EECS 143
Microfabrication
Technology

Lab Report 2

Table of Contents

TOTAL = 100 points (+ 5 points)

This report will summarize characterization of your test structures. The two purposes of characterization are to teach you how to use the equipment and techniques common to semiconductor device analysis, and to compare the actual behavior of your devices with that predicted theoretically. Each group of two (or three) students will submit one joint report. Please follow the outline given in the table of contents above, which will allow the TAs to grade the reports clearly based on the within-section point values described below.

Working vs. Non-working devices

We understand that some of your devices may not work for a variety of reasons. If this is the case for your group, you are allowed to borrow a wafer from other groups to get functioning device characteristics. However, if your devices do not display precisely the same characteristics as shown in the Device Characterization Outine, do not panic. Keep in mind that the point of this lab report is for you to compare your results to the reference and explore which fabrication steps might have caused that problem. If particular devices do not work in your entire lab section's wafers, please talk to your TA about the procedure to proceed with the parameter extractions and discussions for this report.

Report Submission date

Lab report 2 is due by 5pm on Friday, Dec 10, 2010. This is a firm deadline. Please turn in the Cory dropbox or online on bSpace.

Removed parts

We removed some parts of the characterization to relieve you from being overwhelmed. Please know that your lab report doesn't have to include the following devices:
Capacitors (device #6); transistors (device #12, 13); Circuits (device#15, 16); MEMS (device #17,19, 20,21)

1. **Measurements (20 points):** The measurements you are responsible for taking and analyzing, are described in the Device Characterization page. They can be split up into 2 groups by the kind of electrical equipment required:

Grading for this section: 14 points for 34 plots, 3 points for correct labels and titles and 3 points for device diagrams.

    1. **HP4155B: Semiconductor Parameter Analyzer (3 stations): EXPECTED total of 25 PLOTS.**

Extract the data and make the plots for the:
- **Resistors** (1 plot from each of devices #2 a and b) (1points) (total 2 plots)
- **Contact-Chain Resistors** (1 plot from each of devices #2 c and d) (1 point) (total 2 plots)
- **Diode** (1 plot-forward (normal) operation only; 1 plot–reverse operation specifically showing the breakdown region and breakdown voltage—from device #7) (1point) (total 2 plots)
- **MOSFETs** (2 plots—described at the Device Characterization page—from each of devices #8 a-d, and 2 plots from each of devices#9 a-c, and 2 plot from each of devices #10 and #11) (8.5points) (8 plots + 6 plots + 4 plots = total 18 plots)
- **Inverter** (1 plot from device #14) (0.5point)

   **2. HP4284A: Precision LCR Meter (1 station): EXPECTED total of 4 PLOTS**

Extract the data and make the plots for the
- **Field Oxide Capacitor** (1 plot from device #3), (0.5 points)
- **Gate Oxide Capacitor** (2 plots from device #4—one each lights on/off), (1 point)
- **Intermediate Oxide Capacitor** (1 plot from device #5) (0.5 point)
- Remember to remove the intrinsic capacitance of the HP4284A and wires from your data before plotting!

NOTE: Label ALL plots and indicate corresponding device number.

    NOTE: Correct labeling and giving title to plots (title should specify the corresponding device number clearly) will be worth 0.5 point for each device type (6major device types). NOTE: There is NO PARTIAL CREDIT for this because correct labeling means that ALL axes of a plot should have the correct labels.

    For each of the 6 major device types (resistor, contact-chain resistor, diode, MOSFET, and inverter), include a top down picture of the device, and a brief description of what (if any) stimulus was applied and what (if any) measurements were taken at each of the contact pads. Note that for the MOSFET, this will require three diagrams—one for each of the three plots you generated for each device. For example, the contact-chain resistor would look like:

2d metal - poly
contact res

V sweep, -10 to 10
Volts; I, V
measured

GND
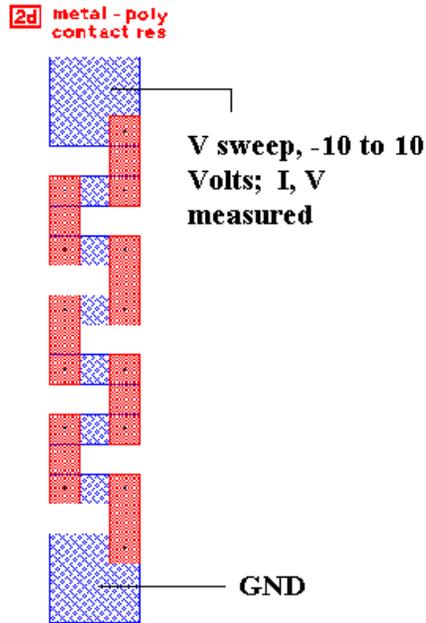
Again, each *correctly labeled, titled* **device diagram will be worth** **0.5 point.**

2. **Parameter Extraction (25 points)** From the data taken above, find the following device parameters. Show all procedures and calculations and include a circuit representation of the device (no circuit for line widths). **To make life easier, follow the hints at the Device Characterization page**…

    I.   Line Width and Misalignment 1 pts

        Measure the line widths on the test patterns for each lithography step. Create a table of all the line widths.

        Measure the misalignment for each lithography step (with precision, using the Verniers). (This section can basically be copied over from lab report 1, if a thorough job was done) You only need to provide tables one each for final line widths measurements (after etching) and misalignment for each layer (Vernier measurement value and calculated misalignment for each layer). Please do not provide any pictures. They carry no credit.

    II. Resistors (2a, b) 2 pts

        Extract the resistance of each structure. Use the final measured line width data (and therefore, the overetch/underetch data) from the above problem, to calculate the dimensions of the poly resistor, 2b.

        Calculate the sheet resistance for each structure. For 2a, use the junction depth value calculated in Lab Report 1 to determine the doping concentration and electron mobility from standard tables in Muller and Kamins. For the poly resistor 2b, calculate the polysilicon resistivity in (ohm-cm).

        If data was bad for your wafer and you used data from another wafer, explain why your devices did not work.

    III. Contact-chain resistors (2c, d) 2 pts

        Extract the resistance of each structure.

        Calculate the contact resistance for the contacts of each structure, using the sheet resistance values from the previous calculations section (resistors).

3

If data was bad for your wafer and you used data from another wafer, explain why your devices did not work.

IV. Capacitors **4 pts**

Field Ox Cap (3)—determine the capacitance in the accumulation region (close to -5V). Calculate the field oxide thickness.
Gate Ox Cap (4)—determine the minimum capacitance, both with lights on and off.
Calculate the gate oxide thickness and C' (capacitance / unit area)
Calculate maximum depletion width and substrate doping concentration.
Extract the flat band capacitance (C_{FB}), flat band voltage (V_{FB}) and calculate interface fixed charge density (Q_f).
Report/Estimate the V_{Tn}
Intermediate Ox Cap (5)—determine the capacitance at –5 V.

V. Diode **2 pts**

Extract the turn-on voltage and the series resistance.

VI. MOSFETs **12 pts**

Fill in the values of the parameters listed in the table below.

VII. Inverter **2 pts**

Extract V_{OH}, V_{OL}, V_{IH}, V_{IL}, and approximate V_M for one of the three curves in your inverter plot (specify your choice of V_{DD})

3. Theoretical Calculations (33 points)

The theoretical values should be calculated totally independent of characterization measurements made in the second section of lab. You should use only values from report 1. Use the measured physical value of device dimensions and process parameters instead of the expected values in your theoretical calculations whenever you can. You need to use your earlier measured or extracted t_{ox}, X_j, $N_{surface}$ and lateral diffusion from the first lab report. At the beginning of this part, please list all of the measured physical value from your lab report 1. Provide this data in the form of a table. **2 pts**

I. Resistors (2a, b) **2 pts**

Using the thickness and/or junction depths and doping from report 1 determine the expected theoretical sheet resistance for both 2a and 2b.

II. Contact-chain resistors (2c, d) **2 pts**

Consult Jaeger's section on contact resistance and report values for theoretical contact resistances that one would expect for devices 2c and 2d.

III. MOS Capacitors **11 pts**

Based on geometries defined in lab report 1, draw a schematic for the two capacitors mentioned below (the cross section) and label all pertinent capacitances. (2 points)
Describe the physics of the MOS capacitor (what does MOS mean? Discuss the three regions of a MOS capacitor). (2 points)
Based on the geometries report the theoretical equations and plot the theoretical CV (as a function of bias voltage) for the following capacitors.
1. Field Ox Capacitor (calculate V_{Tn} and V_{FB}) (3 points)

2. Gate Oxide Capacitor (you do not need to include photoelectric effect in your calculations but discuss expected photo electric effect, also calculate V_{Tn} and V_{FB}) (4 points)

IV. Diode 1 pt
Calculate the built in potential or turn on voltage for the pn junction. You can assume a step junction here.

V. MOSFETs 13 pts
Calculate the theoretical values for the MOSFET parameters listed in the table below. Use the empirically measured values of W/L for report 1. You do not need to calculate $V_{T, sat}$. Determine the mobility as a function of the doping (Howe and Sodini have a nice plot of this, or see Richard Muller's book that is EE130 textbook before). The oxide capacitance will be calculated from empirical measurements of the gate oxide thickness in report #1. Calculate $V_{T, lin}$ (same as equations used for the MOS gate capacitor).   Also, k is the product μC_{ox}.
Calculate the expected value of the body factor (γ).

VI. Inverter 2 pt
Draw well labeled equivalent circuit to be analyzed. Simplify to voltage divider with variable resistors. Construct and check truth table as a function of input voltages and V_{DD} using the MOS parameters determined in previous sections.

4. Discussion (15 points)

1. Create one master table with all of the measured values from the parameter extraction section, all the theoretical values from the theoretical calculations section, and the percentage difference between the two. (So, three columns for each device parameter.) You can use the table below as a reference. For each of the device parameters, discuss what may have caused the discrepancy (if any) between the measured and theoretical values. Draw up this point-by-point discussion in a **numbered, organized and concise** form. Write only several sentences per point. Be concise, but thorough.(**15 points**)

5. MEMS discussion (7 points)

1. Draw cross-sectional profiles of the MEMS comb drive across the cut-line AA' shown in the diagram below for each step in the process flow. Indicate all layers and specify important details such as the non-planar interfaces, isotropic etch profiles, point-source Al evaporation, thermal oxidation growth, etc. Label each feature and indicate thicknesses (make roughly proportional sketches). These drawings should have significantly more detail than those on the lab manual website. (3 points)
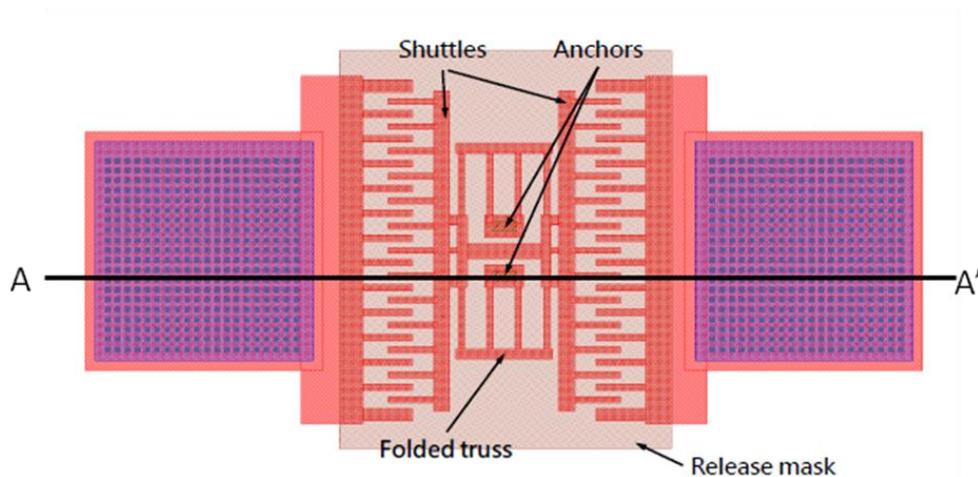
2. Based on the discussion of the comb drives in lab, speculate as to what problems are associated with the comb drive process. What tests would you perform during/after the process to figure out all the problems related to the MEMS structure? What are some ways to improve the process to obtain working comb drives? (4 points)

6. Device Discussion (5 points) [Bonus]

1.

a) Plot ideal square law MOSFET characteristics against one of your MOSFETs [8d, 9a, 10]. Describe the non-ideal effects that can explain the differences between the two plots.

b) Is your $V_{t, lin}$ different from your $V_{t, sat}$? Give reasons as to why or why not.

7. Tips for writing your report

1. The objective of your report is to convince the reader of the following:
   ▪ You measured the data required.
   ▪ You plotted the data correctly.
   ▪ You extracted parameters from the plots.
   ▪ You carried out accurate calculations and gave a convincing discussion of how (if) the results of these calculations differ from theory, and why.

2. Your lab report **MUST** follow the structure given above—even if you think you have a better plan for organizing your analysis, stick to ours so that we may grade your efforts fairly. Following the exact format will ensure fair grading.

3. **MOST IMPORTANT:** When things don't turn out perfectly, present a plausible explanation of why and where in the process, things went wrong. Also explain what should have happened and what you would have done. Do not fudge data. Well thought out explanations and insight into the problems in IC devices are worth more than perfect devices.

Summary of MOSFET Parameters

Parameter	Measured/Extracted	Theoretical	Units
t_{ox} (gate)			
C'_{ox} (gate)			
N_D			
N_A			
x_D			
C_{FB}			
Q_{SS} (Q_f)			
μ_{eff}			
ΔL (linear)			
V_t (field oxide)			
$V_{T, lin}$			
(8a) W/L=15/4			
(8b) W/L=15/6			
(8c) W/L=15/8			
(8d) W/L=15/10			
(9a) W/L=10/20			
(9b) W/L=15/20			
(9c) W/L=20/20			
(10) W/L=100/100			
$V_{T, sat}$			
(8a) W/L=15/4		---	
(8b) W/L=15/6		---	
(8c) W/L=15/8		---	
(8d) W/L=15/10		---	
(9a) W/L=10/20		---	
(9b) W/L=15/20		---	
(9c) W/L=20/20		---	
(10) W/L=100/100		---	

k			
(8a) W/L=15/4			
(8b) W/L=15/6			
(8c) W/L=15/8			
(8d) W/L=15/10			
(9a) W/L=10/20			
(9b) W/L=15/20			
(9c) W/L=20/20			
(10) W/L=100/100			
γ			
(8a) W/L=15/4			
(8b) W/L=15/6			
(8c) W/L=15/8			
(8d) W/L=15/10			
(9a) W/L=10/20			
(9b) W/L=15/20			
(9c) W/L=20/20			
(10) W/L=100/100			

Please print this page and insert it in your lab report 2

Fall 2010

Note: please print your name.

Lab session: _____

Name_____   _____
       (last)   (first)

Department_____

Name_____   _____
       (last)   (first)

Department_____

Name_____   _____
       (last)   (first)

Department_____

Part 1: Measurement	/20
Part 2: Parameter extraction	/25
Part 3: Calculation	/33
Part 4: Discussion	/15
Part 5: MEMS discussion	/7
Part 6: Device discussion (optional)	/5
Total score	/100