From Classrooms to the Real Engineering World: The Training Program in the Microelectronics Research Center at Georgia Tech

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Abstract—The purpose of this paper is to introduce a training program that helps students transfer their classroom knowledge to hands-on equipment-operating and device-processing skills in the Microelectronics Research Center at the Georgia Institute of Technology, Atlanta. The program is designed to bring down the barrier between engineering students and well-equipped research facilities, while decreasing the mistakes caused by new users. Since the program started three years ago, more than 500 on-site classes (a one-time class with a maximum of eight attendees per class) have been offered, and more than 3000 attendees have gone through the program. The program has had a strong impact on clean-room operation and the processing capability in the center. More importantly, students are prepared more thoroughly for the real engineering world.

Index Terms—Clean-room operation, device fabrication, equipment training, microelectronics research, processing training, student preparation, student training, training program.

I. INTRODUCTION

Imagine that a new graduate student was instructed by his or her advisor to fabricate an advanced device in a class-10 or class-100 clean room. The student’s knowledge of the fabrication procedure is limited to a few books or papers. He or she learned a few tips from his or her advisor. But when the student entered the clean room and discovered hundreds of different kinds of instruments and equipment in a facility a few thousands square feet in size, he or she did not have a clue where to start. When he or she is trying to find a staff member to ask a question, he or she learns that staff members are extremely busy in repairing equipment with no time to systematically explain the equipment and processes to him or her.

This typical scenario in a university microelectronics research laboratory/center is usually handled by the laboratory/center, depending on their specific situations. For example, the Stanford Nanofabrication Facility (SNF), Stanford University, Stanford, CA, uses staff members for all of its equipment and processing training for a fee. To receive individual training at SNF, the user must have had, at minimum, safety training and a coral account. The training staff will conduct the equipment and processing training through appointment [1]. The Berkeley Microfabrication Laboratory (Microlab), University of California, has established an Equipment Qualification protocol [2] to ensure that a new user becomes a general qualified user before he or she is allowed to use the equipment independently. The new users are responsible for familiarizing themselves with the clean room and its equipment by reading the manuals and working with qualified users. The staff of the Microsystems Technology Laboratories (MTL), Massachusetts Institute of Technology (MIT), Cambridge, provides training to all new users of the facility to ensure safe and careful operation of MTL equipment. The training consists of a series of “hands-on” sessions and continues until the user is comfortable with the equipment and the staff member is convinced that the user can safely and effectively operate the piece of equipment [3]. One of the prerequisites for the MTL facility training is completion of the Microelectronics Processing Technology (6.152J) course. The class introduces the theory and technology of integrated-circuit fabrication and involves basic processing techniques, such as diffusion, epitaxy, photolithography, chemical vapor deposition, and plasma etching. It provides background for research work in microelectronics.

Different from all of the previously described training programs, the approach taken by the Microelectronics Research Center (MiRC), Georgia Institute of Technology (Georgia Tech), Atlanta, is to organize the experienced clean room users to train incoming new users on a monthly basis without charge. This paper will explain in detail how the rigorous equipment and processing training program, as a part of the CMOS as a Research Platform project [4], helps the new users of the MiRC clean room to excel in an orderly fashion. The program structure, the training classes, and the impact on the advanced devices research at Georgia Tech will be discussed.

II. PROGRAM STRUCTURE

The training program at MiRC is designed to teach new clean-room users basic equipment-operating procedures and basic device-processing skills in the clean room to meet their research needs. The trainees may never have been previously exposed to a clean room. They may come from nonengineering disciplines and may be from nonelectronics industries. Four important components have been constructed to make sure that training goes smoothly: a training team, a set of online instructions for equipment operation and basic processing, a web-based training administration, and a dynamic training development, as shown in Fig. 1.

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The training team consists of a training manager, 20 equipment trainers, three processing trainers, two safety trainers, and one web administrator. Except for the training manager and three MiRC staff, all other personnel are either graduate or undergraduate students who have been working in the center’s clean room for at least one year. They have support from their academic advisors to participate in the training program without compensation so that the training program might remain free of direct charge for trainees and their advisors. The training manager and three staff members are full-time employees of the MiRC. They spend less than 10% of their time for the training program, focusing mainly on orientation, safety training, special equipment training, processing training, and training administration. Since experienced clean-room users conduct the majority of training on a volunteer basis, there is no specific budget for the training program from MiRC.

Every piece of major equipment in the clean room has a customized online instructional explanation (http://cmos.mirc.gatech.edu/documents/equipment/) of its usage written by a training team member or a staff member, based on the operation manual provided by its manufacturer. A few readings are required by equipment specialists and the training manager before the instructions are approved for web publication. Since the instructions are online, all potential clean-room users will be able to access them without going into the clean room. This web access is particularly beneficial for off-campus users, for they may determine whether or not certain equipment is useful for their work without taking a trip to midtown Atlanta.

One important facet of the training program is the dynamic training development. It constantly develops new online instructions as new machines become available. It also looks forward to better technology, such as nanotechnology and biotechnology, and makes them part of the training portfolio.

The web-based administration handles class requests, class announcements, class sign-ups, trainee check-off requests, trainer evaluations, training program evaluations, and training database management. It makes the training program a true paperless process.

To recognize the volunteers who offer their service to the training program, MiRC issues certificates, signed by the center director and the training manager, to participating trainers on a yearly basis. A top trainer and an honorable-mention trainer will be elected by the trainees each year based on performance. The name of the top trainer of the year will be permanently displayed on a plaque mounted in the clean-room hallway.

III. TRAINING CLASSES

The training classes offered in MiRC include clean-room orientation, two kinds of device-processing training, two kinds of equipment training, and one chemical safety refresher. Two processing trainings are the complementary metal–oxide–semiconductor (CMOS) baseline processing training on a daily basis, and a specific processing module training as the need arises. The equipment training consists of monthly general equipment training and need-based special equipment training.

As shown in Fig. 2, the program requires all trainees to first go through the clean-room orientation and then request either equipment training or processing training. The chemical safety refresher is given periodically to all new and existing users. This section will show the detailed logic and sequence of the training program.

A. Clean-Room Orientation

The clean-room orientation familiarizes a new user with the clean-room environment, which is totally different from other regular engineering laboratories. During orientation, a staff member will first cover general safety topics, such as personal protective equipment, chemical safety, electrical concerns, and evacuation plans. He will then explain clean-room policies and procedures and equipment training and usage. The clean-room orientation is a mandatory prerequisite before anyone can access the MiRC clean room.
B. Equipment Training

Equipment in MiRC is divided into two categories: generally accessible and special permission required. Therefore, the training is also divided into two categories: monthly general equipment training and need-based special equipment training.

The majority of equipment in the MiRC clean room belongs to the generally accessible category. Therefore, most equipment-training classes are designed for them. To better use and manage resources, the training classes are arranged in week-long sessions offered on a monthly basis. There are 16 machineside training classes offered per session. Each class covers one particular piece of equipment such as the Karl Suss MA6 mask aligner, Hitachi scanning electron microscope (SEM) & Gold Coater, surface technology system plasma-enhanced chemical-vapor deposition (STS PECVD), plasmatherm inductively coupled plasma etcher (ICP), and CVC DC sputterer. The class size is limited to eight trainees on a first-come, first-serve basis.

Fig. 3 shows the registration statistics of the training sessions (vertical axis on the left) and accumulated number of attendees (vertical axis on the right). It indicates that more than 2500 attendees have gone through these equipment-training classes alone since the training program started three years ago. These equipment-training classes have been the most popular classes in the training program.

A potential equipment user must go through on-site group training and a one-on-one check-off before he or she is allowed to operate any equipment in the clean room. The following is a more detailed procedure of how an individual becomes eligible to access clean-room equipment.

Potential trainees are required to consult with their advisors or MiRC trainers to get approval on which equipment they should be trained. Planning for at least one month ahead of time is strongly encouraged since the training class is offered once a month.

Once the trainees decide which equipment they wish to be eligible to use, they go to http://www.mirc.gatech.edu/training to sign up for a class. As mentioned previously, sign up is on a first-come, first-serve basis. If they are unable to sign up for a class because the class is full or is not in session, they can request a new class from the website. After signing up for the classes, the trainees are required to read the online equipment instructions from the web page http://grover.mirc.gatech.edu/instructions.shtml before the actual group training to maximize training effectiveness.

The trainers and the trainees work closely with the equipment during the group training (Fig. 4). The trainers of each machine will show the basic operation, the application, and some do’s and don’ts. The trainees are encouraged to ask questions and perform hands-on operations under the supervision of the trainers.

After the initial group training, the trainees are allowed to operate the machine with the help of their research group members or friends who have been authorized to operate the machine independently. When the trainees feel sufficiently comfortable and confident to operate the equipment, they are required to make an appointment with their trainers to be checked off. At the one-on-one check-off session (Fig. 5), the trainers will determine whether the trainees are qualified to independently operate that particular piece of equipment. The trainee becomes an equipment user as soon as the trainer checks him or her off.
tool over another. Once approved, a special training session will be arranged for a particular group of trainees. Similar training procedures will guide the trainees to their independent operation.

Statistics also show that many students take the advantage of this free training program and participate in different training classes just for the purpose of finding the best way to do their research. As E. Zheng, a current Ph.D. student, expressed, “The first time I got into the clean room, I had no idea how to get my work done, and especially didn’t know how to operate the equipment at all. Through the training program, I have not only learned how to operate the equipment, but also gained the knowledge of which machine is good for what process. For example, after comparing how the E-Beam Evaporator and DC Sputter work, I will use the E-Beam Evaporator for the seed layer deposition for MEMS [microelectromechanical systems] switches since I need the high stress and smooth surface. I have also learned from the training program that I need to use the E-Beam Evaporator for lift-off process since the deposition is more directional. If I had not gone through the training program, I would not have the systematic knowledge of each machine, which means I wouldn’t have understood the related process so well. The training program provided me with the processing knowledge of patterning, metallizing, and depositing dielectric materials and helped my research in design and fabrication of microwave structures to get started quickly and smoothly.”

C. Processing Training

To facilitate advanced device research and to establish a device fabrication-friendly culture in the clean room, MiRC is working to establish a variety of baseline processing sequences. Currently, a CMOS baseline processing training program is being offered to graduate students. The baseline processing training mainly focuses on familiarizing researchers with the N-well, 2-metal, 2-poly process baseline and its recipes, while other facets of the CMOS platform will also be introduced. As of today, there are at least six different research groups that have participated in complete processing training, and three research groups are using the CMOS baseline processing to integrate/fabricate the advanced devices. The syllabus of the CMOS baseline training is listed hereafter. The whole baseline training takes approximately 15 weeks on a 4-h/week basis.

1) MiRC CMOS Baseline Processing:
   1) Introduction to the CMOS platform
      Background, summary, and operation of the platform
      Lecture: 1 h;
   2) Simulations
      CMOS process simulation and the cross section
      Lecture: 2 h;
   3) Equipment operation
      All CMOS-related equipment and its operation
      Lecture: 2 h; CR: 4 h;
   4) Processing techniques
      CMOS-related processing techniques, such as tool cleaning, wafer handling, and processing integration
      Lecture: 2 h; CR: 4 h;
   5) Chip layout and lithography procedure
      Description of mask levels and their alignment
      Lecture: 2 h; CR: 4 h;
   6) Test and measurement
      In-line test and final test of the CMOS chip
      Lecture: 2 h;
   7) Process flow and recipes
      Familiarize the processing steps and related recipes.
      Work with own wafers.
      Lecture: 4 h; CR: 33 h.

For those who are interested in device processing but are unable to commit to a long period of time, MiRC also offers individual processing module training free of direct cost to the users. The modules include wet/dry oxidation, low-pressure chemical-vapor deposition (LPCVD) nitride and/or polysilicon growth, reactive ion etching (RIE) nitride and poly etch, optical lithography, multilevel interconnection, or any combination thereof. They are offered on a need basis. This kind of training is best for the groups that make passive and/or simple devices.

For example, a chemical mechanical polishing (CMP) research group in a school of mechanical engineering wants to study its polishing technique on dielectric and/or metal, with line/spacing of patterns around 1 μm, in wafer scale. This project does not require the knowledge of all of CMOS processing. Therefore, the training for this group
focused on wet/dry oxidation, optical lithography, PECVD nitride/oxide growth, metal sputtering/electroplating, and RIE dielectrics/metal etch. The training of the combination of the individual processing modules for the group helped them to understand the real semiconductor processing procedures and offered them an opportunity to apply their CMP technique, which was designed for unpatterned wafer polishing, to a study on the dishing and erosion of copper vias on a patterned silicon wafer. Dr. C. Zhou of Lam Research, who was a Postdoctoral Fellow in charge of the CMP project while in Georgia Tech from 2000 and 2002, said, “The MiRC training program provided me with better technology for advanced CMP research and helped me raise my research goals. I am still benefiting from what I have learned from the MiRC training program even though I am now with a major semiconductor equipment manufacturer. I am glad I participated in the MiRC training program. It really prepared me well for what I need to do daily here.”

To help those who never performed device research previously, the training manager keeps daily office hours to offer free consultation on mask making and processing basics. Trainers are also available in the clean room to answer questions on processing and device integration.

### D. Chemical Safety Refresher

The purpose of this refresher seminar is to review chemical safety in the clean room of the MiRC on a semi-annual basis to keep users alert to potentially dangerous chemicals and to be aware of the risks. The seminar focuses on prudent general chemical handling with emphasis on hazardous chemicals commonly encountered in the clean room.

Specific topics to be covered include types of chemical hazards, safety information, safety equipment, and safety procedures. Fig. 6 shows a chemical safety refresher seminar in session with over 100 attendees.

### IV. RESULTS AND IMPACT

The direct results of the training program and its impact on the clean-room operation and processing capability can be summarized with the following three conclusions.

#### A. More Users in the Clean Room

Before the standardized training program was established, only the students who had some fabrication experience or those who had friends in the clean room were using the clean room. The training program systematically explained clean-room equipment and processing to the students, bringing down the barrier between students and a well-equipped device research facility so that more and more students, including those in the schools of Electrical and Computer Engineering, Mechanical Engineering, Materials Science and Engineering, Physics, Chemical and Biomolecular Engineering, Chemistry and Biochemistry, Industrial and Systems Engineering, and Biomedical Engineering at Georgia Tech, could easily become familiar with the MiRC clean room and use it to perform their research.

People use the MiRC clean room as their primary research laboratory while they are with Georgia Tech. They also carry the skills learned from MiRC to their real job even though it might not be the same as what they performed in the MiRC clean room. Tazrien Kamal, a former user of the MiRC, wrote, “As a process integration engineer at Advanced Micro Devices, Inc. (AMD), I do not directly work with the tools; however, it is important for me to have a basic understanding of different processing tools so that I can communicate with the process engineers and understand their concerns and issues with the tools and process variations. The time I spent at the MiRC training program, doing hands-on work, definitely has helped me in this respect. Better understanding of process variables enables me to design processes that are more robust yet meet the design requirements.”

Fig. 7 shows the number of clean-room users in the past seven years. It clearly indicates a sharp increase between the years 2000 and 2002, which is largely because of the free and friendly training program.

#### B. Better Processing Techniques

MiRC of Georgia Tech was basically a workshop for small device research, such as miniature actuators and sensors, optoelectronic devices, and some device-related material research before the training program started. There was no active silicon device research and no standard processing activities at all. The device fabrication capability was at the level of about 3 μm.

The introduction of E-beam lithography, 1-μm CMOS baseline technology, and related processing techniques to the MiRC clean room, by the processing training program, has improved the clean-room processing capability in two major areas: narrower lithography technique for making individual and/or integrated devices with better functionality and finer thin-film techniques for MEMS devices.

Clean-room users can now learn and use the 1-μm-or-less lithography technique to make radio-frequency devices, optical devices, sensing devices, fuel-cell devices, ultrasonic devices, and other CMOS-compatible devices. Fig. 8 shows a 1-μm line-space SiO₂ stripe array coated with Ta–Cu seed layer for CMP research.

Utilizing the processing modules from CMOS baseline also raised the MEMS processing capability to a higher level. The training and application of LPCVD processing to obtain 400-nm conformal coating (Fig. 9), cavity sealing, waveguide layers, and membrane fabrication has pushed the integration of CMOS and MEMS devices at MiRC further toward reality.

In the second half of 2003, MiRC will finish the installation of an advanced E-beam nanolithography machine and the development of baseline E-beam lithography and related processes.
Fig. 7. MiRC clean-room usage in the past seven years.

Fig. 8. Cross section showing Ta–Cu seed layer on a 1-μm-wide SiO₂ stripe array.

Fig. 9. 400-nm conformal coating of high-temperature oxide on silicon.

Fig. 10. Mask production in recent months at MiRC.

integration. By then, MiRC will be well positioned to train students on nanofabrication skills so that they will be ready for a variety of nanoscience and nanotechnology activities when they graduate from Georgia Tech.

The processing seminar series offered by the training program has constantly challenged device researchers at MiRC for their processing techniques. For example, a Lithography and Mask Making at MiRC seminar given in February 2002 sprouted a mask-making frenzy in the following months (Fig. 10) which is obvious evidence of the researchers’ desires to develop smaller and more complicated microelectronics devices at MiRC. Given the fact that many research groups either did not possess the technology of optical lithography or did not know how to design and construct a fine mask, the processing training offered a better technique for their research.

C. Improved Device Culture and Equipment Maintenance

Under the influence of the CMOS baseline and the device-processing training program, many device-related projects are established in MiRC clean room. Projects making active devices are also on the rise. The number of lithography steps involved in fabrication has been increased from less than five to 19.

Clean-room users now understand that more than one piece of equipment and more than one processing step are often needed to make a device. Therefore, a set of well-maintained equipment and its scheduling/usage policies are extremely important to the success of the device fabrication process, which often demands high yield.

The device fabrication process cannot afford equipment failure during processing. As expectations of equipment status become higher, the equipment status checking and preventive maintenance has been included in the CMOS equipment maintenance schedule.

V. CONCLUSION

The training program in the MiRC at Georgia Tech has attracted more users to the clean room by lowering the barrier between engineering and science students and well-equipped device research facilities. It has also elevated the research and development capability of the device integration in the clean room via its processing training classes. With all these improvements, students at Georgia Tech have not only been provided with an excellent environment for creative thinking, but have also been prepared more thoroughly for the real engineering world, as reflected in the following quotes from former students of Georgia Tech.
Dr. L. T. Seals, Member of Technical Staff, Hewlett-Packard Corporation, stated, “While I was a graduate student at the Georgia Institute of Technology, I found the MiRC training program to be an invaluable part of my education. Through both formal interactions with the MiRC technical staff as well as informal collaboration with various research scientists, I was personally able to develop a thesis topic that led to patent-pending research. Upon graduation I found that exposure to industrial practices, procedures, and technologies gleaned from the MiRC made me more attractive to prospective employers. The technical skills that I learned through the MiRC training program were of equal value as my academic education to major corporations. My ability to obtain a research position at Hewlett-Packard Corporation as well as various other research opportunities were greatly enhanced by my experiences at the MiRC of Georgia Tech.”

Todd G. Ulmer, a Staff Member at MIT Lincoln Laboratory, also noted, “The MiRC training program helped me get up and running in the clean room quickly and efficiently. Thanks to the personalized attention I received via the program, I learned not just to navigate the control interfaces of the processing tools, but also some of the fundamental physics and chemistry behind the processes. The hands-on instruction provided practical engineering experience that no textbook or traditional classroom course could hope to offer. The processing skills I acquired in the training program were essential to the success of my doctoral research and are utilized daily in my career as a device engineer at a federally funded research and development center.”

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REFERENCES


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