registered lab-users, are required to immediately evacuate the lab should any of these conditions exist: without exception.

The following procedure should be utilized in the event of an evacuation:

1. **Immediately** stop what you are doing, aborting your process.
2. Proceed quickly to the closest available emergency exit. Do not run unless you perceive a life-threatening situation exists. ***DO NOT STOP TO REMOVE YOUR CLEAN-ROOM GARMENTS.***
3. When exiting the lab, engage the Hazardous Gas Shutoff button. In case of fire, trigger the Fire Alarm.
4. Check to see that other lab-users are leaving the lab; if anyone cannot exit under his/her own power, call for emergency assistance. ***DO NOT STOP TO REMOVE YOUR CLEAN-ROOM GARMENTS.***
5. After exiting the lab leave exit to the first floor of the Bingham Building and call Security at x3333 and notify them of the evacuation. Provide security personnel with all requested information.
6. Notify MFL Staff, if they are not present.

The waste streams generated within the MFL may be classified according to the following categories, and are handled in accordance with all ***Department of Occupational and Environmental Safety Services'*** regulations and guidelines.

Aqueous Acid / Base Waste

The processes which generate Aqueous Acid / Base Waste are the following:

1. Piranha Organic Clean
2. Metal and Aluminum Films Etch

3. Chemical Develop
4. Buffered Oxide Etch (BOE)
5. RCA Clean
6. Metal Films Lift-Off

All these procedures, without exception, are carried out in the following MFL Clean Room Hoods:

Chemical and Develop Hood

1. Piranha Organic Clean
2. Buffered Oxide Etch
3. Chemical Develop
4. Hydrofluoric Acid dip*

Metal Films Etch / Metal Films Lift-Off Hood

1. Metal and Aluminum Films Etch
2. Metal Films Lift-Off

RCA Clean Hood

RCA Clean

1. Hydrofluoric Acid dip*

*The Hydrofluoric Acid dip is an integral step of the RCA Clean procedure, but may also be done after a Piranha Organic clean procedure for certain thin film device wafers.

Acid and Base Chemicals are purchased in either polypropylene or glass containers. When empty of all chemicals the containers are to be 'triple-rinsed' with De-Ionized water, with the contents dumped down the drain of the hood in which the chemical has been used. The glass bottles are collected for special disposal and the poly bottles may be thrown in the trashcans within the MFL.

The drains for each hood are connected to special PVC piping, designed to be inert to the acid/base waste. The waste is collected from the drains into a neutralizing tank located in the basement of the Bingham Building. The waste stream is then adjusted automatically to a pH solution of between 6.5 and 8.0 and then dumped into the appropriate waste line emptying from the building.

<u>Solvents</u>

The most commonly used organic solvents in the Clean Room include:

1. Acetone
2. Butyl Acetate
3. Methanol
4. 2-Propanol or Isopropanol (IPA)

These solvents are most commonly used for cleaning equipment surfaces and photolithography masks, or stripping photo-resist solution from device wafers.

The solvents may only be used in either the ***Solvent Hood***, located in the **Sputtering/Etch Aisle**, or to clean the ***Wafer Spinner*** located in the **Photo Aisle**. The only exception to this is; acetone is used to facilitate <u>*Metal Film Lift Off*</u> in the ***Metal Etch/Metal Film Lift-Off Hood***, also located in the **Photo Aisle**.

Any waste or scrap solvent should be disposed into the solvent waste container located in the ***Solvent Hood***. All solvent soaked rags used for cleaning should be disposed into the special red waste can located in the **Photo Aisle**. Empty polypropylene plastic solvent containers may be discarded into the any standard waste canister in the MFL Clean Room. Empty glass containers should be retained for disposal in the same manner as glass acid/base containers.

Spill Clean-up

Any minor acid/base spill which occurs in either the ***Chemical and Develop Hood, Metal Films Etch / Metal Films Lift-Off Hood***, or the ***RCA Clean Hood***, may be rinsed down the drain with DeIonized Water. A major spill may require specialized equipment beyond the scope of the MFL to provide, and therefore ***Department of Occupational and Environmental Safety Services*** would be notified.

A minor organic solvent spill may be wiped up with Beta wipes or with spill control pillows available from the ***Chemical Hygiene and Safety Officer*** as necessary. A major spill may require specialized equipment beyond the scope of the MFL to provide, and therefore ***Department of Occupational and Environmental Safety Services*** would be notified.

ENGINEERING CONTROLS

Fume Hoods

The MFL Clean-Room is equipped with four (4) exhaust hoods. Two are located in the **Photo Aisle**, the ***Chemical and Develop Hood*** and the ***Metal Films Etch/ Metal Films Lift-Off Hood***.
A third is located in the **Furnace Aisle**, the ***RCA Clean Hood.*** These three hoods vent by a common fan to a "scrubbed" exhaust system on the roof of the Bingham Building. As previously mentioned, a visual alarm alerts Lab-Users to a "loss of exhaust" condition should this system fail. A system failure requires that all personnel evacuate the MFL Clean-Room facility.

The fourth hood is a stainless solvent resistant steel hood located in the **Metal/Etch Aisle**. It is used primarily for cleaning procedures using the available solvents of the MFL. Also, a small bench-top resist spinner is located in this hood for application of poly-imide resist materials. The fumes in this hood are not scrubbed, but are exhausted to the roof of the building with a powerful ventilation fan.

Scrubber Systems

The MFL operates and maintains three (3) "scrubber" systems. These specialized equipment systems serve to "scrub" toxic airborne materials from the exhausted atmosphere of several specialized pieces of semiconductor equipment, including the ***Chemical and Develop Hood, Metal Films Etch/ Metal Films Lift-Off Hood*** and the ***RCA Clean Hood*** cluster, the ***APCVD Silcon Carbide Reactor*** and the LPCVD Furnace tubes, including ***321-1*** {Silicon Nitride film growth), ***321-2*** {Polysilicon film growth}, ***321-3*** {Doped Polysilicon film growth}, ***321-4*** (LTO/PSG film growth}, and ***323-3*** {Silicon Carbide film growth}. These systems are periodically evaluated and maintained by the MFL Staff, with professional service purchased when necessary to maintain the safe operations of the systems.

Hood Face Velocity Check

Hood Face air velocity is evaluated by ***DOES*** annually. Actual measured values are posted using a small sticker, located on the hood face, and include the following data:

1. Average Air Velocity
2. Date of Evaluation
3. Time of Evaluation
4. DOES Personnel performing the Evaluation

Any hoods that do not meet required safety specifications are adjusted, serviced, etc… until full safety compliance is achieved.

Warning Lights

The ***Chemical/Develop Hood,*** the ***Metal Etch Hood*** and the ***RCA Clean Hood*** are ventilated by the same chemical vapor scrubber and cabinet fan located on the roof of the Bingham Building. If ventilation to these hoods are lost, an amber warning light mounted above each of these hoods will be triggered, providing a visual indicator that hood function has been lost and that all lab-users must immediately evacuate the MFL Clean-Room.

The ***Solvent Hood***, located in the **Vacuum Aisle** is monitored using a ventilation flow sensor. If air flow is diminished or lost, an amber warning light mounted on the front panel of the hood will be triggered. While this condition does not present a life threatening circumstance, lab-users should notify MFL Staff immediately of the circumstance.

The ***MDA Toxic Gas Monitoring System*** is connected to a series of blue warning lights coupled to emergency air-horn sirens. In the event of a toxic gas detection by the system, the lights will begin flashing and the sirens will emit a sonic warning signal, indicating that all lab-users must immediately evacuate the MFL Clean-room.

SPECIALIZED EQUIPMENT SAFETY

Silicon Carbide Reactor

The silicon carbide lab contains a reactor to deposit silicon carbide thin films. A cold wall, atmospheric pressure chemical vapor deposition (APCVD) system consisting of 4 major sub-systems: gas supply, reactor chamber and RF (Radio Frequency) heating, exhaust gas conditioning, and a combined safety interlock and emergency power off (EPO) system is used for this purpose. The first three systems are critical to the deposition of silicon carbide while the last provides an adequate degree of safety for the system and a high degree of safety for the operator and laboratory. Where possible, the system components are enclosed in vented cabinets. There are four cabinets to the system: a gas cabinet, reactor cabinet, gas delivery cabinet and scrubber cabinet. The following diagram illustrates the reactor design.

The reactor chamber consists of a double-walled quartz tube. The inner tube has an inner diameter of 170 mm and the outer tube has an inner diameter of 225 mm. The chamber is encompassed by a ten-turn work coil that is connected to a 50-kilowatt RF generator for inductive heating of a graphite susceptor.

All cylinders for the gas supply are housed in ventilated gas cabinets with purge panels. The gases are plumbed to the system in electro polished, welded, and stainless steel tubing. All connections are made using VCR fittings with nickel-plated gaskets. Silane, diborane, and phosphine gas lines are made of double-walled tubing, with the volume between the tubing under vacuum with gauges to monitor vacuum pressure.

A Westinghouse 50 kilowatt RF generator is used to heat the graphite susceptor. The generator is water-cooled using deionized water, which is pumped through the generator from an RF generator-cooling skid.
The gases used to grow SiC are flammable, highly toxic and are not completely consumed during growth runs. Before venting the exhaust gas to atmosphere, the gases are sent to a scrubber, which burns them is a controlled fashion. This scrubber was purchase from CVD Equipment Corporation.

Safety Systems

The SiC reactor safety systems consist of an Emergency Power Off system (EPO), an interlock system, and the operator. The EPO and interlock systems are physically located in a single rack-mounted chassis, known as the EPO box. A number of critical system parameters are monitored for deviation from nominal operation. The interlocks assure that all parameters are nominal before the flow of hazardous gases can be initiated. When a parameter deviation occurs during operation, the EPO system shuts down the reactor and puts it into a safe state. The system also allows an operator to initiate an EPO by actuating any one of 3 conveniently located red EPO mushroom slap buttons.

To ensure system and operator safety, a set of procedures must be followed before, during, and after the operation of the system. For details concerning these procedures, see the enclosed *Start Up* and *Shut Down* sheets. All of the above components mesh to form a complete safety system.

The safe state of the system is as follows:

1. RF power is turned off
2. Process gas valves are shut off at the gas cylinders and the gas manifold
3. Argon purges the system from the gas manifold through the CVD chamber and exhaust manifold to the scrubber
4. The scrubber remains on so that it can continue to burn any process gases that purge out of the system.

The room, gas cabinets, and MFC cabinet are constantly monitored for toxic gases by the MDA toxic gas system. Should the MDA detect a toxic gas leak it will automatically initiate an EPO.

SiC Operator Training

Operator training consists of an intensive three-week training course that includes operation of the reactor, an overview of the gas delivery system, and a detailed presentation of the safety systems.

The first week consist of a trainee observing the start up, wafer deposition, and shut down procedures of the reactor. An explanation of theory of operation of the SiC reactor and all safety systems is also presented, as well as training for installation, removal, and use of purge panels for all the gas cylinders.

In the second week of training, a new operator is required, under the direct supervision of the instructor, to operate the reactor. There is interaction between instructor and the trainee on issues concerning theory, operation, maintenance, and any other questions that might arise. The objective of this week is to give the trainee guided supervision.

During the third week of training a trainee is expected to operate the reactor with out any guidance from the instructor. The instructor will only interact with the new operator if he or she is about to deviate from any operational procedures, and will intervene if a dangerous situation arises. For a trainee to advance to operator, he or she must demonstrate successful, unguided operation of the reactor to the complete satisfaction of the trainer.

A refresher course is required of all operators who do not use the SiC reactor in a two-month period. The refresher course is a one-day review of the gas delivery and safety systems, as well as the start up and shut down procedures of the reactor. The trainee must demonstrate unguided operation of the reactor at this time.

The following table illustrates the potential hazards associated with gases used during the operations of the Silicon Carbide reactor.

Potential Hazards in the Silicon Carbide Reactor Lab

Hydrogen (H_2)	Highly Flammable Explosion Hazard

Silane (SiH_4)	Pyrophoric: spontaneously combusts upon contact with air. Exposure will cause headache/nausea
Propane (C_3H_8)	Flammable Explosion Hazard
Diborane (B_2H_6)	Flammable Explosion Hazard Potentially fatal if inhaled Respiratory tract burns
Phosphine (PH_3)	Flammable/Pyrophoric **Maybe fatal if inhaled** Respiratory irritant
Electrical	High voltage (440V, 220V, and 110V) in the lab.

SiC Reactor Startup Procedure

The following instructions demonstrate the start-up procedures for the SiC Reactor, with no wafers laded within the deposition chamber.

Date ___________________

Operators ___________________

Run # ___________________

1. _____ Turn key on System Enable Box
2. _____ Power up purifier (if off)

Gas Pressure

3. _____ SiH_4 ___________
4. _____ C_3H_8 ___________
5. _____ PH_3 ___________
6. _____ B_2H_6 ___________
7. _____ Ar ___________
8. _____ H_2 left ___________
9. _____ H_2 right ___________
10. _____ Air ___________

Loading and Pumping Down

1. ______ Chamber Open and Argon gas flowing
2. ______ Record ID #'s of 2 spin dried wafers in log
3. ______ Load wafers

4. _____ Raise Elevator
5. _____ Tighten ring until overpressure is observed
6. _____ Close Ar valve and set MFC to zero
7. _____ Close Process line
8. _____ Pump chamber to 2 Torr
9. _____ Tighten elevator flange
10. _____ Close Pump Line to chamber
11. _____ Backfill chamber with Ar (4 slm MFC) to burst pressure of relief valve (~800 Torr)
12. _____ Let Ar flow through relief valve for 1 min.
13. _____ Turn Off Ar at MFC
14. _____ Open Pump Line to Chamber
15. _____ Pump to less than 2 Torr
16. _____ Backfill with Ar to 750 Torr @ 4 slm
17. _____ *Repeat Above 3 steps*
18. _____ Pump to Base Pressure (< 200 mTorr)
19. _____ Close pump line to chamber
20. _____ Allow to outgas for 2 minutes
21. _____ *Repeat above 3 steps until outgassing is minimal*
22. _____Ultimate base pressure _______ mT
23. _____ Leakup rate over at least the next 10 minute period __________
24. _____ Turn Off Pump
25. _____ Close Pump Exhaust
26. _____ Backfill chamber with Ar
27. _____ Let chamber sit at ~ 800 Torr for 1 min. then open chamber vent valve
28. _____ Wait 2 minutes.

Non-contact Cooling Water

1. ____ Open Return
2. ____ Open Supply
3. ____ Increase NCCW pressure to 10 psi

RF Generator / Bake out

1. _____ Open Desired Cylinders (**except H_2**)
2. _____ Verify scrubber ready (900 °C and purged)
3. _____ Verify purifier ready (400 °C)
4. _____ Close Main Power Switch to generator

5. _____ Verify RF cooling level and flow
6. _____ Close Contacter switch
7. _____ Transformer Voltage ____
8. _____ Ready light illuminates
9. _____ Chamber vent valve should be open
10. _____ Close H_2 cylinder Ar purge
11. _____ Open H_2 cylinder.
12. _____ Open Purifier Bleed to 2.5 SLM
13. _____ Let H_2 purifier stabilize at 400°C.
14. _____ Open Purifier supply valve
15. _____ Open regulator input isolation valve
16. _____ Let sufficient H_2 pressure build up at H_2 regulator (150 psi)
17. _____ Open regulator output isolation valve
18. _____ Flow H_2 into chamber at 18 slm
19. _____ Switch Ar to vent line at 1 slm
20. _____ Wait until purifier temp reaches 380°C
21. _____ Flow H_2 at process flow rate
22. _____ Verify that purifier temp is rising
23. _____ Turn off vent line
24. _____ Turn off Ar at MFC
25. _____ **RUN PROCESS**

<u>SiC Reactor Shutdown Procedure</u>

The ***Sic Reactor*** has a two-step **'Power Down'** procedure:

1. *CVD Scrubber*
    a. To power down the CVD scrubber, press the large red button in the upper left hand corner of the scrubber control panel.
    b. On the South wall of the laboratory is a power box labeled **SCRUBBER:** turn the switch to the **"Off"** position.
2. *Johnson Matthey Hydrogen Purifier*
    i. On the right hand side of the Johnson Matthey Hydrogen Purifier, there is a flow-meter with a bleed-off gas valve. Turn this bleed-off valve clockwise, to halt gas flow. When zero (0) gas flow is achieved, locate the hydrogen gas valve on the back of the scrubber: turn this valve to the "Off" position, i.e., perpendicular to the gas line.
    ii. On the lower left hand corner of the Johnson Matthey Hydrogen Purifier control panel, there is a power switch. Move the switch to the "Off" position.

<u>Refilling Acid/Base Reservoirs on Aqueous Waste Treatment Equipment</u>

Introduction

The following information illustrates the safety protocol for refilling the Acid and Base reservoirs on the Aqueous Waste Treatment Equipment located in the basement of Bingham Building (Room 31). This equipment neutralizes all the non-solvent aqueous waste generated inside the Micro Fabrication Laboratory (MFL) in room 320 of Bingham. This waste stream typically contains any of the following materials:

MATERIAL	FORMULA
Aluminum Etchant (Phosphoric, Acetic, Nitric acids mix)	$H_3PO_4/CH_3COOH/HNO_3$(80/15/3)
Ammonium Hydroxide	NH_4OH
AZ 400K Developer (5% soln)	NaOH
AZ Developer Concentrate (5% soln)	KOH
AZ 312 MIF Developer (5% soln)	$(CH_3)_4NOH$
Buffered Hydrofluoric Acid	HF/NF_4
Hydrochloric Acid (95%)	HCL
Hydrofluoric Acid (49%)	HF
Hydrogen Peroxide (30%)	H_2O_2
Microposit 351 Developer (5% soln)	NaOH
Microposit Developer Concentrate (5% soln)	KOH
Nickel Etchant (aqueous solution with water)	HNO_3
Nichrome Etchant (Ceric Ammonium Nitrate w/ Nitric Acid)	$Ce(NO_3)_6(NH_4)_2$, HNO_3
Nitric Acid (70%)	HNO_3
Phosphoric Acid (85%)	H_3PO_4
Sodium Hydroxide (50%)	NaOH
Sulfuric Acid (95%)	H_2SO_4

The manufacturer, unless otherwise stated, dilutes these materials, with water to the indicated percentage. Materials listed in **bold print** are trade names; the primary ingredient is listed in the formula. Material Safety Data Sheets for all these products are stored and maintained in the MFL Staff office, Bingham 342. The waste treatment equipment is monitored and maintained by MFL staff.

Required PPE

The following PPE must be worn while performing this procedure:

- Vinyl apron, chemically inert model
- Trionic chemical resistant gloves
- Full-face mask **respirator**, with approved vapor cartridges

The PPE's chemical resistance is listed below, as taken from the catalog of the supplier **[Laboratory Safety Supply, 1-800-356-0783].** The first number represents the "breakthrough" time in minutes, while the second number represents the "permeation" time, also in minutes. ***Breakthrough*** is defined as the elapsed time between initial contact of the chemical with the outside surface of the protective material and the point at which the chemical is detected at the inside surface of the material by means of a selected analytical technique. ***Permeation*** is defined as the process by which a chemical moves through a protective clothing material on a molecular level; this occurs in three steps:

1. Absorption of chemical molecules onto the outside surface of the material.
2. Diffusion of the absorbed molecules through the material to the inside surface.
3. Desorption of the chemical molecules from the inside surface to a collecting medium.

	H_2SO_4	NaOH
Coverall:	480/ND	480/NT
Gloves:	ND/NT	ND/NT
Respirator:	NA	NA

(“ND” indicates None Detected; “NT” indicates Not Tested, or test not performed; “NA” indicates Not Applicable.)

NOTE: the CWRU Department of Occupational and Environmental Services (DOES) must certify all respirator use. No operators may execute the subsequent protocol unless they have a valid certification for respirator use.

Titanium Nickel (TiNi) Vacuum Sputtering System

The TiNi Vacuum Sputtering System is a fabrication tool used to deposit TiNi thin films on silicon device wafers. The following procedure covers emergency shutdown of the system.

1. Depress the ***Auto Enable*** switch and ensure that the associated LED indicator is *NOT* flashing.
2. Confirm that the ***Rotation Power*** and Heat Power LEDs are off.
3. Depress the ***HiVac Valve*** switch and ensure that the associated LED indicator is *NOT* flashing.
4. Depress the ***Turbo Pump*** switch and ensure that the associated LED indicator is *NOT* flashing
5. Depress the ***Backing Valve*** switch and ensure that the associated LED indicator is *NOT* flashing.
6. Depress the ***Mech Pump*** switch and ensure that the associated LED indicator is not flashing.
7. Turn off machine power by depressing the red ***‘Stop’*** knob.

MEDICAL ISSUES

Any approved lab-users with medical concerns regarding hazards, potential chemical exposures, or health related questions about working in cleanroom conditions should direct their questions to the ***Chemical Safety and Hygiene Officer***, the ***MFL Manager***, or the **C.W.R.U.** ***Department of Occupational and Environmental Safety*** at any time.

INFORMATION SOURCES (References)

Kovacs, Gregory T.A.: **Micromachined Transducers-Sourcebook.** WCB/McGraw-Hill Publishers, NY, NY. (1998)
Wolf, S., Tauber, R.N.: **Silicon Processing for the VLSI Era, Volume 1-Process Technology.** Lattice Press, Sunset Beach, CA, (2000)

EQUIPMENT LIST

The following is a list of equipment and the manufactures/vendors of the particular piece of equipment: in general, all instruments are tooled for 100mm (4”) wafers.

Measurement Aisle

Instrument	*Manufacturer*	*Tool Description*
FSM 128	FSM Incorporated	Film stress measurement of deposited films.

Toho 500	Toho-KLM Inc.	High temperature film stress measurement, to 500C
Ellipsometer	Rudolph Industries	Measures Si derivative thin films, up to 2 microns
NANO-Spec 4000	NanoSpec Industries	Measures various films and film stacks to 30 microns
DekTak	Veeco Mfg.	Stylus profilometer measures “height” of patterned features
Four Point Probe	Veeco Mfg.	Measures electrical resistance of appropriate thin films
Microscope	Leica	Visual inspection of patterned wafers
Fluorescing MS	Leica	Visual inspection of patterned photo resist on wafers

Vacuum Aisle

Tegal 803	Tegal Mfg. Corp.	Oxide, SiC etch tool
LAM 490	Lam Industries	Polysilicon, SiN etch tool
Discovery 24	Denton Vacuum, Inc.	Metal thin film PVD tool
Technics Etcher	Technics, Inc.	Silicon Dioxide etch tool
Polyimide Spinner	Laurell Industries	Polyimide spin applicator for wafers
Mask Washer	Ultrasonic Mfg.	Mask cleaning tool for 5” masks

Photo-Lithography Aisle

MA6 Aligner	Karl Suss Industries	UV exposure tool for lithography.
Solitec 5110C	Solitec Wafer Processing	Spin application tool for PR coating.
Clean Room Oven	Blue-M/Lindbergh Ind.	Convection oven for curing PR coated wafers.
Plasma Asher	TePla Industries	Oxygen plasma strip process tool for removing PR.
HMDS Oven	Yield Engineering Systems	HMDS dehydration bake, vapor prime oven.
Chemical Hoods	Air Control Industries	Various chemical clean processing w/ DI HOH rinse basins.
Spin Rinse Dryers	Semitool Mfg./Rhetech Inc.	Heated DI HOH rinse w/ heated N2 dry of 100mm wafers.
EVG 501	EV Group	Wafer bonding tool.

Furnace Aisle

LPCVD/APCVD furnaces	MRL Industries	Twelve silicon derivative growth and deposition furnaces.
RCA Clean Hood	Air Control Ind.	Chemical clean hood for 100mm Si wafers.
RCA Spin Rinse Dryer	Verteq, Inc.	Heated DI HOH rinse w/ heated N2 dry of 100mm wafers.