A Web-assisted Electronics Course using the S.m.i.L.E Program*

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This paper reports on a project, called S.m.i.L.E, which was launched by the Institute of Electronics, University of Federal Armed Forces, Hamburg, Germany. The intention of this project is to improve and supplement existing methods of teaching electrical engineering using a web-based and interactive course program. The paper describes the concept and contents of S.m.i.L.E and introduces its basic principles: simple usage, vivid and concise illustration and a high level of comprehensibility. The paper also presents the experiences made during the first two years of project lifetime. The technical realisation of S.m.i.L.E and future directions are presented as well.

INTRODUCTION

THE RAPID DEVELOPMENT of the World-Wide Web (WWW) and its multimedia features inaugurated a new era of information and communication technology. In particular the Internet medium provides an opportunity for higher educational institutions, especially universities, to enhance their traditional teaching methods. Many web resources that deal with the subject of electrical engineering are already available, but most of them are either focused on special topics [8–12] or they are not freely accessible [6]. Another site [7] offers excellent contents, but it is too specific and complex and therefore not suited for educational purposes within the basic study period. For this reason the S.m.i.L.E project was launched in Spring 2000 by the Institute of Electronics, University of Federal Armed Forces, Hamburg, Germany [1], in order to improve the education of electrical engineers. S.m.i.L.E (Studieren mit dem inter-aktiven Lehrbuch für Elektronik = Studying with an Interactive Textbook for Electronics) is comprehensible and it matches the contents of a basic electronics lecture. The course program is already in use for teaching purposes, but it is still in the stage of development and its contents are permanently being updated. The current version is freely accessible for everyone via the Internet [2].

CONCEPT OF THE COURSE PROGRAM

S.m.i.L.E is a web-based course program that includes all major subjects of modern microelectronics (semiconductor physics, electronic devices, circuit design and production processes

of integrated circuits) and thus it covers all important areas from basics to applications. S.m.i.L.E basically consists of a collection of online documents in HTML format. Each document is focused on one particular subject, for instance 'pn junction', 'MOS transistor' or 'C-MOS process'. Complex physical effects, mathematical formulae and dynamic processes are illustrated by interactive animations, simulations, formula evaluators, film sequences and short, concise explanations.

S.m.i.L.E has been designed to supplement but not to replace actual lectures. Since spring 2001, the Institute of Electronics, University of Federal Armed Forces, has utilised this program accompanying its electronics- and VLSI-design courses. With the aid of a notebook and a video projector, the lecturers can use the multimedia features of S.m.i.L.E in order to illustrate complex correlations. The benefits of this teaching method are obvious:

> time-consuming, often imprecise and static blackboard drawings are replaced by accurately designed and dynamic animations so that the lecturer can focus on his explanations and the dialog with the students. Since S.m.i.L.E is freely accessible via the Internet, the students can use the course program as a self-help tutorial, for recapitulation and intensification.

S.m.i.L.E was conceived to be platform-independent, compatible and independent from additional software. Therefore only open Internet standards such as HTML, Java and Java-Script have been utilised. Any popular and up-to-date Java-compatible web browser will suffice to work with S.m.i.L.E. There is no need to download or purchase extra software, plugins or libraries. The minimum hardware requirements are: monitor resolution 800×600 pixel (1024×768 recommended) and 28kB modem (56 kB recommended).

Fig. 1. Navigation frame and main frame of the S.m.i.L.E program.

USAGE AND NAVIGATION

S.m.i.L.E is accessible from the homepage of the Institute of Electronics, University of Federal Armed Forces, http://www-elo.unibw-hamburg.de or directly by using the URL http://smile.unibw-hamburg.de. Upon entering, the visitor will see the S.m.i.L.E start page (Fig. 1). It consists of two frames, a navigation frame for simple navigation within the course program, and a main frame to display the chosen online documents.

In order to make the use of S.m.i.L.E as easy as possible, a uniform and concise document structure was chosen (Fig. 2). Each online lecture starts with a short introduction to the subject, followed by an interactive animation or simulation. Below that, a 'what-to-see' section follows, summarising the most important facts. The lecture ends with a 'continue-with' section, giving a link to the next document. Technical terms which are explained in other lectures are realised as hyperlinks, so that navigation and usage of S.m.i.L.E become

very simple. The interactive animations are self-explanatory so that there is no need for further operating instruction or online help. Nevertheless, S.m.i.L.E provides a mail hotline for technical questions, suggestions or bug reports. (The mail-hotline can be found in the 'FAQs'-section of the navigation frame.)

DIDACTICS

Easy-to-use interactive animations and simulations are the essential parts of S.m.i.L.E. Great importance was attached not to overload them with information. Therefore in most of the documents it was refrained from using a physically exact presentation, for the benefit of comprehensibility and in order to draw the attention to the interesting effects only.

Another basic principle of S.m.i.L.E is to examine complex correlations from different angles. To demonstrate this, a selection of online-documents

Fig. 2. Uniform document structure of S.m.i.L.E. The included Java applet visualises the electrical behaviour of a MOS transistor.

is presented in the following section in order to illustrate the functionality of a MOS transistor using different views (Fig. 3).

Teaching electronics using S.m.i.L.E—an example

We present a selection of S.m.i.L.E online documents, focused on different aspects of the MOS transistor: The electrical and physical behaviour, the manufacturing process and MOS-related device structures are shown as well as a circuit simulation of a MOSFET application.

- *Electrical behaviour of the MOSFET.* The document shown in Fig. 2 explains both the MOSFET's internal distribution of charge carriers as well as its external current-voltage characteristic, using one single Java applet. The user can interactively adjust the voltages UGS and UDS and immediately notice the corresponding effects. This combined illustration allows the user to establish a link between charge distribution and electrical behaviour.

- *Physical behaviour of the MOSFET.* Energy band diagrams represent another important method to explain the functionality of a MOS transistor. The Java animation shown in Fig. 4 illustrates a basic MOSFET characteristic: the effect of the gate (G) potential on the channel conductance between source (S) and drain (D). The applet allows the user to vary the voltage UGS and directly notice the band bonding underneath the oxide and the resulting alteration of the barrier between source and drain. A much simplified mathematical model has been used to calculate the two-dimensional energy bands in order to keep the illustration concise and comprehensible. The shown Java applet is exclusively focused on the above-mentioned physical effect. Thus, the only adjustable parameter is UGS. Other effects are visualised by specific animations (not shown in this paper).

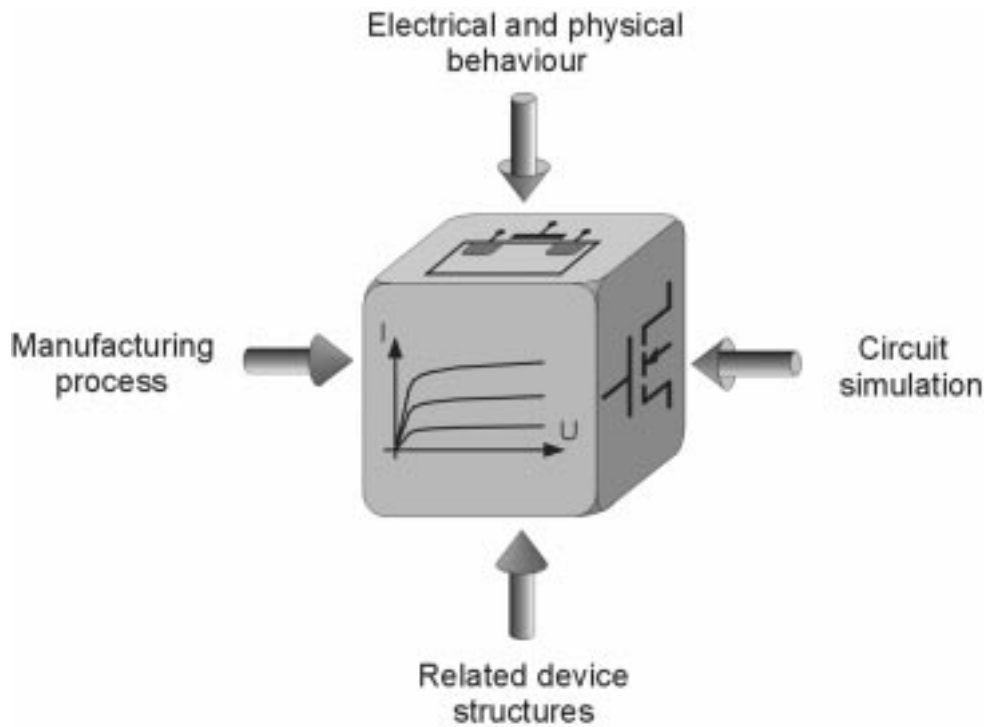- *Manufacturing process.* The knowledge of the

Fig. 3. S.m.i.L.E examines complex correlations from different angles in order to deepen user comprehension.

MOS manufacturing process is important for both the comprehension of its device characteristics and the design of microelectronic circuits. Therefore animated film sequences have been applied to S.m.i.L.E in order to visualise dynamic processes. The Java applet in Fig. 5 shows all relevant process steps of a simplified N-MOS process from oxidation to planarisation. It allows the user to either navigate between arbitrary process steps or proceed from one process step to the next. Each step is visualised by a short video sequence. In a
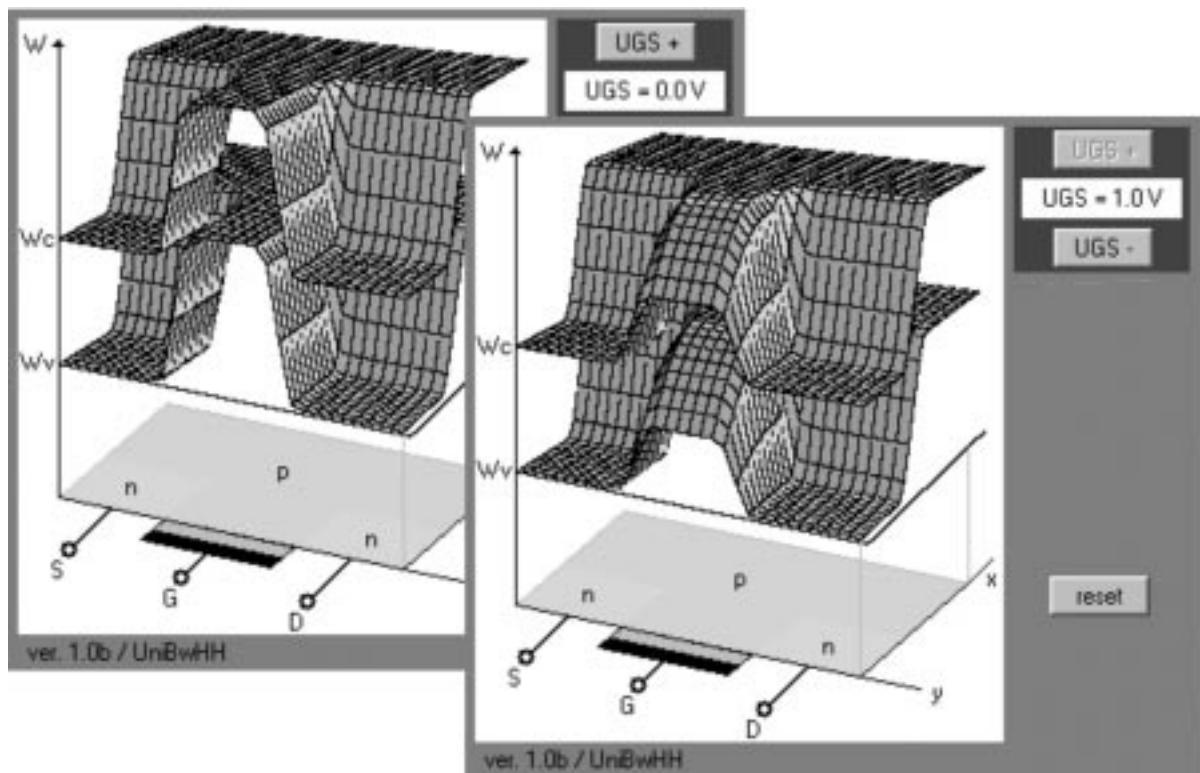

Fig. 4. Java applet showing the two-dimensional energy band diagram of an n-channel MOSFET.
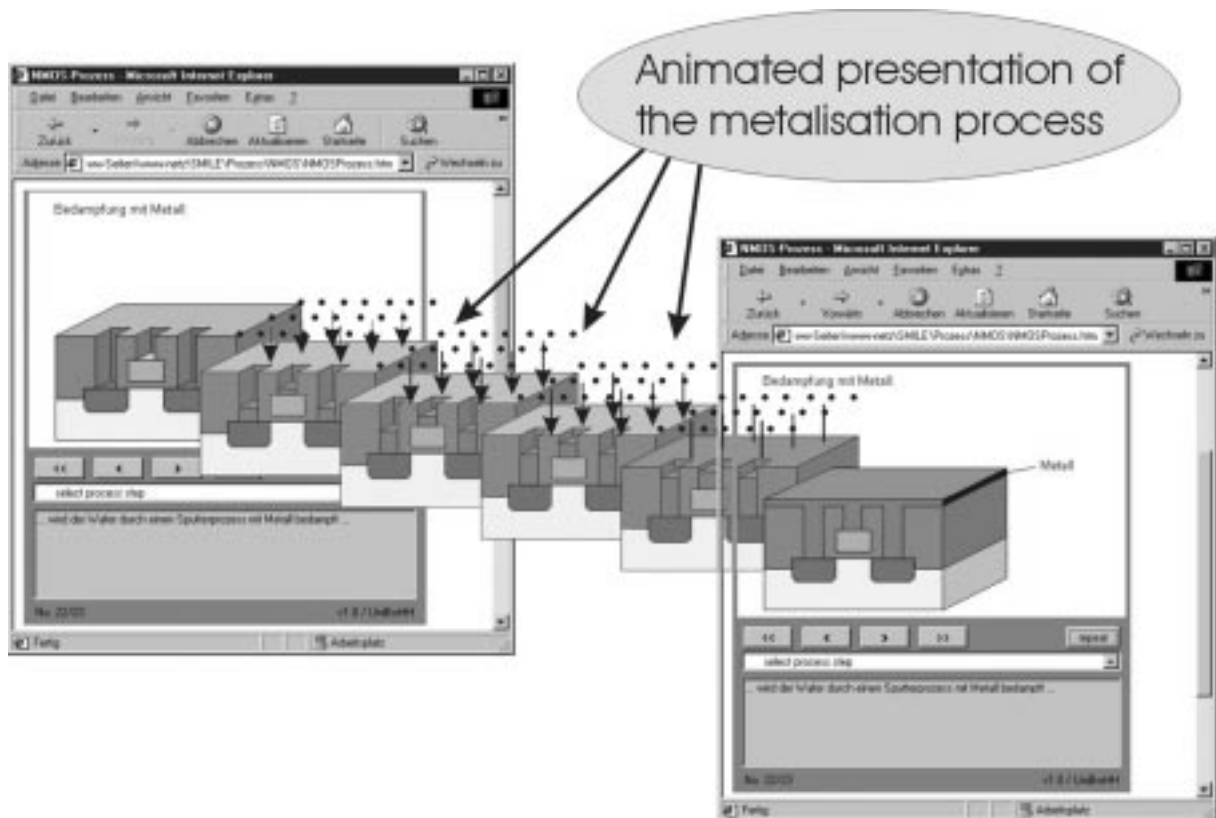
Fig. 5. Applet using animated film sequences to visualise the N-MOS manufacturing process.

separate text field a brief description of the process step is given.

- *Circuit simulation with WebSpice.* In addition to the illustration of physical-electrical behaviour and manufacturing processes, S.m.i.L.E provides online simulations of electronic circuits via the Internet in order to deepen the user comprehension of circuit design. For these purposes *WebSpice* has been developed as a client-server-interface between the user's web browser (client) and the commercial circuit simulation program *SPICE* (running on the S.m.i.L.E web server). Figure 6 shows the *WebSpice* control panel for the simulation of a push-pull-amplifier with complementary MOS transistors. The control panel consists of a brief description and a schematic diagram of the amplifier, followed by a 'circuit parameters' section and an 'analysis setup' section, which allow the user to change circuit parameters and select different analysis types (DC, AC, transient or Fourier analysis). Pressing the 'Start Simulation' button will cause *Web-Spice* to send the chosen parameters to the S.m.i.L.E web server in order to create a netlist and start the Spice simulation based on that netlist. After the simulation has finished (generally a few seconds), *WebSpice* analyses and graphically post-processes the simulation results in order to display them in the user's browser (Fig. 6). Since *WebSpice* is freely configurable, the S.m.i.L.E administra-

tor can determine the layout of the *WebSpice* control panels, in particular the electronic circuits, associated descriptions, changeable parameters and analysis types. The analysis of the simulation results is also configurable. In addition to the graphical output, value-dependent comments are supported. This feature can be used to utilise *WebSpice* as a 'virtual laboratory', where the user has to calculate missing parameters of electronic circuits. In the example given in Fig. 6 the user has to find the value of the offset voltages Vap in order to minimise the crossover distortions. In the case of a wrong solution, a helpful hint can be displayed in order to support the student to self-dependently find the correct value and to understand the underlying principles.

- *Related device structures.* In addition to standard devices, S.m.i.L.E also explains special components as for example ferroelectric devices or Flash-EEPROM cells. Not only because of its structural similarity to the MOS transistor, the Flash-EEPROM cell will also be of interest to the student. The Java animation shown in Fig. 7 allows the user to manually program or erase the cell and immediately notice the internal physical processes (tunnelling effect) as well as the corresponding change of the cell's electrical behaviour (threshold voltage shift) which is responsible for the non-volatile memory function of the device. The tunnel effect with its
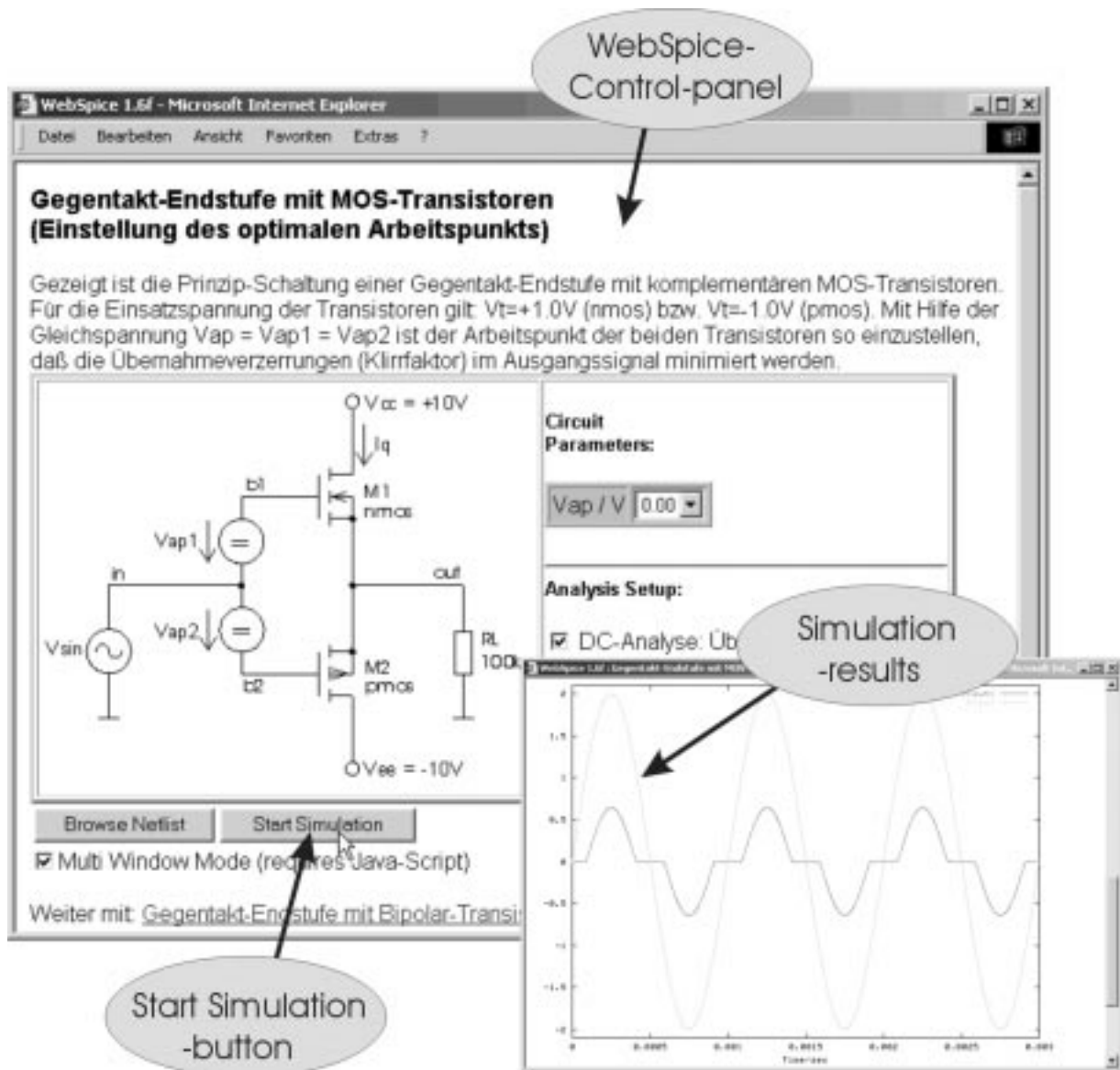
Fig. 6. *WebSpice* control panel for the simulation of a C-MOS push-pull-amplifier incl. simulation results.

transient character is a suitable example to demonstrate the advantage of animated online lectures over conventional textbooks.

TECHNICAL REALISATION

The S.m.i.L.E Java applets have been created using Borland JBuilder 3. To ensure the maximum possible compatibility and independence of additional Java classes, only standard AWT (Abstract Window Toolkit) components have been utilised. All animations are based on a special Java class named *SmilePanel( )* which in turn was derived from the original AWT-class *Panel( )*. Fundamental co-ordinate transformation and draw methods have been added to *SmilePanel( )* as well as an intelligent *paint( )* routine with double buffering technology for the acceleration of time-critical animations. In general, physical behaviour

and mathematical formulae are internally evaluated and then displayed by the applets (Fig. 2). In order to illustrate complex processes or formulae (without spending too much time in program development), some applets have been realised as 'image browser'—they simply browse pre-cast diagrams (Fig. 4) or animated film sequences (Fig. 5) according to the chosen parameter values.

WebSpice is written in PERL and is freely configurable by its own scripting language. The program can handle multiple electronic circuits. For each circuit a dedicated configuration file is required, which specifies the layout of the simulation control panel (schematic, description, arbitrary circuit parameters and analysis types, etc.) as well as the method of analysing and post-processing the simulation results. On startup, *WebSpice* loads the configuration file assigned to the current circuit and then dynamically generates the HTML code for the corresponding simulation
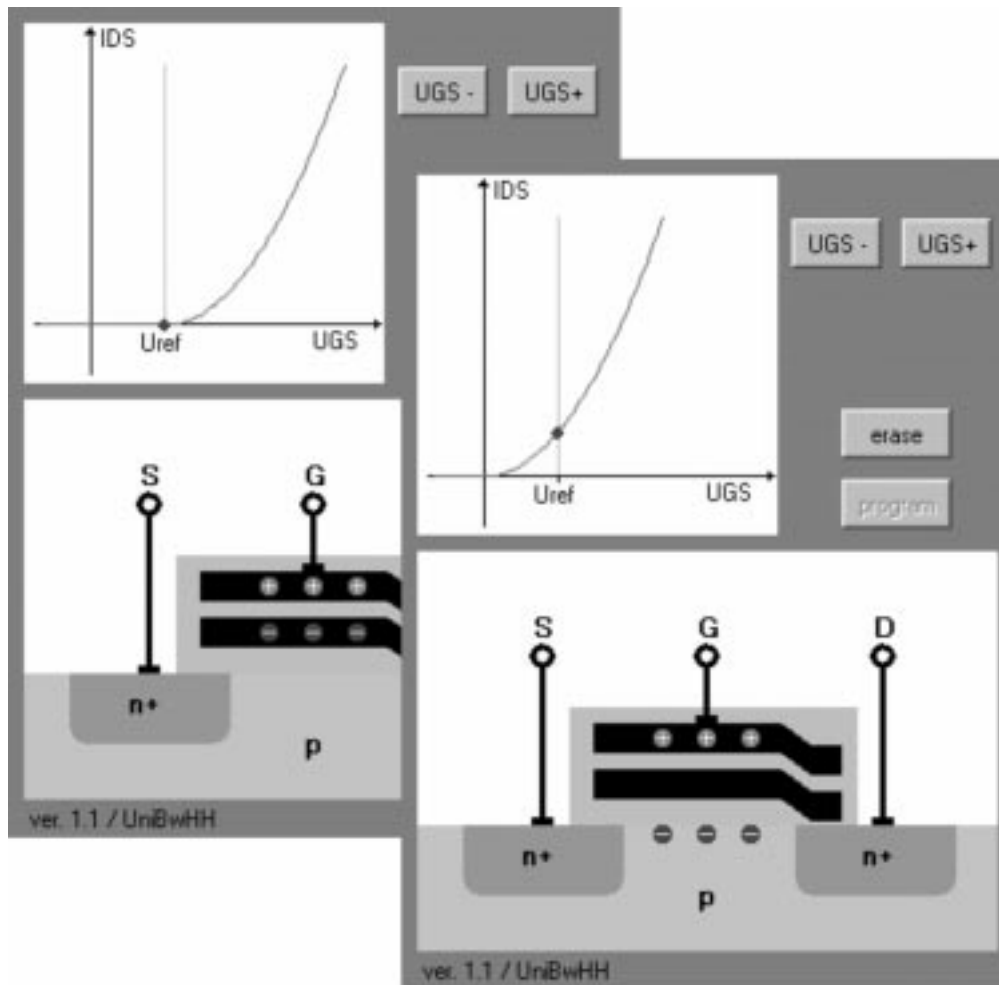
Fig. 7. Java applet showing the internal physical processes and the electrical behaviour of a Flash-EEPROM cell.
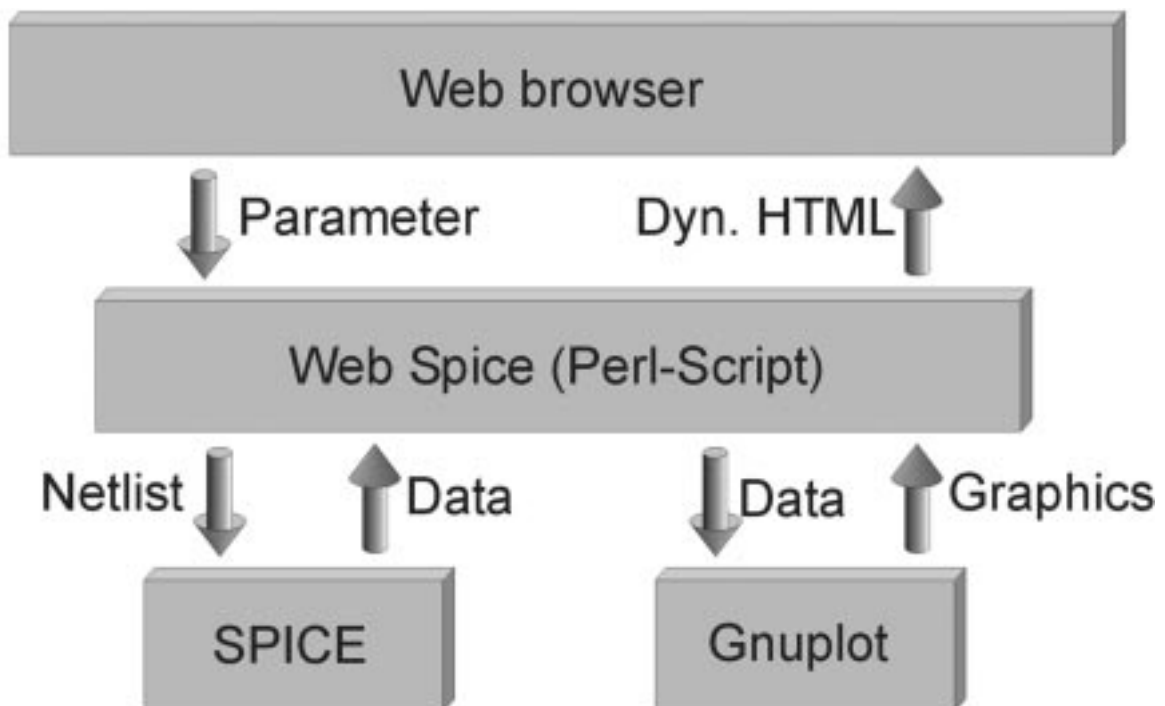

Fig. 8. *WebSpice* serves as an interface between the user's web browser and the circuit simulation program SPICE.

control panel (Fig. 6) which will be displayed in the user's browser. Pressing the 'Start Simulation' button will cause *WebSpice* to send the chosen circuit parameters to the S.m.i.L.E web server in order to create a netlist and start the SPICE simulation based on that netlist. After the simulation has finished, *WebSpice* uses *Gnuplot* in order to convert the simulation results from ASCII format into portable network graphics (png) format. (*Gnuplot* is a public domain plotting program.) Furthermore, an appropriate configuration assumed, *WebSpice* generates comments depending on the values of predefined simulation results, for instance a warning or a helpful hint in the case of an incorrectly chosen parameter value. Finally, *WebSpice* dynamically creates an HTML document containing all relevant results, graphics and comments in order to send it back to the user's web browser (Fig. 8).

The complete S.m.i.L.E system is based on the Microsoft Internet Information Server 5, currently running on a Windows 2000 Computer and an Active-PERL-Interpreter as an extension to the web server program.

USER FEEDBACK AND SURVEY RESULTS

Since S.m.i.L.E understands itself as a dynamically evolving teaching program, user feedback is essential for its further development and improvement. For this reason the *Centre for Institutional Research and Quality Assurance (CIRQA)* [4] was consigned to conceptualise and analyse a survey among those students of the University of Federal Armed Forces, which have attended the electronics lecture and thus worked with S.m.i.L.E. The *CIRQA* decided to realise the survey in the form of a questionnaire. In this context, the acceptance of S.m.i.L.E and its reasonable and effective use have been of prime interest, whereas expert ratings of design features have not been taken into consideration [5]. The most significant results of the survey are:

- The vast majority of the students embraced the basic idea to explain complex correlations by using a web-based and interactive course program, in so far as it supplements but not replaces traditional lectures.
- Most of the respondents stated that the comprehensibility of S.m.i.L.E is 'very good', and therefore the course program has become an integral part of their studies, in particular for recapitulation, intensification and preparation for exercises. (This fact is also confirmed by the access statistics of the S.m.i.L.E web server.)
- The information content was rated from 'not bad' up to 'very good' (the median is 'good'). Some students criticised inadequate explanations and missing special topics.

Although S.m.i.L.E is still in the development stage, survey results confirm that the course program is widely accepted by the students and that it has become a useful complement to the electronics lecture. The denoted suggestions for improvement are presently being analysed and will be considered for the further development of S.m.i.L.E.

SUMMARY

In this paper the S.m.i.L.E project of the Institute of Electronics, University of Federal Armed Forces, Hamburg, Germany has been presented. By means of examples, the simple usage and the high level of comprehensibility have been demonstrated as the basic concepts of this interactive course program, which, in conjunction with the wide subject area, make it a useful supplement to traditional teaching methods as lectures, exercises and practical work.

For the future the *WebSpice* section of S.m.i.L.E will be extended to a 'virtual laboratory' where the user can simulate and examine the most important analogue circuits. A 'virtual tutor' will be implemented that assists the student in the case of problems. When S.m.i.L.E leaves the development stage, an English version and a downloadable offline version will also be available.

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