

## DEVELOPMENT OF JAVA APPLLET RESOURCES FOR SOLID STATE MATERIALS

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### ABSTRACT

We have developed a set of educational Java applet programs which provide visual simulation of concepts in solid state materials and devices. These applets were tested in a control group of students from a junior-level solid state devices course. The impact of applet simulation on the student learning process was found to be overwhelmingly positive as judged from the student comments and test performance. In this paper we discuss issues related with the development of educational Java applets, course utilization of applets, and organizing the applets by individual instructors. We stress the importance of support materials such as introductory tutorials and applet worksheets.

Key Words: educational Java applets, solid state materials and devices, impact assessment.

### I. Introduction

Learning the concepts of solid state materials and devices by electrical engineering majors is perhaps as difficult as learning of thermodynamics by materials science majors. In light of a nationwide trend of decreasing enrollment in the solid state device courses, with a reason frequently quoted being the difficulty of the subject material, a visual dynamic learning tool to help illustrate the abstract physical concepts can be a resource useful for the learning process. The underlying physical concepts in materials and devices are inherently abstract, and their proper understanding is important for later learning of the device operating principles and of the fabrication technology of devices and circuits. We have developed Java applets which provide a visual simulation of the physical concepts of semiconductors and devices [1, 2]. The initial feedbacks from various universities and from our own students are overwhelmingly positive. We report here a preliminary outcome assessment. We used the applets in a selected group of students and compared the exam performance between the control group and the general class.

With respect to the Soloman's inventory of learning styles [3, 4], the visual simulation programs of Java applets have good characteristics to appeal to the visual learners (relative to input), to the global learners (relative to understanding), to both sensing and intuitive learners (relative to perception), and to both active and reflective learners (relative to processing). In spite of the many beneficial results that are expected and/or actually produced by using the multimedia simulation tools in education [5, 6], one important factor for success is to make students actually do their hands-on simulation. One method is to incorporate the multimedia tools during lecture if it is held in a class room equipped with computers for projection and/or for student use [3, 7-8]. This, however, brings an additional pressure on time management and requires a costly investment in the classroom infrastructure. In this paper we suggest two alternative methods when involving Java applet resources in a course. Assignments and recitations involving Java

applets demand less overhead in the instructor's lecture preparation and lecture time and require less computer resources in the class room than lectures demand.

## II. Development of the Applets

### 1. Selection of Topics

There are four broad topics in a typical solid state devices course: materials physics, device principles, simple circuits, and device/circuit fabrication technology. We have developed and/or used several applets in each category of topics. Student feedbacks indicate that the applets for materials and device principles produce most positive impact on their learning process. The visual simulations using applets of the intricate physical processes seem to help them sort out the concepts more clearly. Even though it was initially thought that the visual/interactive/animated illustration of the multi-step semiconductor device/IC fabrication procedures could benefit the learners much, user responses indicate otherwise. We did not have enough applets on the circuits to judge their effectiveness. Applets on the amplification processes by bipolar transistors (BJT) and field effect transistors (FET) will be used for impact assessment as they become available. Our immediate next effort will be on writing additional applets for solid state materials and devices. We also plan to develop a few applets for BJT/FET amplifiers and CMOS gates to study their impact on student learning.

### 2. Applet Design and Implementation

For a given topic, an applet can be limited to a single concept, or can involve several related concepts. For example, in illustrating the meaning of the Fermi distribution function in the occupancy of energy states by electrons, one can limit the applet variables (i.e., the user control variables) to Fermi level  $E_F$  only or to both  $E_F$  and the temperature  $T$  in the same applet [9]. Separating the key concepts into independent control variables for the applet helps users learn more clearly. Selection of a proper topic for an applet and good design practice are extremely important. Often the applets implemented by students lack the required clarity of the conceptual contents.

Being a visual tool for learning, the user interface layout of the applet is important. A bad design of the graphical user interface (GUI) layout can lead to an applet that is not much useful after spending so much effort in development. The applet GUI can be developed separately from other parts of the applet, taking advantage of Java's object-orientation. The GUI's can be developed using visual development tools such as Microsoft's Visual J++ or SUN's Java Workshop. These tools provide quick prototyping ability for the GUI layout. Other parts of the applet (i.e., the technical contents and actual simulation) are developed separately from the GUI. Here again, a disciplined approach in design within the object-oriented design paradigm is beneficial for future maintenance of the program and for enhanced programming productivity. Development of reusable Java classes can lead to a Java class library in the particular subject area. This class library will greatly facilitate the software reuse and enhance the programming productivity.

### 3. Support Materials for Educational Applets

Each applet is either embedded within a tutorial text or accompanied by a separate introductory text. In addition to the introductory text (a tutorial), another not-so-obvious yet very important support material is an applet worksheet (or question sheet) that the students are required to complete. The worksheet is a set of simple easy-to-answer questions that can be answered by using the applet. A sound worksheet could assist instructors to integrate the applet resources into their course by requiring students to hand in the answers to the worksheet as part of a homework assignment. In our applet website, we need to do further work to organize the applets around weekly assignments along with tips, sample problems, home work assignments, and solutions in a manner similar to ref.[7].

Our experience shows that no matter how good a software simulation tool may be, students simply do not use it unless required. Within the framework of a conventional course, applets can be easily incorporated as a required element of the course in the forms of homework assignments and recitations.

#### 4. Dependence on the Java and Browser Technologies

One problem of a Java applet for educational use is its dependence on the technology, and particularly on the support by popular web browsers of the Java version in which the applet was written. The Java technology is less than 4 years old as is the popular use of web browser technology. Both technologies are rapidly evolving. The current Java version is 1.1 supplied as the Java Development Kit 1.1 (JDK1.1) by SUN Microsystems, Inc. However the web browsers, Netscape Navigator and Internet Explorer, support JDK1.0, but not JDK1.1. Therefore, applets developed in the JDK1.1 can not run in these popular web browsers as of December 1997. Applets from JDK1.1 can be executed using the Appletviewer program or the HotJava 1.1, both from SUN Microsystems, Inc. The Appletviewer program requires the installation of Java1.1 runtime system in the local computer and a proper setting of the directory search path and the CLASSPATH environment variable in the computer startup file (such as AUTOEXEC.bat of Windows) which must point to the directory containing the Appletviewer program and to that containing the Java core class files. The HotJava1.0 is too slow in many machines and thus is not very practical at the moment. At present, it is necessary to develop educational applets in JDK1.0 even though its event handling model is much less efficient and less flexible than that of JDK1.1. An additional problem that needs to be dealt with in the future is that the event model in JDK1.0 and that in JDK1.1 are not compatible with each other and all the JDK1.0 applets will need conversion to JDK1.1 when the browsers are updated to JDK1.1.

### III. Course Utilization, Assessment and Feedback

#### 1. Course Utilization of Applets

A lecture presentation involving Java applets may be categorized according to the temporal point at which they are introduced in the teaching process. Applets may be used to help seal the conceptual learning by using the applets as a demonstration example or as a summary of the subject topic (a 'posterior' approach). Applets may be used as an introducing vehicle for new topics (a 'prior' approach). Applets may be used at any point in time of the teaching ('integral' approach). This is discussed in this section.

Posterior Approach : The applets are used after a new topic has been introduced in a traditional manner. This is perhaps the most effective use in that they can visually show *what is really going on*. In this approach, applets are used in the recitation sessions and/or in homework assignments. The applets could be used to seal the learner's understanding of new concepts and also to assist them to gain quantitative senses. The interactive and instant computational ability of applets can be a great tool for the latter purpose.

Prior Approach : In this approach, the applets are used at the beginning of introducing a new topic. It may be used to show an overall view of the topic or to stimulate student attention before a detailed discussion begins. An example where this approach may work well is the applet that shows the multi-step device fabrication procedure [10]. This approach may also work for simple and fundamental concepts such as the Fermi level and Fermi distribution function applet [9].

Integral Approach : The applets are intermingled with lecture, recitation, and homework assignments. The applets are used at any point during lecture as the instructor deems appropriate. As the applets become more abundant and more readily available for many topics, this could be the main approach.

## 2. Student Feedback and Impact Assessment

We have used the Java applets, in a recitation class which was formed separately from the regular recitation classes, on a volunteer group of students. This separate group was formed to assess the impact on student performance. Twelve students out of the entire class (of 68 students) attended the applet sessions on a regular basis. The rest of the class were not required to study the applets nor were they prevented from using it. It was found that only two students out of the rest of the class (56 students) used the applets on their own. It is thus important that the applet simulations be made mandatory in the course to have impact on all students. We used the twelve students of the applet recitation class plus the two students, who used applets individually, as the control group.

The recitation sessions were held in a networked computer lab. A Teaching Assistant led a walk-through of each applet, followed by hands-on simulation by the students, completing the worksheet attached to the applet. In a typical one-hour recitation session, 2 or 3 applets were completed.

Student feedback, as collected through a questionnaire, indicated a very strong positive impact on their learning process. The following are some excerpts from their comments:

*The applets have been a great help for me in this course. The Fermi level, p-n junction, etc. applets made a great impact on my learning process. I learned the basics of semiconductor so well that I did not have any problem in the later material.*

*The applets were incredibly helpful for the first third of the class. This covered everything through diodes and  $p^+n$  junctions. I found the applets much more effective than the book and lecture for initial understanding of material, but the book and lecture*

*are still necessary. It would be very helpful to do the applets before covering the material in lecture.*

*Applets helped especially in understanding concepts where multiple factors are involved simultaneously. The ability to change values of parameters helped greatly in appreciating the importance of certain parameters and in what magnitude they have effect on the model.*

*They provided a visual "theory". It was possible to see the effects of changes without having to do the tedious calculations. A visual realization of theory.*

*I found that the applets "grabbed" my attention at the beginning of the course. As with any subject, the outcome of the course is directly related to the initial enthusiasm. Also I found that the applets help to illustrate certain topics that were extremely obscure.*

*I found that I got more out of an applet when it was presented after the topic was covered, than before it was.*

*Definitely helped. Better than static pictures because it showed how the holes and electrons moved, esp. in the band gap diagram. Most applets helped with concepts more than problem solving.*

Student comments show that the applets help accomplish several goals well: increasing student motivation toward subject; helping to lay solid (conceptual) foundation at the beginning of the course; clarifying concepts that involve multiple parameters; etc.

During the current semester, only the first exam was on topics where a sufficient number of applet programs were available (about ten applet programs on the semiconductor materials and on the pn-junction diodes). The exam questions included both calculation types and qualitative questions requiring short answers. It also asked the students to draw pn-junction band diagrams and to indicate important junction parameters on the diagram. The student performance in the exam is shown in Table-1. A substantially improved performance was found in the applet group when compared with the entire class. The average (cumulative) Grade Point Average (GPA) of the control group was slightly better than that of the rest of the class.

Table-1 Student performance in Quiz No.1 on Semiconductor materials and pn junctions.

category	No. of students	Average Exam (100 max)	St. Deviation Exam	Average GPA (4.0 max)	St. Deviation GPA
applet group	14	85.3	11.7	3.06	0.53
rest of class	54	73.4	16.7	2.90	0.65
entire class	68	75.9	16.4	2.93	0.62

#### IV. Organizing the Applet Resources by Individual Instructors

The applet resources may be custom-organized by individual instructors. Based on a particular course subject, a customized list of applets can be quickly and easily made into a hyper-linked web page format. This page then serves as the initial starting page for the course.

##### Using as-is

The applet pages as supplied from our website should be usable in other courses without modification by the instructor. The organization in our Table Of Contents (TOC) page can be used by most users.

##### Instructor-organized index and TOC page

When a more compact list is desirable, the instructor can quickly write a single-level index page to support his or her course. This is composed of titles, with an optional short description about the applet, which is hyper-linked to each individual applet page in our website. If the instructor wishes to provide his or her own introductory texts and own pedagogy, it can be easily done as described next.

##### Instructor-implemented pedagogy and texts for the applets

The instructors can include the Java applets from our website in their own tutorial notes and thus implement their own pedagogy. The applet worksheets or problem sets can be implemented also. Within the instructor's *html* text, the applet tag only needs to include a *codebase* parameter. For example, the Biased PN Junction Diode applet, served from the [\*http://jas.eng.buffalo.edu/webserver/\*](http://jas.eng.buffalo.edu/webserver/) in the *applets/education/pn/BiasedPN/* subdirectory, needs to use the following lines in the html page.

```
<applet codebase="http://jas.eng.buffalo.edu/applets/education/pn/BiasedPN/" code =  
"BiasedPN.class" width=460 height=420> </applet>
```

An example of this approach can be found in ref.[11] which is the web version of ref.[1]. This web version has fully functional Java applets in the place of the static figures of ref.[1].

#### V. Summary and future direction

We have discussed issues related with developing educational Java applets, utilizing applets in a course, and how to organize the applet resources by individual instructors to support his or her class. With regard to developing educational applets, some topics (e.g., physical concepts on materials and device operating principles) were found to produce more impact on student learning than others (e.g., the multi-step device fabrication procedures). Good design of the technical contents in an applet and the graphical user interface layout are both important for higher impact on student learning. The importance of support materials such as a tutorial text and an applet worksheet can not be over stressed. Through these support materials a pedagogy can be implemented. The course integration of applets can be facilitated by these support materials.

We tested the applets in a junior-level electrical engineering course on a solid state devices course. The students feedback from a control group expressed an overwhelmingly positive impact on their learning process. The student exam performance also showed a substantially improved result.

Our immediate next effort will be centered on further development of additional applet programs on solid state materials and devices, on improvement of existing applet programs for performance, and on development and improvement of applet tutorials and worksheets. Weekly homework assignments, tips, sample questions, problems, and solutions are another area needing further development for our solid state applets. However, all future efforts are contingent upon the availability of external funding as the applet development work is an extremely time-intensive endeavor.

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10. See, for example, <http://jas.eng.buffalo.edu/applets/education/fab/pn/diodeframe.html>. This webpage shows pn junction diode fabrication steps, interactively.
11. The web version of ref.[1] is given in [http://jas.eng.buffalo.edu/papers/mrs96\\_jme/paper.htm](http://jas.eng.buffalo.edu/papers/mrs96_jme/paper.htm) where the figures are replaced by "live" applets.