机械电子英语阅读教程

李义府　陈孝先　朱泗芳　秦瑞卿　编译

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前　言

本书为适应普通高等学校本科“双语教学”和外语教学不断线的要求而编写，目的在于增强学生的专业英语阅读能力，提高阅读外语专业文献的水平。

本书共分3章。第1章为小功率整流器，包含整流电路、半导体二极管、单相整流器和电压和电流脉冲的滤波器。第2章为放大器，包含有放大的过程与分类、晶体三极管、半导体放大器及RC耦合放大器。第3章为画法几何，包含投影法的分类以及点、线面的投影。

本书特点是适用性强，由于原文选自外语原版教材，语言规范，又配以翻译的中文，特别适合大学生进行专业英语的学习。本书适合机械类、电子类、自动化类及计算机科学类以及其他工科学生学习专业英语的需要。可作为普通高等学校相关专业的学生学习专业英语的教材，亦可作为其他专业的的学生学习英语的参考书。

本书由中南大学组织集体编写，由李义府、陈孝先、朱泗芳、秦瑞卿编译。其中第1章英文由陈孝先负责翻译成中文，李力争审校，原文选自I. Kaganov著的《Electronics in Industry》(Peace Publishes. Moscow)中Chapter One。第2章由李义府负责翻译成中文，罗桂娥审校，英文选自I. Kaganov著的《Electronics in Industry》中Chapter two。第3章3.3.1～3.3.6英文由朱泗芳负责翻译成中文，3.3.7～3.4.5由秦瑞卿负责翻译，贺志平审校，原文选自A. T. Chahly著的《Descriptive Geometry》。在编写过程得到中南大学信息科学与工程学院和机电工程学院许多同志的大力支持与帮助，在此向他们表示衷心感谢。

由于编者经验有限，书中错误难免，恳请广大师生指正。

编　者

2002年6月

目　　录

1 LOW-POWER RECTIFIERS

1.1 SIMPLE RECTIFYING CIRCUIT, ELECTRIC RECTIFIER AND THE REQUIREMENTS IT MUST MEET

An electric circuit, consisting of metal conductors, conducts equally well in either direction, i. e., conduction of the circuit does not depend on the direction of the current flowing through it. Therefore, if such a circuit is connected to an alternating voltage source, the current in the circuit will be alternating current.

If we are faced with the task of obtaining a single-direction current (direct current) in a circuit supplied by a source of alternating voltage u_1 (Fig. 1. 1a and b), this can be done by including a mechanical switch (Fig. 1. 1a), which would complete the circuit only for a certain portion of the alternating-voltage cycle, or an electric rectifier (Fig. 1. 1b), which passes current in one direction only.

The direction of the source voltage u_1, which coincides with the direction of conduction, is assumed to be positive, while the negative direction of the voltage u_1 corresponds to the nonconductive state.

If the speed and contacting time of the mechanical switch are adjusted so that the circuit would be completed during the entire positive half-cycle of the alternating voltage, then current will flow through the circuit during the entire half-cycle, as shown in the diagram (Fig. 1. 1c). When the voltage is negative, no current flows through the circuit. Approximately the same

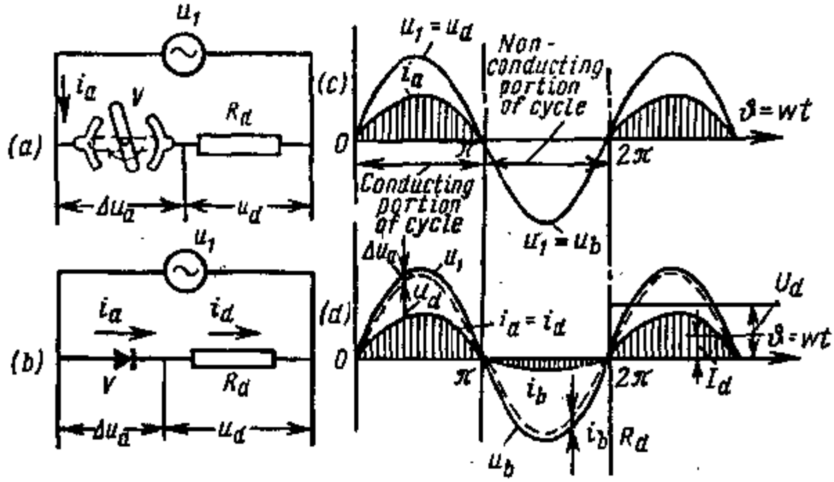

Fig. 1. 1 Halve-wave rectification

(a) circuit with a mechanical switch;

(b) circuit with an electrical rectifier;

(c) voltage and current diagrams of an ideal rectifier;

(d) of an actual rectifier

conditions are set up in a circuit with an electric rectifier.

Let us consider how voltage is distributed between the rectifier and the load resistance during the conducting and non-conducting portions of the cycle.

If we disregard the internal voltage drop across the rectifier, we come to the conclusion that during the conducting portion of the cycle, the source voltage u_1 is applied in full to the load resistance (Fig. 1. 1c). If the voltage drop Δu_a(Fig. 1. 1d) across the rectifier is taken into account, the voltage across the load resistance during the conducting portion of the cycle u_d will be less than u_1.

During the non-conducting portion of the cycle, when no current flows through the circuit (Fig. 1. 1c), all the source voltage u_1 is applied to the rectifier ($u_b=u_1$), as now the latter is equivalent to a break in the electric circuit. In some of the rectifiers in actual use, there can be a certain (relatively low) current i_b. This current is known as the reverse (or back) current, and the voltage drop across the rectifier during the non-conducting portion of the cycle as the reverse voltage. If there is no reverse current (Fig. 1. 1c), the reverse voltage for a given circuit is determined solely by the negative voltage of the supply source, but reverse current i_b lowers the reverse voltage across the rectifier u_b by a value $i_b R_d$ (Fig. 1. 1d).

The current i_a in the conducting direction is known as the forward current, and the voltage drop Δu_a, produced by this current as the forward voltage across the rectifier or the internal voltage drop across the rectifier.

The mean direct current flowing through the load R_d, is called the rectified current and is designated as I_a, while the mean voltage across the load is called the rectified voltage and is designated U_d.

In the simple circuits shown in Fig. 1. 1a and b, which include only one rectifier, the rectified current flows through the circuit only during positive half-cycles of the alternating voltage. The current obtained in this way is intermittent.

A continuous rectified current curve can be obtained by using a number of rectifiers in the circuit, which would pass current alternately during each half-cycle of the alternating voltage.

In a number of types of electric rectifiers the values of internal voltage drop Δu_a and the reverse current I_b are so small that they can initially be neglected when the operation of circuits employing such rectifiers is analysed. In this way the properties of an electric rectifier are idealized. Rectifiers with zero forward voltage and reverse current are called ideal rectifiers. Any actual rectifier is only a certain approximation of an ideal rectifier.

The voltage and current curves in Fig. 1. 1c correspond to those of an ideal rectifier, while the curves in Fig. 1. 1d to an actual rectifier.

The principal criteria for evaluating actual rectifiers are the following:

(1) mean and peak forward currents which the rectifier can pass during the conductiong portion of the cycle without overheating while still retaining its rectifying properties;

(2) the internal voltage drop Δu_a produced by the forward current;

(3) the peak reverse voltage U_{bmax}, which the rectifier can withstand without breakdown and excessive increase in its reverse current. The voltage U_{bmax} determines the electrical strength of the rectifying device;

(4) the life of the rectifier.

An electric rectifier is the more perfect the lower the value of the internal voltage drop Δu_a, as this affects the electric power converted in the rectifier into heat, and consequently, the efficiency of the rectifier.

Indeed, as can be seen from the diagram in Fig. 1.1b, the instantaneous power loss in the rectifier during the conducting portion of the cycle is

$$\Delta P_a = \Delta u_a i_a \tag{1-1}$$

The power consumed by the load (calculated from the direct components of the current and voltage) is

$$P_d = U_d I_d = U_d I_a \tag{1-2}$$

Taking $\Delta u_a = \text{const} = \Delta U_a$, we obtain the following expression for the power loss in the rectifier:

$$\Delta P_a = \frac{1}{2\pi}\int_0^{2\pi} \Delta P_a d(\omega t) = \Delta U_a \frac{1}{2\pi}\int_0^{2\pi} i_a d(\omega t) = \Delta U_a I_a \tag{1-3}$$

Determining the efficiency by the ratio of the power P_d to the sum of P_d and ΔP_a, we obtain:

$$\eta = \frac{P_d}{P_d - \Delta P_a} = \frac{U_d I_a}{U_d I_a + \Delta U_a I_a} = \frac{U_d}{U_d + \Delta U_a} \tag{1-4}$$

From (1-4), it follows that for a given U_d, not only is the efficiency of the rectifier the higher the lower the value of ΔU_a, but also that for a given type of rectifier and a definite value of ΔU_a, the efficiency of the rectifier is the higher the higher its working voltage.

The value of the peak reverse voltage of a rectifier determines the peak rectified voltage obtainable in a rectifier circuit, and the number of rectifiers which have to be connected in series, if one rectifier is insufficient for obtaining the required value of rectified voltage.

A sufficiently long life is also an important criterion in evaluating the quality of a rectifier due to the fact that during the operation of some types of valves certain factors may limit their normal time of operation.

Among the types of rectifiers which meet the above requirements in various degrees are:

(1) electronic rectifiers (valve diodes);

(2) ionic rectifiers;

(3) semiconductor rectifiers.

The physical properties and characteristics of all three types of low-power rectifiers employed in the supply circuits of electronic equipment will be dealt with in the following three paragraphs prior to a description and analysis of the operating conditions of rectifying circuits.

1.2 SEMICONDUCTOR DIODES

Semiconductors are substances with specific resistance between 10^{-5} and 10^{2} ohms m. The semiconductor diodes used as rectifiers are combinations of semiconductor layers with various types of conduction. Before embarking on a study of the structure and physical properties of semiconductor diodes, let us first familiarise ourselves with the nature of this conduction in semiconductor substance.

1.2.1 Two Types of Semiconductor Conduction

Electrons can travel through semiconductors either as free particles, when they are not bound to the atoms of a crystal lattice, or they can pass from atom to atom, occupying vacant energy levels (holes) in the atoms of the substance's crystal lattice. The conduction which develops in the first case is called electron or n-conduction, and that developing in the second case-hole or p-conduction.

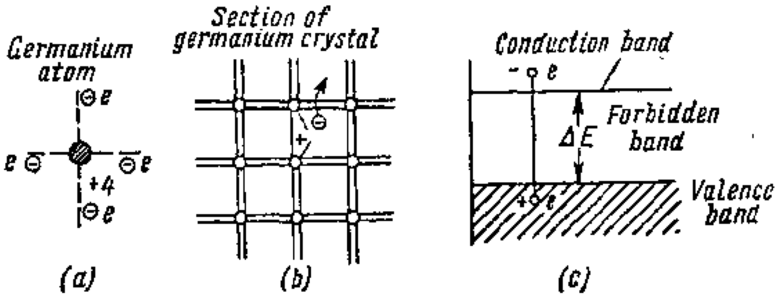

Fig. 1. 2 The appearance of a free electron and a hole in a germanium crystal

(a) valence electrons in germanium atom;

(b) escape of an electron from a crystal element valence bond and formation of a hole;

(c) energy diagram

In order to understand the conditions under which one or the other type of conduction takes place, let us consider a certain volume of the crystal lattice of germanium, the material used in manufacturing one of the common types of semiconductor rectifiers.

Germanium belongs to the fourth group of elements of the Mendeleyev periodic table. As shown in Fig. 1. 2a, each of its atoms contains four valence electrons. During the crystal forming process, these atoms take up positions at the points of the body crystal lattice, schematically shown in Fig. 1. 2b, for the sake of simplicity as a flat lattice. The double lines drawn between the lattice points represent the valence bonds between each pair of electrons belonging to different atoms. In the case of an ideal crystal, all the points of the lattice at absolute zero temperature are taken up by atoms and all the electrons participate in valence bonds.

All the energy levels, which are occupied by valence electrons at absolute zero temperature, form the band of occupied (or valent) levels. In the energy diagram in Fig. 1. 2c this band is hatched. Above the valence band of insulators and semiconductors lies a forbidden level band in which (as long as there are no defects in the lattice or impurities of atoms of other substances) electrons cannot possess energies in conformity to the band. Still higher lies the band of free levels or conduction band. The latter is called thus because the electrons with energies corresponding to this band become free of bonds with atoms and can therefore travel through the crystal, taking part in either chaotic or directed motion, if there is an electrical field inside the crystal.

For an electron to pass from the valence band to the conduction band in the presence of a forbidden band, it is necessary to impart to it additional energy not less than that corresponding to the width of the forbidden band. In the case of germanium, the width of the forbidden band is 0. 72 eV (electron-volts), while for silicon which is also used in semiconductor devices, it is 1. 11 eV wide. The additional energy required for liberating electrons from valence bonds can be imparted to them in the form of thermal energy, taken up by the crystal atoms or radiant energy.

At temperatures above absolute zero, some electrons already possess sufficient energy to cross over to the conduction band. The amount (concentration) of such electrons in the conduction band per 1 cm^3 is given by the equation

$$n_e = Ae^{-\frac{\Delta E}{2kT}} \qquad (1\text{-}5)$$

where A is a physical constant, the numerical value of which depends on the type of crystal;

ΔE is the width of the forbidden band, determined by the difference in energy levels, erg;

$k = 1.37 \times 10^{-16}$ erg/deg is the Boltzman constant;

T is the absolute temperature in K.

From (1-5) it can be seen that the number of electrons which have passed over to the free level band is the higher the narrower the band and the higher the temperature of the semiconductor. In the case of silicon, for example, the electron concentration in the free level band is less than in germanium at the same temperature, since ΔE for silicon is greater than for germanium.

An electron passing out of the valence band sets free the energy level which it occupied there. An empty level in the valence band of a crystal is known in physics as a "hole".

As the absence of an electron is equivalent to the presence of a positive charge in that place, a hole is said to possess such a charge. This is illustrated in Fig. 1. 2b.

In the energy diagram (Fig. 1. 2c), the departure of an electron from a valence bond corresponds to the appearance of an electron in the conduction band and the simultaneous appearance of a hole in the filled level band.

A hole can be filled with an electron from a neighbouring atom, and the newly formed hole filled with the next electron. In this way, a motion of electrons is set up along the vacant places or holes. The motion of electrons along valence levels is equivalent to the motion of holes in the opposite direction.

While there is no field, the holes, just as electrons, move chaotically. In the presence of a field, a certain direction is superimposed on this motion. Thus hole conduction is set up in a semiconductor. If both free electrons and holes are present, conduction is made up of both electron and hole type conduction.

Even though the motion of holes is actually the motion of electrons, nevertheless it is essential to differentiate between these two types of conduction, as they determine not only the rectifying but also other properties of semiconductor structures.

In impurity-free semiconductors, both types of conduction take place simultaneously. These are intrinsic types of conductions. At normal temperatures, they are usually low. Semiconductors with impurities are characterised by considerably greater values of conductivity. One or the other type of conduction (electron or hole) predominates, depending on the type of impurity.

If there is an excess of valence electrons in the impurity atoms as compared to the atoms of the basic substance, the introduction of an impurity atom into the crystal lattice will liberate a surplus electron. Such (donor) impurities increase the number of free electrons. These semiconductors are called semiconductors with electron or n-type conduction.

If the impurity atoms possess one valence electron less than the atoms of the basic substance, the introduction of the impurity atom into the crystal lattice will bring about the formation of a hole. With such (acceptor) admixing, the number of holes in the semiconductor and its hole conduction increase. Such impurity semiconductors are called hole or p-type semiconductors.

When p-type semiconductors come into contact with a metal or other semiconductor, they can accept electrons, while semiconductors of the n-type donate electrons.

The type of a semiconductor can be found by passing direct current through it in the presence of a constant magnetic field directed at right angles to the current lines. This will cause a transverse potential difference in the semiconductor, whose sign depends on the semiconductor type (Hall effect).

In order to obtain germanium (included in the fourth group of the periodic table) possessing predominantly electron conduction, after ridding it of random impurities, it is doped by one of the elements of the fifth group (usually antimony or arsenic), the atoms of which contain five valence electrons, as shown in Fig. 1. 3a (donor impurity). On entering into the crystal lattice point, four of the valence electrons of the impurity atom become bound to the neighbouring atoms of germanium, while the fifth electron is liberated as shown schematically in

Fig. 1. 3b. Having lost an electron, the impurity atom becomes a positive ion. The energy level of such ions, which have been disseminated in a crystal lattice, usually lies witbin the forbidden band, close to the freelevel band, as shown in Fig. 1. 3c. Four ions of donor material (represented by crossed-out circles) are shown here in the forbidden band. The electrons they have given up have passed into the conduction band. As long as the freed electrons do not go far away from their ions, the microvolume of the semiconductor remains electrically neutral. When they pass to more distant volumes, the remaining ions create a surplus positive space charge in the microvolume of the semiconductor.

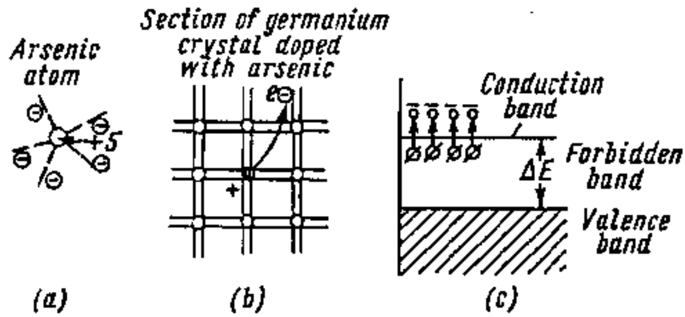

Fig. 1. 3 Appearance of a free electron and a hole in a germanium crystal on introduction of a donor arsenic atom

(a) valence electrons in arsenic atom;

(b) escape of a free electron and formation of a ositive ion;

(c) energy diagram

For converting tetravalent germanium into an extrinsic semiconductor with predominantly hole conductivity, it should be doped with one of the elements of the third group of the periodic table (usually indium or gallium), the atoms of which possess three valence electrons, as is shown in Fig. 1. 4a. Such an impurity atom, on substituting a germanium atom (acceptor doping), brings about the formation of an empty place (hole) in one of its valence bands, as shown in Fig. 1. 4b. The hole is readily filled (even at room temperature) with an electron from one of the adjacent atoms, which results in the impurity atom becoming a negative ion. The energy level of such an ion is located in the forbidden band, closer to the band of filled levels, as shown in Fig. 1. 4c. The energy diagram in Fig. 1. 4c shows four atoms of acceptor material (represented by crossed-out circles), which have bound electrons from the filled level band. When holes are filled with electrons from more distant volumes of the crystal (in other words, when holes depart) a negative space charge appears in the microvolume, produced by impurity ions.

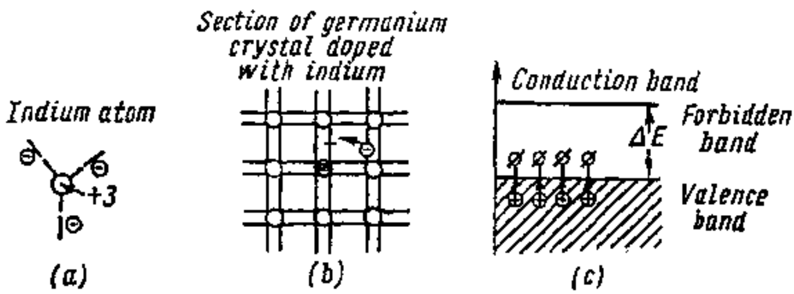

Fig. 1. 4 Appearance of a hole and a negative ion in a germanium crystal on introduction of an acceptor indium atom
(a) valence electrons in indium atom;
(b) bounding of an additional electron to the impurity atom and formation of a hole;
(c) energy diagram

Depending on the weight fraction of the impurity, the conductivity of the extrinsic semiconductor increases in comparison to that of an intrinsic semiconductor by tens and hundreds of thousands of times. The charge carriers which determine the type of conduction of an extrinsic semiconductor (electrons in an n-type semiconductor and holes in a p-type semiconductor) are the majority carriers, while those of the opposite sign are called the minority carriers.

A feature of either type of semiconductor is that the product