EE 105 Formal Laboratory Report Guidelines

Experiment 4: Integrated-Circuit Resistors

See http://www.writing.eng.vt.edu/workbooks/laboratory.html for some additional help from Virginia Tech's excellent technical writing program.

Abstract (75 word limit)

Technical papers have a short abstract for the purpose of describing the essential results, so that indexing services (e.g., *INSPEC* for electrical engineering-related fields) can search for key terms to classify the paper. The abstract should be written last and contain a concise description of the topic and your key experimental results. Engineers agonize over every word in an abstract in order to maximize its information content, while not bending the rules of English grammar to the point of unintelligibility.

Introduction

This section primarily tells the reader enough background information to understand (i) the technical essentials and (ii) the goal of the measurements. The cross sections of the Microlinear process are examples of important background material. Copying or paraphrasing the relevant sections of the lab manual is *not* adequate. You should include references to the textbook and other material that you find helpful in providing the background information. Use the IEEE format in http://standards.ieee.org/guides/style/section7.html for citing your references, which you should collect at the end of your report.

Procedure

This part should summarize the experimental procedures you followed, as well discuss important issues with the experimental methods and measurement techniques. In this section, you should be *very* careful in describing details that could be important for someone trying to reproduce your experiment. Your laboratory notes will provide the raw material for this section, so be sure to be very thorough in recording your results.

Why should you bother with this level of detail? Because the reproduction of experimental results is the foundation of both engineering and science! Over my career, there have been many times when companies and other academic groups have contacted me to confirm details of the procedure section in one of my group's papers and to discuss reasons why their experiments yielded different measurements. In one case, we looked in the records to find the relative humidity in the Berkeley Microlab and in another case, the graduate student visited a research group at a national lab to reproduce his experiments on their equipment. We have also used other groups' results in our experiments. An EE graduate student in BSAC has spent many months over the past year trying to extract a protein from a biological sample using a procedure published by a biosciences group in Germany in 2002. A long conference call last summer revealed that the German scientist had not provided enough detail in his procedure section; he looked into his lab book and then remembered some very important and very helpful tips! As a final example, a former graduate student of mine spent several weeks trying to understand how his own complex gyroscope interface circuit operated when the chips returned from the foundry. His sloppy and incomplete design report was impossible for his to decipher, only six months later! After learning his lesson the hard way, he's now a leading analog IC designer.

In this Experiment, the SMU setup on the parameter analyzer, including the current compliance settings, are examples of important details.

Results

This extremely important section includes all the measurements and plots from your lab notebook. The resistance measurements in this lab are used to extract estimates of the contact (e.g., metal-silicon interface) resistance. The precision of your measurement, as well as the uncertainty (error bars) will be very important in evaluating your results. You should therefore be careful in estimating the number of significant figures in your data. Instrumentation error is a common issue in the technical literature; in my experience as an editor of an IEEE journal, many authors did more measurements at the request of reviewers, since they felt that the paper didn't adequately address issues with the measurements.

Your results should be well organized, with the axes on your graphs clearly labeled and an informative caption added. For example, a caption stating "Effect of Gate Voltage on Drain Current for a MOS Transistor" is much better than "I vs. V"). Tables are also helpful to summarize measurements.

For several groups, simply plugging in the numbers into the equations in the lab manual will lead to negative resistance values, which are physically possible. You will need to describe how measurement errors can lead to this outcome in the analysis section.

Analysis

In this section, you should comment on whether or not your results matched your expectations and explain the meaning of your plots. Your understanding of the instrumentation and how the measurements were made can be very important in this process. The manuals for the Agilent instruments on available on the web, in case you want to dig into the details of what went on inside the "box." By the way, this lab involves measurements of resistance on what are inherently non-linear integrated-circuit structures, as I've emphasized throughout the lectures. Perhaps you can investigate whether or not there are significant nonlinearities.

Finally, your analysis and interpretation of the results give meaning to what is otherwise raw data. You must communicate to the reader exactly what you have done in the data analysis. Force-fitting data to a preconceived model is a serious violation of the ethical code of our profession, since it's a form of dishonesty. You may find that there are "outliers" in your data, which you feel you must ignore to make sense of the overall picture. If that's the case, tell the reader what you're doing and include the outliers in your initial results.

Discussion and Conclusions

The final section involves your interpretation of the experimental results and analysis. You should include enough theoretical background for the reader to understand the principles behind the equations. The origin and assumptions behind the equations used in analyzing your data should be discussed. The textbook and lab manual are not sufficient for this purpose; you should look into other references.

Furthermore, you should interpret your results and your level of confidence in them. Are they reasonable and consistent with the literature? They should be presented in the standard form. For example, contact resistances are usually normalized to the contact area, which you can estimate from the layout.

A longer report might include a separate conclusion section, but for Experiment 4 I think that a merged section will be adequate. You should describe whether your results are consistent with literature values, if you can find parallel or typical results from textbooks or technical papers.

Additional Resources

See http://www.writing.eng.vt.edu/workbooks/laboratory.html for some additional help from Virginia Tech's excellent technical writing program.

The Chemistry Department at Smith College has some good advice on the appropriate English style for lab reports.
http://www.science.smith.edu/departments/Chem/Courses/labreports.htm

Passive vs. active voice: You may have been advised in other classes to avoid the passive voice in your writing. (The previous sentence is an example of passive voice; the active version would say, "Instructors in other courses may have advised you to avoid the passive voice.") In general, use of the passive voice adds unnecessary complexity. However, scientists often use passive voice, particularly when describing experimental protocols. *This is not because scientists are bad writers!* If we did the experiment well, anyone should be able to reproduce it, and we emphasize that fact by reporting the experiment as if the identity of the experimenter were inconsequential. For example, most chemists would say, "The solution was heated at 100º C for 5 hours," rather than "I heated the solution at 100º C for 5 hours." Please follow this convention and report your actions in the passive voice.

Past vs. present tense: Verb tense follows the philosophy described above: we want to convey that the experiment could be done at any time with the same outcome. Therefore, while actions that took place in the past are rightly described in the past tense, results are assumed to reside in the present and are described in the present tense. For example, we write, "The solution was heated at 100º C for 5 hours," because that action was carried out at a specific past time. However, if you took an infrared spectrum of the sample you made, to describe the spectrum to the reader you would use the present tense: "The absence of peaks above 3000 cm^{-1} confirms that no OH groups remain."

Never start a sentence with a numeral ("2" is a numeral; "Two" is not). When reporting a quantitative amount at the start of a sentence, use the following format: "Salicylic acid (1.00 g) was added to. . . ." It is incorrect to write "1.00 g salicylic acid was added. . . ," and it is imprecise to write "One gram salicylic acid was added. . . ."

For general questions of grammar and usage an excellent reference is Strunk and White's *The Elements of Style.* This book covers many of the most common errors made in writing, scientific and otherwise. Of special note for lab reports:

1. "Data" is a plural word; the singular form (for one point) is "datum." Saying "The data shows that. . ." is like saying "The people says that. . . ."

2. "Spectrum" is a singular word; more than one spectrum is a group of "spectra."