Project Based Learning in Microelectronics: Utilizing ICAPP

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Abstract:

This paper presents a project based learning model (PBL) and its practical application in the Microelectronics course for undergraduate Electronics engineering students. A software application ICAPP for microelectronic devices calculations and design is developed and used to facilitate the design process. The ICAPP data base contains physical parameters of the layers and design rules which can be changed depending on the peculiarities of the fabrication process. Some basic physical constants are included as well.

1 Introduction

Project based learning (PBL) as a useful approach to learning has been widely applied in various universities’ courses, including engineering [1], [2]. PBL involves students in explorations of compelling problems and put them in an active role of: problem solver, decision maker, investigator, or documentarian. In the examined literature [3], [4] and also from our experience as major benefits are considered: deeper understanding through the technical complexity of developed work; springboard knowledge e.g. previous knowledge acts as a basis for problem solving and insight into new information; interdisciplinary approach - knowledge from various disciplines is needed to solve complex problems; project management skills, decision making skills, communication and collaboration skills development. Learning of Microelectronic technologies and design techniques has always been a challenge for the students due to the multidisciplinary character of the courses that requires knowledge in physics, high level mathematics, and practical limitations of the technology as well as the electronic circuits’ synthesis and analysis. In the area of Microelectronics the PBL is an important factor for equipping students with thinking and problem-solving skills that will support their participation in real situations where the problem is more complex. In addition, we hope to stimulate students to become more creative, innovative, and enterprising.

One good way to accomplish these goals is to harness new tools, applications and methods for stimulating knowledge capturing, creative thinking and motivation, and for developing unique artefacts.

In this paper the created PBL model and its practical adoption in the Microelectronics course is presented. The main focus is on technology assistance of PBL trough environment building. A software application ICAPP for microelectronic devices calculations and design is developed and used to facilitate and automate hard manual and often repeating operations in the process of project development.
2 Project Based Learning Implementation

In our big practice we have experimented with several PBL models and the optimal solution is presented and explained in several steps below (Figure 1):

(1) Introducing students with the *State art of Problems* in the area of Microelectronics and showing them the huge potential of working topics. This often contributes to motivating students.

(2) *Conceive* of the problems and ideas arising about possible topics. The project commenced once students identified a challenging problem. Therefore, students started the project by generating many possibilities before zooming to the final problem.

![Figure 1. PBL model for Microelectronics Education](image)

(3) The *driving questions* explicate what will be accomplished and embeds the content to be studied. The tasks should be engaging, challenging and doable.

(4) *Environment* is provided with print and digital resources including textbooks, guide books, hypertext links, web-based open courses, tutorials, best practices, papers, datasheets, and software automating several PBL activities.

(5) The *process* and investigation include the steps necessary to complete the task or answer the driving question. The process includes activities that require higher-level and critical thinking skills, such as analysis, synthesis and evaluation of information.

(6) *Guidance* is provided when students need. These include student-educator interactions, peer counselling, guiding, project templates, etc.

(7) During this phase, the *collaboration* among students working in groups of three is important for clarifying the bottlenecks.
Through assessment the students’ knowledge and competences as a result of the project work are evaluated. These may include relevant in-class discussions, journal entries or even follow-up questions about what students have learned.

3 Project design example

Project based learning is usually understood as a learning environment, that facilitates the acquisition of various knowledge and skills. The design of such learning environment to support and challenge the students' thinking is so important task both of educators and students. Students search online and use different information resources (all media types) and instructional materials (all media types) as sources of information. The materials do not teach, but rather support the learner's inquiry or performance. In the domain of Microelectronics in order to be solved a specific problem only resources are not enough and automating software might be appropriate for utilizing. Such software assists learners with better examination of the problem within this domain and one software solution is described in the next section.

3.1 Environment

The important part of PBL environment is originally developed application ICAPP with an aim to enhance the students’ performance in the final stage of the project development. ICAPP is written for Windows and is used to calculate the geometry size of the regions (i.e. emitter, base, etc.) that compose each device (i.e. BJT, FET, diffusion resistor etc.) in the Integrated Circuits (ICs) and some parameters of these devices. ICAPP provides students with a better understanding of what are they doing and with the basics concepts of the devices design because in order to use ICAPP they have to be acquainted with the technology and its limits, devices’ physics and electronics. ICAPP is a user friendly and flexible tool. The design rules that specify the minimum value of the features or the minimum separation between the features, included in the data base, can be easily changed.

Figure 2. The main ICAPP application’s functions
physical parameters of the layers (i.e. resistivity, minority carrier diffusion coefficients etc.) can be changed as well depending on the project task that should be solved.

The ICAPP application’s features are captured applying use case analysis. The collected use cases specify the man existing ways of utilizing the design tool (Figure 2).

### 3.2 Course description

3212 Microelectronics course (4 ECTS credits) introduces students to (i) basic processing used in fabricating integrated devices and the use of these process steps in fabricating a diode, bipolar junction transistor or FET. Topics include diffusion and ion implantation, epitaxy, oxidation, photolithographic techniques, film deposition, assembly and packing; (ii) design of bipolar and FET transistors, diodes, resistors and capacitors, (iii) design of digital and analog ICs.

The objectives of the Microelectronics course are to:
- introduce Electronic engineering students to processing steps used in fabricating integrated devices
- provide the students with the theoretical knowledge of the theories and the physical structure of the modern electronic devices
- ensure that the students can apply semiconductor theories to design electronic devices and ICs, and investigate their performance

Prerequisite are 1022 Physics and 3148 Semiconductor Components. The ICAPP is developed to satisfy the third of the objectives, listed above.

### 3.3 Example of a design problem

Use ICAPP for minimum size layout design of ICs single emitter n-p-n bipolar junction transistor (BJT) with a structure shown in Figure 3. Determine the complete small-signal model parameters for $I_C = 4 \, \text{mA}$, $U_{CE} = 2 \, \text{V}$, $U_{CS} = 2 \, \text{V}$, $U_{BE} = 0.5U_{bi}$ ($U_{bi}$ is a build in voltage for the emitter-base).

The minimum layout area of the BJT is mainly determined from the working (emitter) current of the transistor ($I_E$). The obtaining of a minimum area is often limited due to the technology boundaries, i.e. the minimum feature and the minimum separation between the features. Assume the base current ($I_B$) is negligible and $I_E = I_C$. The emitter area ($S_E$) depends on the maximum emitter current according the formula [3]:

$$ I_E = \frac{qS_EQ_Bn_i^2}{N_Bw}e^{\frac{q}{kT}U_{BE}}, \quad (1) $$

where $q$ is the electronic charge, $D_B$ is the minority carrier diffusion coefficient in the base, $N_B$ is the base doping, $w$ is a base quasi-neutral width ($w = h_B - h_E$), $\varphi_T = 0.026 \, \text{V}$ is a thermal potential and $n_i$ is an intrinsic doping ($n_i = 1.5 \times 10^{10} \, \text{cm}^{-3}$ for Si at temperature 300 K). $I_E$ is known, and $D_B$, $N_B$ and $w$ from an equation (1) are included in the ICAPP data base. Therefore, it is easy to determine the size of the emitter region and subsequently the sizes of the base and collector region (Figure 3). ICAPP significantly reduces the time for the layout size calculations. To obtain the dc common base current gain ($\alpha_0$) and the dc common emitter current gain ($\beta_0$) are used the following equations [4].

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\[
\alpha_0 = \frac{1}{1 + \frac{D_E w N_B}{D_B L_E N_E} + \frac{1}{2} \left( \frac{w}{L_B} \right)^2} \Rightarrow \frac{1}{1 + \frac{D_E w N_B}{D_B L_E N_E}} = \frac{\beta_0}{1 + \beta_0}
\]

\[
\beta_0 = \frac{1}{\frac{D_E w N_B}{D_B L_E N_E} + \frac{1}{2} \left( \frac{w}{L_B} \right)^2} \Rightarrow \frac{D_B L_E N_E}{D_E w N_B} = \frac{\alpha_0}{1 - \alpha_0} \tag{3}
\]

where \(N_E\) is the emitter doping, \(D_E\) is the minority carrier diffusion coefficient in the emitter, \(L_E\) is the minority carrier diffusion length in the emitter, and \(L_B\) is the minority carrier diffusion length in the base. These parameters are included in ICAPP database as well and can be changed if the student wants to find the optimal values of these parameters for the device performance.

The junction capacitance depends on the junction area \(S\):

\[
C_j = \frac{C_{j0}}{\sqrt{1 + \frac{U}{U_{bi}}}}, \tag{4}
\]

where \(C_{j0}\) is the zero bias depletion capacitance \(C_{j0} = \frac{q e_D e N_A N_D}{2 (N_A + N_D) U_{bi}}\), and \(U\) is the voltage applied on the junction.

The transit frequency:

\[
f_T = \frac{1}{2\pi \tau}, \tag{5}
\]
where \( \tau = \varphi \frac{C_{JE}}{I_E} + \frac{W^2}{5D_B} + (C_{JC} + C_{CS})r_C \).

\( C_{JE} \) is the emitter-base capacitance, \( C_{JC} \) is the collector-base capacitance, \( C_{CS} \) is the collector-substrate capacitance and \( r_C \) is the parasitic collector resistance. Figure 4 illustrates \( r_C \) and its calculation using ICAPP.

## 4 Conclusions

The PBL approach in Microelectronics delivers attractive results both in terms of technical achievement as well as experience in its applying as a learning strategy. In several cases project results lead to further research and development activities.

The practice shows that PBL is a successful solution to instruction for a variety of reasons: it helps students retain the information they learn, engages students’ interest and motivates them to learn, students are encouraged to explore their own interests and to make connections to the world beyond university, it encourages a deeper level of thinking by involving students in answering questions for themselves. PBL facilitates students develop the same kinds of 21st-century skills - such as problem solving, critical thinking, communication, collaboration, and creativity. Tackling long-term, student-led projects can help students build real-world skills and knowledge.

Technology is an important feature for the engineering courses that not only support and automate several operations, but also lead to forming the creativity skills. The developed ICAPP software is designed as a flexible environment and it is extended during the project working by students with constants, parameters and examples.

## References:


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