2006-1635: DESIGN OF A MICROELECTRONIC MANUFACTURING LABORATORY

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Design of a Microelectronic Manufacturing Laboratory

Abstract

The design of an undergraduate microelectronic manufacturing laboratory for teaching will be described in the following paper. This laboratory emphasizes learning the processes of semiconductor manufacturing and clean room protocol. The laboratory is housed in a 500 square foot, class 10,000 facility.

In the laboratory the students, with a junior standing and a science based background, will use a pre-made six mask set to create P and N type transistors as well as inverters and diodes. The students will be conducting oxidization, RCA clean, photolithography, etching, diffusion, metallization and other processes. A brief description of these processes and the methods used to teach them will also be described. In addition to these processes students will also learn about clean room protocol, chemical safety, and testing devices. All of these skills will be marketable to future employers and graduate schools. These same skills and processes will be covered in a seminar course for educators, with the main purpose of inspiring the high school teachers to teach about semiconductor manufacturing.

The cost effective design is what makes the laboratory unique. The expenditure control is important due to the size of the Electrical Engineering department. The department has only 250 undergraduates and 40 graduate students, thus internal funding is difficult to obtain. A user fee paid by the students will cover the funding. This fee will be small and manageable for any college student.

Introduction

Microfabrication is the cornerstone of many important research and industry areas. It is fundamental in the design and building of electronic devices, directly coupled to microelectromechanical systems (MEMS) and instrumental in nanotechnology. Introduction to the basic concepts of microfabrication as an undergraduate is imperative. The learning experience is enhanced if the student has the opportunity to learn the fundamentals while concurrently being exposed to the actual microfabrication processes in a hands-on laboratory setting. A laboratory of this type will not only be useful for future engineering jobs/training, but will also stimulate interest in graduate study of microelectronics and microfabrication fields. Many higher education institutions have successfully implemented microfabrication courses for undergraduates into their curricula. A common factor in these programs is a laboratory component where students are able to reinforce the theoretical principles learned in the classroom. This practical experience creates an improved understanding of the fundamental issues and creates a well-rounded engineer or scientist. This experience also prepares the graduating engineers to meet the demands of research and industry.

Supported research programs and the need for training demonstrated that there was a real need for a curriculum that includes microfabrication technologies in the state.

Previously, our state did not have a program that incorporated microfabrication into the curricula, although several faculty members at Montana State University have in the past and continue to support research programs that focus on the development of microdevices and related fields. There are also several local companies that require personnel to be trained in microdevice design, fabrication and testing.

Discussion

The primary objective of creating the new microelectronic fabrication course was to develop and implement a laboratory-intensive course that would train undergraduate students in microfabrication technologies. The objective has been completed. The course exposed students to a limited set of microfabrication tools and clean room safety protocol. It focused on the fabrication techniques used to create basic PMOS and NMOS transistors. A second course is planned that will expand on the fabrication skills and reinforce design issues pertinent to microelectromechanical systems (MEMS), culminating in the fabrication of prototype MEMS device.

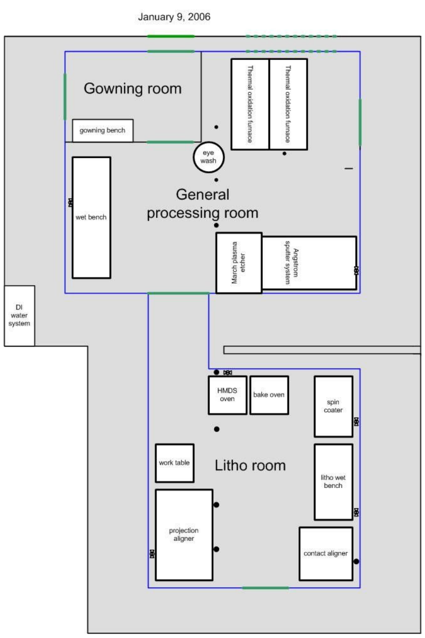

Figure 1. Clean Room Layout

The success of the primary objective required two subtasks to be completed. The first was the development of the laboratory space and the second the development of the course material. The Electrical and Computer Engineering (ECE) department had already allocated 1000 square feet of laboratory space and the Dean of Engineering budgeted funds to modify the facilities and began the instrumentation of the space. The results were a 500 square foot, class 10,000 facility. (See Figure 1**)**

Once the laboratory was designed and the appropriate equipment was installed, a test run was completed to demonstrate the functionality of the equipment and laboratory design. The laboratory course material was adapted from similar programs at other larger universities[1,2]. After the laboratory was effectively demonstrated, the course was offered to the undergraduate students. The initial offering of the class had an enrollment of 13 students, a mixture of juniors, seniors and graduate students from the Electrical and Computer engineering department. This first offering was not advertised across the campus in order to reduce enrollment and ease the initial implementation of the course material. The textbook used for the course was Introduction to Microelectronic Fabrication by Jaeger, the fifth volume in Modular Series on Solid State Devices[3]. The future offerings of the microelectronic fabrication will be opened to students with junior standing in the colleges of Letters and Sciences and Engineering.

The laboratory course material was developed as a summer assignment for an undergraduate senior. This material was based on similar work done at other universities[4-6]. The student, who had taken the VLSI design course at MSU, was given the responsibility to develop the mask sets that were used in the laboratory. He spent the next three months designing the six masks required to produce the NMOS and PMOS transistors as well as other pertinent test structures and devices. The devices on the masks were designed to show different properties of the device as well as semiconductor physical attributes. The set of 6 masks defines each process. The formation of an n-well, n+ and p+ regions, contacts, gate oxide and a metallization layer are defined on the masks. The masks can be used as a full set of six or a shortened course can be done with just four masks. From the whole six mask set a variety of devices defined including resistors, diodes, 2 types of p and n type MOSFETs and inverters. The device's sizes vary from 160 x 190 micron active area transistors to 6 x 12 micron transistors. This range in devices shows the difference in current handling capabilities due to size and other attributes. The masks also define resistors to show the change in resistance of a metal with respect to size and shape. Diodes defined by the mask set are used to demonstrate the built-in voltage of a p-n junction due to doping concentration. The masks are also designed to show the difference of mobility between electrons and holes with the use of balanced and unbalanced inverters. Showing these properties of semiconductor devices to the future engineers is important to their fundamental understanding of how these devices work.

After the masks were designed and manufactured, the testing of the fabrication sequence was started. The same student who designed the masks did this fabrication sequence as an undergraduate research course. A shorted fabrication sequence was initially tested using only 4 masks. The four mask set includes the n+ region, gate oxide, contacts, and the metallization layer. This fabrication sequence, a shortened version of the laboratory for the students, started off with the oxidation of a four inch p type silicon substrate. The sequence then progressed through photolithography, RCA cleaning, and then diffusion of phosphorous. After the diffusion, the wafer was stripped of all thermal oxide and phososilicate glass (PSG) and the thermal oxide was grown again. The wafer then progressed through photolithography again to define the area the gate oxide would be grown. The gate oxide is 1000 angstroms of wet oxide. From here the contacts were defined by photolithography and cleared using a 6:1 Buffered Oxide Etch (BOE) solution. The metal was deposited using a Modulab[7] Physical Vapor Deposition (PVD) system (shown below), and for the last time the wafer progressed through the photolithography sequence and the last processing step was completed. A Phosphoric-Acetic-Nitric (PAN) etch was used to remove the excess aluminum. Testing the first fabricated wafer was done on a Cascade Microtech RF-1 probe station using an Agilent B1500A semiconductor analyzer. The equipment used is shown in figure 2 on the next page.

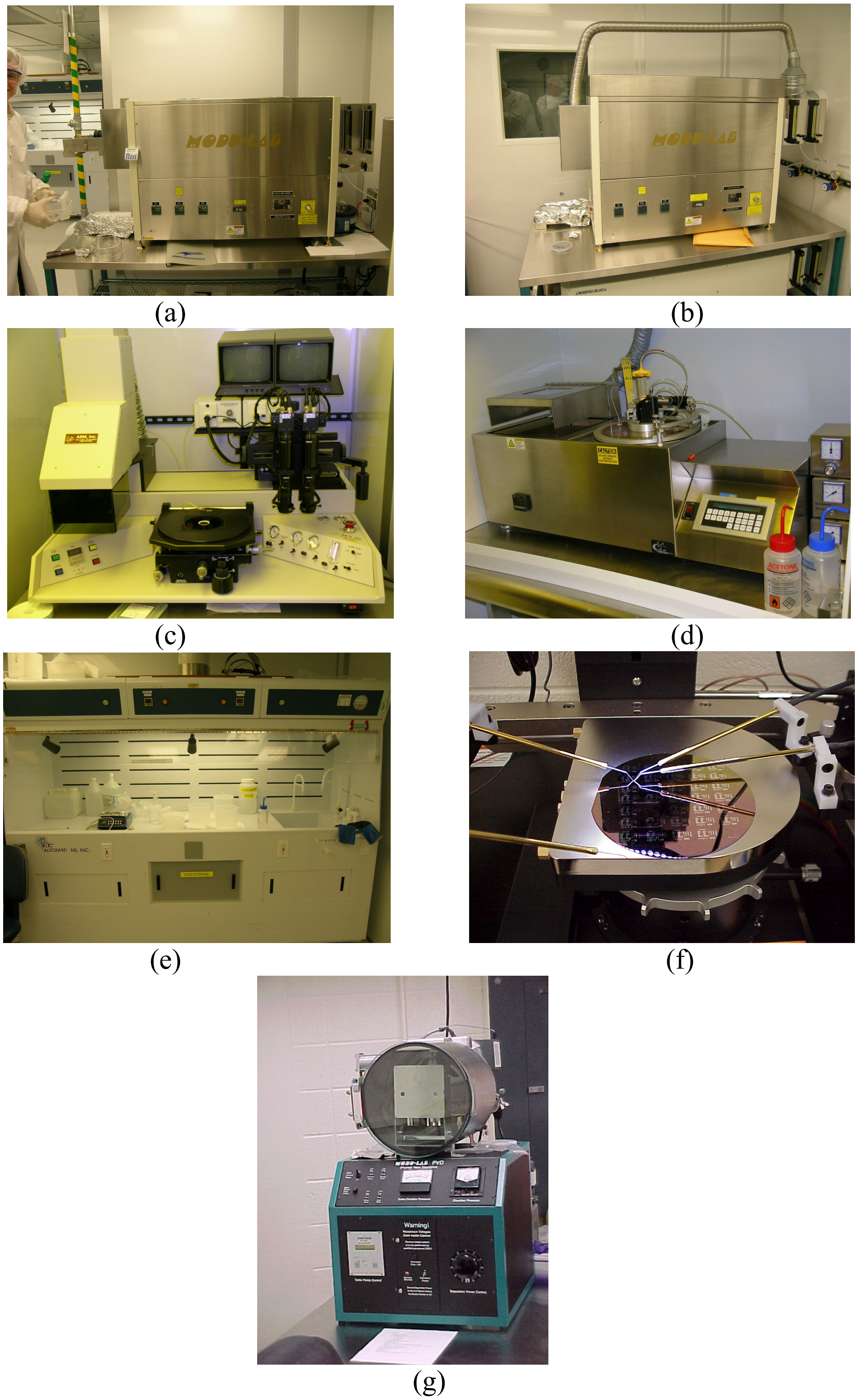

Figure 2. (a) Oxidation Furnace, (b) diffusion furnace, (c) Mask Aligner, (d) Programmable photoresist spinner, (e) Acid wet bench and (f) Cascade Microtech RF-1 probe station shown during a wafer testing (g) Modulab PVD

The photolithography system used in this class is research caliber. A feature that is 2.5 x 2.5 microns is easily realized. This allows us to make smaller more realistic sized devices. The programmable spin coater and mask aligner are shown above in figure 2.

The microelectronic fabrication course completes all the processing steps in the 6 mask set. The course covers both the theory and the practical aspects of fabrication. There were a total of 13 electrical and computer engineering student enrolled in the initial offering of the class. (Shown in figure 3) These students are divided into three laboratory sections. Each of these three sections used the same processes while the process parameters where changed: varied field oxide thickness, doping concentration, and gate oxide thickness.

Figure 3. Student using furnace

Funding for the initial offering of the microelectronic fabrication class has come from the original course improvement grant. Operating the laboratory was costly due to expensive chemicals and disposable items. Thus the course was designed to control costs. Such cost saving measures included using only half a wafer carrier resulting in only six wafers being processed per laboratory section. This allowed a smaller volume of chemicals to be used in the small Teflon buckets. These buckets only need 2.5 liters of chemicals when processing a batch of wafers. (Shown in figure 4) The 6 to 1 Buffered Oxide Etch was reused through out all three-lab sections. Also to cut costs the lab class sizes were kept small this allowed the students in different lab sections to share clean room garments and tweezers. Another measure under consideration is to assess a lab fee to each student of 150 dollars to cover the disposal garment and chemicals used by each student.

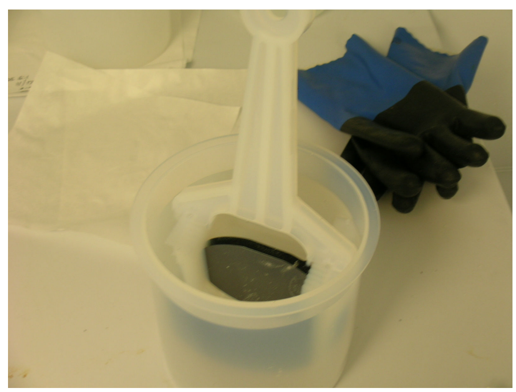

Figure 4. Teflon Bucket

Conclusion

Future work on this project includes developing a relationship with secondary school teachers and students. Two forums will be created for this to occur. The development of these forums will occur after the Microelectronic fabrication course has been set up and its operation has been demonstrated. The first forum is a two-week continuing education workshop, which will introduce teachers to the microfabrication laboratory. Here science and math teachers, as well as future science and math teachers, will be exposed to the techniques used to make transistors and integrated circuits. An instructional package will be given to workshop attendees to assist them in learning microelectronic fabrication techniques. The package would include materials to help the teacher present the fundamentals of microfabrication to the high school and middle school students. Teaching material in the package will include presentation material such as PowerPoint presentations and interactive websites that convey the essence of the technology. This workshop will place an emphasis on understanding the process of problem solving and that engineering is a form of applied problem solving. By having direct exposure to the facility the secondary school teachers will have a better understanding of the processes required to develop the fundamental circuits used in modern technology. This would be transferred to the student at an early age and instill a desire to enter the fields of science and engineering. This workshop will make use of the facility during the summer months, when historically few engineering students register for courses and teachers seek additional education.

The second forum will be focused towards the students themselves. This focus will be on students in secondary schools who are still impressionable and have yet to decide on a career path. Students will be brought to the microfabrication laboratory and shown basic manufacturing techniques of the microprocessors that have become a component of their every day life. Early exposure to engineering concepts will increase the student's understanding of the technical world around them. An example of a simple demonstration is to have the students create a simple black and white computer generated drawing. Transfer this figure to a metalized substrate using photolithography, and then etch away the metal layer, creating an image of their design on the substrate. Here the students would get an introduction the Computer Aided Design (CAD), optics and chemistry. The students would also leave with a souvenir of their own design. This demonstration is aimed at stimulating and recruiting the next generation of scientists and engineers.

Currently there is a design team partially composed of students from the microelectronic fabrication class working on developing a Microelectromechanical Systems (MEMS) fabrication laboratory. This laboratory will use the existing equipment to manufacture simple MEMS devices and test structures.

This project has successfully implemented a microelectronic fabrication laboratory. Thirteen graduate and undergraduate students have learned hands on microfabrication skills and cleanroom protocol. These students have better understanding of electrical engineering and are better candidates for companies that are involved in with microfabrication technologies. This is a unique opportunity for the students because of the size of our university.

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