Remote Microelectronics Fabrication Laboratory MEFLab

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***Abstract*—Over the last decade, there has been a move towards using remote laboratories in engineering education. The majority of these laboratories are static, involving limited user-controlled mechanical movements. The University of South Australia has developed such a laboratory, called NetLab that has been successfully utilized for teaching both on-campus and transnational programs in electrical and electronics engineering. Following this success, we are now developing a remote laboratory for microelectronic fabrication, MEFLab. The first stage of the development is a remote laboratory for visual inspection and testing of electronic circuits directly on the silicon wafer under a microscope which is normally conducted in a cleanroom. The major challenge of this project is the accurate positioning of micro-probes remotely over the internet. This paper presents the details of the setup of this new remote laboratory, with a particular emphasis on the development of the hardware, software and graphical user interface.**

***Index Terms*—Graphical user interface, Microelectronics cleanroom, Remote laboratory.**

I. INTRODUCTION

Due to the high cost of microelectronic fabrication laboratory, 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 the existing industry willing to share their facilities with students [3]. The invention of remote laboratories (RL) certainly 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 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 visual inspection of the silicon wafer, and characterization of the microelectronic components of the circuit designed by students. This phase is normally done by students in the cleanroom under the microscope with an aid of specialized expensive equipment. We considered this as an excellent opportunity to convert the conventional facility into a remote laboratory for electrical testing of miniature circuits on silicon wafers under the microscope. Fig. 1 shows the equipment of the existing real laboratory placed in the cleanroom at UniSA. The laboratory is used by students to test circuits they design and fabricate as part of the course Microengineering Technology offered in the School of Electrical and Information Engineering. The development of the remote laboratory aims to enable students to test their designs remotely, and without the need to enter the cleanroom. This will improve the cleanliness of the room, enhance the safety of students and will allow students to spend more time on testing the circuits that will enhance student learning outcomes.

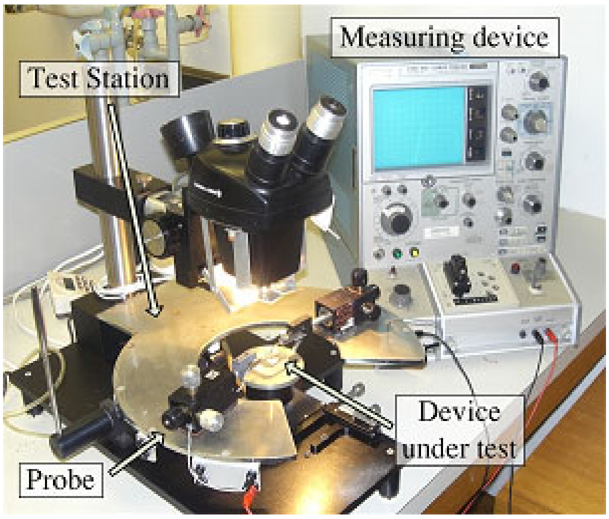

Figure 1. The Existing real laboratory setup

II. REMOTE MICROELECTRONIC LABORATORIES

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

A. WebLab [4], MIT, Cambridge, Massachusetts

The MIT Microelectronic WebLab is a batch type RL where a student types in values of all input data required by the graphical user interface (GUI) for the particular experiment and then submits the experiment for execution. When the experiment is completed, the system automatically disconnects the user and stores data into a database for later retrieval by the student. Switching matrix (Agilent E5250A) allows students to select one of eight devices for testing. This eliminates the need for the operator to frequently change the device under test (DUT). The semiconductor parameter analyzer (Agilent 4155B) is used to obtain the required family of characteristics for the tested electronic component like transistor, diode, etc.

B. AIM-Lab[5], Rensselaer Polytechnic Institute (RPI) in Troy, New York

The AIM-Lab (Automatic Internet Measurement Laboratory) is developed in collaboration with Norwegian University of Science and Technology (NTNU). The lab offers students a number of batch type experiments all of which are performed on an in house fabricated CMOS chip and a number of light emitting diodes (LEDs). This chip is the central part of the test-bed and has one row of N-MOSFETs and one row of P-MOSFETs. Each MOSFET has different dimensions and thus different characteristics. Selection of a particular experiment invokes the corresponding GUI which requires the student to enter test parameters. Submitting the experiment to the execution initiates a switching matrix (Agilent E5250A) to connect particular devices according to the selected experiment and entered parameters. A DC source/monitor instrument (HP 4142B) is used for characterization of the configured component or DUT.

C. LAB-on-WEB[6],University Graduate Center, Norwegian University of Science and Technology (Unik/NTNU)

This laboratory is an advanced version of AIM-Lab. The central part of the test-bed is the Alpha chip developed as an international collaboration project between universities in the European Union and Latin America. Alpha chip is a component rich CMOS chip that includes a number of diodes, capacitors, MOSFETs, inverters, etc.

D. Next-Generation Laboratory (NGL) [7], Department of Physical Electronic, Norwegian University of Science and Technology

NGL includes further advancements of LAB-on-WEB and AIM-Lab both in software and in hardware. The central device in the test-bed is the analog CMOS chip with nine operational amplifiers (OPAMPs) designed by 4^{th} year master students. Experiments in this RL investigate frequency responses of the OPAMPs. This RL has been further enhanced by addition of PAnIC chip (Programmable Analog Integrated Circuit) which adds flexibility to the system without a need for switching matrices [8].

E. RETWINE [9], University of Bordeaux, France, University Autonoma of Madrid, Spain and University of Applied Sciences of Münster, Germany

RETWINE (Remote Worldwide Instrumentation Network) is a joint project of the three European universities. Each of the three universities has a RL with a very similar equipment set up. This RL uses a number of expensive instruments including, semiconductor parameter analyzers (HP 4145B and HP 4155B), precision RCL meter (HP 4284A), network analyzer (HP 8510B), impedance and gain/phase analyzer (HP 4194A) which are also complex and require students to learn how to use them before attempting the experiments. For this, special tutorials are developed for students to practice the control of instruments. Experiments range from characterization of capacitance, bipolar transistors to characterization of CMOS devices. Students remotely access not only the RL of their university but also all RLs within the RETWINE project.

A detailed overview of these laboratories is given in [10]. Unlike all these laboratories that use packaged integrated circuits, 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 that can access any point in the visual field under the microscope and make reliable contacts for electrical testing of the circuit. This development is described in the following sections.

III. THE UNISA REMOTE MICROELECTRONICS LAB

The School of Electrical and Information Engineering at the University of South Australia has a microelectronic laboratory with traditional facilities for microelectronic circuit fabrication. The laboratory plays a significant role in teaching microelectronics at an undergraduate and postgraduate level.

Encouraged by the previous successful experience with our remote laboratory NetLab [11], we decided to offer the whole fabrication process on-line, in the form of a remote laboratory. Microelectronic circuit fabrication involves many processing steps like:

- Wafer cleaning
- Photolithography
- Ion implantation
- Oxidation
- Chemical/Physical vapor deposition
- Dry/Wet Etching
- Wafer testing (the focus of the remote lab)
- IC packaging
- IC testing

Due to the large scale of the project, it will be realized in stages. The first stage is to develop an RL for the visual inspection of microelectronic circuit and the component characterization process. Unlike other microelectronic RLs listed above, our laboratory will allow students to view the silicon wafer under the microscope. It will also give students much more freedom in accessing, wiring and testing the components and circuits manufactured from their own design. To accomplish this it is necessary to develop hardware; both mechanical and electrical, as well as software to support student work in this new RL.

IV. SYSTEM SETUP

A. Laboratory Hardware

The hardware setup of the new RL is shown in Fig. 2 and is similar to the conventional laboratory setup shown in Fig. 1. Both laboratories have a microscope, a test station with microprobes, and a measurement instrument for parameter characterization of the microelectronic devices. In addition, the RL has a server for remote access, two cameras for visual feedback and a matrix switch.

All movements in the conventional laboratory are done manually. This includes microscope zoom and focus, positioning microprobes, movement of the test station and also wiring of probes to the test instrument. However, in the remote laboratory all these mechanical movements have to be accomplished remotely via the internet, and thus the following modifications were needed:

- The microprobes were redesigned for digital control from a computer. This process involved the installment of Brushless DC (BLDC) motors and the design of specialized motor controllers that allowed computer communication. The resulting product allows user-controlled movement in three dimensions (3D). [12] details the design of the motor controllers and their communication abilities. Fig. 3 shows the motorised micro-probe with all the control electronics. The precise design and accurate control of the motors has produced a practical movement resolution of 10µm. "Probe 1" in Fig. 4 shows how the probes fit in the laboratory setup.
- The wafer positioner was redesigned, in a similar way to the micro-probes, to allow user control in 3D, in addition to the ability to rotate the wafer.
- The microscope has been digitally controlled in a similar way to the probes. This allows users to adjust both the zoom and the focus settings of the microscope. Two BLDC motors with controllers have been used for this purpose.
- A camera has been mounted onto the microscope to view enlarged circuit images. Another camera has been installed to show a front view of apparatus (Fig 2).
- Lighting is now digitally controlled from both the side and through the optics of the microscope, to allow for both bright & dark field views of the wafer. Users can choose between three different intensities for each set of lights.
- A new probe station has been designed and built to accommodate for the new changes in hardware. This includes new platforms for the probes and the motorised wafer positioner.
- A computer controlled measurement instrument, Source Monitor Unit (SMU) NI PXI-4130 [13] has been added, that allows users to perform electrical tests, acquire the characteristics and download measurement data to the user's computer for later processing.
- A matrix switch allowing users to remotely wire probes to the measurement instrument. As shown in Fig. 4, the Matrix switch NI PXI-2529 [14] allows users to remotely connect the SMU's 3 input/output terminals to any combination of the probes, thus giving the user much improved flexibility.

B. *Laboratory Software*

To interface all these new devices together, a structured interface network has been developed for reliable and fast communication. Fig. 4 shows the architecture and the communication interfacing between the various components of the system. The architecture includes the following building blocks:

- Specially designed communication units that manage communication between the server and the motor controllers (as shown in Fig. 5). The communication unit supports USB communication with the server, on one side, and I2C (Inter Integrated Circuit) communication with motor controllers on the other side.

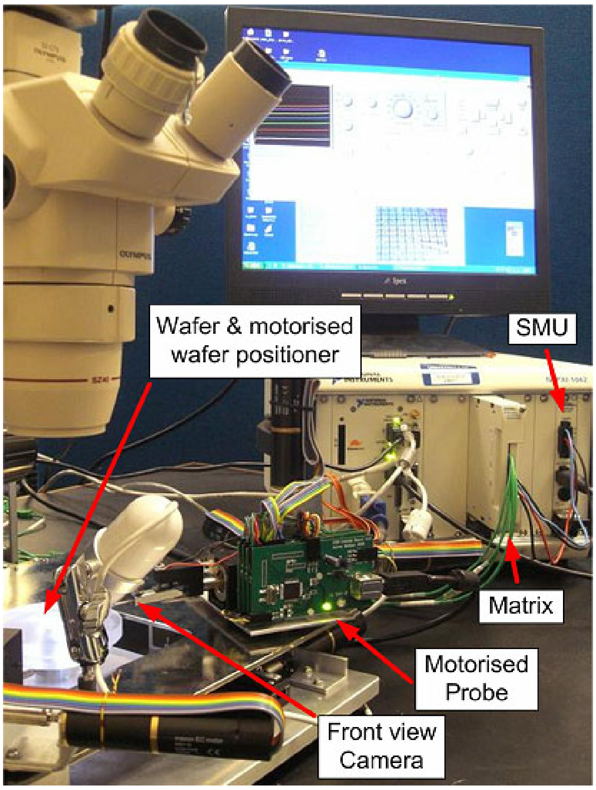

Figure 2. Remote laboratory setup with wafer view from two cameras

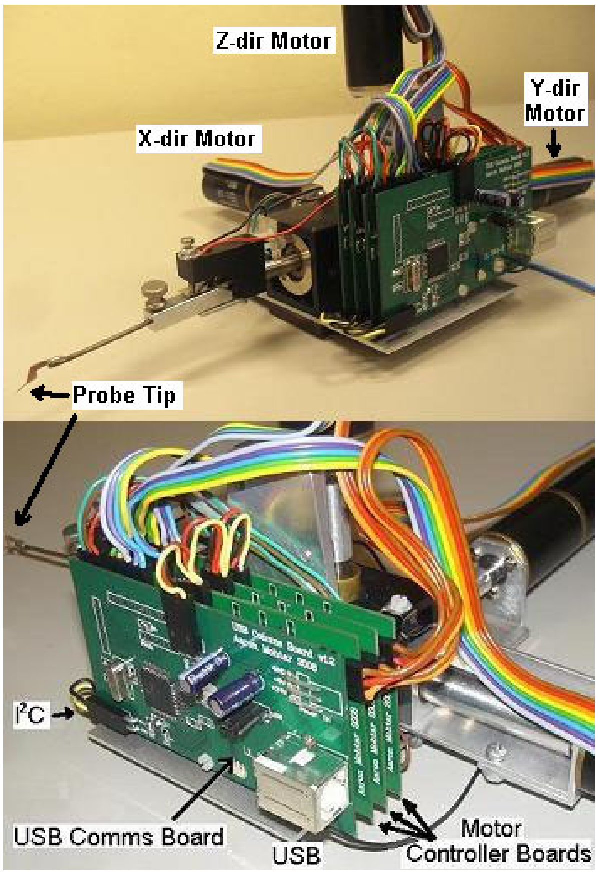

Figure 3. A complete motorised micro-probe

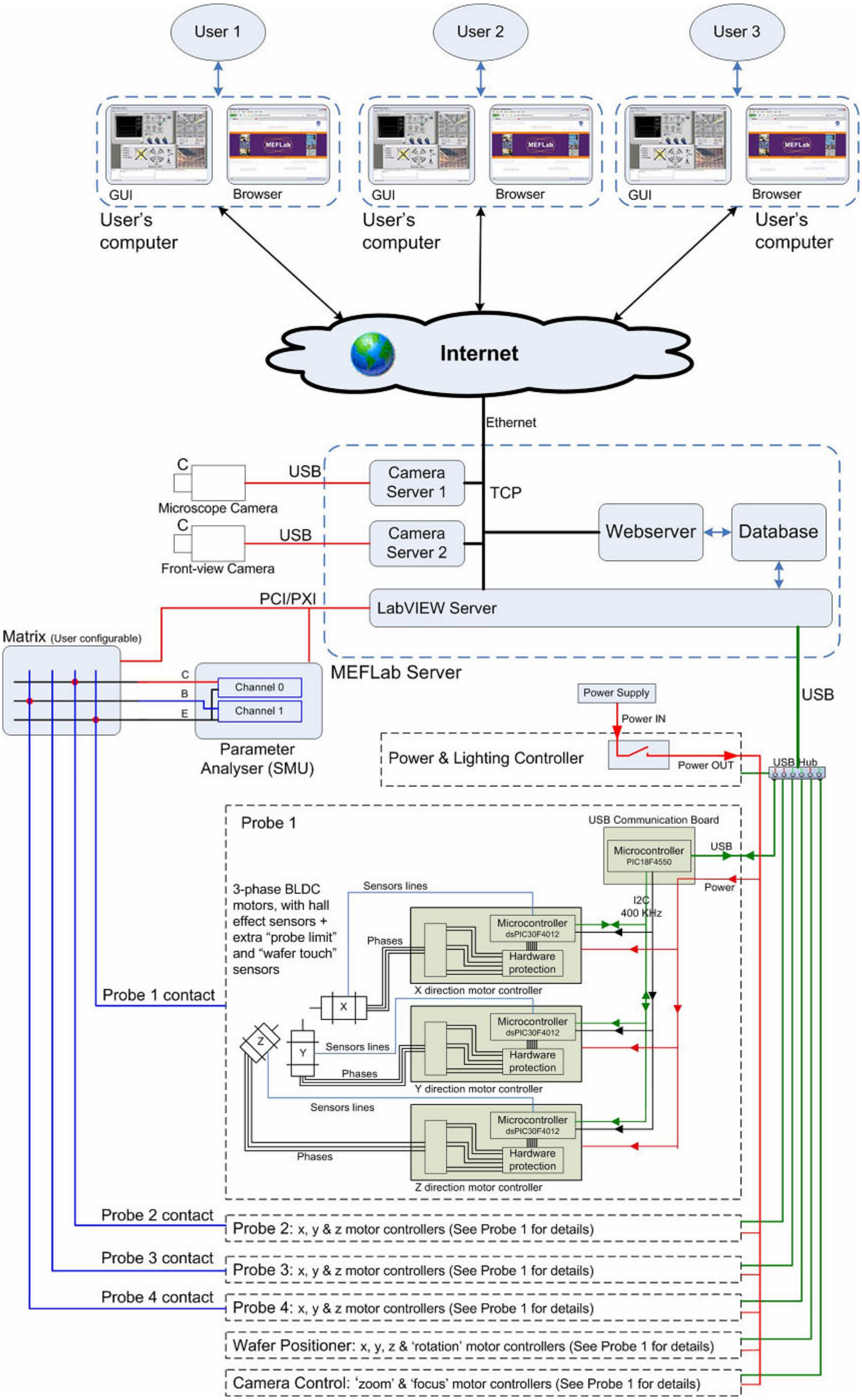

Figure 4. Interfaces between the devices

- A LabVIEW server that maintains the communication between all devices in the lab (except for the cameras). It ensures that all requests from the users are dealt with appropriately and all issues are logged and rectified. The server communicates with the SMU & Matix via the PXI bus. It communicates with the probes, wafer positioner, microscope, power & lighting via USB. It also maintains connections with the system's users via an Ethernet connection to the internet.
- Camera Servers that work independently to the main LabVIEW server and allow the user interface to interact with the cameras directly.
- A webserver that will allow users to create and access their accounts and bookings. It will give users access to the main GUI and will also hold all the teaching and support material required to conduct experiments using this lab.

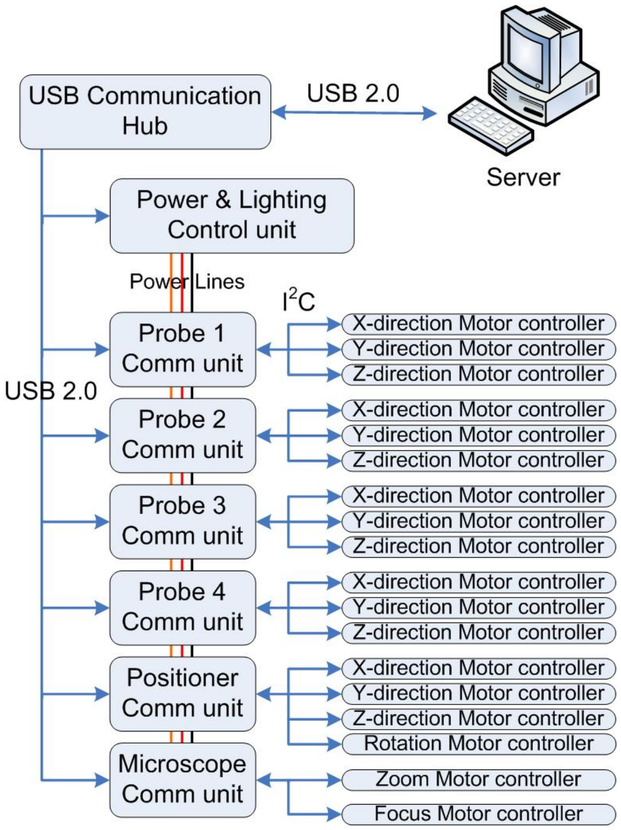

Figure 5. The interfaces in the developed motor-controller network

C. *Graphical User Interface (GUI)*

To allow the user easy control of the system, an intuitive GUI has been developed as shown in Fig. 6. The GUI shows two camera video feeds. A stationary camera shows the front view of the wafer and has a smaller zoom (10x) than the second camera mounted on the top of the microscope. As the GUI shows, students can remotely increase or decrease zoom and adjust the focus of this camera (top right-hand corner). The two cameras allow visual inspection of electronic circuits on the silicon wafer which is a very unique feature, not implemented in other microelectronic remote laboratories. Another unique feature of this laboratory is the ability of the user to freely move and position four electronic microprobes at a desired place for performing tests. This eliminates the need of switching between a limited number of connection points.

Remote positioning of micro-probes and the test station are performed by a number of BLDC motors that can be remotely controlled using the "movement controls" window shown in the GUI (Fig. 6). As shown, each probe can move in 4 directions in the horizontal plane parallel with the wafer, and the step size can be adjusted. In addition, the height of the probe can be controlled and again the step can be adjusted for coarse or fine positioning. The selected probe is highlighted in the GUI for easier recognition. In a similar way the user can control the position of the wafer by moving the positioning unit,

The two cameras give the view of the apparatus from two different angles enabling a better feel for the 3D positioning. However, camera delay has to be minimized for easier positioning of probes and to avoid possible instabilities of the motor-control system.

The measurement device allows users to test the characteristics of the microelectronic circuits and consists of a Source Monitor Unit (SMU), NI PXI-4130 [13] from National Instruments. This unit comes as a module that plugs into a PXI system shown in Fig. 2. Due to the fact that this unit is not a stand alone device with a front control panel, a customized GUI has been created to allow users to use its functions, but yet resembles the front panel of a typical stand alone device of its kind.

The SMU contains 6 input/output pins (4 of which are being used) that can be connected to any of the four probes. To allow the user to connect these remotely, a 8x16 switching matrix NI PXI-2529 [14] is used. The matrix also comes as a plug-in module for the PXI system. This module is necessary for probes to be able to access test points of the circuits regardless of their relative position on the wafer; otherwise a probe may need to by-pass another probe to reach the required test point which may not be possible.

The GUI also includes chat window as a simplest communication tool to allow students who collaborate on an experiment to communicate with each other in order coordinate their action in the laboratory as all students have full control of all equipment. The window in the lower right-hand corner of the GUI, "the notification pane", broadcasts the action of each user which helps collaboration of distant concurrent users.

The composition of the MEFLab GUI has been designed and implemented to resemble the GUI of our already established RL NetLab. It is expected that students who embark on MEFLab will already be familiar with NetLab and the consistency in the design will ease their adaptation to the new laboratory.

V. CONCLUSIONS

In this paper we presented a design of a new remote laboratory for microelectronic circuit fabrication; more precisely, the final stage of the visual inspection and testing of circuits directly on silicon wafer under a microscope. We believe this is a significant development that will make teaching of microelectronic circuit fabrication available to wider academic community.

The system is still under the development. Most of the hardware has been developed and tested. The system still needs to be integrated by an additional software development and thus hasn't yet been used for teaching. However, the initial tests of modules look promising and we hope to implement the system later this year and to present our teaching experience and student feedback in later publications at http://meflab.unisa.edu.au .

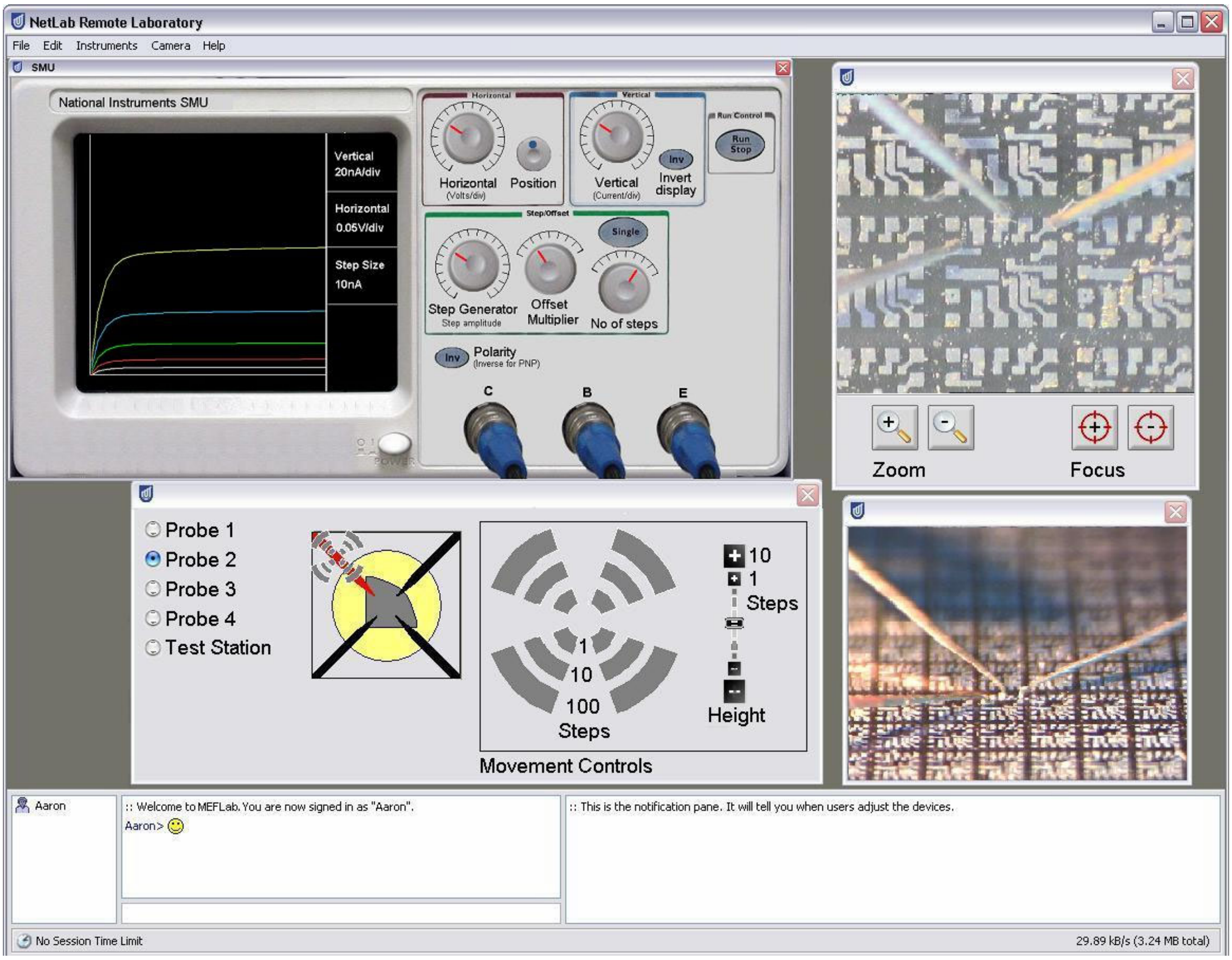

Figure 6. Remote laboratory GUI

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