

The Creation of Microelectronics-based Visualizations to Enhance Science Education and Literacy

John C. Bean, James F. Groves and Niladri Kansari
School of Engineering and Applied Science, University of Virginia
Charlottesville, Virginia 22904-4743

Melissa Appleyard and Chris Lehmbeck
Darden School of Business Administration, University of Virginia

Tony Wayne and Michael Brittingham
Albemarle County Virginia High Schools

Abstract - This paper describes an ongoing project to create web-based visualizations based on microelectronics and its underlying science. The visualizations are being designed to serve diverse groups ranging from high school science students, to upper division engineering undergraduates, to graduate business students. By substituting highly visual and interactive explanations for mathematical expressions, the project engages students with limited engineering background, while inspiring students who already have a strong general science background to pursue microelectronics in more depth. The paper describes both completed and planned modules, as well as the software tools investigated and/or employed.

1. Introduction

This project grew from a diverse set of teaching experiences. The first was that of teaching an undergraduate course on microelectronics. The course's lavish use of mathematics meant that it could be offered only well into a specialized Electrical Engineering curriculum. In even these circumstances, it was observed that many students had great difficulty connecting the mathematics and static 2D blackboard drawings with the dynamic 3D devices they represented. The second experience was of teaching freshman university science and engineering courses. Here, faculty tended to select very generic foundation materials they "knew" the students would eventually need. Students, instead, believed that they had finally reached the point where the mysteries of science and engineering would be dramatically revealed. This disconnect prompted many students to opt out of more challenging majors or, indeed, out of science and engineering entirely. Finally, work with business students studying the competitive dynamics of the electronics industry revealed a hunger, on their part, to more deeply understand the science and technology of this

industry. These concerns led us to seek simplified, non-mathematical means of introducing students to pervasive yet mysterious technologies such as microelectronics.

Inspiration was drawn from two sources: the tremendous impact of illustrated books such as David Macauley's "The Way Things Work" [1] and the explosion of dynamic 3D imagery beginning to appear in computer games. These suggested that it should be possible to develop web-based materials drawing on students' existing scientific experience and computer literacy, and to then expand that knowledge through the use of interactive, fully three dimensional visualizations. Further, it suggested that a basic, but nevertheless accurate, understanding could be conveyed in single web session or a handful of classroom/lab hours. Subsequent discussions with high school science teachers then suggested that the same materials could demonstrate to their students the utility of introductory science courses. With this expanded goal and team, supporting funds were solicited from the National Science Foundation's program of "Course Curriculum and Laboratory Improvement" (CCLI). While this proposal was being evaluated, it was learned that there was a surprisingly similar effort emerging within our Darden School of Business Administration. With the receipt of NSF funding, these efforts were allied in a larger development program that has been titled "eXplore Microelectronics."

2. Existing and Planned Materials

We are now at the midpoint of the three-year development project. An overall map of the materials has been developed along with selected modules in most categories. The general plan is to permit different student populations to connect modules in different sequences based on their interests. For instance, a high school student might begin with a basic science module that reinforces instruction in an introductory

physics course. That student will then be offered modules illustrating the use of that scientific principle in a microelectronic device. Then, links will be offered to depict how this device fits into and enables a familiar consumer device, such as a cell phone. The business student may follow the reciprocal route that starts with a non-technical student's desire to better understand what is inside her cell phone. Modules would then take apart that cell phone in virtual reality exposing the components. A given component could then be selected and a general explanation of its operation provided. This explanation could then be expanded by linking to modules illustrating the basic science involved.

For the more advanced or curious students, another set of modules will be linked through buttons labeled "How's it made?" These will carry the student to modules depicting both the device's fabrication sequence and selected microfabrication tools.

We provide preliminary examples of these materials. The full visualizations for each can be viewed by visiting our webpage describing the project:

www.people.virginia.edu/~jcb6t/Reserch/Explore/explore.htm

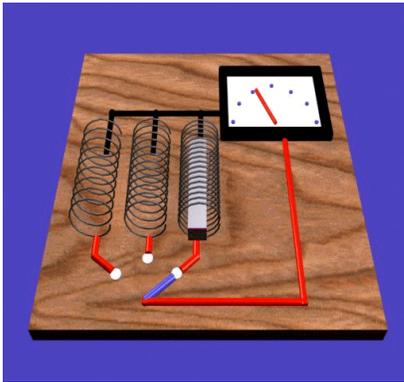


Figure 1. Frame from virtual experiment depicting electromagnetic induction (Conor Hiney)

Starting with the needs of the high school student we confront the fact that mandated high school science curricula often provide few opportunities for wide-ranging exploration [2][3]. Further, instructors are so heavily burdened that they cannot afford the time to seek out supplementary materials for individual lessons. It is thus essential that we not only link to the most common curricula but also that we provide a block of materials supporting an extended unit of instruction. Our solution is to complement common physics classroom experiments. Instructors already provide a variety of very effective and engaging demonstrations on electrostatics and electromagnetics, but students can become confused as they try to visualize the movement of microscopic charges or the interactions of invisible fields. Virtual reality can fill the gap. We provide, first, a visualization that reproduces, on the

computer screen, what the student has seen in the classroom demonstration. This is illustrated by the demonstration of electromagnetic induction shown in figure 1.

A second visualization, using "Superman X-ray vision" then abstracts and augments the view of that demonstration. For instance, fields materialize, microscopic charged particles appear, and unnecessary hardware fades away to emphasize the underlying mechanisms of the interaction. Next, the student is offered a link to a practical application of this science, for instance, the virtual reality depiction of the inner workings of a cell phone's speaker, as shown in figure 2.



Figure 2. Frame from visualization showing operation of a speaker and its use inside a common cell-phone (Conor Hiney)

A similar sequence of visualizations, moving from classroom reality to "X-ray vision" to application, will be provided for a dozen or more common demonstrations on electromagnetics and electrostatics. This large body of material will, we hope, so enrich extended units of physics high school instruction that they will more than justify the time instructors must invest to weave them into their courses.

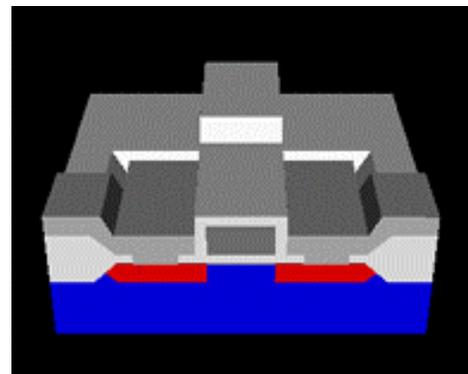


Figure 3. Frame from visualization showing fabrication of MOSFET transistor (John Bean)

The materials supporting high school instruction merge naturally with modules supporting microelectronics education at a higher level. For instance, demonstrations on electrostatics naturally link to a visualization depicting the electrostatic attraction that is at the heart of a MOSFET transistor. In turn this will link to a visualization depicting the fabrication sequence of such a transistor, as shown in figure 3.

For the most curious high school student, or for university students coming to our site with a specific interest in microelectronics, we will also provide modules that explore the process of microelectronic fabrication. Two examples are provided in figures 4 and 5 that depict both conventional photolithography and a possible successor to it, the "SCALPEL" [4] process of electron projection lithography.

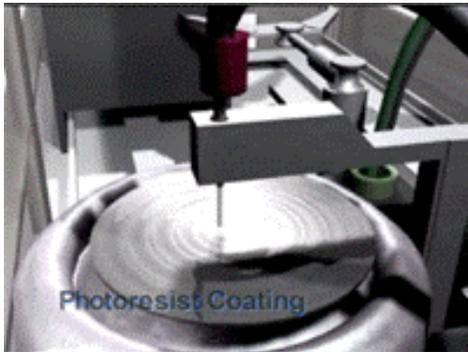


Figure 4. Frame from visualization depicting the microelectronics fabrication step of photolithography (Lucas Hardi and Matt Shields)

3. Software Tools

The above examples (at least when viewed in their entirety), illustrate the potential power of virtual reality in education. Readers are invited to revisit our project website which is intended as a working diary that will be continuously updated and expanded. This brings us to the question of how these visualizations are created and, more importantly, what functionality must still be added to fully attain our vision. A particularly savvy observer once described our efforts as not "leading-edge" but "bleeding-edge." He captured the fact that while the best of movie special effects or commercial games offer the capabilities we seek, that is in no way equivalent to saying that we as educators can yet access or afford the necessary programming tools. Our challenge is compounded by the fact that we seek to deliver our materials through generic web connections to PC's with a variety of capabilities and flavors. This means that we cannot choose software for which the user will be charged, or software requiring obscure user plug-ins, or software usable on only a single flavor of computer, or computers of particularly aggressive

capabilities. Have the above materials achieved this goal? Not yet, but we believe that goal is now in sight.

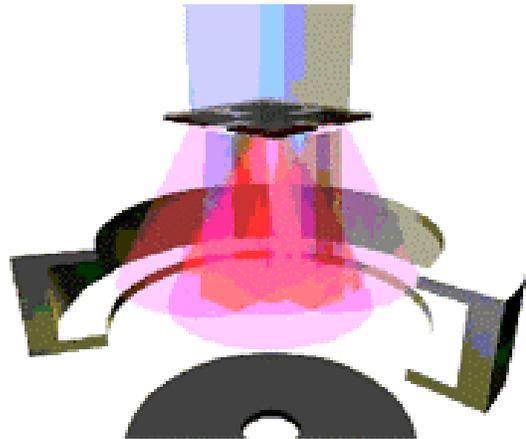


Figure 5. Frame from visualization depicting a possible future lithographic tool based on electron projection lithography (Niladri Kansari)

The requirement for cross platform compatibility (in both software and hardware) suggested that our materials would have to be playable through a generic web-browser with common user plug-ins. This ruled out a large number of otherwise very intriguing programming tools. At the outset, the remaining possibilities seemed to be the Virtual Reality Modeling Language (VRML) and the Java language that drives most common web applets. We investigated VRML [5][6]. It is concise and easy to learn but we found that it is not really a programming language. It can efficiently present objects but provides little native capability for doing much more than rotating them or moving through them. Current versions have neither the math nor logic, both of which are essential for depicting complex motion or achieving deeper user interaction. These capabilities can be added only through cumbersome multiple levels of interfacing to external Java or Javascript code.

This suggested, instead, that we simply use Java and its native graphics capability. Unfortunately, versions of Java currently supported by browsers do not achieve graphics that are intrinsically 3D. 3D objects can be depicted but only through laborious programming that dynamically re-evaluates the 2D projection of an object as it moves, or the user manipulates it. Sun Microsystems has developed the beta version of a Java extension (the "3D API") that is intrinsically 3D [7]. We explored this extension in depth but encountered several critical limitations. First, the extension builds on "Java 2" (actually version 1.2.2) which is not yet incorporated in all browsers, and the extension itself calls for an additional plug-in that even developers struggle to add. Secondly, the current implementation of the extension, while powerful,

provides few high level programming routines. As a result, for instance, we found that even a simple geometrical object could require page upon page of code as every vertex, face, normal vector, texture, material and color was enumerated. We did, ultimately, succeed in depicting a MOSFET similar to figure 3, but only after a prohibitive amount of programming effort.

At this point we turned to a program designed to create content for electronic games, "3D Studio MAX" produced by the Discreet Division of Autodesk [8][9]. This tool resembles a 3D CAD program but it emphasizes final appearance and ease of creation rather than numerical precision. Further, it incorporates a slider that allows one to depict objects at various times and it will then automatically interpolate color, visibility and shape between the specified time points. This information can then be "rendered" into the movie (e.g. widows avi format) that you will view in the above examples. This rendering process can go so far as to compute surface reflections and shadowing between objects with a degree of accuracy that is difficult to distinguish from films of actual objects (view, for example, the full visualization of figure 4).

From an educational point of view, the shortcoming of 3D Studio MAX is that, until recently, it could produce only bit-mapped movies. The movies in our examples above are only 1-2 minutes long but can run over 25 MB in size with even the most aggressive compression. They can thus be delivered over a high-speed internet connection or on a CD, but not through the modem connections still common in many classrooms. Further, because they are programmed movies, user interaction is limited to their selection and then to stopping and starting play.

The solution has, we believe, now been offered by the April 2001 announcement of Macromedia Corporation's software package "Director V8.5" [10][11]. Director is very well established program the content of which is played through browsers by the common "Shockwave" plug-in. With version 8.5, 3D objects, such as those created in 3D Studio MAX can be imported into the Director programming environment. Further, they are imported as concise geometrical descriptions rather than as bloated bitmap files. Once in this environment, their behavior can be programmed by a variety of means including a fully developed scripting language, or provisions added to allow for extensive user interaction. The resulting webpages are compact (often only 10's of KB in size) and readily delivered over conventional modems. Rendering is then accomplished by the efficient Shockwave plug-in on the user's PC. We have just received copies of this software and are now in the process of converting many of the above 3D MAX based movies into Director and Shockwave format. These should be available on our website shortly.

4. Conclusion

Dynamic 3D visualizations offer younger and non-specialized students an intuitive understanding of material that can otherwise only be presented through advanced and often intensely mathematical courses. Further, for even the advanced student, visualizations can capture a process or an object in a manner otherwise impossible in the conventional classroom. The necessary programming software is just now becoming available to educators and we are exploring its use through a project aimed at a wide variety of students.

5. Acknowledgements

We would like to acknowledge a grant from NSF's Division of Undergraduate Education (DUE-9950207), a gift of software from Discreet Inc., and the support of the School of Engineering and Applied Science, the Darden School Foundation, and the Office of the Vice President for Research and Public Service of the University of Virginia. We are also indebted to a growing cadre of undergraduate and graduate programmers that has included Lucas Hardi, Conor Hiney Ray Hwang, Matt Shields and Vinu Vijay Kumar.

6. References

- [1] David Macauley, "The Way Things Work, Houghton Mifflin, 1998
- [2] The "Virginia Science Standards of Learning" can be accessed at www.pen.k12.va.us/go/Sols/science.html
- [3] The "National Science Education Standards" can be accessed at www.nap.edu/readingroom/books/nses/
- [4] L.R. Harriott et al., J. Vac. Sci. Technol., B14(6), 3825 (1996)
- [5] The "Web3d Consortium" provides ongoing information on VRML development at www.vrml.org/
- [6] We recommend Jed Hartman and Josie Wernecke, "The VRML 2.0 Handbook, Addison Wesley, 1996
- [7] Extensive information on Java and its 3D extension can be found at Sun Microsystem's site: www.java.sun.com/
- [8] Discreet's website is www.discreet.com
- [9] We recommend Michele Matossian, "3D Studio Max R3 Visual Quickstart Guide," Peachpit Press, 1999
- [10] Macromedia's website is www.macromedia.com
- [11] We recommend Gary Rosenzweig, "Using Macromedia Director 8," Que, 2000