1 Measurements & Parameter Extraction

1.1 Line Width/Misalignment

1.1.1 Measured line widths

Nominal Linewidth	ACTV (dark field)	POLY (clear field)	CONT (dark field)	METAL (clear field)
2μm	3	4	1.869	2.520

1.1.2 Misalignment

1.2 Four-Point Resistors [2a, 2b]

1.2.1 Measurement Setup

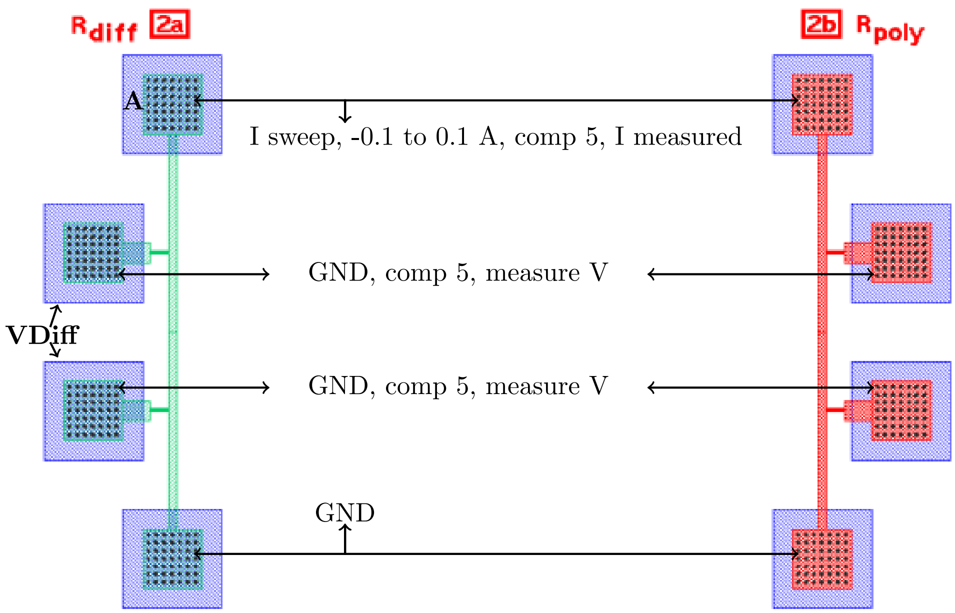


Figure 1: Device 2a is a diffusion resistor and 2b is a poly resistor.

1.2.2 I-V plot for the diffusion resistor, 2a

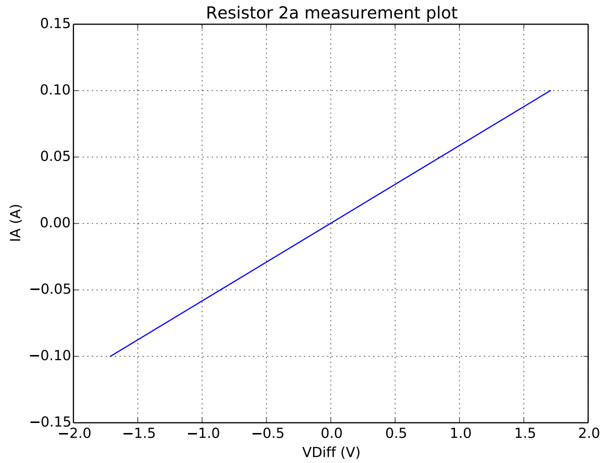


Figure 2: A plot of the measurement data taken for resistor 2a. The plot is based off of 2 data points.

From the plot above we can calculate our resistance. Note that the slope of the above plot will be equal to 1/R. Since I = V/R, where I is our dependent variable (y axis) and V is our independent variable (X axis). A resistance of $R = 17\,\Omega$ was calculated. Our width and length values are $10\mu m$ and $200\mu m$. However our final $2\mu m$ line after the ACTV mask was 3 μm which means that we had a overetch of about 50%. This means that

$$R_s = \frac{W}{L} R_{\text{diff}} = \frac{10(1.50)}{200} 17 = 1.28\,\Omega$$

From the previous lab report we have a junction depth of $1\,\mu m$. This means that our Resistivity is $\rho = R_s x_j = 1.07 \times 10^{-4}$ Ω-cm. Using the Irvin curves in Jaeger [1], we can estimate the surface concentration $N_0 \approx 10^{21}$. Now the mobility can be calculated using a table of values from Appendix xx.

$$\mu_e = \mu_{\min} + \frac{\mu_0}{1 + (N/N_{\text{ref}})^{\alpha}} = 92 + \frac{1268}{1 + (10^{21}/1.3 \times 10^{17})^{0.91}} = 92.4\,\text{cm}^2/V - s$$

1.2.3 I-V plot for the poly resistor, 2b

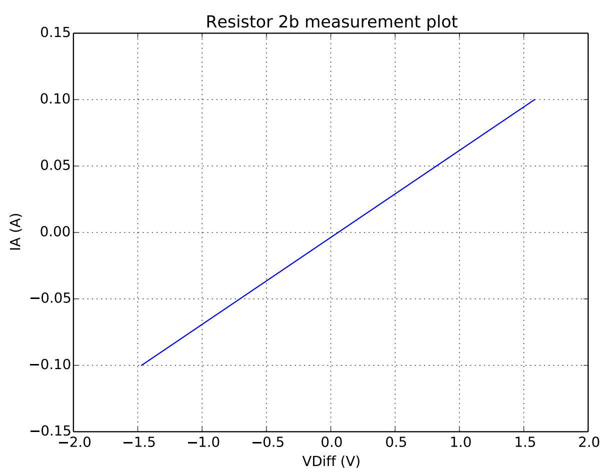


Figure 3: A plot of the measurement data taken for resistor 2b. The plot is based off of 2 data points.

From the plot above we calculate a 1/slope value of 15. Hense $R = 15\,\Omega$. This means that

$$R_s = \frac{W}{L} R_{\text{poly}} = \frac{10(1.26)}{200} 15 = 0.945\,\Omega$$

Our Resistivity is then $\rho = R_s t_{\text{poly}}$ where t_{poly} is the polysilicon thickness which is 0.4 μm, Hense $\rho = 0.378\,\Omega$-μm.

1.3 Four-Point Contact Resistor [17a, 17b]

1.3.1 Measurement Setup

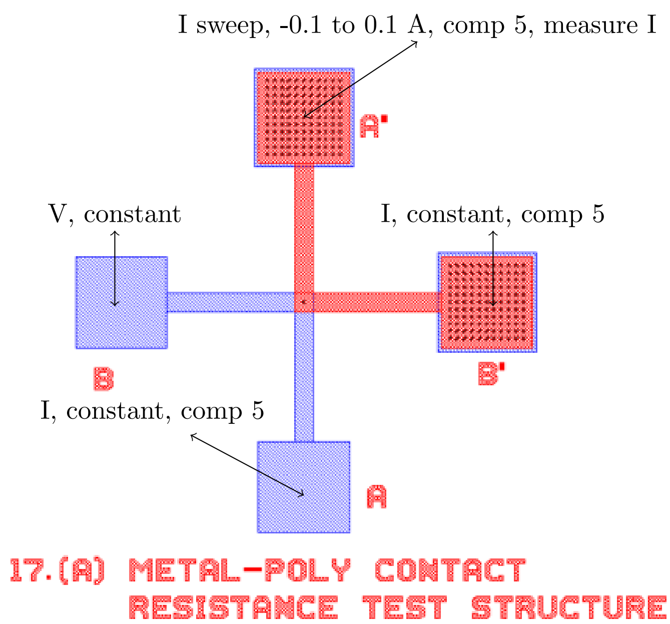


Figure 4: Measurement setup for 17a poly contact resistor. The same setup is used for the diffusion contact resistor, 17b.

1.3.2 I-V plot for 17a, poly reisistor

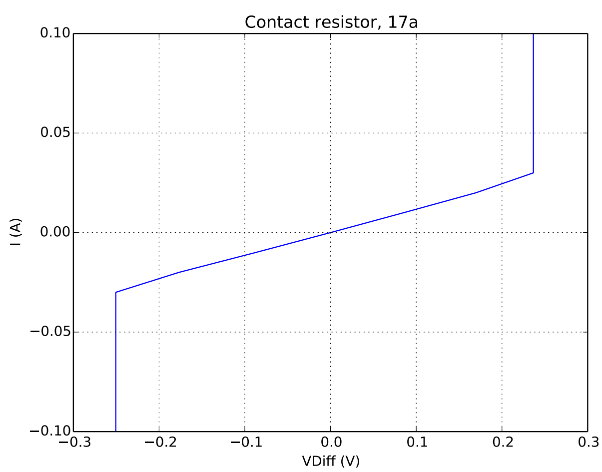


Figure 5: A plot of the measurement data taken for resistor 17a.

From the above plot we calculated a resistance of $R = 8.54\Omega$. Note that the slope above gives us $1/R$ so we need to take the inverse to find the resistance.

1.3.3 I-V plot for 17b, diffusion resistor

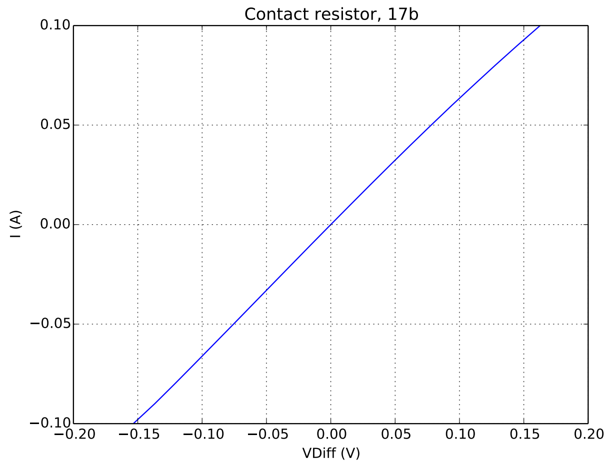


Figure 6: A plot of the measurement data taken for resistor 17b.

Similarly, from the above plot we calculated a resistance of $R = 1.46\Omega$.

1.4 Four-Point Contact-Chain Resistor [2c, 2d]

1.4.1 Measurement Setup

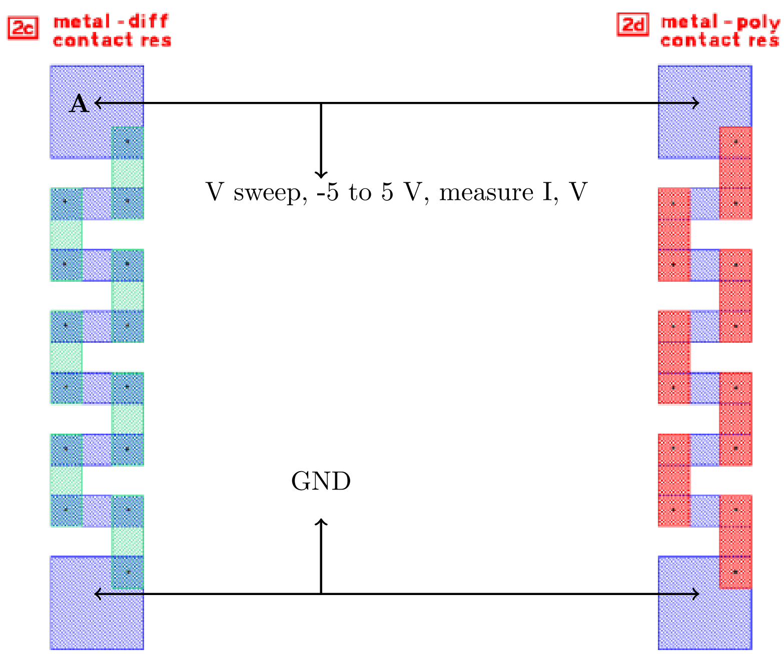


Figure 7: Chain resistor setup for diffusion and poly resistors.

1.4.2 b. I-V plot for diffusion resistor, 2c

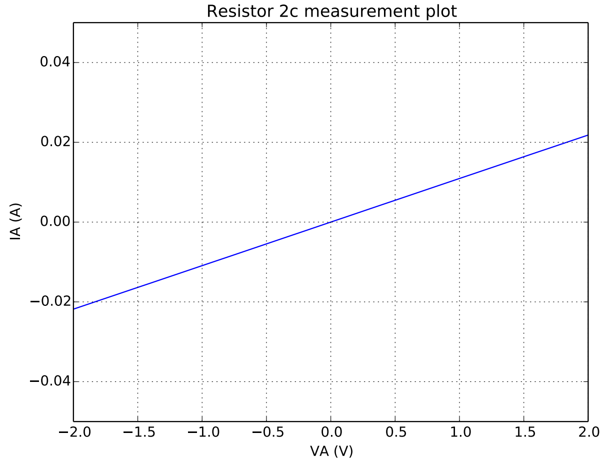


Figure 8: A plot of the measurement data taken for resistor 2c. The plot is based off of 2 data points.

The resistance calculated from the graph here is $R = 91.2\Omega$. Using sheet resistance from 2a/b and the total resistance from the slope above, we can solve for the contact resistance

$$R_{\text{total diff}} = 7(\eta R_{\text{S diff}} + R_{\text{C diff}}) \Rightarrow R_{\text{C diff}} = \frac{1}{7}R_{\text{total diff}} - \eta R_{\text{S diff}} = \frac{1}{7}(91.2\Omega) - 2.3(1.07\Omega) = 10.6\Omega$$

1.4.3 b. I-V plot for poly resistor, 2d

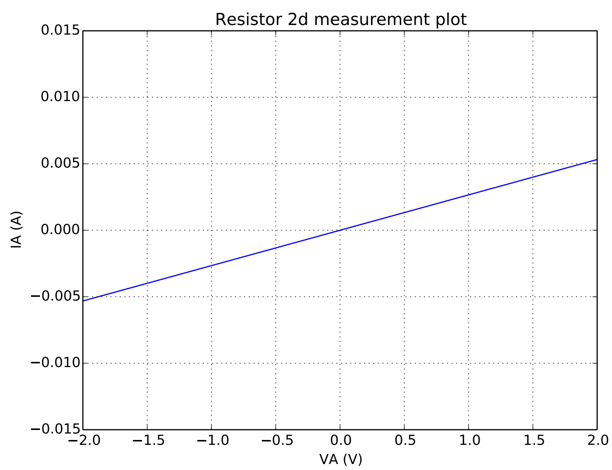


Figure 9: A plot of the measurement data taken for resistor 2d. The plot is based off of 2 data points.

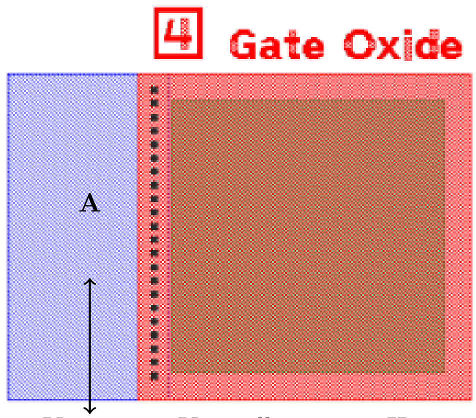
The resistance calculated from the graph here is $R = 370\Omega$. Using sheet resistance from 2a/b and the total resistance from the slope above, we can solve for the contact resistance

$$R_{\text{total poly}} = 7(\eta R_{\text{S poly}} + R_{\text{C poly}}) \Rightarrow R_{\text{C poly}} = \frac{1}{7}R_{\text{total poly}} - \eta R_{\text{S poly}} = \frac{1}{7}(370\Omega) - 2.3(0.945\Omega) = 50.7\Omega$$

1.5 Gate Oxide Capacitor, 4

1.5.1 Measurement Setup

Stage connector set to GND



V sweep, -10 to 10 V, step 0.2 V, oscillation 0.02Hz, integration medium

Figure 10: Gate capacitor setup.

1.5.2 C-V plot of gate oxide capacitor w/ lights ON

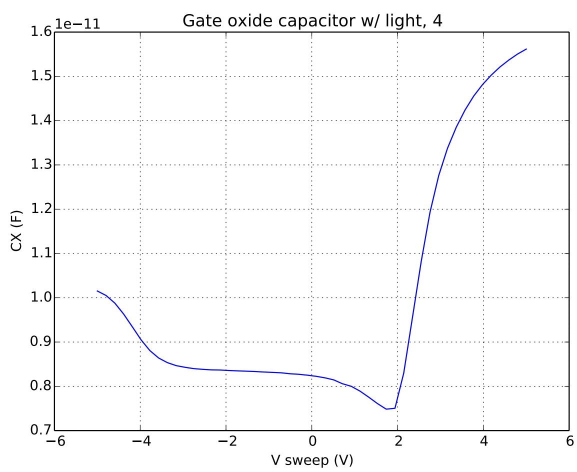


Figure 11: A plot of the measurement data taken for the gate capacitor, 4. Lights on.

The minimum capacitance from the plot above is 7.48 pF. The accumulation region capacitance at about 5 V is 15.7 pF. The active area is 200 μm by 200 μm while the pad+ring area is 240 μm by 335 μm. Also note the gate oxide thickness calculated below for the field oxide capacitors is 1.15 μm.

$$C_{\text{measured}} = A_{\text{active}} \frac{\epsilon_{\text{ox}}}{t_{\text{gox}}} + A_{\text{pad-ring}} \frac{\epsilon_{\text{ox}}}{t_{\text{fox}}}$$

$$t_{\text{gox}} = [\frac{1}{A_{\text{active}}}(\frac{C_{\text{measured}}}{\epsilon_{\text{ox}}} - \frac{A_{\text{pad-ring}}}{t_{\text{fox}}})]^{-1} = [\frac{1}{4 \times 10^{-8}}(\frac{15.7 \times 10^{-12}}{(3.9)8.85 \times 10^{-12}} - \frac{8.04 \times 10^{-8}}{1.15 \times 10^{-6}})]^{-1} = 0.104\,\mu\text{m}$$

The capacitance per unit area in this case would be 15.7 pF / (240μm $\times$ 335μm). C/area = 1.95 pF/μm or 1.95 F/m^{-2}. Now in order to calculate the maximum depletion region we use an equation from lecture notes. Note the max and min capacitance we calculated earlier,

$$\frac{1}{C_{\text{min}}} = \frac{1}{C_{\text{max}}} + \frac{1}{A_{\text{pad-ring}} C_{\text{Dmin}}}, \text{ where } C_{\text{Dmin}} = \frac{\epsilon_{\text{si}}}{x_{\text{dmax}}} \tag{1}$$

Solving for the maximum depletion region we get,

$$x_{\text{dmax}} = A_{\text{pad-ring}}\epsilon_{\text{si}}(\frac{1}{C_{\text{min}}} - \frac{1}{C_{\text{max}}}) = (8.04 \times 10^{-8})(11.7 \times 8.85 \times 10^{-12})(\frac{1}{7.48 \times 10^{-12}} - \frac{1}{15.7 \times 10^{-12}}) = 0.583\mu m$$

Another equation from lecture will help us solve for the substrate doping concentration,

$$x_d = \sqrt{\frac{2\epsilon_{\text{si}}}{q}\frac{1}{N_A}|\psi_s|} \tag{2}$$

where ψ_s is the potential drop and has a typical value of 0.3, q is the charge of an electron 1.602×10^{-19} C, and N_A is the doping concentration.

$$N_A = \frac{2\epsilon_{\text{si}}|\psi_s|}{q{x_d}^2} = \frac{2(11.7 \times 8.85 \times 10^{-12})(0.3)}{1.602 \times 10^{-19}(0.583 \times 10^{-6})^2} = 1.14 \times 10^{21}\,\text{cm}^{-3} = 1.14 \times 10^{27}\,\text{m}^{-3}$$

From the curve above (Figure 11) we can see that the flatband voltage is $V_{FB} \approx 5.5$ and the corresponding $C_{FB} \approx 15.5$pF. To find the charge per unit area at the oxide silicon interface we can use the Q = CV equation.

$$\frac{Q_{ss}}{A} = \frac{C_{FB}V_{FB}}{A_{\text{pad-ring}}} = \frac{(5.5)(15.5 \times 10^{-12})}{8.04 \times 10^{-8}} = 1.06\,\text{mF/m}^2$$

To calculate the threshold voltage we will assume that $V_{SB} = 0$. First we must also calculate Q_{BO} which is the charge stored in the depletion region,

$$Q_{BO} = \sqrt{2q\epsilon_{si}N_B 2\phi_F} = \sqrt{2(1.602 \times 10^{-19})(11.7 \times 8.85 \times 10^{-12})(1.14 \times 10^{27})(2 \times 0.3)} = 1.51 \times 10^{-1}\,C/\text{m}^2$$

Now to calculate/estimate threshold voltage. Note that the work function ϕ_{ms} is zero for n+ doped poly gate.

$$V_t = \phi_{ms} + 2\phi_f - \frac{Q_{ss}}{C_{\text{max}}} + \frac{Q_{BO}}{C_{\text{max}}} = 0 + 0.6 - \frac{1.06 \times 10^{-3}}{1.95} + \frac{1.51 \times 10^{-1}}{1.95} = 0.677V$$

1.5.3 C-V plot of gate oxide capacitor w/ lights OFF

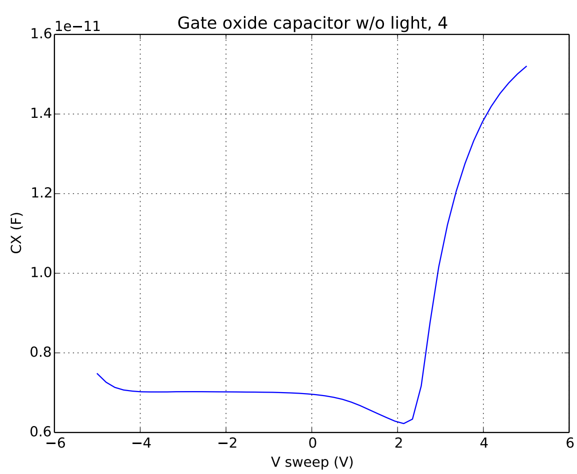


Figure 12: A plot of the measurement data taken for the gate capacitor, 4. Lights off.

minimum capacitance ...

1.6 Field Oxide Capacitor, 3

1.6.1 Measurement Setup

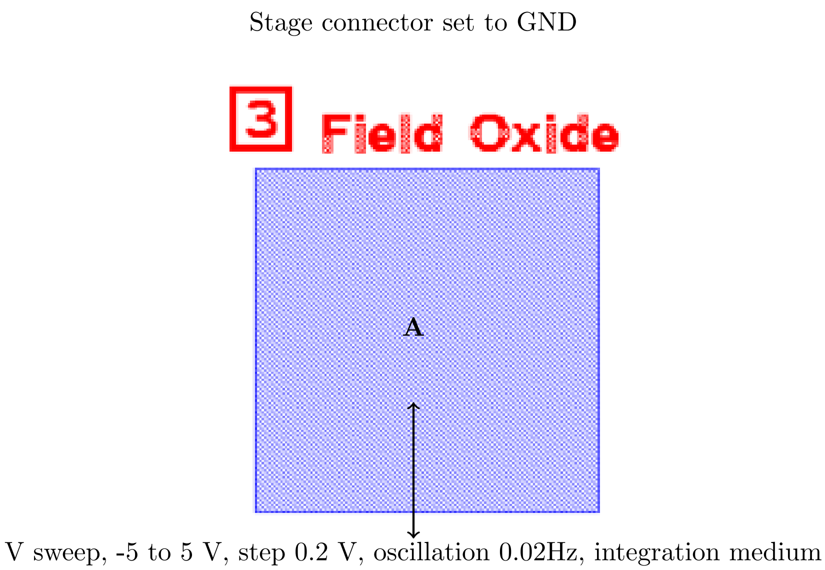


Figure 13: Field oxide capacitor setup.

1.6.2 C-V plot of field oxide capacitor

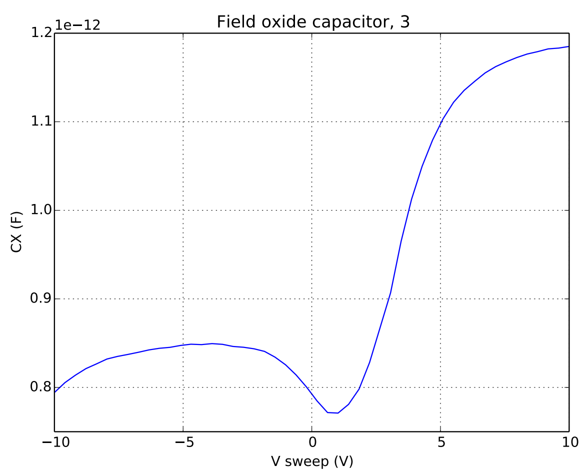


Figure 14: A plot of the measurement data taken for the field oxide capacitor, 3

From the plot above we see that at the accumulation region of ≈ 10 volts we have a corresponding capacitance of $C \approx 1.2$pF. Noting that the area of the capacitor plate is 200 μm by 200 μm, we can now solve for the dieletric (oxide) thickness.

$$C = \frac{A\epsilon_{\text{ox}}}{t_{\text{fox}}} \Rightarrow t_{\text{fox}} = \frac{3.9A\epsilon_0}{C} = \frac{3.9(4 \times 10^{-8})(8.85 \times 10^{-12})}{1.2 \times 10^{-12}} = 1.15\,\mu\text{m}$$

1.7 Intermediate Oxide Capacitors, 5

1.7.1 Measurement Setup

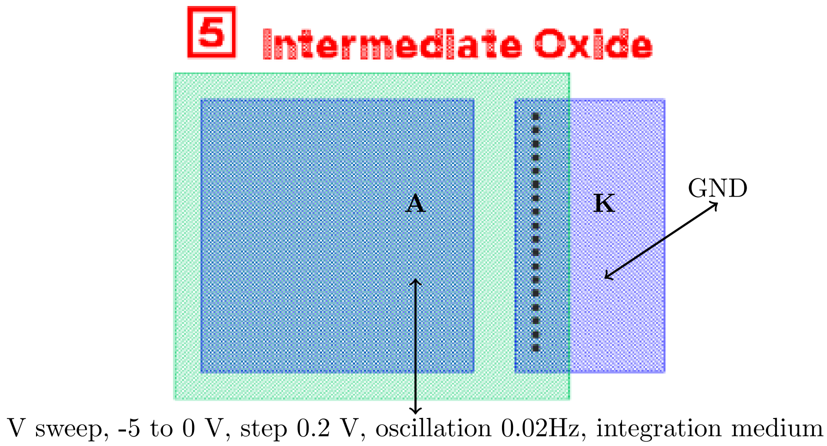


Figure 15: Intermediate oxide capacitor setup.

1.7.2 C-V plot of intermediate oxide capacitor

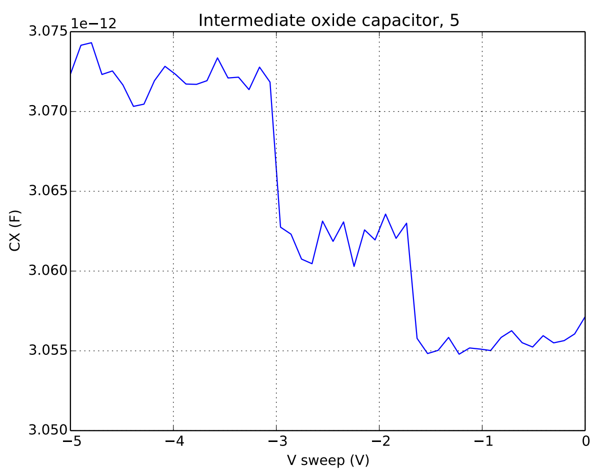


Figure 16: A plot of the measurement data taken for the Intermediate oxide, 5

The capacitance at the accumulation region of ≈ 5 V is about 3.0725 pF.

1.8 Diode, 7

1.8.1 Measurement setups for forward and reverse operations

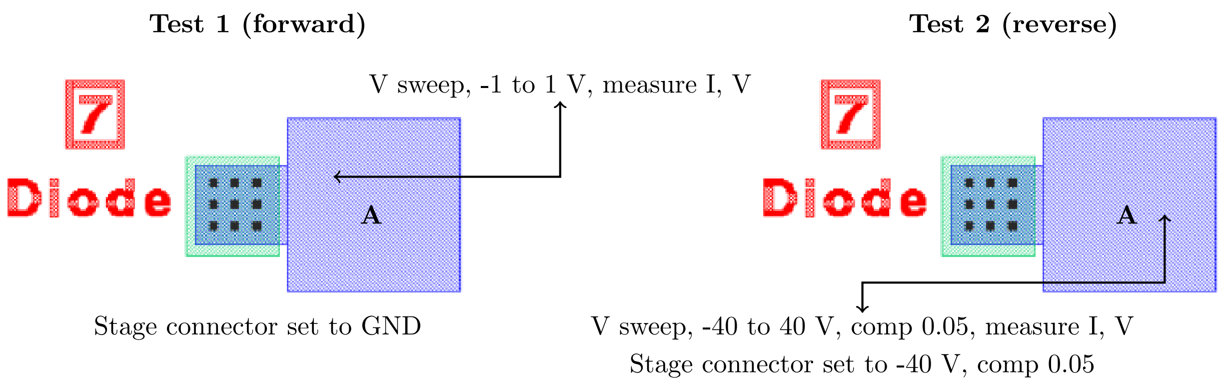


Figure 17: Two tests were performed on this diode; both measurement setups are shown above.

1.8.2 I-V plots for forward and reverse operation

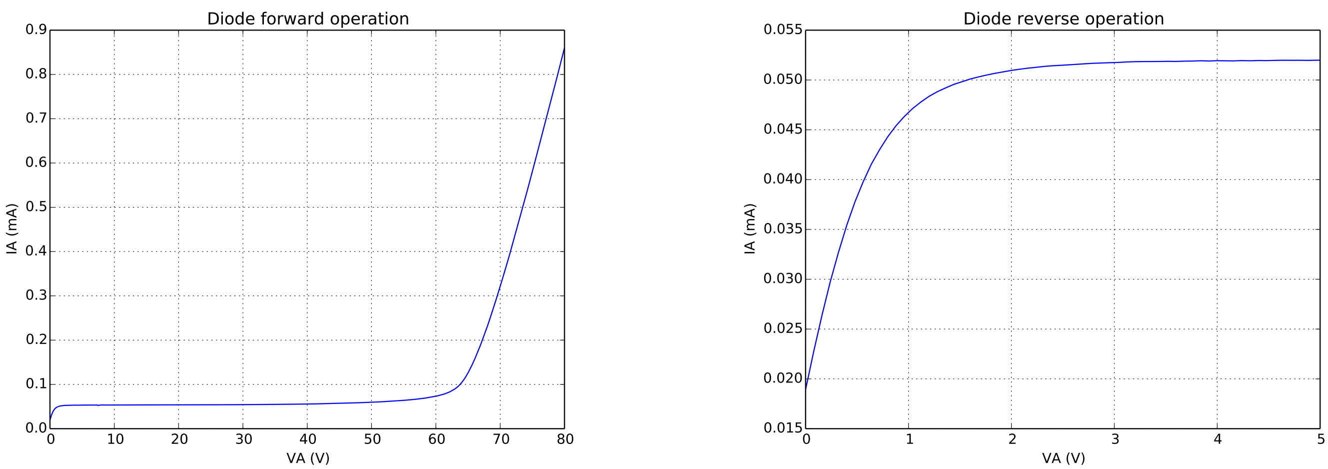


Figure 18: Plots of forward and reverse operation of Diode 7.

Looking at the plots above, the forward turn on voltage is $V_F \approx 70V$ while the reverse bias turn off voltage is about $V_{RB} \approx 0.5V$. To calculate the series resistance in the forward bias we look at the region of the curve where V is greater than 65 V. The inverse of the slope there results in $R = 17.8\,k\Omega$. Similarly for the reverse bias plot, looking at the region below 0.5 Volts, we find that the inverse of the slope is $R = -22.1\,k\Omega$.

1.9 MOSFETs of Varying Length, [8a-d]

1.9.1 Measurement setups

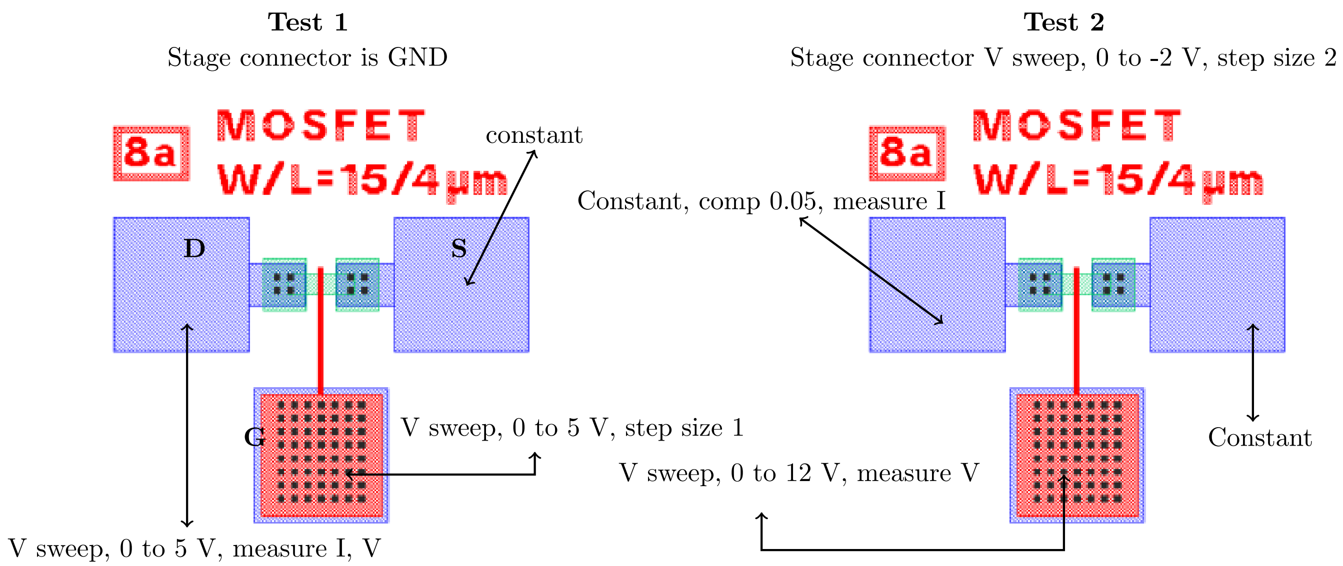


Figure 19: Measurement setup for Mosfet 8a. The same setup is used for Mosfets 8a-d. The only difference is the channel length which changes from 4 (8a) to 6 (8b) to 8 (8c) to 10 (8d) microns.

1.9.2 Plots of I_D-V_D, sweeping V_G

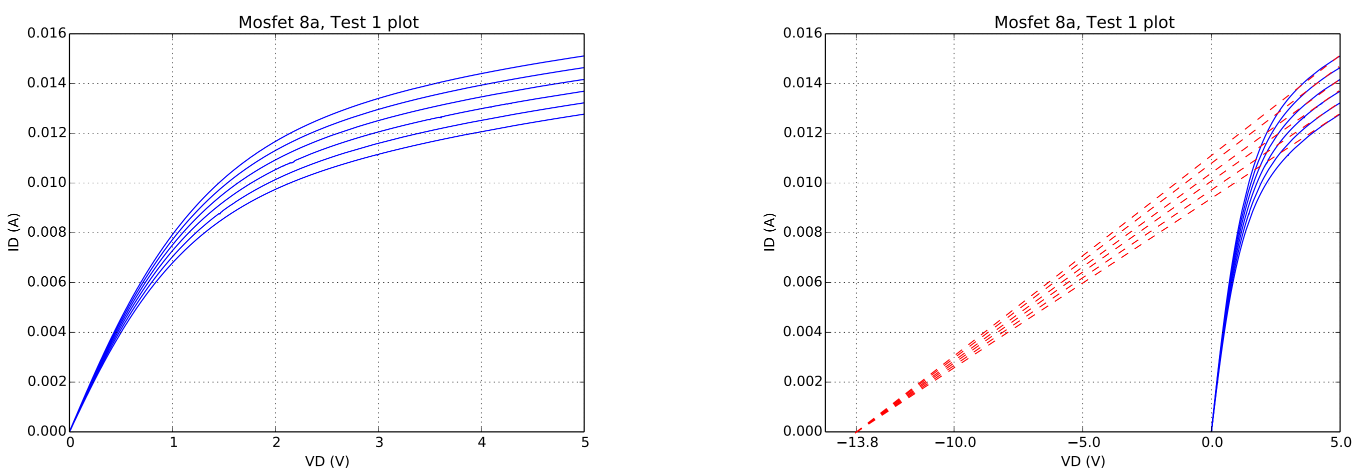


Figure 20: Test 1 for Mosfet 8a with extended x axis range in order to calculate lambda.

We see that everything intersects at about -13.8 V. This corresponds to $\lambda = \frac{1}{-13.8} = -0.0725$.

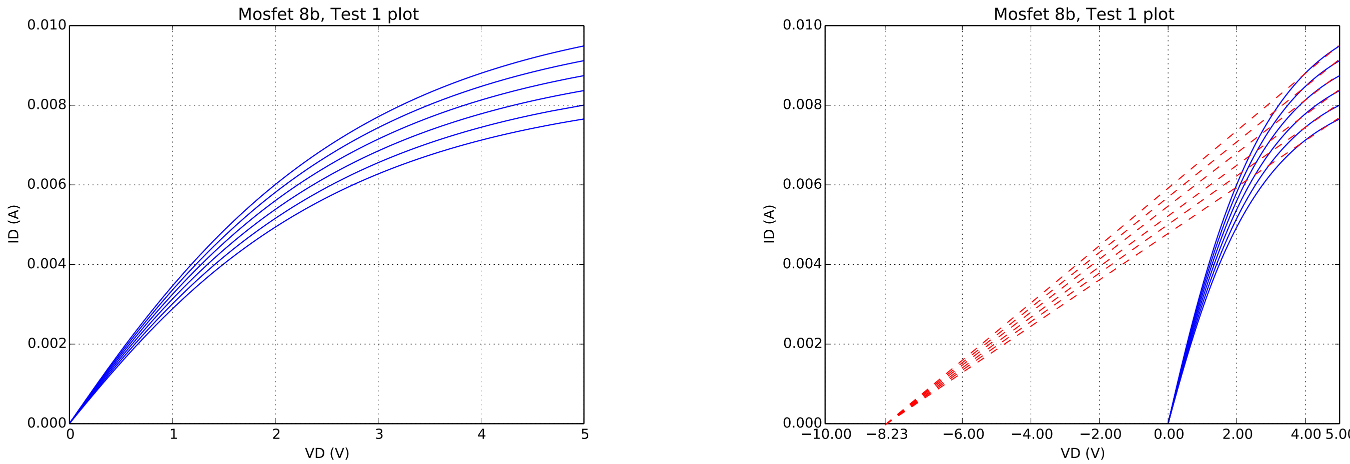


Figure 21: Test 1 for Mosfet 8b with extended x axis range in order to calculate lambda.

We see that everything intersects at about -8.23 V. This corresponds to $\lambda = \frac{1}{-8.23} = -0.122$.

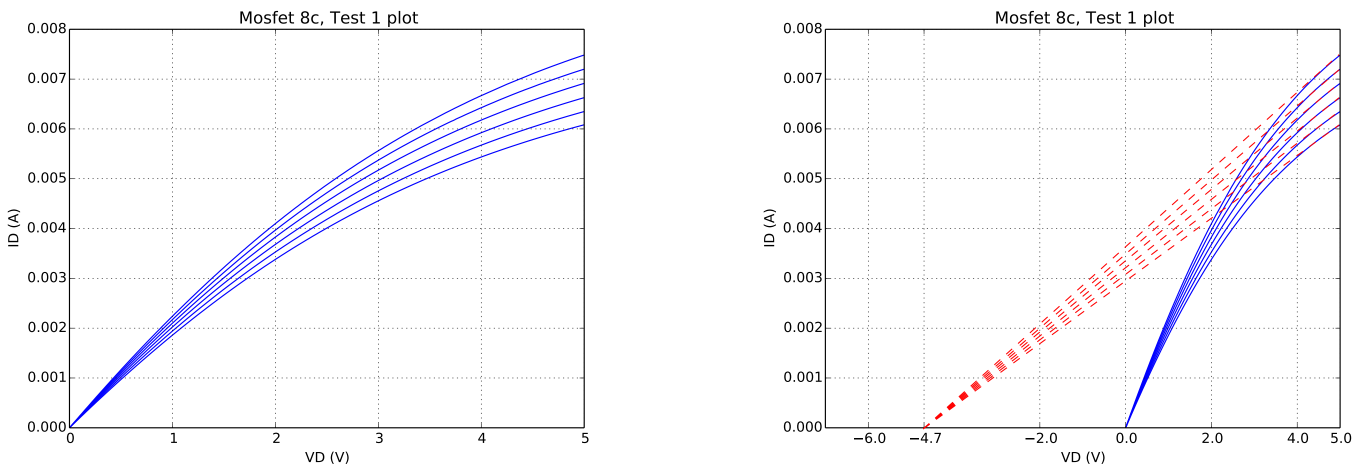


Figure 22: Test 1 for Mosfet 8c with extended x axis range in order to calculate lambda.

We see that everything intersects at about -4.70 V. This corresponds to $\lambda = \frac{1}{-4.70} = -0.213$.

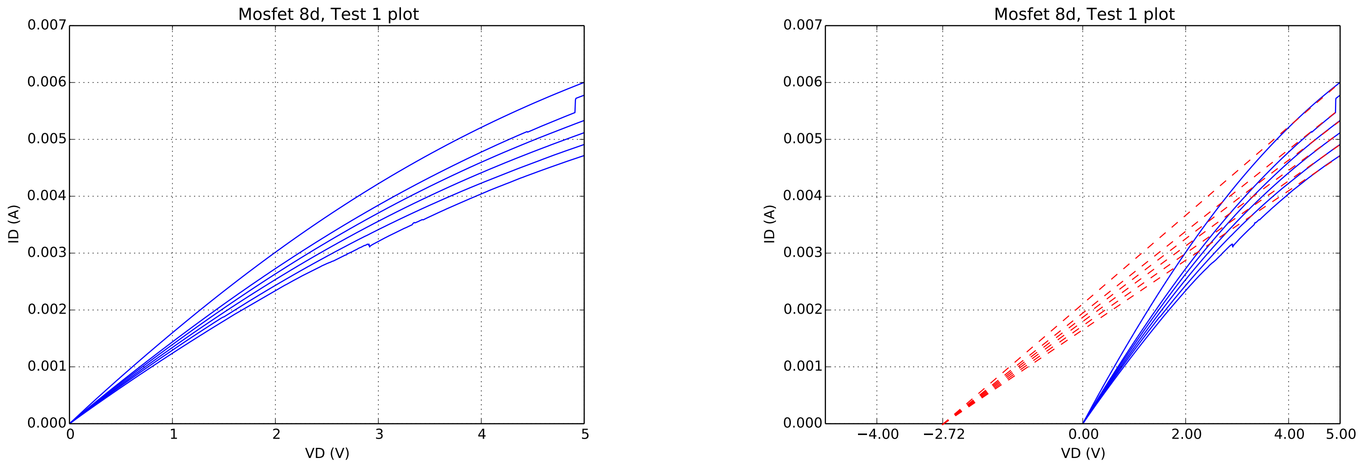


Figure 23: Test 1 for Mosfet 8d with extended x axis range in order to calculate lambda.

We see that everything intersects at about -2.72 V. This corresponds to $\lambda = \frac{1}{-2.72} = -0.368$.

1.9.3 λ vs $L_{\mathbf{Drawn}}$

To summarize, here is a table of all λ values calculated,

MOSFET device	λ (V^{-1})	L_{drawn} (μm)	Fig #
8a	-0.0725	4	20
8b	-0.122	6	21
8c	-0.213	8	22
8d	-0.368	10	23

Figure 24: all λ values for mosfets 9a-d along with gate lengths.

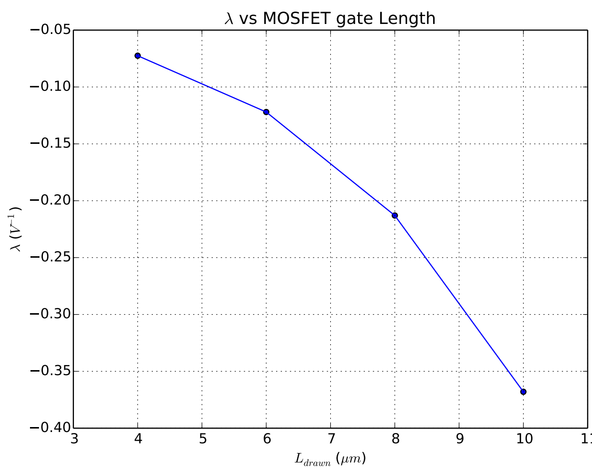


Figure 25: λ for each 8a-d device vs the gate length.

1.9.4 Plots of I_D-V_G, sweeping V_B

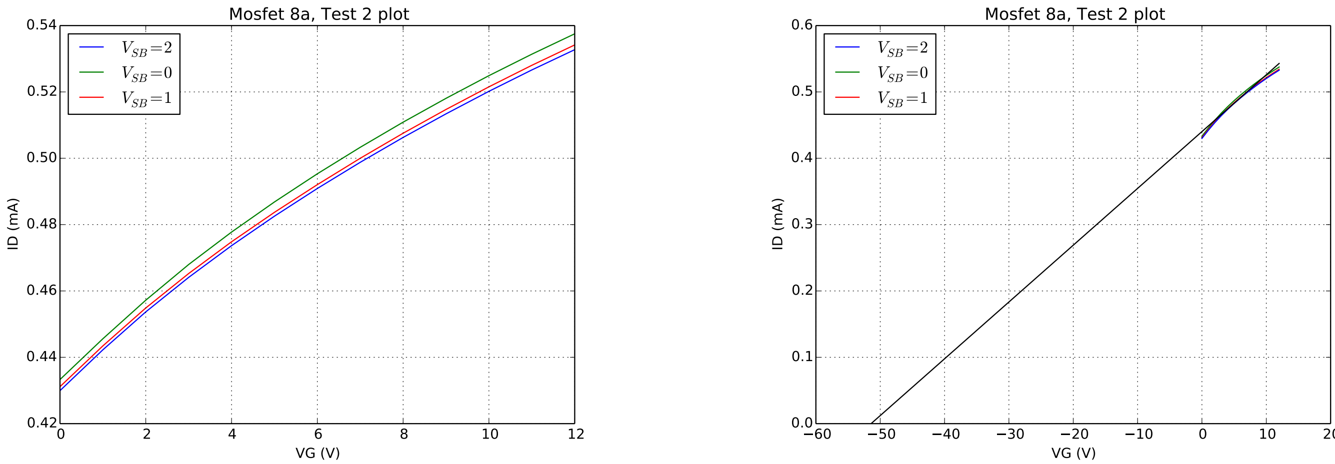


Figure 26: Test 2 for Mosfet 8a. On the right side we did a linear regression on the $V_{SB} = 0$ line in order to get a estimate of the threshold voltage.

Since it is quite difficult to see where a slope change occurs in order to find the threshold voltage, we can do a linear regression using the $V_{SB} = 0$ line. With linear regression, $V_t = -51.4V$. One reason why there is no slope change might have to do with the fact that most of our MOSFETS show characteristics of junction leakage.

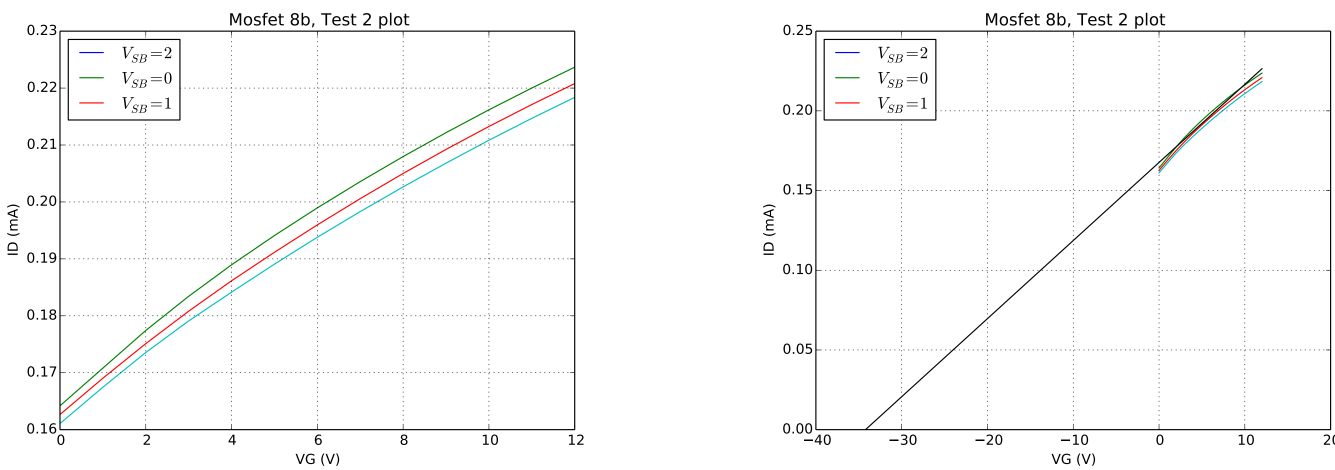


Figure 27: Test 2 for Mosfet 8b. On the right side we did a linear regression on the $V_{SB} = 0$ line in order to get a estimate of the threshold voltage.

Similarly, the threshold voltage is not clear in the figure above. Using linear regression again with $V_{SB} = 0$ we get $V_t = -34.2$.

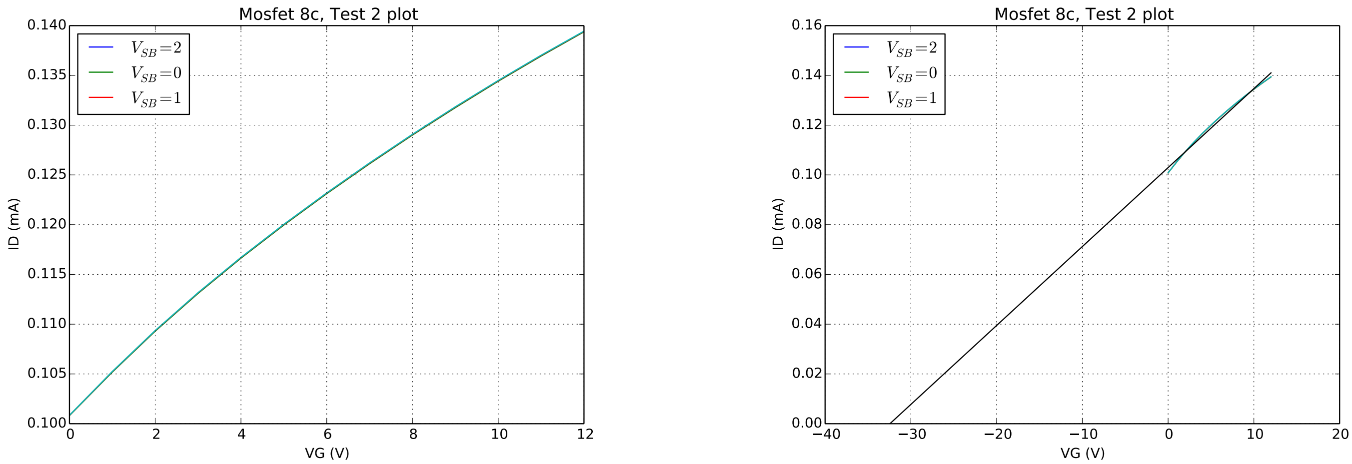


Figure 28: Test 2 for Mosfet 8c. On the right side we did a linear regression on the $V_{SB} = 0$ line in order to get a estimate of the threshold voltage.

Similarly, the threshold voltage is not clear in the figure above. Using linear regression again with $V_{SB} = 0$ we get $V_t = -32.4$.

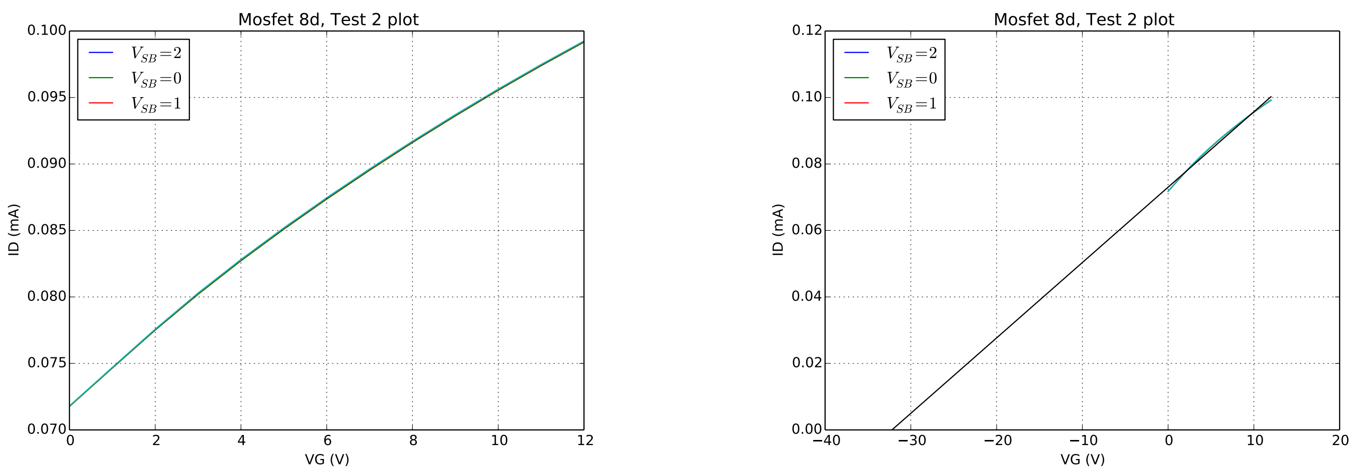


Figure 29: Test 2 for Mosfet 8d. On the right side we did a linear regression on the $V_{SB} = 0$ line in order to get a estimate of the threshold voltage.

Similarly, the threshold voltage is not clear in the figure above. Using linear regression again with $V_{SB} = 0$ we get $V_t = -32.2$.

1.9.5 Estimate of ΔL

To summarize the threshold voltages calculated in the last section,

MOSFET device	$V_t(V)$	L_{drawn} (μm)	Fig #
8a	-51.4	4	26
8b	-34.2	6	27
8c	-32.4	8	28
8d	-32.2	10	29

Figure 30: Threshold voltages for all MOSFET 8 devices.

Now the first step in calculating ΔL is to find the extended Resistance. We can do this by plotting the measured resistance vs gate Length at various voltages (from lecture). This plot looks like the following:

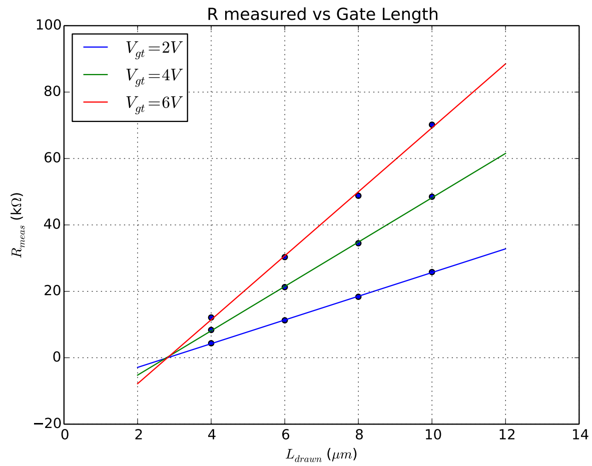


Figure 31: Measured Resistance vs Gate length for various lengths and voltages

The Y value from the origin (0) to the point of intersection would be the extended Resistance value. However in our case the lines intersect at just about 0; this means that $R_{\text{ext}} \approx 0$. Now we can solve for ΔL by using the following equation from lecture:

$$R_{\text{meas}} = \frac{L_{\text{drawn}} - \Delta L}{\mu W C_{\text{gox}}(V_{\text{gs}} - V_t)} + R_{\text{ext}} \tag{3}$$

Solving for ΔL and noting that from earlier that $C_{\text{gox}} = 1.95\text{pF}/\mu m^2$ and $\mu_n = 92.4\text{cm}^2/\text{V-s}$. We will also choose $V_{gs} - V_t = 2V$, $L_{\text{drawn}} = 4\mu m$, and $R_{\text{meas}} = 8.368k\Omega$. Note that W = 15 μm and $R_{ext} = 0$.

$$\Delta L = L_{\text{drawn}} - R_{\text{meas}}\mu_n C_{\text{gox}}(V_{\text{gs}} - V_t) = (8.368 \times 10^3\Omega)(92.4\text{cm}^2/\text{V-s})(15 \times 10^{-6}\text{m})(1.95 \times 10^{-7}\text{F/cm}^2)(2\text{V}) = 1.59\,\mu m$$

1.10 MOSFETs of varying width [9a-c]

1.10.1 Measurement setup

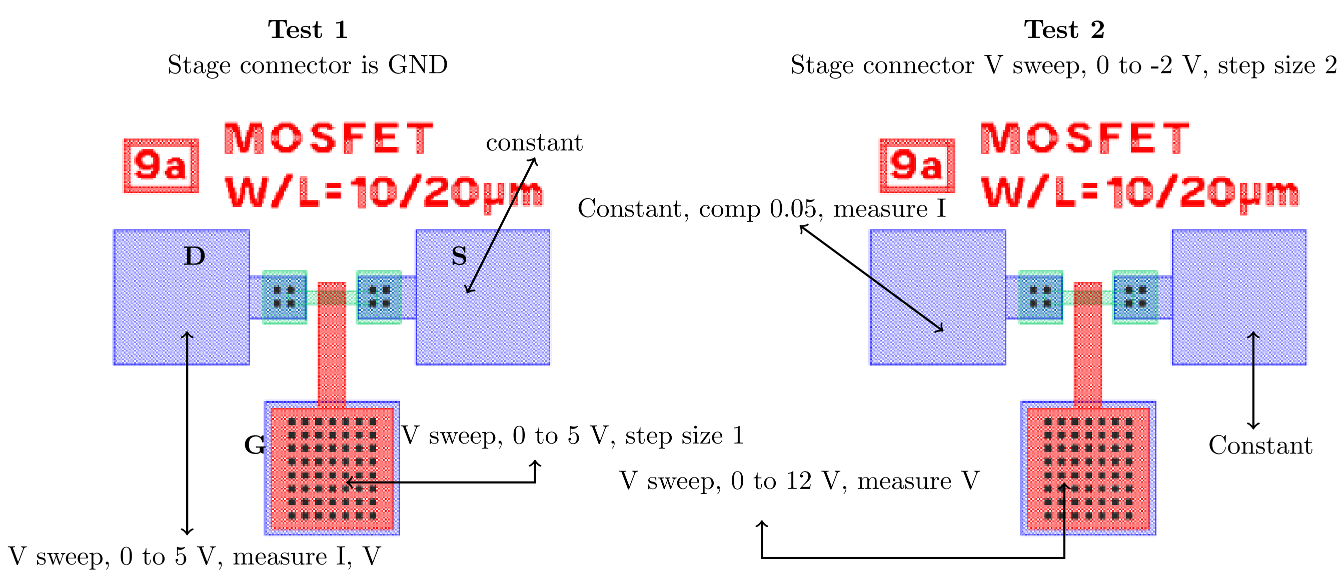


Figure 32: Measurement setup for Mosfet 9a. The same setup is used for Mosfets 9a-c. The only difference is the channel widths which changes from 10 (9a) to 15 (9b) to 20 (9c) microns.

1.10.2 Plots of I_D-V_D, sweeping V_G

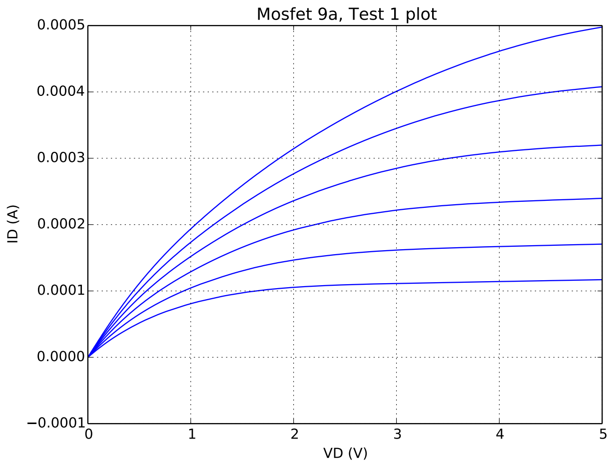


Figure 33: Test 1 for Mosfet 9a

Calculate stuff here...

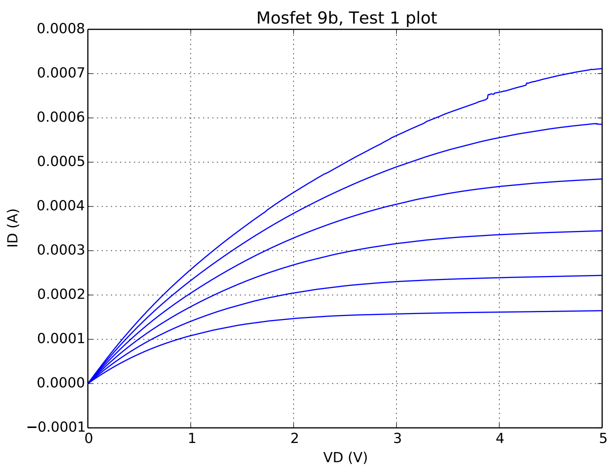


Figure 34: Test 1 for Mosfet 9b

Calculate stuff here...

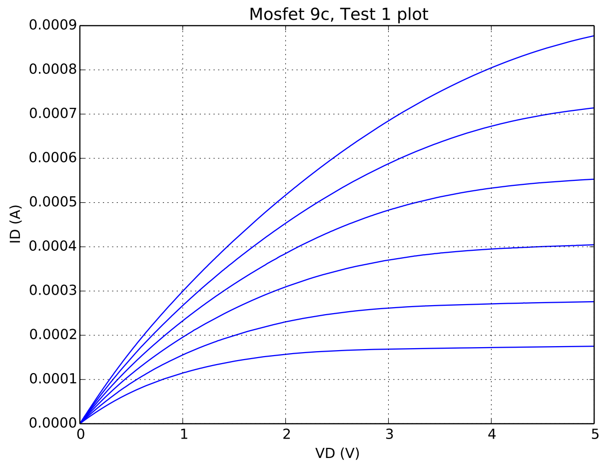


Figure 35: Test 1 for Mosfet 9c

Calculate stuff here...

1.10.3 Plots of I_D-V_G, sweeping V_B

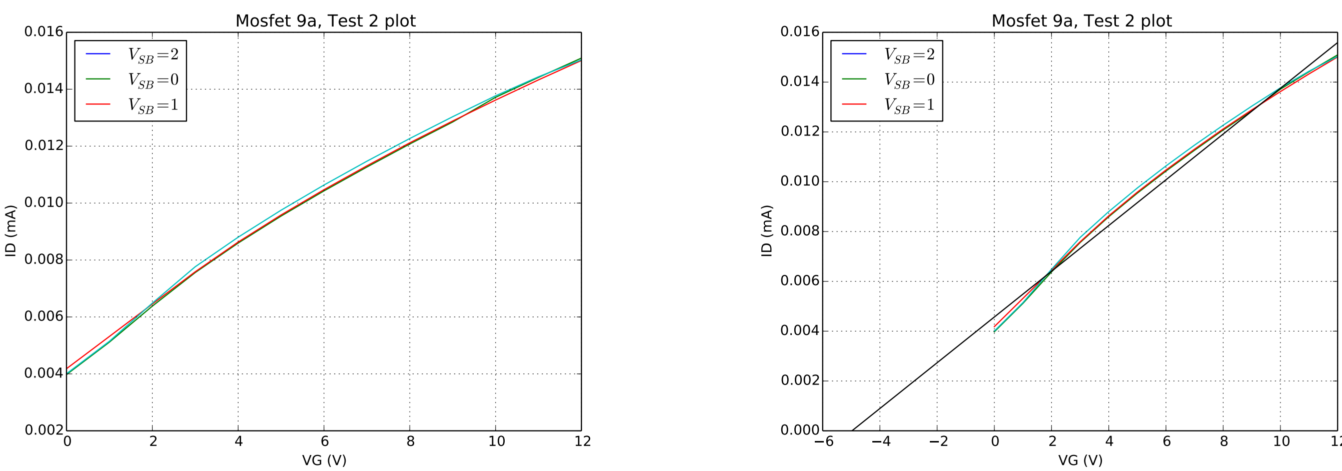


Figure 36: Test 2 for Mosfet 9a. On the right side we did a linear regression on the $V_{\mathrm{SB}} = 0$ line in order to get a estimate of the threshold voltage.

Using linear regression, we calculated a threshold voltage of $V_t = -4.98$.

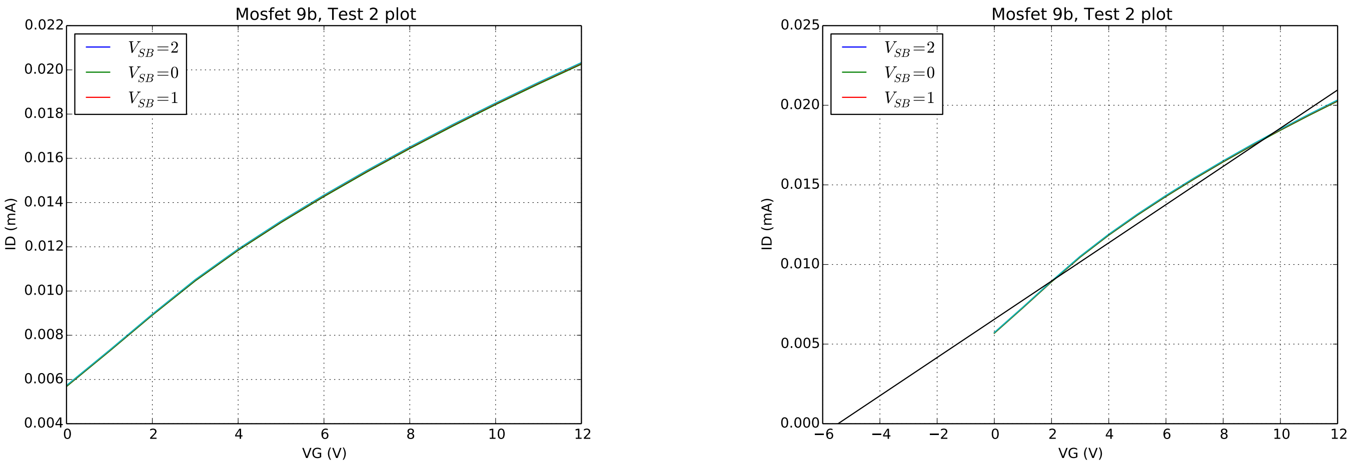


Figure 37: Test 2 for Mosfet 9b. On the right side we did a linear regression on the $V_{\mathrm{SB}} = 0$ line in order to get a estimate of the threshold voltage.

Using linear regression, we calculated a threshold voltage of $V_t = -5.46$.

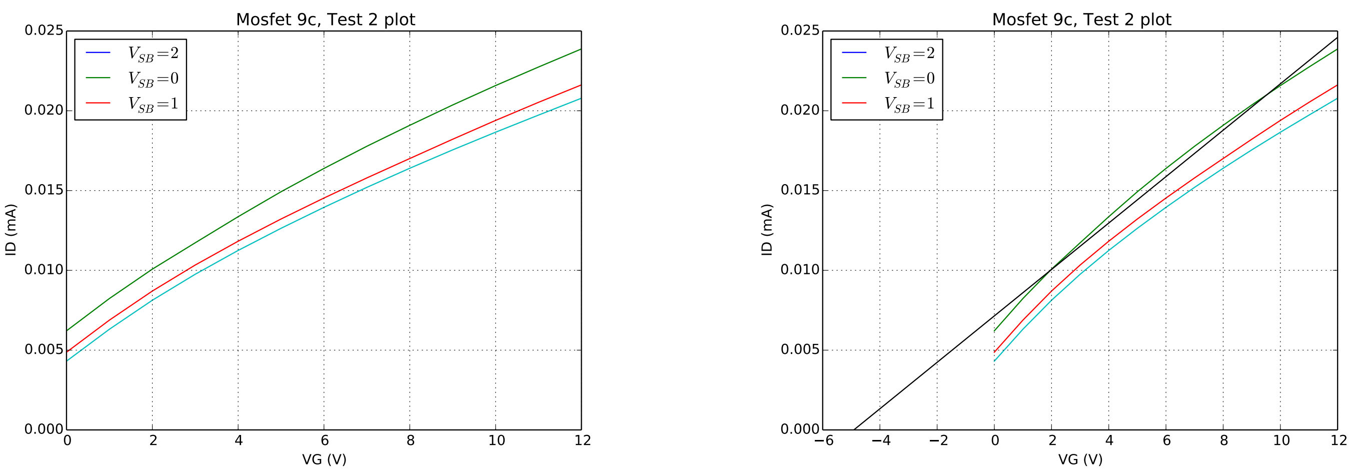


Figure 38: Test 2 for Mosfet 9c. On the right side we did a linear regression on the $V_{\mathrm{SB}} = 0$ line in order to get a estimate of the threshold voltage.

Using linear regression, we calculated a threshold voltage of $V_t = -4.91$.

1.10.4 W calculation and plot

To summarize the threshold voltages calculated in the last section,

MOSFET device	$V_t(V)$	W_{drawn} (μm)	Fig #
9a	-4.98	10	36
9b	-5.46	15	37
9c	-4.91	20	38

Figure 39: Threshold voltages for all MOSFET 8 devices.

Now to calculate the channel width we first plot the reciprocal of the measured resistance vs channel width (from lecture).

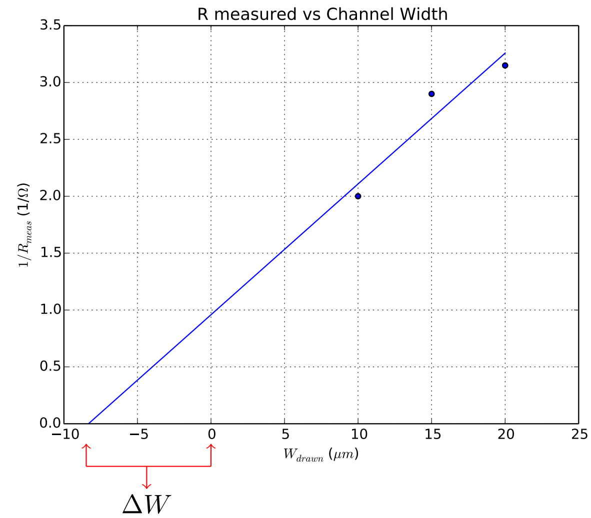


Figure 40: 1/R vs the channel Width. A linear regression was used to fit the data points. Note that it intersects zero at a negative length.

The line above intercepts the x axis at -8.33 μ. Hense our $\Delta W = -8.33\mu m$. Now to plot the threshold voltage vs the efffective channel width we can use Figure 39. Note that $W_{\text{eff}} = W_{\text{drawn}} - \Delta W$.

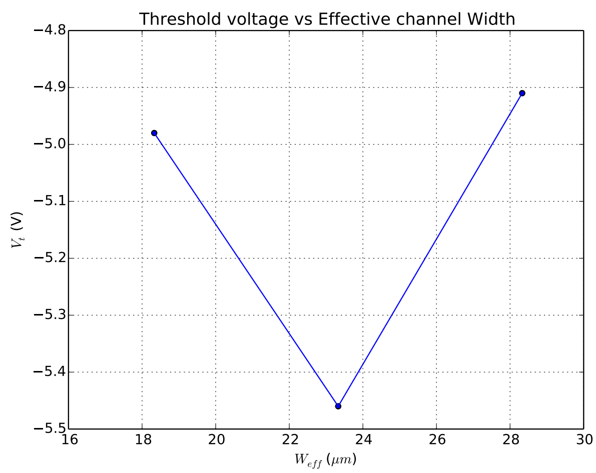


Figure 41: Channel threshold voltage vs the channel width. Note the odd V shape which appears because of the calculated threshold voltages.

1.11 Large MOSFET, 10

1.11.1 Measurement setup

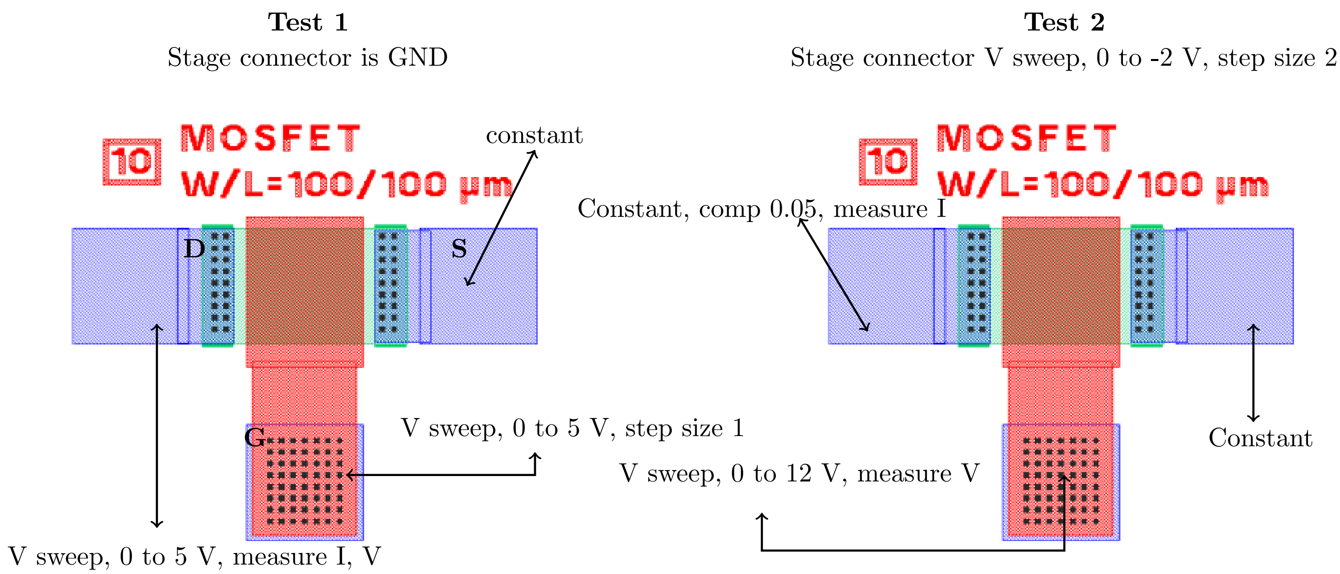


Figure 42: Measurement setup for Mosfet 10. This mosfet has very large dimensions compared to others.

1.11.2 Plots of I_D-V_D, sweeping V_G

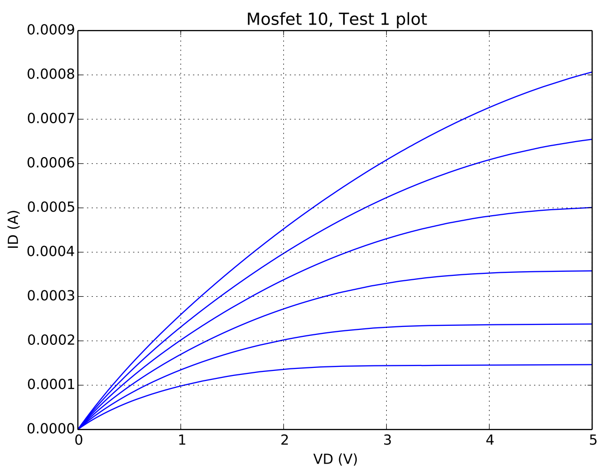


Figure 43: Test 1 for Mosfet 10

1.11.3 Plots of I_D-V_G, sweeping V_B

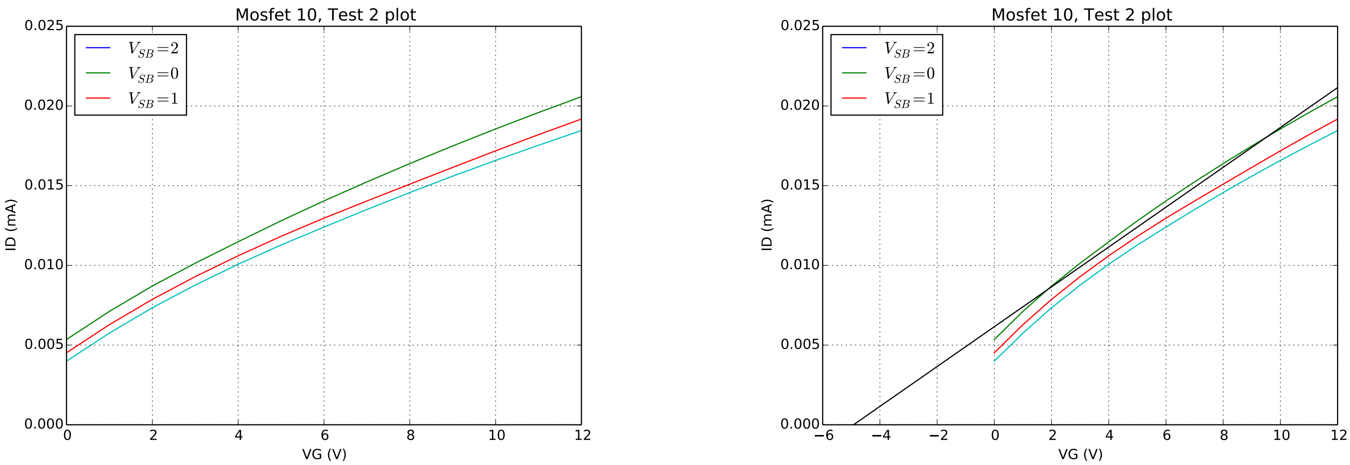


Figure 44: Test 2 for Mosfet 10. On the right side we did a linear regression on the $V_{\text{SB}} = 0$ line in order to get a estimate of the threshold voltage.

The threshold voltage here is $V_t = -4.92V$.

1.11.4 Calculating mobility, threshold, and other parameters

To calculate the effective electron mobility we will use the following equation,

$$\mu_{\text{eff}}(V_G) = \frac{I_D}{\frac{W_{\text{eff}}}{L_{\text{eff}}} C_{\text{gox}}(V_{GS} - V_t)V_{DS}} \tag{4}$$

Note that I_D depends on V_G from the previous plot. For ΔW and ΔL we will use values calculated earlier (-8.33 and 1.59 μm). MOSFET 10 has a W and L value of 100 μm. Threshold voltage was calculated as $V_t = -4.92V$ and $V_{DS} = 0.05V$. C_{gox} was also calculated earlier as 1.95pF/μm^2.

$$\mu_{\text{eff}}(V_G) = \frac{I_D}{\frac{W_{\text{eff}}}{L_{\text{eff}}} C_{\text{gox}}(V_{GS} - V_t)V_{DS}} = \frac{I_D(V_G)}{\frac{(100+8.33)\times 10^{-6}}{(100-1.59)\times 10^{-6}}(1.95 \times 10^{-15})(V_{GS} + 4.92)(0.05)} = \frac{I_D(V_G)}{1.07 \times 10^{-8}(V_{GS} + 4.92)} \text{cm}^2/\text{V-s}$$

Now we plot $\mu_{\text{eff}}(V_G)$ vs V_G using the values for $I_D(V_G)$ from the previous graph (Figure 44).

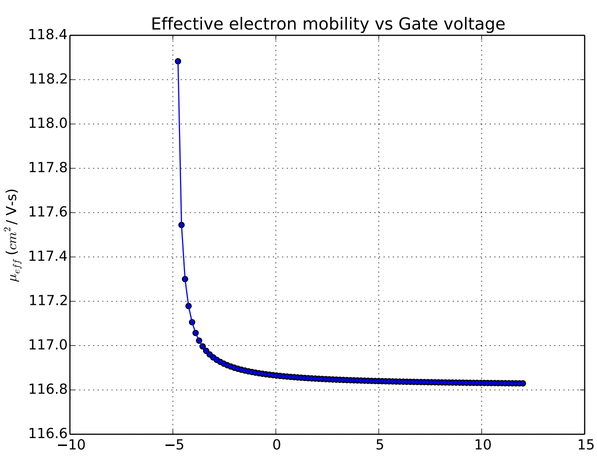


Figure 45: Note how the graph levels off almost immediately. The first few data points are right above the threshold voltage.

Now if we do a linear fit to each line in Figure 44 we get the following results,

V_{SB} (V)	V_t (V)
0	-4.92
1	-4.55
2	-4.18

Figure 46: Results from doing a linear fit to each line in Figure 44 above.

With this data we can now make a $V_t(V_{SB})$ vs $\sqrt{V_{SB}+0.7}$ plot in order to estimate our body effect parameter γ.

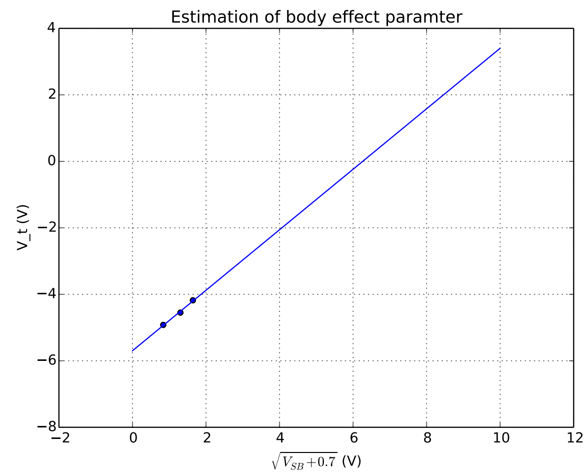


Figure 47: The slope of the above plot is our body effect parameter

Since we only have 3 data points for V_{SB} our plot is not very accurate and does not show the change of slope as would be present in the theoretical case. Nonetheless, the slope for the above plot is$\gamma = 0.910$. The equation for γ, the body effect parameter, is:

$$\gamma = \frac{\sqrt{2\epsilon_{\text{si}} q N_A}}{C_{\text{gox}}} = \tag{5}$$

Solving for the surface concentration and using previous values of $C_{\text{gox}} = 0.195\mu\text{F}/\text{cm}^2$.

$$N_A = \frac{(\gamma C_{\text{gox}})^2}{2q\epsilon_{\text{si}}} = \frac{(0.910 * 0.195 \times 10^{-6})^2}{2(1.602 \times 10^{-19})(11.7 \times 8.85 \times 10^{-12})} = 9.49 \times 10^{14}\text{cm}^{-3}$$

Finally, we plot a log plot of the data in Figure 44.

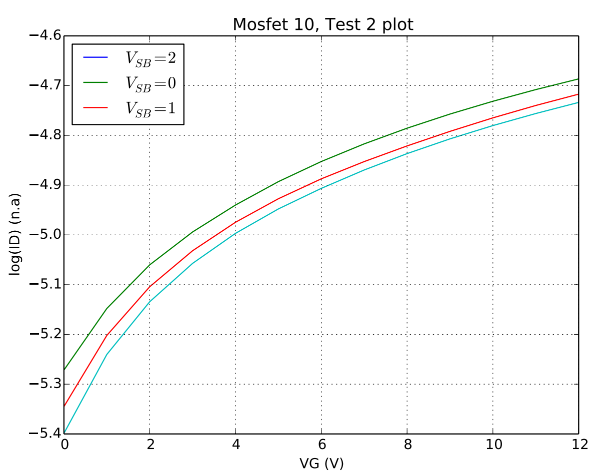


Figure 48: Log plot of Figure 44.

The subthreshold slope was calculate between $V_G = 0$ and $V_G = 1$. This slope was calculated to be 0.12 (V^{-1}).

1.12 Inverter, 14

1.12.1 Measurement setup

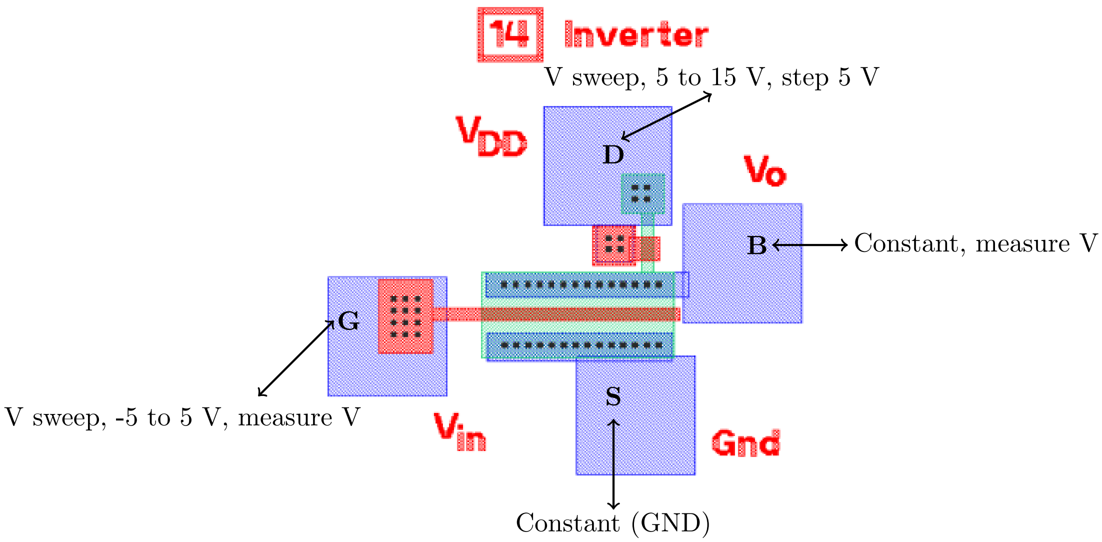


Figure 49: Setup for the inverter. Note that the source is connected to a GND and not the stage connector.

1.12.2 b. $V_{\text{in}} - V_{\text{out}}$ plot

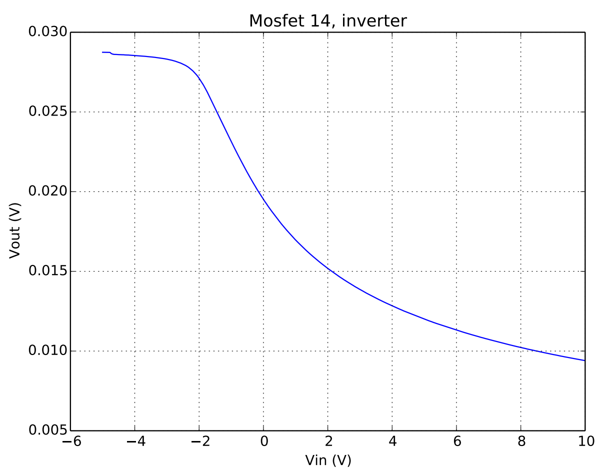


Figure 50: Plot for Inverter. Note both axis are in units of Volts.

To find the point where $V_{IN} = V_{OUT}$ we ran a simple loop to find the closest point. We calculated $V_M = 0.025V$. At that voltage $|V_{OUT} - V_{IN}|$ is minimized.

2 Theoretical Calculations

2.1 Measured Physical Dimensions and Parameters

Parameter	Measured Value
Field t_{ox}	477.2 nm
Gate t_{ox}	86.5 nm
Intermediate t_{ox}	320 nm
X_j	1000 nm
$X_{j,\text{lateral}}$	880 nm
N_D	10^{21} cm^{-3}

2.2 Resistors [2a,2b]

2.3 Contact Resistances [17a,17b]

From jaeger Figure 7.6 [1] we that the specific contact resistivity 10^{-2} $\mu\Omega$-cm^2. The contact area of resistors 17a and 17b is $5\mu m$ by $5\mu m$. This means the theoretical contact reisistance for our contact resistors is

$$R_c = \frac{\rho_c}{A} = \frac{10^{-2}\mu\Omega - \text{cm}^2}{25\mu m} = \frac{10}{25} = 0.4\Omega$$

2.4 Contact-Chain Resistors [2c, 2d]

2.4.1 Diffusion chain resistor, 2c

R_c is the contact resistance calculated earlier and R_s is the sheet resistance calculate for the diffused resistor. η is a geometrical constant that has a value of 2.3

$$R_{\text{total}} = 7(\eta R_s + R_c) = 7((2.3)(R_s) + (0.4)) =?$$

2.4.2 Poly chain resistor, 2d

R_c is the contact resistance calculated earlier and R_s is the sheet resistance calculate for the poly resistor. η is a geometrical constant that has a value of 2.3

$$R_{\text{total}} = 7(\eta R_s + R_c) = 7((2.3)(R_s) + (0.4)) =?$$

2.5 Gate/Field Oxide Capacitors[3,4]

2.6 Diode

We make the assumption that the junction is a step junction and that the concentrations of dopants are constant across respective regions of the device. Built-in potential for a p-n diode is given by the function:

$$\phi = \frac{kT}{q} \ln \frac{N_A N_d}{{n_i}^2} \tag{6}$$

Where T is room temperature, N_A is the p-sub dopant concentration ($8{\times}10^{14}$cm^{-3}), N_d is the n+ dopant concentration (10^{21}cm^{-3}), and n_i is the instrinsic carrier concentration for silicon (10^{10}).

$$\phi = \frac{kT}{q} \ln \frac{N_A N_d}{{n_i}^2} = \frac{1.38 \times 10^{-23}(298)}{1.602 \times 10^{-19}} \ln \frac{(8 \times 10^{14})(10^{21})}{10^{20}} = 0.92V$$

2.7 MOSFETs

2.7.1 MOSFETs of varying length [8] and width [9]

2.7.2 Large MOSFET

2.8 Inverter

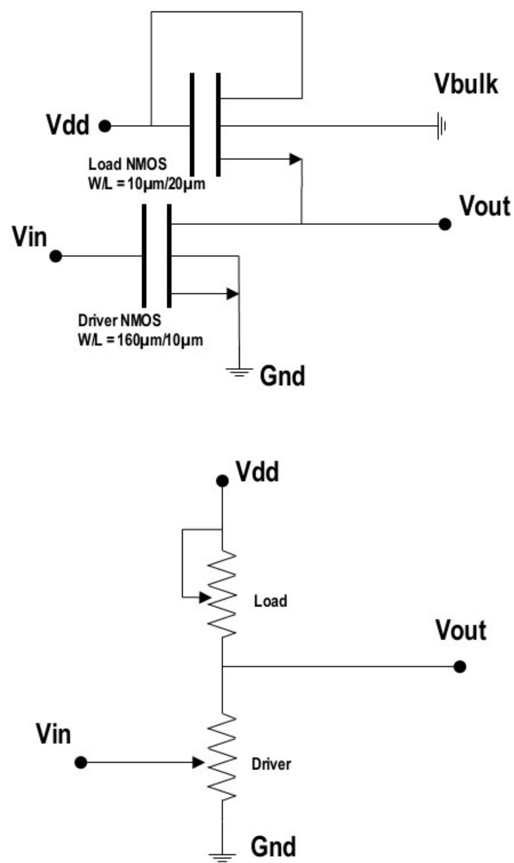


Figure 51: Setup for inverters.

The load resistor has Vdd connected to the drain and the gate. Since

$$V_{DS} = V_{dd} - Vout$$
$$V_{GS} = V_{dd} - V_{out}$$

Then

$$V_{DS} = V_{dd} - V_{out} >= V_{dd} - V_{out} - V_{tnl} = V_{GS} - V_{tnl}$$

So the load transistor is always in the saturation region, regardless of Vdd. It therefore acts as a variable resistor dependent on Vdd. The threshold voltage for both NMOS transistors is:

$$V_{TN} = V_{FB} + 2|\Phi_F| + (1/C_0)\sqrt{2\epsilon_s q N_B(2|\Phi_F| + V_{sb})}$$

They differ in V_{sb} so

$$V_{tnl} = V_{TN0} + (1/C_0)\sqrt{2\epsilon_s q N_B}(\sqrt{2|\Phi_F| + V_{out}} - \sqrt{2|\Phi_F|})$$
$$V_{tnd} = V_{TN0}$$
$$\text{Where } V_{TN0} = V_{TND} = 0.03$$

Since V_{tnl} is dependent on V_{out} and vice versa, V_{out} can only be determined by iteration. For the purposes of graphing, we will make the simplfying assumption that the effect of substrate bias is small, and thus that V_{tnl} can be estimated to be V_{TN0}. This is not the case in reality, but should serve the purpose of illustrating the expected curves.
For the drive transistor: In the cutoff region ($V_{in} < V_{tnd}$), no current flows through the driver transistor, therefore the drain currents are zero for both transistors.

$$I_{Dl} = K_L(V_{dd} - V_{out} - V_{tnl})^2 = 0$$

Therefore $V_{out} = V_{dd} - V_{tnl}$. In the saturated region ($V_{out} > V_{in} - V_{tnd} > 0$), both transistors are saturated. Their drain currents must be equal.

$$I_{dl} = K_L(V_{dd} - V_{out} - V_{tnl})^2 = K_D(V_{in} - V_{tnd})^2 = I_{Dd}$$
$$V_{out} = V_{dd} - V_{tnl} - \sqrt{K_D/K_L}(V_{in} - V_{tnd})$$

In the linear region ($V_{in} - V_{tnd} > V_{out} > 0$), the driver transistor is in the linear region and the load transistor is in the saturated region. Since their drain currents must again be equal:

$$I_{dl} = K_L(V_{dd} - V_{out} - V_{tnl})^2 = 2K_D(V_{in} - V_{tnd} - 0.5V_{out})V_{out} = I_{Dd}$$

Here the dependence of Vin on Vout is becomes non-linear.

$$V_{in} = \frac{(K_L/K_D)(V_{dd} - V_{out} - V_{tnl})^2 + V_{out}^2 + V_{tnd}V_{out}}{2V_{out}}$$

Also note that for our transistor, the aspect ratio should be

$$\frac{K_D}{K_L} = \frac{W_D L_L}{L_D W_L} = \frac{160 * 20}{10 * 10} = 16$$

For V_{tnl} and V_{tnd} we will use a value of 0.3 as mentioned above. V_{dd} will range from 0 to 5 volts.

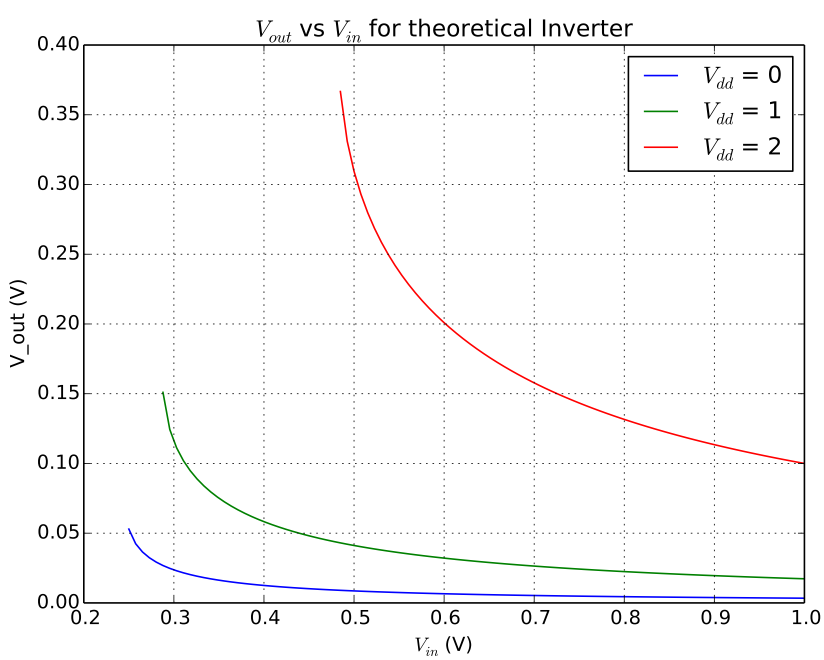


Figure 52: Theoretical inverter plot.

3 Discussion

4 Optional Questions

5 Appendix

6 References

1. Jaeger, Richard. *Introduction to microelectronic fabrication.* New Jersey: Prentice Hall, 2002. Print.