Board 29: Creating a Virtual Reality Simulation of Plasma Etcher to Facilitate Teaching and Practice of Dry Etching in Nanotechnology Education

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Abstract

Plasma etching is the process by which material is removed from the surface of a sample, called substrate, through the use of plasma or reactive gases. The process of plasma etching prohibitally relies on high-cost materials and machines. This cost is potentially expanded as students attempting to learn the process run the risk of damaging the substrates or the machines, and any mistakes they make could result in great time and monetary loss. One potential solution to this conundrum is found in virtual reality (VR). VR allows schools to teach students in a safe, hazard free environment where students can make mistakes without losing much time or costing the university any money. This paper details the VR simulation Utah Valley University (UVU) is creating in order to allow students to simulate the etching process. The further goals of this paper are to explain the rationale behind the creation of the simulation and its potential in the student learning of nanotechnology.

Introduction

The National Nanotechnology Initiative (NNI) defines nanotechnology as " ...the understanding and control of matter at the nanoscale, at dimensions between approximately 1 and 100 nanometers" [1]. As nanotechnology grew it became necessary to manipulate at the nanoscale via multiple methods, one such method being nanomanufacturing. The process of nanomanufacturing, defined by the NNI as "...scaled-up, reliable, and cost-effective manufacturing of nanoscale materials, structures, devices, and systems", was created in order to further allow scientists to produce products at the nanoscale. Nanomanufacturing has been further split into top-down, or the reducing of large pieces of materials down to the nanoscale, and bottom-up, or the creation of materials by building them up from molecular- or atomic-scale components [2]. Plasma etching is a form of top-down nanomanufacturing that has been in use for nearly 40 years, especially in the creation of Si integrated circuits, however the history of the process goes back even farther. The term "plasma" being used in conjunction of partially ionized gases is first attributed to Irving Langmuir in the late 1920s. Etching in nanotechnology first started with wet, or chemical, etching but as the desire for less chemical waste grew the process of plasma, or dry, etching was developed. Breakthroughs such as the ability to strip photoresist using oxygen plasma were discovered in the 1960s and the first all dry-etched device was developed in 1975 by Texas Instruments [3].

Due to the importance of etching in the creation of circuits, microprocessors, and other devices it is necessary for students to become familiar with the process. However the cost of all the materials and machines needed to accomplish this can be prohibitive to a university setting. A basic plasma machine used just for cleaning substrates costs around $6,000 [4] (See Fig 1).

Fig 1: PE-25 Plasma Cleaner from Plasma Etch with a starting cost of $5,900

Tanks of oxygen gas can cost at a range from $70 to $500 [5] and the 100mm wafer samples used as substrates cost ~$100 per five wafers [6]. Assuming that each student will perform the etching process three times per semester, a class of 30 students could result in a price of ~$9,000 per semester just for the substrates alone. This does not include any substrates that could be lost through normal lab risks such as students dropping the wafer, nor does it include the price of machine upkeep and repair. Adding these other important variables would increase the price drastically. Such exponentially increasing monetary complications create barriers that prevent smaller universities and colleges from adequately providing their students the opportunity to learn the process of nanomanufacturing, let alone become the masters the industry needs. Due to these two issues: price and risk, it became necessary to look for an alternative means of teaching students plasma etching.

Knowing the problems connected to learning nanomanufacturing researchers at UVU began diving into the potentials of virtual reality technology. The first hurdle to overcome was cost: high-end VR equipment comes at a cost of $400-$800 (see Fig 2) but this is not the only price to consider.

Fig 2: HTC Vive bundle. Priced at $599 when researchers began initial work

In order to be effective VR equipment must be connected to a powerful computer, which can range in price starting at $1,000 [7]. Despite these costs, the total cost of VR equipment is minimal in comparison to the cost of a standard plasma etching lab, as the sum of the VR equipment is less than the plasma machine alone. The next hurdle to overcome was the question if VR could adequately complement standard methods of teaching the etching process. There have been multiple explorations into the realm of VR as an educational tool, including biology, chemistry, and mathematics. The University of Michigan's Department of Chemical Engineering did an in-depth study into VR as an educational tool, providing a well-thought analysis of the potentials, obstacles, and benefits of using it [8]. Such benefits include visualization of concepts and phenomena not normally observable, allowing students to learn in ways more suited to them that standard educational practices overlook, and increased sensory input which gives students more means of absorbing the information presented. These benefits, including the low cost of implementation, make VR an attractive alternative to standard methods of teaching the etching process.

Armed with this information researchers at UVU started creating a VR environment as a method of familiarizing students with the nanomanufacturing process. The team began by creating a multiple labs including a scanning electron microscope lab, and a photolithography lab. Upon completion of the photolithography lab the team decided to have some continue work on the SEM lab while other members of the team began work on the etching lab. These labs will be placed in a connecting environment which will eventually culminate in an experience that will help train the next generation of nanotechnology engineers. This paper will specifically delve into the plasma etching lab. The plasma etching virtual reality lab includes the proper use of the machine, familiarization with the etching interface, and the care and storage of substrates.

The plasma module was developed over the course of a few months using industry standard tools such as Autodesk Maya (Maya), Allegorithmic Substance Painter (Substance), Unity 3D (Unity), Steam VR, and Virtual Reality Toolkit (VRTK). Two types of VR hardware were used, Samsung Odyssey and HTC Vive. This was done in order to test compatibility with multiple VR types, the rationale for doing so shall be explained later in this paper. The lab experience was designed following a real-world lab that UVU is creating for students to use once they have tested and grown their abilities in VR. Upon completion of the VR lab, students were asked to test the virtual reality experience. Before and after testing the VR etching lab students were given surveys about their prior experience with VR as well as their thoughts on the VR etching lab. The results from which researchers will utilize to improve said lab and make any adjustments necessary to increase its potential in helping students prepare for careers in the nanotechnology industry.

Rationale

The goal of this module is to provide students a safe, risk-free, cost-effective, learning environment where they can become familiar with the features, capabilities, and controls of a plasma etching machine. Due to the virtual nature of the lab, universities run no risk of students damaging expensive equipment as they learn the controls of the etching machine. Nor is there risk of lost or damaged substrates, tools, or smaller equipment. Furthermore, this method of learning prevents high energy costs caused by running etching equipment. In addition, due to the nature of virtual reality, universities can allow multiple students to perform the lab at the same time at a fraction of the cost that it would take to obtain, set up, and run physical etching labs.

Finally, institutions with few resources can still implement the plasma etching training without needing to purchase costly equipment.

Virtual reality stands in a unique place in education because it allows students to take full responsibility for the lab without putting them, or the lab, at risk. This is especially significant in fields where hands-on experience is important to understanding the material, process, and application of their learning. Such responsibility results in accelerated learning as they must be more fully engaged in the process. Instructors are freed up to provide more instruction and in-depth learning as they don't have to carefully monitor the students in the lab lest they make costly mistakes. This freedom, for both instructors and students, creates a unique learning atmosphere that would not be possible otherwise. Another benefit of utilizing virtual reality is the ability to actually see the etching as it is occuring, giving students a better understanding of the scientific principles behind their actions. Additionally virtual reality allows for an unlimited supply of virtual etching materials at no additional cost.

Plasma Etching Education

Before entering the virtual module students are instructed in the functionality and use of plasma etching. This instruction is done through lectures complimented by slide presentations, homework, and diagrams. Figure 3 shows one such diagram that demonstrates the parts of a plasma chamber. Students are also shown diagrams that demonstrate the results of different forms of etching, including wet etching. They are further instructed in the applications of etching and how it relates to the other processes involved in nanotechnology.

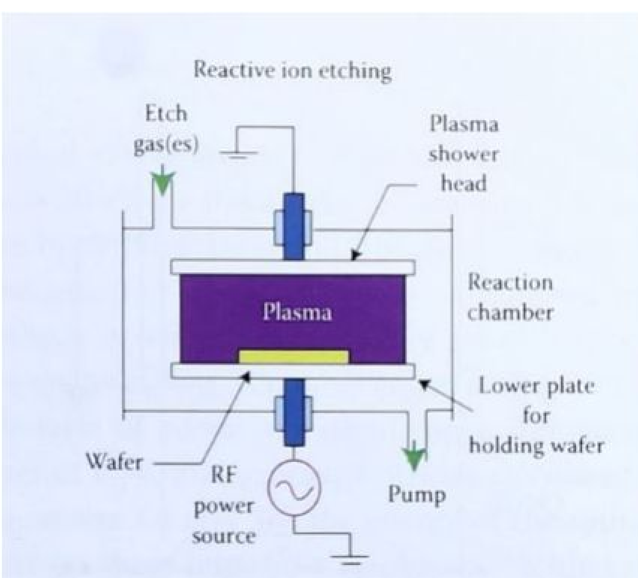

Fig 3: Diagram of plasma chamber for radio frequency generated plasma

Students are further instructed on how the machinery operates. They also receive knowledge on how the plasma is created in the machine and how the plasma succeeds in etching the substrate. Students learn that one such method of creating plasma is radio frequency (RF). RF plasma is created by introducing a neutral gas into an low vacuum chamber wherein two RF powered electrodes create a magnetic field. This magnetic field causes the gas to ionize and become plasma which is then attracted to the negatively charged electrode located underneath the substrate. Leading to material being removed from the substrate as these ions bombard the wafer (See Fig 4). The virtual plasma etching machine was designed to follow this method of plasma generation.

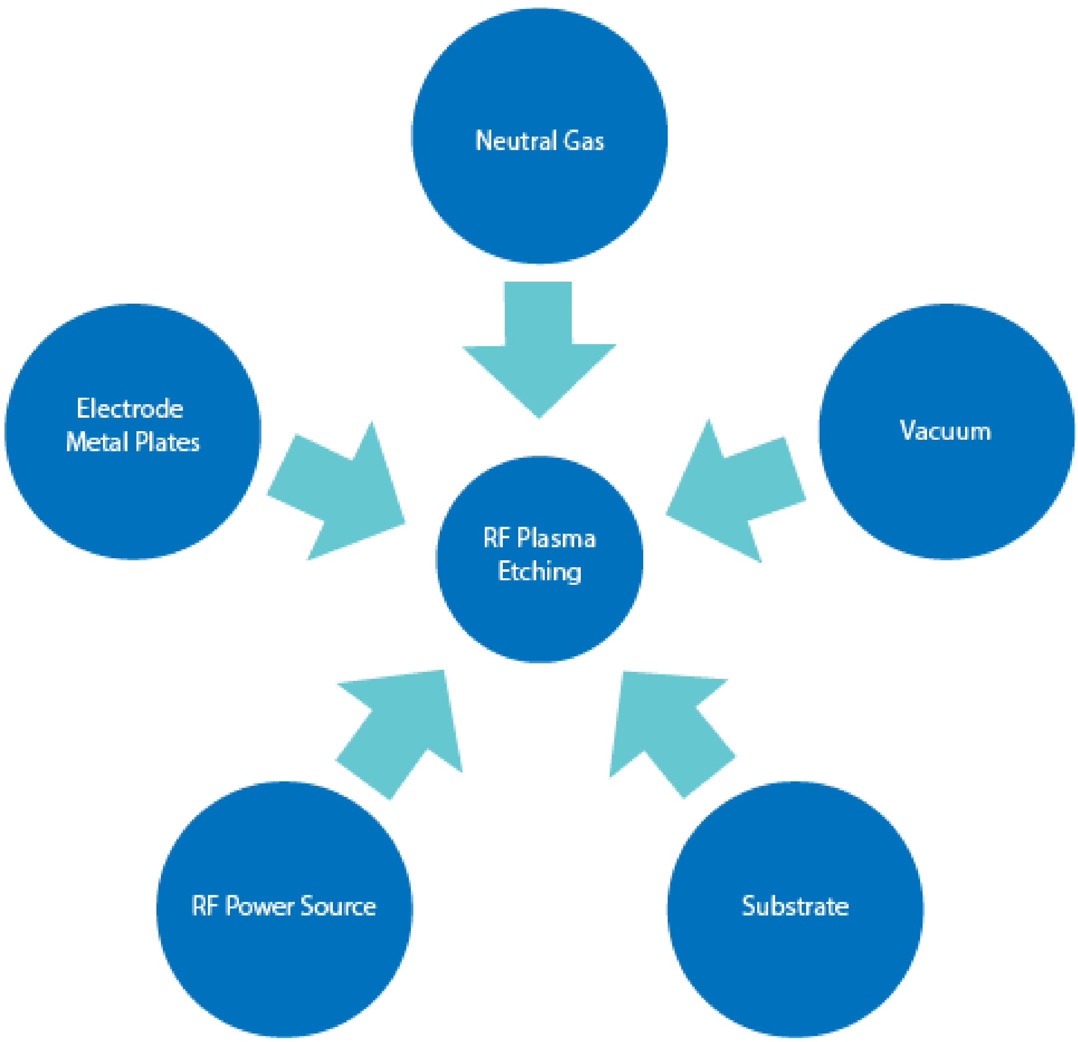

Fig 4: Components of RF plasma etching

Upon gaining an understanding of the methods and processes behind plasma etching, students are then instructed in the steps they will take to etch a wafer in both virtual and real-world labs.

They begin by preparing the substrate for etching. Following that they are instructed to ready the machine by providing the components needed for RF plasma etching. Next they are taught what computer systems and settings are used to etch the substrate. Once the sample has been etched they learn about proper machine shutdown procedures and storage of substrates (see Fig 5). Only after having received this instruction are students allowed to enter the virtual lab and try the process for themselves.

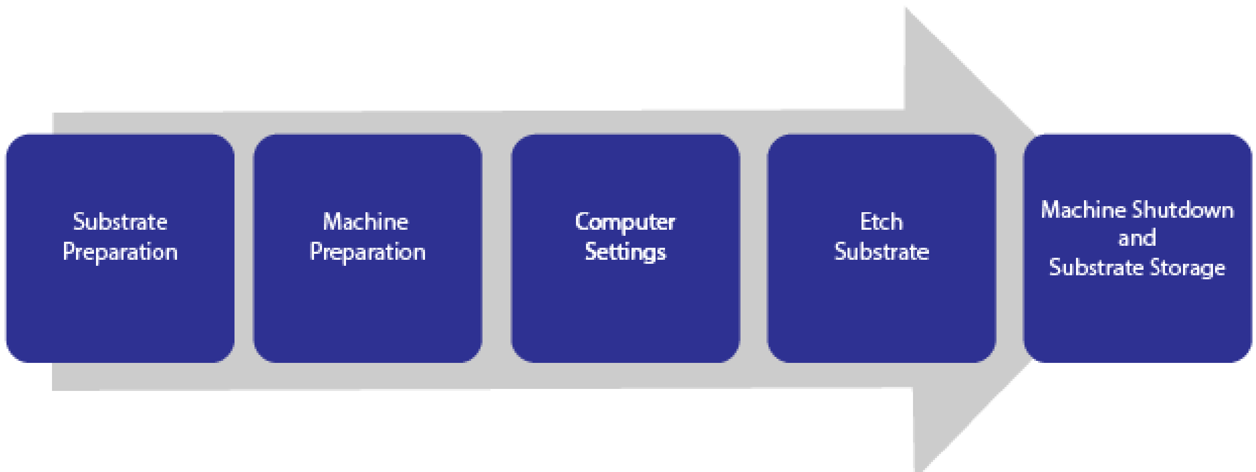

Fig 5: Steps students take to properly etch a wafer

Virtual Module

Creation of the virtual etching module began with a demonstration of a physical dry etching lab UVU already had in place. Researchers were instructed in the process of plasma etching and provided opportunities to observe and document the machines involved therein. These machines were: the plasma etcher, a vacuum pump, gas tanks, an air compressor, and the computer controlling it all. This live instruction took place over the course of one day but recordings which the researchers took were referenced continually throughout the creation process. After observation was complete they began creating 3D models of the machines using the industry standard tool for 3D modeling: Autodesk Maya. This process began with rough “block” models to get a sense of scale. Once the scale was found these basic models were improved upon until they met the style previously decided upon in the prior-mentioned photolithography module (see Fig 6).

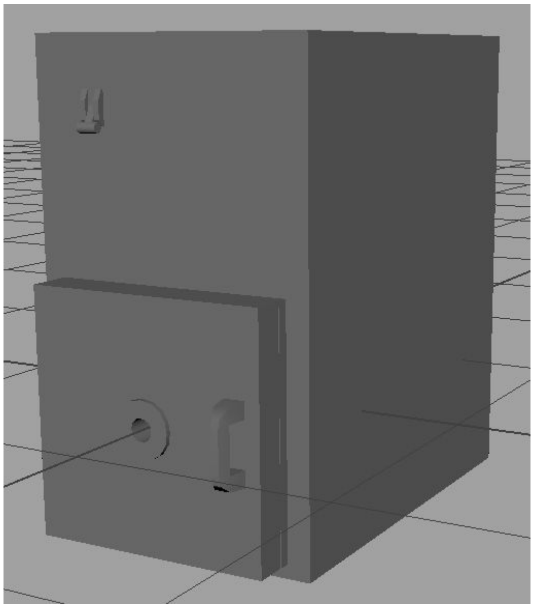

Fig 6: Block model in Maya

Following the modeling process the more complex models were given color and texture with Substance Painter while the simpler models were given color using Maya (see Fig 7). Upon finalization of the models the team imported those assets into the game engine, Unity3D. Utilizing a combination of Unity, two plugins for Unity: VRTK, and Steam VR, and the C# coding language the research team created a rough simulation of the physical lab (see Fig 8).

Fig 7: Model texture in Substance Painter

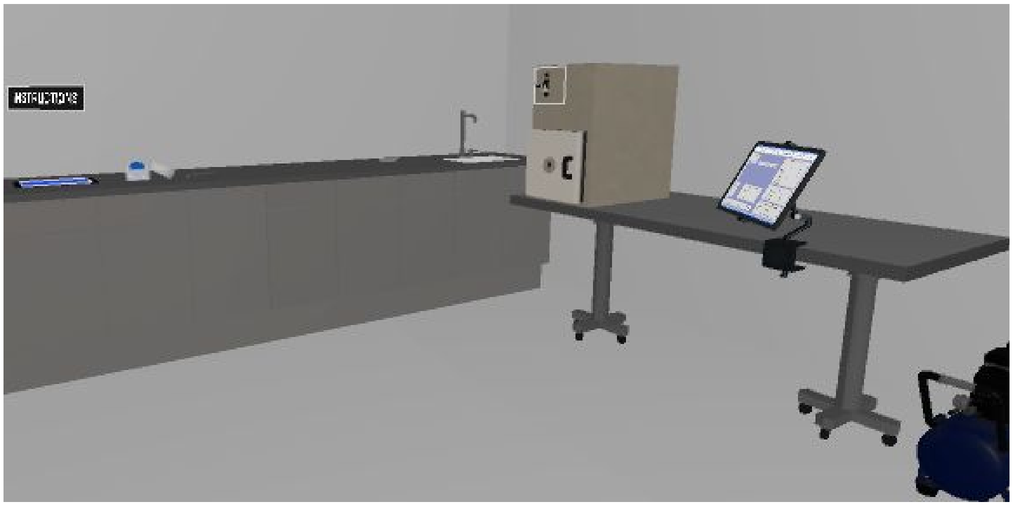

Fig 8: Rough layout of etching room

This rough simulation was used as proof of concept and submitted for approval. At this time instructors tested the lab and gave suggestions for improvement. The research team took their comments and utilized them to bring the VR etching lab up to the standard set by the photolithography module (see Fig 9).

Fig 9: Left: etching room, right: photolithography room

They also took this time to stabilize the code controlling the module, creating a better, smoother experience for the user.

VR Hardware

Researchers were initially interested in using the HTC Vive (Vive) virtual reality equipment. The modules were originally designed to follow the standards, and limitations, of this gear. The team had already completed the initial prototype of the etching lab when they were informed that UVU had been given a grant for the purpose of creating a virtual reality lab to be used in the creation of simulations such as the one the team was currently developing. Those in charge of the VR lab's creation chose the Samsung Odyssey (Odyssey) VR equipment as the primary equipment for the lab. This gave researchers the unique opportunity to test the possibility of making the VR nanotechnology lab compatible with multiple different headset types. Initial tests were encouraging as the combination of VRTK and Steam VR made it easy to switch headsets. After a few days of testing the team is fairly confident that the simulation will work with the current standard headsets for VR, giving institutions greater freedom in implementing the VR lab into their current curriculum.

Student Testing and Input

Once the research team had finished creating the initial version of the etching lab, students were invited to test the virtual lab. Each student was given a survey before taking the lab and another once they had completed the module. Each survey contained questions asking them to detail their experience with VR as well as any concerns or comments they had on the module itself. Upon entering the VR environment students had minimal contact with researchers as the team wanted to see how they would adapt to VR, and what improvements could be made to make such adaptation easier.

The module begins with the student in the middle of the room so they can easily see the contents of the lab (see Fig 10). A tablet that they can carry around with them gives the students instructions as they learn the etching process (see Fig 11).

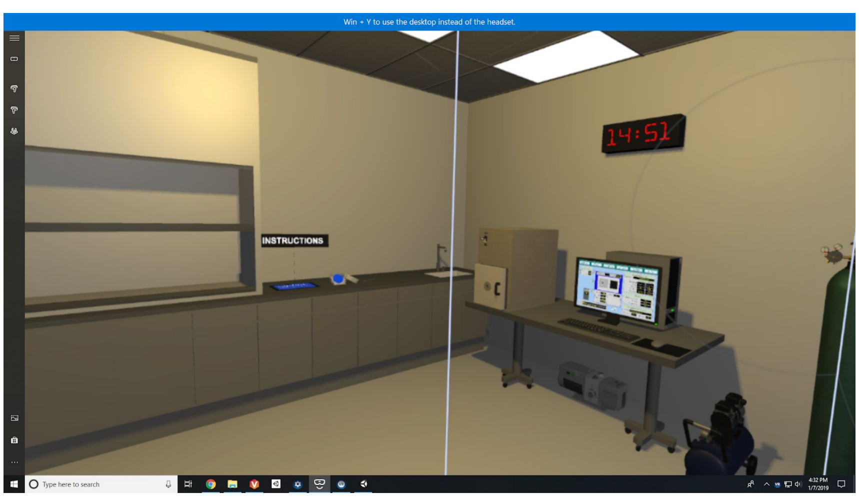

Fig 10: The etching room as seen in VR

Fig 11: Tablet with sample instructions

In these initial stages many students struggled with movement and interaction in the virtual world. But as they spent more time in the simulation such problems resolved themselves as they became more familiar with VR. In order to facilitate this learning, the very first step requires students to cross the entire room and turn on the gas tanks which supply the plasma etching machine (see Fig 12).

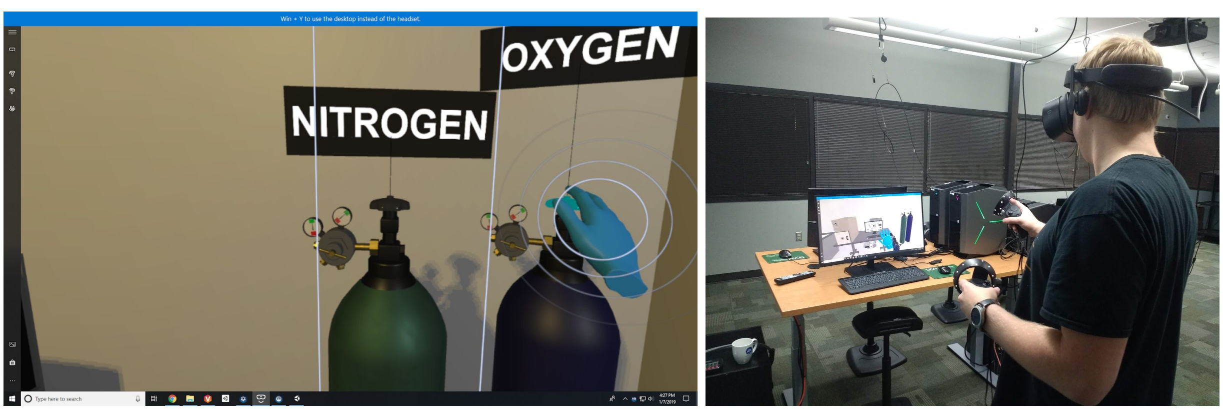

Fig 12: Left: VR view of a student turning on the tanks, right: student using VR gear to perform the simulation

Once students have had this opportunity to orient themselves to VR they are asked to prepare the machine and substrate for etching by turning on the machine and placing the substrate inside it (see Fig 13).

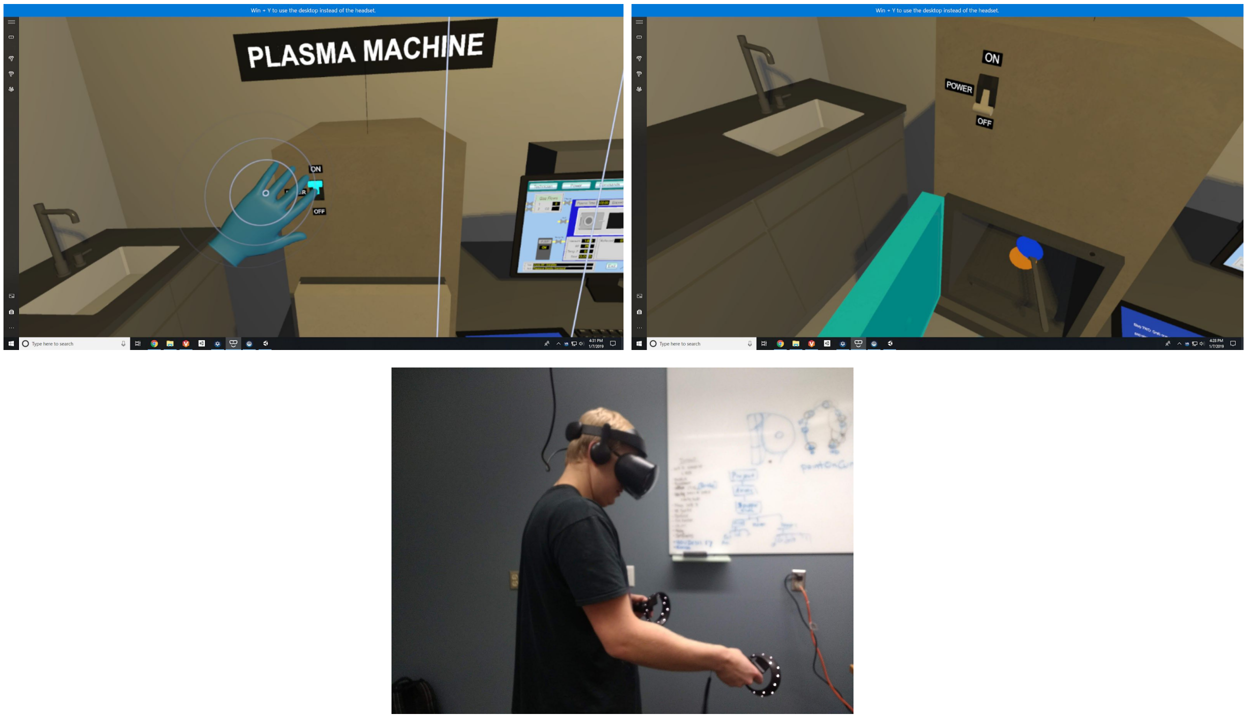

Fig 13: Top left: VR view of machine being turned on, top right: VR view of wafer being placed in etching machine, bottom: student performing displayed actions

After that students went to the VR computer and activated additional power systems, then provided instructions to the plasma etcher as to how long the machine should etch the substrate. During this researchers came to find that another common issue was reading was difficult due to VR's rather restrictive resolution. This problem was solved by increasing the size of the computer screen when students approached to it. (see Fig 14)

Fig 14: Various interfaces students used to perform operations on the VR computer

Once the plasma cycle is complete students are prompted to properly care for the substrate by placing the sample in a fume hood. They also are instructed to turn off the machine, gas, and other systems in a manner that will help them gain appropriate habits for real-world lab experiences (see Fig 15).

Fig 15: Student storing wafer in fume hood.

Upon completion of the module students are graded based on their ability to safely operate the plasma etching machine, care for substrates and time spent performing the lab. Their grade is displayed on a VR whiteboard along with information relative to each step so they can see opportunities to improve (see Fig 16). Students are given 15 real-world minutes to complete the module, and most did so in about 10 minutes (see Fig 17).

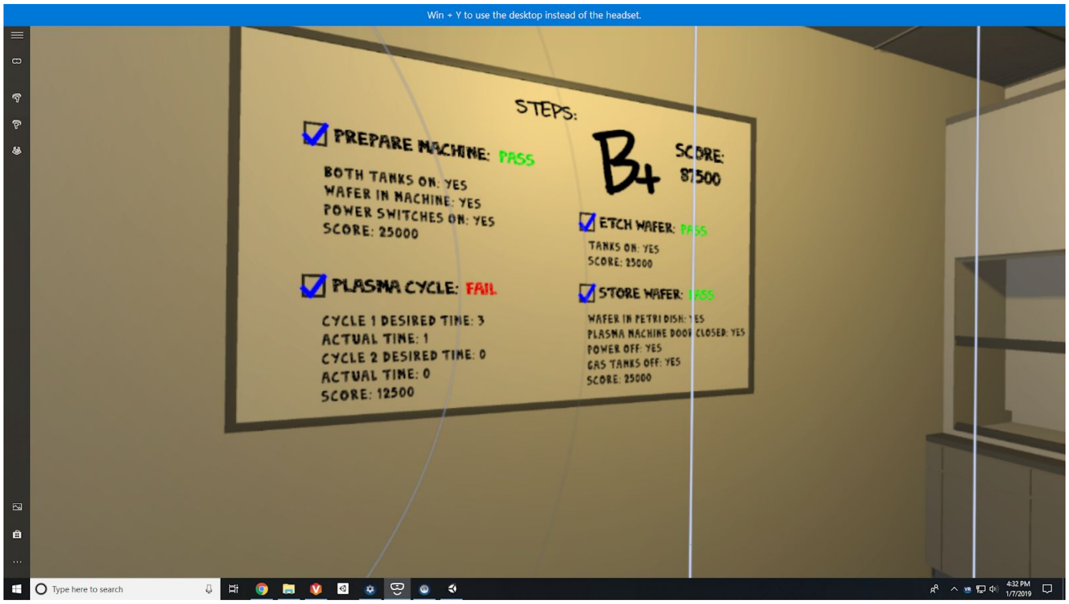

Fig 16: Student score displayed on whiteboard

Fig 17: Clock shows the minutes/seconds students have left to complete the module

In their survey responses students had the opportunity to give their thoughts on the lab. Their responses were encouraging, saying the following:

“Very satisfied.”
“Overall it was a fun, interactive, and learning experience.”

Students unfamiliar with the plasma etching process also noted the following when asked if they felt the lab prepared them for a real-world etching lab:

"I feel ready to try the same thing in the real lab."
"Yes"

Conclusion

Understanding how the plasma etching process is performed is a needed skill in the ever-growing sphere of nanomanufacturing and nanotechnology. By creating a VR simulation of the plasma etching process UVU facilitates more opportunities for student learning at a manageable cost. This program also enables students to learn and practice etching fundamentals in a safe, risk-free environment without sacrificing practical experience. Thereby affording students the opportunity to increase in understanding and innovate upon what they've learned. They gain appreciation for the tools involved in plasma etching as well as the habits necessary for safe use of this technology. Furthermore, institutions with low resources can still utilize this program to teach students plasma etching, providing them with crucial experience needed to enter an ever-growing industry. By providing universities and colleges with more opportunities and ways to train students in this critical aspect of nanotechnology it is hoped that they will be more equipped to train the next generation on nano-engineers.

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