

A Remote Laboratory for Microelectronics Fabrication

Aaron Mohtar, Zorica Nedic and Jan Machotka

University of South Australia, aaron.mohtar@unisa.edu.au, zorica.nedic@unisa.edu.au, jan.machotka@unisa.edu.au

Abstract - During the last decade there has been a move towards using remote laboratories in engineering education. These labs allow students to control either electrical or mechanical systems remotely via the internet. At the University of South Australia (UniSA), we have been developing a remote lab that will allow users to visually inspect and test microelectronic circuits under a microscope. In this paper, we describe the architecture of the laboratory and discuss the obstacles that are faced in designing and building a remote laboratory that deals with the accurate manipulation of micro-probes for testing microelectronic circuits. Challenges include mechanical construction of probes, motor control for accurate positioning of probes and the development of a realistic graphical user interface (GUI) which will give students an environment that closely resembles that of a real lab. This laboratory is the extension of the existing, fully functional UniSA remote lab, NetLab, which has already been successfully used in teaching students on-campus as well as off-shore.

Index Terms – Distance learning, Microelectronics fabrication, Remote laboratory.

INTRODUCTION

Due to the high cost of microelectronic fabrication laboratories, teaching microelectronic circuit fabrication is very much driven by the availability of resources at the tertiary institution providing such courses. Some institutions find a solution in developing virtual laboratories for microelectronic fabrication [1, 2]. Others are teaming with existing industry partners that are willing to share their facilities with students [3]. The creation of remote laboratories not only encourages ideas of sharing such expensive facilities on the internet among tertiary institutions, but also providing remote access to on-campus students of the institution which owns the facility. The remote access has an additional advantage of students not physically entering the facility which reduces the risk of the contamination of the facility. It also addresses the safety risk by keeping students away from dangerous chemicals used in the process of microelectronic circuit fabrication. In this paper, we present a part of a remote laboratory for microelectronic circuit fabrication that we have been developing at the University of South Australia (UniSA).

The currently developed part involves the final stage of the fabrication which is the visual inspection of the silicon wafer, and characterization of the microelectronic components of the circuit designed by students. This phase is normally conducted by students in the cleanroom under the microscope with the aid of specialized expensive equipment. We considered this as an excellent opportunity to convert this conventional facility into a remote laboratory which is the topic of this paper.

CHALLENGES IN A MICROELECTRONICS LAB

The School of Electrical and Information Engineering at the University of South Australia (UniSA) has been fortunate to own a laboratory for microelectronic circuit fabrication, which provides students with hands-on experience in microengineering technology. Students design their own simple integrated circuit, and under the supervision of the technical officer, participate in its production. In the final phase of the project, students make an appointment to access the facilities in order to test their circuit. However, working in a microelectronic fabrication lab includes challenges that arise from the special nature of the devices under test. The main challenges are cleanliness and the small size of the devices.

- Cleanliness

Microelectronics fabrication deals with the creation of sub-micron features. Due to the small size of these features, dust particles or even human contamination (e.g. skin particles, hair, etc.) can bridge features together resulting in a deterioration in quality and possibly the discarding of an electronic circuit. To reduce the contamination, microelectronics fabrication takes place in a special area called a *cleanroom*. This room includes special air filtration equipment which eliminates dust particles from air as soon as possible. To reduce the risk of contamination, users of the cleanroom go through a multi-stage process of decontamination before entering the room. In addition to this, cleanroom equipment is designed in a way not to introduce the contamination itself, and hence the special requirement on the devices used in the remote laboratory for this experiment. This will be further discussed in a later section of this paper.

- Small feature size

Due to the small sizes of electronic features and small distances between electrical test points, the control of precise positioning of test probes in the laboratory setup is required. The test probes, in the current convention microelectronics lab, allow three dimensional movement with an approximate resolution of $10\mu\text{m}$. Figure 1 is an image of a silicon wafer sample under the microscope with electronic circuits used for experiments by students.



FIGURE 1
TOP VIEW OF AN ELECTRONIC CIRCUIT WITH A PROBE UNDER THE MICROSCOPE.

Figure 2 shows the schematic of the pattern. The size of each pattern is 1mm^2 .

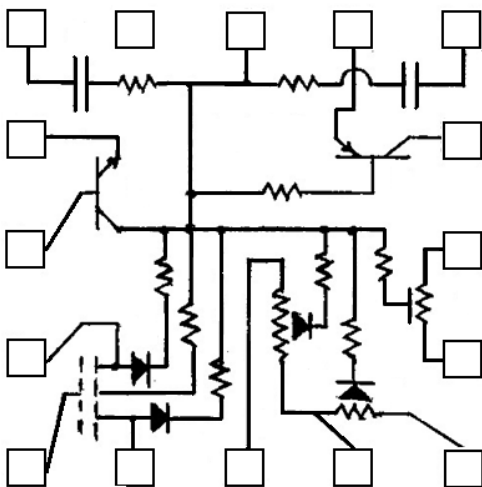


FIGURE 2
SCHEMATIC OF THE CIRCUIT SHOWN UNDER THE MICROSCOPE IN FIGURE 1.

SYSTEM SETUP

The existing UniSA conventional microengineering laboratory setup, shown in Figure 3, includes a test station

which accommodates a series of test probes, and a curve tracer to display the characteristic curves of the electronic device under test.

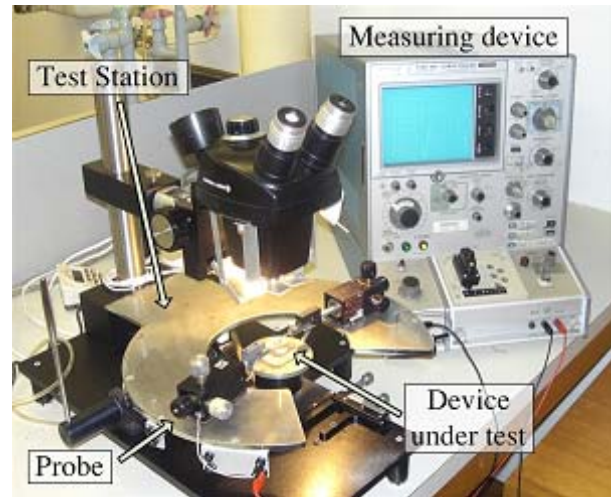


FIGURE 3
CONVENTIONAL MICROELECTRONIC LABORATORY SETUP

The remote microengineering laboratory as shown in Figure 4 looks very similar to the conventional laboratory setup, and includes:

- A new *test station* that allows for a digital interface.
- Modified *probes* that allow digital manipulation from a computer.
- A microscope with a mounted camera that allows remote digital control of both zoom and focus.
- Another camera to show the *device under test* from another aspect (front view).
- Digitally controlled lighting.
- A PXI unit from National Instruments (NI) that includes:
 - A controller (stand alone computer),
 - A source monitor unit (SMU) to measure the characteristics of the device under test (DUT) and,
 - A matrix switch that allows the users to connect the SMU outputs/inputs to the probes they desire.

As shown in Figure 5, the software architecture includes the following:

- A LabVIEW server that maintains communication with all the hardware and communicates with the database and the Graphical User Interface (GUI).
- A GUI that provides a user-friendly intuitive interface that allows the user to control all probes, probe station, microscope, lighting and the measuring instrument along with the matrix.

- A database that contains all the user details including log on details and bookings.
- A web server that allows users to change their details in the database and book time slots to conduct experiments. It will also hold a variety of support material that will assist the user in acquiring background knowledge of the field, along with the instructions on how to use the laboratory.

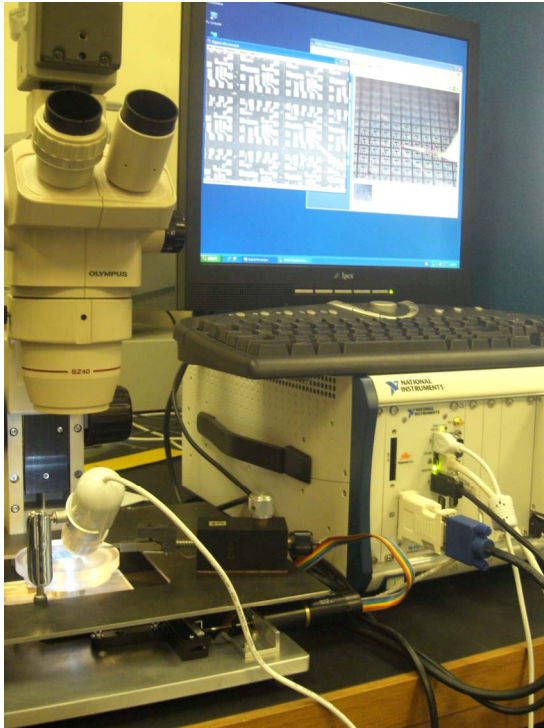


FIGURE 4
UNISA REMOTE MICROELECTRONIC LABORATORY SETUP

CHALLENGES FACED IN THE REMOTE LABORATORY SETUP

As mentioned before, a significant effort had to be invested by the UniSA microelectronic remote laboratory developers to overcome a certain number of problems. The main problems faced during the development are described in this section.

Accuracy of the probe manipulations

Due to the miniature size of the features and electrical test pads, the step size of the probe is important. Building new probes from scratch proved to be an extremely complex and involved project due to the accuracy in mechanical construction. As a result, the older-conventional probes were modified to allow for motor control. The movement in each direction is conducted using the screw and bolt principle for transforming a rotational movement to a linear one. The screw-bolt combination used in the probes

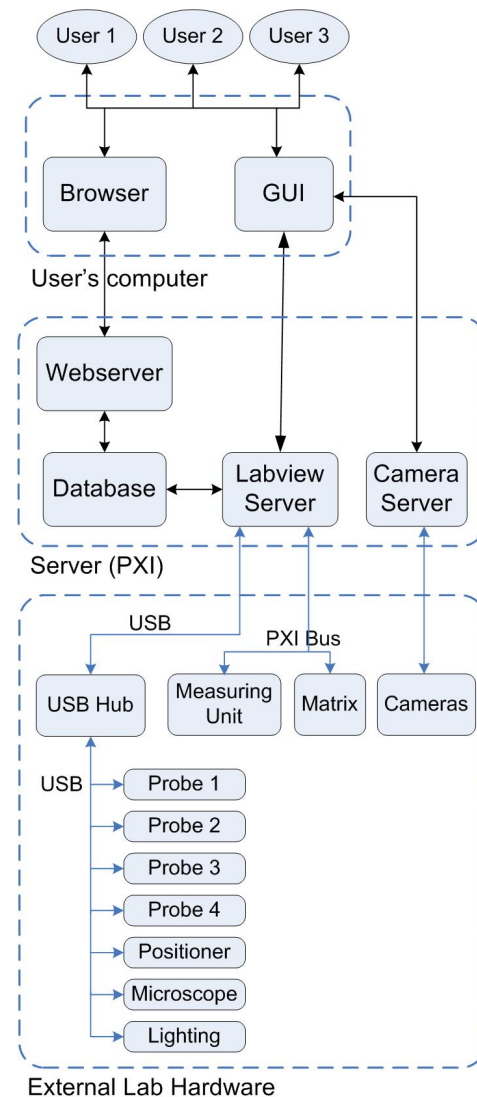


FIGURE 5
REMOTE LAB ARCHITECTURE

involves a BNC 8-32 thread which has a thread pitch of 0.794mm, as shown in Figure 6. This means that every 360° rotation of the nut will result in a 0.794mm linear movement. To achieve the required linear step size ($10\mu\text{m}$), the rotation step size will be 4.5° . The details of how to accomplish this rotational step size are given later.

Another problem, arising from this bolt-nut approach, is the backlash that exists and threatens the accuracy of the probe. The size of the backlash for such a thread is in the order of the required step size, which is a complete compromise of both accuracy and repeatability of the probe positioning. To reduce this problem, a backlash eliminator is employed. In this case, it involves using a spring to push the screw so as the contact between the nut and screw is always on one side.

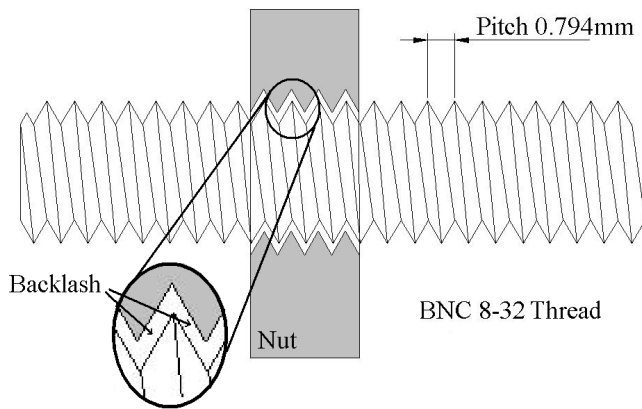


FIGURE 6
THREAD DETAILS

Cleanliness of the setup

As mentioned earlier, the cleanliness of the setup is vital to maintain the quality of the micro-electronic circuits under test, thus the materials and devices used to create this setup should contribute the least possible to the contamination of the room. The main possible sources of contamination from our modified setup are the brushes in the control motors. Motor brushes can not only cause contamination to the cleanroom, but also impose a safety hazard due to possible sparking, in addition to a maintenance issue which is associated with the wear and tear of the brushes. For these reasons, Brushless DC motors (BLDC) have been selected for use for all mechanical movements.

Network of accurate motor controllers

The use of BLDC motors not only minimizes contamination of the cleanroom, but also provides accurate step control, however with some disadvantages. The main disadvantage for the use of BLDC motors is the complex control circuitry required to accurately control the motion.

A BLDC motor is a permanent-magnet DC motor that uses electronic switching instead of brushes and commutator to transfer power to the windings. Figure 7 illustrates the hypothetical brushes of the BLDC motor, and also indicates the expected phase sequence. The motor control heavily relies on the accurate estimation of the rotor position for a jitterless efficient motion. To provide a smooth rotation, the motor coils should be energized at a precisely specific time. This time is derived from the location of the rotor determined by utilising the Hall-effect sensors which are usually installed as a standard feature on the BLDC motor. These sensors are placed at 120 electrical degrees out of phase, and the combination of the digital outputs from these sensors indicates the position of rotor.

To provide a smooth operation of these motors a motor controller has been designed to read the Hall-effect sensor outputs and determine which phases to drive (energize). Due to the need for high precision positioning and monitored speed control, the dsPIC30F4012 microcontroller was selected to be implemented in this application. The completed hardware which includes protection circuitry and the power stage for driving motors is shown in Figure 8. More details on the controller design can be found in [4].

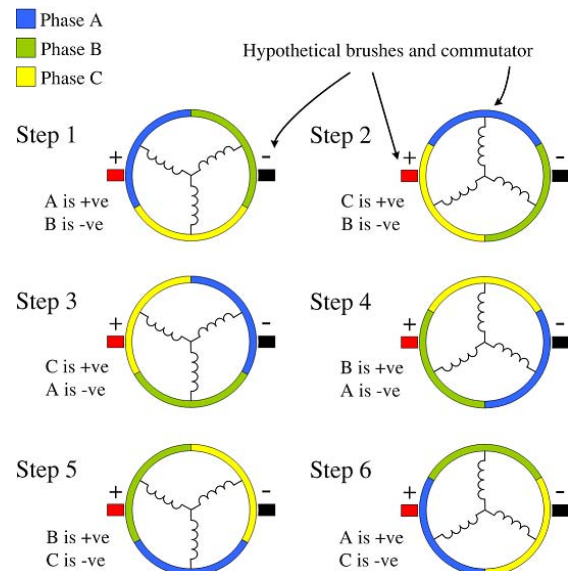


FIGURE 7
ILLUSTRATION OF BLDC MOTOR STEPS AND PHASES

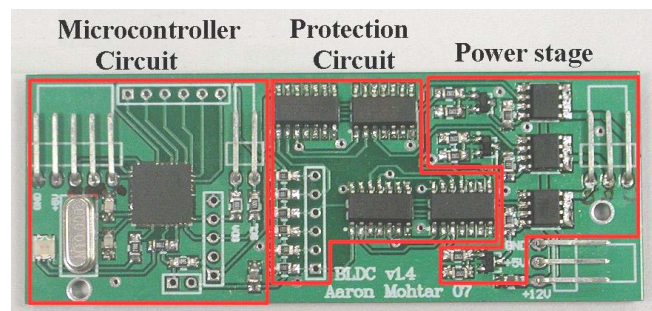


FIGURE 8
THE COMPLETED BLDC MOTOR CONTROLLER HARDWARE

The number of motors required for the whole setup is 18, and therefore a structured network has been constructed to manage all the digital control. The main communication between devices and the computer/server is USB, whereas the communication within the devices uses the I²C (Inter Integrated Circuit) protocol. This architecture is shown in Figure 9.

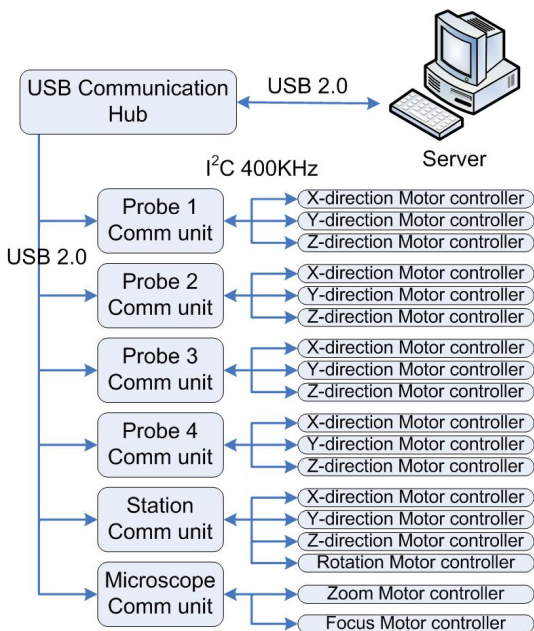


FIGURE 9
MOTOR CONTROLLER NETWORK

Sufficient visual feedback for stable control

Due to the mechanical nature of this setup and the requirement from the user to accurately position the probes, sufficient and quick visual feedback is required. This feedback is accomplished by the use of two cameras that provide zoomed views from two different angles: one through the microscope, as shown in Figure 1; the other from the front of the setup as shown in Figure 10. This gives the user a three dimensional feel and thus better control over the positioning of the probes.

Another issue with controlling probe positioning is the speed of the video feedback. If the feedback is delayed, it can cause difficulty in positioning probes and even instability in controlling the system. This also means that the speed of the connection has to be sufficient.

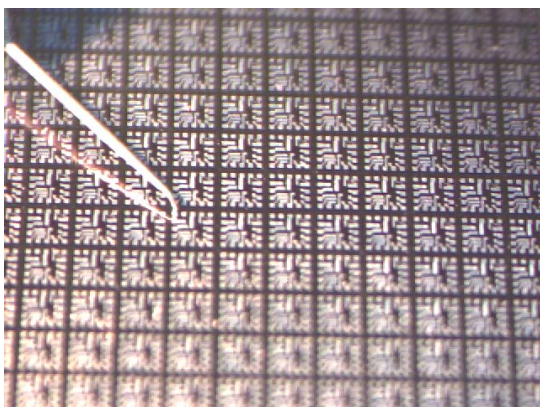


FIGURE 10
FRONT CAMERA VIEW OF THE DEVICE UNDER TEST

Realistic GUI and Collaboration

This laboratory is an extension of the UniSA existing remote laboratory NetLab which is already successfully implemented in teaching on-campus and off-shore students. [5]. As such, we applied the same basic principles that we applied for NetLab development: the work in this remote laboratory should closely resemble the work in the real laboratory. This includes a realistic GUI shown in Figure 11 that uses photographic images of the front panels of instruments with animated controls, and a possibility of student collaboration during remote experiments.

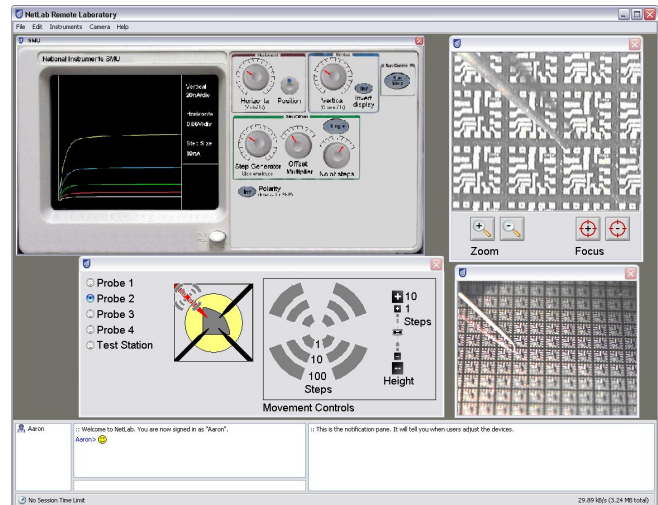


FIGURE 11
REMOTE MICROELECTRONICS LABORATORY GUI

REMOTE MICROELECTRONIC LABORATORIES

Currently there are a number of remote microelectronic laboratories that facilitate parameter characterization of electronic components. Probably the most well known are:

- WebLab [6], MIT, Cambridge, Massachusetts;
- AIM-Lab [7], Rensselaer Polytechnic Institute (RPI) in Troy, New York;
- LAB-on-WEB [8], University Graduate Center, Norwegian University of Science and Technology (Unik/NTNU);
- Next-Generation Laboratory (NGL) [9,10], Department of Physical Electronic, Norwegian University of Science and Technology;
- RETWINE [11], University of Bordeaux, France, University Autonoma of Madrid, Spain and University of Applied Sciences of Münster, Germany;

A detailed overview of these laboratories is given in [12]. Unlike all these laboratories that use packaged integrated circuits (ICs), our laboratory allows students to test their circuits directly on the silicon wafer under a microscope. The advantage of this approach is that the system is completely independent of the circuit design and does not require any pre-wiring. However this comes at a price - it requires high precision positioning of test probes to be controlled remotely via the internet. Consequently a significant effort had to be invested in the development of motorized probes, as described before, that can access any point in the visual field under the microscope and make reliable contacts for electrical testing of the circuit.

CONCLUSION

In this paper we presented the development of a remote laboratory for microelectronic circuit fabrication – more precisely, the visual inspection and testing of circuits on a silicon wafer under a microscope in a cleanroom. Unlike other microelectronics laboratories, we decided not to use packaged IC for pedagogical reasons. We believe that seeing the circuit directly on the wafer will be more motivational for students. They can also visually inspect the circuit they designed in the previous sessions and can freely move across the wafer surface and explore the characteristics of different components in their design. This approach eliminates the need of the operator to pre-wire and configure different ICs for different students. However, this approach requires an extra effort by the developer of such remote laboratory. In this paper, we presented our design solution and the challenges we faced during the development of the microelectronic remote laboratory at UniSA.

The initial feedback from students has been positive and encouraging. They have enjoyed the opportunity to conduct experiments at their own time and location, and more importantly, being able to repeat experiments in case they doubt their results. This is almost impossible in the case of conventional microelectronics fabrication laboratory situated in a cleanroom which would require extensive cleaning procedure and supervision due to safety issues.

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AUTHOR INFORMATION

Aaron Mohtar Lecturer and PhD candidate, University of South Australia, aaron.mohtar@unisa.edu.au

Zorica Nedic, Senior Lecturer, University of South Australia, zorica.nedic@unisa.edu.au

Jan Machotka, Senior Lecturer and Program Director, University of South Australia, jan.machotka@unisa.edu.au