AC 2007-1090: AN UNDERGRADUATE SUMMER RESEARCH PROJECT: SIMULATION OF NANOSTRUCTURE-BASED DEVICES AND ASSOCIATED STUDENT LEARNING

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An Undergraduate Summer Research Project: Simulation of Nanostructure-Based Devices and Associated Student Learning

Abstract

Undergraduate Summer Research Projects open up the opportunities for students to gain research experience. Research experiences for undergraduate students not only enhance students' ability to apply the learned knowledge in practical applications but provide students with opportunities to develop life-long learning skills as well. In 2002, our institution launched a summer research program under the umbrella of the Summer Research Institute to increase the involvement of undergraduate students in research activities. The other goal of the program was to involve regional high school students in undergraduate research in partnership with university students and faculty, and to attract them to join our institution after their graduation from high school. In Summer 2006, the Engineering Technology programs were funded for the first time for two research projects. This paper describes one such research project entitled "Design and Simulation of Nanostructure-Based Devices." Due to funding and time limitations, the summer research project was a challenge not only for the students but also for the project director .The scope and objectives of the research project were clearly defined to accomplish the results with in the eight-week period. Under this program of undergraduate research, a senior student participating in the project served as mentor to a high school student. During the course of this project, students were required to do literature search related to the project, design a device, and simulate the designed device. Although time limitations and student abilities of participating students posed challenges, the basic objectives of the project were achieved. The participating students presented their research at the Summer Research Institute symposium held on the university campus in Fall 2006. This research program can serve as a model at other institutions.

Introduction

Missouri Western State University is a public four-year, state-supported institution. It offers a variety of degree programs through the colleges of liberal arts and sciences. It is also set on a course to offer selected graduate programs in the near future. Faculty members are expected to excel in areas of teaching, scholarship, and service. The normal faculty load is 23-25 hours for the academic year, which leaves faculty with very little time for research. In order to increase the faculty and student participation in research activities, the university initiated the Summer Research Institute (SRI) in 2002¹. During each summer, SRI sponsors several research project teams consisting of one faculty member, one current undergraduate student, and from one to three entering freshmen students from local high schools. The SRI program provides faculty with time and resources to engage in research with students during summer. Students on the other hand, get the benefit of undergraduate research project "Design and Simulation of Nanostructure-Based Devices" was sponsored by the SRI. The following sections describe the various aspects of this project.

The objective of this project was to engage undergraduate engineering technology (ET) students and talented local high school students in the cutting-edge technologies related to nano engineering, and to provide students with real-world research experience through a Summer Research Institute project. The students involved in the project team would not only gain knowledge in nanotechnology but also gain experience working with computer simulations and electronic devices. The project team consisted of one faculty member, one junior ET undergraduate student, and one junior high school student. The undergraduate student was selected from one of ET classes during Spring 2006 semester. Student selection was based on student's academic performance, motivation, and willingness to participate in the project. The high school students were selected based on their ACT score, school recommendation, and the student coursework completed at high school. The selection of qualified and motivated students was the key to success of the summer project within the eight-week period.

Nano Device Simulation Project

Driven with ideas, scientists and engineers build smaller, complex, and more efficient machines. The development of micro-scale engineering in the area of electrical and computer engineering demonstrates technology advancements in low cost, high efficiency, and miniaturization. The understanding of the structure and properties of materials, coupled with system-driven design, fabrication, and optimization of materials, leads to the development and exploitation of new materials and devices for future microand nano-systems². Reliable modeling and simulation are the basis for understanding and optimization of materials and structures of devices, and the basis for development of the emerging nanoelectronic devices. The idea behind the 2006 Summer Research Institute project was to design and simulate the novel nanotransistors using simulation software. The project is a continuation of one author's Ph.D. research; however due to the limitation of the facilities at our university and available funds from SRI, the simulation of the nanodevices was selected instead of the physical device fabrication. The team was to design transistors in novel structure, build mathematical model (extract parameters), and run simulation with the variation of different parameters. Therefore, the team (faculty-students) was able to find the optimum design for a given material and structure. As stated in our objective, the team was to apply new nano-material (such as siliconcarbon superlattices) in transistor design, and based on the properties of the material, extract the parameters and build the mathematical model. Finally, the goal was to run the simulation with the variation of various parameters. As a team, we were able to determine the optimum material structure and properties for certain transistors. The project results provided a better or a complete new structure for certain devices and with an optimized material structure for further research.

Simulation Software

TCAD software from Silvaco International was used in our project, which starts with understanding the physics of the basic semiconductor, dielectric, and conducting materials. The software provides a Virtual Wafer Fab technology simulation environment enabling the ATHENA process technology simulators and the ATLAS device technology simulators to prepare, run, optimize, and analyze semiconductor experiments to achieve optimal process recipes and device targets³. In our project, the ATLAS device simulator was used to simulate the electrical behavior of our devices. The software includes several modules: S-Pisces/Device3D, 2D/3D device simulators; Blaze, 2D & 3D device simulator for advanced materials; LASER/VCSEL, laser simulator; Quantum, simulation for quantum confinement effects; etc. The ATLAS can be easily used to analyze DC, AC, and time domain responses of semiconductor devices. In addition, TonyPlot and TonyPlot3D were used for visual presentations of simulator results. The following figure shows the input and output of ATLAS device simulator⁴.



Structure file was manually created by the undergraduate student based on the design because DevEdit and ATHENA were not used in our project. The user may easily monitor the simulation by observing Runtime Output from screen; the user may pause and check simulation status at any time. The simulation results were recorded in log files and solution files, which further were used as input files for TonyPlot for visual presentation.

Project Process

Due to the special team structure, all team members were assigned to perform certain roles in the project based on their academic level, and each team member was responsible for his own role in the project. All student team members were first required to search literature about the historical development and the current status of nano-devices. Therefore, they had a basic idea about the nanotechnology field, especially nanoelectronic devices, and what they were going to be doing in the project. The junior ET student, with his sound background in electronics and devices, focused on designing and extracting parameters, adjusting simulation parameters for different runs. The high school student was encouraged to give input in the design. Primarily, the high school student concentrated on input design, running simulation, and documentation. The ET student acted as a mentor for the high school student during the entire course of the project.

Before the start of the project, the faculty proposed a schedule for the project describing the time duration and the task to be accomplished during that time duration. The project was divided into three stages:

- Stage 1: The first stage, preparing stage, ran from week 1 through week 3. The task for this stage included students learning basic knowledge of nanotechnology and basic principles of electronic devices and the simulation. At the start of the first week, a lecture was given on the historical development of nano science and nano engineering. The students gained the necessary knowledge preparing for the next stage including basic physical properties of electronic materials, structures of devices, and basic operation of the simulation software, TCAD from Silvaco. The undergraduate student focused on the properties and structures of devices, which are bases for the device design. The high school student concentrated on the operation of ATLAS, especially Blaze, TonyPlot, and TonyPlot3D.
- Stage 2: The second stage, design and simulation stage, lasted from week 4 through week 7. This core period of the project involved design and simulation of the device. The undergraduate student was responsible for the structure design, simulation result analysis, and parameter optimum, including writing structure and command files. The high school student assisted the undergraduate with entering parameters, running simulation, and visualization of the simulation results.
- Stage 3: The final stage, referred to as the dissemination stage, lasted one week during the eighth week of the project. Students prepared poster for presentation at the SRI symposium held on our university campus.

At the end of each week, each student was required to turn in a two-page short paper and a summary of what he did during the week. Each week the team had a meeting discussing the work accomplished. At times, it required adjusting the schedule. The details for tasks in the coming week were worked out during these meetings. At the end of eight-week period of SRI, a SRI symposium was held on campus. All parents of the high school students and community were invited. The following photographs show our undergraduate team member explaining our project to a high school student's parent and our team discussing our project with Missouri Western's Provost and Vice President for Academic and Student Affairs.



Results and Discussion

The followings are the results of the project design and simulation. The project included the structure and doping design, and the simulation of electrical characteristic of the device.





Figure 1 Structure of the device

Figure 2 Doping profile of the device

Figure 1 demonstrates the structure of the device. It consists of a source, a gate, and a drain. There are two pn junctions formed under the source and the drain. Figure 2 illustrates the doping profile of the device simulated. The highest doping density is around the gate, the red area. Next doping density is under source and drain.



Figure 3 Drain current vs gate voltage



Figure 4 Drain current vs drain voltage

Figure 3 shows the drain current vs the gate voltage for different drain voltages. The threshold voltage of this device is 0.63V. Figure 4 indicates the drain current vs drain voltage. There is a significant difference of drain current at breakdown voltage with different models.

Figure 5 below demonstrates the gate to substrate capacitance vs gate voltage with different gate doping density. The capacitance decreases as the doping decreases.



Figure 5 Gate to substrate capacitance vs gate voltage

In our research and simulations it was evident that the constraints of size contribute many obstacles to nano structure development⁵. The control of doping levels and location within the structure plays a vital role in the operation of the transistor. As the size is reduced, the processes to inject the dopant and control its placement throughout the device become more complex. Capacitive and inductive influences can also be more pronounced, especially when considering billions of components are densely placed on an IC.

Conclusion

The project was designed to involve local and regional high school students and undergraduate ET students in the cutting-edge technology research activities in the area of nanotechnology. The other goal of the project was to attract high school students to fields of engineering technology through their active participation in hands-on research. The participating students obtained basic knowledge of nanotechnology, electronic devices, and computer software especially TCAD simulation software from Silvaco International.

Overall, the basic goals of the project were achieved. The project director directed the university undergraduate student and the high school student in a way that the two working as a team helped each other to derive the maximum benefits out of this applied learning research opportunity. As a culmination of their eight-week research experience, the participating students presented their results at the Summer Research Institute symposium in Fall 2006. Indeed it was a great achievement and students received high marks for their work.

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