EVROPSKÁ UNIE
Evropské strukturální a investiční fondy
Operační program Výzkum, vývoj a vzdělávání

MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

5. Fundamentals of semiconductors

5.1. Basics of semiconductor physics, PN junction

5.2. Semiconductor diodes

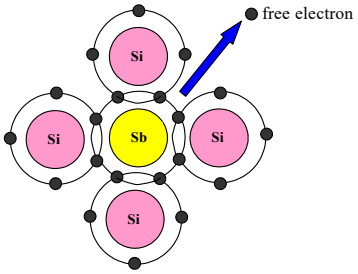
5.3. Bipolar transistor, thyristor, triac

5.4. Basic applications in electrical devices

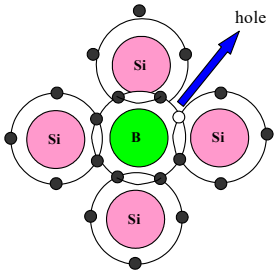
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January 2018

5.1 Basics of semiconductor physics, PN junction

Semiconductors like silicon or germanium provide no conduction at the temperature of 0 K, but at higher temperatures a finite number of electrons can provide some current. Because the conduction of these so-called intrinsic semiconductors is low, doped semiconductors are used in the semiconductors technology. The doping of semiconductors means an addition of a small percentage of foreign atoms in the regular crystal lattice of silicon or germanium. This doping produces dramatic changes in electrical properties of semiconductors and n-type and p-type semiconductors are created.



N-TYPE



P-TYPE

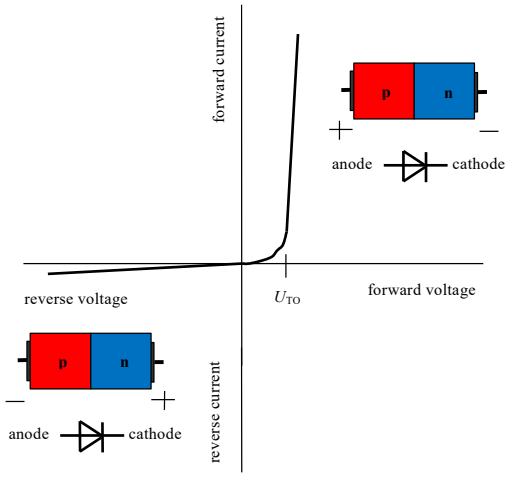
To produce n-type semiconductors, elements with five valence electrons must be added. These so-called donor impurities (antimony, arsenic or phosphorous) create free electrons as shown in the figure. To produce p-type semiconductors, elements with three valence electrons must be added. These so-called acceptor impurities (boron, aluminum or gallium) create holes as shown in the figure.

When p-type and n-type materials are placed in contact with each other, the junction enables the current to flow in one direction (forward biasing) but not in the other (reverse biasing). The basic diode is created (G. Rizzoni: Fundamentals of electrical engineering).

5.2 Semiconductor diodes

The *i-v* characteristic summarizes the behavior of the basic semiconductor (p-n junction) diode as seen in the figure. In the practical applications, some other types of diodes are used, e.g.:

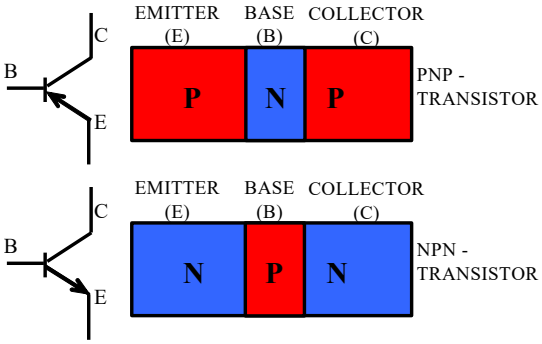
- Zener diode: conducts in reverse bias. It is used to stabilize voltage across a load to which is connected parallel and in reverse direction
- Light-emitting diode (LED): charges that cross the p-n junction emit photons. Depending on the material, colors from the infrared to the near ultraviolet may be produced. It is connected in series into circuit, and used as semiconductor light source.
- Photodiode: operates in reverse bias and converts light into electrical current so it is used in photovoltaic cells, in optical communication, photometry, etc. (https://en.wikipedia.org/wiki/Diode).

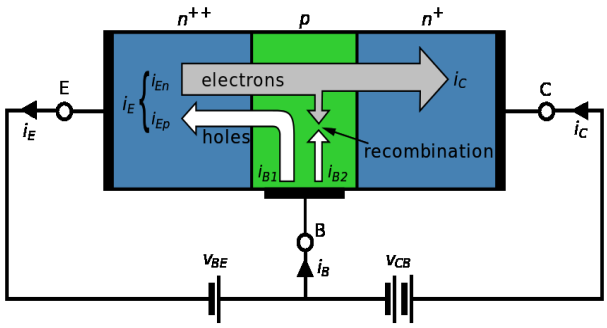


5.3 Bipolar transistor, thyristor, triac

5.3.1 Bipolar transistor

Bipolar transistor uses two junctions of three semiconductors types, so bipolar transistors of the type NPN and PNP are created. The base-emitter (BE) junction is forward-biased and acts as a diode. Nevertheless the base section must be much narrower than the emitter section of the transistor to minimize the recombination of electron and holes and to maximize the diffusion of the carriers towards to the base-collector (BC) junction which is reverse-biased, so the most of the carriers are swept into the collector. In the case of the NPN type, the electrons are “emitted” by the emitter, reach the very narrow base region, and after a few are lost to recombination in the base, most of these electrons are “collected” by the collector (G. Rizzoni: Fundamentals of electrical engineering).

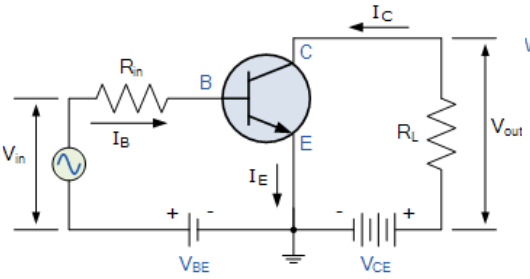


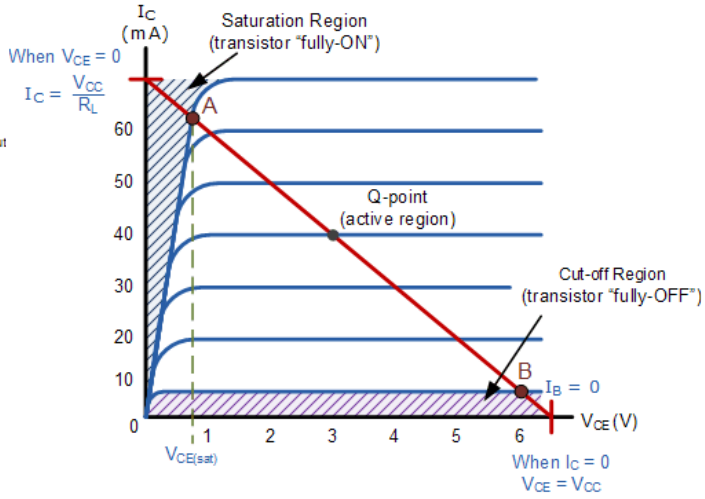


The transistors are used as amplifiers or switches, commonly in the connection called as the common emitter. If used as the amplifier, a current amplification factor β is defined as:

$I_C=\beta I_B$

Where I_C is collector current and I_B is base current. Typical values of β range from 20 to 200.

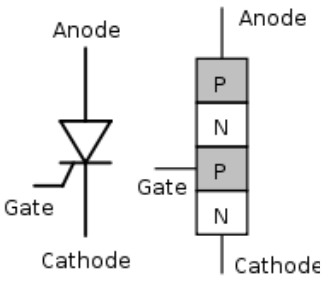


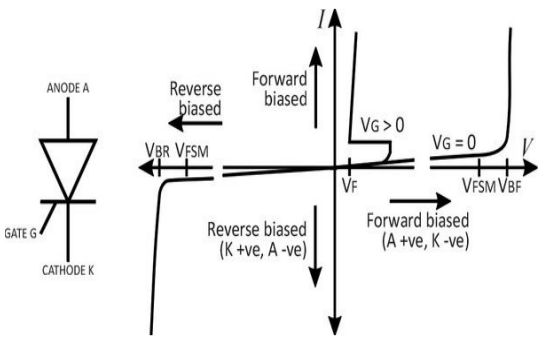


As the amplifier the transistor operates in the active region (e.g. the point Q in the picture), as the switch in the point A (ON, when the transistor is open with V_{CE} voltage of a fraction of volt and base current large enough to drive the transistor into the saturation region), or in the point B (OFF, when the transistor is closed with base current equal to zero) (G. Rizzoni: Fundamentals of electrical engineering).

5.3.2 Thyristor

The thyristor is a four-layered semiconductor device with three p-n junctions and three terminals: anode, cathode and gate. Each layer consists of alternately n-type or p-type material. The gate is a control terminal, which is attached to the p-type material near the cathode. To switch the thyristor, a positive potential must be applied at the gate. After the thyristor is switched on, the gate voltage can be removed, the thyristor continues to conduct (in contrast to the transistor), so the gate voltage can be a voltage pulse. The thyristor can be switched off if the external circuit causes the anode to become negatively biased (https://en.wikipedia.org/wiki/Thyristor).

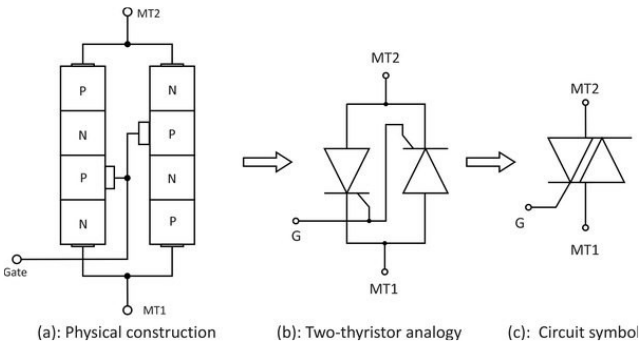


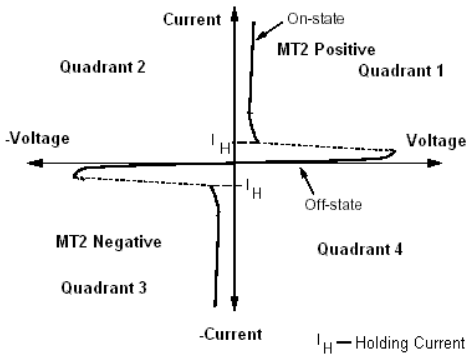


The *i-v* characteristic summarizes the behavior of the thyristor as seen in the figure. In contrast to the diode, the thyristor is controlled device used e.g. to control voltage and current on a load.

5.3.3 Triac

The triac is a semiconductor device which allows to current flow in both directions, so it is not reverse biased. It operates like two antiparallel connected thyristors. It can be triggered by applying a voltage pulse to the gate (analogous to the thyristor) The *i-v* characteristic summarizes the behavior of the thyristor as seen in the figure. It is used in many applications to control alternating voltage (https://en.wikipedia.org/wiki/TRIAC).





Triac Ampere-Voltage Characteristic Curve

5.4 Basic applications in electrical devices

The semiconductor devices are used in many industrial and household devices and appliances, and in modern computerized control and logic circuits.

- rectifiers (to convert AC current into DC current): diodes, thyristors
- inverters (to convert DC current into AC current): transistors
- amplifiers (to magnify signals): transistors
- switches (as contactless switch): transistors
- voltage regulators: thyristors, triacs
- voltage stabilizers: Zener diodes
- in photovoltaic power stations: photodiodes
- in electrical drives (speed control of motors): thyristors, transistors, triacs
- control and logic circuits in many technical applications: all

In the figure is shown how the production of semiconductors is split into main market segments.

