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An Undergraduate Micro Fabrication Course at the Northern Malaysia University College of Engineering

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ABSTRACT

This paper presents the development of a new course conducted by the School of Microelectronic Engineering at the Northern Malaysia University College of Engineering or Kolej Universiti Kejuruteraan Utara Malaysia (KUKUM) in the area of microfabrication. Two related courses offered by the School are namely, semiconductor process technology and microelectronic fabrication. The course consists of a lecture and laboratory component. It is a new approach, as compared to the conventional undergraduate program, which is designed with 60% of the students' contact time, is dedicated to laboratory and workshop work, while the other 40% is for lectures. Therefore, a new 115 m^2 cleanroom was developed and equipped with all basic tools that is necessary to fabricate and test microelectronic devices. The setup is mainly to expose the student with actual cleanroom operation environment. The course content and the format of the courses are presented. The detail of the synopsis and the list of custom designed experiment for both courses are also provided. Such curriculum developed and offered by KUKUM is geared towards promoting the National Industrial Master Plan, especially in the semiconductor industry.

I. INTRODUCTION

This paper describes a comprehensive curriculum for the School of Microelectronics Engineering at the Northern Malaysia University College of Engineering, or Kolej Universiti Kejuruteraan Utara Malaysia (KUKUM). However, the focus of the discussion is on the design, development and operation of the microfabrication. List of custom designed experiments for both courses are also presented. The School of Microelectronics was established on 30th April 2002. The curriculum offered is the first to be developed for an undergraduate programme in Microelectronics, first in Malaysia. The aim of this program is to meet the needs of the industrial manpower requirement.

The curriculum developed by the School of Microelectronics Engineering comprises of three categories of subjects, i.e. Engineering Specialization Courses, Engineering Foundation Courses and University Required Courses. About 92% of the total credit hours are allocated for Engineering Foundation Courses and Engineering Specialization Courses while the other 8% is for University Required Courses. We continually rewise our curriculum by taking into consideration several parties' opinions such as: research findings and feedback from the community especially the industries, requirements of professional advisory bodies such as Institute of Engineers Malaysia (IEM) and Board of Engineers Malaysia (BEM).

Assessment of each subject offered is 60% from course work evaluation and the other 40% from the final examination. The total credit hours required for graduation in the four year programme of full time study is 135 hours, i.e. 120 units for the core courses and 15 units for the University Required Courses.

The entry requirement for our undergraduate program is similar to other universities; a Matriculation Certificate from the Malaysian Ministry of Education, a Malaysian Higher Certificate of Education, a Diploma in Electronics or Computer Technology Engineering from Polytechnic or other qualifications approved by the KUKUM Senate.

II. Microelectronics Engineering Subjects

A brief synopsis of each Microelectronics Engineering specialization subject is provided in Table 1. This would provide a comprehensive knowledge to the students.

Table 1: Microelectronics Engineering Subjects and Synopsis

Subject	Synopsis
Introduction to IC Design	VLSI Devices, CMOS Combinational Logic Design, CMOS Sequential Logic Design, CMOS Layout, Arithmetic Blocks Design, Interconnects, Timing Issues, Memory and Array Structures, Design Methodologies.
Digital IC Design	Hardware Modeling with the Verilog HDL; Event-Driven Simulation and Testbenches; Logic System, Data Types and Operators for Modeling; User-defined Primitives; Models for Propagation Delay; Behavioural Descriptions; Synthesis; Switch-level Models.
Analog IC Design	Bipolar Analog IC Design, MOS Analog IC Design, MOS Analog Subsystem Design, Mixed-Signals Design.
System on Chip	Techniques in IC Systems Design, Mixed-signals Design Issues, On-chip System Implementation, CAD Tools, CORE Design and Intellectual Properties.
MEMS Technology	Introduction to MEMS, MEMS Design and Simulation, Sensor and Actuator Technology, Electrical and Mechanical Sensors, MEMS Fabrication Technology, MEMS Testing and Characterization, MEMS Packaging, IC and MEMS Design comparison.
Semiconductor Process Technology	Cleanroom technology, Cleanroom protocol, Wafer handling, Contamination control, Safety, Semiconductor materials, Silicon technology, Vacuum technology, Wafer preparation, Wafer cleaning, Silicon substrate preparation, Thin Films, Oxidation process, Diffusion in silicon, Wet processing, Lithography process, Mask and Reticule Fabrication, Dry Etching, Deposition process, Ion Implantation.
Microelectronics Fabrication	Introduction to process integration, Isolation Technologies, Thin Gate Oxide, Dielectric, LDD Structure, Well formation, Silicide and contact technology, Multilevel metal and interconnect system, Planar technology, Advanced Lithography process, CMOS process integration, CMOS process sequence, Bipolar process integration, BiCMOS process integration, Memory process integration, Device simulation, Process simulation.
Semiconductor Physics	Electrons in Solid, carrier transport and recombination, PN junction – current voltage Behavior, PN junction – Reverse breakdown and capacity, Metal touch and Partial conductor, silicon – oxide system characteristic, Bipolar transistor, MOSFET, Photonic devices.
Reliability and Failure Analysis	Failure Analysis Technique, Failure Modes, Failure Mechanism, Materials characterization technique, Packaging Technique and Materials, Testing, Reliability, Manufacturing and wafer yield, Statistical Design of Experiment (DOE).

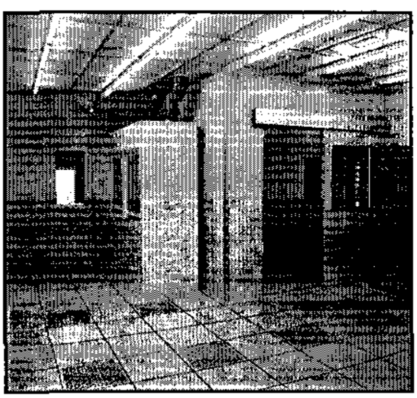
The teaching approach for all the subjects listed above is both theoretical and practical; each three hours of lecture will be accompanied by two hours of laboratory work. This approach is intended to give more opportunity for students to enhance the theory imparted in lectures.

In conjunction with our program objectives, to meet 60% of the students' time for laboratory experiments, our program needs to have well-equipped laboratories, both for the design and process aspects of Microelectronics. Hence, we have Electronic Labs I and II, Digital Electronics Lab, Computer Programming Lab, IC Design Lab, Control Systems Lab, MEMS Design Lab, FPGA Design Lab, IC Fabrication Process Simulation Lab, Microprocessor Lab, Optoelectronics Lab, Testing & Measurement Lab, Power Electronics Lab, Research Lab I, Mask Making Lab, Electronics Workshop, Mechanical Workshop, Students' Project Lab, Failure Analysis Lab, IC Packaging Lab, Electronics Material Lab and Wafer Fabrication Lab.

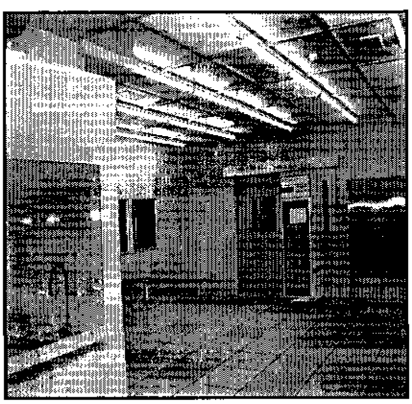
III. MICRO-FABRICATION FACILITIES

Cleanroom Design and Development

The main strength of this emerging engineering program is a newly developed clean room for micro fabrication laboratory experiments. This facility is primarily used for teaching undergraduate microelectronics program leading to a degree. Like all other teaching laboratories in the world, besides teaching the education aspect of the course, our intention is also to expose our students to a fully functional clean room environment.



(a) Photo taken from air shower



(b) Photo taken from exit door

Figure 1: The completed micro fabrication clean room

The clean room, which is designed and developed by KUKUM is the first of this type in Malaysia, built for teaching the undergraduate program. It was completed in December 2003 as shown in Figure 1. The cleanroom was built in an empty existing building. The size of the cleanroom built is approximately 115m^2 with cleanliness class from ISO Class 5 to ISO Class 8. The total area of the cleanroom comprise of yellow room (ISO Class 5), white room (ISO Class 6), characterization room (ISO Class 6), preparation room (ISO Class 6), changing room (ISO Class 7) and grey area (ISO Class 8). The cleanroom layout is shown in Figure 2.

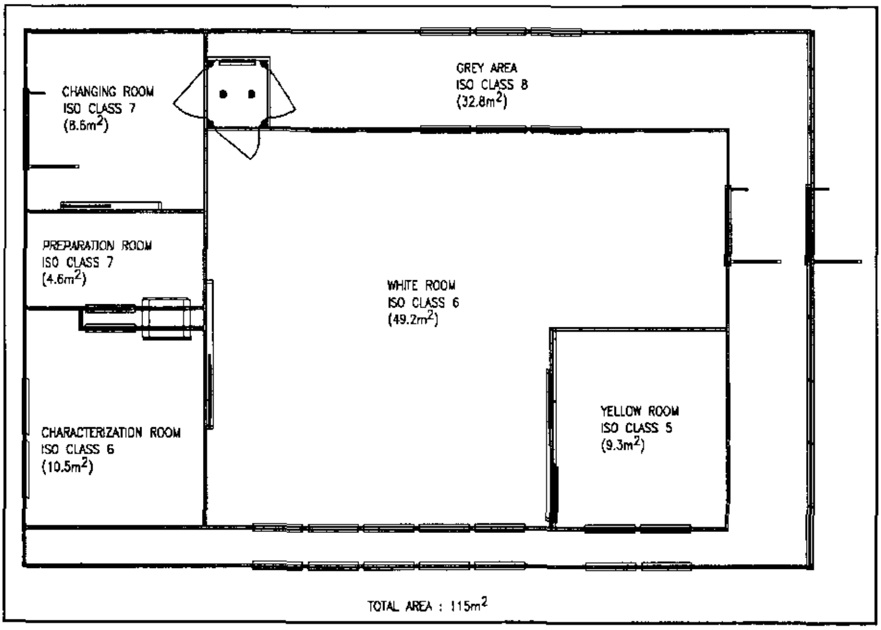


Figure 2: Micro Fabrication cleanroom layout

The cleanroom is equipped with distributed process gases such as purified nitrogen (N_2), oxygen (O_2) and compressed dry air (CDA). A 18.0M? ultrapure de-ionized water system is provided for three fume hoods within the clean room, with two sets located in the white room, and one set in yellow room. Exhaust air from the fume hood is exhausted to the laboratory scrubber system for treatment.

Despite being a teaching facility the cleanroom constructed, was designed and specified to ISO Class 5 cleanroom standard, and provided with features such as air shower, talk through and pass boxe, usually found in commercial facilities. It is our intention to expose and teach students to appreciate the stringent cleanroom protocols, health and safety requirement in addition to the formal course works.

Equipment and Process Setup

The cleanroom currently equipped with ten-process module comprising of oxidation, diffusion, photolithography, physical vapor deposition, wet etching, wet cleaning, wafer test and characterization, scanning electron microscope and E-beam lithography module. With this tool set up, the student should be able to fabricate micro electronic devices. The equipment is categorized, as such, to simplify the process undertaken by the student so that they can have better understanding of the processes. On the other hand, it helps the laboratory management to maintain the equipment as well as for students to process and manage the experiment undertaken. Table 2 shows a list of the equipments for each process module, which is currently available.

Table 2: Process Module and Equipment

Process Module	Equipment list
Oxidation Module	i. Wet oxidation furnace ii. Dry oxidation furnace
Diffusion Module	i. n-type diffusion furnace ii. p-type diffusion furnace
Photolithography Module	i. Photoresist spinner ii. Hot plate iii. Convention oven iv. Exposure system v. Mask Making software
Physical Vapor Deposition (PVD) Module	i. PVD system ii. In-situ deposition rate measuring system
Wet Etching Module	i. Wet etch bench ii. Spin dryer iii. Oxide etch solution iv. Aluminum etch solution v. Photoresist stripping solution
Wet Cleaning Module	i. Wet cleaning bench ii. Spin dryer iii. RCA cleaning solution iv. Hot plate
Wafer Test Module	i. IV/CV test system ii. Electrical probe station iii. Four point probe iv. Conduction gauge
Wafer Characterization Module	i. High power microscope ii. Low power microscope iii. Spectrophotometer iv. Stylus surface profiler
Scanning Electron Microscope Module	i. Scanning electron microscope ii. Sputter coater iii. EDX
E-beam Lithography Module	i. E-beam lithography system ii. PMMA resist

Three process modules are located in the yellow room as a requirement of the photoresist process namely lithography module, scanning electron microscope module and e-beam lithography module. Photolithography module is accommodated in the cleanness room, which is ISO Class 5 at the size of 9.3 m^3. Whereby the other two modules, which also require yellow room, are place in the cleanroom ISO Class 6. The other seven modules are operated in the white room at ISO Class 6. This set-up has been designed to allow up to 12 student, plus two engineers and one lecturer, to work efficiently simultaneously. Although the yellow room lithography was designed and built to ISO Class 5 or class 100 in conventional standard, we found that it is actually closer to ISO class 4 standards.

Currently, our facility and equipment setup is mainly for MOSFET process and devices that allows us to produce NMOS, PMOS, diode, resistor and simple MEMS on 4 inch (100 mm) wafers at the minimum resolution of 25 um. Nevertheless, with the existing of E-beam lithography, we are now able to produce structure down to 50 nm. This combination allows us to extend our current capability to nano technology application.

Cleanroom Operation

To work in the micro fabrication cleanroom, the student is provided with the standard cleanroom garments such as coverall, high booty, face mask, hair cover, rubber glove and safety glass. The students must ware all the garments provided if they going to deal with wafer in the cleanroom. Otherwise, they are not necessarily to wear rubber glove and face mask to cut the operation cost. Even though the cleanroom operation cost is comparatively high, but our intentions is to expose and teach students to appreciate the stringent cleanroom protocols, health and safety requirement. They have to follow strictly the cleanroom protocol and work etiquette.

In order to certify, to enter the cleanroom, each student sits individually for the cleanroom protocol and work etiquette test. For to this examination, the student to attend two classes, which describe in detail about the cleanroom protocol and work etiquette. In this manner, the students will be able to appreciate the protocol and working procedure in the cleanroom. Table 3 describes the detail of the KUKUM gowning and de-gowning procedure. Beside the cleanroom protocol, the students are also taught on the work etiquette in the cleanroom as described in Table 4. These cleanroom requirements and procedures act as guidelines for the student to follow for their own benefit when working in the real environment.

Table 3: *Cleanroom gowning and de-gowning procedure*

Gowning Procedure	De-Gowning Procedure
i. Put on Disposable Hair Cover	i. Enter Air shower (Wait until back door closed).
ii. Put on Hood and Face Mask	ii. Remove gloves and throw into dustbin.
iii. Put on the Coverall (Don't allow coverall to touch the floor)	iii. Walk to gowning bench. Remove one of high top booty.
iv. Walk to gowning bench and wear high top booty	iv. Swing over to pre-clean area and remove another high top booty.
v. Swing over to clean area after wearing booty at one side.	v. Remove coverall, hood, permanent facemask and hair cover. Hang properly to garment cabinet.
vi. Check in front of mirror.	vi. Wear clean shoe.
vii. Put on gloves. (Ensure the glove tight under your garment)	
viii. Walk along the tacky mat to air shower.	
ix. Enter main air shower (maximum three persons). Make few rotations when air is blown. Wait until air blow stops.	

Table 4: Cleanroom work etiquette taught and practice in KUKUM

	Cleanroom Work Ettiquette
i.	Only authorized and trained personnel will be allowed to enter clean room. Visitor must be escorted by clean room personnel.
ii.	Any Contractors/supplier work must be supervised by authorized clean room personnel.
iii.	For safety reason, at least two persons will be at any place in clean room.
iv.	Enter or out from or to clean room must pass through air shower except for emergencies.
v.	Do not touch any product or equipment with bare hand.
vi.	Never touch your garment or other surface when wearing gloves.
vii.	No bare street clothes allowed inside clean room.
viii.	Pregnant women are not allowed to enter clean room.
ix.	Sick worker; flu, coughing etc should be temporarily assigned to tasks outside of the clean room.
x.	No eating or drinking.
xi.	Cutting and drilling work must follow standard procedure. Curtain must be used when perform those jobs. Permission must be obtained first.
xii.	Do not block the airflow from the HEPA filter to the product.
xiii.	No spitting and yelling in the clean room.
xiv.	Do not allow hair uncovered at the front of the head on the fore line.
xv.	Do not wear soiled or sweaty street clothes under the clean room garment.
xvi.	Do not used any external medications.
xvii.	When not in use, clean room clothing should not be allowed to come into contact with any possible contamination.
xviii.	Never comb hair in clean room or changing room. Mirror at changing room only purposely used to check proper garment wear by personnel.
xix.	Wallet may be carried out but worn under garment and not remove in the clean room.
xx.	No smoking at any time inside the wafer fabrication building.
xxi.	Do not expose any street clothing.
xxii.	Rapid walking or any quick motions that create turbulence.
xxiii.	Wearing a torn or soiled clean room garment.

Safety

Student safety is our main concern. We are dealing with a large number of young and inexperienced students who are proned to mistakes. In this respect, the cleanroom and experiments are designed in such a way that is very friendly and safe to operate. No gases and chemicals involved in the experiments are classified as highly toxic and dangerous. For example hydrogen (H_2) gas, which is the main ingredient for wet oxidation is replaced with the vapor that contains H_2 and O_2. Hydrogen gas is a flammable gas that can easily cause fire. Dry etch process, which require toxic gasses is not involved in any of the experiments. All liquid chemicals, except DI water, enter the cleanroom in glass or plastic bottles as appropriate, and all wastes whether liquid or solid, are removed from the cleanroom in the appropriate plastic waste containers by KUKUM OSHA department. We ensure not to mix any chemicals waste. KUKUM OSHA regularly monitors the operation to ensure that the on going activities are done in compliance with all requisite operation procedures.

Safety goggles, face shields and vinyl gloves are the additional cleanroom accessories provided to the student which are necessary to be worn when working with chemicals in the wet bench stations and fume hood. Further more, face shields are only necessary to be used when working with acids. Extra attention will be given by the engineer in-charge to the student particularly when working with the chemicals. However, the student are provided with the Material Safety data Sheet (MSDS) for them to be read and understand the safety requirement before allowing them to work with the chemicals.

The buddy system is used in KUKUM cleanroom. As implemented here, the buddy system requires that a minimum of two personal be inside the cleanroom at all times and they should both be authorized users. This is to ensure the safety of the users. Lists of emergency phone numbers are located in the cleanroom and in the changing room outside the cleanroom. In addition, three fire alarms are installed in three different location in the cleanroom. If the alarm is activated, the student has to stop the experiments and exit the building immediately.

IV. MICRO FABRICATION COURSE DEVELOPMENT

The goal of micro fabrication related course is to produce high-quality graduates in microelectronics who are well prepared with hands-on experience in micro fabrication to make immediate technical contributions theoretically and practically to the semiconductor industry in particular. Mettine the goal requires a so call "hands-on" or lab-oriented teaching approach in which students have the opportunity to become familiar with cleanroom environment, cleanroom work etiquette, cleanroom protocol, processing equipments and metrology test equipment. This hands-on experience combined with good and promising curriculum will give added advantage to the student in the market place. Currently, the course designed is only offers to the microelectronic program students. Due to the lab size limitation, the course enrolment is only restricted to 60 students for each semester. Thus, every year 120 students utilize the micro fabrication cleanroom.

Course Content and Format

There are two micro fabrication-based subjects, which require cleanroom to conduct the experiment, namely, semiconductor process technology and microelectronics fabrication. Semiconductor process technology is the first course offer by the microelectronics program to the second year student which is in the second semester and then followed by the microelectronics fabrication subject which is a third year course offered in the first semester. Generally, semiconductor process technology is a pre-requisite subject to the microelectronics fabrication.

Semiconductor process technology is a 3-credit hour course. Despite having 2 hours lectures in the classroom, students are requested to attend 2 hours practical section conducted in the cleanroom. The topics coves for the lecture are as shown in Table 1. The course enrolment is limited to only 60 students. Due to the limited space and high maintenance cost, only 12 students are allowed to enter the cleanroom at every session. Therefore, five-laboratory sessions are created to accommodate 60 students for each semester. In each lab session, the student will be guided and supervised by two engineers to assist them to do the experiment. With this format, the student will have more exposure and obtain valuable hands-on experience in micro fabrication process, which is difficult to obtain in other universities in Malaysia.

The second course, which is microelectronic fabrication, is a four credit hour course, that offer three hour lectures and two hours laboratory section. The maximum enrolment for the course and lab section is the same as the above courseIt is an advance course in micro fabrication based on subjects which emphasise on advance processes and integration covering both digital and analog devices. The topics covered for the course are shown in Table 1. In addition to the advance processes, students are also taught on the process and device simulation. It will help the students to understand the operation of the device.

Micro Fabrication Laboratory Activities

The experiments for the semiconductor process technology course have been designed to be generic and modular in nature. In this manner, combination of the experiments in this course can be used to fabricate any device proposed for the next experiment offered by microelectronics fabrication course in the following semester. The lists of custom designed experiments are presented in Table 4. A group of two students is required to execute the experiment sequentially until it is complete. At least eight experiments are needes as per course requirement. In this manner, they will obtain a valuable hands-on experience in micro fabrication process.

Table 5 : Custom-designed experiments for semiconductor process course

Exp No	Title
1	Wafer Fab Design and Services
2	Cleanroom protocol and Wafer handling procedure
3	Cleanroom Safety
4	Wafer preparation and Inspection
5	Spin Speed and Photoresist Thickness Characterization
6	Exposure Latitude Characterization
7	Pattern Transfer Process
8	Wet Oxidation (SiO_2) Process
9	Dry Oxidation (SiO_2) Process
10	Aluminium Deposition and Characterization
11	Silicon Oxide (SiO2) Wet etching process
12	Aluminum Metal (Al) Wet etching Process
13	Spin On Boron and Thermal Diffusion Process
14	Spin On Phosphorus and Thermal Diffusion Process
15	IV/CV device characterization

After completing the first experiment related course, the student should be able to fabricate at least simple devices such as diode, resistor, p-n junction as well as NMOS and PMOS transistor. The approach for the second experiment is slightly different whereby they have to treat and execute the experiment as a mini-project. They have to complete three experiments in 15 weeks to meet the course requirement. In principle, the experiment is

categorized in three groups, namely, equipments operation documentation, process characterization and device fabrication as listed in Table 6. The group size for each category varies from 6, 3 and 2 respectively. The students are allowed to discuss among themselves, the proposal of experiment, before starting the running of the experiment. In addition to the laboratory-based experiment, the students are also exposed to produce cleanroom related operating documentation. It will be very useful experience to the student before entering the real work place in the semiconductor industry.

Table 6: Custom designed experiment for microelectronic fabrication

Exp Categories	Exp No	Exp Title
Device Fabrication	1	Fabrication and characterization NMOS Transistor
	2	Fabrication and characterization PMOS Transistor
Process Characterization	3	Photolithography process characterization
	4	Wet/Dry oxidation process characterization
	5	N/P type diffusion process characterization
	6	Aluminum/Oxide wet etching process characterization
	7	Wet cleaning process characterization
	8	Metal deposition process characterization
Equipment Operation Documentation	9	SOP for Photolithography process module
	10	SOP for Oxidation process module
	11	SOP for diffusion process module
	12	SOP for Wet etching process module
	13	SOP for Wet cleaning process module
	14	SOP for PVD process module
	15	SOP for metrology and test module

V. CONCLUSION

We have discussed about our curriculum development as well as our new micro fabrication cleanroom facilities that are being the first ia a Malaysian university teaching fab for an undergraduate program. The cleanroom construction work was designed and supervised by experience team from the school of microelectronics engineering. We also have discussed our strategies in strengthening the infrastructure of the microelectronics curriculum especially the micro fabrication related courses and the experiments designed by the school for hands-on experience. Having a good balance between theory and practice, our badge of young engineers will hopefully be able to contribute significantly to the demanding needs of the manpower requirement in the microelectronics industry in Malaysia.

Even though our cleanroom is still new, we already have few research projects, which are in progress.. This is due to the good teamwork spirit, and a combination of experienced academic staff from industrial as well as educational background.

VI. ACKNOWLEDGEMENT

The authors would like to thank all staff members of the School of Microelectronics Engineering for their technical advice and contributions, either directly or indirectly.

VII. REFERENCES

1. Ibrahim Ahmad and Nasri Sulaiman. (2002). Review on policies, research & development microelectronics industry in Malaysia. *ICSE.*

2. *Malaysia Industrial Development Authority.*(1993). Annual Report 1.

3. *KUKUM-Industry Forum-1.* (1993).Report.

4. Lynn Fuller, (1993) Undergraduate Microelectronic Engineering Programs and Laboratory Facilities. *Education News-Newsletter of IEEE Educational Board.*

5. Muhammad A. Khaliq. (2001). Undergraduate Microelectronics Education in Engineering and Technology Programs at Minnesota State University, Mankato. *Education News-Newsletter of IEEE Educational Board.*

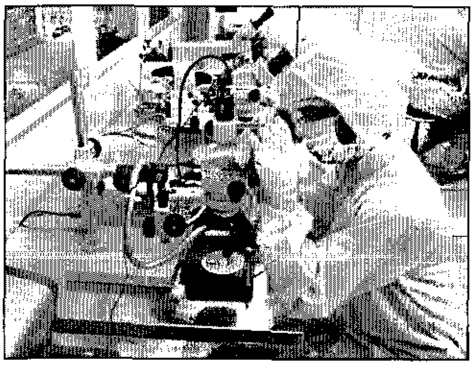
6. M. Mahmudur Rahman and Cary Y. Yang. Undergraduate Microelectronics Education. *Education News-Newsletter of IEEE Educational Board.*

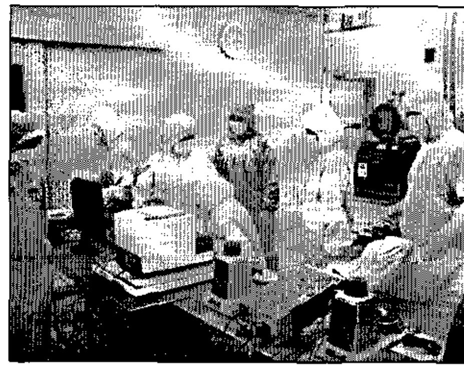
7. Robert W. Hendricks, Louis J. Guido, James R. Heflin, and Subhash Sarin. (2003). An Interdisciplinary Curriculum for Microelectronics. *Proceedings of the 2001 American Society for Engineering Education Annual Conference & Exposition.*

8. S. Parke, S. Duttagupta, S. Burkett, N. Rafla. (1997). *"A New Microelectronics Program at Boise State University",* Proceedings of Twelfth Biennial UGIM Symposium, 40-42.

9. L. Savage. (1997). *"Universities offer hands-on training",* Solid State Technology, 57-61.

APPENDIX
General Views of the Cleanroom in Operation

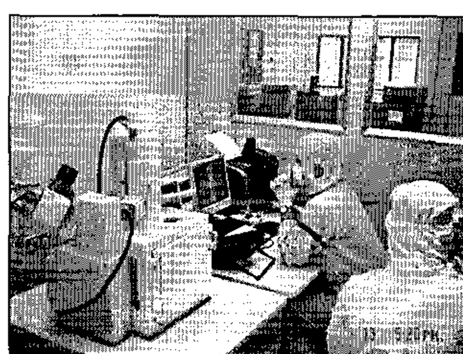

(a) optical observation


(b) Resistance measurement


(c) film thickness measurement


(d) step height measurement


(e) photoresist coating


(f) e-beam lithography