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ИНОСТРАННЫЙ ЯЗЫК

ЭЛЕКТРОНИКА И НАНОЭЛЕКТРОНИКА. СИЛОВАЯ ЭЛЕКТРОНИКА

FOREIGN LANGUAGE
ELECTRONICS AND NANOELECTRONICS. POWER ELECTRONICS

Методические указания к практическим занятиям для студентов магистратуры направления 11.04.04

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Данные методические указания составлены для использования на практических занятиях по дисциплине «Иностранный язык». Предлагаемый материал направлен на развитие навыков технического перевода, анализа оригинальной литературы по специальности, накопление и усвоение лексического материала в рамках профессиональной тематики, преодоление трудностей перевода и приобретение разговорных навыков по специальности.

Методические указания предназначены для студентов специальности 11.04.04 «Электроника и наноэлектроника», изучающих английский язык.

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ВВЕДЕНИЕ

Данные методические указания к практическим занятиям по английскому языку предназначены для студентов специальности 11.04.04 «Электроника и наноэлектроника», направления подготовки «Силовая электроника». Методические указания составлены в соответствии с учебной программой по дисциплине «Иностранный язык» для формирования иноязычной профессиональной компетенции будущих специалистов.

Предложенные методические материалы предназначены для аудиторной работы студентов и состоят из пяти разделов, содержащих информацию о наноэлектронике и силовой электронике. Каждый текст сопровождается комплексом предтекстовых и послетекстовых заданий и упражнений, направленных на контроль понимания прочитанного материала, формирование умения ориентироваться в оригинальных научно-технических текстах, отработку и закрепление лексико-грамматического материала в устной речи, контроль навыков перевода.

Изучение предложенного материала имеет целью развитие и совершенствование навыков чтения и перевода оригинальной научной литературы по наноэлектронике и силовой электронике, расширение словарного запаса, преодоление трудностей перевода и приобретение разговорных умений в сфере профессиональной деятельности.

UNIT 1MICROELECTRONIC TRANSISTORS

TEXT 1.1 Structure and Operation

1 Read and translate the text.

In digital circuits, the transistor is usually used as a two-state device, or switch. The state of a transistor can be used to set the voltage on a wire to be either high or low, representing a binary one or zero, respectively, in the computer. Logical and arithmetic functions are implemented in a circuit built using transistors as switches.

The transistor's second function in a computer is amplification. A small input electrical signal can control an output signal many times larger. Amplification allows signals to be transmitted through switches inside the computer without loss of strength. The primary types of transistors in use today are the FET (filed-effect transistor), in which a voltage is imposed on the device to control a second output voltage or current, and the bipolar junction transistor (BJT), in which a current is used to control another current.

The metal-oxide semiconductor FET (MOSFET) has been by far the most common type of transistor in modern microelectronic digital circuits, since Shockley's explanation of the device in 1952. Properly designed MOSFET circuits use very little power and are economical to fabricate. As shown in Fig. 1, the field effect transistor has three terminals which are called the source, the drain, and the gate.

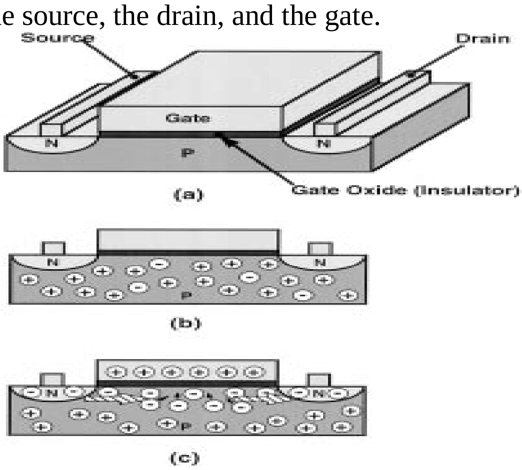


Fig. 1. Schematic cross section of a NMOS transistor. (a) The transistor shown in the schematic cross section is the basic building block of microcomputers. (b) When there is no voltage applied to the gate electrode, no current can flow through the semiconductor. (c) However, when voltage is applied to the gate electrode, the electrons (negative circles) segregate from the holes (positive circles) to form a “channel” which permits current (large white hatched arrows) to flow between the source and the drain

Although the novel designs that are discussed below for nanometer-scale electronic switching devices operate according to principles quite different from a MOSFET, all retain the same essential features: a source, drain, and (usually) a gate in the same conceptual roles as in a MOSFET. The channel through which current may flow from source and drain is altered more drastically in making the transition to nanoelectronic devices. Thus, to introduce the device components in a relatively familiar context and to establish a basis for comparison with conventional technology, we briefly explain the operation of a MOSFET.

The name “metal-oxide-semiconductor field effect transistor” stems from its constituent materials. MOSFET’s are built upon a crystalline substrate of the doped semiconductor silicon. Pure silicon is a very poor conductor, so dopant impurities, such as boron or arsenic, are introduced into the silicon to create an excess of mobile positive or negative charges. Negatively doped (N-doped) silicon contains free electrons that are able to move through the bulk semiconductor. Positively doped (P-doped) silicon contains electron vacancies, commonly known as “holes,” which act as positive charges that move freely through the bulk material.

A metal electrode separated from the semiconductor below by an insulating oxide barrier serves as the gate of the MOSFET, whose voltage and associated electric field controls the flow of current from the source to the drain. This is why the device is called a “field-effect” transistor. When the voltage on the gate is low, the region between source and drain contains few mobile negative charges, and very little current can flow. This is shown in Fig. 1(b). However, as illustrated in Fig. 1(c), increasing this voltage sufficiently attracts electrons to the region under the gate, opening the channel and allowing masses of electrons to flow from the source to the drain. This corresponds to a dramatic rise in current [1].

2 Read and translate the following words. Practice pronouncing them correctly.

Crystalline, drain, drastically, bipolar junction transistor, bulk material, semiconductor, dopant impurities, sufficiently, circuits, amplification.

3 Give the verbs corresponding to the following nouns:

association, discussion, implementation, representation, attraction, introduction, explanation, transmission.

4 Work with a partner. Discuss the questions below.

- What functions are implemented in a circuit built using transistors as switches?
- When has the metal-oxide semiconductor FET been the most common type of transistor?
- What allows signals to be transmitted through switches inside the computer without loss of strength?
- Why are dopant impurities introduced into the silicon?

5 Translate into Russian paying attention to the form of the verb-predicate in the Passive Voice.

1. This process of nanotechnology engineering is used to produce materials with enhanced properties, like higher durability with less physical mass. 2. Nanotechnology is used in various fields of applied sciences such as chemists, physicists, biologists, medical doctors and engineers. 3. In other words, not only can nanotechnology be used to structure new types of food ingredients, it can also be used to build new types of food packages, food quality detection tools, and other types of measurement and detection systems. 4. Nanomaterials can be used to reinforce mechanical strength, enhance gas barrier properties, increase water repellence, and provide antimicrobial and scavenging activity to food packaging. 5. For the small size of the nanoelectronic device cannot be used for the moving of heavy load like a mechanical device. 6. This small power can be used to power up devices placed inside the body like pacemakers or sugar-fed nanorobots.

TEXT 1.2 Obstacles to Miniaturization

1 Translate the following words.

Dissipation, circuitry, intractability, gate length, the avalanche breakdown, depletion, nonuniformity, scaling result, unevenness, evident, thermodynamic, molecular scale, quantization, gallium arsenide.

2 Match the words to make collocations. Translate into Russian.

1 electron	**A** arsenide
2 current	**B** surges
3 fundamental	**C** regime
4 dense	**D** tunneling
5 molecular	**E** transistors
6 gallium	**F** circuitry
7 nanometer-scale	**G** limitations
8 electronic	**H** nanoelectronics
9 microelectronic	**I** network

3 Scan the text to discover the right variant of mentioned above collocations.

Despite formidable challenges, however, many of those in the research community and industry do envision close variants of conventional microelectronic transistors becoming miniaturized into the nanometer-scale regime. For example, The National Technology Roadmap for Semiconductors, published by the Semiconductor Industry Association, projects that chips **will be made** from transistors with major features (gate lengths) of 70 nm in the year 2010.

Individual working transistors with 40 nm gate lengths **have** already **been demonstrated** in silicon. Transistors with gate lengths as small as 25 nm **have been made** using gallium arsenide. It is unclear, though, whether such transistors **can be made** sufficiently uniform and reliable to build a densely integrated computer containing a billion or more of them. Additionally, a dense network of such transistors **could be slowed down** by the flow of current through extremely narrow wires from one device to the next. Detailed treatments of the fundamental limitations upon small electronic circuitry and of the scaling problem for FET's (filed-effect transistor) **may be found** elsewhere in the literature, including this issue of the Proceedings. However, to provide points of reference for contrasting nanoelectronic devices with scaled-down FET's, a few of the obstacles to FET scaling **are** simply **enumerated** below, in increasing order of their intractability.

High electric fields, due to a bias voltage being applied over very short distances, can cause "avalanche breakdown" by knocking large numbers of electrons out of the semiconductor at high energies, thus causing current surges and progressive damage to devices. This may remain a problem in nanoelectronic devices made from bulk semiconductors.

Heat dissipation of transistors (and other switching devices), due to their necessarily limited thermodynamic efficiency, limits their density in circuits, since overheating can cause them to malfunction. This is likely to be a problem for any type of densely packed nanodevices.

Vanishing bulk properties and nonuniformity of doped semiconductors on small scales. This **can** only **be overcome** either by not doping at all (accumulating electrons purely using gates, as has been demonstrated in a GaAs heterostructure) or by making the dopant atoms form a regular array. Molecular nanoelectronics is one path to the latter option.

Shrinkage of depletion regions until they are too thin to prevent quantum mechanical tunneling of electrons from source to drain when the device supposedly is turned off. The function of nanoelectronic devices **is** not similarly **impaired**, because it depends on such tunneling of electrons through barriers.

Shrinkage and unevenness of the thin oxide layer beneath the gate that prevents electrons from leaking out of the gate to the drain. This leakage through thin spots in the oxide also involves electron tunneling.

The thermodynamic obstacle to FET scaling, heat dissipation, suggests that it would be desirable to find replacements for FET's that might permit the construction of circuits that require fewer switching devices in order to perform the same functions. Below, it **is discussed** how alternative nanoelectronic devices can accomplish this. Further, all but one of the other obstacles to scaling result from the simultaneous decrease in the effectiveness of doping and the increase in the significance of quantum mechanical effects. Once electronic devices approach the nanometer and the molecular scale, the bulk properties of solids **are replaced** by the quantum mechanical properties of a relatively few atoms. Properties associated with uniformly doped semiconductors will become less evident and influential in the operation of an electronic device. Quantum mechanical effects, such as energy quantization and tunneling, become much more significant. In order for a transistor-like device to operate on the nanometer- scale and, ultimately, on the molecular scale, it would be advantageous if it did not depend upon doped materials and if it operated based on quantum mechanical effects, rather than in spite of them [2].

4 Translate the text above from English into Russian noticing the form of the verb-predicate in the Passive Voice.

5 Decide whether the statements are *TRUE* (T) or *FALSE* (F).

1. Shrinkage of depletion regions until they are too thin to prevent quantum mechanical tunneling of electrons from source to drain when the device supposedly is turned off.
2. Quantum mechanical effects, such as energy quantization and tunneling, become less significant.
3. A dense network of such transistors could be speeded up by the flow of current through narrow wires from one device to the next.
4. High electric fields, can cause “avalanche breakdown” by knocking large numbers of electrons out of the semiconductor at high energies.
5. Shrinkage and evenness of the thin oxide layer above the gate prevents electrons from leaking out of the gate to the drain.
6. Transistors with gate lengths as small as 25 nm have been made using gallium arsenide.

6 Scan the text above and complete the sentences.

1) The function of nanoelectronic devices is …
2) Once electronic devices approach the nanometer …
3) This may remain a problem in nanoelectronic devices …
4) The thermodynamic obstacle to FET scaling, suggests …
5) This can only be overcome either by not doping at …
6) Individual working transistors with 40 nm gate lengths have …

UNIT 2 NANOELECTRONIC DEVICES

TEXT 2.1 Solid-State Quantum-Effect

1 Read and translate the following words. Practice pronouncing them correctly.

Gallium arsenide, artificial atoms, mobilities, fabricate, semiconductors, collisions, coherently, periodic table, confinement, defect-free junctions.

2 Read and translate the text.

A number of nanometer-scale solid-state replacements for the bulk-effect semiconductor transistor have been suggested to overcome the difficulties. All of these devices function by taking advantage of effects that occur on the nanometer-scale due to quantum mechanics. The essential structural feature that all of these devices have in common is a small "island" composed of semiconductor or metal in which electrons may be confined. This island of a nanoelectronic device assumes a role analogous to that of the channel in an FET (filed-effect transistor). As is explained in greater detail below, the extent of confinement of the electrons in the island defines three basic categories of solid-state nanoelectronic devices. Quantum Dots (QD's or "artificial atoms"). Island confines electrons with zero classical degrees of freedom remaining. Resonant Tunneling Devices (RTD's). Island confines electrons with one or two classical degrees of freedom. Single-Electron Transistors (SET's). Island confines electrons with three classical degrees of freedom.

The composition, shape, and size of the island gives the different types of solid-state nanoelectronic devices their distinct properties. Controlling these factors permits the designer of the device to employ quantum effects in different ways to control the passage of electrons on to and off of the island. For example, the mean free path of mobile electrons can be much greater in semiconductors than in metals. Thus a mobile electron might travel coherently all the way across a semiconductor island, without severe collisions. This means that conductivity of a device can be strongly enhanced or suppressed by quantum mechanical interference between separate paths an electron might take through the device. As is well known, microelectronic devices are made primarily from silicon (Si), an element in group IV of the periodic table. Presently, however, most solid-state nanoelectronic devices incorporate semiconductors made from combinations of elements from groups III and V of the periodic table—e.g., gallium arsenide (GaAs) and aluminum arsenide (AlAs). The mobilities of electrons are higher in these III–V semiconductors, and it is also easier to fabricate defect-free junctions between different III–V semiconductors than it is for junctions between two group IV semiconductors, such as Si and Ge [3].

3 Work with a partner. Discuss the questions below.

- What are the basic categories of solid-state nanoelectronic devices?
- What gives the different types of solid-state nanoelectronic devices their distinct properties?

4 Give the Russian equivalents of the following word combinations.

Mobile electrons; essential structural feature; quantum mechanics; nanoelectronic device; passage of electrons; defect-free junctions; quantum mechanical interference; taking advantage; degrees of freedom.

5 Insert the appropriate form of the Participle.

1. The materials and devices (to use) in nanoelectronics are so small that the interatomic interactions and quantum mechanical properties of such materials need to be studied extensively. 2. This drift, which (to be) witnessed first by examination of the past data, soon (to become) a standard and objective for the growth of semiconductor technology and manufacturing. 3. The technique (to be) based on transforming thin-film growth thickness control into planar wire arrays. 4. Top-down approach (to discuss) about the slicing or successive cutting of a bulk material in order to get nano-dimensional particles. 5. These deficiencies (to lead) to extra challenges in the device design and construction. 6. Bottom-up methodology (to employ) chemistry which (to be) not so expensive, to stimulate self-assembly of multifarious mesoscopic structures [4].

6 Fill in the gaps using the words in the box. Translate the text.

bands	conduction	tunneling	atom	semiconductors	quantum

But **1** ______ can occur and charge can flow toward the drain only if there is an unoccupied **2** _________ energy level in the well at an energy that matches one of the occupied energy levels in the source band. In extended systems, such as the bulk metals or **3** _______in the source and drain, the allowed energy levels for electrons are so closely spaced that they form **4** ________over a range energies, in contrast to the discrete energy levels in a single or **5** ________in a nanometer-scale potential well. The electrons occupying the source **6** _______band range continuously in energy from that of the lowest energy level in the band at the "band edge" to the level of the highest energy conduction electrons at the "Fermi level".

7 Translate into English using the appropriate form of the Participle.

1. Прогресс в области нанотехнологии полупроводников и сверхпроводников сделал возможным получение твердотельных приборов, которые способны излучать в терагерцевом диапазоне длин волн. 2. Интегральные схемы могли нести сотни миллионов транзисторов в одном кристалле (многоядерные процессоры - и миллиарды). 3. Волновые, квантовые, закономерности вышли на первый план в нанометровом масштабе. 4. При уменьшении размеров провода ещё задолго до атомного уровня вся физика процесса менялась радикально. 5. В наноразмерном проводе не соблюдался закон Ома - вольт-амперная характеристика из линейной превращалась в степенну́ю, проводимость менялась в миллион раз, реакция на примеси тоже была степенной. 6. В тонких нанопроволоках электрон не мог достичь второго контакта, минуя другие электроны - он их проталкивал перед собой, при этом между частицами возникало сильное кулоновское взаимодействие, разделялся перенос спина и заряда. 7. Кремниевая интегральная электроника не очень хорошо работала в экстремальных условиях, например, космических. 8. После определённых биологических достижений нанотехнологии распространились в материаловедение и химию.

TEXT 2.2 Islands, potential wells, and quantum effects.

1 Read and translate the following text. Make up plan of the text.

The smallest dimension of the island in a solid-state nanoelectronic device ranges from approximately 5–100 nm. The island may consist of a small region or layer different from the surrounding material. Otherwise, edges of the island may be defined by electric fields from small electrodes patterned in the shape of the desired island boundary. Often, the island is embedded between two narrow walls of some other material, or an insulating oxide of the island material, or an insulating defect zone in the substrate. In any case, therefore, the island is surrounded by potential energy barriers, which impede the movement of electrons in and out of the island region. This is illustrated in Fig. 2, in which the energy barriers arise from walls of a different material.

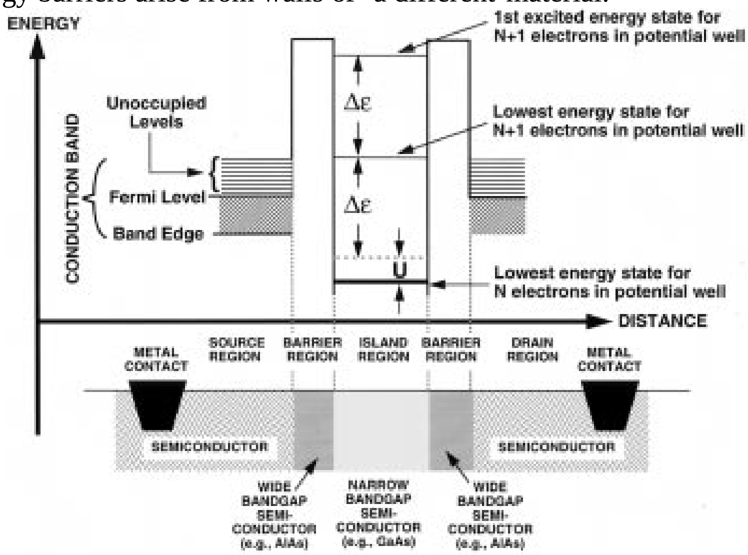


Fig. 2. Quantum well for a resonant tunneling diode (RTD).

The barrier regions around the island in the RTD shown at the bottom of the figure create the potential energy “well” graphed in the top part of the figure. Energies of the electrons trapped in the well on the island are “quantized”-they can only have the energy states or “levels” shown. Mobile electrons in the source region (and the drain region) occupy the energy levels between the band edge and the Fermi level, with unoccupied energy levels above that in energy. If N mobile electrons are on the island, the energy cost of adding one more from the source has two components: the charging energy U, plus the excitation energy. For an RTD, U usually is even smaller, relative to, than is shown in the figure.

Within the island, mobile electrons will tend to form a puddle that usually is much smaller than the dimensions of the island. The puddle is surrounded by a depletion region that forms (for example) because electrons in the puddle are repelled from surface charges that collect on the boundaries of the island. Thus, the physical features that form the island may have to be fabricated many times the size of the useful region for electron confinement. This is one factor that works against the miniaturization of such quantum-effect and single-electron solid-state devices. (Despite the fact that the depletion region confines mobile electrons to only a portion of the island, we shall not make a distinction in our terminology between the shape and size of the island and those of the potential well for electrons on the island.).

Two essential quantum mechanical effects are exhibited by electrons confined to nanometer-scale islands between closely spaced potential energy barriers. First, quantum mechanics restricts each electron's energy to one of a finite number of one-electron energy levels (quantum states with discrete, "quantized" energies). The smaller the distance between the barriers (i.e., the smaller the island), the more widely spaced in energy are the levels for the electrons in the potential well between the barriers. Second, if the potential barriers are thin enough (approximately 5–10 nm or less, depending on the height of the barriers), electrons occupying energy levels lower than the height of the barrier have a finite probability of "tunneling" through the barrier to get on or off the island. However, for an electron of a given energy to tunnel through a barrier, there must be an empty state with that same energy waiting on the other side.

These two effects, energy quantization and tunneling, strongly influence the flow of electrons through a nanoelectronic device. When a bias voltage is applied across the island, it induces mobile electrons in the conduction band of the source region to attempt to move through the potential well in the island region to get to the region of lower potential in the drain region. The only way for electrons to pass through the device is to tunnel on to and off of the island through the two high potential barriers that define the island and separate it from the source and the drain [5].

2 Answer the following questions.

- What is the only way for electrons to pass through the device?
- What is surrounded by a depletion region?
- What energy levels are occupied with mobile electrons in the source region?

3 Match the words to make collocations. Translate into Russian.

1 excitation	**A** fields
2 defect	**B** region
3 nanoelectronic	**C** confinement
4 depletion	**D** electrons
5 surface	**E** barriers
6 electric	**F** energy
7 mobile	**G** zone
8 electron	**H** device
9 energy	**I** charges

4 Translate into Russian. Find the Participle II.

1. Inorganic nanocrystals such as nanotubes and nanowires, named after their physical shape determined through the use of growth kinetics, were typically low-dimensional structures. 2. Substantial progress had been made on carbon nanotube (CNT) from the time of its discovery in the early 1990s. 3. The use of aligned MWCNTs delivered a new bottom-up arrangement for fabricating trustworthy nanoelectrode arrays. 4. High-resolution thin-film device had been synthesized to sense texture by means of touch. 5. Thin-film transistors based on controllable electrostatic self-assembled monolayer SWCNT network had been prepared by varying the density of nanotubes on the substrate [6].

UNIT 3MOLECULAR ELECTRONICS

TEXT 3.1 History

1 Read and translate the following terms.

Electrochemical molecular devices, supramolecular structures, covalently bonded, molecular wires nanometer-scale, photoactive/photochromic molecular, molecular switches, the photoactive device, molecular electronics.

2 Read and translate the text.

Molecular electronics uses primarily covalently bonded molecular structures, electrically isolated from a bulk substrate. Devices of this description, wires and switches composed of individual molecules and nanometer-scale supramolecular structures, sometimes are said to form the basis for an "intramolecular electronics". (This is to distinguish them from organic microscale transistors and other organic devices that use bulk materials and bulk-effect electron transport just like semiconductor devices.).

As indicated above, solids have the significant disadvantage that it is relatively difficult and expensive to fabricate or "sculpt" in them the many millions or billions of nearly identical nanometer-scale structures that will be needed in each ultra-dense computer chip. Individual molecules, natural nanometer-scale structures, easily can be made exactly the same by the trillions of billions. The great power and variety of organic chemistry also should offer more options for designing and fabricating nanometer-scale devices than are available in silicon. Increasingly, this is driving investigators to design, model, fabricate, and test individual molecules and nanometer-scale supramolecular structures that act as electrical switches and even exhibit some of the same properties as small solid-state transistors. Molecular electronics does remain a more speculative research area than solid-state nanoelectronics, but it has achieved steady advances consistent with Aviram's strategy for making molecular electronic circuits viable, inexpensive, and truly integrated on the nanometer scale.

After more than two decades of work, at least four broad classes of molecular electronic switching devices can be distinguished in the research literature: electric-field controlled molecular electronic switching devices, including molecular quantum-effect devices; electromechanical molecular electronic devices, employing electrically or mechanically applied forces to change the conformation or to move a switching molecule or group of atoms to turn a current on and off; photoactive/photochromic molecular switching devices, which use light to change the shape, orientation, or electron configuration of a molecule in order to switch a current; electrochemical molecular devices, which use electrochemical reactions to change the shape, orientation, or electron configuration of a molecule and hence to switch a current.

Many examples and details about the various types of molecular electronic devices are provided in the references cited above and elsewhere. Here, however, we shall focus primarily on the first two categories of molecular electronic devices. The electric- field controlled molecular electronic switches are most closely descended from the solid-state microelectronics and nanoelectronic devices described above and promise to be the fastest and most densely integrated of the four categories. The electromechanical molecular switching devices are also promising, since they too could be laid down in a dense network on a solid substrate.

Each of the other two categories, while quite promising in general, has a major drawback for use in nanocomputers. Photoactive devices in a dense network would be difficult to switch individually, since light cannot be easily confined on length scales very much below its wavelength (approximately 500 to 1000 nm). Electrochemical molecular devices would likely require immersion in a solvent to operate.

Before we discuss specific device designs, however, we provide some additional background information, plus a discussion on the key topic of the molecular wires that will be needed to link together such molecular switches [7].

3 Discuss these questions with a partner.

- What structures can be made identical by the trillions of billions?
- What devices could be laid down in a dense network on a solid substrate?
- What devices would require immersion in a solvent to operate?

4 Translate into Russian noticing Modal Verbs.

1. The major conclusion of any review of nanoelectronics **must be** that the silicon transistor through CMOS is the dominant technology and will remain so for the foreseeable future. 2. Nanoelectronics **should be** discussed in the background of today's microelectronic capabilities. 3. Nanomaterials to be used in nanoelectronics **must** consist of assemblies of nanostructures workable in different optoelectronics and other devices. 4. Nanotechnology **could** become the most influential force to take hold of the technology industry since the rise of the Internet. 5. Nanotechnology **may** make it possible to manufacture lighter, stronger, and programmable materials that require less energy to produce. 6. Nanoscale electronic, magnetic, and mechanical devices and systems with unprecedented levels of information processing **may be** fabricated, as may chemical, photochemical and biological sensors for protection. 7. Nanotechnology **can** provide solutions for cleaning contaminated soil and water. 8. The impact of MTJs on micro and nanoelectronics **may** go further than traditional embedded applications, although considerable work is still needed to develop the alternative paradigms of computation of the future involving spintronics.

5 Match the following English terms with the Russian equivalents.

1	microscale transistors	**a**	супрамолекулярные структуры
2	individual molecules	**b**	нанометровая шкала
3	photoactive devices	**c**	внутримолекулярная электроника
4	molecular switches	**d**	полупроводниковые приборы
5	electrochemical reactions	**e**	молекулярные провода
6	molecular electronics	**f**	ковалентно связанный
7	supramolecular structures	**g**	фотоактивные устройства
8	covalently bonded	**h**	электрохимические реакции
9	intramolecular electronics	**i**	микромасштабные транзисторы
10	semiconductor devices	**j**	молекулярная электроника
11	nanometer-scale	**k**	молекулярные переключатели
12	molecular wires	**l**	отдельные молекулы

TEXT 3.2 Background

1 Read and translate the following words and word-combinations.

Mechanosynthesis, methods for nanofabrication, molecular rectifier, spiro-switch, molecular rectification, electrical switches, individual molecules, molecular rectification, hemosynthesis, nanoprobes, scanning-tunneling electron microscope, atomic force microscope.

2 Read and translate the text.

The search for individual molecules that would behave as electrical switches began in 1974, with the pioneering work of Aviram and Ratner, who proposed a theory on molecular rectification. Research on molecular electronics was stimulated in the early 1980’s by such visionaries as the late Forrest Carter and by some notable research efforts later in the decade. Aviram’s further work in the late 1980’s and early 1990’s, helped enlist a new cadre of investigators and establish a plan for the development of the field.

Finally, in the 1990’s, interest in the field has grown rapidly. Tour et al., have synthesized the spiro-switch proposed by Aviram, and different variants of the molecular rectifier have been made. Much work has been done to measure the conductance and other electrical properties of individual molecules or to model them. This growth has been driven by recognition of the need for ultra-miniaturization of electronics, and it has been catalyzed by the wide availability of sensitive new methods for imaging, manipulating, and fabricating molecular and supramolecular structures.

Role of New Methods for Nanomanipulation and Nanofabrication: Although the structure and workings of molecular electronic devices are emphasized in this overview, no discussion of molecular electronics can ignore the exciting new methods for nanofabrication that have made research on molecular electronics feasible and important. Especially significant are the methods for mechanosynthesis and chemosynthesis of nanometer-scale structures. Mechanosynthesis is the fabrication of nanostructures molecule by molecule using nanoprobes, such as the scanning-tunneling electron microscope (STM), the atomic force microscope (AFM), and the new microelectromechanical systems (MEMS) chips that contain arrays of these STM’s and AFM’s.

These sensitive new tools, invented in the 1980's, have opened a plethora of new experimental possibilities with molecules. Nanoprobes also have provided realtime visual and tactile feedback and an increased sense of contact with the behavior of the molecular-scale experimental systems that are essential for progress in molecular electronics. By providing a means to image and manipulate individual atoms and molecules, STM's and AFM's have given much impetus to research on molecular electronics. The topic of nanoprobes is discussed more thoroughly in other papers in this issue.

Chemosynthesis includes the growing study of the chemical "self-assembly" of nanostructures, which also is having considerable impact on the fabrication of solid-state circuit elements. It also includes the application of methods borrowed from biochemistry and molecular genetics, as well as creative and elegant organic syntheses of molecular electronic devices in individual organic molecules. As one example of the application of chemosynthetic self-assembly to molecular electronics, we note that Martin *et al*, used a self-assembled Langmuir–Blodgett film to demonstrate molecular rectification of the type first suggested in Aviram's and Ratner's theory. Also, in very promising recent work, an interdisciplinary group at Purdue University, West Lafayette, IN, has used self assembly to fabricate and demonstrate functioning arrays of molecular electronic quantum confinement structures connected by molecular wires [8].

3 Decide whether the statements are *TRUE* (T) **or *FALSE*** (F)**.**

1) The sensitive tools, invented in the 1980's, have opened a plethora of new experimental possibilities with molecules.
2) The study of the "self-assembly" of nanostructures does not have impact on the fabrication of solid-state circuit elements.
3) Much work has been done to measure the electrical properties of individual molecules.

4 Match the following English terms with the Russian equivalents.

1	feasible	**a**	хемосинтез
2	mechanosynthesis	**b**	молекулярная ректификация
3	nanoprobes	**c**	молекулярная ректификация
4	spiro-switch	**d**	молекулярный выпрямитель
5	molecular rectification	**e**	отдельные молекулы
6	hemosynthesis	**f**	механосинтез
7	individual molecules	**g**	спиро-переключатель
8	molecular rectification	**h**	электрические переключатели
9	electrical switches	**i**	выполнимый
10	molecular rectifier	**j**	нанозонды

5 Translate into Russian noticing Modal Verbs.

1. Wearable, flexible nanoelectronics **could be** embedded in textiles, enabling 'smart clothing' of all shapes, sizes, and uses. 2. Nanoelectronics **may** use totally different architecture from traditional microelectronics circuits, and their working principle **may be** totally different from. 3. Well-developed nanoelectronics **can be** applied in different fields, and are especially useful for detecting disease-causing agents and disease biomarkers. 4. A robust probabilistic modeling and design methodology for nanoelectronics **has to be** investigated to handle such a crucial challenge. 5. As the physical barriers are insurmountable for CMOS, this lone star in the sky of nanoelectronics **may** no longer **be** able to bear the burden of nanoelectronics. 6. Modern advances in nanotechnology have found that nanoelectronic biosensors **could be** used to detect and treat cancer, due to their optical and electrical properties. 7 The responses of the tissue and cells to the mesh nanoelectronics **must be** characterized; that is, whether it elicits an immune response. 8. The silicon-based electronics, the study of the nanoelectronics **has to** develop all the conventional electronic components such as wires, diodes, transistors, and memory devices. 9. Research in nanoelectronics **must** undergo a paradigm shift as the CMOS scaling approaches its ultimate limits. 10. A computer engineering bachelor with emphasis on nanoelectronics **may** select a master programme in electrical engineering.

UNIT 4 MOLECULAR ELECTRONIC DEVICES

TEXT 4.1 Switching Devices

1 Read and translate the text.

Electromechanical molecular switching devices are not so closely analogous to microelectronic transistors as are the molecular devices we have considered so far. They are controlled by deforming or reorienting a molecule rather than shifting around electrons. The input may even be mechanical rather than electrical. However, just like all those other switches, they can turn on or off a current between two wires, which makes them interesting for nanocomputing.

Single-Molecule Electromechanical Amplifier. It is already possible to make such switches composed of only one or a few molecules. The two researchers – C.Joachim and J.Gimzewski – have been able to measure conductance through a single buckyball held between an STM (scanning-tunneling electron microscope) tip and a conducting substrate. By pressing down harder on the STM tip they deformed the buckyball and tuned conduction onto and off of resonance, producing a 50% reduction of current off resonance. The deformation was reversible, a measure of the strength and resilience of the carbon fullerenes. Clearly it would be impractical for computers to use an STM to operate each switch, but C.Joachim and J.Gimzewski recommend replacing the STM tip with a small in-situ piezoelectric gate or other electromechanical actuator. The only fundamental limit to the speed of such a device would be the vibrational frequency of a buckyball – over 10 THz (10^{13}Hz), though the prototype misses this goal by 12 orders of magnitude.

Atom Relay. A team of researchers at the Hitachi Corporation in Japan has simulated a two-state electronic switch of atomic dimensions. The concept for this proposed device, termed an “atom relay,” has some similarities to the molecular shuttle switch. In the atom relay, a mobile atom that is not firmly attached to a substrate would move back and forth between two terminals.

The atom relay would be made from carefully patterned lines of atoms on a substrate. The Hitachi simulations showed that such a line, or “atom wire,” can conduct a small electric current. Two atom wires connected by a mobile switching atom form the relay. If the switching atom is in place, the whole device can conduct electricity. However, if the switching atom is displaced from the two wires, the resulting gap dramatically reduces the amount of current that can flow through the atom wire. A third atom wire that passes near the switching atom is termed the "gate" of the atom relay in analogy to the gate of a field effect transistor. Placing a small negative charge on the gate wire moves the switching atom out of its place in the wire. The switching atom is pulled back into place by a second "reset" gate after each use of the switch.

However, the designs for logic gates using atom relays could be limited to a two-dimensional plane. The Hitachi group did not demonstrate how two separate atom wires could cross. Without crossing wires, only a subset of all possible logic functions can be implemented with atom relays. On the positive side, individual relays would have the advantage of being extremely small, on the order of 10 square nm. The speed of the relays would be limited only by the intrinsic vibrational frequency of atoms (approximately 10 cycles per second), which is several orders of magnitude faster than present-day semiconductor transistors. Energy requirements, while not reported by the authors, would be rather low, resulting mostly from frictional forces between a single atom and the substrate.

On the other hand, not much energy would be required to evaporate a switching atom off the substrate and out of the plane of the atom wires, thereby destroying the switch. For this reason, it seems likely that atom relays could only work at very low temperatures. While switching based on atom movement has the advantages of high speed and low power dissipation, incorporating this mechanism into a more reliable device would improve its chances for practical applications [9].

2 Read and translate the following terms and expressions from the text above.

A molecular switching device, an electromechanical amplifier, to measure conductance, a conducting substrate, reversible, an electromechanical actuator, a two-state electronic switch, to implement, intrinsic vibrational frequency, frictional force, a buckyball.

3 Read the text above and answer the following questions.

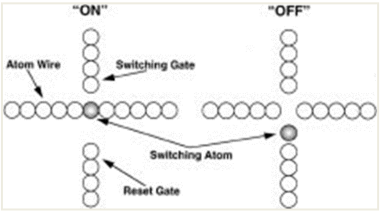
- What is the difference between electromechanical molecular switching devices and microelectronic transistors?
- What are the practical results of the research conducted by C.Joachim and J.Gimzewski? What problem occurred there and how can it be tackled?
- What device was proposed by the Hitachi Corporation? What concept underlies its operation?
- How is the switching atom moved in the two-state electronic switch simulated by the Hitachi group?
- What are the benefits and limitations of the 'atom relay'?

4 Translate into Russian paying attention to the conditionals and the modal verbs *would, could* and *might*.

1. The electric field of a nearby gate **would force** the switching atom to rotate in or out of the atom wire. 2. A more reliable two-state device based on atom movement **might use** the rotation of a molecular group to affect an electric current. 3. The use of a rotating group, or a 'rotamer', to effect atom switching **would prevent** the evaporation of the mobile switching atom, alleviating one of the principal weaknesses of the atom relay. 4. If the molecular relay **was refined**, the rotamer in this refined relay **would** likely **be** faster but also more sensitive to energetic perturbations than the molecular shuttle, because the rotamer **would be** lighter and **would have** a much smaller range of motion between switching positions. 5. This configuration **might lend** itself to use in nanoelectronic computers, if many such molecules **were affixed** to a substrate and switched individually. 6. If the shuttle ring **completed** an electric circuit in one of its two positions, the rate of switching **would be limited** by two factors: the speed of electron transfer to and from the benzidine, and the sluggish motion of the ring, which is very heavy compared to an electron.

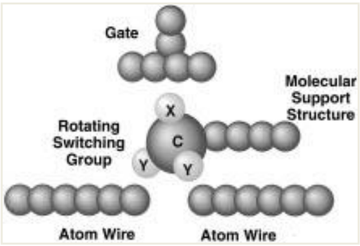
5 Look at the figures and schemes below. Using the information from the text and these figures and comments talk about the advantages and limitations of *atom relay* and the ways to improve it comparing the models proposed by various researchers in the field. Make up a

3-minute speech using conditional sentences (the second conditional) with the modal verbs *would, could* and *might* (see exercise 4).

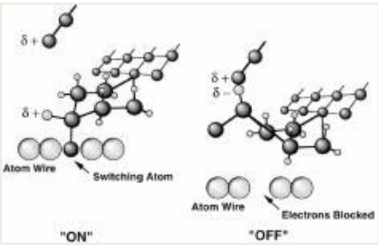


<u>Atom relay</u>
(a) Upon charging a line of atoms termed a switching gate, a mobile switching atom (shaded circle) is moved into a line of conductive atoms or "atom wire" in order to turn on a current through the wire.
(b) The current is turned off by charging the reset gate to move the mobile atom back out of the atom wire.

A more reliable two-state device based on atom movement might use the rotation of a molecular group to affect an electric current.



<u>Refined molecular switch</u> *Type 1*
Refining by attaching the switching atom to a rotating molecular group. The orientation of the rotating group is to be controlled by a nearby gate molecule, to which a voltage can be applied for that purpose.



<u>Refined molecular switch</u> *Type 2*
Attaching of switching atom to a "rotamer" that permits the atom to (a) be swung into position to turn the switch "on" by filling the gap in the atom wire, or (b) the switching atom is wung up out of the wire to turn "off" the current in the wire. Orientation of the rotamer is to be controlled by adjusting the polarity of the charge on the gate molecule.

TEXT 4.2 Next-Generation Transistors

1 Search for and explain in English the meaning of the following terms.

Graphene, current density, chalcogenides, 2D or 3D channel materials, two-dimensional transistor.

2 Scan the extract from the article about the recent advancements in nanoelectronics. Find answers to the following questions:

- What is the key difference and advantage of the new transistor developed at the University at Buffalo?
- What is its size and power? What unique characteristics does it have?
- What makes the device stand out among other transistors of the type?
- What are the prospective spheres of its application?

Atom-thin transistor uses half the voltage of common semiconductors

The researchers of University at Buffalo, USA, are reporting a new, two-dimensional transistor made of graphene and the compound molybdenum disulfide that could help usher in a new era of computing.

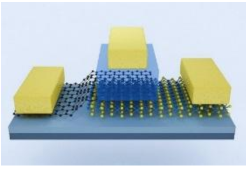
As described in a paper accepted at the 2020 IEEE International Electron Devices Meeting, the transistor requires half the voltage of current semiconductors. It also has a current density greater than similar transistors under development.

This ability to operate with less voltage and handle more current is key to meet the demand for new, power-hungry nanoelectronic devices, including quantum computers.

“New technologies are needed to extend the performance of electronic systems in terms of power, speed and density. This next-generation transistor can rapidly switch while consuming low amounts of energy,” says the paper’s lead author, Huamin Li, assistant professor of electrical engineering, School of Engineering and Applied Sciences (SEAS).

The transistor is composed of a single layer of graphene and a single layer of molybdenum disulfide, or MoS2, which is part of a group of compounds known as transition metals chalcogenides. The graphene and MoS2 are stacked together, and the overall thickness of the device is roughly 1 nanometer — for comparison, a sheet of paper is about 100,000 nanometers.

While most transistors require 60 millivolts for a decade of change in current, this new device operates at 29 millivolts.



An illustration of the transistor showing graphene (black hexagons) and molybdenum disulfide (blue and yellow layered structure) among other components.

It is able to do this because the unique physical properties of graphene keep electrons "cold" as they are injected from the graphene into the MoS2 channel. This process is called Dirac-source injection. The electrons are considered "cold" because they require much less voltage input and, thus, reduced power consumption to operate the transistor.

An even more important characteristic of the transistor, Li says, is its ability to handle a greater current density compared to conventional transistor technologies based on 2D or 3D channel materials. As described in the study, the transistor can handle 4 microamps per micrometer.

"The transistor illustrates the enormous potential of 2D semiconductors and their ability to usher in energy-efficient nanoelectronic devices. This could ultimately lead to advancements in quantum research and development, and help extend Moore's Law," says co-lead author Fei Yao, assistant professor in the Department of Materials Design and Innovation, a joint program of SEAS and the College of Arts of Sciences [10].

3 Read the text again and find the English equivalents to the following terms and word-combinations.

Открывать новую эру; современные полупроводники; иметь дело / работать с чем-либо; энергоемкие наноэлектронные устройства; увеличивать производительность; с точки зрения мощности, скорости и плотности; состоять из; транзистор нового поколения; около / примерно; энергоэффективные устройства; уникальные физические свойства, входное напряжение; пониженное энергопотребление;

традиционные технологии; демонстрировать огромный потенциал; достижения.

4 Make up 2-3 sentences of your own using the expressions from exercise 3.

5 The article contains the examples of present and past participles. Translate the following sentences from the text paying attention to the role of participles.

1. The University at Buffalo researchers are reporting a new, two-dimensional transistor **made of** graphene and the compound molybdenum disulfide. 2. As **described** in a paper **accepted** at the 2020 IEEE International Electron Devices Meeting, the transistor requires half the voltage of current semiconductors. 3. This ability to operate with less voltage and handle more current is key to meet the demand for new, power-hungry nanoelectronic devices, **including** quantum computers. 4. This next-generation transistor can rapidly switch while **consuming** low amounts of energy. 5. The transistor is composed of a single layer of graphene and a single layer of molybdenum disulfide, or MoS2, which is part of a group of compounds **known as** transition metals chalcogenides. 6. An even more important characteristic of the transistor is its ability to handle a greater current density **compared to** conventional transistor technologies based on 2D or 3D channel materials.

6 Follow-up: making a presentation.

The article mentions the 2020 IEEE International Electron Devices Meeting where the new invention was presented. This is an annual conference held in the USA.

Study the latest abstracts and proceedings of the research undertaken in the sphere of microelectronic devices on the website of the conference: https://ieeexplore.ieee.org/xpl/conhome/1000245/all-proceedings.

Choose the research that interest you most and make a 3-5-minute presentation on the subject highlighting the main achievements in the field.

UNIT 5 NANOTECHNOLOGY OF THE FUTURE

TEXT 5.1 Carbon Electrodes and Nanotubes

1 Read and translate the text.

This is a review written by Parva Chhantyal, a Project Manager at Steinbeis R-Tech, holding a Master's degree in Chemical Engineering with Energy and Environment from The University of Manchester and a PhD in Nanotechnology from the Leibniz University Hannover, Germany.

Carbon Electrodes to Revolutionise EV Battery Performance
(Part 1)

France-based Nawa Technologies (NAWA) has introduced a ground-breaking ultra-fast carbon battery with unique electrode materials, combining the best nano and clean technologies to store more electricity than current batteries and improve performance.

The transportation sector contributes approximately 23% of greenhouse gases worldwide. In 2015, to address this problem, 'Paris declaration on ElectroMobility and Climate Change and Call to Action' announced plans to reduce global warming by more than 2 degrees Celsius. This goal is only achievable if 20% of all vehicles by 2030 are electric vehicles (EV).

EV Battery Performance

With the battery being the most expensive EV component, many different types of batteries have been researched to meet essential characteristics, such as efficient energy storage, lower cost, safety, and longer life.

A battery's state of health (SOH) is understood to deteriorate over time, affecting the maximum usable range directly over time.

Canadian company, Geotab, has developed a fleet management tool based on the analysis of 6,300 fleet and consumer electric vehicles. The study confirms that EV battery lifespan is around eight years or 100,000 miles on average. This analysis depends upon the manufacturer, country, and several other factors, including charge level, topography, temperature, driving habits, and vehicle load.

Although the EV battery possesses an incredibly prosperous future, the current limitation of lower power energy, life cycle and safety demonstrates enhancement areas. Current electrodes are believed to have low electrical, thermal and ionic conductivity, and poor mechanical behavior when discharged and recharged. This leads to early delamination and degradation.

Ultra-Fast Carbon Electrodes

The availability of freely moving electrons makes carbon a highly conductive material. Another incredible advantage of carbon is its stability at high temperatures, making it a tough and durable material.

Oxford-based ZapGo has previously exploited the first carbon-ion battery that combines the super-fast charging capabilities of a supercapacitor with a Lithium-ion battery's performance.

In 2014, Power Japan Plus revealed a new battery technology, Ryden dual carbon, focusing on medical devices and satellite applications, using carbon materials that last longer and charges 20 times faster than lithium.

NAWA's new Vertically Aligned Carbon nanotube (VACNT) electrode for batteries is expected to increase battery capacity by a factor of up to three while reducing charging time down to minutes instead of hours. 'NAWA's Ultra Fast Carbon Electrode will allow us to charge batteries faster, go further and for longer – and all with a product based on one of the world's most abundant and green materials: carbon', said Ulrik Grape, CEO, NAWA Technologies.

Carbon Nanotubes

Carbon Nanotubes (CNTs) are covalently bonded carbon atoms that consist of rolled-up sheets of single-layer graphene. Their sp2 molecular orbitals with the fourth free valence electron is believed to be highly mobile, giving them their desirable properties of high conductivity and strength.

CNTs have 400 times the mechanical tensile strength of steel and a superior thermal conductivity to diamonds. Due to its VACNTs with the arrangement of 100 billion nanotubes per cm2, NAWA's newly discovered Ultra-Fast Carbon Electrode is associated with the highest ionic conductivity with the highest electrical and thermal conductivity [11].

2 Answer the following questions.

- What innovation has the French NAWA company introduced? Why was it called ground-breaking?
- Why does the innovation have the significant effect and contribute to global warming reduction?
- What problems might occur when electric vehicle batteries are used?
- What significant advantages does carbon possess? Describe the benefits of carbon nanotubes.

3 Explain the meaning of the following terms.

A carbon battery, a battery's state of health, delamination, a lithium-ion battery, carbon nanotubes.

4 Read the text again and find the English equivalents.

Новаторский, сверхбыстрый, решать проблему, улучшать производительность, приблизительно, ухудшаться, влиять, срок службы батареи, в среднем, долговечный материал, высокая проводимость.

5 Translate the following sentences from the text into Russian paying particular attention to the infinitive constructions with Complex Subject.

1. A battery's state of health **is understood to deteriorate** over time, affecting the maximum usable range directly over time. 2. Current electrodes **are believed to have** low electrical, thermal and ionic conductivity, and poor mechanical behavior when discharged and recharged. 3. New Vertically Aligned Carbon nanotube electrode for batteries **is expected to increase** battery capacity by a factor of up to three while reducing charging time down to minutes instead of hours. 4. Carbon Nanotubes are covalently bonded carbon atoms that consist of rolled-up sheets of single-layer graphene. Their sp2 molecular orbitals with the fourth free valence electron **is believed to be** highly mobile, giving them their desirable properties of high conductivity and strength. 5. New tech **is said to bring** revolutionary improvements in power, energy, lifecycle and charging time.

TEXT 5.2 Nanotechnology: EV Battery Development

1 Read and translate the second part of the review.

Electric Vehicle Battery Developments
(Part 2)

Despite the challenges of high price and manufacturing techniques, popular EV manufacturers, such as Tesla, Honda, BMW, Ford, and Porsche, have utilized lithium-ion battery technology in their EV in an attempt to replace combustion engine vehicles.

With the electrodes accounting for almost 25% of the total battery cost, today's global lithium-ion battery market is worth more than $35 billion.

The blooming opportunities in EV batteries to complement the existing technology has been an exciting challenge for many scientists. Researchers at the University of Texas at Austin have explored cobalt-free Lithium iron phosphate cathodes to reduce the cost, increase lifecycles, discharge, and recharge rates.

Another invention, a glass battery, adds sodium or lithium to the glass to form an electrode in the battery. This is more affordable, stable and can handle higher temperatures better.

A startup in Cambridge, UK, Echion Technologies, has reportedly developed a mixed niobium anode for high-capacity lithium batteries to reduce the charging time to as little as six minutes.

Alternatively, sulfur as a common element has been designed with lithium to produce a lithium-sulfur battery at Monash University. It has been tested to give a longer battery life of five days on a cell phone.

NAWA's Ultra-Fast Carbon Electrode is a considerable step towards designing effective electrodes that are safe and affordable.

Since it eliminates powder-based systems and relies less on rare-earth materials, the technology reduces battery systems' negative environmental impact.

NAWA also believes that its new design can offer significant cost savings while providing several desirable characteristics in one package, such as a considerable increase in power, energy storage, and lifecycle, as well as being clean. Due to its high durability, the ultra-fast carbon electrodes are applicable in many different applications, such as telephones, cars, renewable energies and buildings [12].

2 Skim the text and find the English equivalents.

Способы производства, заменять автомобили с двигателем внутреннего сгорания, оцениваться, дополнять, исключать, оказывать негативное влияние на окружающую среду, возобновляемый.

3 Learn the expressions from exercise 2 and make up 2-3 sentences using the active vocabulary of the unit.

4 Watch the video with the experts of NAWA company in France talking about the new generation of ultracapacitors and be ready to discuss it.

NAWA Technologies' Ultra Fast Carbon battery: the next generation of the ultracapacitor: https://www.youtube.com/watch?v=i_VE3O1Geds&t=197s.

Discussion points:

- the new development
- its properties and the metaphors used
- material structure
- areas of application
- the future of this technology

5 Summary.

Using the terms and expressions from texts 5.1 and 5.2 write a short summary on electric vehicle battery development describing the benefits and existing limitations. Make sure to include a sentence containing the Complex Subject to help you sound more formal and academic.

ANSWER KEY

Unit 1

TEXT 1.1: Structure and Operation

Ex. 3: 1 to associate; 2 to discuss; 3 to implement; 4 to represent; 5 to attract; 6 to introduce; 7 to explain; 8 to transmit.

TEXT 1.2: Obstacles to Miniaturization

Ex. 2: 1 D; 2 B; 3 G; 4 I; 5 H; 6 A;7 C; 8 F; 9 E.

Ex. 5: 1 T; 2 F; 3 F; 4 T; 5 F; 6 T.

Unit 2

TEXT 2.1: Solid-State Quantum-Effect

Ex. 6: 1 tunneling; 2 quantum; 3 semiconductors; 4 bands; 5 atom; 6 conduction.

TEXT 2.2: Islands, Potential Wells, and Quantum Effects

Ex. 3: 1 F; 2 G; 3 H; 4 B; 5 I; 6 A;7 D; 8 C; 9 E.

Unit 3

TEXT 3.1: History

Ex. 5: 1 I; 2 L; 3 G; 4 K; 5 H; 6 J; 7 A; 8 F; 9 C; 10 D; 11 B; 12 E.

TEXT 3.2: Background

Ex. 3: 1 T; 2 F; 3 T.

Ex. 4: 1 I; 2 F; 3 J; 4 G; 5 B; 6 A; 7 E; 8 C; 9 H; 10 D.

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ИНОСТРАННЫЙ ЯЗЫК

**ЭЛЕКТРОНИКА И НАНОЭЛЕКТРОНИКА.
СИЛОВАЯ ЭЛЕКТРОНИКА**

**FOREIGN LANGUAGE
ELECTRONICS AND NANOELECTRONICS.
POWER ELECTRONICS**

***Методические указания к практическим занятиям
для студентов направления подготовки 11.04.04***

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