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

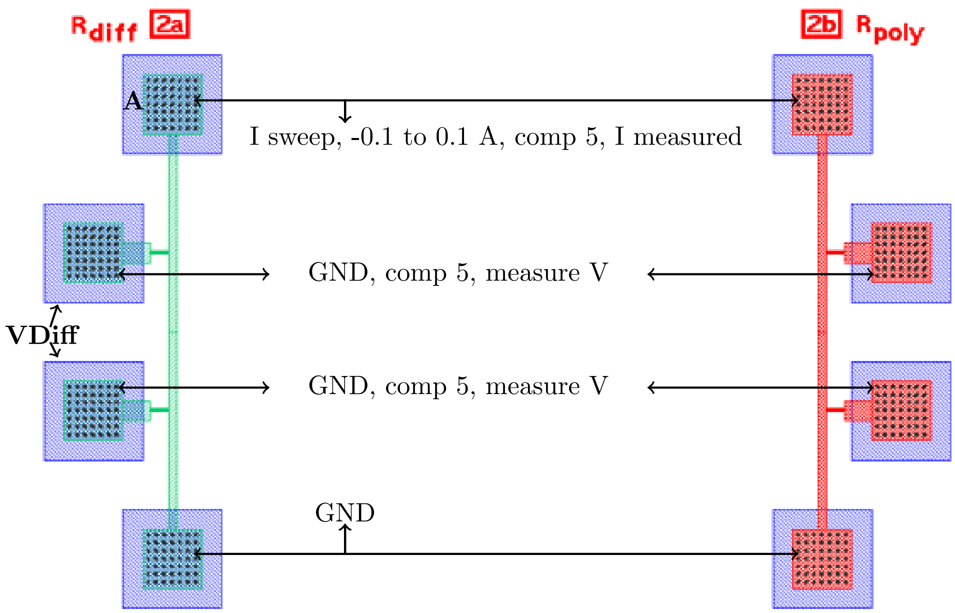


Figure 1: Device 2a is a diffusion resistor and 2b is a poly resistor.

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

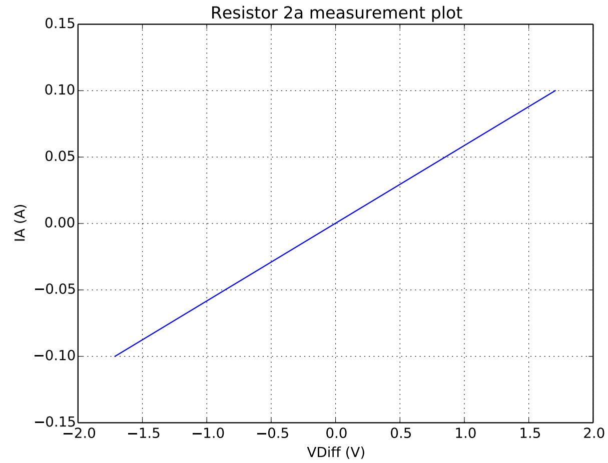


Figure 2: A plot of the measurement data taken for resistor 2a. The plot is based off of 2 data points.

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 was 2.520 μm which means that we had a underetch of about 26%. This means that

$$R_s = \frac{W}{L}R_{\text{diff}} = \frac{10(1.26)}{200}17 = 1.07\,\Omega$$

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

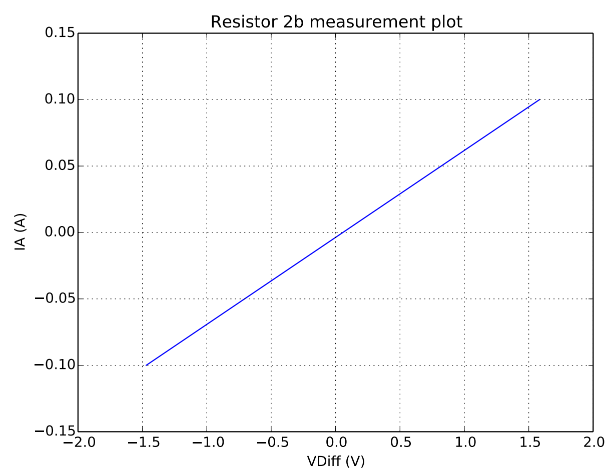


Figure 3: A plot of the measurement data taken for resistor 2b. The plot is based off of 2 data points.

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

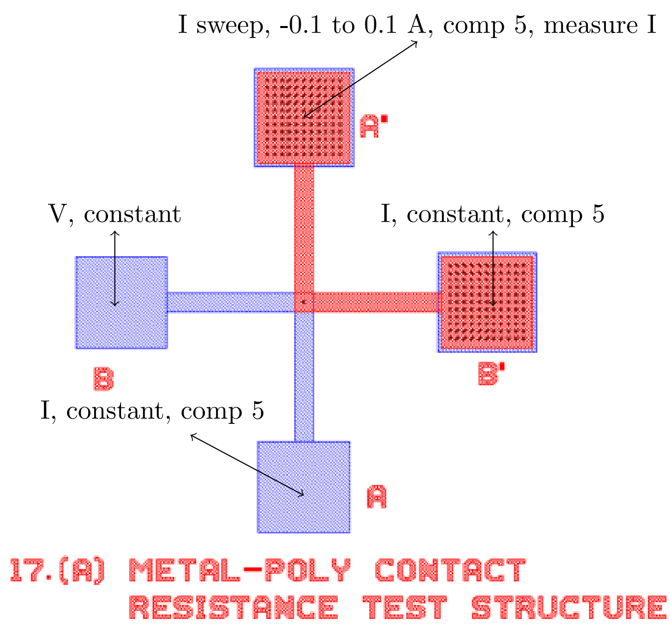


Figure 4: Measurement setup for 17a poly contact resistor. The same setup is used for the diffusion contact resistor, 17b.

1.3.2 I-V plot for 17a, poly reisistor

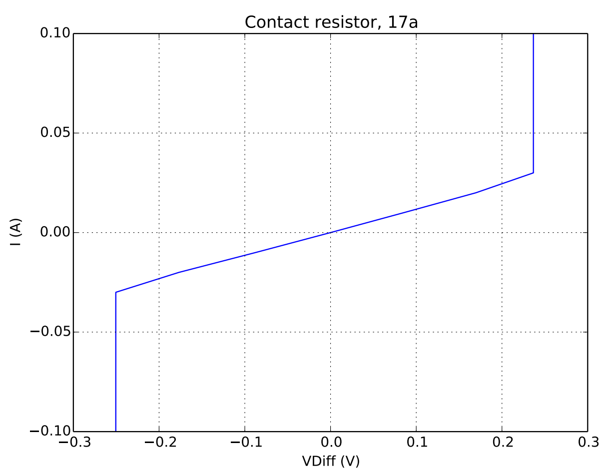


Figure 5: A plot of the measurement data taken for resistor 17a.

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

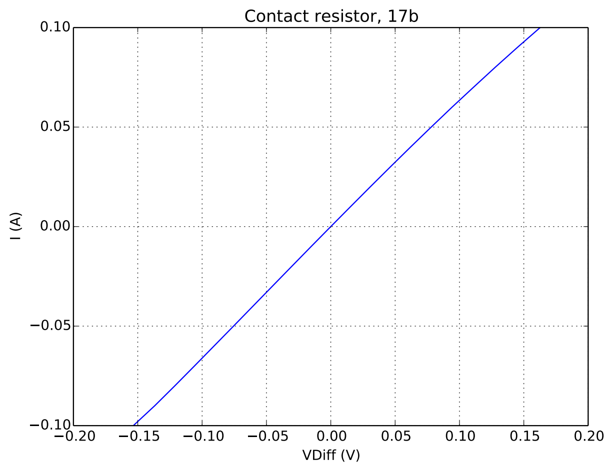


Figure 6: A plot of the measurement data taken for resistor 17b.

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

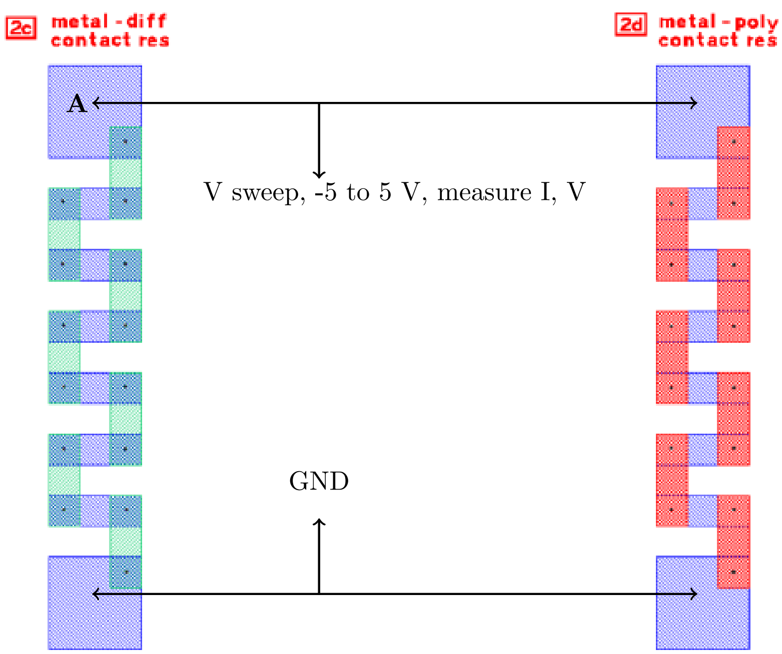


Figure 7: Chain resistor setup for diffusion and poly resistors.

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

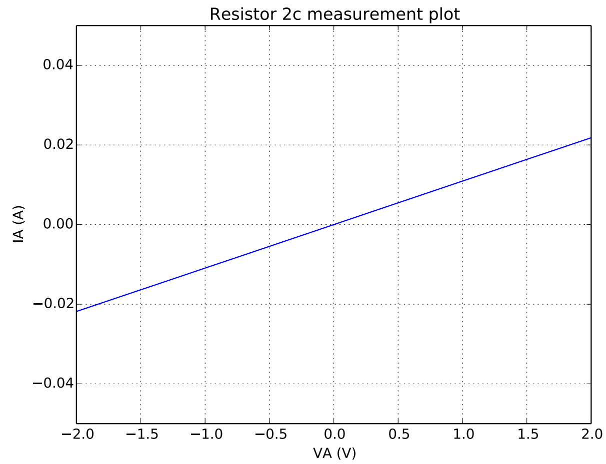


Figure 8: A plot of the measurement data taken for resistor 2c. The plot is based off of 2 data points.

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

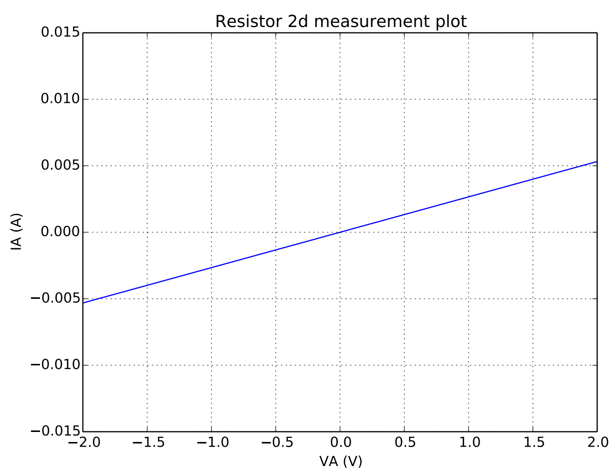


Figure 9: A plot of the measurement data taken for resistor 2d. The plot is based off of 2 data points.

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

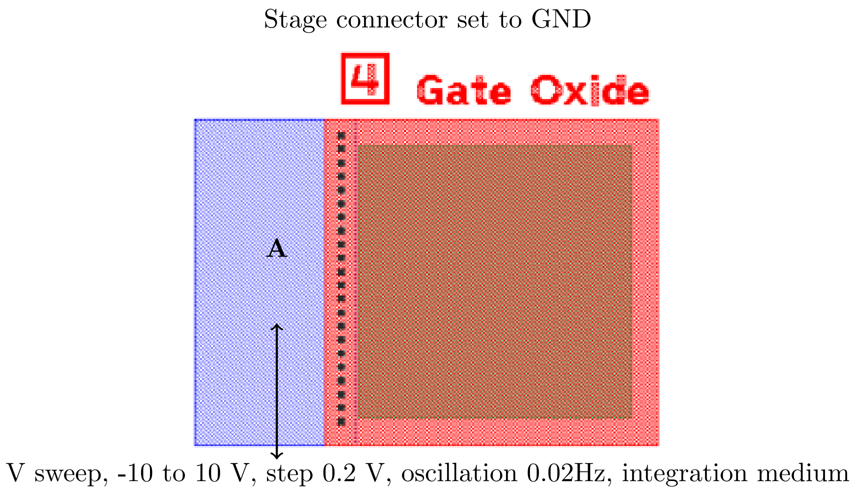


Figure 10: Gate capacitor setup.

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

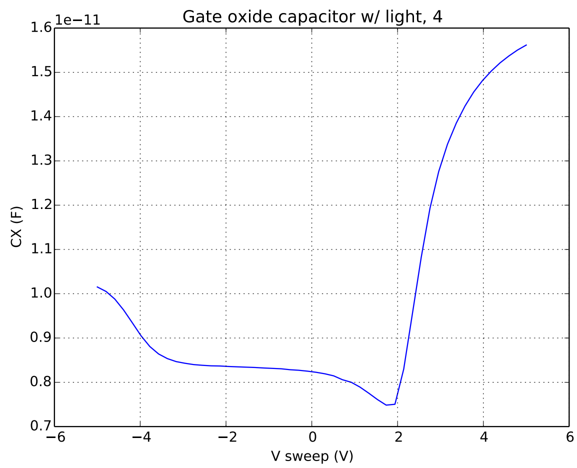


Figure 11: A plot of the measurement data taken for the gate capacitor, 4. Lights on.

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 / ($240\mu m \times 335\mu m$). C/area = 1.95 pF/μm. 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.

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

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,

$$Q_{BO} = \sqrt{2q\epsilon_{si}N_B2\phi_F} = \sqrt{2(1.602 \times 10^{-19})(11.7 \times 8.85 \times 10^{-12})(1.14 \times 10^{21})(2 \times 0.3)} = 1.51 \times 10^{-4}\,C/\text{m}^2$$

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

$$V_t = \phi_{ms} - 2\phi_f - \frac{Q_{ss}}{C_{\text{max}}} - \frac{Q_{BO}}{C_{\text{max}}} = 0 - 0.6 - \frac{2.06 \times 10^{-3}}{15.7 \times 10^{-15}} - \frac{1.51 \times 10^{-4}}{15.7 \times 10^{-15}} = -1.41 \times 10^{11}V$$

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

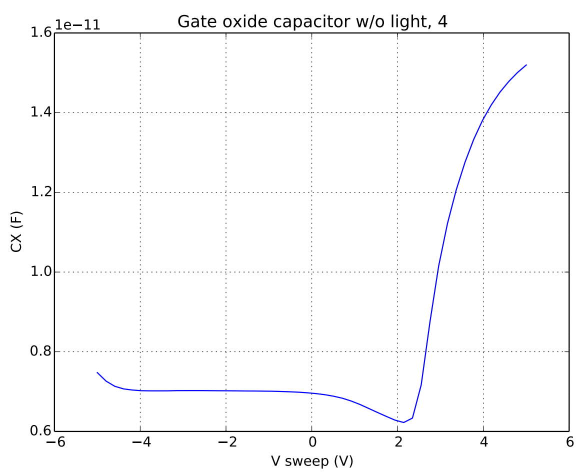


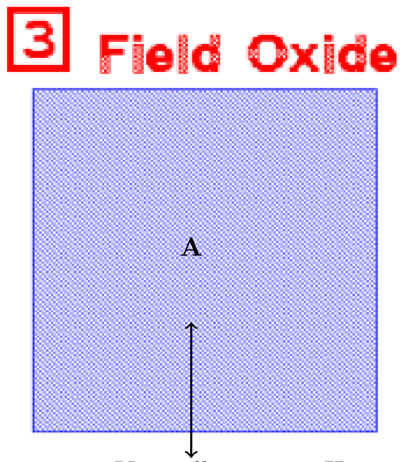
Figure 12: A plot of the measurement data taken for the gate capacitor, 4. Lights off.

minimum capacitance ...

1.6 Field Oxide Capacitor, 3

1.6.1 Measurement Setup

Stage connector set to GND



V sweep, -5 to 5 V, step 0.2 V, oscillation 0.02Hz, integration medium

Figure 13: Field oxide capacitor setup.

1.6.2 C-V plot of field oxide capacitor

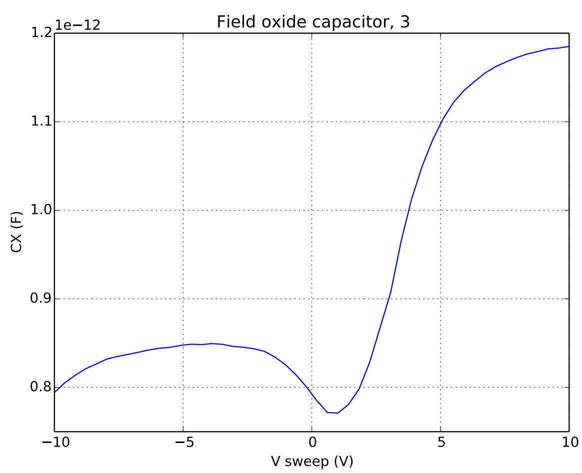


Figure 14: A plot of the measurement data taken for the field oxide capacitor, 3

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

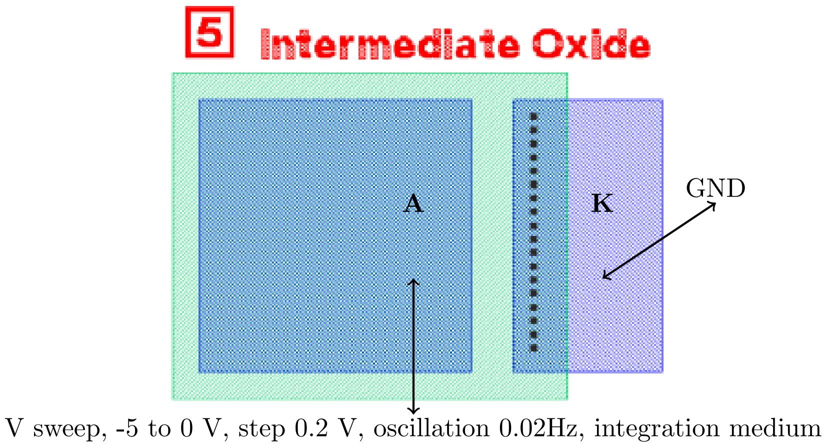


Figure 15: Intermediate oxide capacitor setup.

1.7.2 C-V plot of intermediate oxide capacitor

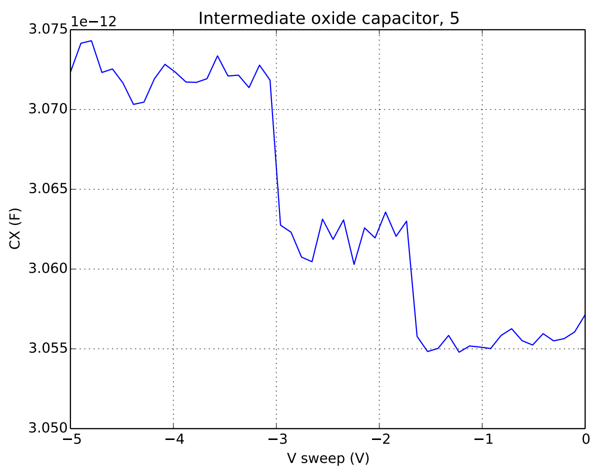


Figure 16: A plot of the measurement data taken for the Intermediate oxide, 5

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

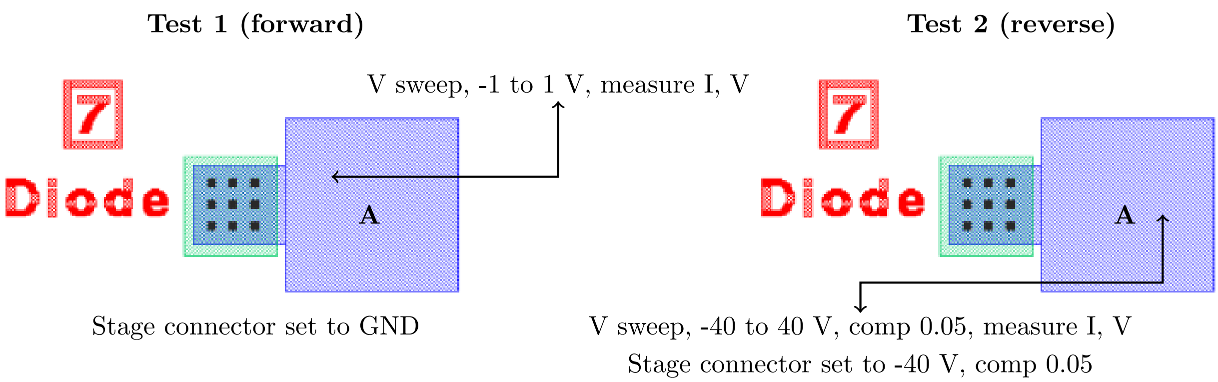


Figure 17: Two tests were performed on this diode; both measurement setups are shown above.

1.8.2 I-V plots for forward and reverse operation

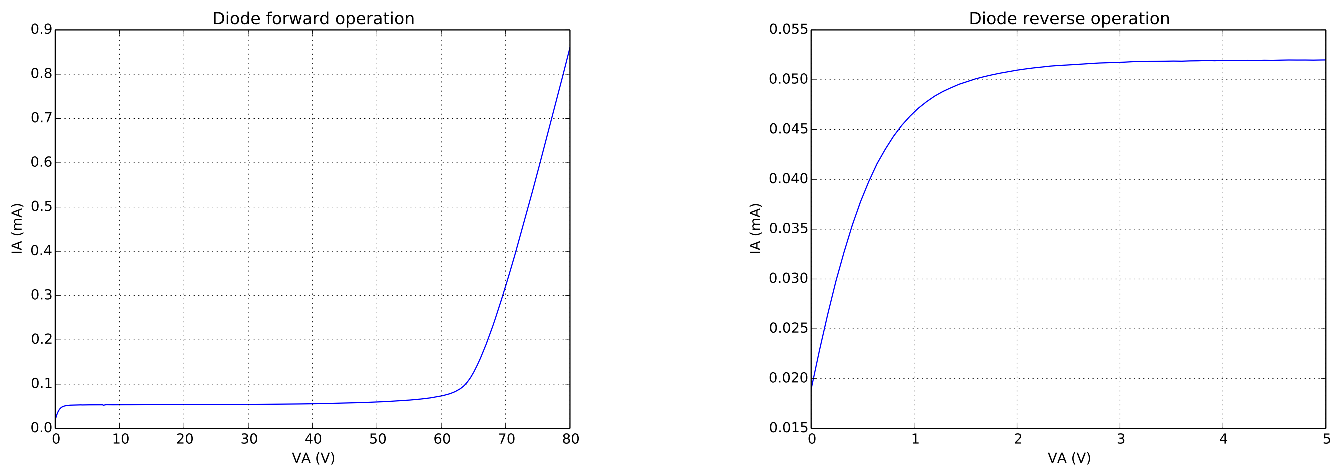


Figure 18: Plots of forward and reverse operation of Diode 7.

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

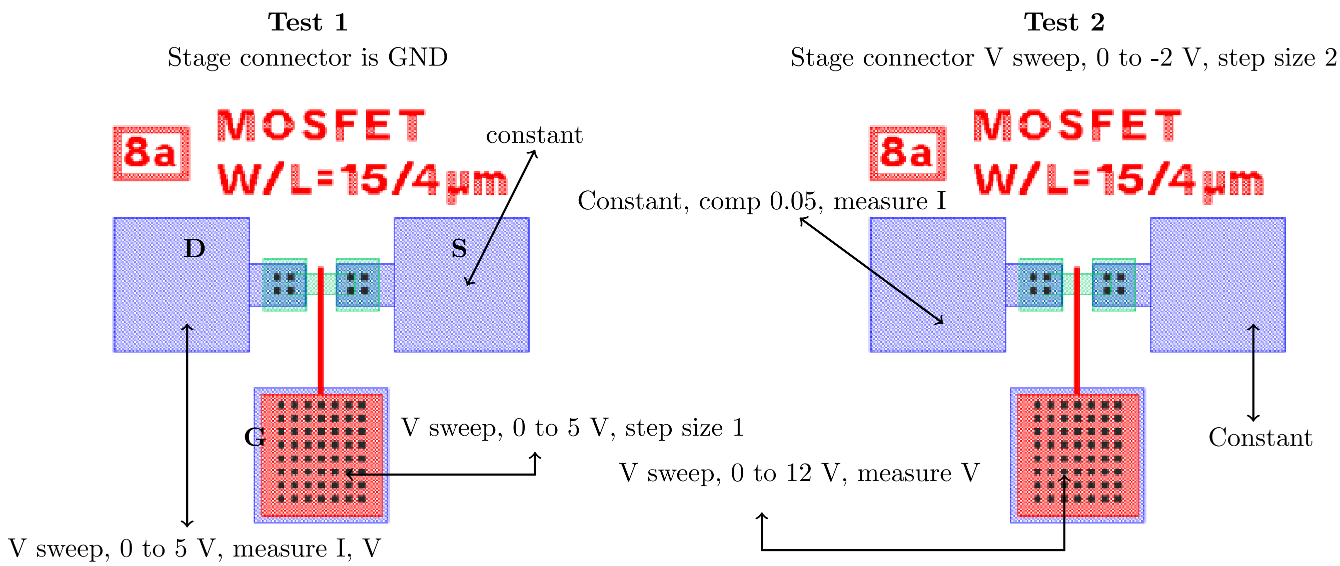


Figure 19: Measurement setup for Mosfet 8a. The same setup is used for Mosfets 8a-d. The only difference is the channel length which changes from 4 (8a) to 6 (8b) to 8 (8c) to 10 (8d) microns.

1.9.2 Plots of I_D-V_D, sweeping V_G

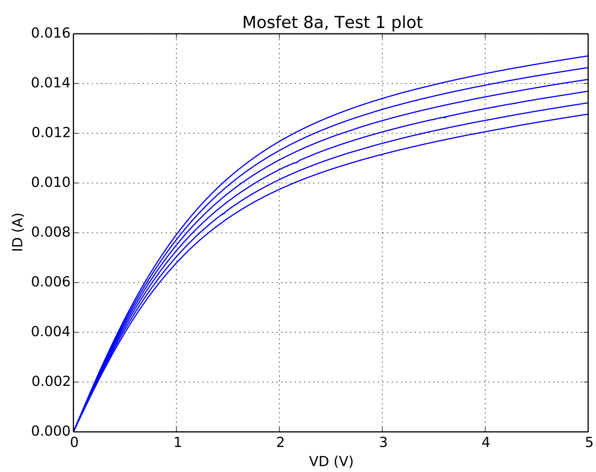


Figure 20: Test 1 for Mosfet 8a

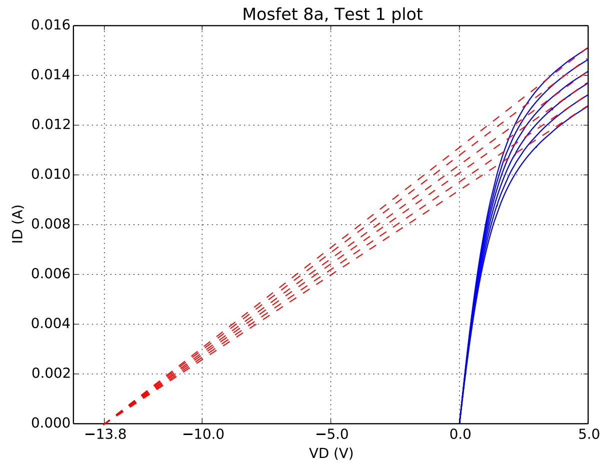


Figure 21: Test 1 for Mosfet 8a with extended x axis range in order to calculate lambda.

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

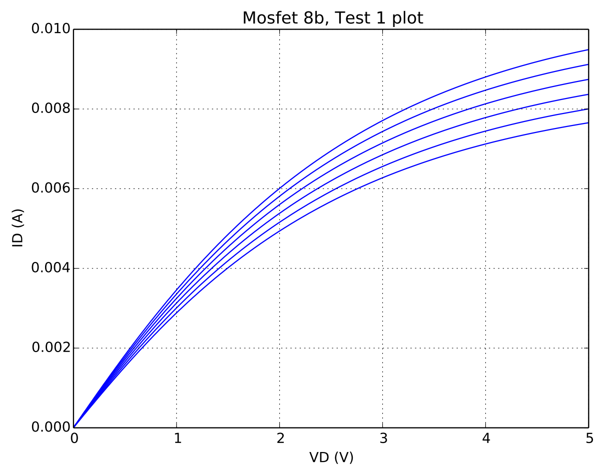


Figure 22: Test 1 for Mosfet 8b

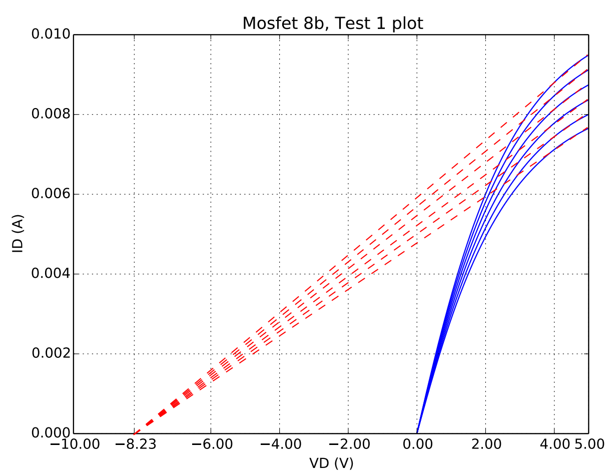


Figure 23: Test 1 for Mosfet 8b with extended x axis range in order to calculate lambda.

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

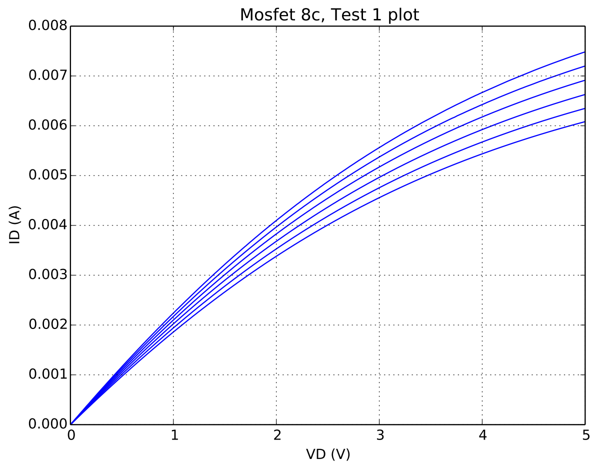


Figure 24: Test 1 for Mosfet 8c

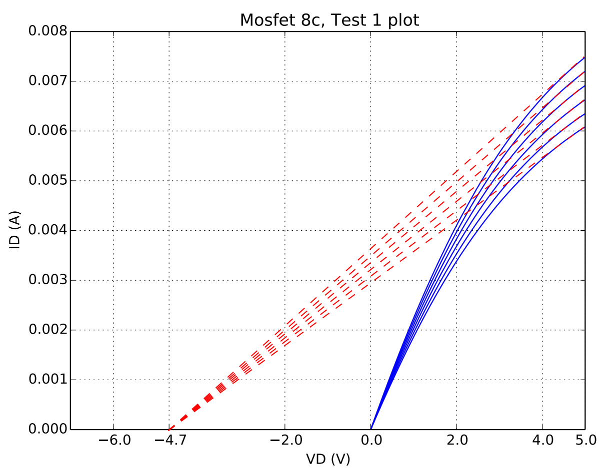


Figure 25: Test 1 for Mosfet 8c with extended x axis range in order to calculate lambda.

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

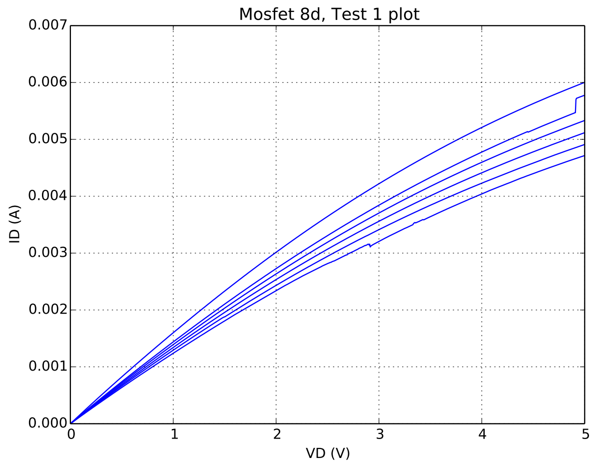


Figure 26: Test 1 for Mosfet 8d

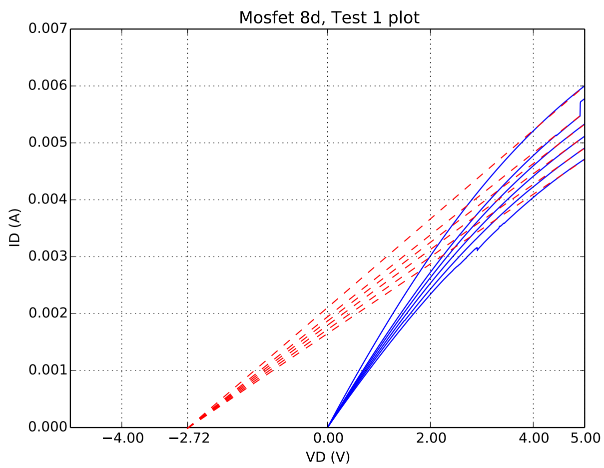


Figure 27: Test 1 for Mosfet 8d with extended x axis range in order to calculate lambda.

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	21
8b	-0.122	6	23
8c	-0.213	8	25
8d	-0.368	10	27

Figure 28: all λ values for mosfets 9a-d

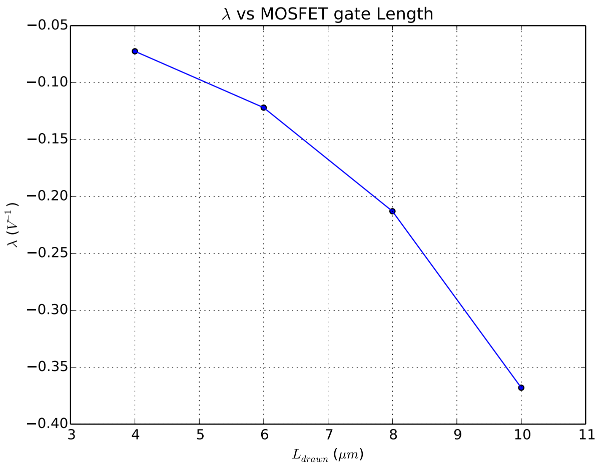


Figure 29: λ for each 8a-d device vs the gate length.

1.9.4 Plots of I_D-V_G, sweeping V_B

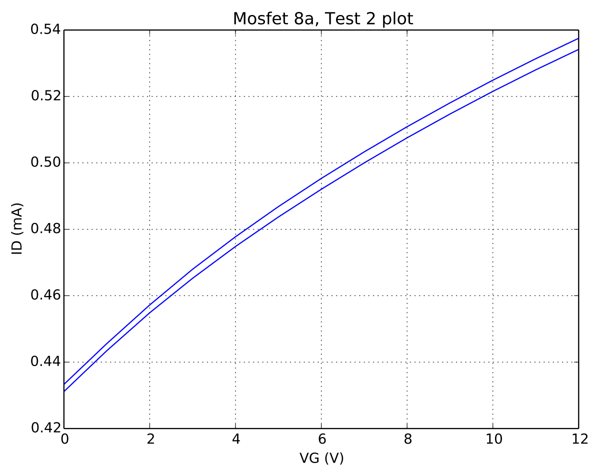


Figure 30: Test 2 for Mosfet 8a

Calculate stuff here...

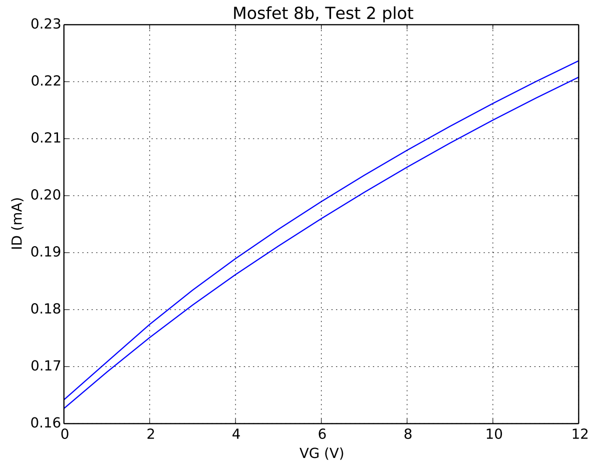


Figure 31: Test 2 for Mosfet 8b

Calculate stuff here...

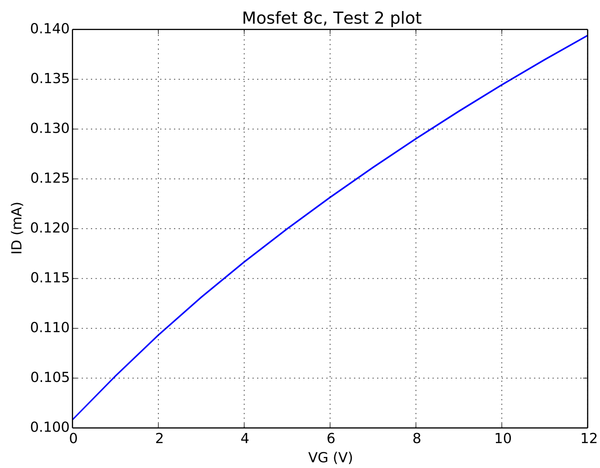


Figure 32: Test 2 for Mosfet 8c

Calculate stuff here...

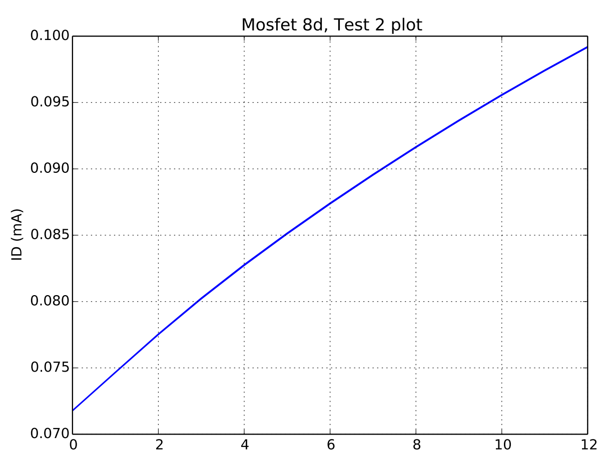


Figure 33: Test 2 for Mosfet 8d

Calculate stuff here...

1.10 MOSFETs of varying width [9a-c]

1.10.1 Measurement setup

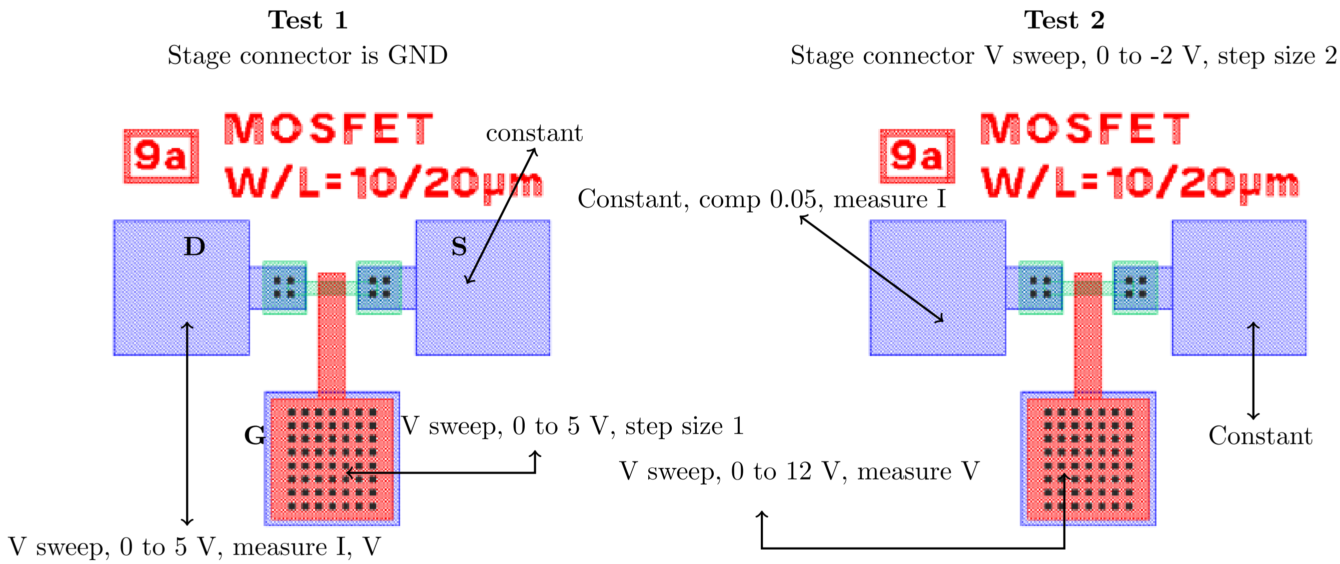


Figure 34: Measurement setup for Mosfet 9a. The same setup is used for Mosfets 9a-c. The only difference is the channel widths which changes from 10 (9a) to 15 (9b) to 20 (9c) microns.

1.10.2 Plots of I_D-V_D, sweeping V_G

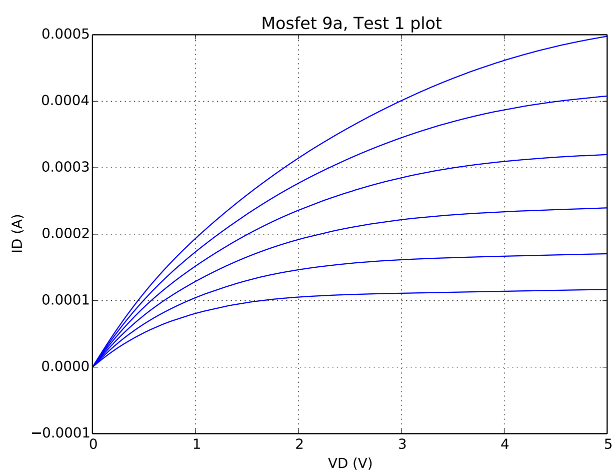


Figure 35: Test 1 for Mosfet 9a

Calculate stuff here...

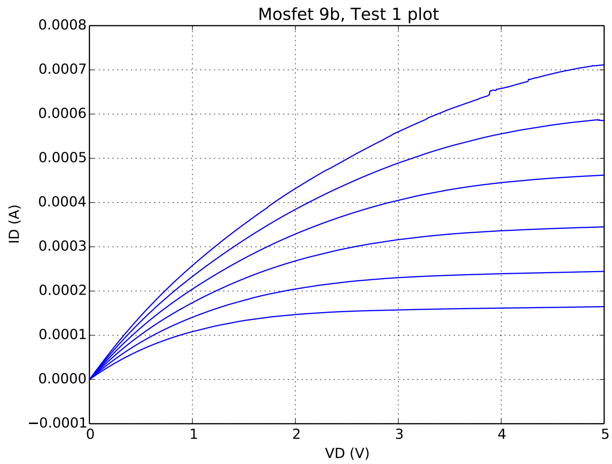


Figure 36: Test 1 for Mosfet 9b

Calculate stuff here...

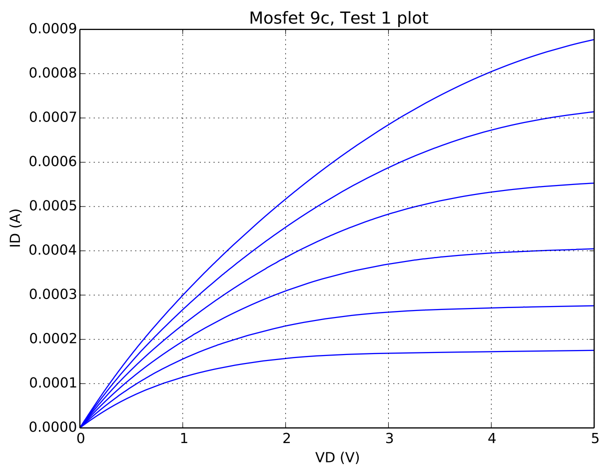


Figure 37: Test 1 for Mosfet 9c

Calculate stuff here...

1.10.3 Plots of I_D-V_G, sweeping V_B

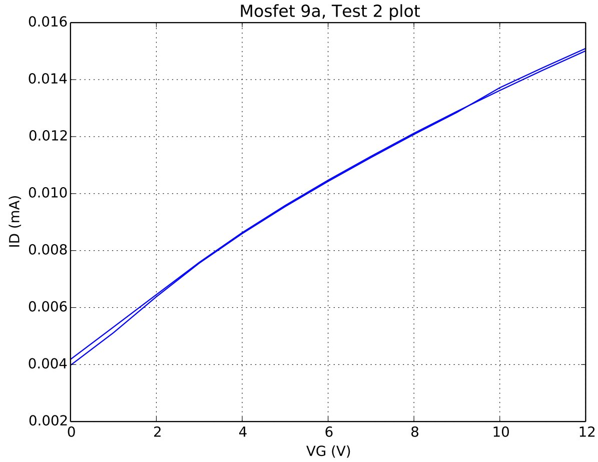


Figure 38: Test 2 for Mosfet 9a

Calculate stuff here...

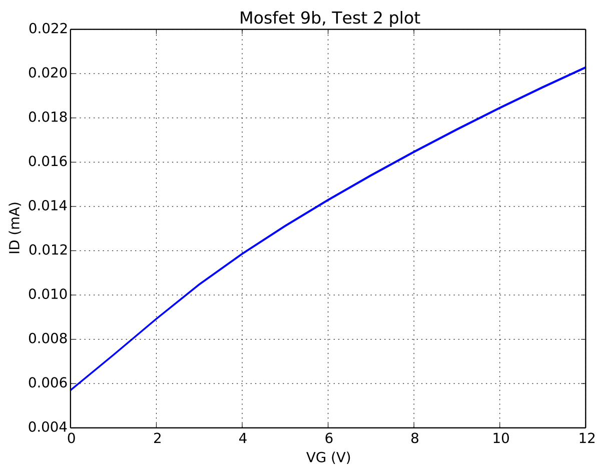


Figure 39: Test 2 for Mosfet 9b

Calculate stuff here...

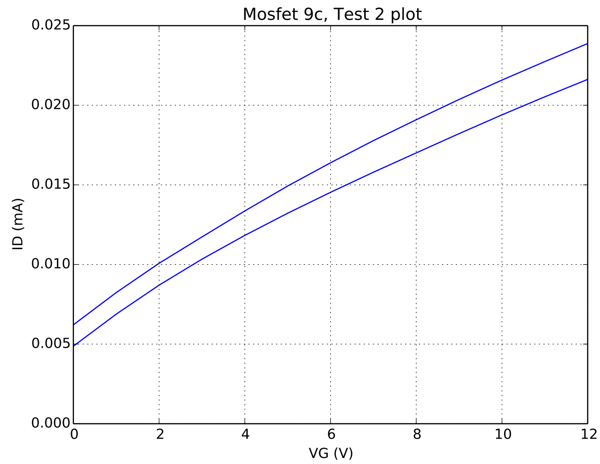


Figure 40: Test 2 for Mosfet 9c

Calculate stuff here...

1.11 Large MOSFET, 10

1.11.1 Measurement setup

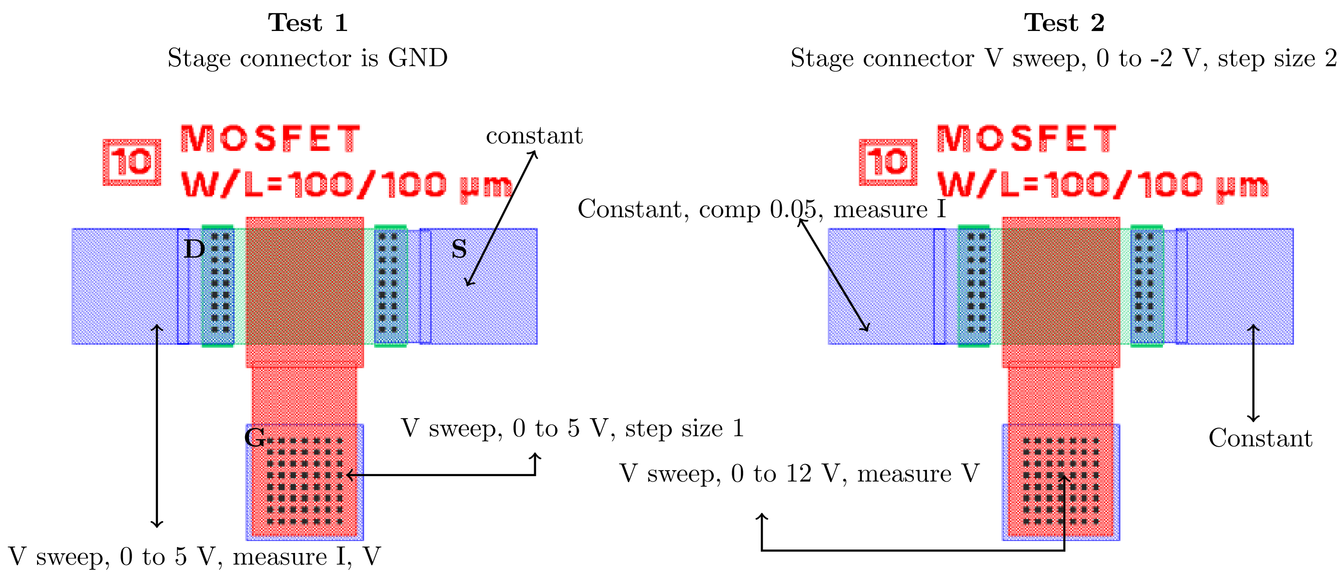


Figure 41: Measurement setup for Mosfet 10. This mosfet has very large dimensions compared to others.

1.11.2 Plots of I_D-V_D, sweeping V_G

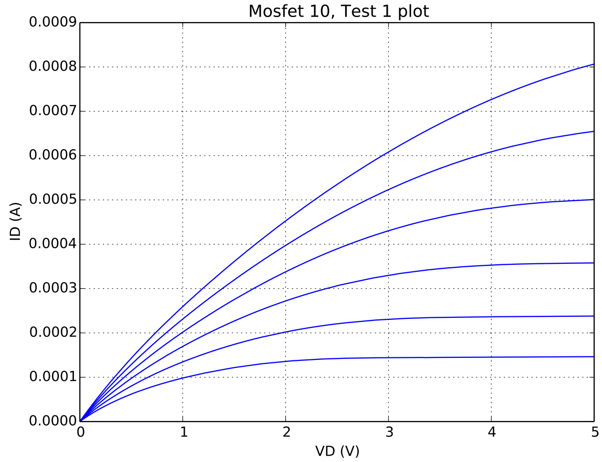


Figure 42: Test 1 for Mosfet 10

Calculate stuff here...

1.11.3 Plots of I_D-V_G, sweeping V_B

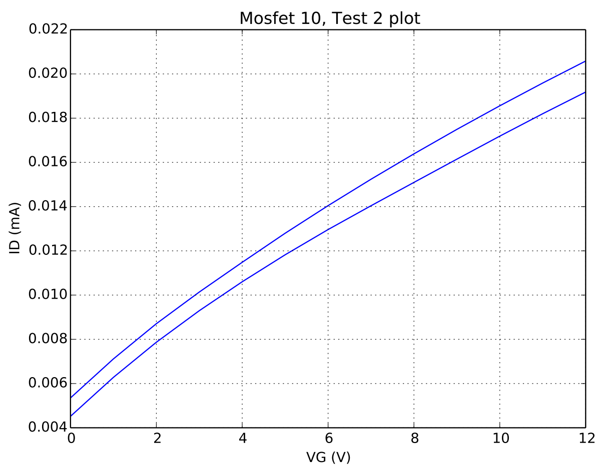


Figure 43: Test 2 for Mosfet 10

Calculate stuff here...

1.12 Inverter, 14

1.12.1 Measurement setup

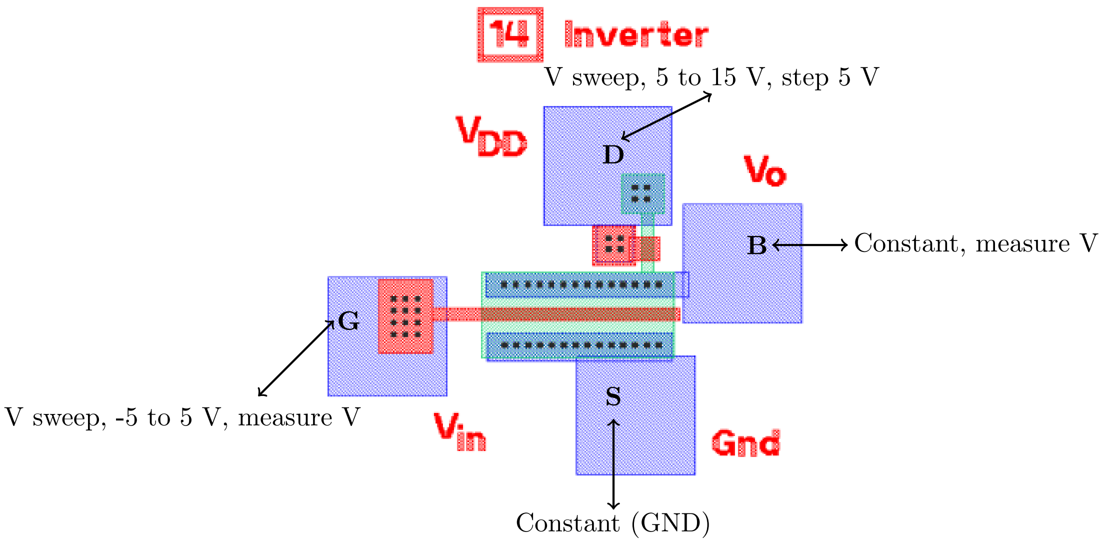


Figure 44: Setup for the inverter. Note that the source is connected to a GND and not the stage connector.

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

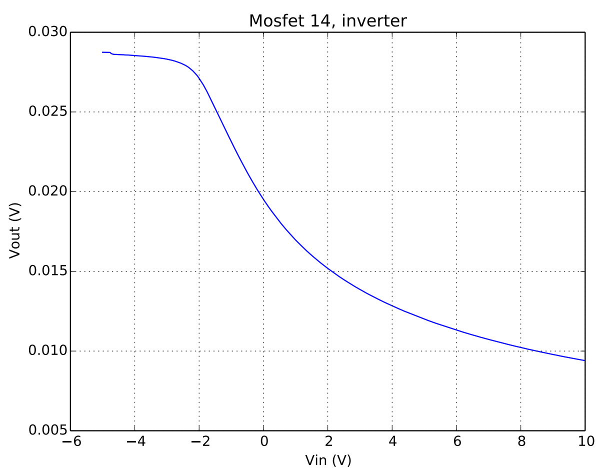


Figure 45: Plot for Inverter. Note both axis are in units of Volts.

1.12.3 Estimate V_M

calculations here....

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

2.7 MOSFETs

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

2.7.2 Large MOSFET

2.8 Inverter

3 Discussion

4 Optional Questions

5 Appendix

6 References

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