MARITIME UNIVERSITY OF SZCZECIN

ORGANIZATIONAL UNIT:
DEPARTMENT OF MARINE COMMUNICATION TECHNOLOGIES

INSTRUCTION

ELECTRICAL ENGEENERING AND ELECTRONICS
Laboratory
Exercise No 3: Semiconductor elements

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3. SEMICONDUCTOR ELEMENTS

3.1. The purpose and scope of the exercise

The aim of the exercise is to have knowledge in the field of construction, parameters, characteristics and application of basic semiconductor devices including rectifier diode systems, Zener diodes, light emitting diode, photodiode, transistor, thyristor.

Issues

1. Solid state band model.
2. Conductors, semiconductors, insulators.
3. P-n junction model.
4. Construction, parameters, characteristics and application of a rectifying diode.
5. Construction, parameters, characteristics and application of a Zener diode..
6. Construction, parameters, characteristics and the use of an light emitting diode.
7. Construction, parameters, characteristics and the use of photodiode.
8. Construction, parameters, characteristics and application of the transistor.
9. Construction, parameters, characteristics and application of the thyristor.

Control questions

1. Discuss the structure of the p-n junction.
2. What phenomena occur in the p-n connector after its connection to the power source ?
3. Draw and explain the shape of the current-voltage characteristics of the rectifying diode.
4. Draw and explain the shape of the current-voltage characteristics of the Zener diode.
5. Provide and discuss examples of the use of diodes: rectifier, Zener, capacitive and photodiode.
6. Describe the types of diodes and their parameters.
7. Draw the characteristics and discuss the use of the capacitive diode.
8. Draw and explain the shape of the characteristic $I_c = f(U_{ce})$ of the transistor in the common-emitter system.
9. List the basic parameters of the transistor.
10. For what purpose the transistor is practically used?
11. What is it and what a light emitting diode is used for.

3.2. Description of the laboratory stand

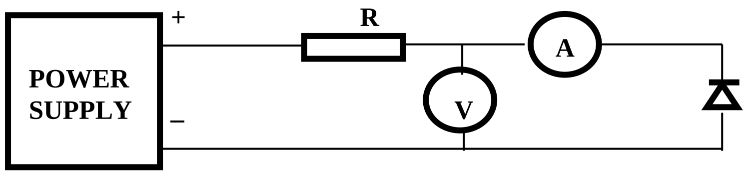
A set of instruments:
- two power supplies,
- three digital meters,
- circuit board for testing of semiconductor components.

Remember to set the voltage from the power supply to 0V after measurements and connect the power supply only after assembling the measuring circuit.

3.3. The course of the exercise

3.3.1. Diode testing

Connect the circuit for measure the diode characteristic in the blocking direction (reversed bias) (Fig. 3.3.1.).



Rys. 3.3.1. The connections for measuring the diode characteristic in the reversed bias

For the rectifying diode, measure the current flowing through the diode in the blocking direction (reversed bias) according to the voltages given in the table. Turn on the R_1 resistor.

Connect the circuit for measure the diode characteristic in the direction of conduction (forward bias) (Fig. 3.3.2.).

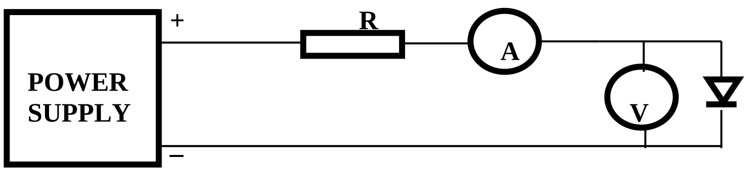


Fig. 3.3.2. The connections for measuring diode characteristic in the forward bias

For the rectifying diode, measure the voltage in the forward bias (direction of conduction) for the currents given in the table.

For the currents lower than 1mA use a R_1 resistor, for others –R_2 resistor.

3.3.2. Zener diode testing

Connect the circuit for testing the characteristics of the Zener diode (Fig. 3.5.3.). Measure the characteristics of the Zener diode in the blocking direction (reversed bias) according to the voltages and currents given in the table.

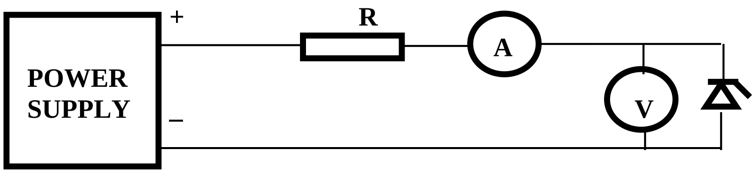


Fig. 3.3.3. The circuit for measure the characteristics of the Zener diode

Measure the transient characteristics of the simple stabilizer with the Zener diode (Fig. 3.3.4.) according to the voltages given in the table. To measure voltages, use two same digital voltmeters.

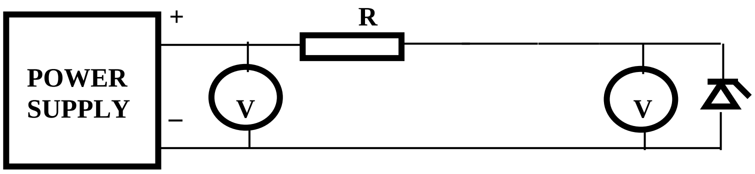


Fig. 3.3.4. The circuit for measure the transient characteristics of the stabilizer with the Zener diode

3.3.3. Transistor testing

Connect the system to measure the characteristics of I_c = f(U_{ce}) of the transistor (Fig.3.3.5.). For the voltage values given in the table, measure the value of collector current I_c with the base current set in the current stabilization, respectively: I_B = 1 mA, 2 mA, 3 mA (or given by the lecturer).

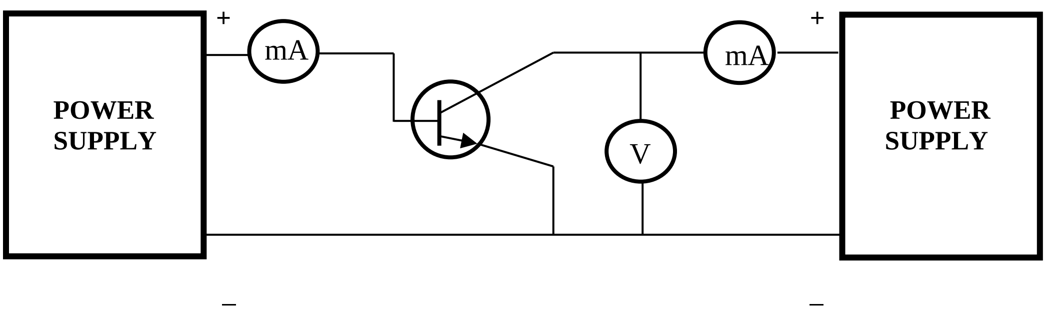


Fig. 3.3.5. The circuit for measure the transistor characteristics

3.4. Assessment conditions

The condition for assessment of the exercise is:

- to write a short test at the beginning of the class with a positive result;
- to do the exercise;
- preparing a report according to the instructions below;
  - positive assessment of the report on the next class;

The report should include:

- a measuring card,
- drawn characteristics $I_D = f(U_D)$ (I and III quarter of the coordinate system; set the scale for the forward bias: 100 mA – 5 cm, 2V – 4.cm, for the reversed bias 2μA – 1 cm, 30 V – 5cm),
- measurement circuits,
- explanation why the measurement circuits for measuring diode characteristics differ in the position of the ammeter and voltmeter,
- calculated resistance of the diode in the reversed bias and forvard bias for the last measurement points
- drawn characteristics $I_D = f(U_D)$ of the Zener diode in the reversed bias (III quarter of the coordinate system; set the scale: 10 mA – 5 cm, 15 V – 5 cm),
- Zener voltage read from the graph,
- dynamic resistance calculated according to the formula:

$$R_d = \frac{\Delta U}{\Delta I}$$

  where ΔU and ΔI are values read from the part of the graph in which the voltage is stabilized,
- plotted characteristics of a simple stabilizer with a Zener diode $U_{wy} = f(U_{we})$ (I quarter of the coordinate system; set the scale: 15 V – 5 cm),
- plotted transistor characteristics $I_C = f(U_{CE})$, (I quarter of the coordinate system; set scale: 500 mA – 5 cm, 2V – 8 cm),
- calculated mean (for different base current values) current gain coefficient, according to equation:

$$\beta = \frac{I_C}{I_B} \qquad \text{for } U_{CE} = 1.5 \text{ V}$$

- own conclusions and observations.

3.5. Theoretical part

3.5.1. P-n junction

The most commonly used semiconductors are silicon and germanium. They are elements from the fourth group of the periodic table, so they have four electrons in the last orbit. These electrons form the so-called covalent bonds such that each elemental atom is bound to four adjacent atoms by a bond consisting of two electrons. One electron from a given atom, the other from an adjacent atom. Coventent bonds keep the atoms of the element at fixed distances, creating a regular crystal lattice. Such a regular network exists at a temperature close to zero Kelvin.

Supplying energy from the outside, by raising the temperature of the crystal, or in another form, e.g. by irradiation, causes the electrons to be pulled out of the bonds. In this way, free electrons endowed with a negative charge are created, and holes being places with torn electrons, endowed with a positive charge. Both electrons and holes can move freely in the crystal structure.

The movement of electrons is obvious. The holes move in such a way that the electron from the neighboring bond complementing the torn bond forms a hole in the adjacent bond, thanks to which the hole moves from the binding to the bond. Electrons and holes are carriers of electric charge. The process of the formation of electrons and holes is accompanied by a reverse process called recombination consisting in the fact that if the moving electron is near the hole, the bond is restored and the hole and the free electron disappear simultaneously. The processes of hole-electron pair formation and recombination are in equilibrium. The amount of free charge carriers in a crystal depends only on the value of external energy supplied, i.e. on the temperature, If the temperature is higher there are more charge carriers and therefore semiconductor conductivity increases.

The mechanism for the formation of charge carriers described above concerns a semiconductor called spontaneous, i.e. without additives. For the construction of semiconductor devices such as diodes, transistors or integrated circuits, doped semiconductors are used. Doping consists in introducing a small amount of atoms of another element into pure silicon or germanium. If they are elemental atoms from the fifth group of the periodic table, such as phosphorus or arsenic, it will be a donor doping, if dopants are atoms of the third group of the periodic table, such as gal or ind, it will be an acceptor doping.

The donor atoms have five electrons in the last orbit, of which only four enter into covalent bonds with atoms of native silicon or germanium. The fifth electron, which does not fit the crystal lattice, is very loosely bound and a small dose of energy is enough to release it. This creates a free electron without creating a hole at the same time. The ionized atom of the admixture becomes a localized positive charge. Such a doped silicon or germanium is called an n-type semiconductor because electrons are the majority carriers in it. Formed in the n-type semiconductor due to the thermal generation of the hole, they constitute minority carriers.

The acceptor atoms have three electrons in the last orbit, so that they create a full bond with the neighboring silicon or germanium atoms, they capture the missing electron from the closest binding, creating a hole at this point. The dopant atom becomes a localized negative charge. Such a doped silicon or germanium is called a p-type semiconductor because the holes constitute majority carriers in it. The electrons formed in a p-type semiconductor as a result of thermal generation are minority carriers.

The connection of the n-type and p-type semiconductor results in the p-n connection. As a result of diffusion, electrons from the n area pass through the junction to the p region, where they recombine with holes. As a result, movable power carriers disappear on both sides of the connector. In the junction area n, therefore, the unbalanced positive charge layer (positive ions) remains, and in the p region the unbalanced negative charge layer remains (negative ions). These layers create a potential barrier, which when U_0 = 0.2 V for germanium is reached, and U_0 = 0.65 V for silicon, prevents the majority of carriers from continuing to flow from area n to area p and vice versa. The potential barrier is not an obstacle to the flow of minority carriers, generated thermally near the joint.

The connection of the external voltage with polarization plus to the area p, and minus to the area of n, greater than the value U0, causes the liquidation of the potential barrier and enables the current to flow through the connector. This is called polarization towards conduction (forward bias). Applying an external voltage with reverse polarity increases the potential barrier and prevents the current from flowing through the connector. This is called polarization in the blocking direction (reverse bias).

3.5.2 Rectifying diode

The rectifier diode is composed of interconnected p-type and n-type semiconductor regions with an admixture concentration of one atom of an admixture per 105 silicon or germanium atoms. The electrode derived from the area p is called anode and the electrode which is derived from the area n - cathode. The characteristic and symbol of the rectifying diode is shown in Fig. 3.5.1

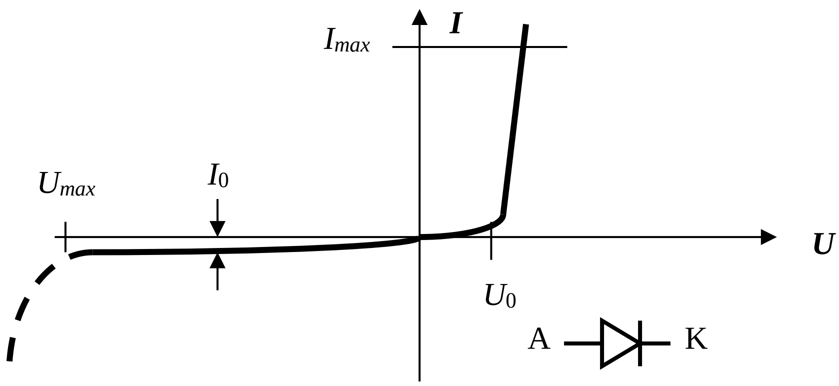


Fig. 3.5.1 Characteristics and symbol of the rectifying diode

The main task of the rectifying diode is straightening, i.e. converting alternating current into one-way current which flows in only one direction. The diode conducts when the positive voltage pole (plus) is connected to the anode and the negative (minus) to the cathode. In the reverse polarity, the current through the diode does not flow. The basic parameters of the rectifying diode are:

- maximum current in the towards conduction I_{max} **- (***its exceeding causes the diode to be destroyed due to overheating*),
- maximum voltage in the blocking direction U_{max} **- (***its exceeding causes the destruction of the diode due to a puncture of the connector),*
- diode reverse current I_0 **-** *(current flowing in the blocking direction, smaller when diode is better; its value increases with temperature and increases slightly when increasing the voltage in the blocking direction),*
- potential barrier voltage U_0 – (*this voltage is about 0.2 volts for germanium diodes and about 0.65 volts for silicon diodes; only after crossing it, the diode begins to conduct electricity).*

3.5.3 Zener diode

Zener diode is constructed, similarly as rectifying one, from connected areas of p-type and n-type semiconductor with the exception that the concentration of admixtures is higher (in the order of one atom of admixture per 104 silicon atoms). Zener diodes are practically only made as silicon. In the production of the Zener diode, special technology is used to ensure a very even distribution of admixtures in the crystal. Thanks to this, the puncture of the joint, occurring after exceeding the Zener voltage, is a reversible phenomenon. After the voltage drops below the Zener voltage level, the barrier properties of the connectors are restored. The Zener diode is used to stabilize the voltage. It is used to work in the blocking direction (plus to the cathode, minus to the anode). The characteristics and symbol of the Zener diode is shown in Fig. 3.5.2.

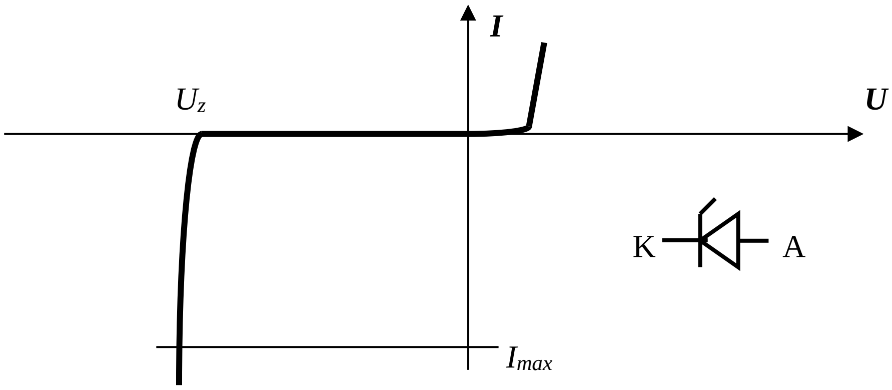


Fig.3.5.2 Characteristics and symbol of the Zener diode

Zener diodes can be made for different voltages, depending on the amount of added admixtures. The most common voltage diodes are from 3 V to 30 V.

Fig. 3.5.3 presents the principle of operation of a simple stabilizer on the Zener diode.

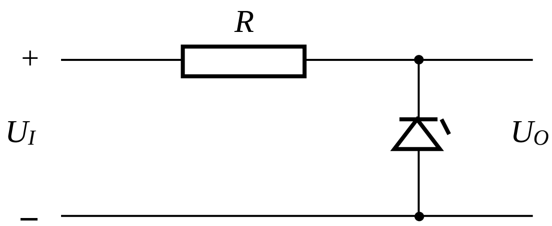


Fig. 3.5.3 Simple stabilizer on the Zener diode

If the input voltage is higher than the Zener diode voltage, the current will flow through the diode in the blocking direction. The higher the input voltage, the higher the current will flow in the circuit. The output voltage according to Kirchhoff's law will be the difference between the input voltage and the voltage drop across the resistor *R*:

$$U_O = U_I - I\,R$$

and in accordance with the characteristics of the Zener diode, it will be practically a constant quantity.

The basic parameters of the Zener diode are:

- Zener voltage U_Z – *(the voltage at which the breakdown of the connector occurs, its value for most of the diodes changes slightly when the temperature changes. Zener voltage for diodes made at about 6.5 V, practically does not depend on the temperature),*
- maximum current I_{max} – (*the highest current flowing through the diode after exceeding the Zener voltage, which does not cause its destruction due to the heat emitted).*

3.5.4 Capacitive diode

Each diode has a certain connector capacity. It results from the fact that there are two layers of electrical charge on the connector, similar to a capacitor, separated from each other. In capacitive diodes, the connector is shaped so as to obtain a relatively large capacity and that this capacity is strongly dependent on the value of the voltage supplied in the reverse direction. It is possible to treat a capacitive diode as a capacitor with variable capacity, which can be adjusted by changing the voltage supplied. The characteristics of capacity changes as a function of the control voltage and the diode symbol are shown in Fig. 3.5.4.

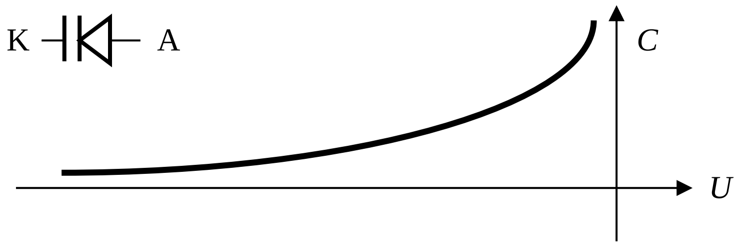


Fig. 3.5.4 Characteristics and symbol of the capacitive diode

The capacitive diode is used in automation systems, e.g. for automatic tuning of radio or television receivers to a selected station.

3.5.5 Photodiode

The photodiode is constructed in the same way as a rectifying diode, but it has a hole in the casing with an inserted lens to direct the incident light onto the p-n connector. The light rays cause the cents to be knocked out of the covalent electrons, resulting in the generation of a pair of holes - an electron. In this way, minority carriers arise that flow through the connector in its polarity in the reverse direction. The amount of carriers created, and therefore the amount of current depends on the intensity of incident light φ. The characteristics and diode symbol are shown in Fig. 3.5.5.

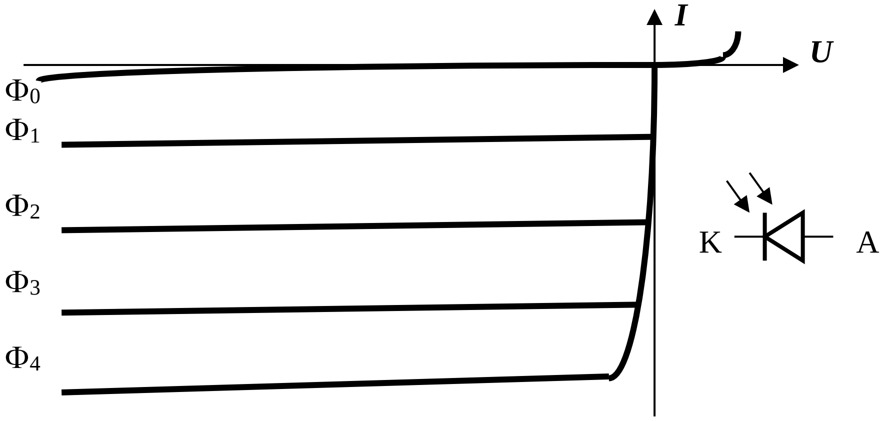


Fig. 3.5.5 Characteristics and symbol of the photodiode

The photodiode is commonly used in automation systems (automatic opening of doors, protection of objects against theft, etc.). The diode is turned in the blocking direction. As long as the light reaches the diode, the current flows through it. Obliteration of the light beam falling on the diode results in the loss of current in the circuit, which is detected by means of a suitable sensor and causes the actuation system to operate.

3.5.6 Transistor

The layer transistor is made of three alternating layers of a doped semiconductor. Depending on the order of the layers, we have transistors n-p-n and p-n-p. Three electrodes are led out from the semiconductor layers, outside the casing. The electrode derived from the inner layer is called the base. The electrode from one of the outer layers, dimensionally larger, is called the collector and the electrode from the second outer layer is called the emitter. Figure 3.5.6 shows the basic characteristics of the transistor. It is the dependence of the collector current on the collector - emitter voltage. The characteristic parameter is the base current.

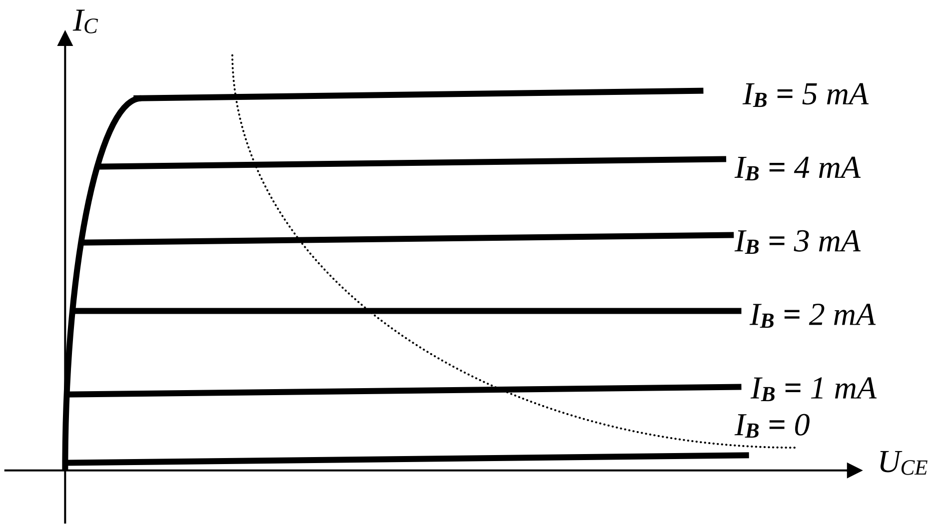


Fig. 3.5.6 Collector characteristic curves for various values of I_B.

The characteristics show that if the collector voltage - emitter is greater than a certain U_{CE0} value, the collector current I_C practically does not depend on this voltage, but depends on the value of the I_B base current. This dependence is approximately proportional and is expressed by the equation:

$$I_C = \beta \cdot I_B$$

where: – β is the current transistor gain factor and for modern transistors it is within limits 50 –1000.

Dotted line in Fig.3.5.6 shows the admission power of the transistor.

$$P_a = I_C \cdot U_{CE}$$

This is the maximum power that can be released in the transistor without fear of its destruction under the influence of the heat released.

The transistors are mainly used to amplify electrical signals - each change in the current in the base circuit causes a proportional but much larger change in the current in the collector circuit.

The basic parameters of the transistor are:

- I_{Cmax} – maximum collector current,
- U_{Cmax} – maximum collector–emitter voltage,
- P_a – admission power**,**
- I_{CE0} – zero current of the transistor; this is the current flowing in the collector - emitter circuit, in the absence of control in the base circuit (I_B = 0),
- β – current gain factor.

Figure 3.5.7 shows the symbols of the transistors n-p-n and p-n-p, and the polarity of the supplied bias voltage.

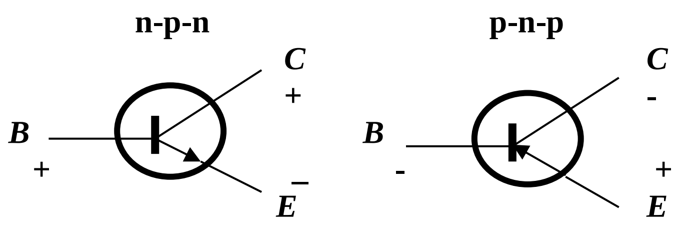


Fig. 3.5.7 Layer transistors symbols

3.5.7 Thyristor

The thyristor is a semiconductor element consisting of four semiconductor layers. Its construction and symbol are shown in figure 3.5.8.

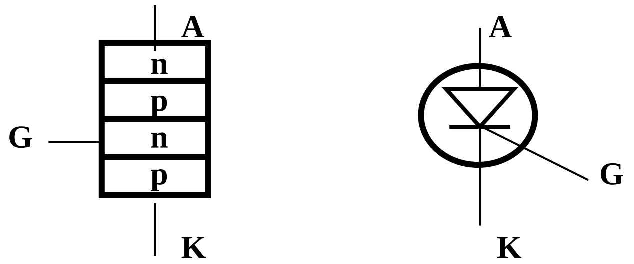


Fig. 3.5.8 Construction and symbol of thyristor

If we supply the polarization voltage to the thyristor: plus to the cathode, minus to the anode, the current through the thyristor will never flow (as in the case of a diode polarized in the reverse direction). With reverse polarity, i.e. plus to the anode, minus to the cathode, the current through the thyristor can flow but the condition of its flow is the prior inclusion of the thyristor. To do this, give a short-term positive voltage pulse to the gate G in relation to the cathode; this will cause the current to flow through the thyristor. To turn off the thyristor, reduce the voltage between the cathode and the anode to zero. If then the voltage increases again, then to turn on the thyristor one must again bring to the gate a short-time positive voltage pulse. The process of switching on the thyristor resembles lighting in the stairwells.

Thyristor is mainly used for power regulation in AC circuits. In contrast to regulation by means of resistors or autotransformers, power regulation performed by thyristor, practically does not bring losses on regulatory elements. In addition, thyristors are definitely smaller than resistors or autotransformers.

3.5.8 Light emitting diode

The light emitting diode is made of a different type of semiconductor, namely gallium arsenide. A characteristic feature of gallium arsenide is that recombined energy is released in the form of light and not heat, as was the case for silicon or germanium. So if the gallium arsenide diode is connected in the forward bias, the current will flow through it, which will be accompanied by strong recombination and the diode will emit light radiation.

Diodes made of gallium arsenide emit radiation in the infrared range, and thus invisible. In order to obtain visible radiation, diodes are made of a mixture of gallium arsenide and gallium phosphide. The color of the light emitted depends on the proportion of the components of the mixture.

Light emitting diodes are used as different types of voltage indicators. When the forward voltage is applied to the diode, the diode is on. When the voltage is off, the diode does not light up. This type of indicator differs from a normal incandescent lamp that consumes very little energy. This is particularly beneficial for devices powered by batteries or accumulators.