Multimedia Textbook Paradigm A Demonstration in Solid-State Device Electronics

Cuong T. Nguyen Man Wong Johnny K. O. Sin
K. C. Smith *
Dept. of Electrical & Electronic Engineering
University of Science and Technology, Hong Kong

Abstract

A multimedia textbook on solid-state device electronics is being developed. It is based on the understanding that the traditional print medium is limited and inefficient in imparting knowledge, in view of the dynamism and complex interactions possible with multimedia technology. In this paper we discuss the motivation for this effort and the design philosophy in creating this multimedia textbook. A demonstration vehicle will be presented in the form of an interactive courseware for solid state device electronics developed on the PC platform.

1 INTRODUCTION

For many years multimedia technology has been recognized as having the potential to revolutionize education by introducing new modes of teaching and learning. Understanding the impact of this new technology and effectively utilizing it are part of an evolving process. One obvious area of application is to improving the traditional static textbook model. The question is how to do so appropriately. Data exist to show the superiority of computer-aided instruction (CAI) compared to textbook-based learning, for example, in comparing test scores among high-school students who prepared for standardized examinations, one group with textbooks and the other with commercial test preparation software[1]. However, such data must be carefully interpreted to assess how much of the improvement is due to effective use of the computer medium as opposed to other factors, e.g., better content preparation or correlation to the standardized tests. Nevertheless, the positive contribution of the new medium is clear, as was demonstrated in a comparison of college students asked to answer the same set of questions on Third World development[2]. One group used a regular textbook while the other was given its electronic version, which contained the same text but with search capabilities: the latter yielded better scores.

The motivation for employing multimedia to enhance traditional textbook is strong. However powerful are the insight and eloquence possessed by the traditional textbook authors, the demonstration of dy-

*On leave from the Dept. of Electrical and Computer Engineering, University of Toronto, Canada

ISBN-0-7803-1963-X

namic behavior, complex multivariable interactions, and even simple experimentations, are impossible in the print medium. Print is sufficient only for the visualization of static images and textual descriptions. In the traditional teaching-learning mode, such limitations can be circumvented through the use of creative classroom lectures, orchestrated demonstrations, and laboratory classes. While these approaches are used and do help, their success usually depends on special circumstances, and special individuals. What is needed is a more unified and structured approach to alleviating the deficiencies of the conventional print medium as a key element in the teaching process.

2 DESIGN PHILOSOPHY

The idea of a computer-based textbook is not new (see, e.g., [3,4]). However, many are either simply hypertext translation of the static text (i.e., identical text with hyperlinks for cross-referencing, indexing, tagging, etc.) or are topic-oriented courseware intended for tutoring or laboratory use. Furthermore, technological advances are rapid, and what was not possible or practical a few years ago now needs to be considered so that the full advantage of "multimedia" can be realized. The use of graphics, animation, sound and video in courseware has become feasible. At the same time we recognize that the success or usefulness of the multimedia textbook is not so much limited by the leading edge of technology as it is by user acceptance. In a study of instructional software accompanying books, it was found that three quarters of the readers had never used the software, citing personal, technical, economic and other reasons[5]. Technology-phobia limits the appropriateness of computer-based instruction to a smaller segment of the population. The delivery platform also imposes a barrier against adoption – not everyone has a computer, or owns one with the necessary capabilities, or can conveniently get to one.

As computer technology evolves into an integral part of society, these problems are expected to diminish. However, it is always possible to misuse or abuse technology; we are all too well aware of text written in 15 different typefaces or figures drawn using all colors of the rainbow simply "because it is possible". The equivalent in courseware development is to present a dizzying multitude of options which confuse more than teach. Those who can communicate well to computers still need to learn to communicate well through computers. Good teachers are vital to the development of a multimedia textbook. It has been suggested metaphorically that on the road of computer-based teaching, if technology is the vehicle and education the passenger, it is "the arts, through a sensitive teacher, that should be the driver"[6].

Keeping all of this in mind, in developing a multimedia textbook, the paradigm to be followed is that of classroom interactions: how a good teacher brings a subject to life with sketches, graphs, by pointing and explaining, etc. Animation and interactivity can be used to illustrate dynamic behavior, while audio augmentation can provide more striking effects resulting in better retention of the subject matter by students. The computer also makes it possible to perform "virtual" experiments that may not even be possible in a laboratory setting because of physical or cost constraints. In addition, the learning process is accelerated by hyperlinks which instantly bring up reference or explanatory material whenever needed. In traditional textbooks, materials are forced to be arranged in a linear sequence of "chapter" even in the absence of clear logical dependence of any chapter on the immediately preceding one. With multimedia such restrictions do not exist, and more logical linking of different modules of the subject matter in a dynamic, multi-dimensional manner is directly possible.

The textbook of the future should also enhance the actual classroom experience by being operable in two modes: self-directed learning and lecturer-paced. The latter can include generating lecture notes[7] or allowing the lecturer to interact with the material in front of students in a classroom equipped with appropriate audio-visual equipment. Indeed with the coming of high-speed wide-area networks, a multimedia textbook can serve as a basis for interactive distance education.

3 DEMONSTRATION VEHICLE - A MULTIMEDIA TEXTBOOK

We have chosen the topic of introductory semiconductor device physics, a mature subject matter with several excellent textbooks[8,9,10] available in print. Animation is used to illustrate and to help visualize dynamic behavior of the systems under study, such as bond breaking, the generation of electrons and holes, the diffusion and drift of charged particles, and the important difference between *dynamic* and *static* equilibria, etc. Animation is combined with interactability to allow a variety of simulated experiments to be performed by the users. Examples include the dependence of charge carrier density on changing temperature, the respective dependence of diffusion and drift current components on varying concentration gradient and electric field, etc. Such visual parametric experiments can distil information much more effectively than words, and help the student develop an *intuition* for the underlying physical principles.

3.1 Knowledge organization

In the demonstration vehicle, concepts are presented in a series of logically connected "slides" in a manner similar to the presentation of the same concepts in consecutive pages in textbooks. Hence slides are to lecture-based presentations like pages are to textbooks. While it is not necessary for each page to have defined themes, each presentation slide should be relatively self-contained with clearly defined themes.

The desired grouping of the slides is dependent on a multitude of factors. Some of these are strictly logical groupings such as a series of slides showing the development of energy bands from discrete atomic states as crystals are formed from a collection of isolated atoms, and finally leading to the idea of an energy gap separating the conduction and valence bands in semiconductors. Icons are provided for the users to move freely along this linear chain of slides.

Oftentimes, it is not necessary to derive a concept starting from the most fundamental ideas because the latter are relatively well known to the students so that their inclusion would be disruptive to the continuity of the presentation or would make the presentation less "appealing" because of the lack of apparent "sophistication". Hence a hierarchical organization is adopted in which concepts are explained in terms of more fundamental ones and the meanings of which are assumed known to the students. If it is desired to elaborate on these fundamental concepts, the explanation can be invoked (or "referenced") at any time during the presentation by "clicking" instances of the representations of these concepts in the presentation slides. Such instances may appear as keywords, graphical icons, etc. Once invoked, a new series of presentation slides dealing specifically with the fundamental concepts in terms of yet more fundamental ones will be activated. This process can be repeated indefinitely until the level of the most basic concepts is reached.

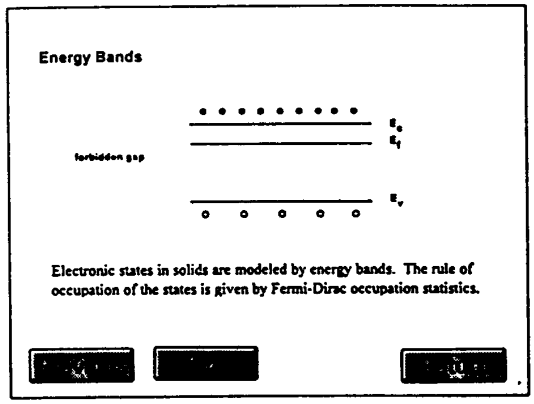


Figure 1: Energy band diagram showing interaction icons.

This idea is illustrated in Figure 1 where the energy band diagram of a typical semiconductor is shown. For students who already have the basic understanding of the energy band theory and the definitions of "E_c", "E_v", and "E_f", etc., they can move on to the adjacent presentation slides by "clicking" on the "previous" or "next" button shown in the bottom of the Figure. However, for the students who are not yet familiar with these concepts and want to learn more about them, they can click on the labels "E_c", "E_v", or "E_f" to invoke explanations of these concepts. A "return" button similar to the one shown in this slide will also be available in the invoked slides so that once the students are satisfied with the explanation, they can return to the "referencing" slide by clicking on the corresponding "return" button.

It is clear that the more fundamental a concept is, the more general it becomes. Hence, it will be encountered in and referenced from various presentation slides from different levels of sophistication. Each time the explanation of the more fundamental concept is invoked and finished, presentation will be resumed from the particular slide from which the concept is referenced. This "layered" approach allows the students to probe progressively deeper into the foundations of any chosen topic and to stop at the appropriate level of explanation desired by the students.

The hierarchical organization of the presentation slides not only makes it possible to match the "sophistication" of the lecture to the level of the students, it also makes good pedagogical sense since fundamental concepts are always referenced by higher level concepts which not only set the context but also provide the "motivations" for the introduction of the more fundamental ideas.

By providing suitable "entry points" to different levels of the top-down hierarchical organization of the presentation slides, traditional divisions of "topics" such as *pn* junctions, field-effect transistors (FET), and bipolar junction transistors (BJT), etc., can be retained. Figure 2 shows such a presentation slide in which the different topics in the multimedia book can be selected.

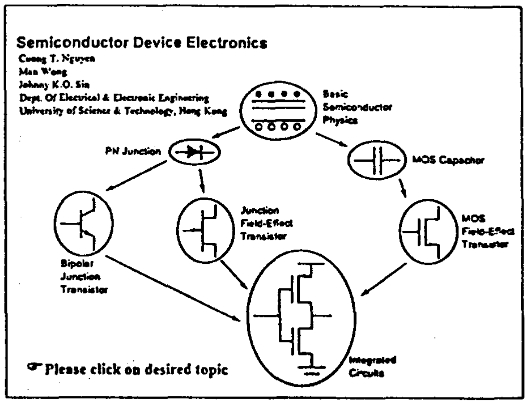


Figure 2: Hierarchical organization and the section of the device electronics "topics".

Furthermore, user-defined logical linking of smaller self-contained topics is implemented to enable self-guided learning of the subject matter. For example, while the topics of *pn* junction and metal-oxide-semiconductor (MOS) capacitor do not have strict relative logical precedence, both should be preceded by the treatment of the band structure and its behavior under an external electric field. Thus the sequence of band structure-*pn* junction-BJT can be followed while skipping the topic of MOS capacitor or the path of band structure-MOS capacitor-MOS FET can be followed while skipping the topic of *pn* junction.

3.2 Interactivity

Interactivity is already needed with the knowledge organization presented in the previous Section. Interaction icons are provided to allow users to move along presentation slides, to "jump" to a more fundamental level of explanation, and to "return" to a higher level of presentation, etc.

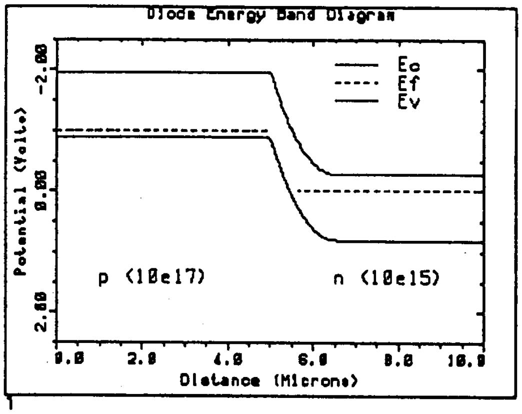
It can also be used for performing simulated experiments. Thus by providing an interactive means to change a certain set of input variables, such as the bias across a *pn* junction, students can "observe" the induced effects, such as the change in the band bending across the junction. Figures 3a, 3b, and 3c show examples of the band diagrams at bias levels of -1V (reverse bias), 0V, and 0.5V (forward bias), respectively. For different user-defined settings on the "voltage dial", the corresponding band diagrams will be different. Depending on the specific dial setting, one of these diagrams will be shown.

As an illustration of the different levels of "sophistication" of the presentation, the band diagrams equivalent to those shown in Figure 3 are depicted in Figures 4 and 5 for "long" and "short" carrier lifetimes, respectively. The variations of the electron and hole quasi-Fermi levels across the junction and their dependence on the lifetimes are explicitly shown. These variations are deliberately left out in the more basic level of explanation given in Figure 3, where the majority carrier quasi-Fermi levels are not extended beyond the space charge layer.

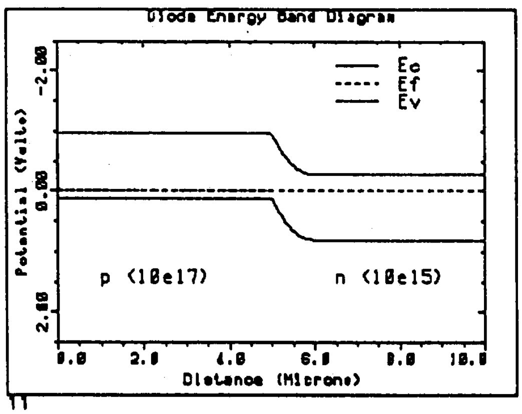
While it is true that simulated experiments cannot replace physical experimentation, they do sometimes complement the lecture presentation either because the inclusion of physical demonstration is disruptive to the lecture or because physical experimentation is not adequate or even impossible in the illustration of some abstract concepts.

3.3 Multimedia effects

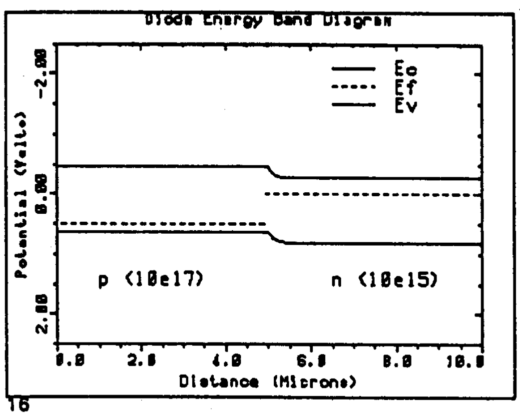
Besides embedding interaction capabilities in the texts, figures, tables, and graphics, all of which are means available to the traditional print medium, audio effects, animation, and video can be exploited much



(a)



(b)



(c)

Figure 3: Energy band diagrams at (a) -1V reverse bias, (b) 0V bias, and (c) 0.5V forward bias.

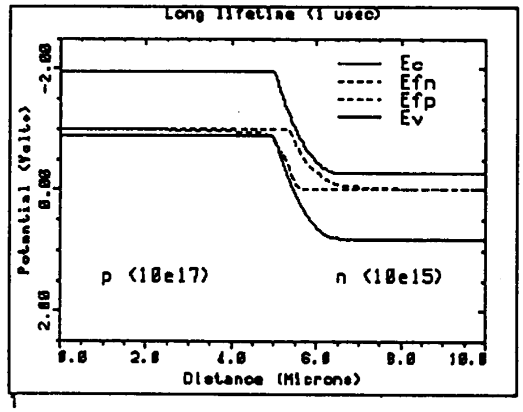


Figure 4: Variation of the quasi-Fermi levels for a reverse-biased *pn* junction with "long" carrier lifetime.

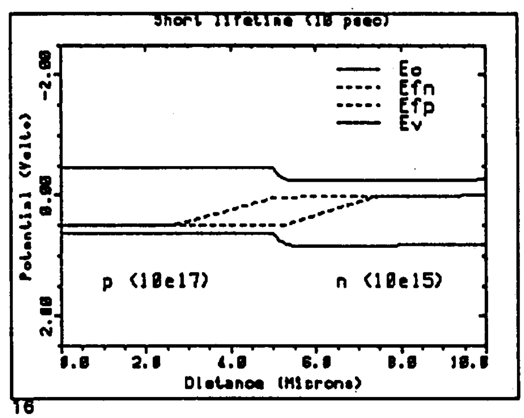


Figure 5: Variation of the quasi-Fermi levels for a forward-biased *pn* junction with "short" carrier lifetime.

more thoroughly and effectively in multimedia based presentation slides.

Some subjects, like the study of audio engineering or music, can benefit naturally from the inclusion of audio effects. But even a "silent" science like device physics can benefit from using sound effects to supplement textual explanation or to dramatize visual effects such as graphics or animations.

One of the most powerful techniques available to multimedia but not to the traditional print medium is animation. No longer limited to simple mathematical derivation of the behavior of dynamic systems, the derivation can be supplemented by "visualizing" in multimedia the actual behavior of the system using animation rather than static images. The best that can be done in the traditional print medium is to use a series of static images at different stages of the development of the dynamic system and to call upon the power of imagination of the students to fill in the missing links. With animation, such limitation is removed and a deeper understanding of the subject matter can be achieved.

One example of the use of animation to illustrate properties of a dynamic system is the concept of dynamic equilibrium across an unbiased *pn* juction as opposed to static equilibrium. If a "picture" were taken of a system in dynamic equilibrium and compared to that of a system in static equilibrium, no difference could be discerned. With animation, the concept can be nicely illustrated by showing the carriers in motion and that equilibrium is achieved by balancing the "drift" and "diffusion" of carrier.

4 SUMMARY

It is apparent that the traditional textbooks fail to meet the expanding needs to present increasingly complex technical material to increasingly inhomogeneous groups of potential readers. The static, linear nature of such texts have led to the production of a large numbers of alternative texts, all trying to perfect the linear presentation format. Mere translation of a standard linear-text format to hypertext can help make the reading process more efficient. But to take full advantage of multimedia to improve the reaching-learning dynamics in the textbook of the future, we must learn to effectively utilize the power of animation, interactivity, and the multidimensional nature of multimedia technology. This work is one such attempt.

5 REFERENCES

[1] H.V. Knight, L.J. Acosta, and B.D. Anderson, "A comparison of textbook and microcomputer instruction in preparation for the ACT," *Computer-Based Inst.,* vol. 15, no.3, pp.83-87, Sum. 1988.

[2] R. Riding and P. Chambers, "CD-ROM versus textbook: a comparison of the use of two learning media by higher education students," *Ed. & Training Tech. Int.,* vol.29, no.4, pp.342-349, Nov.1992.

[3] S. Brandt and H.D. Dahmen, *Quantum Mechanics on the Personal Computer,* Berlin:Springer-Verlag, 1989.

[4] D.C. Jain and F.R. Pomilla, "Electronic textbook: a model CAI system," *Conf. on Comp. in Physics Ed. Proc.,* Redwood city, CA, p.586, Aug. 1988.

[5] R.F. Vernon, "What really happens to complimentary textbook software?," *J. Computer-Based Inst.,* vol.20, no.2, pp.35-38, Spr. 1993.

[6] J.D. Burnett, "Who's in the driver's seat? technology, the arts and education," *Computers & Educ.,* vol.18, no. 1-3, pp.149-154, Jan.-Apr. 1992.

[7] B.L. McManis and L.W. Shell, "Exploring the 'electronic textbook': computerized lecture notes for student access," *7th Ann. Info. Sys. Ed. Conf.,* Dallas, TX, p.234, Oct. 1988.

[8] B. G. Streetman , *Solid State Electronic Devices.* 2nd ed., Englewood Cliffs:Prentice-Hall, 1980.

[9] R. S. Muller and T. I. Kamins, *Device Electronics for Integrated Circuits,* 2nd ed., New York:Wiley, 1986.

[10] E. S. Yang, *Microelectronic Devices,* New York:McGraw-Hill, 1988.