# Issues of Effective Study of Semiconductor Device Properties in Engineering Educational Institutions

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*The article justifies the importance of developing new interactive pedagogical technologies for the study of semiconductor physics in higher and secondary technical educational institutions. Interactive teaching methods developed by humanities teachers have been shown to be ineffective due to their lack of understanding of technical tools, structures, and machines. It is shown that semiconductor devices are present in the construction of equipment intended for any task, and the physical phenomena occurring in their volume are shown to affect the accurate and efficient operation of the equipment. A new innovative method was proposed based on the teaching of technical sciences, the physics of semiconductors. The interactive methods "Internet-zombie" and "Scheme fragment method" developed for lectures and laboratory sessions were recorded. The results of the experimental lessons were analysed. It has been shown how important it is to develop new teaching methods by experienced pedagogues of technical universities.*

*Keywords: semiconductors, physics, electronics, industry, devices, electro-physical properties, method, teaching technology, education*

## INTRODUCTION

In parallel with the development of science and technology, demands on the knowledge of young professionals studying at higher and secondary technical engineering educational institutions are also increasing. There are many reasons for this. These include the transition of the world's economic system to a market economy, the increase in the world's population at the expense of young people who need to be provided with permanent jobs, increased competition, the emergence and importance of competent operation of modern machinery, technology, etc. In all these problems there is a key solution. It lies in the steady increase of improvement and modernization of learning processes (Valentyna, C. V., et.al., 2020), (R.I. Zinurova, et al., 2010), (Borisova, I. I., et.al., 2011), (Kraevsky, V. V., et.al., 2007) with a maximum approximation of the technological structure of technical devices, instruments and automation systems (Guryanova, 2011).

It should be noted that practically in all countries of the world, scientists with pedagogical or humanities education are the most engaged in the field of education (Kudryavtsev, R. A., et.al., 2013), (Tarasov, V.A., et.al., 2013), (Nesbor, 2010), (Kovtaradze, 2009), (Sokolova, 2006). Due to the lack of technical education

these researchers, despite hundreds of scientific developments and prerequisites to improve the quality of education, have not yet satisfied the needs of production about the knowledge and skills requirements of young professionals. Of course, there are some works of engineering scientists (Vladimirov, 2011), (Kuzmina, 2011), (Krayevsky, V.V., et.al., 2007), (Borisova, 1991), (Polat, E.S., et.al., 2008), (Tan, T., et.al., 2010), but the branch of engineering education is so wide (Timoshenko, L.I., at.al., 2011), (Timoshenko, 2014), (Shibaev, 2012) that it has not yet been possible to cover completely at least one direction.

In this connection, in the age of micro- and nano-technology, the focus on e-learning and electro-technical training requires that teachers of higher and secondary vocational education institutions improve their methods of teaching special subjects and develop increasingly new interactive teaching methods (Timoshenko, 2014), (Shalimova, 2010), (Borisova, 1991), (Polat, E.S., et.al., 2008), (Tan, T., et.al., 2010).

## MISSION STATEMENT

Modern industry relies on electronic devices which are mainly made from semiconductor materials (Shalimova, 2010), (Ter-Martirosyan, 2008). Semiconductors are known to occupy an intermediate region between metals and dielectrics by their electrophysical properties. These properties favourably act in the creation of devices and devices nowadays and are widely used in industrial enterprises, mechanical engineering, aviation, robotics, mechatronics, optoelectronics and in many branches of science and technique. The correct operation of semiconductor devices depends entirely on the knowledge of the personnel operating them, and this contributes to extending their service life, improving the quality of work performed and achieving economic gains by eliminating the need to purchase new equipment when old devices fail.

Based on the above considerations, it can be concluded that the in-depth study of the subject of semiconductor technology has a significant impact on positive production performance. This dictates the importance of developing teaching methods for high school students, students at vocational-technical schools, as well as students at courses and centres for professional development, to even more advanced and refined teaching methods. In addition, the move towards IT and computer technology not only makes it possible for students to master the subject matter to a high standard but also for research in this area to be carried out at a state-of-the-art level.

Scientific research is an integral part of education. This conclusion is supported by the need to troubleshoot appliances and devices when they break down or fail. A positive solution to these problems is expected with the specialist's in-depth knowledge. The meaning of deep knowledge lies in the skills to analyze and synthesize the operating and technological modes of semiconductor devices, the mutual influence of the electro-physical, performance properties of materials from which parts or components of assemblies are made, the influence of temperature or other environmental factors on the operation of the plant in operation and so on. Each of these factors has a wide range of aspects, which should be carefully considered not only during operation but also during fabrication.

For example, semiconductor materials have, in addition to their many properties, a strong temperature dependence on their internal electro-physical parameters. Failure to take this factor into account will never allow a well efficient device to be created. Because a semiconductor device that gives very good results at room temperature does not give the expected performance in harsh climatic conditions. After all, the planet is made up of continents with different climatic conditions. In addition, the presence of seasonal weather conditions and daily variations in temperature can also have a significant influence on the results obtained. This dependence is one side of the issue. When one considers the presence of optical, mechanical, structural, thermal, radioactive and even degradation influences on semiconductor parameters in the atmosphere, one can easily understand such an important scrupulous approach to teaching students in higher and secondary technical schools.

There is another subtle side to the issue. It is difficult of mastering the subject of semiconductor engineering. Unlike humanities subjects where there are no complex formulas, diagrams and drawings, or graphs, semiconductor engineering requires the ability to work with the listed elements of engineering

technology. Most students succumb to the boredom of lectures and laboratory classes where diagrams, drawings and mathematical formulas are subject to study. This is where a teacher is required to be highly creative, professional, skilful and much more (Kapp, 2012), (Kasimakhunova, M., et.al., 2021), (Hoyt, S., et.al., 2020). If we take into account the fact that in foreign and domestic literature, there is practically a paltry amount in the field of teaching with new innovative technologies, then we can conclude that in this direction it is necessary to strengthen the work with an accelerated pace and a wide scope. Because the introduction of computer technology into operational and research work, in itself, requires the development of many modelling techniques, programming, mathematical calculations and a proper understanding of the laws of physics, chemistry, etc. Without taking the above factors into account, it is not possible to improve engineering education.

There is another challenge. It requires a sound psychological approach on the part of the teacher of a technical school. A proper and timely understanding of the psychological state of the trainee opens the door to interest in the subject. If we consider the fact that in most technical schools the subject of psychology is taught poorly and an engineer, after this school, starts teaching, then we can see the inferiority of the degree of education. It is not for nothing that pedagogical scholars recommend playful methods of teaching. The whole secret of good knowledge lies in the maximum engagement and focus of students during lectures and laboratory and practical sessions. Now the question arises: are there many new interactive and innovative methods for teaching the physics of semiconductors, which is the basis for semiconductor technology, micro- and nano-electronics? Of course, here it is impossible to answer positively. And, such a task requires the development of research work to increase teachers' creativity not only in semiconductor physics and semiconductor technology but also in other branches of physics: nuclear, molecular, optical, etc.

In connection with the above statement of the problem, in the present and subsequent works, we pay attention to research on the development of methods to enhance the creativity of teachers of engineering universities, innovative interactive methods of teaching students to master and deeply understand the physical processes occurring in the semiconductor material volume, the relationship of the electrical and physical parameters of materials, research work both theoretical and computational and experimental measurements.

## TEACHING METHODS

The lecturer delivering the course should take into account the following problematic points: the excessive length of the topic, the large number of trainees, and the psychological state of the students. The latter is very much affected when delivering a class in the last couple of classes. Fatigue, absent-mindedness and other reasons have an almost negative effect on the listener's brain reception of knowledge.

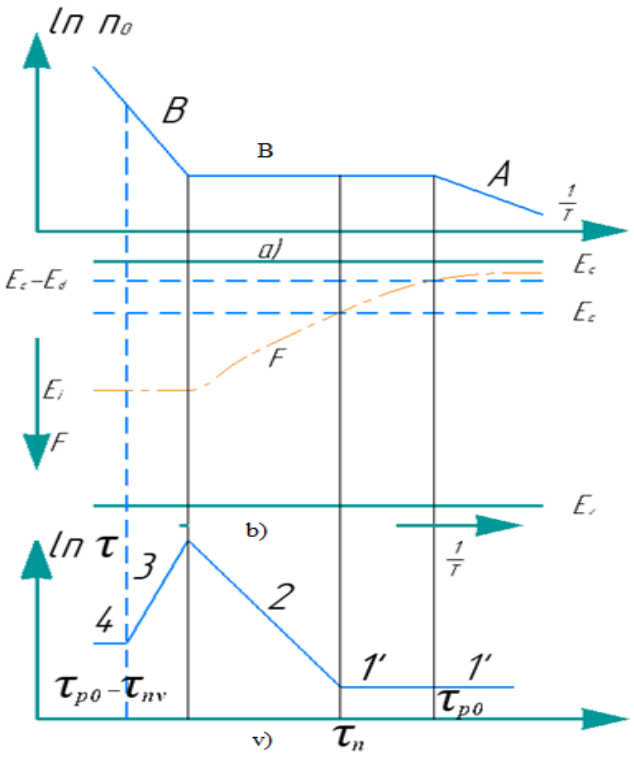
The methodology developed for explaining the topic should be based on examples of well-known phenomena in nature, life cases or, from the life of the students themselves, as well as on their strongly appealing elements, amusements and hobbies. Experience has shown that even some things that are not related to semiconductor physics can also serve as good examples of explanations if one wishes to do so. So, for example, a football game - very well applied when explaining elastic and inelastic strokes of electrons in semiconductor volume, "good" and "bad" student - when calculating the value of efficiency factor of this or that device, military training of soldiers - when explaining generation and recombination process under the influence of external or internal energy and so forth. Therefore, the authors of this work consider it effective to draw students' attention to life situations; no matter whether they are positive or negative. There is an explanation for everything. Here, the ingenuity and skills of the teacher to correctly apply and explain what is happening to play an essential role.

Our recommended methodology for explaining e.g., the topic "Temperature dependencies of electro-physical properties of semiconductor materials" adopts the "Internet zombie" method. The name was not chosen by chance. Today's youth is almost 95% covered by the Internet and its content. The influence of mass media (mass media), Youtube, Facebook, and Tik-Tok channels as well as a lot of entertainment is evident. Even the upbringing of the younger generation is also influenced by it. A skilful approach to the

issue not only allows for an accessible and comprehensible mastering of the topic under study, but also helps to remember for a long time, to remember from the first time when reminded of the name of the method and, most importantly, educates the younger generation.

The sequence of work in this method is as follows. First, the teacher briefly explains the essence, usefulness and negative side of the Internet. The students' notion of the Internet is quite broad, and concerning the possibilities of the Internet in obtaining information on the material both in the form of textbooks and videos, photo information, and reference data, they should smoothly move on to the positive and negative sides of this server. To give an example of how films about heroes, patriots, and noble people affect the psychology of the young generation, it is necessary to tell how immoral films, about murder and violence, fantasy, and war are reflected... Then, under the perception of this information, how they affect on psyche and nerves of weak-minded people. After that, liken the effect of temperature on the electro-physical parameters of a semiconductor material, designating each physical parameter as one of the weak-minded people. Suppose conductivity is Man-1, resistivity is Man-2, thermocouple coefficient is Man-3, etc. Thus, it is possible to simultaneously indicate and observe the dependencies of these "Man"-parameters, and how the respective parameters behave. For clarity, the graphical dependence of these parameters on temperature should be drawn, as shown in Figure 1.

**FIGURE 1**
**DEPENDENCE OF EQUILIBRIUM CONCENTRATION (A), FERMI LEVEL (B), AND CHARGE CARRIER LIFETIME (*V*) ON TEMPERATURE FOR A DONOR SEMICONDUCTOR**




Here "Man-1" is the equilibrium concentration of charge carriers (Fig.1*a*), "Man-2" is the Fermi level (Fig.1*b*) and the carrier lifetime of the charge (Fig.1*v*). All these parameters to a greater or lesser degree depending on temperature. The temperature dependence of the first parameter.

Fig.1*a* has three regions. Two of them strongly vary, one region practically does not depend on it. When explaining these dependencies (or even independencies), students need to reveal the reasons for the change

(or not). In the “Internet Zombie” method, such dependencies are explained for what reasons a person who is dependent on the Internet can do either criminal or useful things. Using the example of a semiconductor, when the concentration of carriers increases (or decreases) and how temperature affects it, or which physical process contributes to its stability of quantity - everything is explained based on the theory of similarity. The teacher should pay attention to the usefulness of the parameter.

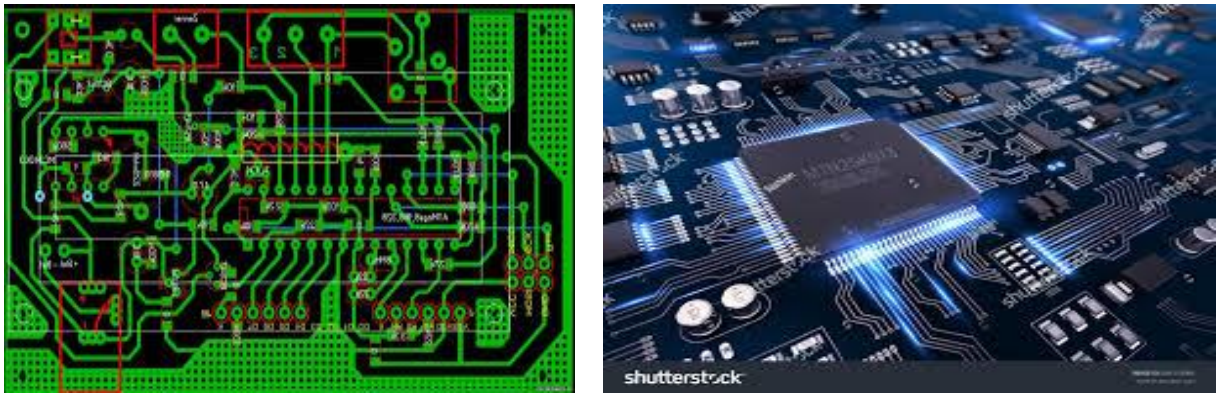
Similarly, changes in the Fermi level can be analyzed (Fig. 1*b*). Moreover. It is important to tell the story of the physical phenomena occurring in the volume, or contact, of a p-n junction. Because it is the Fermi level that determines the degree of curvature of the p-n junction in the contact. This approach instils the skills of a researcher. The student will gain a deeper understanding of the relationship of changes between parameters and how such dependencies can have a final impact on the output parameters of a semiconductor.

Figure 1*v* shows a very interesting dependence of the carrier lifetime on temperature. Here, a distinct peak-shaped curve suggests the presence of some kind of abnormal influence. This, by the example of the “Internet zombie” method, can be likened to a nervous breakdown or psychological influence. In this case, it is considered important to remind people who are highly susceptible to information not only from the Internet but also from their environment. It is also necessary to teach the student to be alert to such abnormal occurrences. It is not uncommon for such occurrences to conceal the world’s scientific discoveries, as was the case, for example, with the great physicist, the father of semiconductor technology, A. F. Ioffe.

As this method is recommended to be used during lectures, a full audience of students can express their opinions on such examples. Because the teacher has the opportunity to ask the students how well the example was used, or if they have encountered similar cases in their life. After the topic has been explained, the students will be asked follow-up questions. If time permits, the most active students will be allowed to give an example and justify their assumptions. At the same time, an opposition group is created in which the participants have to find dissimilarities or other flaws in the example given. Here it is important to keep the audience focused on the issue at hand.

The teacher then provides students with curves of the temperature dependencies of other parameters of a semiconductor device on the board, or a pre-prepared presentation board. The task is to analyze the dependencies of these parameters on temperature, or other factors, with examples of how the media or other sources of influence affect a person, his actions, or his destiny. The task may be given as a self-study to be carried out at home, or any other option may be used. Assessment of the work is compulsory and mistakes made are indicated.

**FIGURE 2**
**INTEGRATED CIRCUIT BOARD (A) AND GENERAL VIEW AFTER MOUNTING THE ELEMENTS ON IT (B)**




*a)* *b)*

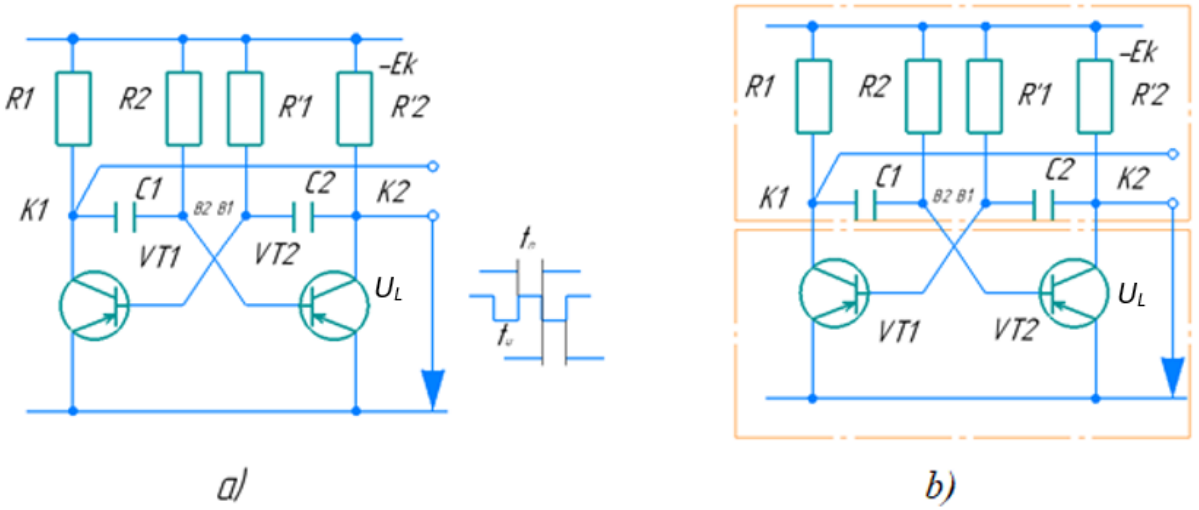
The next method is called the 'Circuit Piece Method'. This method, which we have developed, allows for a good understanding of the operation of electrical devices assembled from semiconductor devices. As it is known, the micro and nanoelectronics industry creates devices for automatics, cybernetics, robotics and many other industries based on BIS (large integrated circuits) and MIS (small integrated circuits, Fig. 2).

These circuits include dozens, sometimes even hundreds of transistors, diodes, thyristors, stabilizers, resistors and capacitors, various mini amplifiers, analogue and digital converters (ADCs and DACs). Although these circuits are assembled and wired in the factory, it is not uncommon for repairs to have to be carried out. In addition, reading circuitry is an important skill in technical schools. And circuits are sometimes so complex that making sense of them is time-consuming. However, the prerequisite for knowing how to read a circuit remains the same. To meet these requirements, students must first be taught how to make sense of circuits, how to assemble and assemble them, how to connect them correctly to appropriate currents and voltages, how to read circuit diagrams and how to interpret their operating principles.

Since the direct explanation of circuits and drawings does not always enable the skills to be instilled in a thorough understanding of them, some new methods of studying them should be developed. Only improved methods will lead to free work of wiring diagrams, uncomplicated reading of circuit diagrams and the creation of new semiconductor devices.

The essence of the method is as follows. Any schematic diagram of a semiconductor device is taken. In our case, it is a multivibrator circuit (Fig. 3).

**FIGURE 3**
**SCHEMATIC DIAGRAM OF MULTIVIBRATOR**




In other cases, it may be an automaton, a robot, a relay, a regulator, etc. The teacher explains the principle of its operation. To control it, one of the active listeners is required to tell the principle of operation of the circuit of the device explained by the teacher. Then the same circuit is divided into several pieces (to facilitate the work, pieces of the circuit in several copies are made in advance by the teacher).

The number of pieces depends on the complexity of the circuit. The pieces of the scheme are handed out to students forming small groups. In a group, the number of students can be between three and five.

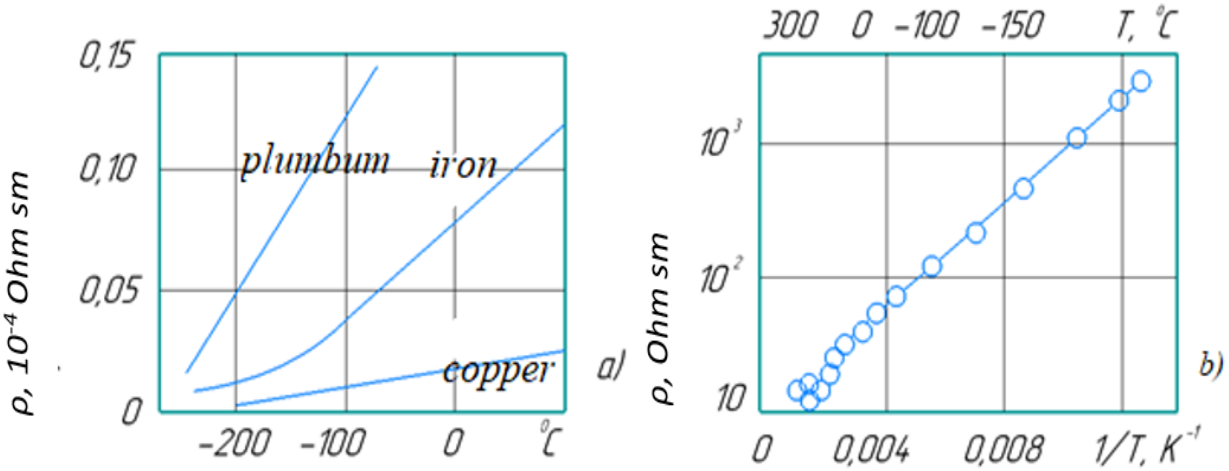
The students are instructed to assemble the circuit into one piece. A student who has understood the principle of the circuit can assemble the circuit. Because, when assembling a circuit, it is possible to encounter different values of voltages, currents and even frequencies, with the different nature of signals

(analogue, digital, etc.). After all, the completed task is checked by the teacher, evaluated and errors explained. The dotted lines in figure 3*b* correspond to the cut-offs of the circuit.

## RESULTS

Experimental testing of mastering the studied topics by the method of "Internet-zombie" was conducted with second-year students of the group "Electrical Engineering, electromechanics and electrotechnology" of the Andijan Machine-Building Institute in Andijan. The number of students was 24 people. The experiment was conducted during laboratory work, in which the dependence of the properties of semiconductor materials on the influence of temperature was studied. The students were given graphical dependences of lead, iron and copper for the experiment (Fig. 4).

**FIGURE 4**
**TEMPERATURE DEPENDENCE OF RESISTIVITY OF METALS (A) AND SILICON (B)**




The use of these metallic materials makes it possible to more clearly separate and notice differences in the electrophysical properties of solids. In principle, only semiconductors could be taken, but the proximity of their properties could still make it difficult for students to see the reasons for the large differences. The parameter to be investigated was the resistivity of materials of all the listed samples.

The assignment was to identify the reasons for the variation in the temperature dependence curves of the three samples. As can be seen from figure 4*a*, lead has a very strong dependence of resistivity on temperature. Iron has a relatively lower dependence. Copper has a very low dependence. To compare and contrast this physical phenomenon, the temperature dependence of the resistivity of semiconducting silicon is given (Fig.4*b*).

The teacher pointed out the huge differences between the parameters of these elements, both in graphical increase and numerical value.

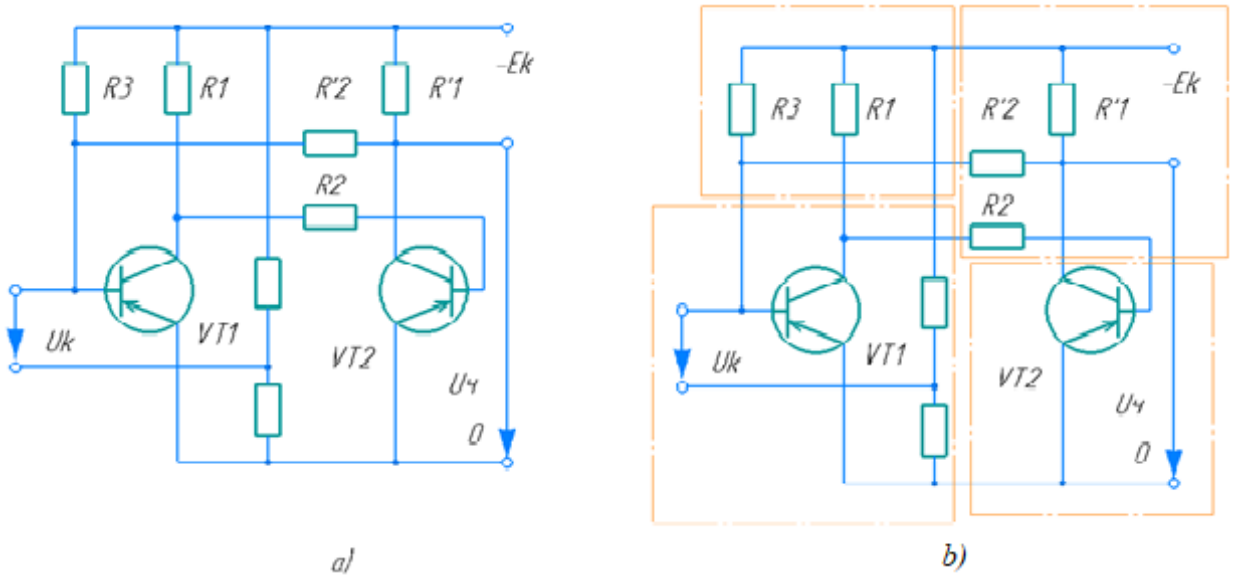
After this, the students, given a command by the teacher, began to look for reasons for the "strong", "medium" and "small" temperature dependencies of the samples. As their knowledge progressed, they began to write explanatory instructions for the laboratory work, likening the parameter changes to human actions that "depend on the internet". One assignment per two students was allowed for discussion. The lesson was accompanied by lively analysis, discussion and speculation.

There was no noise, but light laughter and persistent persuasive assumptions and statements could be heard. At the end of the assignment, 12 variants of the analyzed papers were listened to. Three of the options provided were similar. 2 options almost had a completely correct answer. 7 options were relatively correctly

interpreted in one way or another. In the end, the students were found to have a good activity, satisfactory knowledge of the topic and the ability to demonstrate comprehension and interpretation skills.

Experiments to test students on the study of semiconductor device circuits (Circuit Piece Method) were conducted during the laboratory work on the subject “Relay Protection and Automation” on the example of a relay circuit operating in the relay mode of a two-stage amplifier (Fig.5).

**FIGURE 5**
**SCHEMATIC DIAGRAM OF A TWO-STAGE AMPLIFIER OPERATING IN RELAY MODE**




The principles of operation of the relay, functions, and initial power supply parameters were explained. Then pieces of the circuits were handed out in subgroups. The circuits assembled by glueing were checked for correctness. The result was good. Probably the good result was due to the uncomplicated nature of the circuit. In the next stage, the students assembled the circuits and checked their operation. Out of 12 circuits, 9 worked right from the first time. So about 80% of the work was done successfully.

## CONCLUSION

Development and use of interactive teaching methods for students of secondary technical schools and students of higher education institutions on semiconductor engineering and physical aspects of semiconductor materials are one of the most important tasks of specialists in the educational system today. An in-depth study of the physics of semiconductors enables engineering students to easily and correctly understand the physical phenomena occurring within a semiconductor and the modes of operation of semiconductor devices. A competent attitude to modern devices built based on p- n-junction, opens a wide way to accelerated development of industrial samples and devices of operation, carrying out repair and restoration works, and creation of new samples of semiconductor technique and technology. Also, it is necessary to note, in comparison with other subjects and specialities to expand areas of research on the modernization of training processes and development of methods of interactive pedagogical technologies and increase of creativity of teachers of high schools. For this purpose, it is advisable to attract highly qualified specialists among engineering staff with extensive experience both in production and higher education institutions.

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