**Chapter 10**

**10.1**

 (a) p-type; inversion

 (b) p-type; depletion

 (c) p-type; accumulation

 (d) n-type; inversion

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.2**

1. (i)



 V





 cm

 or m

 (ii)

 V



 cm

 or m

1. V









 so cm

 (i)

 V



 cm

 or m

 (ii)

 V



 cm

 or m

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.3**



 1st approximation: Let V

 Then

 cm

 2nd approximation:

 V

 Then

 cm

1. V

 V

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.4**

 p-type silicon

 (a) Aluminum gate

 We have

 V

 Then

 or

 V

 (b) polysilicon gate



 or

 V

 (c) polysilicon gate



 or

 V

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.5**

 V





 V

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.6**

1. cm

1. Not possible - is always positive.

1. cm

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.7**

 From Problem 10.5, V



 F/cm



 V

 F/cm



 V

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.8**

1. V

 V

(b)

F/cm

 (i)

 V

 (ii)

 V

1. V

 F/cm

 (i)

 V

 (ii)

 V

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.9**

 where

 V

 Then

 or

 V

 Now

 or

 We have

 or

 F/cm

 So now

 C/cm

 or

 cm

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.10**

 V



 cm





 C/cm

 F/cm









1. n poly gate on p-type: V

 V

1. p poly gate on p-type: V

 V

1. Al gate on p-type: V

 V

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.11**

 V



 cm





 C/cm

 F/cm









1. n poly gate on n-type: V

 V

1. p poly gate on n-type: V

 V

1. Al gate on n-type: V

 V

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.12**

 V

 The surface potential is

 V

 We have

 V

 Now

 We obtain



 or

 cm

 Then

 or

 C/cm

 We also find

 or

 F/cm

 Then

 or

 V

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.13**

 F/cm



 C/cm

 By trial and error, let cm.

 Now

 V



 cm





 C/cm

 V

 Then





 Then VV

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.14**

 F/cm



 C/cm

 By trial and error, let cm

 Now

 V



 cm





 C/cm

 V

 Then





 Then V, which is within the specified value.

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.15**

 We have F/cm

 C/cm

 By trial and error, let cm

 Now

 V



 cm





 C/cm

 V

 Then





 V

 Then V V which meets the specification.

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.16**

1. V



 F/cm

 Now



 V

 V



 cm





 C/cm

 Now



 or V

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.17**

 (a) We have n-type material under the gate, so

 where

 V

 Then

 or

 cmm

 (b)

 For an polysilicon gate,



 or

 V

 Now

 or

 C/cm

 We have

 C/cm

 We now find



 or

 V

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.18**

 (b)

 where

 V

 and

 V

 Then

 or

 V

 (c) For



 We find

 or

 cmm

 Now

 or

 C/cm

 Then



 or

 VV

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.19**

 Plot

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.20**

 Plot

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.21**

 Plot

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.22**

 Plot

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.23**

1. For Hz (low freq),



 F/cm



 F/cm



 Now

 V



 cm

 Then

 F/cm

 (inv)F/cm

1. MHz (high freq),

 F/cm (unchanged)

 F/cm (unchanged)

 F/cm (unchanged)

 (inv)F/cm

1. V



 Now



 C/cm



 V

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.24**

1. Hz (low freq),



 F/cm



 F/cm



 Now

 V



 cm

 Then

 F/cm

 (inv)F/cm

1. MHz (high freq),

 F/cm (unchanged)

 F/cm (unchanged)

 F/cm (unchanged)

 (inv)F/cm

1. V



 Now



 C/cm

 Then

 V

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.25**

 The amount of fixed oxide charge at *x* is

 C/cm

 By lever action, the effect of this oxide charge

 on the flatband voltage is

 If we add the effect at each point, we must

 integrate so that

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.26**

 (a) We have

 Then





 or



 or

 V

 (b)

 We have



 Now

 or



 or

 V

 (c)

 We find

 or

 Now



 which becomes

 Then

 or V

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.27**

 Sketch

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.28**

 Sketch

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.29**

 (b)



 or

 V

 (c) Apply V, V

 For V,



 n-side:



 at , then

 so

 for

 In the oxide, , so

 constant. From the

 boundary conditions, in the oxide

 In the p-region,

 at , then



 At ,

 So that

 Since , then

 The potential is

 For zero bias, we can write

 where are the voltage drops across

 the n-region, the oxide, and the p-region,

 respectively. For the oxide:

 For the n-region:

 Arbitrarily, set at , then

 so that



 At , which is the voltage

 drop across the n-region. Because of

 symmetry, . Then for zero bias, we

 have

 which can be written as

 or

 Solving for , we obtain



 If we apply a voltage , then replace by

 , so



 We find



 which yields

 cm

 Now



 or

 V

 We also find



 or

 V

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.30**

 (a) n-type

 (b) We have

 F/cm

 Also

 or

 cmnm

 (c)

 or

 which yields

 C/cmcm

 (d)





 which yields

 F/cm

 or

 pF

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.31**

 (a) Point 1: Inversion

 2: Threshold

 3: Depletion

 4: Flat-band

 5: Accumulation

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.32**

 We have



 Now let , so





 For a p-type substrate, is a

 negative value, so we can write



 Using the definition of threshold voltage ,

 we have

 At saturation

 which then makes equal to zero at the

 drain terminal.

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.33**



 mA



 mA

1. Same as (b), mA



 mA

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.34**



 mA



 mA



 mA

1. Same as (c), mA

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.35**





 mA



 mA

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.36**

1. Assume biased in saturation region



 V

 Note: VV

 So the transistor is biased in the saturation region.

 mA



or

 mA

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.37**

 F/cm



 A/V=1.111 mA/V

1. ,

 V, V,



 mA

 V, V,



 mA

 V, V,



 mA

 V, V,



 mA

(c) for V

 V,



 mA

 V,



 mA

 V,



 mA

 V,



 mA

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.38**

 F/cm





 A/V=0.961 mA/V

1. ,

 V, V



 mA

 V, V



 mA

 V, V



 mA

 V, V



 mA

(c) for V

 V



 mA

 V



 mA

 V



 mA

 V



 mA

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.39**

1. From Problem 10.37,mA/V

 For V,

 , V



 mA

 V, V



 mA

 V, V



 mA

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.40**

 Sketch

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.41**

 Sketch

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.42**

 We have

 so that

 Since , the transistor is always

 biased in the saturation region. Then

 where, from Problem 10.37,

 mA/Vand V

 Then

|   | (mA) |
| --- | --- |
|  0 1 2 3 4 5 |  0 0.336 2.67 7.22 14.0 23.0 |

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.43**

 From Problem 10.38, mA/V





 For V,

 For V,



 For V,



 mA/V

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.44**







 mA/V

 mA

 mA

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.45**

 We find that V

 Now

 where

 or

 F/cm

 We are given . From the graph, for

 V, we have

 ,

 then

 or

 or

 which yields

 cm/V-s

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.46**

 (a)

 or

 V

 (b)

 so

 which yields

 A/V

 (c)

 V

 so



 or

 A

 (d)





 or

 A

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.47**

 F/cm

 (i)

 A/V

 or A/V

 (ii)





1. (i)

 A/V

 or A/V

 (ii)





\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.48**

 From Problem 10.37, mA/V



 so mA/V



 so mA/V

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.49**

 From Problem 10.38, mA/V



 or mA/V



 or mA/V

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.50**

 Now

 F/cm

 Then

 V

1. V

 (i)

 cm





 C/cm





 V





 A/V

 or mA/V

 For , V

 For

 V

1. (i) For , V

(ii) V,





 V

 V

 (iii) V,





 V

 V

 (iv) V,





 V

 V

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.51**

 V







 or

 V

 Now



 V

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.52**

 F/cm





 V

1. V







 V

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.53**

 (a) poly-to-p-type V

 V

 also



 or

 cm

 Now

 or

 C/cm

 Also

 or

 F/cm

 We find

 C/cm

 Then



 or

 V

(b) For NMOS, apply and shifts in a

positive direction, so for , we want V.

So

 or

 or

 which yields

 V

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.54**

 Plot

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.55**

 (a)





 or

 mS

 Now

 which yields

 or

 k

 (b) For V, mS

 Then

 mS

 or

 which is a 12% reduction.

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.56**

 (a) The ideal cutoff frequency for no overlap

 capacitance is,



 or

 GHz

 (b) Now

 where

 We find





 or

 F

 Also





 or

 S

 Then



 or

 F

 Now





 or

 F

 We now find



 or

 GHz

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10.57**

 (a) For the ideal case

 or

 GHz

(b) With overlap capacitance (using the

values from Problem 10.56),

 We find



 or

 S

 We have





 or

 F

 Then

 or

 GHz

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_