Reverse Engineering as a Didactic Tool in Nano- and Micro Technology

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ABSTRACT

This paper describes a student exercise in the field of nano & micro technology from the course “Solid State Electronics and Micro Technology”. The course corresponds to a 10 ECTS point workload and is aimed at the bachelor student level. The timeframe for the exercise is 3x4 hours distributed over two weeks of study. The exercise is based on reverse engineering of a commercial piezoresistive pressure sensor and the students discover and analyse how this device is made. Based on their observations they calculate the expected performance of the device and compare it to the measurements they have performed. The use of reverse engineering as a didactical tool thus promotes active learning.

KEYWORDS

Active learning, reverse engineering, nano technology

INTRODUCTION

The Technical University of Denmark (DTU) provides a 10 ECTS credit course on solid state electronics and micro technology. The course is aimed for students attending the Physics and Nano Technology line of study and for students in the field of electrical engineering. The course covers the physics and technology of a range of devices including pn junction diodes, bipolar transistors, metal oxide semiconductor field effect transistors, and capacitive and piezo resistive micro electro mechanical systems (MEMS). The course uses the book Semiconductor Devices by Neamen [1] and a series of lecture notes.

The layout of the course is shown on Figure 1. The course consists of 26 lessons each lasting 4 hours. The first part of the course deals with an introduction to the theory of semiconductors including the concept of bandgaps, carrier distributions and transport equations for electrons and holes. This first part of the curriculum is assessed at a poster session where the students present different topics related to the theory part. This presentation counts 10% of the final evaluation.

The next part of the course covers pn-junction and Schottky diodes and fabrication of such devices. Again, this part of the course is summarised at a poster session counting 10% of the evaluation.

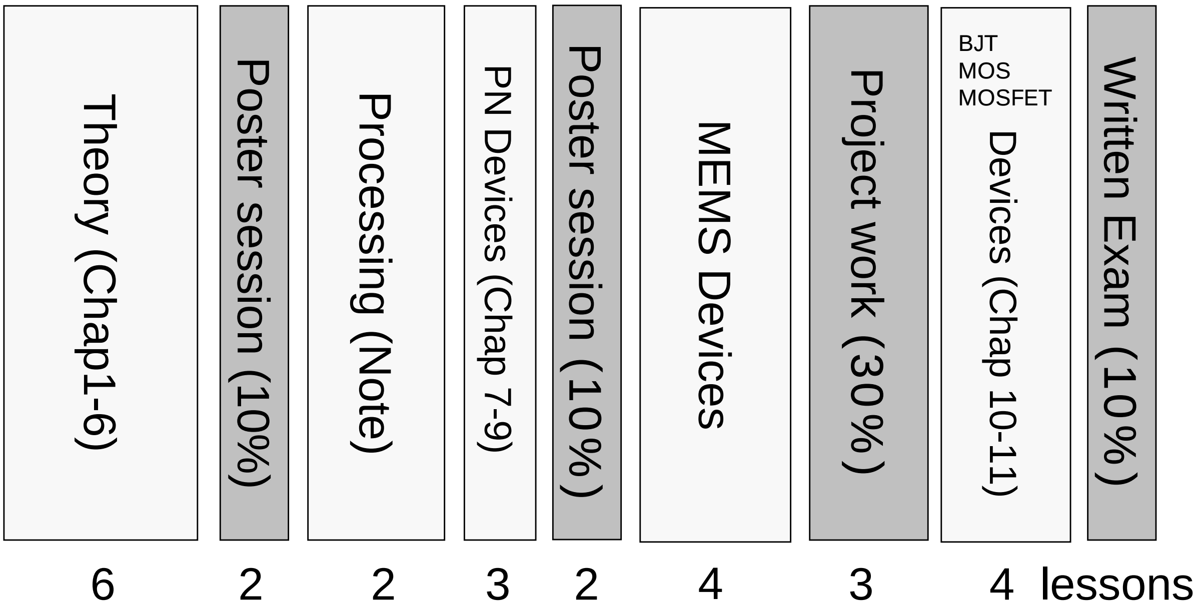

Figure 1. The course consists of different elements. The dark grey boxes are elements which are part of the evaluation.

The topic is now shifted to MEMS devices and for this part of the course a lecture note is used. The MEMS devices investigated includes piezoresistive and capacitive pressure sensors and accelerometers. Fabricating such devices can take months and actual design and fabrication of such devices is thus well beyond the scope of this course. To circumvent this situation reverse engineering of a commercial pressure sensor device from Honeywell, shown on Figure 2, is used for active learning. The students describe their finding in a report counting 30% of the evaluation. Finally the theory of transistors is covered and the final exam is a written test counting 50% of the evaluation.

LEARNING OBJECTIVES

During the course the students have learn about the theory for piezo resistive pressure sensors and have obtained skills that allow them to design such sensors using both analytical and numerical methods and sketch possible fabrication processes for such devices. These skills are now used to analyze how the pressure sensor works.

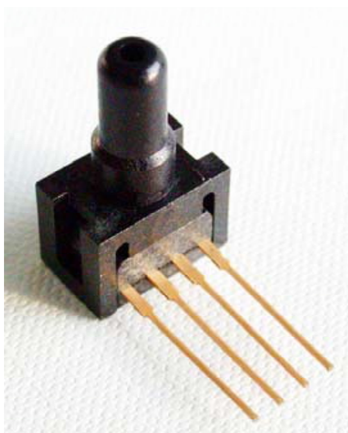

Figure 2. A pressure sensor made by Honeywell is used in the exercise. The advantage of this device is that it is possible to take it apart with simple means.

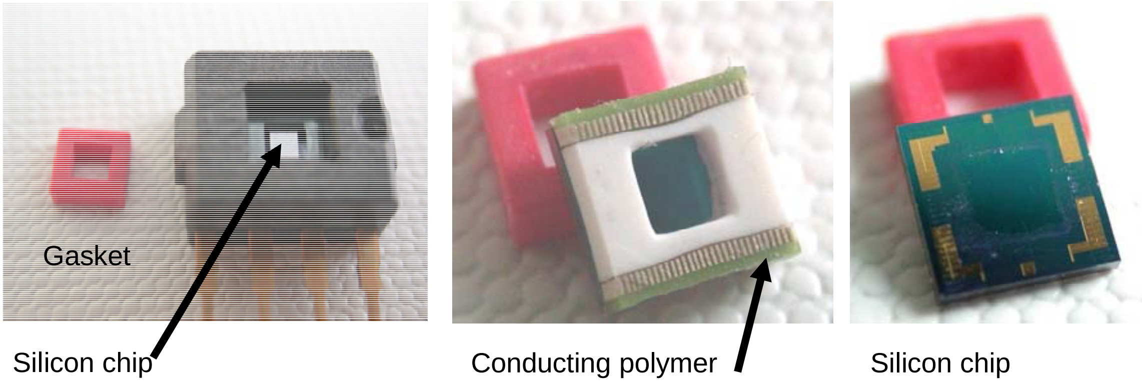

Figure 3. When the pressure sensor is taken apart the two gaskets and the silicon chip are clearly seen. One of the gaskets contains a conducting part serving to transfer the signal from the sensor to the electrical connections on the package.

The major learning objectives for this exercise are:

- Apply theoretical models to describe the performance of the pressure sensor
- Design a process flow for fabrication of the pressure sensor
- Describe how commercial sensors can be made in silicon
- Explain how packaging can be done
- Work in teams with a complex problem

The assessment is based on a report written by the team.

EXERCISE STRUCTURE

The students work in teams of three students and each team receive a pressure sensor together with the datasheet. Most students have never seen such a datasheet before and the difficulties in understanding the very short and concise text are initially overcome.

Measurements

In the first part of the exercise the students use the supplied datasheet to figure out how the electrical characterisation must be performed and they measure the (linear) output voltage-pressure relationship for the device and compare the measured sensitivity to the value in the datasheet. For this purpose the students have access to a pressure controller, a power supply and a multimeter allowing them to measure the output voltage of the device. The students discover a linear relationship between output voltage and pressure as expected from the basic theory. However, they also discover an offset, i.e. the output voltage is not zero for zero pressure. This comes as a surprise for the students and they discover that they need to take into account that in the real device, as opposed to the idealised device in the text book, not all piezo resistors have the exact same value of resistance causing the observed offset.

Discovering the packaging scheme

The next step is to find out how to take the device apart and examine its inner workings in detail. Inside the polymer encapsulation the students discover a silicon chip and two gaskets, as shown on Figure 3, performing the sealing of the device. One of the gaskets contains a conducting polymer that serves to connect the silicon chip to the electrical leads on the package and at the same time perform sealing. The students have never seen or heard about such a conductive gasket and have to discover how it works.

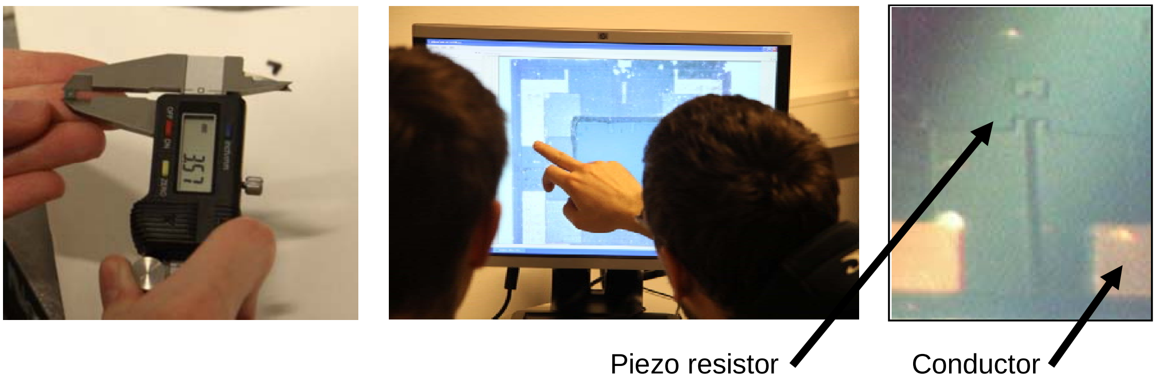

Figure 4. The size of the silicon chip is measured using a vernier caliper. The chip is inspected in an optical microscope revealing piezo resistors and conductors.

Analysing the silicon chip

The size of the silicon chip is measured using a vernier caliper. Using optical microscopes the silicon chip can be examined and the details of the design can be discovered. The students discover, that the hole which has been etched for the membrane of the pressure sensor has sloped sidewalls, and they can calculate the angle and conclude, using their knowledge of crystallography, that this corresponds to (111) planes supporting the conclusion that this is actually a silicon chip made on a (100) silicon substrate. On the surface of the chip several piezo resistors are seen, Figure 4, and it is concluded that these are connected in a Wheatstone bridge. Once the design of the device has been discovered the students perform measurements of the dimensions of the device, the silicon chip, location of the piezo resistors and other important details of the design.

Calculations

Based on the measurements of the chip the students perform analytical and finite element calculations to calculate the mechanical stress in the membrane. Combining these calculations with the theory of piezo resistance allows them to make a model of how the output voltage depends on the pressure. Thus, they can predict the performance of the sensor and compare these models to the measured voltage-pressure characteristics.
Figure 5a shows results from a finite element programme calculation.

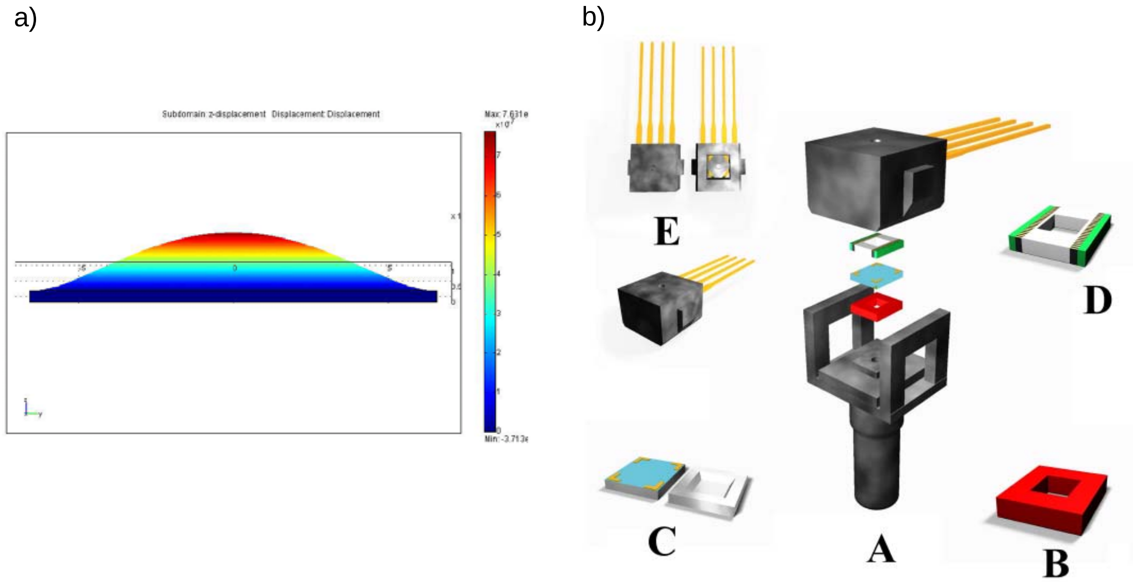

Figure 5. These pictures are from one of the student reports. a) Results from a finite element model showing the deflection profile of the membrane. b) Although making three dimensional sketches is not part of any course for the students they learn to use such tools by them selves and used it for illustrating their findings.

Report

Finally, the students describe their findings, Figure 5b, in a report which is evaluated and each team gets written and oral feedback.

ACHEIVEMENTS

The evaluation of the course reveals that the reverse engineering exercise is very well rated by the students. The really appreciate that they can work on their own hand and the process of discovery followed by calculations and predictions and comparison with measured data is described as being very inspiring. The students put a lot of energy and time into the exercise and this is reflected in the reports which are generally of a very high quality.

Table 1 compares the average marks for the reports compared to the average mark for the written exam and Table 2 describes the mark scale used. Although the marks vary somewhat from year to year it is clearly seen, that the marks for the reports are higher that those obtained at the written exam. This is attributed to the observation that the students are very active during the exercise. In evaluation of the report emphasis is on the methods chosen, the correctness of the analysis and the clarity of the report.

Table 1
Marks for the report and the written exam

Year	2010	2009	2008	2007	2006
Average grade - report	10,5	9,6	10,3	9,6	8,4
Average grade - exam	8,6	7,5	7,7	9,6	8,1

Table 2
Description of the Danish grade scale used in Table 1 compared to the ECTS grade system.

	ECTS	Description
12	A	For an excellent performance displaying a high level of command of all aspects of the relevant material, with no or only a few minor weaknesses.
10	B	For a very good performance displaying a high level of command of most aspects of the relevant material, with only minor weaknesses.
7	C	For a good performance displaying good command of the relevant material but also some weaknesses.
4	D	For a fair performance displaying some command of the relevant material but also some major weaknesses.
2	E	For a performance meeting only the minimum requirements for acceptance.
0	Fx	For a performance which does not meet the minimum requirements for acceptance.
-3	-F	For a performance which is unacceptable in all respects.

CONCLUSION

The advantage of this reverse engineering approach is that students over a short period of time can learn how all steps in the design and manufacturing of a device have been integrated into a product and at the same time develop their design and modelling skills by performing the same type of calculations that would be needed to design the device directly from at set of specifications.

Reverse engineering has also been used in teaching other fields such as Mechanical Engineering [2][3] and Mechatronics [4][5]. In conclusion, reverse engineering is also a very effective tool when teaching nano and micro technology.

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Biographical Information

Erik V Thomsen is teaching solid state electronics and fabrication of micro and nano structures. He is heading the board of educational affairs at DTU Nanotech, teaches at the "Teaching and Learning" course provided by Learning Lab DTU, he is heading the MEMS Applied Sensors research group and supervises bachelor, master and PhD students within the field of micro and nanotechnology. He has been member of the evaluation board for the Finnish Aalto University and served as reviewer for the Norwegian Agency for Quality Assurance in Education.

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