LA-CoNGA physics
Introduction to Measurements Systems
Diode Circuits

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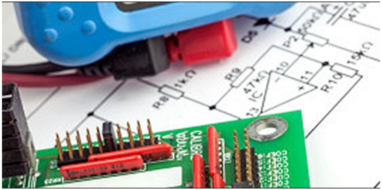
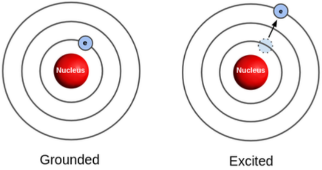


- Band Theory of solids
- How diode works
- Diode IV characteristics
- Types of diodes
- Diode circuits
- SiPMs

Atomic Model

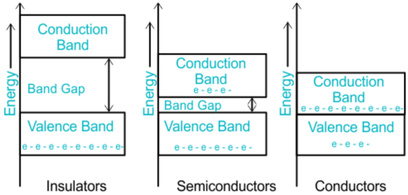
Energy levels

- The atomic energy levels describe the energy level of electrons within an atom, occupying a specific orbital.
- An electron can absorb energy to transfer to an orbital further away from the nucleus, or emit (release) energy to transfer to an orbital closer to the nucleus.



- If an atom absorbs energy from the outside (for example, by absorbing a photon), an electron can be promoted to a higher energy level.
- Conversely, an electron that falls from a higher to a lower energy level emits a photon.

- In a solid the individual energy levels become Energy bands, their structure depends on the type of material

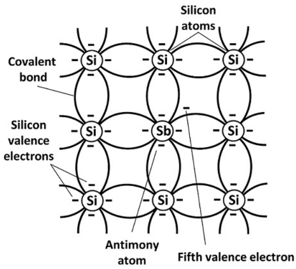


- When an electron in a semiconductor moves from the valance band to the conduction band, it leaves behind a vacancy in the valance band. This vacancy is called a hole.
- The hole behaves as if it were a positive particle

Doping Semiconductors

N-type semiconductor

- Substituting a *Si* atom with a *Sb* a free electron, Such an impurity is called an **donor**.

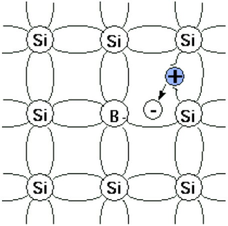


- The effect of this is to add filled, **localized energy levels** to the band structure.
- **Donors** are free to move in the solid and can contribute to electric current if an external voltage is applied.

Doping Semiconductors

P-type semiconductor

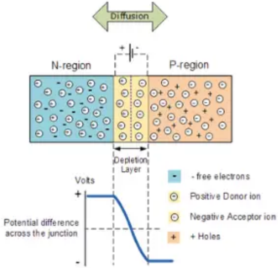
- Conversely, suppose we dope our pure *Si* with *B* (valence 3).



- *B* has one less electron than *Si* and thus has a vacancy in its highest energy level. Such an impurity is called an **acceptor**
- The holes in valence bands allow electronic conduction if an external voltage is applied.

The PN junction

- Now we consider what happens when we bring together a piece of *n-type* semiconductor and a piece of *p-type* semiconductor



- *Diffusion* of electrons into the *p-type* material creates a net charge near the junction.
- The electric field created by the net charge stpos the diffusion process.

- A diode is a non-lineal element, current can flow in only one direction.

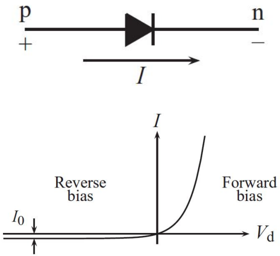


Figure: Diode schematic symbol and IV characteristic curve of a diode

- If forward biased

$$I = I_o \left(e^{qV_d/kT} - 1 \right) \tag{1}$$

Breakdown

- Reverse biased current I_o can increase in two ways:
  - **Avalanche Breakdown** electrons have enough energy to ionize atoms and increase current.
  - **Zener breakdown** The electric field in the depletion zone is large enough to make the current increase.

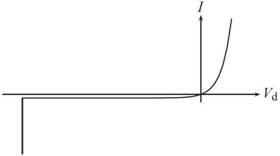
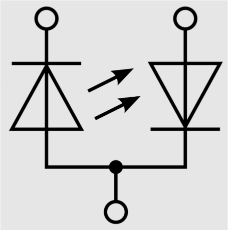


Figure: IV characteristic with breakdown

- Note that while the breakdown current increases rapidly, the voltage stays fairly constant (**breakdown voltage**).
- Despite the name, both types of breakdown are non-destructive.

Photon emission and absorption

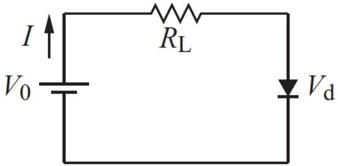
- Another interesting effect of a diode is the possibility of producing light or changing the electrical properties of the diode through photon absorption.
- The ubiquitous Light Emitting Diode (LED) emmits light when forward biased
- Photons can also be absorbed by the diode increasing the current that flows through it. This is the basis of the photo-diode, which is used in many applications as a light detector.



Basic diode circuit analysis

- The diode has an unusual I–V characteristic: it conducts readily for forward bias but does not conduct very much for reverse bias (assuming the reverse bias is less than the breakdown voltage).
- Applying KVL to this circuit we obtain:

$$V_o - IR_L - V_d = 0 \tag{2}$$



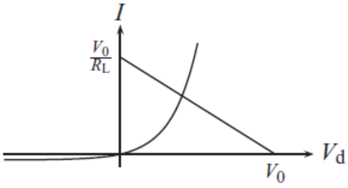
where V_d is the voltage across the diode.

Basic diode circuit analysis

- Using equation (1) we found that:

$$I = \frac{V_o - V_d}{R_L} = I_o \left(e^{qV_d/kT} - 1 \right) \tag{3}$$

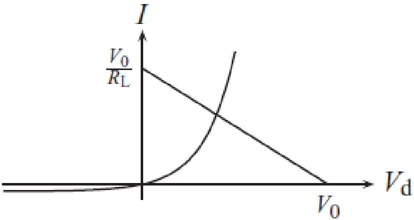
- This equation cannot be solved analytically for V_d,
- A second way is to solve the equation graphically.



- the second is the plot of $I = (V_o - V_d)/R_L$ and is called the **load line**

Load line method

- This graphical solution is often called the **load line method** in electronics. Note that the x- and y-intercepts for the load line are V_o and V_o/R_L, respectively, and the slope of the line is $-R_L^{-1}$.

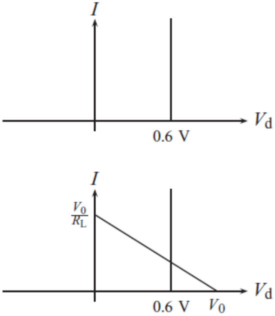


- note that the analysis is not restricted to positive V_o. If V_o is negative, the x- and y-intercepts will be on the negative portion of the x- and y-axes

Simplified model of diode

Series and parallel

- It is thus common practice to employ a **simplified model of the diode I–V** characteristic that allows for analytical solutions



- In words: the diode will not allow current flow unless it is forward biased; when it is forward biased, the voltage drop across the diode is $0.6V$.

Simplified model of diode

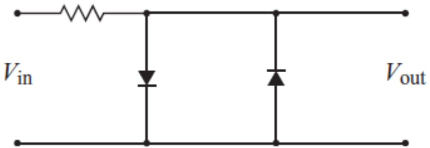
- Assuming the diode is forward biased, eq.(3) now yields

$$I = \frac{V_o - 0.6V}{R_L} \tag{4}$$

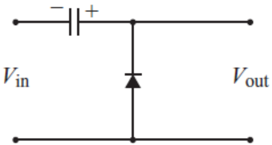
- how do we know at the start if the diode will be forward biased? When $V_d > 0.6V$
- The value $0.6V$ is appropriate for diodes made from silicon, the most common material. For Germanium $V_d = 0.3V$ and $V_d = 1.2V$ for LEDs.
- What do we do if it is not? A current I_o flows.
- I_o is so small ($\approx nA$) that can be approximated as $I_o = o$ when reverse biased

Diode applications

- Diode limiter

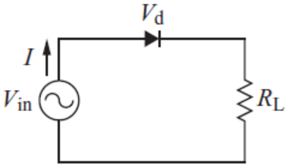


- Diode clamp

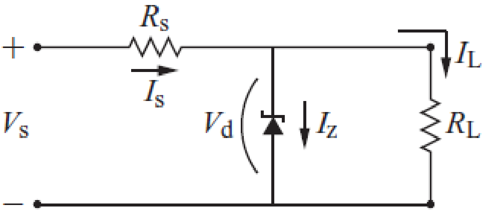


Diode applications

- Rectifier

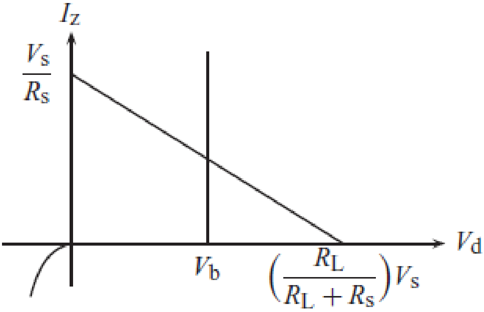


- Working at breakdown



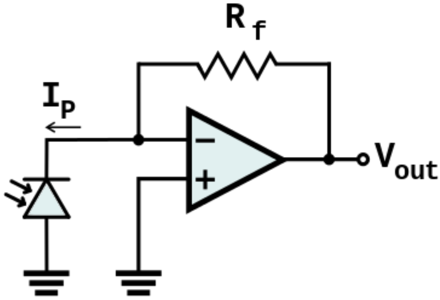
Diode Applications

- Working at breakdown



- Note that the axes are inverted

- Avalanche photodiodes (APDs) is a highly sensitive semiconductor photodiode detector that exploits the photoelectric effect to convert light into electricity.



- APDs are set near to the Breakdown voltage, when light hits the APD avalanche effect occurs increasing the current in the circuit.

Exercises

- Design and simulate a rectifier circuit:
  - Use a 100Hz 5V sinusoidal wave as input
  - Use a 1K resistor
  - Add a capacitor in parallel to R and vary its value (1μ, 10μ, 100μ
  - Fix the value of C (100μ for example) and decrease the value of R to 100Ω
  - Give a qualitative explanation of your results