Exam – modern electronics (ETIN70)   2017-10-26   8.00-13.00

GOOD LUCK!
Total number of points = 20
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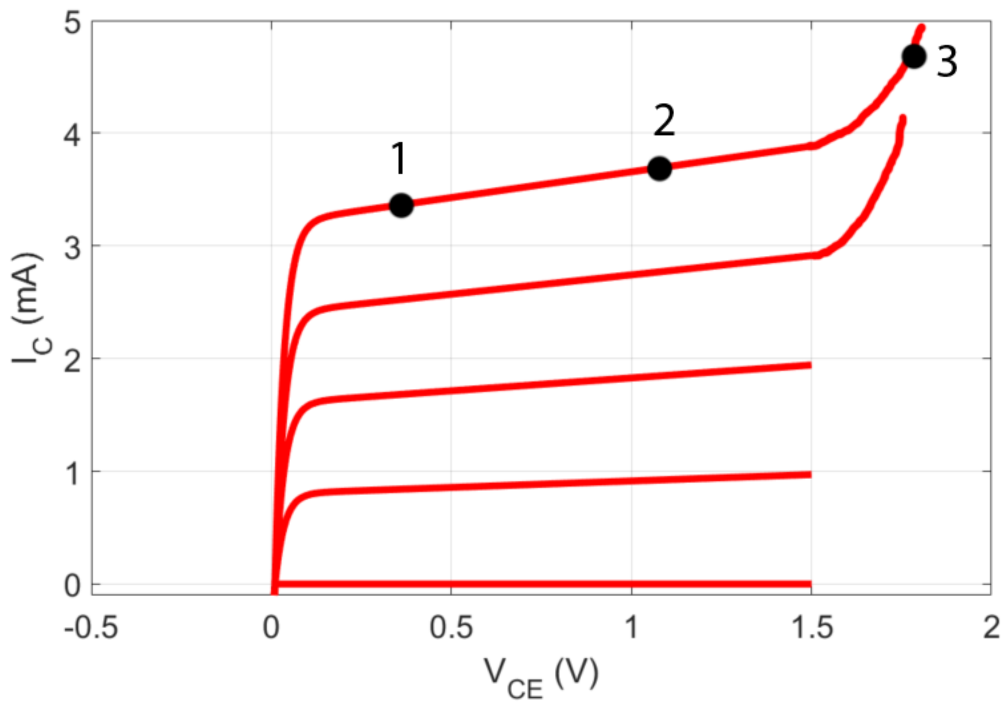
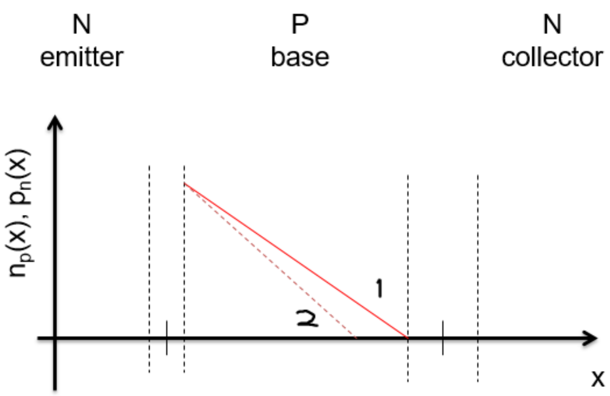
1. BJTs (4p)

A NPN BJT gives the I_C-V_{CE} characteristics below.



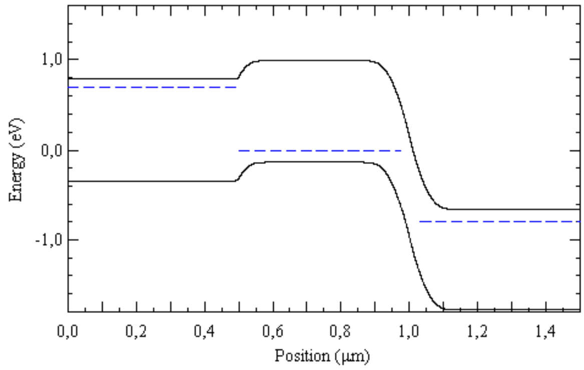
a) Sketch the minority carrier concentration in the base for the bias conditions in point 1 and 2 and clearly indicate any differences. You can assume that the base is short i.e. recombination can be disregarded. (1 p)



b) Calculate the Early voltage using the data in the figure. (1 p)

The slope between to VCE points (fixed VBE) can be used to extrapolate to IC=0 on the negative VCE axis resulting in an Early voltage VA=7 V.

c) I_C increases rapidly for sufficiently high V_{CE} (point 3 in the figure). Sketch the band structure (not carrier concentration) for bias point 3 and explain the reason for the rapid increase in I_C.   (1 p)



If the base-collector pn-junction is too reverse biased, avalanche multiplication and/or tunneling due to the high electric field occurs resulting in rapidly increasing current.

2. MOSFETs (4p)

In some MOSFETs the current does not saturate above $V_{DS} > V_{GS}-V_t$ but show a slow increase with V_{DS} in the saturation region.

a) What is the name of this effect? Why does the current increase with V_{DS}?   (1 p)

This is called the channel length modulation effect. The current increase with VDS is due to that the effective channel length decreases as the drain voltage "counteracts" VGS close to the drain resulting in region which is not inverted. The shorter effective channel increases the electric field along the channel resulting in higher drift velocity and thus an increase in ID.

b) Describe two changes to the MOSFET in order to decrease this effect and obtain better saturation. Motivate why your suggestions would improve saturation. You can ignore if other characteristics gets worse.   (1 p)

Increase the channel length: Since the increase in ID depends on the relative change in the effective channel length a longer channel would give a smaller relative (with respect to the case without channel length modulation) change in ID and thus better saturation. The total ID would however decrease due to the longer channel.

Decrease doping in drain the doping in the channel: The depletion width of the pn-junction between the channel and the highly doped drain region is dependent on the relation between the doping in the drain and channel region i.e. a the depletion region is mainly on the lowly doped side of a pn-junction. An increase in VDS would thus mainly widen the depletion region on the drain region i.e. the effective channel length would be less affected. This would increase the drain resistance.

c) Three different Si n-MOSFETs have been measured and the results can be seen in the table below. The source is grounded (V_S=0 V). Fill out the missing information in each row. Note that device 1 has been measured at two different bias conditions. You should present your full calculations for the values and motivate your answers for the operating modes. The three possible operating modes are cut-off, saturation and linear. k´/2*(W/L) = 2.92 mA/V^2 for all the devices. (2 p)

Device	V_t [V]	λ [V^{-1}]	V_{GS} [V]	V_{DS} [V]	I_D [mA]	Operating mode
1	0.5	**???** **0.07**	**??? (same as below)** **1.5**	2.5	3.427	**???** **Saturation**
1	0.5	**???** **0.07**	**??? (same as above)** **1.5**	2	3.325	**???** **Saturation**
2	0.8	0.1	0.6	3	??? **0**	**???** **Cut-off**
3	??? **0.3**	0.05	1.25	0.75	2.516	**???** **Linear**

--- Device 1 ---

Need to first figure out if this is in saturation or linear region. Test on 2nd bias point since if this is in saturation also the first have to be (higher VDS).

Linear: 3.325=2.92*(2*(VGS-0.5)*2-2^2). Solving gives VGS= 0.78 V. Since VDS > VGS-Vt (0.78-0.5) this can't be in the linear regime.

Use saturation for both bias points

3.427 = 2.92*(VGS -0.5)^2 * (1+ λ *2.5)

3.325 = 2.92*(VGS-0.5)^2 * (1+ λ *2)

Insertion gives

3.325* (1+ λ*2.5) = 3.427 * (1+ λ *2)   which gives

λ *1.4585 = 0.102   ->   λ=0.7

Use any of the two bias points

3.325 = (VGS-0.5)^2 * (1+ 0.07 *2)   ->   VGS = sqrt((3.325/2.92)/(1+ 0.07 *2)) = 1.5 V

--- Device 2 ----

Since VGS < Vt the device is in cut-off and ID=0

--- Device 3 ----

Test linear region

2.516 = 2.92 (2*(1.25-Vt)*0.75-0.75^2)   ->   Vt = -(2.516/2.92+0.75^2)/(2*0.75)+1.25 = 0.3 V

Test saturation

2.516 = 2.92 ((1.25-Vt)^2*(1+0.05*0.75))   -> Vt = 1.25 – sqrt((2.516/2.92)/(1+0.05*0.75)) = 0.34 V

But for this result VDS < VGS – Vt so it have to be in linear regime.