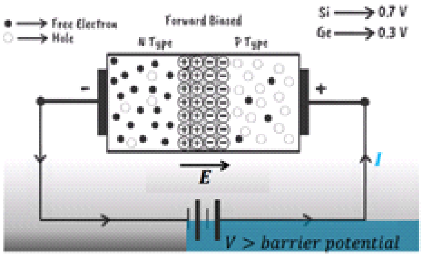
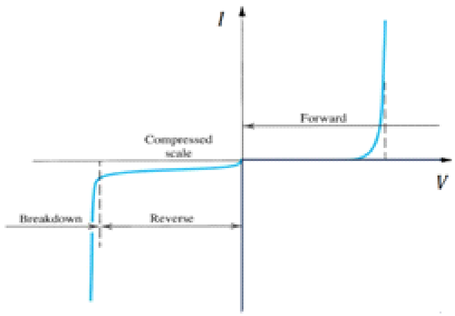
LEC-1PNDiodes

Thursday, 23 May 2024 09.22

19 / 41 100%

PN junction- forward bias

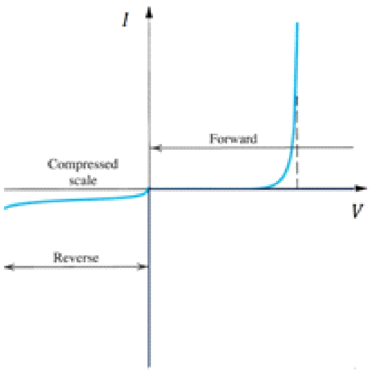




- Battery V pushes the free electrons (majority charge carrier) from N to P.
- As long as the battery can provide current, the current can flow from P to N.
- The current increases dramatically as V increases.
- A 'fully conducting' diode → voltage drop is 0.6 V ~0.8 V

20 / 41 100%

PN junction- Shockley's equation



$$I = I_s\left(e^{\frac{V}{nV_T}} - 1\right)$$

For anything with PN junctions

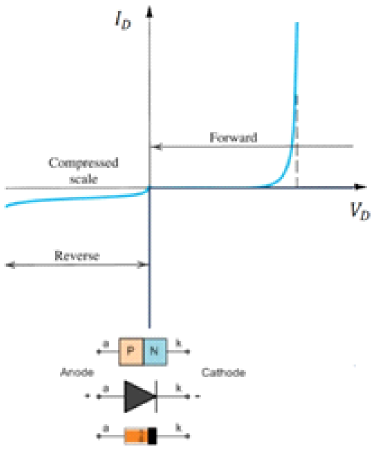
I_s : reverse saturation current, given in datasheet
V: voltage across the junction
n: ideal factor, depending on the construction of the PN junction, $1 < n < 2$, $n = 1$ for ideal PN junction
V_T: thermal voltage

$$V_T = \frac{KT_K}{q}$$

K: Boltzmann's constant = 1.38×10^{-23} J/K
T_K: the absolute temperature in kelvins = $273 + x$ °C
q: the magnitude of electronic charge = 1.6×10^{-19} C
$V_T \approx 26$ mV @ 27 °C

I_s and V_T are temperature dependent.
I_s doubles for every 5°C rise in temperature.

PN diode



$$I_D = I_s\left(e^{\frac{V_D}{nV_T}} - 1\right)$$

- I_s : reverse saturation current, given in datasheet
- V_D: voltage across the diode
- n: ideal factor, depending on the diode's construction, $1 < n < 2$, $n = 1$ for ideal diode
- V_T: thermal voltage, $V_T \approx 26$ mV @ 27 °C

When a diode is forward-biased:

$$I_D \approx I_s\, e^{\frac{V_D}{V_T}}$$

- For $V_D \gg V_T$ ($V_D > 4V_T$ in practice), $e^4 \approx 54.5$
- $n = 1$

Lec. 1: assignment 1.1

In the laboratory, 2 sets of related values of current and voltage at two temperatures have been measured for the diode 1N4001:

- At 25°C : (V_{D1}, I_{D1}) = (540 mV, 1mA), and (V_{D2}, I_{D2}) = (450 mV, 0.1mA)
- At 75°C: (V_{D1}, I_{D1}) = (420 mV, 1mA), and (V_{D2}, I_{D2}) = (315 mV, 0.1mA)

a. Calculate the constants of the diode equation: n and I_s for each temperature.
b. Calculate the temperature coefficient [mV/K] of the diode at current = 1 mA.

$$\boxed{\begin{gathered} I_D \approx I_s\, e^{\frac{V_D}{nV_T}} \\ V_D = nV_T \ln\frac{I_D}{I_s} \end{gathered}}$$

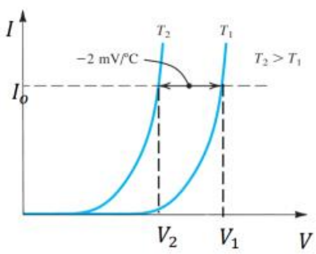
$$V_{D_2} = nV_T \ln\frac{I_{D_2}}{I_s} \ \&\ V_{D_1} = nV_T \ln\frac{I_{D_1}}{I_s} \Rightarrow n = \frac{V_{D2} - V_{D1}}{V_T \ln\frac{I_{D2}}{I_{D1}}} \ \&\ I_s = I_{D_1}\, e^{-\frac{V_{D_1}}{nV_T}}$$

$$V_T = \frac{KT_K}{q} \rightarrow V_T(25\ °C) = 25.7 \text{ mV} \ \&\ V_T(75\ °C) = 30 \text{ mV}$$

At 25 °C: $n = \frac{450\ mV - 540\ mV}{25.7\ mV \ln\frac{0.1\ mA}{1\ mA}} = 1.52$ & $I_s = 1mA\, e^{-\frac{540\ mV}{1.52 * 25.7\ mV}} = 1\ nA$

At 75 °C: $n = \frac{315\ mV - 420\ mV}{30.0\ mV \ln\frac{0.1\ mA}{1\ mA}} = 1.52$ & $I_s = 1mA\, e^{-\frac{420\ mV}{1.52 * 30.0\ mV}} = 100\ nA$

$$\frac{\Delta V_D}{\Delta T} = \frac{420\ mV - 540\ mV}{75\ °C - 25\ °C} = -2.4 \text{ mV/ °C}$$

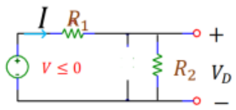


Kursusløninger

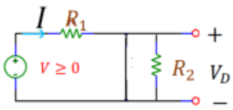
Lec. 1: assignment 1.2 –ideal model

No/Neg voltage

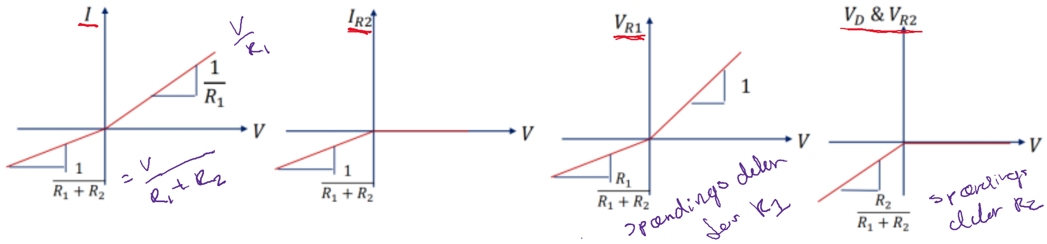
Voltage is on



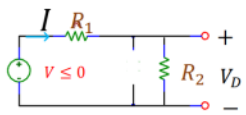
$I = I_{R_2} = V/(R_1+R_2)$
$V_{R1} = VR_1/(R_1+R_2)$
$V_D = V_{R2} = VR_2/(R_1+R_2)$



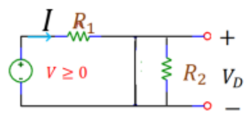
$I = V/R_1$
$I_{R_2} = 0$
$V_{R1} = IR_1 = V$
$V_D = V_{R2} = 0$



Lec. 1: assignment 1.2 –ideal model



$I = I_{R_2} = V/(R_1+R_2)$
$V_{R1} = VR_1/(R_1+R_2)$
$V_D = V_{R2} = VR_2/(R_1+R_2)$



$I = V/R_1$
$I_{R_2} = 0$
$V_{R1} = IR_1 = V$
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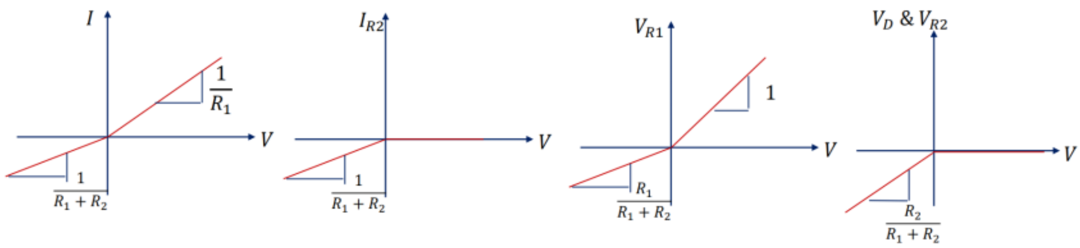
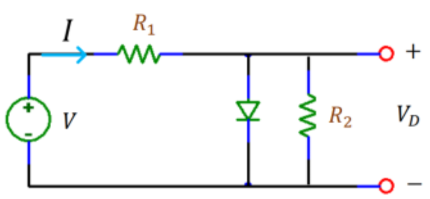


Lec. 1: assignment 1.2



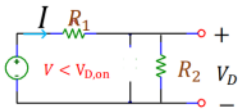
2. Constant voltage drop model

Draw the equivalent circuit and calculate I, I_{R_2}, V_{R1}, V_D and V_{R2}

- When $V < V_{D,on}$
- When $V = V_{D,on}$
- When $V = \frac{R_1+R_2}{R_2} V_{D,on}$
- When $V > \frac{R_1+R_2}{R_2} V_{D,on}$

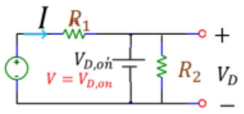
a. The I-V curve.
b. The I_{R_2}-V curve.
c. The I_D-V curve.
d. The V_{R1}-V curve, with V_{R1} denoting the voltage across R1.
e. The V_D-V curve, with V_D denoting the voltage across diode.

Lec. 1: assignment 1.2 –constant voltage drop



$V < V_{D,on}$

$$I = I_{R_2} = V/(R_1 + R_2)$$
$$V_{R1} = VR_1/(R_1 + R_2)$$
$$V_D = V_{R2} = VR_2/(R_1 + R_2)$$



If we assume $V = V_{D,on}$, *the diode is on* → *the voltage drop across* R_1 *will be 0* → $I = 0$ *(1)*

The diode is about to turn on → $I_D = 0$

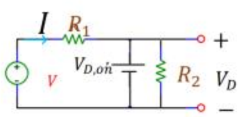
However, $I_{R2} = \frac{V_{D,on}}{R_2} \neq 0$

And $I = I_D + I_{R2} \neq 0$ *(2)*

(1) And (2) conflicts → *the diode should be off* → *same results as for* $V < V_{D,on}$

$$I = I_{R_2} = V/(R_1 + R_2)$$
$$V_{R1} = VR_1/(R_1 + R_2)$$
$$V_D = V_{R2} = VR_2/(R_1 + R_2)$$

Lec. 1: assignment 1.2 –constant voltage drop



$$V = \frac{R_1 + R_2}{R_2} V_{D,on}$$

If we assume $V = V_{D,on}$, *the diode is on* → $I = \frac{V - V_{D,on}}{R_1} = \frac{V_{D,on}}{R_2}$ *(1)*

The diode is about to turn on → $I_D = 0$

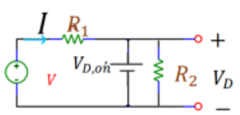
And, $I_{R2} = \frac{V_{D,on}}{R_2}$

And $I = I_D + I_{R2} = \frac{V_{D,on}}{R_2}$ *(2)*

(1) And (2) true → *the diode should be on*

$$I = I_{R_2} = \frac{V_{D,on}}{R_2}$$
$$V_{R1} = IR_1 = \frac{R_1 V_{D,on}}{R_2}$$
$$V_D = V_{R2} = V_{D,on}$$

Lec. 1: assignment 1.2 –constant voltage drop

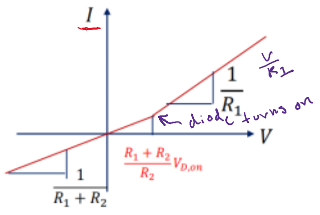


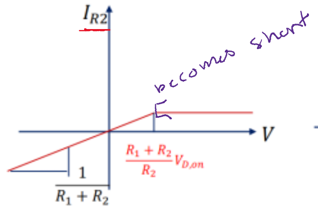
$$V > \frac{R_1 + R_2}{R_2} V_{D,on}$$

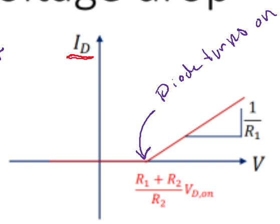
the diode is on → $I = \frac{V - V_{D,on}}{R_1}$

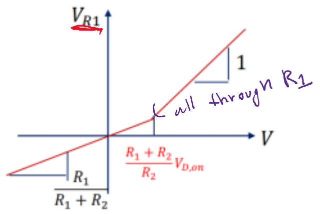
$$I_{R2} = \frac{V_{D,on}}{R_2}$$
$$I_D = I - I_{R2} = \frac{V - V_{D,on}}{R_1} - \frac{V_{D,on}}{R_2}$$
$$V_{R1} = IR_1 = V - V_{D,on}$$
$$V_D = V_{R2} = V_{D,on}$$

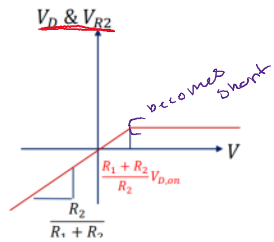
Lec. 1: assignment 1.2 –constant voltage drop



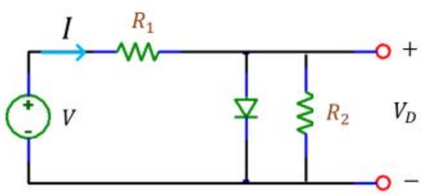








Lec. 1: assignment 1.3



Assuming the constant voltage drop model and the diode in reverse and forward bias regions,

a. The I-V curve.
b. The I_{R_2}-V curve.
c. The I_D-V curve.
d. The V_{R1}-V curve, with V_{R1} denoting the voltage across R1.
e. The V_D-V curve, with V_D denoting the voltage across diode.
f. The V_{R2}-V curve, with V_{R2} denoting the voltage across R2.