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ECE 542

Homework #12

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ECE 592

HW #12

10.3, 5, 6, 7

① Consider PMOS $V_T = -0.35V$ and $S = 70\,mV/decade$. The drain current at the threshold voltage is 1mA. How much current flows at zero gate voltage

$$\frac{0.35\,V}{70 \cdot 10^{-3}\,\frac{V}{dec}} = -5\,\text{decades} \Rightarrow I = (1mA) \cdot 10^{-5} = 10^{-3} \cdot 10^{-5} = 10^{-8}\,A$$

② Consider NMOS structure with P-type silicon substrate doped with $N_A = 5 \cdot 10^{17}\,cm$ boron atoms. The source & drain are doped with $N_D = 10^{19}\,cm^{-3}$. The drawn gate length $L_{drawn} = 0.7\,\mu m$. The insulator is SiO_2 wit thickness $0.7\,\mu m$. The insulator SiO_2 with thickness 20nm. $N_{SS} = 2 \cdot 10^{10}\,cm^{-2}$. The gate is polysilicon gate heavily doped n-type. Electron mobility $\mu_n = 350\,cm^2/V \cdot s$ $W = 5\,\mu m$. The $V_T = 0.8V$

ⓐ What is the effective gate length L', with 0 V_{app}?

$$L' = L_{drawn} - 2x_p = 0.7\,\mu m - 2x_p$$

$$x_p = \sqrt{\frac{2\varepsilon_s\varepsilon_0}{qN_A}\left(\frac{N_D}{N_A + N_D}\right)(V_{bi} - V_{app})} \;;\; V_{bi} = \frac{k_BT}{q}\ln\left(\frac{N_A N_D}{n_i^2}\right) = 0.0259\ln\left(\frac{5 \cdot 10^{17} \cdot 10^{19}}{10^{20}}\right) = 0.9959$$

$$x_p = \sqrt{\frac{2(11.8)(8.854 \cdot 10^{-14})}{1.6 \cdot 10^{-19} \cdot (5 \cdot 10^{17})}\left(\frac{10^{19}}{10^{19} + 5 \cdot 10^{17}}\right)(0.9959 - 0)} = \sqrt{(2.612 \cdot 10^{-11})(0.9524)(0.9959)} = 4.977 \cdot 10^{-6}\,cm$$

$$0.7\,\mu m - 2(4.977 \cdot 10^{-6}\,cm) \cdot 10^{-4} = 0.7 - 2(0.04977) = 0.60046\,\mu m$$

ⓑ I_{DS} vs V_{DS} $V_{DS} = 0$ to 5V $V_{GS} = 2V$; gate length does not change with voltage

$V_{D,sat} = V_{GS} - V_T$

$$C_i = \frac{\varepsilon_i\varepsilon_0}{t_i} = \frac{3.9(8.854 \cdot 10^{-14})}{20 \cdot 10^{-7}} = 173\,\frac{nF}{cm^2}?$$

$W = 5\,\mu m$

$\mu_n = 350$

Graph shown via Python

ⓒ $L' = L_{drawn} - x_p - x_p$

$$x_p = \sqrt{(2.612 \cdot 10^{-11})(0.9524)(0.9959 + 5)} = 1.22 \cdot 10^{-5}\,cm^{-3}$$

$$0.7\,\mu m - 0.122 - 0.04977 = 0.528\,\mu m$$

1 voltage varies length and one it doesn't

ⓓ Graph shown via Python

(3) For Mosfet in Problem #2, Calculate Sub-threshold Current for

$V_{GS} = 0.25V$ & $V_{DS} = 1V$ $\quad V_T = 0.8$ $\quad V_{GS} < V_T \therefore I_{DS} = 0$

$$I_{DS} = \mu_n \frac{W}{L}\sqrt{\frac{\varepsilon_s \varepsilon_0 q N_A}{2\phi_{sb}}}\left(\frac{k_0 T}{q}\right)^2 \exp\left(\frac{q(V_{GS}-V_T)}{k_0 T}\right)\left[1-\exp\left(-\frac{qV_D}{k_0 T}\right)\right] = 350\frac{cm^2}{V \cdot s}\frac{(5\cdot 10^{-6}m)}{(0.6\cdot 10^{-6}m)}\sqrt{\frac{11.8(8.854\cdot 10^{-14})(1.6\cdot 10^{-19})(5\cdot 10^{17})}{2(2(0.0259)\ln(\frac{5\cdot 10^{17}}{10^{10}}))}}\cdot(0.0259)^2$$

$$\exp\left(\frac{(0.25-0.8)}{0.0259}\right)\left[1-\exp\left(-\frac{1}{0.0259}\right)\right] =$$

$$= 0.000622212(5.99\cdot 10^{-10})(0.0259)^2 = 2.500143\cdot 10^{-16}$$

(4) Python

(5) For MosFET in Problem #2, Calculate new threshold voltage using a modified depletion Charge from Eq. 10.8. Use $V_{DS} = 5V$. This is DIBL effect.

$$Q_D' = Q_D + \frac{qN_A}{2L}W_{dm}x_{p,s} + \frac{qN_A}{2L}W_{dm}x_{p,D} \quad ; \quad V_{FB} = \phi_{GB} - \frac{Q_{ss}}{C_i} \qquad \phi_G = 4.05 \text{ Per ex } 5.5$$

$$V_T = V_{FB} + \phi_{SB} - \frac{Q_D}{C_i} \qquad \phi_B = \frac{1}{q}\left(4.05 + 0.56 + 0.0259\ln\left(\frac{5\cdot 10^{17}}{10^{10}}\right)\right) = 5.07 \quad \phi_{GB} = 4.05 - 5.07 = -1.02V$$

$$Q_{ss} = qN_{ss} = (1.6\cdot 10^{-19})(2\cdot 10^{10}) = 3\cdot 10^{-9}\,cm \; ; \; C_i = 173\frac{nF}{cm^2} \; ; \; V_{FB} = -1.02 - \frac{3\cdot 10^{-9}}{(173\cdot 10^{-9})(10^2)} = -1.02017V$$

$$\phi_{SB} = 2\cdot 0.0259\ln\left(\frac{5\cdot 10^{17}}{10^{10}}\right) = 0.91828 \; ; \; Q_D' = \left(-(1.6\cdot 10^{-19})(5\cdot 10^{17})(4.897\cdot 10^{-6})\right) + \frac{1.6\cdot 10^{-19}(5\cdot 10^{17})}{2(0.6\cdot 10^{-6})}(4.897\cdot 10^{-6}) + \frac{1.6\cdot 10^{-19}(5\cdot 10^{17})}{2(.6\cdot 10^{-6})}(4.897\cdot 10^{-6})$$

$$W_{Dm} = \sqrt{\frac{2(11.8)(8.854\cdot 10^{-14})(0.91828)}{(1.6\cdot 10^{-19})(5\cdot 10^{17})}} = 4.897\cdot 10^{-6} \qquad = 0.6529$$

$$V_T = -1.02017 + 0.91828 - \frac{0.6529}{173\cdot 10^{-9}\cdot 10^2} = -37739.98V$$

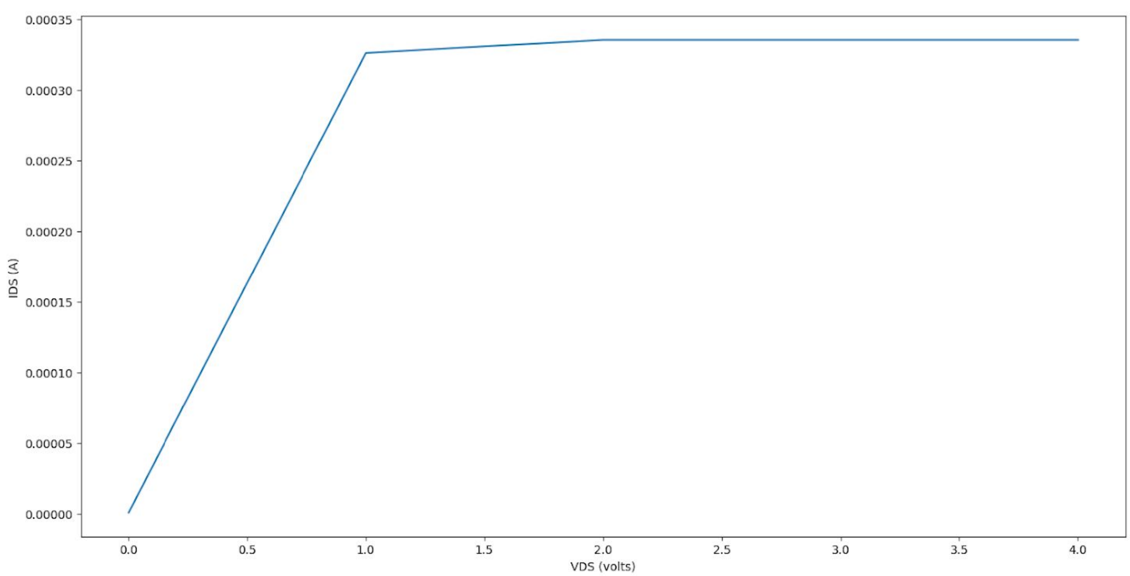
(6) For MOSFET in #2, Calculate new threshold voltage if Substrate is biased at -1V. ignore DIBL.

2b)

```
import matplotlib.pylab as plt
import matplotlib.pyplot as pltt
import math


VDS_list = []
IDS_list = []
x = 0
VGS = 2
VT = 0.8
Ci = 173*(10**-9)
L = 0.65023*(10**-6)
W = 5*(10**-6)
VD_Sat = VGS - VT
```

```
u = 350
IDS = 0

for i in range(5):
    x = i + 0.001
    VDS_list.append(x)
    if VGS <= VT:
        IDS = 0
    elif (VGS > VT) and (x <= VD_Sat):
        IDS = u*Ci*(W/L)*((VGS-VT)*x-(0.5*(x**2)))
    elif (VGS > VT) and (x >= VD_Sat):
        IDS = 0.5*u*Ci*(W/L)*((VGS-VT)**2)
    IDS_list.append(IDS)


plt.plot(VDS_list, IDS_list)
plt.xlabel("VDS (volts)")
plt.ylabel("IDS (A)")
plt.show()
```

plot:



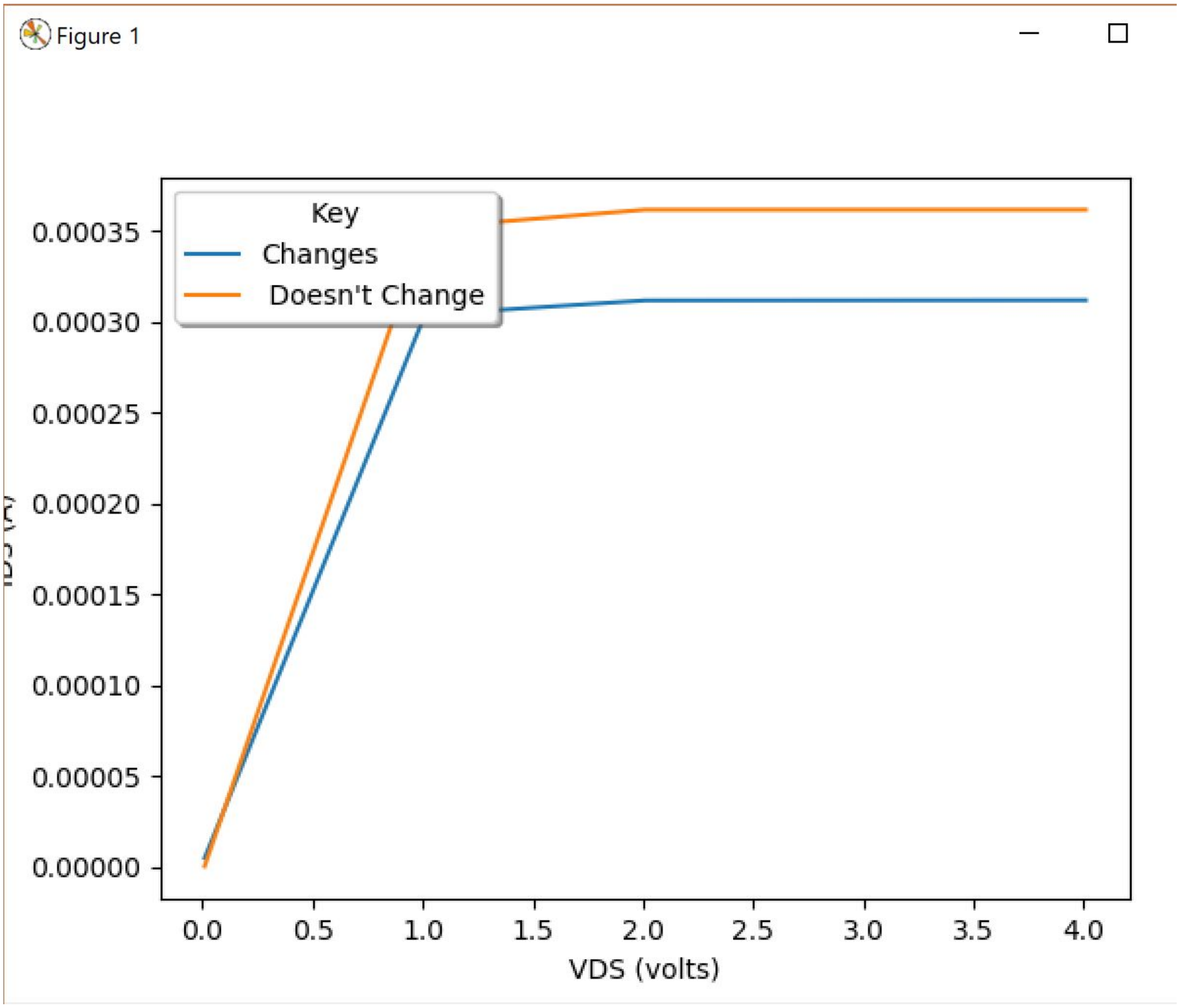
2d)

Code:

```
import matplotlib.pylab as plt
import matplotlib.pyplot as pltt
import math

VDS1_list = []
VDS_list = []
IDS_list = []
IDS1_list = []
x = 0
```

```python
VGS = 2
VT = 0.8
Ci = 173*(10**-9)
L1 = .6023*(10**-6)
W = 5*(10**-6)
VD_Sat = VGS - VT
u = 350
IDS = 0
x1 = 0
const = 0.000004988

for i in range(5):
    x = i + 0.01
    VDS_list.append(x)
    L = (0.7*(10**-6))-((const * ((x+0.9959)**0.5))*(10**-4))-((4.977*(10**-6))*(10**-4))
    if VGS <= VT:
        IDS = 0
    elif (VGS > VT) and (x > VD_Sat):
        IDS = (0.5*u*Ci*(W/L)*((VGS-VT)**2))
    elif (VGS > VT) and (x <= VD_Sat):
        IDS = u*Ci*(W/L)*(((VGS-VT)*x)-(0.5*(x**2)))
    IDS_list.append(IDS)


for i in range(5):
    x1 = i + 0.001
    VDS1_list.append(x1)
    if VGS <= VT:
        IDS = 0
    elif (VGS > VT) and (x1 <= VD_Sat):
        IDS = u*Ci*(W/L1)*((VGS-VT)*x1-(0.5*(x1**2)))
    elif (VGS > VT) and (x1 >= VD_Sat):
        IDS = 0.5*u*Ci*(W/L1)*((VGS-VT)**2)
    IDS1_list.append(IDS)


plt.plot(VDS_list, IDS_list, label="Changes")
plt.plot(VDS_list, IDS1_list, label=" Doesn't Change")
plt.xlabel("VDS (volts)")
plt.ylabel("IDS (A)")
plt.legend(loc="upper left", shadow=True, title="Key", fancybox=True)
plt.show()
```

plot:



The changes plot should be sloped up in saturation and it is not in the graph due to an error somewhere that I could not figure out.

4)

Code:

```
import matplotlib.pylab as plt
import matplotlib.pyplot as pltt
import math

VGS1_list = []
IDS1_list = []
VDS = 5
x = 0
VT = 0.8
Ci = 173*(10**-9)
L1 = .6023*(10**-6)
```

```
W = 5*(10**-6)
u = 350
IDS = 0
x1 = 0
const = 0.000000417


for i in range(3):
    x1 = i + 0.001
    VGS1_list.append(x1)
    eq = math.exp((x1-VT)/0.0259)
    if x1 <= VT:
        IDS = const*eq
    else:
        IDS = 0.5*u*Ci*(W/L1)*((x1-VT)**2)
    IDS1_list.append(IDS)


plt.yscale("log")
plt.xlim(0, 1.5)
plt.plot(VGS1_list, IDS1_list, label="")
plt.xlabel("VGS (volts)")
plt.ylabel("IDS (A)")
plt.legend(loc="upper left", shadow=True, title="Key", fancybox=True)
plt.show()
```

plot:

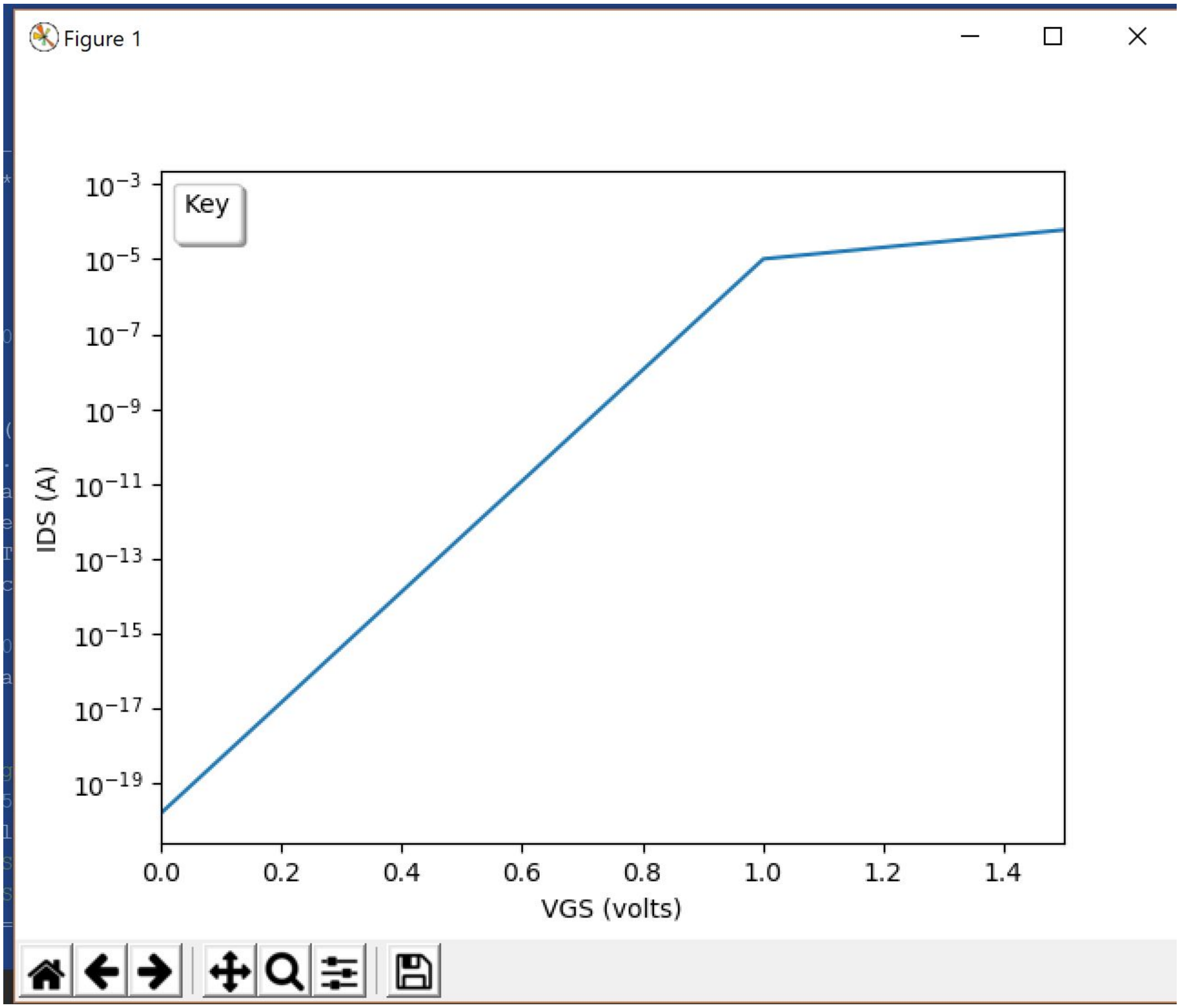


Figure 1
Key
10^{-3}
10^{-5}
10^{-7}
10^{-9}
10^{-11}
10^{-13}
10^{-15}
10^{-17}
10^{-19}
IDS (A)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
VGS (volts)